PAPER
1

CLIMATE CHANGE AND BIODIVERSITY IN THE AMERICAS

TOM E. LOVEJOY[1] and MARIANNE B. KARSH[2]

[1]The H. John Heinz III Center for Science, Economics and the Environment
[2]Adaptation and Impacts Research Division, Environment Canada

ABSTRACT: Biodiversity in the Americas is being transformed by human-induced climate change. There have already been many noted changes among numerous species in times of nesting and flowering, as well as changes in geographical distributions, population dynamics and genetics. Increased CO_2 in the atmosphere has made oceans 0.1 pH unit more acid, negatively affecting tens of thousands of species that depend on calcium carbonate to build skeletons. On land, the alteration of the hydrological cycle has increased the probability of wildfire, which is devastating to biodiversity in regions with no previous adaptation to fire. Besides climate change, human activities are also accelerating loss in biodiversity. Exotic species are being introduced far beyond their natural biogeographical boundaries. Native and non-native species alike must contend with pollutants for which they are unable to adapt. In the tropics, the widespread clearing and burning of forests is not only increasing CO_2 levels but also reducing biodiversity. Ironically, some of the destruction is due to the increased demand for ethanol and biodiesel (soybean and palm oil) by countries seeking to wean themselves off of oil. The habitats that do remain are becoming increasingly fragmented and isolated. Habitat fragmentation leads to genetic impoverishment and eventual extinction, as species can no longer adjust their ranges to climate change. Driven by habitat loss in tropical moist forests and by fragmented habitats and climate change, the current rate of extinction is 100 times faster than expected. If greenhouse gas emissions continue to run unchecked until 2050, future rates could be 1,000 times faster than expected. The impacts on biodiversity will be disastrous. Habitat fragmentation and climate change are the new challenges for biodiversity conservation. The current protected area system used in much of the Americas is insufficient given the realities of climate change. To ensure that biodiversity is protected - to offset synergistic interactions of fragmentation with other human effects - multiple large reserves are required, tens to hundreds of thousands of square kilometers in size, stratified along major environmental gradients to capture regional biota. All regional reserve networks and landscape connectivity must be wed with effective modeling of future climate change. To implement the changes necessary for sustainable ecosystems that are biologically healthy, functional and diverse, humanity also needs hope and the ability to dream of a glorious coexistence with a planet teeming with life. Part of the solution lies in the natural world and its ability to instill wonder. Awakening the biophilia inherent in humanity can improve the outlook for biodiversity if everyone has more contact with life on earth and becomes more aware of the negative trends that threaten it.

Keywords: habitat fragmentation, ecosystems, species, biodiversity, conservation, reserves, climate change, carbon dioxide, fire, genetics

1. Climate Change and Biodiversity

Our understanding of climate change and biodiversity has changed considerably in the last 10 years. Since the publication of *Global Warming and Biological Diversity* (Peters and Lovejoy, 1992), the term "climate change" has replaced "global warming" in recognition of the fact that greenhouse gases are causing much more than just temperature shifts. Meanwhile, "biological diversity" is now known by its more familiar contraction, “biodiversity.” Thanks largely to the widespread realization that we can no longer take it for granted, the term “biodiversity” has moved beyond scientific usage and become part of everyday language.

Biodiversity is the total variety of life on Earth – the sum of all species of plants, animals, insects and micro-organisms – a number that is still unknown: estimates range from 1.5 million to 30 million. Encompassing biological processes and operating at scales greater than single ecosystems, it is the totality of diversity, from the genetic level through organisms to ecosystems and landscapes. The analysis of biodiversity must include the physical environment, natural history and human-driven stressors, as well as the principle of sustainable ecosystems that are biologically healthy, functional and diverse.

Biodiversity is not evenly distributed on the planet. There are hotspots – highly diverse regions of biodiversity with endemic species unique to a limited area – and these are often found in isolated, fragmented landscapes (Myers *et al.*, 2000). Species are locally rare throughout all or much of their range in tropical rainforests, in part because of the acidic, nutrient-poor soils that limit fruit and flower production and decrease foliage nutrient content (reviewed by Laurance *et al.*, 2002). On top of this matrix of incredibly rare and undiscovered biodiversity is the pressure of human development. Most habitable land on Earth – an estimated 70% in high biodiversity areas – is dominated by human use (Myers *et al.*, 2000). This overpowering presence often threatens the very survival of other species.

While there was already growing concern about the state of the environment in 1980, when the word “biodiversity” was first coined, it was yet unknown how extensive the impacts of climate change were. Today, it is clear that climate change is the major new threat confronting biodiversity, and that if greenhouse gas emissions run unchecked until 2050 or beyond, the long-term consequences for biodiversity will be disastrous.

Popular images, such as the polar bear trying to grab hold of a shrinking and disappearing ice pan, have precipitated a growing concern about how species will cope with the expected change in climate and how the loss of biodiversity may accelerate even more change. Determining how species respond to ongoing climate change has become the most important priority of present-day ecology.

