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Climate Change and Biodiversity in the Americas

Edited by
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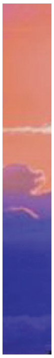

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TABLE OF CONTENTS

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Adam Fenech
Environment Canada

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Adam Fenech
Environnement Canada

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PREFACE

The changing climate is a significant driver of biodiversity and is already altering many ecosystems throughout the Americas. It is necessary to prevent and mitigate these changes to preserve the biodiversity and ecological integrity of the region. At the same time, governments, organizations, industries and communities need to consider adapting to the impacts of current and future changes in biodiversity in their planning, infrastructure and operations.

In order to begin addressing these issues, Environment Canada and the Smithsonian Institution co-hosted an international science symposium on *"Climate Change and Biodiversity in the Americas"* at the Smithsonian Tropical Research Institute in Panama City, Panama, February 25-29, 2008. The goals of the symposium were to: review the baseline data and systematic observation networks to assess biodiversity conservation and policy responses to global climate change; integrate our knowledge of likely future changes on forest biodiversity from a changing climate; report on predictive models and decision support tools to guide the design and selection of adaptation strategies from local to regional scales; and establish a framework for future collaborative research on climate change and biodiversity.

The symposium brought together top researchers, industry representatives and managers of climate change and forest biodiversity research and monitoring activities from North, Central and South America, as well as the Caribbean. It provided an opportunity for researchers and decision makers from a wide range of disciplines to share results and information in a pan-America event. The symposium program included invited keynote and plenary presentations, panel presentations, poster sessions, training sessions and study tours.

The symposium was opened by the Smithsonian Tropical Research Institute's acting director, Eldredge Bermingham, who stated that "having this Symposium in Panama has been especially significant, since the Isthmus has been the cause and effect of major changes, both natural and anthropogenic. The scientific research conducted by the Smithsonian in Panama for almost 100 years allows us to provide a base of scientific knowledge to develop accurate measurements of environmental services to find the best management models for the biodiversity and biological richness of our planet in light of changes in the future."

Canada's ambassador to Panama, Jose Herran-Lima, gave an impassioned speech in which he identified the main challenge facing science as improving our capacity to understand and predict changes in climate and biodiversity, with the goal of guiding effective management and policy actions. Herran-Lima enumerated some cost-effective measures for doing this, including:

- supporting biodiversity and climate monitoring networks (standardized protocols);
- prioritizing many small protected areas over a few large ones;
- protecting high priority conservation areas prior to development;
- managing the impacts from human activities;
- employing anticipatory adaptation and prevention;
- adopting a prevention approach to invasive species; and
- applying integrated mapping and modelling of landscapes and climate.

Herran-Lima praised the Panama Statement that emerged from this symposium (see Appendix) as providing some good future directions. Specifically, he proposed that:

- international leadership interlinking climate change and biodiversity issues and needs must continue to be proactive;
- a leadership group is required to implement guidance and advice from international conventions and agreements, as well as country-based strategies, science assessments and research activities; and
- integrated actions on climate change and biodiversity are necessary, such as:
  - establishing an integrated monitoring/modelling capacity of the synergies between climate, climate variability, climate change and biodiversity;
  - providing sound, scientific expert advice to decision- and policymakers;
  - promoting standardized monitoring protocols and training capacities;
  - fostering community-based partnerships, including the integration of indigenous knowledge;
  - engaging education and outreach programs; and
  - investing financial resources in science and partnerships.

From the left:
STRI Acting Director Eldredge Bermingham, Canadian Ambassador to Panama Jose Herran-Lima and keynote speaker Thomas Lovejoy, president of the John Heinz Center for Science, Economics and the Environment

The keynote address was delivered by Thomas Lovejoy, president of the John Heinz Center for Science, Economics and the Environment, who gave an alarming overview of the threat of climate change to biodiversity in the Americas (see Paper 1). He made it clear that 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.*

The symposium was honoured by the presence of other invited speakers representing international organizations such as the World Meteorological Organization (WMO), the World Conservation Union (IUCN), the Convention on Biological Diversity (CBD), the UN Framework Convention on Climate Change (UNFCCC), the UN Education, Science and Cultural Organization (UNESCO), the World Wildlife Fund (WWF), Conservation International (CI), the Nature Conservancy and the Smithsonian Tropical Research Institute (STRI), as well as several universities and the energy and forestry sectors. In all, there were 55 papers presented, 28 posters presented and more than 130 scientists registered at the symposium. Twenty-one countries in the Americas were represented, with speakers from Argentina, Belize, Bolivia, Brazil, Canada, Costa Rica, Cuba, Jamaica, Mexico, Panama, Peru, Puerto Rico, St. Vincent and the Grenadines, and the U.S.A.; posters were presented from Canada, Guyana, Paraguay and Venezuela; and participants came from Colombia, Guatemala, Haiti and Uruguay.

We hope that you enjoy this collection of peer-reviewed papers representing some of the leading thinkers on biodiversity and climate change. The papers are organized in this book around the three general themes of "Climate Change and Biodiversity," "Impacts of Climate Change on Biodiversity" and "Applications for Managing Climate Change and Biodiversity." An additional set of scientific papers is being prepared for publication as part of the Smithsonian Institution's Scholarly Publication Series. These papers, together with the Panama Statement (see Appendix), stand as a worthy contribution to our continuing efforts to collectively build our adaptive capacity to climate change.

The Editors,

Adam Fenech, Don MacIver and Francisco Dallmeier



PRÉFACE

Le climat changeant est un moteur significatif de la biodiversité et il modifie déjà plusieurs écosystèmes partout dans les Amériques. Il est nécessaire de prévenir et d'atténuer ces changements afin de préserver la biodiversité et l'intégrité écologique dans cette région. Parallèlement, les gouvernements, organisations, industries et collectivités doivent envisager de s'adapter aux impacts des changements actuels et futurs de la biodiversité dans leur planification, infrastructure et opérations.

Afin de commencer à réagir à ces questions, Environnement Canada et le Smithsonian Institution ont été les cohôtes d'un symposium scientifique international sur « Le changement climatique et la diversité dans les Amériques » au Smithsonian Tropical Research Institute dans la Ville de Panama au Panama, du 25 au 29 février 2008. Le symposium visait à examiner les données de base et les réseaux d'observation systématique pour pouvoir évaluer les politiques élaborées et les mesures du maintien de la biodiversité prises pour lutter contre le changement climatique; à intégrer nos connaissances sur les changements futurs éventuels de la biodiversité des forêts qu'un climat changeant risque d'entraîner; à diffuser les modèles de prévision et les outils d'aide à la décision qui orienteront la conception et la sélection des stratégies d'adaptation de l'échelle locale à celle régionale; et à établir un cadre pour la recherche coopérative future sur le changement climatique et la biodiversité.

Le symposium a rassemblé des chercheurs de renom, des représentants de l'industrie et des gestionnaires du changement climatique et de la recherche de la biodiversité forestière et des activités de surveillance de l'Amérique du Nord, l'Amérique centrale et l'Amérique du Sud ainsi que les Caraïbes. Il constituait une occasion pour les chercheurs et les décideurs de différentes disciplines de partager des résultats et des renseignements dans le cadre d'une activité panaméricaine. Parmi les activités à l'ordre du jour, mentionnons des discours programmes et des séances plénières, des présentations de groupes d'experts, des présentations par affiches, des séances de formation et des visites pédagogiques.

Le symposium a été ouvert par le directeur par intérim du Smithsonian Tropical Research Institute, Eldredge Bermingham, qui a déclaré que « la tenue du symposium à Panama est particulièrement importante, étant donné que l'isthme de Panama est la cause et la conséquence d'importants changements tant naturels et qu'anthropiques. La recherche scientifique effectuée par Smithsonian à Panama depuis près de 100 ans permet de fournir une base de connaissances scientifiques qui contribuera à l'élaboration de mesures précises des services environnementaux pour trouver les meilleurs modèles de gestion possibles de la biodiversité et de la richesse biologique de notre planète à la lumière des changements futurs. »

Jose Herran-Lima, ambassadeur du Canada à Panama a fait un discours dans lequel il identifiait le principal défi que la science doit relever comme étant l'amélioration de notre capacité de comprendre et de prévoir les changements du climat et la biodiversité dans le but de guider la gestion efficace et les mesures stratégiques. Herran-Lima a énuméré certaines mesures rentables pour accomplir cela, y compris :

- appuyer les réseaux de surveillance de la biodiversité et du climat (protocoles normalisés);
- accorder la priorité à un grand nombre de petits aires protégées plutôt qu'à quelques grandes zones;
- protéger les aires de conservation de haute priorité avant l'exécution des travaux de développement;
- gérer les effets de l'activité humaine;
- prendre des mesures anticipées d'adaptation et de prévention;
- adopter une approche de prévention contre les espèce envahissantes;
- utiliser des représentations cartographiques et des modèles intégrés des paysages et du climat.

Herran-Lima a louangé la déclaration de Panama qui a découlé de ce symposium (voir l'annexe) puisqu'elle fournit de bonnes directions pour l'avenir. Plus précisément, il a proposé que :

- le leadership international liant le changement climatique et la diversité ainsi que les besoins doit continuer à être actif
- un groupe de leadership est requis pour mettre en œuvre l'orientation et les conseils
- des mesures intégrées sur le changement climatique et la biodiversité sont nécessaires telles que :
  - établir une capacité intégrée de surveillance/modélisation des synergies entre le climat, la variabilité du climat, le changement climatique et la biodiversité;
  - fournir un conseil expert juste et scientifique aux décisionnaires et responsables des politiques;
  - promouvoir des protocoles standardisés de surveillance et des capacités de formation;
  - favoriser les partenariats axés dans la collectivité, y compris l'intégration des connaissances autochtones;
  - faire intervenir l'éducation et les programmes de communications externes;
  - investir des ressources financières en science et dans les partenariats.

De gauche :
Eldredge Bermingham, directeur par intérim STRI, Jose Herran-Lima, ambassadeur canadien à Panama et conférencier principal; Thomas Lovejoy, président du John Heinz Center for Science, Economics and the Environment

Le discours principal a été donné par Thomas Lovejoy, président du John Heinz Center for Science, Economics and the Environment, qui a clairement exprimé que la biodiversité dans les Amériques est transformée par le changement climatique provoqué par les êtres humains.