Projected climate change is faster and more profound than anything in the past 40,000 years, and probably the last 100,000 years (Bush *et al.*, 2004; IPCC, 2007). The planet is warming rapidly, and the effects are perceptible now, within our own lifetimes (IPCC, 2001a). There has been an average increase of mean global air temperature of 0.7°C over pre-industrial times and it is predicted that warming this century could be as high as 5.8°C at the extreme (IPCC, 2001a). Since even small shifts in temperature have profound impacts on species such as trees, changes of this magnitude will be truly devastating.

Already impacted by the extreme El Niño events of the past few decades, coral reefs could be obliterated with double pre-industrial CO_2 levels (reviewed by Lovejoy and Hannah, 2005). Compunded by the problems of waste and nutrient runoff into the oceans and dynamite-based fishing techniques, increased CO_2 in the atmosphere has made oceans 0.1 pH units more acid – a significant quantity given that pH is on a logarithmic scale (reviewed by Lovejoy, 2006). Tens of thousands of species, including corals, depend on calcium carbonate to build skeletons. This is a trend that was not even on the scientific radar screen five to seven years ago. With sudden ocean warming, corals expel their symbiotic algae, often resulting in their own deaths. Coral reefs have an important association with marine species of fish, so their demise could lead to the downfall of many other organisms, as well.

The current or potential impacts on land and sea, from trees to coral reefs, indicate that sustainable thresholds in the atmosphere may be exceeded by the build-up of CO_2 and greenhouse gases. This forces us to ask: how much climate change is too much? The climate system is fragile, highly interconnected and vulnerable to human interference, making it difficult to know what constitutes excessive interference. Landmark events, such as the melting of all tropical and temperate glaciers, will punctuate the emergence of an environment vastly different from any previous one in the evolutionary history of most modern species. With the rate and speed of all these changes, there is an urgent need to track what is happening and to work to stem the tide of biodiversity loss through mitigation and adaptation.

The best measure of the distortions caused by changes in climate and the chemistry of the atmosphere and ocean is biodiversity – locally, regionally and globally – as it is the most sensitive barometer of environmental change. Biodiversity is now faced with temperature change, changing rainfall patterns, declining water balances, increased extreme climate events, changes in oscillations such at El Niño, rising sea levels, the melting of glaciers and the rise of 0°C isotherm in the tropics. On top of all these impacts, many ecosystems have to simultaneously contend with fragmentation, invasive species, disease, acid rain, nitrogen loading, hunting and a host of other stresses. Moreover, all of these impacts are acting synergistically to create even greater change.

Some might say that change is a constant in biology, even the evolutionary impetus for species to adapt. But there are two major differences between now and the past tens of millions of years as the reality of climate change confronts the biota. The first is the likelihood that rates of change will be faster than the flora and fauna have ever experienced. The second is that they must respond in a highly modified landscape. Increasingly, the terrestrial biota is confined to isolated parks and reserves that are essentially locked in by human populations. Even if species are able to move quickly enough to track their preferred climate, they will have to do so within a major obstacle course set by human society's massive conversion of the landscape – a course that serves to block animal and plant species that would otherwise be dispersing to track required climatic conditions.

What past change tells us is that species respond individualistically to climate change, not as coherent communities. They move in their own direction and at their own speed, and the consequence is that ecosystems disassemble and novel ones are assembled. It is no longer possible to assume that the same communities of organisms will be assembled elsewhere under a changing climate. Natural succession will not necessarily lead to the community composition that it would have in previous eras.

Little is known about eco-physiology, resource allocation, plant interactions, competitors, predators and parasites under climate change and elevated CO_2. Despite all we do not know, climate-change effects on the distributions, life histories and very survival of species are already being documented (IPCC, 2001b). There have been changes in times of nesting, flowering and geographical distributions of species, as well as changes in phenology, population dynamics and genetics (reviewed by Lovejoy, 2006; Lovejoy and Hannah, 2005). Increased plant fertilization attributed to higher CO_2 levels has been measured with accelerated tree growth – and accelerated mortality and recruitment – in the 1990s relative to the 1980s (Laurance *et al.*, 2004c,d). This accelerated forest productivity could have a deleterious effect in terms of carbon storage. While undisturbed Amazonian forests appear to be functioning as important carbon sinks, the faster growing general which show the greatest response to increased CO_2, have a competitive advantage over the longer lived, more dense species they are replacing.

Butterflies in North America have shifted northward in range, tropical bird species are shifting their range upslope (Hughes, 2000) and shifts in tree-community composition in Panama have apparently been caused by strong droughts (Condit *et al.*, 1996). The range shifts are attributed mainly to changes in temperature. Biodiversity is strongly impacted by warming of nighttime temperatures, which is occurring faster than the changes in daytime temperatures (IPCC, 2001a). There is also evidence that photoperiod in plants can evolve quickly as a response to climate change and that some traits are subject to rapid genetic selection. It is these photoperiod changes and genetic responses that may actually allow species to successfully shift their range. At the same time, however, long-distance dispersal capacities appear to be negatively affected by rapid climate change.

For invasive species, climate change could mean a world of new opportunities. The effect on ecosystems may be one of simplification and dominance by weedy species. Species-rich rainforests are relatively resistant to invasions (Laurance and Bierregaard, 1997), but as degraded lands draw nearer, the pressure from invading species is likely to increase.

Threats to biodiversity were once thought to be solely a result of extreme stress from human activity as populations increased, used more resources and moved alien species from place to place. Only recently has climate change been acknowledged as one of the major threats to biodiversity. Since it is now clear that climate change is not acting alone but in the context of other stresses, we first need to know what else is happening in the threatened environments of the Americas in order to discover how to mitigate impacts and help ecosystems to adapt.

2. Other Threats and Synergies

With the majority of Earth's habitable surface now dominated by human activities, deforestation, fragmentation and loss of habitat is proceeding at a dangerously accelerated rate. The simplifying of the ecological structure from forest to soybean fields or ranchland, the increased probability of fire, the introduction of invasive species and other climate-mediated threats takes us into unknown bio-climate territory (Pounds *et al.*, 2006). Each threat to biodiversity is a formidable one in and of itself, but they are collectively worse because they interact together. Systems under multiple stresses behave in unpredictable ways and these synergies may be the determining factor that drives ecosystems over the edge.

The Amazon, whose basin contains over half of Earth's remaining tropical rainforests, is being deforested at a rate of more than 20,000 km^2 annually. Part of this is due to the increased demand for ethanol and biodiesel (soybean and palm oil) by countries trying to wean themselves off of oil – an ironic development, given the marketing of these fuels as "environmentally friendly." The cutting down of forests is happening so quickly that two-thirds of the Brazilian rainforest could be disturbed and degraded in just 15 years. Trees account for up to 40% of the accumulated rainfall in Brazil and northern Argentina. At current rates of deforestation, the hydrological cycle will be impacted in uncharted ways, triggering an irreversible drying trend and increasing the probability of wildfire. While Amazonian forests have withstood significant climate change in the past, they have not had to withstand fire.

The destruction and burning of forests in the tropics not only increases CO_2 in the atmosphere and the risk of wildfire but also reduces biodiversity more directly. The interior regions of the tropics enjoy a climate of high and uniform temperatures combined with a superabundance of moisture – conditions more favorable to the development and abundance of lepidopterous insects than perhaps any other part of the world. As the burning in the Amazon escalates, so too does the loss of these species. Elevated nutrient deposition from ash produced by the forest fires and reduced tropical cloud cover and moisture also jeopardizes species in the sea. The coastal waters in the Gulf of Mexico are so exposed to an excess of nitrogen from industrial agriculture that dead zones are created where very few species live (reviewed by Lovejoy, 2006).

Added to these threats is a host of chemicals released into ecosystems and impacting species in ways that they have no previous evolutionary adaptation to (Mooney and Hobbs, 2000). In the 1960s, peregrine falcons (*Falco peregrines*), bald eagles (*Haliaeetus leucocephalus*) and brown pelicans (*Pelecanus occidentalis*) decreased substantially in population size because of the use of chlorinated hydrocarbons – regardless of whether these species were located in protected areas or not (Riseborough, 1986; Wiemeyer *et al.*, 1975).

While human actions can and do singly destroy habitats, more often it is a cumulative death by a thousand cuts. The net result of human encroachment is fragmented and isolated patches of forest – in the range of 1-100 ha – too small to sustain viable populations of biodiversity.

Trees' responses to forest fragmentation are highly individualistic. Faster-growing canopy and emergent trees (not pioneers) will increase at the expense of slower-growing sub-canopy trees, a highly diverse assemblage notable for their slow growth, dense wood and ability to reproduce in full shade (Thomas, 1996; Laurance *et al.*, 2004a,b). The large old-growth trees are predicted to decline under fragmentation, a particularly worrisome development, since these are species that live for more than 1,000 years and thus store carbon for very long periods. As the biomass from the dead trees decomposes, it is converted into greenhouse gases such as carbon dioxide and methane. This loss of living biomass is not offset by the increased numbers of lianas and small successional trees, which have lower wood densities and therefore store less carbon than the old-growth trees they replace (Laurance *et al.*, 2002).

Forest edges around fragments are less stable than forest interiors and are associated with higher tree mortality, more invasive species and greater vulnerability to windstorms and droughts. Lianas – structural parasites that reduce tree growth, survival and reproduction – increase near fragment edges and lead to tree mortality (Laurance *et al.*, 2001a,b). Accumulation of leaf litter at the forest edges negatively affects seed germination and seedling survival. In addition, forest edges are vulnerable to fire during droughts (reviewed by Laurance *et al.*, 2002).

Much of our knowledge of the impacts of fragmentation comes from the forest fragments study begun in 1976, north of Manaus in the Brazilian Amazon (Laurance *et al.*, 2002; **www.inpa.gov.br/pdbff**). As the world's largest and longest-running experimental study of habitat fragmentation, it found that 100-ha fragments lose half of their forest interior bird species in less than 15 years. It also determined that local extinctions of birds, primates and butterflies are more rapid in 1- to 10-ha fragments than in 100-ha fragments. Moreover, if species are present when fragments are isolated, the remaining population is too small to persist (reviewed by Laurance *et al.*, 2002; van Houtan *et al.*, 2007). This type of impact is not confined to the inhabitants of the Brazilian Amazon. The loss of bird species from Barro Colorado Island in the Panama Canal, subsequent to its isolation as the Gatun Lake filled with water in 1914 (Willis, 1974), is well documented. So, too, is the loss of large mammal species from western parks of the United States: isolated in small reserves, their populations proved highly vulnerable to extirpation when the population density of people in surrounding areas was high (Newmark, 1987).