On observe depuis quelques temps déjà de nombreux changements chez bien des espèces en période de nidification et de floraison, ainsi que des changements dans la distribution géographique, la dynamique des populations et la génétique de ces espèces. La hausse du taux de carbone dans l'atmosphère a entraîné l'augmentation du taux d'acidité des océans de 0,1 unité de pH, ce qui a des effets négatifs sur les dizaines de milliers d'espèces qui ont besoin de carbonate de calcium pour fabriquer leurs squelettes. Sur terre, la perturbation du cycle hydrologique accroît les risques de feux de forêt, un coup dur pour la biodiversité dans les régions qui n'ont jamais eu à s'adapter au feu auparavant. Outre le changement climatique, les activités humaines contribuent à la perte de la biodiversité. Les espèces exotiques s'éloignent de plus en plus de leurs limites biogéographiques naturelles. Les espèces indigènes et étrangères doivent composer avec des polluants pour lesquels elles n'ont aucune capacité d'adaptation. Dans les régions tropicales, le défrichage et le brûlage répandus des forêts contribuent non seulement à augmenter les quantités de CO_2, mais aussi à diminuer la biodiversité. Ironiquement, cette destruction est due en partie à la demande croissante pour l'éthanol et le biodiesel (huiles de soya et de palme) par les pays cherchant à se passer du pétrole. De plus, les habitats maintenus sont de plus en plus fragmentés et isolés. La fragmentation d'habitat mène à l'appauvrissement génétique et, éventuellement, à l'extinction d'espèces qui ne peuvent pas plus s'adapter aux effets des changements climatiques. Étant donné la perte de l'habitat dans les forêts humides tropicales, la fragmentation des habitats et les changements climatiques, le taux actuel d'extinction est 100 fois plus élevé que prévu. Si les émissions de gaz à effet de serre continuent jusqu'en 2050, le taux futur d'extinction pourrait être 1 000 fois plus élevé que prévu. Les effets sur la biodiversité seront désastreux. La lutte contre la fragmentation des habitats et les changements climatiques constitue le nouveau défi de la conservation de la biodiversité. Le système actuel d'établissement de zones protégées utilisé dans la plupart des régions des Amériques ne suffit pas, compte tenu des réalités du changement climatique. Pour assurer la biodiversité – et contrebalancer les interactions synergiques de la fragmentation des habitats et des autres effets humains – plusieurs grandes réserves doivent être établies; ces dernières doivent couvrir une superficie d'une dizaine à une centaine de milliers de kilomètres carrés et être stratifiées le long d'importants gradients environnementaux de façon à accueillir le biote régional. Tous les réseaux de réserves régionales et de connectivité du paysage doivent s'appuyer sur un système efficace de modélisation des changements climatiques futurs. Afin de mettre en oeuvre les changements nécessaires à l'assurance de la durabilité des écosystèmes qui sont biologiquement sains, fonctionnels et variés, les êtres humains doivent pouvoir garder espoir et croire qu'ils pourront un jour coexister avec les nombreuses formes de vie qui existent sur notre planète. La solution se trouve en partie dans le monde naturel et dans sa capacité d'émerveiller. Si l'on peut susciter chez l'être humain l'amour de tout ce qui est vivant, l'avenir de la biodiversité pourra être assuré, et ce, si tout le monde établit plus de contacts avec les autres formes de vie sur terre et prend de plus en plus conscience des tendances négatives qui menacent celles-ci.

Le symposium a été honoré par la présence d'autres conférenciers invités représentant des organismes internationaux tels que l'Organisation météorologique mondiale (OMM), l'Union Internationale pour la Conservation de la Nature (IUCN), la Convention sur la diversité biologique (CBD), la Convention-cadre des Nations Unies sur les changements climatiques (CCNUCC), l'Organisation des Nations Unies pour l'éducation, la science et la culture (UNESCO), le Fonds mondial pour la nature (WWF), Conservation International (CI), Conservation de la nature et Smithsonian Tropical Research Institute (STRI), ainsi que plusieurs universités et des représentants des secteurs de l'énergie et de la foresterie. Au total, 55 communications et 28 affiches ont été présentées, et plus de 130 scientifiques se sont inscrits au symposium. Vingt-etun pays des Amériques étaient représentés avec des conférenciers de St. Vincent et les Grenadines, des ÉtatsUnis; des affiches ont été présentées par le Canada, la Guyane, le Paraguay et le Venezuela; et les participants provenaient de la Colombie, du Guatemala, de Haïti et de Uruguay.

Nous espérons que vous avez aimé cette collection d'articles examinés par les pairs représentant certains des principaux penseurs sur la biodiversité et le changement climatique. Les articles sont organisés dans ce livre autour de trois grands thèmes : « Changement climatique et biodiversité », « Impacts du changement climatique sur la biodiversité » et « Applications pour gérer le changement climatique et la biodiversité ». Une série additionnelle d'articles scientifiques est en préparation pour publication dans le cadre de la série de publications scientifiques du Smithsonian Institution. Ces articles, avec la déclaration de Panama (voir l'annexe) sont une contribution méritoire à nos activités continues pour collectivement développer notre capacité d'adaptation au changement climatique.

Les éditeurs,

Adam Fenech, Don MacIver et Francisco Dallmeier



CHAPTER

1

CLIMATE CHANGE AND BIODIVERSITY

PAPER

1 CLIMATE CHANGE AND BIODIVERSITY IN THE AMERICAS

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

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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.

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PAPER

2

PERSPECTIVES ON CLIMATE CHANGE FROM THE CONVENTION ON BIOLOGICAL DIVERSITY

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ABSTRACT: The Millennium Ecosystem Assessment as well as recent reports from the Intergovernmental Panel on Climate Change has made us all aware that climate change negatively impacts natural resources and that it is one of the main drivers of biodiversity loss. From the dramatic decline in amphibian populations in Central and South America, to the decreased fitness of polar bears in the Arctic, and the spread of the pine beetle in North America's forests, impacts have been felt across the Americas. It is important, as we work to achieve the 2010 Biodiversity Target to significantly reduce the rate of biodiversity loss, that we both consider the role of biodiversity in climate change mitigation and adaptation and enhance the ability of biodiversity to resist and respond to this rapidly emerging challenge. In order to accomplish this, the vital link between two of the most pressing environmental issues facing our planet - biodiversity loss and climate change - needs to be better understood. Some important emerging links between biodiversity and climate change can be found in ongoing discussions on avoided emissions from deforestation and forest degradation, adaptation and vulnerability, traditional and indigenous knowledge and the conservation and sustainable use of critical ecosystems such as wetlands, coastal zones, mountains, and dry and sub-humid lands. The role of protected areas and natural corridors in climate change mitigation and adaptation are also emerging issues for discussion. The Convention on Biological Diversity (CBD) set the international framework regarding biodiversity and very early on looked into the relationship between biodiversity and climate change. The CBD, through its cross-cutting issue on climate change, is enhancing the integration of climate change components within all of the programmes of work of the Convention. The Convention has also built synergies with the United Nations Framework Convention on Climate Change and convened an Ad Hoc Technical Expert Group on climate change and biodiversity to provide scientific and technical guidance on the issue. There remains, however, a number of challenges and opportunities for the further development of interlinkages between biodiversity and climate change, many of which will need to be addressed through national implementation. These include capacity buliding, mainstreaming,communication and awareness-raising and research and technology.

Keywords: biodiversity, climate change, Convention on Biological Diversity, adaptation, mitigation, conservation, sustainable use of biodiversity

Introduction

The fourth assessment report of the Intergovernmental Panel on Climate Change (IPCC, 2007) presents clear evidence that, since the mid-1800s, average annual global temperatures have increased by about 0.74°C. Climate change impacts include atmospheric and oceanic temperature increases, melting glaciers and sea-ice, changes in river flows, shifting patterns of precipitation, heightened storm surges, flooding, drought and rising sea levels. Between 1970 and 2004, global greenhouse gas emissions rose by 70% with carbon dioxide (CO_2)

emissions increasing at the fastest rate (IPCC, 2007). In fact, even if all greenhouse gas emissions were halted today, the impacts would continue to be felt for 50 years.

This global climate change also affects biodiversity. Recent changes in climate, especially warmer regional temperatures and shifting precipitation patterns, have already had significant impacts on biodiversity and ecosystems, through changes in species distribution, population sizes and timing of reproduction, migration events and increases in frequency of pest and disease outbreaks. These changes are projected to exacerbate the loss of biodiversity and increase the risk of extinction for many species. By the end of the century, climate change and its impacts may be the dominant direct driver of biodiversity loss and changes in ecosystem services globally (Millennium Ecosystem Assessment, 2005).

This paper presents the main impacts of climate change on biodiversity, as well as the role of biodiversity in climate change adaptation and mitigation. The paper also illustrates how the Convention on Biological Diversity addresses the issue of climate change, and the different challenges and opportunities that exist in this area.

Observed and Projected Climate Change Impacts on Biodiversity

The relationship between climate change and levels of biological diversity is of increasing concern due to anthropogenic increases in green house gas emissions. Studies of fossil records have shown that biodiversity richness was relatively low and extinction rates relatively high during warm phases, providing the evidence that the global climate impacts biodiversity at the global scale (Mayhew *et al.*, 2007). This pattern is, however, largely based on slowly emerging climatic changes or brief fluctuations during relatively stable cycles. According to the IPCC (2007), if temperature increases exceed 1.5 to 2°C, 20 to 30% of plant and animal species assessed will be at risk of extinction. Climate change is projected to exacerbate the loss of biodiversity and increase the risk of extinction for many species, especially those already at risk due to factors such as low population numbers, restricted patchy habitats, and limited climatic ranges (Millennium Ecosystem Assessment, 2005). Although estimates vary, as many as one million species may face increased threats of extinction as a result of climate change (Thomas *et al.*, 2004).

Climate change has already begun to affect the functioning, appearance, composition and structure of ecosystems. Recently observed changes in the climate, especially warmer regional temperatures and shifting precipitation patterns, have already had significant impacts on biodiversity and ecosystems, including changes in species distribution and population sizes, timing of reproduction or migration events, and increase in frequency of pest and disease outbreaks.

Between 1980 and 2005, summer minimum Arctic ice cover has generally decreased by 7.4% per decade (Lemke *et al.*, 2007). Even though sea ice extent varies with years and seasons, global projected trends for the future show a distinct downward trend. Indeed, simulations based on IPCC emission scenarios suggest a mean reduction of 22 to 33% in annually averaged sea ice area in the Arctic by 2080-2100 (Zhang and Walsh 2006). The marked reduction of the Arctic ice canopy is forcing polar bears to fast for increasingly longer periods of time and has increased the areas of open water across which polar bears must swim. In the course of the last 25 years, the average weight of female bears has dropped in some areas by 20%, thereby endangering their reproductive capacity (NASA 2006).

Climate change also greatly affects tropical areas. The golden toad of Costa Rica, for instance, has not been seen since 1989 (Pounds *et al.*, 1999). It is labelled as one of the first victims of climate change. Other impacts of climate change on ecosystem functions include the widespread bleaching of corals; instances of wetland salinization and salt water intrusion; the expansion of arid and semi-arid lands at the expense of grasslands and acacia; poleward and upward shifts in habitats; replacement of tropical forests with savanna in the Amazon Basin and Mexico; and shifting desert dunes. In fact, climate change impacts every ecosystem and these impacts can also reflect on the health of the biodiversity in surrounding ecosystems.

Even if greenhouse gas emissions were to decrease significantly tomorrow, climate change would continue to affect ecosystems for hundred of years due to global climate feedbacks mechanisms. For example, models suggest that by 2050, the Great Barrier Reef may have lost 95% of its living coral (WWF, 2004). As snow cover decreases and mountain ecosystems change, species living at or above the snowline, such as the mountain pygmy possum, are likely to go extinct (Pickering *et al.*, 2004). In sub-Saharan Africa, between 25 and 40% of mammals in national parks will become endangered while as many as 2% of the species currently classified as critically endangered will become extinct (Boko *et al.*, 2007). In the Succulent Karoo and Fynbos ecosystems in Southern Africa more than 50% of habitat is expected to be lost by 2050 (Boko *et al.*, 2007). By the end of the century, 43% of 69 tree plant species studied could become extinct in Amazonia (Miles *et al.*, 2004).