A key finding of the forest fragments study is that small clearings, cattle pastures, agricultural fields and roads create imposing barriers for many rainforest organisms. Such landscape features serve to keep species isolated – imprisoned in small forest areas – leading to genetic impoverishment, extinction and reduced ability to adjust their ranges to climate change. For extinction-prone species (species not present in 1-ha fragments one year after isolation or in 10-ha fragments three years after isolation), isolation reduced movement by 67%. This is particularly devastating for birds in Amazonia, as they are largely non-migratory and have large areas requirements and strict habitat needs (reviewed by Stouffer *et al.*, 2006).

In human-dominated landscapes, where fragmentation has effectively isolated small populations of resident species, genetic diversity is often severely compromised. Since small fragmented populations lack the full complement of genetic diversity of larger populations, this means that the recessive traits necessary for rapid response to climate change may be lost, reducing the pool of individuals capable of rapid response to climate change or eliminating the genetic variants for rapid response altogether.

Simultaneously, the problem of alien and invasive species is exacerbated in the dual contexts of climate change and globalization. Today, there is scarcely a protected area in the Americas without one or more invasive species. Cases of the purple loosestrife (*Lythrun salicaria*) in the United States (Blossey *et al.*, 2001), marine organisms in ballast waters (Carlton and Geller, 1993) and pests or pathogens in the eastern United States have been increasing in numbers as globalization facilitates their widespread movement from place to place (Levine and D'Antonio, 2003).

As humans lay waste to massive tracts of vegetation, limiting the ability of plants and animals to respond to new threats, an incalculable and unprecedented number of species is being lost. Biologists look to certain keystone species for evidence of species resiliency being pushed too far. Amphibians may be early indicators of species that have already experienced change in excess of critical limits. The golden toad (*Bufo periglenes*) suffered a disastrous decline in numbers within its small range in the Monteverde Cloud Forest Preserve in Costa Rica because of synergistic impacts of habitat loss and changes in temperature and moisture regimes. It has not been seen since 1989 (Pounds and Crump, 1994; Pounds *et al.*, 1999).

The fate of the golden toad could be a sign of things to come. One-third of all amphibian species are expected to be lost because of the synergistic impacts of pollutants, habitat destruction, climate change and epidemic pathogens (Baillie *et al.*, 2004; Stuart *et al.*, 2004; Pounds *et al.*, 2006). This may be the first instance of an entire taxon in trouble.

Is this just the beginning of many? An examination of the historical extinction records through ice cores gives us some insight into the current rate and extent of biodiversity loss. Almost 440 million years ago, some 85% of marine animal species were wiped out in Earth's first known mass extinction. Roughly 367 million years ago, many species of fish and 70% of marine invertebrates perished in a second major extinction. Then, about 245 million years ago, up to 95% of animals – nearly the entire animal kingdom – was lost, followed some 37 million years later by another mass extinction, this time mostly of sea creatures. Finally, 65 million years ago, three-quarters of all species – including the dinosaurs – were eliminated in the fifth and perhaps most famous extinction event of all. It took millions of years to recover from each of the past extinctions.

The consensus among biologists is that we now are moving toward another mass extinction that could rival the past big five. The tsunami of extinction is not reversible. Driven by habitat loss, particularly in tropical moist forests, the extinction rate is 100 times faster than expected. Future rates may be 1,000 times faster. This potential sixth great extinction is unique in that it is caused largely by the activities of humans and ensured by the synergies between fragmented habitats and climate change.

3. Biodiversity Conservation Networks

Now that the situation for biodiversity is so critical, there is even greater incentive and motivation to pool all of our resources to conserve what is left and to see if we can actually help ecosystems re-establish their natural resiliency. Globally, 50% of the rarest plant species occur in 2% of Earth's land area (Myers *et al.*, 2000), and a good percentage of these areas are in the Americas. The Atlantic Forest of Brazil is one such biodiversity hotspot where conservation should be a first priority to avoid imminent extinctions.

Habitat fragmentation and climate change are the new challenges for biodiversity monitoring and conservation. The design and functioning of the protected areas estate is at risk due to the assumption of a stable climate. Regional reserve networks and landscape connectivity must be wed with effective modeling of future climatic conditions and then managed for climate change. Climate-change strategies must be incorporated into conservation planning if goals of maintaining broad biodiversity or specific populations are to be met (Hannah *et al.*, 2002).

Research into forest fragments shows that large reserves, not a series of small ones, are required. Without larger landscapes and their ecological services, biodiversity hotspots and protected areas fail to meet conservation objectives (Jepson and Canney, 2001; Whittaker *et al.*, 2005). As previously noted, species fare poorly in 1-ha fragments, which means that a minimalist approach to conservation will not work. Large areas provide much better conservation for butterflies, birds and small mammals. A buffer of managed or unmanaged forest is needed around reserves and the network of sites must be expanded to protect both present and future patterns of biodiversity and to fill out a representative set of Earth's imperiled ecosystems.

In Amazonia, where the highest percentage of threatened vertebrates on Earth have no protection whatsoever, an amphibian conservation action plan would help to focus efforts on this important taxon (Rodrigues *et al.*, 2004). Prioritization for protection must be based on endemic plant diversity and habitat loss.

Concerns for monitoring and conservation are not just confined to the tropics. Northern ecosystems are also at risk, and studies of Canada's parks indicate that they are not protecting the original representative ecosystems for which they were set aside (Scott *et al.*, 2002). Seventy-five to 80% of Canada's national parks are expected to experience shifts in dominant vegetation under scenarios of doubled levels of CO_2 (Scott and Stuffling, 2000). An examination of probable new bio-climate zones in Canada reveals that most reserves and conservation areas are in places where cities and major agricultural zones are obstacle courses for successful climate-driven dispersal, rapid responses and community reorganization. This situation is true of many such reserves, underscoring the inadequacy of the current protected-area system in North America under climate change. Not only are reserves not supplying the habitat required for species, but the warming of 3°C in the Great Basin of the United States is also expected to result in the loss of between 9 and 62% of mammal species inhabiting mountain ranges within natural reserves (McDonald and Brown, 1992).

Regardless of how effective these reserves will be in the future, there is still a need to recognize that these are the current safe havens from which future biogeographical patterns will emanate. Moreover, it is crucial to think beyond the borders of protected areas to managing a landscape matrix that enables both the dispersal of organisms and allows the fragment to behave as it were a large protected area (Gascon *et al.*, 1999).

Any climate-change-integrated conservation strategy requires regional modeling of biodiversity responses to climate change. Fine-resolution climate models that depict temperature, precipitation change and cloud formation in tropical ecosystems need to be developed. This information can be used in the design of protected-areas systems for future and present patterns of biodiversity.

4. Recommendations for Change

Among the repercussions that climate change is likely to have, the hardest to mitigate is the loss of biodiversity. The impact on agriculture can, in theory, be handled by the development of new strains and agricultural extension, as well as a reduction in intensive fertilization. Certain landscape features such as dikes could also, hypothetically, be relocated if need be.

However, for natural landscapes already so modified, there are limited opportunities for augmenting species dispersal by designing corridors. Populations with genetic resistance to climate change, such as insects with genes for wings suited to long-distance dispersal, can be identified and then protected. In this way, the loss of genetic diversity may be reduced and the number of species capable of rapid response to climate change can be stabilized. Yet it defies the imagination to think that biodiversity can be protected solely through artificial propagation when science is currently unable to estimate the number of species on Earth to within an order of magnitude.

In other words, we cannot rely on technology alone to fix the situation. It is therefore incumbent upon us to do everything we can – from energy efficiency to alternate energies to carbon sequestration – since a single, "silver-bullet" approach clearly will not work.

Today, the crisis in biodiversity is signaling that the sheer numbers of people on the planet has almost reached a point of no return. Just as the problem is compounded by synergies, so too will the solution require a synergy of political will, alternative practices and spiritual insight.

Political advocacy for emissions reductions is critical. Without dramatic reductions in greenhouse gases, there will be continued increases in temperature, changes in precipitation, wildfire and extreme events. Present international targets for greenhouse-gas emissions still allow temperature increases that would give rise to large-scale shifts in vegetation, risking widespread extinctions of species that are unable to re-establish their ranges due to dispersal limitations or the disappearance of suitable habitat. Effective lobbying for more rapid emissions reductions and stabilization of current levels of greenhouse-gas concentrations, rather than projected levels for 2050 and beyond, could help to avoid these problems. Essentially, conservationists need to extend their policy efforts beyond the terrestrial and marine realms to include the atmosphere.

The challenge for us as a society will be ongoing proactive management, as well as a transition to a renewable energy economy. This means becoming carbon-neutral. As radical and as unthinkable as it may sound, a transition to an economy based on carbon-neutral sources of energy entails replacing all current fossil-fuel-based transportation and electricity production. The phasing out of fossil-burning vehicles, aircraft and electricity-generating facilities would need to be combined with implementing massive permanent carbon sequestration (reviewed by Lovejoy and Hannah, 2005).

The amount of biomass on the planet is relatively small in relation to future sequestration needs, and environmentally-acceptable biomass options are limited. Eventually, the transition to a renewable and sustainable energy ecology will be rendered obligatory by dwindling reserves of fossil fuels. The earlier we make the move, the higher the environmental dividends in avoided damage from coal and tar-sand mining. Autos can be converted to hybrid power with efficiency savings of 50% or more to help pay for the transition. The development of a new generation of electric power plants may be one of our next steps in this new field of technology development.

Throughout the process, it will be important to discern the costs and benefits of each move, since seemingly beneficial actions may actually harm ecosystems. An example is the construction of sea walls to protect people from flooding that also end up impeding the migration of turtles. A seawall designed to allow for the movement of turtles, as well as flood protection, would offset the negative impact of this adaptation option. Similarly, many renewable energy technologies that are environmentally benign at small scales have major environmental consequences when applied at the scale necessary to displace current fossil-fuel consumption. For instance, both solar and wind energy would require huge land areas, which would certainly have an impact on remaining natural areas of Earth.