Certain regions are particularly vulnerable to climate change. In Asia, up to 50% of biodiversity is at risk due to climate change while as many as 88% of reefs may be lost over the next 30 years (Cruz *et al.*, 2007). Furthermore, as many as 1522 plant species in China and 2835 plants in Indo-Burma could become extinct (Malcolm *et al.*, 2006). If projected rises in sea level occur, American Samoa could lose 50% of their mangroves and 15 other Pacific islands could face a 12% reduction in mangrove cover (Mimura *et al.*, 2007). Furthermore, a projected 0.5 meter sea-level rise in the Caribbean could cause a 35% decrease in turtle nesting habitat (Fish *et al.*, 2005).

Increasing threats to ecosystem services as a result of climate change have negative consequences for biodiversity-based livelihoods particularly among the poor. While subsistence and biodiversity-based livelihoods, such as subsistence agriculture, artisinal fisheries and handicraft industries, are among the least contributors to climate change, they are expected to be among the most vulnerable to the negative impacts.

Likewise, indigenous and local communities are particularly vulnerable to the negative impacts of climate change. They tend to be among the first to face the adverse consequences of climate change as a result of their dependence on, and close relationship with, the environment. Indigenous and local communities in Small Island Developing States, the Arctic, dry and sub-humid lands and high altitude areas have been identified as being particularly vulnerable.

Impacts of climate change on indigenous and traditional livelihoods include changes in prey availability in the Arctic, increased weed infestations in grazing lands throughout the world and increased exposure of livestock to disease especially in Africa. Loss of livelihoods and traditional practices of populations living in particular ecosystems are already significant. For instance, in communities living in mangroves the harvesting of dyes to treat textiles, nets and fish traps and the gathering of raw materials for handicrafts such as pupu shells in the Cook Islands are threatened.

The negative impacts of climate change on key ecosystem goods and services can affect millions of people at once. For example, the coasts of Africa support vibrant fisheries which provide up to 50% of protein requirements to some coastal communities and support a quarter of Africa's population. In the

Caribbean and Pacific, more than half of the population lives within 1.5 kilometers of the coast and have their livelihoods threatened by increased coastal erosion, damages from storm surges and coral die-offs. In fact, within the next 30 to 50 years coral bleaching could become an annual event in Small Island Developing States, putting at risk local economies and income derived from tourism.

Likewise, while a warming of up to 2 °C may have positive effects on pasture production and livestock in humid temperate regions, the same increase is expected to negatively impact production in arid, semi-arid and tropical regions (Easterling *et al.*, 2007). In Egypt, for example, climate change could, by 2050, decrease the national production of rice by 11% and of soybeans by 28% compared to their production under current climate conditions (Boko *et al.*, 2007). Due to a lack of information, it is unclear what impact should be expected in tropical grasslands and rangelands. However, warming greater than 3 °C is projected to have negative impacts on agricultural production in all regions (Easterling *et al.*, 2007).

Role of Biodiversity in Climate Change Adaptation and Mitigation

Biodiversity contributes to many ecosystem services including the provision of food and fodder, nutrient cycling and the maintenance of hydrological flows. As such, maintaining biodiversity and associated ecosystem functions is an important component of climate change adaptation. Likewise, biodiversity resources such as land races of common crops (including wheat, rice and maize which together account for 50% of the world's dietary requirements), mangroves and other wetlands and vegetative cover can form an integral part of adaptation plans.

As one example, coastal wetlands can provide protection against storm surges and wave action and are an important habitat for fish and birds. In fact, in Malaysia, the value of mangroves for coastal protection is estimated at USD300,000 per kilometer of coast (Gilman *et al.*, 2006). Furthermore, adaptation linked to agricultural biodiversity, such as changing varieties in cereal cropping systems, is expected to avoid 10 to 15% of the projected reductions in yield under changing climatic conditions (IPCC, 2007).

The conservation and sustainable use of biodiversity as a tool to maintain and enhance the resilience of ecosystems are therefore crucial to climate change adaptation and land-use and forest based mitigation. The resilience of ecosystems can be enhanced through the creation of ecological corridors, networks of protected areas, refuges and buffer zones; restoration of native ecosystems; protection and enhancement of ecosystem services; and reduction of other existing threats to biodiversity such as habitat fragmentation, overharvesting, pollution and land use change.

In integrating biodiversity into adaptation and mitigation, it is also important to consider the observed and predicted responses of species and ecosystems to climate change. In particular, climate change will force some species to shift habitat and will favor survival of species that are better able to adapt to changing climatic conditions. In coral reefs, for example, some species of coral have a high degree of natural adaptive capacity. Since such corals will play an important role in maintaining the structure of coral reefs as other corals die off, the identification and protection of these highly adaptive species is critical. Likewise, in the face of sea-level rise, mangroves can move inland while maintaining a functioning coastal ecosystem as long as the inland route is not blocked by development.

To adapt to climate change, adjustments in the way we use and manage biodiversity will be necessary. For instance, drought tolerant crops can be planted and improved water harvesting and storage should be promoted in regions where temperature increases are forecasted. The use of pest-resistant varieties, efficient management of rainwater, and change in timing of planting, irrigation and fertilizer use are other examples of activities that may help reduce the impacts of climate change.

Biodiversity also contributes to climate change mitigation. Forests account for as much as 80% of the total above-ground terrestrial carbon while peatlands, which only cover 3% of the world's terrestrial surface, store 30% of all global soil carbon or the equivalent of 75% of all atmospheric carbon (Parish *et al.*, 2007). As such, healthy forests and wetland systems have the potential to capture a significant portion of projected emissions.

However, each year about 13 million hectares of the world's forests are lost due to deforestation. This deforestation is currently estimated to be responsible for 20% of the annual human induced CO_2 emissions.

On the other hand, sustainable land management in agricultural areas can increase carbon sequestration in the soil through techniques such as integrated pest management, conservation tillage, intercropping, and the planting of cover crops. In fact, when cover crops are used in combination with conservation tillage, soil carbon content can increase annually for a period of up to 50 years.

The sustainable management of grazing land can provide similar co-benefits since such lands contain between 10 and 30% of the world's soil carbon stocks.

Another emerging role of biodiversity in greenhouse gas mitigation is the use of bioenergy, which derived from renewable sources, are considered to be carbon-neutral, since in theory the carbon released during the combustion can be taken up by growing plants. However, the greenhouse gas reduction potential ultimately depends on the type of biomass used and the associated production practices including the extent and type of land conversion for biomass production. If produced in a sustainable way, the use of biomass to produce bioenergy can efficiently mitigate climate change impacts while enhancing biodiversity, especially on degraded lands.

Climate Change and the Convention on Biological Diversity

The Convention on Biological Diversity (CBD) is the international framework for the conservation and sustainable use of biodiversity and the equitable sharing of its benefits. With 191 Parties, the CBD has near-universal participation among countries that have committed to preserving life on Earth. The CBD seeks to address all threats to biodiversity and ecosystem services, including threats from climate change, through scientific assessments, the development of tools, incentives and processes, the transfer of technologies and good practices and the full and active involvement of relevant stakeholders including indigenous and local communities, youth, non-governmental organizations (NGOs) and women.

The Convention's cross-cutting issues on biodversity and climate change and the ecosystem approach allow for the comprehensive consideration of biodiversity-climate change links and response solutions. Both cross-cutting issues take into account the local, national and international levels, as well as the traditional knowledge and the local and indigenous communities.

The CBD is also mainstreaming climate change components within all of the programmes of work of the Convention. This began with a commitment to adaptation activities during the fifth meeting of the Conference of the Parties (COP) in May 2000 which addressed adaptation regarding coral bleaching. Adaptation is also mentioned specifically in the programmes of work on mountains, forests, inland waters, island biodiversity, and protected areas while the programme of work on the biodiversity of dry and sub-humid lands refers specifically to vulnerability to climate change.

In order to support the mainstreaming of climate change, the Subsidiary Body on Scientific, Technical and Technological Advices (SBSTTA) of the Convention established in 2001 an ad hoc technical expert group to carry out an assessment of the interlinkages between biodiversity and climate change, and produced two technical reports (SCBD 2003; SCBD 2006a) based on the best available scientific knowledge.

Based on scientific information and observed changes, Parties to the CBD have acknowledged both the need to facilitate the adaptation of biodiversity to the impacts of climate change, such as in the case of mountain biodiversity, and the contribution of biodiversity to broader adaptation activities, such as peatlands within the inland waters biodiversity programme.

At its ninth meeting in 2008, the COP adopted a comprehensive decision on biodiversity and climate change which called for enhanced synergies between biodiversity, climate change and land degradation, especially at the national level.

Particularly relevant to the climate change issue, COP 8 and COP 9 adopted decisions focusing on the links between the CBD and Nairobi work programme on impacts, vulnerability and adaptation to climate change and the reducing emissions from deforestation mechanism under the United Nations Framework Convention on Climate Change (UNFCCC) was adopted. Since then, the UNFCCC has acknowledged that reducing emissions from deforestation in developing countries can contribute to the achievement of other international conventions. The same decision under the UNFCCC calls on Parties to note the relevant provisions under the CBD when implementing demonstration activities to reduce emissions from deforestation and forest degradation.

Finally, at COP 9, Parties convened a new series of Ad Hoc Technical Expert Group Meetings to provide biodiversity-relevant information to the UNFCCC process. The first meeting of the group will focus on impacts and vulnerability and the links between biodiversity and climate change mitigation. The second meeting will generate scientific and technical advice on the links between biodiversity and climate change adaptation.

The three Rio Conventions—on Biodiversity, Climate Change and Desertification—derive directly from the 1992 Earth Summit. Each instrument represents a way to contribute to the sustainable development goals of Agenda 21 and, as such, the three conventions are intrinsically linked, operating in the same ecosystems and addressing interdependent issues. In 2001, the Rio Conventions established a Joint Liaison Group (JLG) to enhance the exchange of information and explore opportunities for synergistic activities.

Activities for enhanced synergies on adaptation, as identified by the JLG, include providing focal points of all Conventions with up-to-date information on relevant assessments, research programmes and monitoring tools; collaborating on the development of common messages on the linkages among climate change, biodiversity and desertification; developing educational materials; and establishing joint web-based communication tools.

As an initial contribution, the CBD Secretariat, with the support of the Government of Canada, developed a web-based guidance on the integration of biodiversity considerations within climate change adaptation planning (**http://adaptation.cbd.int/**). This web-based communication tool makes relevant materials available to Parties including: a map displaying vulnerable regions, sub-regions, ecosystem types and natural World Heritage Sites; tables outlining the threats to biodiversity from climate change and the impacts of adaptation options on biodiversity; searchable databases of relevant documents and websites; and an interactive map of case studies on biodiversity in adaptation planning.

The three Secretariats also recently launched joint publications on forests, biodiversity, land degradation and climate change and on adaptation, biodiversity and land degradation. These publications raise awareness of the relevant provisions under each convention including emerging issues and opportunities to enhance synergies.