With space in the Americas being at such a premium, an Amazon-wide management plan is needed, one that encompasses a mosaic of protected areas and other forest areas so that the hydrological cycle is robust in the face of stresses from El Niño and Atlantic circulation patterns. To ensure that biodiversity is protected large and multiple reserves are required, tens to hundreds of thousands of square kilometers in size (reviewed by Laurance *et al.*, 2002), stratified along major environmental gradients to capture regional biota. The protected area system has to be designed to be resilient in the face of climate change: a thorough analysis of all threats, protected areas corridors, landscape conservation, ecosystem management, adaptive management, monitoring and ex-situ conservation is crucial. Planning has to include both longer time frames and the current short ones: 50 to 100 years, as well as five to 10 years (reviewed by Lovejoy and Hannah, 2005). It also has to include scales relevant to processes – from continental down to the local – and a major investment in research and monitoring.

Alliances for successful conservation between all the various stakeholders can only be forged with humility. Effective conservation will require new regional collaboration in management, owing to the fact that species range shifts will not respect political boundaries. Satellite images of adjacent countries in the tropics dramatically show how different priorities and policies in conservation have very different impacts on ecosystems. Instead of single-country policies, interstate, inter-provincial and international management strategies need to be framed to identify, monitor and jointly manage species and habitats vulnerable to climate change. Perhaps the struggle of plants and animals to find suitable habitats to survive may be the unlikely impetus that brings politicians with conflicting agendas together.

Society's vision of sustainable development must incorporate a number of protected areas with an absence of people and vast inhabited areas managed with a gentle imprint. One guideline governing human activities is to live as if an atmospheric concentration of 450 parts per million (ppm) carbon dioxide (CO_2) is the limit for what Earth can sustain. This means managing human populations and finding alternative livelihoods for people engaged in extensive resource use.

Last-ditch stands to save species where they currently exist may not be enough unless a plan is in place to meet the basic survival needs of human populations. The greatest number of subsistence farmers is in tropical countries – the same regions where biodiversity is highest. The food-security issue must be addressed, while at the same time taking into account these countries' legitimate aspirations for development. Even temporary shortfalls in food or income may result in permanent loss of forest cover or biodiversity, as people put increased pressure on the land trying to house and feed their families. The development agenda of countries, including activities such as forestry, agriculture and biofuels, has to be integrated with the conservation agenda. If there is to be sustainable development or long-term poverty alleviation, then minimizing the negative synergies of the climate change-biodiversity interaction will be central to it.

In forestry, priorities need to be focused on habitat restoration, especially of riparian habitats and areas connecting landscapes between protected areas (reviewed by Lovejoy and Hannah, 2005). The extreme sensitivity of many species to forest clearings and edge effects suggests that relatively wide, continuous corridors of primary forest must be maintained, with limited hunting, for faunal movement, plant dispersal and gene flow. Only with increased connectivity in the landscape will the necessary dispersal of a significant fraction of biodiversity be possible.

Second growth can be encouraged to reconnect fragments back to contiguous forest. This may be the sole way in which understory birds can persist in small fragments in Amazonia. Second growth also allows for the survival of plants and animals around forest fragments, which has a tremendous impact on orchids, pollinated by euglossine bees, and on the seed dispersal of plants, assisted by dung beetles that bury dung that often contains seeds (reviewed by Laurance *et al.*, 2002). Ensuring the survival of pollinators and the plants they are associated with goes a long way in helping to address the food-security issue, as more than 35% of the world's foods crops are dependent on pollinators (MEA, 2005). Since second growth allows for the sustainability of these pollinators but only naturally establishes once agriculture is abandoned, strategic planning may be needed to ensure a sufficiently large matrix.

Reducing deforestation, as well as taking active steps to manage the carbon debt, has the side benefit of decreasing siltation and sedimentation from forest cutting. This will help the beleaguered coral reefs, as studies have showed that siltation from deforestation negatively affects them (reviewed by Lovejoy, 2006) and that they are less vulnerable to coral bleaching from rising sea temperatures if sedimentation is reduced or eliminated.

Avoided deforestation offers the most promise of uniting countries in conservation activities. With the increasing recognition that trees help mitigate climate change by storing carbon, countries can be encouraged to preserve the carbon sink by not cutting old-growth forests. Some headway has been made in addressing both the conservation needs and debt burdens of developing countries through debt-for-nature swaps. This is a concept whereby nations struggling to meet their financial obligations can reduce their foreign debt in exchange for national conservation activities. Since the concept's inception by the World Wildlife Fund in 1989, debt-for-nature swaps have provided over $3 billion in funds for conservation and millions of hectares of habitat protection.

This new emphasis on avoided deforestation and conservation shows some evidence of success. The Brazilian Amazon, despite all the deforestation and burning, has gone from having only two national forests receiving some sort of protection to more than 40%. Although there is still more to do to conserve the Amazon as a system, this achievement would scarcely have been dreamed of a number of years ago.

It is biodiversity itself that gives us hope for avoiding the most negative impacts of climate change. The power of combined biological activity is enormous. Elimination or drastic reduction of forest burning in the tropics, plus a massive reforestation project worldwide, could easily eliminate two billion tons of CO_2 from the average net increase of 3.5 billion tons. This buys time to work on new energy scenarios that enable us to avoid climate change without grave economic dislocation.

As powerful and imperative as the practical arguments for conservation are, a change in perception and value about our place in nature could achieve vastly more. To give us the spiritual fuel we need to sustain our practical strategies, humanity needs hope and the ability to dream of a glorious coexistence with a planet teeming with life. Our thinking needs to be transformed to see ourselves woven into the very fabric of nature itself.

Part of the answer lies in the natural world and its ability to instill wonder into our souls. Awakening the biophilia inherent in all of us will really improve the outlook for biodiversity if everyone had more contact with life on earth and was aware of the deeply disturbing negative trends threatening it. Allowing ourselves to be inspired by nature and taking time to explore and appreciate the diversity of life will go a long way in preparing us to change our lifestyles and to have a more gentle and benign impact on Earth. In the end, the greatest catalyst for change may yet come from the synergistic impacts of the best of human resourcefulness, combined with the beauty and inspiration of biodiversity, to which our species owes both its survival and its depths of spirit.

References

Baillie, J., C. Hilton-Taylor, and S.N. Stuart (eds.). 2004. IUCN Red List of Threatened Species. A Global Species Assessment. Cambridge, 191 pp.

Blossey, B., L. Skinner, and J. Taylor. 2001. Impact and management of purple loosestrife (*Lythrum salicaria*) in North America. *Biodiv. Conserv.*, 10, 1787-1807.

Bush, M.V., M.R. Silman, and D.H. Urrego. 2004. 48,000 years of climate and forest change in a biodiversity hot spot. *Science*, 303, 827-829.

Carlton, J.T., and J.B. Geller. 1993. Ecological roulette: The global transport of non-indigenous marine organisms. *Science*, 261, 78-82.

Condit, R., Hubbell, S.P., and R.B. Foster. 1996. Assessing the response of plant functional types to climatic change in tropical forests. *J. Veg. Sci.*, 7, 405-416.

Gascon, C., T.E. Lovejoy, R.O. Bierregaard Jr., J.R. Malcolm, P.C. Stouffer, H.L. Vasconcelos, W.F. Laurance, B. Zimmerman, M. Tocher and S. Borges. 1999. Matrix habitat and species richness in tropical forest remnants. *Conserv. Biol.*, 91, 223-229.

Hannah, L., G.F. Midgley, T, Lovejoy, W.J. Bond, and M. Bush. 2002. Conservation of biodiversity in a changing climate. *Conserv. Biol.* 16, 264–268.

Hughes, L. 2000. Biological consequences of global warming: Is the signal already apparent? *Trends in Ecology and Evolution*, 15, 56-61.

IPCC. 2001a. Climate Change 2001: The Scientific Basis: Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Port Chester, New York.

———. 2001b. Climate Change 2001: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Port Chester, New York.

———. 2007. Climate Change 2007: Climate Change Impacts, Adaptation and Vulnerability. Intergovernmental Panel on Climate Change, Geneva.

Jepson, P., and S. Canney. 2001. Biodiversity hotspots: Hot for what? *Global Ecology and Biogeography*, 10, 225-227.

Laurance, W.F., and R.O. Bierregaard Jr. (eds.). 1997. Tropical forest remnants: Ecology, management, and conservation of fragmented communities. University of Chicago Press, Chicago, IL.

Laurance, W.F. 2001a. The hyper-diverse flora of the central Amazon: An overview. In R. O. Bierregaard, C. Gascon, T. E. Lovejoy, and R. Mesquita (eds.). Lessons from Amazonia: Ecology and conservation of a fragmented forest. Yale University Press, New Haven, CT., 47-53 pp.

Laurance, W.F., D. Perez-Salicrup, P. Delamonica, P.M. Fearnside, S. D'Angelo, A. Jerozolinski, L. Pohl, and T.E. Lovejoy. 2001b. Rainforest fragmentation and the structure of Amazonian liana communities. *Ecology*, 82, 105-116.

Laurance, W.F., T.E. Lovejoy, H.L. Vasconcelos, E.M. Bruna, R.K. Didham, P.C. Stouffer, C. Gascon, R.O. Bierregaard, S.G Laurance, and E. Sampaio. 2002. Ecosystem decay of Amazonian forest fragments: A 22-year investigation. *Conserv. Biol.*, 16 (3), 605-618.

Laurance, S.G.W., P.C. Stouffer, and W.F. Laurance. 2004a. Effects of road clearings on movement patterns of understory rainforest birds in central Amazonia. *Conserv. Biol.*, 18, 1099-1109.

Laurance, W.F., A.K.M. Albernaz, P.M. Fearnside, H.L. Vasconcelos, and L.V. Ferreira. 2004b. Deforestation in Amazonia. *Science*, 304 (5674), 1109-1111.

Laurance, W.F., A.A. Oliveira, S.G. Laurance, R. Condit, H.E.M. Nascimenta, A.C. Sanchez-Thorin, T.E. Lovejoy, A. Andrade, S. D'Angelo, and C. Dick. 2004c. Pervasive alteration of tree communities in undisturbed Amazonian forests. *Nature*, 428, 171-175.