The CBD and the United Nations Convention to Combat Desertification are also joining forces with regards to the biodiversity of dry and sub-humid lands. These ecosystems are vulnerable to the combined effects of biodiversity loss, desertification and climate change. Since these areas are usually dominated by agricultural activities there are also significant linkages to the CBD programme of work on agro-biodiversity.

Climate change, as one of the main drivers of change for biodiversity, is also reflected in the 2010 biodiversity target to significantly reduce the rate of biodiversity loss. Target 7 to maintain and enhance resilience of the components of biodiversity to adapt to climate change is crucial in the battle against biodiversity loss. The Global Biodiversity Outlook 2 (SCBD 2006b), which looks at the prospects for achieving the 2010 biodiversity targets, concluded that progress related to target 7 is challenging and depends on protecting the critical habitats, populations of species and genetic diversity that contribute to resilience and/or facilitate adaptation in the face of climate change.

The CBD also has a role to play in raising awareness. People have the power to trigger massive changes. Climate change already benefits from wide media coverage, which increases public knowledge and leads to changes in daily habits or political choices. The level of awareness of the importance of biodiversity and its interlinkages with climate change needs to be raised. To this end, the theme for the 2007 International Day for Biological Diversity, which was celebrated by more than 60 countries and 14 partner organizations, was biodiversity and climate change.

Challenges and Opportunities for the Future

Although much progress on biodiversity conservation and sustainable use and addressing climate change has been made in the international framework, there remains a number of challenges and opportunities for further consideration. Opportunities for collaboration and related emerging issues on the links between the conservation and sustainable use of forest biodiversity and climate change (including within the framework of reducing emissions from deforestation) include monitoring and reporting which are crucial to the implementation of mitigation strategies.

Engagement by the private sector constitutes an important step in the fight against climate change. Already, pioneering initiatives with a business dimension have been established, including the Potsdam Initiative – Biological Diversity 2010, agreed by the G8 + 5 countries (Brazil, China, India, Mexico and South Africa) in March 2007, and the consideration of ecosystem services as one of the four focus areas of the World Business Council for Sustainable Development.

Although climate change activities have not yet been integrated within the programme of work on Technology Transfer, the CBD and the UNFCCC have long been working collaboratively on technology transfer through the exchange of information and efforts to harmonize relevant databases. In addition, Parties and other Governments have committed to exploring possible ways and means by which incentive measures promoted through the Kyoto Protocol can support the objectives of the CBD.

Enhancing the integration of climate change impact and response activities within the programmes of work of the CBD remains of great importance to strengthen collaboration. Accordingly, the links between biodiversity and the programmes of work will be evaluated during all in-depth reviews of implementation and proposals on ways to improve the links will be considered.

The JLG identified a number of opportunities for collaboration on cross-cutting activities including capacity building, technology transfer, research and monitoring, information and outreach, reporting, and financial resources. Promoting synergies at the national level is also crucial and usually represents a challenge. National level cooperation will often allow for the most efficient and effective coordination on the implementation of commitments under each convention.

Conclusion

There is now clear evidence that climate change is already affecting humans and ecosystems, and will continue to do so. Many different assessments now highlight the interlinkages that exist between biodiversity and climate change: biodiversity is threatened by climate change, but the conservation of biodiversity can also promote the adaptation to and mitigation of climate change impacts.

Early on, the Convention on Biological Diversity examined the issue of climate change, taking decisions acknowledging its impact on biodiversity, and its role in adaptation and mitigation. A number of opportunities exist for collaboration on this topic between other Rio conventions, and action is moving towards incorporating climate change and biodiversity considerations into areas such as capacity building, education and awareness raising, technology transfer, and research. There is evidence that the links between the two issues are being recognized at the national level, as many countries are now providing examples of good practice and are showcasing the value of maintaining rich and diverse ecosystems in the face of climate change.

Finally, the consideration of climate change in biodiversity conservation strategies and the integration of biodiversity into climate change adaptation and mitigation plans are crucial. Overall, increased synergies and collaboration at all levels and an enhanced implementation of the Convention are vital in the battle against climate change.

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PAPER

3

BIODIVERSITY AND CLIMATE CHANGE: CHALLENGES FOR THE UNESCO WORLD NETWORK OF BIOSPHERE RESERVES

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ABSTRACT: 531 biosphere reserves in 105 countries to-date have been proposed by UNESCO Member States and recognized by the UNESCO Man and the Biosphere (MAB) Programme. While sites nominated prior to 1995 are mostly conservation areas with buffer zones and, at times, transition areas, post-1995 designations are true land/seascape units with a mix of natural and rural, and some times urban, ecosystems. In the more than 200 post-1995 biosphere reserves legally protected area core zones make up only 11% of the total area; the rest of the 89% is spread across buffer zones and transition areas that have multiple resource use and regulatory regimes and where trade-offs between biodiversity conservation and socio-economic development need to be worked out with the participation of stakeholders. Climate change mitigation presents challenges as well as opportunities in buffer zones and transition areas with the potential to link mitigation tactics with adaptation scenarios for biodiversity extending beyond the legally protected core zones. A six year Plan agreed upon at the 3rd World Congress of Biosphere Reserves held in Madrid, Spain, from 4 to 9 February 2008 presents opportunities to use biosphere reserves as learning places for sustainable development, that is, deriving context specific mix of climate change mitigation, biodiversity conservation and human well-being enhancement measures that could attract sustainable investments into these UNESCO recognized places.

Keywords: biodiversity, climate change, biosphere reserves, UNESCO

1. Introduction

The significance of the anthropogenic component of global climate change today is increasingly acknowledged by decision makers and policy professionals. Human impacts on nature have drawn increasing attention from international organizations over the last 4-5 decades during which the global environmental movement has grown and matured. Pollution and conservation have been the twin pillars of that global environmental movement (Paehlke, 1989). The Man and the Biosphere (MAB) Programme of UNESCO, launched in 1971 was probably the first intergovernmental initiative that provided a framework to address a mix of conservation and pollution problems and issues.

The first 14 projects of MAB (table 1) had an equal share of projects addressing ecological effects of human activities on natural ecosystems in the tropics as well as in temperate regions (projects 1-7); and ecological assessments of the built environments like urban areas (project 11) industrial installations (major engineering works – project 10) and rural landscapes (fertilizer and pesticides use – project 9), respectively.

The UNESCO World Network of Biosphere Reserves (hereafter WNBR) originated under project 8 – conservation of natural areas and the genetic materials they contain. Today's 531 biosphere reserves in 105 countries represent ecosystems that are minimally disturbed by humans, for example, Galapagos (Ecuador); Yellowstone (USA); and Serengeti-Ngorongoro (Tanzania); and others that have been entirely reconstructed after damage during war (Can Gio, Vietnam), designed landscapes (Fontainebleu, France) or a mix of natural, rural and urban ecosystems (Mata Atlantica, Brazil).

The challenge for the WNBR to contribute towards mitigation tactics and adaptation strategies for biodiversity in the face of climate change drew considerable attention in the preparation of the Madrid Action Plan (MAP;

TABLE 1

Projects adopted by the International Co-ordinating Council of the MAB Programme in 1971

1. Ecological effects of increasing human activities on tropical and sub-tropical forest ecosystems.
2. Ecological effects of different land uses and management practices on temperate and Mediterranean forest landscapes.
3. Impact of human activities and land use practices on grazing lands, savannah and grassland (from temperate to arid areas).
4. Impact of human activities on the dynamics of arid and semi-arid ecosystems, with particular attention to the effects of irrigation.
5. Ecological effects of human activities on the value and resources of lakes, marshes, rivers, deltas, estuaries and coastal zones.
6. Impact of human activities on mountain and tundra ecosystems.
7. Ecology and rational use of island ecosystems.
8. Conservation of natural areas and of the genetic materials they contain.
9. Ecological assessment of pest management and fertilizer use on terrestrial and aquatic ecosystems.
10. Effects on man and his environment of major engineering works.
11. Ecological aspects of urban systems with particular emphasis on energy utilization.
12. Interactions between environmental transformations and the adaptive, demographic and generic structure of human populations.
13. Perception of environmental quality.

In 1974, ICC added a 14th Project on environmental pollution and its effects on biosphere.

UNESCO-MAB 2008; see **www.unesco.org/mab** for the full text). MAP was adopted by the 20th International Co-ordinating Council (ICC) of the MAB Programme that convened at the time of the 3rd World Congress of Biosphere Reserves held in Madrid, Spain from 4-9 February 2008. This paper describes some aspects of the evolution of the concept and application of biosphere reserves in order to articulate the potential role WNBR could play in promoting co-operation across the Americas to address issues and problems at the interface between biodiversity and climate change.

2. Biosphere Reserves: concept, practice and the world network

Of the 531 sites in 105 countries that currently make up the WNBR, the distribution in the Americas are as follows: 102 sites in 19 countries of Latin America and the Caribbean; 47 sites in the US; 15 in Canada, respectively.

MAB Project 8 – conservation of natural areas and of the genetic materials they contain (Table 1) – which led to the establishment of the WNBR originated from MAB's vision for integrating people's futures into the management of conservation areas. Scientific research and nature conservation were key attributes for sites to be designated a biosphere reserve during the early phase of the evolution of the WNBR in the late 1970s. In the first year of the inclusion of sites in the WNBR in 1976, the USA successfully proposed 26 of its 47 sites (see **www.unesco.org/mab** for the full set of 531 sites in 105 countries and their year of recognition as biosphere reserves). Those 26 included experimental and research stations such as the H.J. Andrews Experimental Forest (Oregon), Hubbard Brook Experimental Forest (New Hampshire) and the University of Michigan Biological Station (Michigan).

Over the last 32 years however, what defines a biosphere reserve in practice has changed. Those changes are on the one hand responses to shifting perceptions of the human-environment relationships within the international community of nations and on the other a closer match between the concept's practice and the vision of the MAB programme that promoted an integrated approach to planning and management of natural and human-constructed systems as interacting components of integral land/seascapes (Batisse, 1982, 1986 and 1993; UNESCO, 1995).