Laurance, W.F., H.E.M. Nascimento, S.G. Laurance, R.Condit, S. D' Angelo, and A. Andrade. 2004d. Inferred longevity of Amazonian rainforest trees based on a long-term demographic study. *For. Ecol. Manage.*, 190, 131-143.

Levine, J.M. and C.M. D'Antonio. 2003. Forecasting biological invasions with increasing international trade. *Conserv. Biol.*, 17, 322-326.

Lovejoy, T.E. 2006. Protected areas: A prism for a changing world. *Trends in Ecology and Evolution*, 21 (6), 329-333.

Lovejoy, T.E. and L. Hannah (eds). 2005. Climate change and biodiversity. Yale University Press, New Haven, CT.

McDonald, K.A., and J.H. Brown. 1992. Using montane mammals to model extinctions due to global change. *Conserv. Biol.*, 6, 409-415.

MEA. 2005. Ecosystems and human well-being. Biodiversity Synthesis. World Resources Institute, Washington, DC. 100 pp.

Mooney, H.A., and R.J. Hobbs. 2000. Invasive species in a changing world. Island Press, Washington, DC.

Myers, N., Mittermeier, R. A., Mittermeier, C.G., Da Fonseca, G. A. B., and J. Kent. 2000. Biodiversity hotspots for conservation priorities. *Nature*, 403, 853-858.

Newmark, W. D. 1987. A land-bridge perspective on mammalian extinctions in western North American parks. *Nature*, 325, 430-432.

Peters, R.L., and T.E. Lovejoy. 1992. Global Warming and Biological Diversity. Yale University Press, London.

Pounds, J.A. and M.L. Crump. 1994. Amphibian declines and climate disturbance: The case of the golden toad and the harlequin frog. *Conserv. Biol.*, 8, 72-85.

Pounds, J.A., M.P.L Fogden, and J.H. Campbell. 1999. Biological response to climate change on a tropical mountain. *Nature*, 398, 611-615.

Pounds, J.A., M.R. Bustamante, L.A. Coloma, J.A. Consuegra, M.P.L. Fogden, P.N. Foster, E. La Marca, K.L. Masters, A. Merino-Viteri, R. Puschendorf, S.R. Ron, G.A. Sa´nchez-Azofeifa, C.J. Still and B.E. Young. 2006. Widespread amphibian extinctions from epidemic disease driven by global warming. *Nature*, 439, 161-167.

Riseborough, R. 1986. Pesticides and bird populations. *Curr. Ornithol.* 2, 397-427.

Rodrigues, A.S.L. H.R. Akcakaya, S.J. Andelman, M.I. Bakarr, L. Boitani, T.M. Brooks, J.S. Chanson, L.D.C. Fishpool, G. Stavo. A.B. Da Fonseca, K.J. Gaston, M.Hoffmann, P.A. Marquet, J.D. Pilgrim, R.L. Pressey, J. Schipper, W. Secjrest, S.N. Stuart, L.G. Underhill, R.W. Waller, M.E.J. Watts, and X. Yan. 2004. Global gap analysis: Priority regions for expanding the global protected-area network. *BioScience*, 54, 1092-1100.

Scott, D., and R. Suffling. 2000. Climate change and Canada's national park system. Catalogue En56-155/2000E. Environment Canada, Toronto, ON.

Scott, D., J.R. Malcolm and C. Lemieux. 2002. Climate change and modeled biome representation in Canada's national park system: Implications for systems planning and park mandates. *Glob. Ecol. Biogeogr.*, 11, 475-484.

Stouffer P.C., R.O. Bierregaard, C.Strong, and T.E. Lovejoy. 2006. Long-term landscape change and bird abundance in Amazonian rainforest fragments. *Conserv. Biol.*, 20, 1212-1223.

Stuart, S. N., J.S. Chanson, N.A. Cox, B.E. Young, A.S.L. Rodrigues, D.L. Fischman, and R.W. Waller. 2004. Status and trends of amphibian declines and extinctions worldwide. *Science*, 306, 1783-1786.

Thomas, S. C. 1996. Asymptotic height as a predictor of growth and allometric characteristics in Malaysian rain forest trees. *Am. J. Bot.*, 83, 556-566.

van Houtan, K.S., S.L. Pimm, J.M. Halley, R.O. Bierregaard, and T.E. Lovejoy. 2007. Dispersal of Amazonian birds in continuous and fragmented forest. *Ecology Letters*, 10 (3), 219-229.

Willis, E. O. 1974. Populations and local extinction of birds on Barro Colorado Island, Panama. *Ecol. Monogr.*, 44, 153-169.

Whittaker, R.J., M.B. Araujo, P. Jepson, R. J. Ladle, J.E.M. Watson and K.J. Willis. 2005. Conservation biogeography: Assessment and prospect. *Diversity and Distributions*, 11 (1), 3-23.

Wiemeyer, S.N., P.R. Spitzer, W.C. Krantz, T.G. Lamont, E. Cromartie. 1975. Effects of environmental pollutants on Connecticut and Maryland ospreys. *J. Wildl. Manage.*, 39 (1), 124-139.