Three generations of biosphere reserves have been identified (Ishwaran *et al.*, 2008); over more than 30 years the evolution of the concept of biosphere reserves and its application to territories under the sovereign authority of UNESCO Member States has come to emphasize the following:

- Biosphere reserves have three important functions: conservation, development and logistic, respectively. The logistic function is a mix of research and monitoring, training and capacity building and stakeholder dialogue and participation. It is increasingly seen as the knowledge and learning function. The contribution of a biosphere reserve to sustainable development of the region where it is located is determined not merely by its development function which addresses the socio-economic needs and aspirations of the communities resident in the biosphere reserve; but by the context specific nature and effectiveness of the integration of the three functions to generate economic, environmental and social benefits to the region over the long term.
- Parallel to the emergence of the above mentioned functional triple bottom-line of a biosphere reserve was the acknowledgement of the necessity of a three-zone scheme for the management of biosphere land/seascapes. All biosphere reserves now have a legally protected core zone and a buffer and a transition zone; while resident human communities may be absent in the core their presence in buffer and transition zones is a necessary condition for biosphere reserve status. The Seville Strategy and the Statutory Framework for the WNBR adopted in 1995 (UNESCO, 1995; see www.unesco.org/mab/ for a full text) brought about the mind-shift from visualizing biosphere reserves as conservation-cum-research areas to imagining them as adaptive landscapes experimenting with place specific combinations and permutations of the economic, environmental and social pillars of sustainable development. In the more than 200 places designated as biosphere reserves since 1995, only about 11% of the designated territory is in legally protected core zones; the rest of the 89% is in buffer and transition zones, respectively (Ishwaran *et al.*, 2008), where economic growth and socio-cultural well being of human communities are important objectives of management.
- Resident human communities are now an obligatory requirement for nominating a place as a biosphere reserve. In fact places designated in the early days of the history of WNBR, in particular during 1976-1990, are being reviewed with a view to adapt them to current praxis and in some cases where such adaptation is not possible UNESCO Member States have begun withdrawing the sites from the World Network. As part of the statutory requirement to undertake a review of biosphere reserves that have had the UNESCO designation for 10 years or more several States have also modified the boundaries of their pre-1995 biosphere reserves to bring the design and management of the site to match expectations of current management practice.

3. Biodiversity and climate change: risks and opportunities in Biosphere Reserves

As the consequences of climate change become more and more evident any territory of land/seascape set aside for conservation and/or scientific study would become valuable as sites for long-term observations and experiments. The early US biosphere reserves, including some of the research and experimental stations referred to in this paper, have been part of Long Term Ecological Research (LTER) and other global networks that contributed data used in current modelling and forecasting efforts to predict climate change responses of biodiversity. Nevertheless, their value in demonstrating site-specific adaptations of biodiversity to climate change is likely to be limited owing to their small sizes. The same will apply to many protected areas throughout the world that are small in size and have become islands of biodiversity surrounded by land and resource use regimes that do not allow for migration of species or expansion of ranges of species as adaptation to climate change.

Those biosphere reserves that fit the current core-buffer-transition zone scheme however, present significant opportunities to become areas of not only long-term observations, but also for experimenting with adaptations of biodiversity to climate change in land/seascapes. The large size of many of today's biosphere reserves, such as those in Brazil shown in Table 2, make them critical open-air "laboratories" to carry out observations as well as action-research projects to understand adaptations of biodiversity at ecosystem, species and genetic levels to climate change.

Biosphere reserves in the Americas, and particularly those in the US and Canada that are data rich, may provide opportunity to evaluate models that forecast

TABLE 2

Areas of core, buffer and transition zones of Brazilian biosphere reserves
Data source: www.unesco.org/mab/

Name of BR	Core	Buffer	Transition	Total hectares
Mata Atlantica	4,052,044	12,646,302	12,774,638	29,473,484
Cerrado	3,061,014	14,884,200	11,167,300	29,652,514
Pantanaal	664,245	5,392,480	19,100,180	25,156,905
Caatinga	1,000,342	13,545,000	5,353,658	19,899,000
Central Amazon	4,039,149	7,435,687	9,385,142	20,859,987
Espinahaco Range	204,522	1,879,996	991,939	3,076,457

climate change impacts on biodiversity. Nearly all of the Canadian Biosphere Reserves and some US sites, such as the Southern Appalachian, are large territories. Evaluation of models using actual data has been identified as one of the eight needs to improve forecasting effects of global warming on biodiversity (Botkin *et al.*, 2007). The overall availability of data on biodiversity in the Americas is perhaps both quantitatively and qualitatively better than in many other parts of the world. The 102 biosphere reserves in the Americas to-date could provide places that could be aligned along climatic, ecological and other gradients to test the range of models that have been used to forecast climate change impacts on biodiversity and to observe biodiversity responses to climate change at ecosystem, species and genetic levels.

Modelling and forecasting are key tools that have driven the science of global climate change debates and discussions. Even in developed nations it is not evident that all policy and decision makers understand the basis of modelling; particularly the assumptions that modellers have used and the verifiability of model predictions. In less developed countries, however, policy and decision makers may have even lesser appreciation of modelling as a tool to visualize scenarios for the future. Research on the climate change negotiations has revealed that less developed countries have ratified UNFCCC "less out of a deep-felt concern for the problem as a top priority than out of notions like solidarity...the desire to influence rules at the stages at which they are negotiated...and the desire for financial and technological gain" (Gupta, 2001).

Hence, understanding of the scientific validity behind climate change arguments by policy and decision makers and other stakeholders including resident communities in and around biodiversity rich areas will benefit from more context-specific dialogues and debates and possible experimentation in participatory scenario-modelling. People are likely to recognize the seriousness of an issue or problem if forecasts on possible impacts and consequences could be presented in terms of risks and opportunities for their day-to-day livelihoods and futures. Biosphere reserves are ideal platforms for such multi-stakeholder dialogues for translating the concern for global problems and issues into local understanding and appropriate actions. Stakeholder dialogues to resolve issues and problems have become a feature of biosphere reserve management and practice (Bouamrane, 2006). The relevance of climate change to adaptations of sustainable use and conservation of biodiversity in biosphere reserves and their consequences for human well-being will receive considerable attention during the implementation of the Madrid Action Plan (2008) from 2008 to 2013.

While climate change mitigation strategies emphasize minimizing emissions or capturing green-house-gases already emitted or that will be continued to be emitted in the coming years and decades they do constitute an important part of our learning to adapt to the warmer world that has been widely focussed for the latter half of the 21st century. One of the most important aspects of this learning will happen with regard to driving financial investments towards more environmentally-friendly pathways for driving economic expansion and improvements in the socio-cultural well-being of human communities. Buffer and transition zones of biosphere reserves now comprising nearly 90% of the area of biosphere reserves may serve as living land/seascapes where such learning can happen.

As the Kyoto Protocol established under the UN Framework Convention on Climate Change (UNFCCC) has come into operation, a market in carbon-trading has emerged whose value now is estimated in several billions of dollars. A significant segment of the Kyoto-driven carbon markets are linked to the industrial ecological dimension of climate change mitigation, that is sequestering carbon and/or minimizing greenhouse gas emissions of power, mining, oil and gas, construction, transportation, solid waste management and other industries. Land use sectors such as forestry and agriculture, through their contributions to greenhouse gas emissions as high as industrial sectors such as transport, have not significantly benefited from Kyoto-driven markets. Furthermore, avoided deforestation, a mitigation tactic of significant importance to biodiversity, remains an investment opportunity restricted to voluntary carbon markets.

Yet, as awareness of the consequences of global warming and climate change grow, importance of forests to maintaining carbon stocks are gaining increasing recognition within the global investment community. Voluntary Carbon Standards are attracting considerable attention of the research community as carbon-offsets from forestry projects traded within voluntary markets reach 35-50%. Agriculture, forestry and other land use (AFOLU) projects that cover afforestation, reforestation and revegetation (ARR), agricultural land management (ALM), improved forest management (IFM) and reducing emissions from deforestation (RED), are attracting voluntary market interests to an increasing extent (VCS, 2007).

The large area of territory identified as buffer zone and transition area of biosphere reserves could ideally serve as "incubators" for these newly emerging markets in, and business approaches to, environmental and ecosystem services and products. While carbon markets have captured media and public attention owing to the climate change issue, more fledgling services markets in water, biodiversity and other ecological commodities will also perhaps grow in importance in the near future. Wyatt-Gibbs (2005) has imagined a farm of the future that generates half its income via water, biodiversity and carbon dioxide offset credits, certified sustainable timber and renewable electricity. Add to this other income and employment generating services linked to tourism and hospitality and research, monitoring and education and biosphere reserves could easily become centres seeking a new development paradigm that has better chances of sustainability in a world that faces the inevitable consequences of climate change. The current nature of the global environmental stresses may provide opportunities for such innovative development paradigms to be experimented with in an international network constituted by biosphere reserves. Given the fact that some of the markets for ecosystem services including water and biodiversity are making considerable headway in the USA, the biosphere reserve network of the Americas could be a good starting point for testing such new development approaches that are anchored on ecosystem services.

4. Conclusion

The current biosphere reserve design comprising a legally protected core, with substantial areas in buffer and transition zones outside of the core, provides important opportunities for observing and experimenting with biodiversity adaptations to climate change at ecosystem, species and genetic levels. The buffer and transition zones could be increasingly dedicated to experimenting with development pathways that are anchored in the maintenance of ecosystem and environmental services and for attracting investor interests in emerging biodiversity, water and carbon markets, sustainable and certified timber, renewable energy development as well as tourism and hospitality and research and educational services. Experimentation with such new development pathways will serve to link climate change mitigation and adaptation to sustainable development futures. The biosphere reserves of the Americas comprising 164 sites in 21 countries could serve as a network for international co-operation observations and experiments on biodiversity responses and adaptations of human communities to climate change.

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PAPER

4

CLIMATE CHANGE AND BIODIVERSITY IN HIGH LATITUDES AND HIGH ALTITUDES

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ABSTRACT: Present knowledge of environmental processes, and climate modelling, predict that the changes in planetary surface heat flux that appear to be in store will be greatest in high northern latitudes and in the sub-Antarctic. These effects can be expected to be further complicated in rugged mountainous districts, where the combination of low sun angle, great seasonal differences in solar energy received during winter and summer, and very uneven distribution of precipitation result in intense local contrasts in environmental conditions. Somewhat similar extreme environmental conditions prevail also in the highest mountain areas along the spine of the American Cordillera. Ecosystems that have developed in polar, sub-polar and high alpine conditions are typically low-energy systems, with relatively few species at each trophic level, and comparatively simple food chains. Individuals of the constituent species must have the ability to become dormant when conditions are unfavourable, or to migrate, sometimes over great distances. Such ecosystems, highly stressed by physical factors, commonly simple in organization but with great complexity of pattern, are inherently particularly vulnerable to rapid change in climate. They typically have evolved a delicate and complex intertrophic interdependence in which plant germination and growth, development and distribution of insects and other invertebrates including parasites and microfauna, and the life cycles and behaviour of vertebrates, each with a distinctive response and maturation period, are marvellously interlinked. Any rapid or significant change in climate is likely to disrupt this interlocking system and affect the biological diversity. A warming climate will also likely introduce new species from lower latitudes and altitudes, further disrupting the ecosystem. Human activities that affect the global climate and environment have distinctive consequences for the ecosystems and biological diversity of high latitudes. Among the serious effects are enhancement of ultraviolet-B radiation and concentration of toxic contaminants from the long-range transport of air pollution. Some of these characteristics and problems are being studied through the International Tundra Experiment (ITEX); the Zackenberg Ecological Research Operations (ZERO) in Greenland; at the Toolik Field Station in Alaska; and through the UNESCO MAB Global Change in Mountain Regions (GLOCHAMORE) network of Biosphere Reserves; while others are topics in the research of the current International Polar Year (IPY).

Keywords: climate change, biodiversity, altitude, latitude, elevation

1. Introduction

Much of the international research and monitoring activity dealing with the evidence, causes and consequences of changes in biological communities is focussed on biological abundance and complexity. Most studies and discussions of biological diversity are concerned with regions that are biologically rich, with large numbers of interactive species and complex ecosystems. But "The Americas", which extend over 14,000 kilometres and one hundred and forty degrees of latitude, from Kaffeeklubben Island at 82 degrees North Latitude to Diego Ramierez Island at 56 degrees South Latitude, contain lands of less biological abundance. In the high latitude portions of this extensive land mass and coastal area, environmental conditions are such that biological productivity is limited, and ecosystem complexity and diversity is low compared to that of lower latitudes. Because of the limited number of species and pathways of intertrophic interactions in such areas, the local and regional ecosystems are proportionally more sensitive to changes in species diversity.

At the same time, planetary geography and the current pattern of distribution of surface heat by atmospheric and ocean circulation is such that, for a given change in the overall global climate, both the absolute and relative changes in climatic conditions will be greatest in high northern and southern sub-polar areas. The relatively impoverished high-latitude biological systems, already inherently sensitive to changes in climate, will from present knowledge be subjected to the greatest disturbance from the climate changes that appear to be in store for the planet.

Current evidence of such sensitivity, although mostly observational and unconnected to coherent interpretation, is abundant - the plight of undernourished polar bears because the decrease in seasonal sea ice has reduced coastal marine productivity; the replacement of woodland caribou range by moose habitat in the sub-arctic because of the northward migration of shrub vegetation; and the disruption of the "traditional" timing and routes taken by migratory caribou are examples.

In a somewhat analogous fashion, the great Cordilleran chain that stretches from Alaska to Terre del Fuego contains many high peaks and plateaux even in lower latitudes where the environmental conditions are too harsh to support vegetation and its associated animal life in the abundance and diversity of that found nearby at lower elevations. In these areas also, small changes in biological diversity, from whatever cause including climate change, can have severe ecological consequences.

It is therefore important to recognize that changes in biological diversity due to climate change are equally, if not more, important to ecosystems that are already stressed by physical conditions and where species numbers are low, as they are in biologically rich areas. Research and monitoring in these environmentally harsh and deceptively "simple" areas may tell us much about the characteristics and the biological consequences of climate change and global change (Price *et al.*, 1994; MacIver *et al.*, 1994; Chapin and Korner, 1995).

2. Environmental characteristics of high latitudes and high altitudes

The distinct environmental characteristics of high latitude regions are first of all a consequence of the shape of planet Earth, its axis of rotation, and its orbit around the Sun. Because of the tilt of the Earth's polar axis, the Sun, as seen from the Earth's surface at higher latitudes, appears to be "lower" in the sky, and the amount of solar energy received on each square meter of land or sea is less. The average solar energy received on the Earth surface near the equator is about 140 watts per m^2; at 65 degrees north or south about 25 watts per m^2. Although in high latitudes solar energy is received at an oblique angle, the Earth radiates energy perpendicularly to outer space, as it does from every other part of the surface of the planet. There is thus a net loss of energy from high latitudes, mainly in the form of long-wave radiation from the tops of clouds and layers of ice crystals in the stratosphere. This loss is made up through the transport of heat from lower latitudes by atmospheric circulation and ocean currents. The thermal balance between incoming and outgoing energy is achieved in the Polar Regions at a surface temperature considerably lower than the planetary average. The average year-round temperature at the North Pole is today 56 degrees Celsius lower than it is at the Equator (the difference is even greater at the South Pole because of altitude, and other variables).

Furthermore, the tilt of the axis of the spinning planet with respect to its orbit around the Sun (at present about 23.5 degrees) has the result that seasonal differences in net energy at the surface – summer in the hemisphere where the polar axis is tilted toward the Sun, winter when it is tilted away – are progressively greater at higher and higher latitudes. Not only the intensity, but also the period of solar insolation and illumination changes dramatically with latitude. At the Poles themselves, of course, solar illumination, although weak, is continuous for six months of the year in summer, and no direct solar energy at all is received during the alternate six months.

These features make the regional climate at high latitudes very dependent on the transport of heat from low to high latitudes in both hemispheres by atmospheric and ocean currents, and on the heat trapping capacity of clouds and greenhouse gases. Thus, changes in the energy balance and energy circulation for the planet as a whole have a much greater effect on the energy available for biological life in polar and sub-polar regions than the planetary average (Roots, 1989b).

The planetary architecture, the pattern of continents and ocean basins, also has an important influence on the transport of heat from low to high latitudes in each hemisphere, and accounts for much of the difference between the climate of North America and South America at equivalent latitudes. The long north-to-south shape of the American continents acts as a major barrier to the east-west ocean and atmospheric circulation generated by the Earth's rotation, while the clustering of continents in the northern hemisphere and the relatively open round-the-planet west-to-east transport of heat by the Southern Ocean are major determinants of the pattern of world climate. Thus, in North America, the strong south-to-north heat transport in the Atlantic Ocean off its eastern coast serves to warm the lower temperate latitudes, but as the north-flowing Gulf Stream current veers to the east it pulls very cold water and air from the Arctic Ocean basin southward along the east coast, giving that part of the continent anomalously low temperatures. On the west side of North America, circulation of the relatively cool North Pacific Gyre stabilizes the climate of the coastal areas, with an observed decadal oscillation of winter temperatures and precipitation, but provides moisture for the whole northern high latitude region. Quite small variations in this complex system, including those resulting from human-caused influences on the penetration and reflection of solar energy in the atmosphere, have potential to make significant rapid changes in the regional climate.

The climate of the southern part of South America is dominated by the relatively cold south-flowing ocean current along its west side and the turbulent water and air energy mixing of the Drake Passage, where the strong east-flowing circumpolar Southern Ocean is forced through a six-hundred kilometre-wide gap, with associated confused and variable circulation on the eastern side of the continent and some of the highest-energy atmospheric turbulence found anywhere on the planet. The very vigorous atmospheric and ocean energy system in this region has some characteristics similar to those found in the northern hemisphere at relatively higher latitudes; but the turbulence is such that the rapid climate changes which are seen to be ecologically significant in the northern hemisphere would for the most part appear likely to be lost in the "environmental noise" off South America.

The net environmental effect of these energy characteristics at high latitudes is that water in the air, on the surface of the land or ocean, and in the ground is commonly, frequently, or periodically in the solid state (Shulski and Wendler, 2008). Ice and snow on land and waters, permafrost or frozen ground, and ice crystals in the atmosphere are typical. The land is snow-covered, and lakes and rivers are ice-covered, for several months of the year. Much of the surface-to-air heat flux, already weak compared to that typical of lower latitudes, is involved in phase change from liquid water or water vapour to ice or snow crystals and back again without change of temperature. Because biological life as it has evolved on Earth requires liquid water for cell growth and reproduction, the conditions for life in high latitudes are still further restricted.

Global and regional models of climate, based on data of recent and current temperature and precipitation and present knowledge of the characteristics of land/ocean/atmosphere energy fluxes, vary among themselves depending on the assumptions made and scale simplifications, but all are consistent in indicating that the expected net warming in sub-arctic and arctic latitudes will be four to six times the global average for any plausible scenario for planetary climate change. The warming is predicted to be greatest in winter, with indicated temperatures for November to March in inland North America at Latitude 65 degrees North as much as 12 degrees Celsius higher than the average of the past century. Such changes would radically displace the timing and importance of the liquid water/ice phase change, affect snow cover, river and lake ice, the stability of frozen ground, and a range of coastal and marine processes (Weller, 2000).

At high altitudes in the American Cordillera, rugged topography exacerbates the local net heat changes and results in extreme local contrasts in micro-climates. Solar insolation, exposure to wind, and cloudiness may vary drastically within distances of a few hundreds of metres, resulting in extreme differences in diurnal and seasonal temperatures, and local variations in precipitation, accumulation of snow, and of water storage, run-off, or frozen ground (Beniston, 2003). Small changes in regional climate, superimposed on the complex and heterogeneous patterns of local physical environments in high mountainous areas, may trigger large changes in local hydrology, soil moisture, and land stability (Luckman and Kavanagh, 2000; Allard *et al.*, 2002). Such areas are difficult to model or monitor from a climatic aspect, but as they are essential sources of water for human use and life support at lower elevations throughout much of the Americas, knowledge of the sensitivity of high alpine areas to climate change is very important (Roots, 1993; Grabherr, 2005; Bradley *et al.,* 2006).

High altitude areas or plateaux that are not locally rugged are relatively restricted in the Americas. The altiplano of central South America is the type example. These areas commonly experience low average temperature similar to some sub-polar lands, but diurnal and seasonal patterns of solar energy are typical for their latitude. Although data are sparse, it appears that the increase of temperatures experienced by nearby lowland areas in recent decades have been as great or even exaggerated in the higher regions and mountain slopes above the forest limit. Many of the major glaciers are shrinking alarmingly, the duration of seasonal snow cover is reduced compared to the average of the past two centuries, and the meltwater from ice and snow areas, which provides much of the moisture for rivers, forests, and lowland agriculture, is reduced (Bradley et *al.,* 2006; Lugo *et al.,* 2004; Ramierez, 2003).

Throughout much of the Cordillera, glaciers have been shrinking conspicuously for the past half century (Young, 1985; Williams and Ferrigno, 2002; Adam, 2006; Kasser, 2007).

3. Ecological Characteristics of High Latitudes and High Altitude Terrain

There are many definitions and proposed criteria to designate high latitude and high altitude areas from an ecological aspect, but a convenient one for the present discussions refers to areas or terrain where the average annual surface energy flux is not sufficient to maintain the production of erect woody plants, even in the presence of liquid water. Such areas are popularly recognized as "beyond the tree-line". Although the tree-line may be convoluted and with anomalous outliers, and although in the past it has shifted with changes in climate, it usually is clearly recognizable, and marks a genuine ecological boundary (Begin *et al.,* 1999; Danby and Hik, 2007). Areas beyond the northern tree-line that carry a vegetative cover are commonly called tundra; areas still further north or higher, where bare ground predominates over macroscopic plant cover, are referred to as polar desert (Bliss, 1998).

Beyond the tree-line, the low prevailing temperatures, limited periods of liquid water, and interrupted solar radiation result in slow weathering of rocks and soils compared to that typical of temperate or tropical areas, so that there is consequently a slow release of soluble nutrients essential for plant growth. Bacterial action in a treeless tundra may be two orders of magnitude slower than that in a flourishing forest in the temperate regions. These basic factors, which underlie the productivity and vigour of the whole ecosystem, are clearly a direct result of climate conditions (Billings, 1974). But how sensitive the microbiota of high latitude and high altitude soils are or will be to rapid changes in climate is little known (Heal *et al.,* 1998).

Ecosystems that have evolved or survived in polar, sub-polar or high alpine conditions are typically low-energy systems, with relatively few species at each trophic level compared with ecosystems elsewhere (Huber *et al.*, 2005). Arctic marine ecosystems are likewise comparatively simple compared with those of lower latitudes (Muir *et al.*, 2002). Food chains tend to be simple and short. The continuous solar radiation during the brief summer results in a surge of biological productivity during a short period after which growth may be very low or zero (Brown *et al.*, 1980; Zhou *et al.*, 2001). Organisms and communities have developed a number of stratagems to cope with low biological productivity or periods adverse to life (Sorensen, 1941; Molau, 1993; Jonasson *et al.*, 2000). Some, with limited mobility, are widely scattered (individual plants may be spaced far apart on bare ground and arranged in systematic patterns to gather nutrients from a large area); others cluster in limited fertile "niches" from which they expand when conditions improve. Many plants develop extensive almost impregnable seed banks (McGraw and Vavrek, 1989). Dormancy, and the ability to remain viable when metabolic rates drop very low and then revive quickly upon thawing, is an important characteristic for many species (Somme and Block, 1991). For animals with individual mobility, such as some birds, mammals, and fishes, seasonal migration to areas with more abundant food and less harsh environments for part of the year is a successful strategy (Calef, 1981; Stirling *et al.*, 1999; Reale *et al.*, 2003).

Except for the lichens, these marginal conditions for life have by and large inhibited the development of symbiotic linkages between species, so that in comparison with many other parts of the world, biological communities in high latitudes appear to be simple. The species diversity is low, compared to most other terrestrial ecosystems. Such communities, stressed more by physical factors than by biological competition, are inherently sensitive to changes in climate. For example, survival and fertility of isolated populations of alpine rodents vary with fluctuations in climate (Morrison and Hik 2007). There is evidence however that under such stressed conditions, there may be considerable genetic variation within species (McGraw, 1995; Matveyeva and Chernov, 2000). Perhaps because of this, high-latitude ecosystems have proved to be very tough. Such ecosystems in high latitude and high altitude areas rarely reach optimum stability, but are characterized by fluctuation between remarkable abundance and scarcity or near-extinction of critical species. The limited diversity of species in a given area in these regions may be conspicuously reduced by a rapid change in a particular climatic parameter; but because the ecosystem is already impoverished and a "survivor" of harsh environmental conditions, the overall longer-term effect may be less than in some biologically richer areas (MacLean, 1975; Chapin *et al.*, 1996).

Climate change that results in higher ambient temperatures will increase available liquid water and the release of nutrients (Crawford *et al.,* 1995). In winter it will affect snowfall, length of snow cover, and runoff in complex ways (Kudo, 1991). Higher temperatures during the plant growth season will enhance microbiological activity and plant metabolism (Inouye and McGuire, 1991) and also the activity and reproduction of invertebrates, including parasites and migrant species (Kevan,1972; Kukal, 1990; Inouye *et al.,* 2000). Although warming is normally expected to be associated with increased carbon dioxide in the atmosphere near the surface, the biological significance of a change of carbon dioxide concentration appears complex (Skre, 1993; Kane *et al.,* 1996).

Simple changes in weather, due to changes in climate trends, may have unexpected effects on the inter-species relations and thus on diversity. A current apparent example is the increase in late-winter snowfall on some mountains on the northeast side of the Saint Elias Mountains in Yukon, which is popularly and reasonably attributed to warming of the winter climate. The increased snow and milder temperatures have meant that high-altitude grassy slopes which in past decades were bare and windswept in early spring and provided essential forage for mountain sheep are now inaccessible to the sheep; the sheep are starving. The wolves which normally prey on the sheep in the spring appear also to be starving and if some survive, may not have energy to breed. The subsequent effect in the coming summer on the rodent population, for which the wolves are a main control, can at this stage only be speculated. If the rodent population is not checked by the wolves, the rodents are likely to over-graze and destroy their habitat. Thus climate warming on the high mountain slopes may have the result of decreasing the biological diversity and richness of the larger region.

Perhaps the most critical aspect of the potential effect of rapid climate change in high latitude and high altitude areas relates to the disruption of food chains and inter-trophic connections because different species and communities respond at different speeds to a given change in climate conditions (Murray and Miller, 1982; Hobbie, 1993). Because food chains are relatively simple, with few alternative species at each trophic level compared with the many pathways available in most lower latitude ecosystems, it is possible to observe and describe the effect of climatic variations in an instructive manner (Grabherr *et al.,* 2001; Korner and Spehn, 2002).

An example, again from the mountains of the Yukon, may serve as an illustration. The wildlife in the region is dominated by a massive herd of caribou, at present numbering about 130,000 individuals that breed annually on the Arctic Ocean coastal plain, which is fertile for a brief period in summer. The animals then migrate through the mountains and valleys to wintering grounds near the boreal forest tree-line, returning again in the spring. The herd thus undertakes an annual round trip of more than 3500 kilometres (Heuer, 2006). Its numbers are at the limit of the carrying capacity of the region. The routes and timing of the migration have evolved to take advantage of forage and presence of parasites along the way, under recent climatic conditions. After giving birth on the costal plain in early summer, the females and young move southward along the river valleys, feeding on rich early vegetation while the snow on the higher slopes melts (Lapiere and Lent, 1977; Russell *et al.,* 1992). By the time the forage in the lower valleys is nearly exhausted, insect parasites hatch by the billions, and drive the caribou to higher windier areas to escape their tormentors. By this time in most "normal" years, the substantial forage on the upper slopes will have grown and matured and be able to support the herd as it continues south (Russell *et al.,* 1993). However, periods of anomalously warm early spring weather in the last few years, which might be a harbinger of climate change and might at first be thought to be a benefit to the caribou, have only increased their hardship. The early spring has increased the warmth and snowmelt in the lower valleys, but increased the snow depth in the mountains. The result has been that insects, able to respond more quickly than vegetation to a change in climate, have hatched abnormally early in the lowlands, and driven the caribou with their still malnourished young to higher elevations, where because of excessive snow depth plant germination has been delayed and the forage consequently not developed enough to enable the females to produce enough milk to feed their young on the long strenuous migration. Much of the entire huge herd appears to have been debilitated and weakened because of "favourable" climatic conditions in early spring (Russell, 1993).

Similar complex stories of the ecological effects of the changing climates may be expected (Hinzman *et al.,* 2005). It remains to be seen how the biological diversity may be affected (Fry, 1993; Jeffries *et al.,* 1994). There are useful indications from the past, of the links between climate and biological activity in northern regions (Callaghan *et al.,* 1989; MacIver and Meyer, 1998; Rhemtulla *et al.,* 2002). Examples are "anomalous" islands of flora from the Pleistocene Beringia biological invasion which have survived deglaciation events and have then served as oases for recent plant and invertebrate colonization; the growth rings of arctic heather *cassiope tetragona* clumps which are more than a century old and which show decades of slow growth and periods of vigorous growth; timberline trees in Vancouver Island and in Jasper Park in the Rocky mountains which reveal recurring periods of slow growth or death followed by enhanced growth that appears to reflect a climate control; the shrinkage of perennial snowbanks in the lee of mountain ridges in southwest Yukon which has uncovered remains of caribou herds that are not present in the area today (Kuzyk *et al.*, 1999) and human hunting artefacts, indicating different climates and ecosystems 3,500 to 1,000 years BP.

An obvious and often described characteristic of the biological systems in high mountains and high latitudes is that the ecosystems are zoned in response to progressively harsher physical environments. The successive biological zones reflect the climatic gradient from tree-line to arctic desert (Edlund, 1990; Matveyeva and Chernov, 2000) or to highest alpine peaks Breymeyer, 1995; Svoboda and Henry, 1987; Roots, 1993; Seig, 2004).

Plants, with limited individual mobility, express the zoning best; the common succession from trees to small bushes to distinctive arctic or alpine grasses and flowers to mosses to lichens is the standard ecological background to all descriptions and considerations of arctic and alpine areas (Billings, 1997; Levesque *et al.,* 1997). In general, each higher or more northerly zone is more impoverished than the one below it or to the south (Breymeyer, 1996). It contains fewer species, more widely separated plants, and lower living mass; yet because of slow organic decomposition the net biomass may be as great or greater than that at lower latitudes or altitudes (Edlund, 1992; Jonasson *et al.,* 2000).

One common characteristic of plants in more and more difficult living conditions is that a progressively higher proportion of the living tissue is found beneath the surface. At Latitude 80 degrees North in the Canadian Arctic as much as 85 percent of the living matter is below ground (Edlund, 1988; Oechel *et al.,* 1993). Studies of biodiversity in extreme environments must take into account the "subterranean" living component.

Any change in climate that leads to more favourable conditions for growth will of course result in biological response that could shift the vegetation zones (Walker, 1995; Sturm *et al.,* 2001; Cueva, 2002)). The rapidity with which established plant species or communities can adjust to more favourable conditions, compared with the rapidity of environmental change that might be imposed, is not well known (Hengeveld, 1989; Oechel, 1994; Lescop-Sinclair and Payette, 1995); but because high altitude and Arctic plants grow slowly compared to related species in lower altitudes and latitudes - in some cases single plants may take several years to complete a bud-to-flower-to-seed cycle that normally is accomplished in a single year in warmer conditions (Kudo 1992;

Shaver 1992)- it is not unlikely that the ecosystem will become disrupted by a rapid change of climate. Such conditions could also favour the invasion of species from lower latitudes and altitudes, which could not have survived in the colder climate. The biological diversity would be changed (Danby *et al.*, 2003).

4. Effect of human activities on the climate and environment of high latitudes and high altitude terrain

The effects of human activities on the climate and environment of high latitude and high altitude terrain, with the possible consequences for biodiversity, may be considered under three main, but partly interlocking, topics: those effects resulting from activities at a considerable distance or global in nature; effects from activities within the high latitudes or in the high mountains; and those matters of special interest to resident indigenous people.

We are not concerned here with human activities that may or may not be involved in the causes and patterns of broad changes in the global environment or climate, which of course affect high latitude and high altitude areas just as they do other parts of the world. An exception is the relative increase in ultraviolet-B (UV-B) radiation, which is and will continue to be relatively greater in high southern and high northern latitudes because planetary upper atmosphere thermochemical processes, influenced by human activities, result in a greater depletion of stratospheric ozone in the polar regions, and consequently less effective screening of solar ultraviolet radiation. The effect of increased UV-B on high latitude ecosystems is imperfectly known, but research to date in the Arctic and the Antarctic indicates the possibility of severe disturbance in plant seed production and rates of growth, reduction of fertility, and damage to tissues and sense organs in animals. The short or long term effect on biodiversity may be important (Correll, 2004; ACIA, 2004).

The local or regional effect of changes in climate likely affected by human activities that is of direct concern in high latitude or mountain areas is related to changes in water supply. Argentina has taken direct legislative action in this regard. In October 2008 the Chamber of Senators passed a law that establishes a minimum budget *"for the protection of glaciers and the periglacial environment, to preserve them as strategic reserves of water resources and the critical recharging of hydrological basins"* (Villalba, 2008). In Bolivia, the shrinking of winter snowbanks has already resulted in severe water shortages and failure of irrigated agriculture (Peredo-Videa, 2009). In Canada, shrinkage of glaciers and snowpack in the Rocky Mountains is a major factor in the diminished flow of the Athabaska River, leading to serious concern about the adequacy of water to develop and process the bituminous sands of northern Alberta, a major petroleum resource. Indications are that the shrinking will continue.

Of important concern to biodiversity in the context of human activities and climate change in high latitudes and at high altitudes are the effects of far-travelled pollutants from industrial and urban activities (Barrie *et al.,* 1992; Crawford, 1997). The processes and effects of the Long Range Transport of Air Pollutants (LRTAP) have been well studied.

Volatile organic compounds (VOC's), airborne trace metals, and radioactive material attached to airborne particulates can "leap-frog" from industrial sources to high latitudes by successive volatilization, transport and deposition, and revolatilization, after which they may enter the food chain of terrestrial, aquatic or marine animals and be progressively concentrated (Macdonald *et al.,* 2002), The result can be that mammals, birds, and fish in northern latitudes may have body burdens of toxic substances considerably higher than those in animals living closer to the sources of the pollutants (Muir *et al.,* 1992; Thomas *et al.,* 1992). The enhanced level of contaminants in animals used for food is also a serious human concern (Kinloch *et al.,* 1992). The effects on the arctic plants and animal life can include inhibition of reproductive processes with consequent loss of genetic diversity, reduced growth rates, and severing of the linkages between various trophic levels (that is, dislocation of the food chain) (Rapport *et al.,* 1997; Taylor and Pitelka, 1992; Lockart *et al.,* 1992). The biological diversity will be affected.

It is difficult to separate the specific effects of the change in concentration of a single contaminant through the observation of the "health" or debilitation of a natural ecosystem in arctic or alpine areas. Most of the specific information on the effects of contaminants comes from experimental or captive studies of individuals. Such studies cannot account for the complex of stresses and changes in the natural environment. For example, present evidence shows typically a higher concentration of organochlorides in the eggs of peregrine falcons that nest in the Arctic than in nests of the same species in more southerly latitudes. Hatching success appears to be lower, but samples are too few to support firm conclusions about the relationship between contaminant concentration, other changes in the environment, and long-term falcon populations. Similarly, as is well known, the liver and other tissues of polar bears in the eastern Canadian Arctic and western Greenland carry pesticide residues and heavy metals in amounts that are far above those levels considered "safe" for large mammals, and most bears are underweight and not healthy today. But how much of their debility is directly due to contaminants from industrial sources, and how much to decrease in food availability because of changes in sea ice and other ocean conditions that may be the result of climate change cannot be determined.

The effect of further rapid changes in temperature and precipitation on the diversity of biological communities in high latitudes and high alpine areas that are already subject to stress from marginal living conditions needs careful study. It may be that the typical ecosystems in these areas are already more resilient to rapid environmental change than most of those in lower latitudes; or it may be that additional rapid climate change could trigger severe breakdown and disruption of the system, with significant loss of biodiversity (Urbanska, 1997; Martin and Hik, 2002).

Land use for agriculture beyond the tree-line is found in the Americas at present only in the high Andes. Here, pasture and crop land, typically let fallow for long periods between croppings, provide opportunity to observe the processes and rates of changes in biodiversity (Canon, 2003; Sarmiento, 2004). The history of the raising of livestock in Greenland during a period of more benign Arctic climate, and current studies of recovery of disturbed lands near present settlements are instructive examples of biodiversity change in the Arctic (Strandberg, 1997).

The effect on the environment and biodiversity in high latitudes or high altitudes from local or nearby human activities other than pasturing animals is confined to disturbances by settlements, ports, pipelines and transportation corridors, airfields, mines, and from subsistence or sport hunting. There are very few large human settlements north of the tree-line in North America or at high elevations in the Andes. In all cases the disturbances due to the settlements seem to be purely local, although they may be severe on a small scale. Because the rate of organic decomposition is low, special care has to be taken, for human health reasons, with water supply and sewage. When this is successful on a local basis, it appears that the regional biological functions will not be affected. Biodiversity will be maintained. However, climate warming and associated changes in sea level, hydrology, and land stability are almost certain to cause new problems.

The marine ports in Arctic North America are in several cases also sites locally rich in marine life. Care must be taken during construction and operation of the port to avoid undue physical disturbance or pollution which could seriously affect the marine ecosystem and productivity. The problem is particularly difficult for ports which are oil shipping ports or pipeline terminals (Milne, 1978). Ports in northern Alaska and Greenland provide illustrative examples. The longer term effects on biodiversity are not yet known, and the threats that may be brought to the coastal region as a consequence of changing climate, weather patterns or sea ice conditions should be watched with care. A distinctive management problem is that the ports themselves serve as centres for activities such as hunting and tourism, in a location that is biologically vulnerable but where wildlife may appear deceptively to be abundant.

Oil pipelines, with potential for environmental damage through spillage, electric power corridors, roads and airports, among others are activities which require careful and sometimes special management in high latitude-high altitude areas. Good environmental management will maintain the biological diversity. However, such facilities provide routes and may inadvertently provide opportunities for invasion by alien species during periods of climate change when conditions for biological life are more favourable. The biological diversity of the high latitude area may then be adversely affected.

Mines in the permafrost regions of North America and the high Andes constitute specific spots of land disturbance, with sometimes severe potential for pollution of the local environment. The operational period of successful mines can be expected to extend well into the time when the climate has changed from what it is at present; and this should be taken into account in mine design and all phases of its operation and closure. Environmental assessments of proposed mines should also consider likely climate change. Some examples of past damage to watercourses and coastal waters are well known, and have led to strict regulations and guidelines in Alaska, Canada, and Greenland. Care must be taken to control pollution and avoid undue disturbance of the local hydrology, particularly in the case of permanently frozen ground and ice-covered waters; but the regional biological diversity is unlikely to be affected.

A different human dimension to the issues of biodiversity and climate change in the high latitude and high altitude areas of the Americas is that of the knowledge and the concerns of the indigenous people of Arctic North America and the high central Andes. These peoples, with a very long history in the areas, who have a holistic view of inanimate and animate Nature, are very acute observers of the environment and its changes (Krupnik and Jolly, 2002; Fox, 2004) . Their myths, stories, ceremonies and patterns of living celebrate the entire biological diversity of their home regions. Many specific places both in the northern high latitudes and the high Andes are sacred or have special cultural meaning. Often the associated cultural values encompass the entire local ecosystem. Although quite different climates in the past are part of many stories and legends of the indigenous peoples of the areas (Cruikshank, 2001; 2005), the effect of impending climate change, with potential to upset the relationships between humans and the natural world that are so precious to them, may be very disturbing.

These concerns are more troublesome because in both the Arctic and the high Andes many groups of the indigenous people are not receiving full benefits from the economic and social developments of the area where they live. They are being asked to change their here-to-fore environmentally-benign lifestyle to adapt to climate changes resulting from actions in which they have taken no part.

5. Current scientific studies of climate change and biodiversity in high latitudes and high altitude terrain

Since the International Biological Program (IBP) (Bliss, 1977), there have been a large number of monitoring and research programs and individual activities recording and investigating the relationship between climate and biological systems in polar and sub-polar areas and the mountainous regions above tree-line. Some of the more significant current ones are noted below.

5.1 The International Tundra Experiment (ITEX) www.geog.ubc.ca/itex

ITEX began in 1990 as an activity within the Northern Sciences Network of the UNESCO Man and the Biosphere Program MAB, through the initiative of high-latitude researchers from the USA, Canada, Russia, Sweden, Finland, Norway and the United Kingdom, to undertake coordinated and similar studies on plants throughout the tundra biome. It has since developed into a stand-alone international scientific enterprise, involving researchers and institutions in twelve countries. It is coordinated mainly through the Department of Geography of the University of British Columbia, the University of Alaska, and the Danish Polar Center.

The initial focus of ITEX was on the response of selected typical plants with circumpolar distribution to natural variations in climate and to experimental *in situ* warming, with a secondary focus on ecosystem processes and the dynamics of tundra ecosystems (Webber and Walker, 1991). It outlined basic hypotheses and objectives for an international research program, and drew up a uniform set of protocols for standardized monitoring and measurement of ambient and microclimatic conditions and observations of plant growth and vitality (Molau and Molgaard, 1996). Techniques for standardized passive warming using small open-top plastic chambers were developed, for comparison with "unprotected" plants growing nearby (Marion *et al.*, 1993). Later, controlled amounts of carbon dioxide were introduced to some of the experimental chambers, to simulate likely conditions of a warmer climate and observe the response of the vegetation.

The ITEX studies have grown more complex and sophisticated. They now embrace research on microbiota, soil conditions, and the effect of and response to invertebrate fauna (Richardson, 2002). Sites have been added in the mountain and high plateau regions above tree-line in Europe, Asia, South America, sub-Antarctic islands, and Antarctica. There are now 49 listed ITEX sites; 17 of these are in the Americas. The focus is still on obtaining rigorous, comparable, quantitative information on the response of natural vegetation and soil communities to changes in climate.

The ITEX studies have shown the advantages, indeed the necessity, of long term observations monitoring of *in situ* plant responses to changed environments. For example, measurements of the positive growth responses in the first years to elevated temperatures and carbon dioxide concentrations have been followed, in several experimental cases, by loss of growth or reproduction in subsequent years because of increased net transpiration; and soil changes below the depth of observable plant roots have a longer-term effect than expected.

ITEX produces a newsletter, *ITEX Update,* organizes periodic workshops and summary conferences (Hollister, 1999). The findings are reported extensively in the established international scientific literature.

5.2 Zackenberg Ecological Research Operations (ZERO) www.zackenberg.dk

After careful study of candidate sites, the ZERO environmental monitoring and research station was established in 1994 by the Danish Polar Center in cooperation with the government of Greenland on the shore of a major fjord on the east coast of Greenland at Latitude 74 degrees North. The location was chosen because it was suitable for a wide range of terrestrial and coastal marine investigations in the physical and biological sciences, and also because fortuitously it was as far from known major paths of transport by atmospheric or ocean currents of pollution from industrial sources as it was possible to get in the northern hemisphere. A long-term monitoring station at this place, with associated research, could serve, as far as it is geographically possible at the beginning of the 21st century, as a "zero baseline" for continued modern observation of environmental change in the northern hemisphere.

The development of ZERO has fulfilled the expectations. A comprehensive monitoring program structure "*Zackenberg Basic*" was drawn up, supported by a consolidated data service. The observations have been continued annually, with increasing sophistication. Supplementary to the monitoring observations are separate research projects on specific subjects. About forty scientists and staff normally participate in ZERO during the field season.

Zackenberg Basic has four units. (i) ClimateBasis: meteorological observations according to a rigorous detailed program at three sites in different topographical situations; snow cover and chemistry; sea ice behaviour; permafrost and soil characteristics; river hydrology, chemistry, sediment load; carbon dioxide flux; UV-B received. (ii) GeoBasis: geomorphology and landscape monitoring along selected standard profiles from coast to upland; measurements of mass wastage; shoreline and coastal changes. (iii) BioBasis: reproduction, phenology, greening, for dominant and indicative plants (correlated with ITEX); insect and spider sampling, census, and distribution with topography; insect pollination and predation on flowers; breeding census of birds; phenology of shorebirds, waterfowl, upland species; census and behaviour observations on mammals (lemming, ermine, hare, musk-ox, fox, wolf, bear, walrus, seals, narwhal), freshwater zooplankton. (iv) MarineBasis: Sea ice; physical, chemical, nutrient, and biological profiles in fjords; sediment exchanges; oxygen and carbon cycles; benthic animals in plants near shore; body contamination of marine mammals and fish. Individual research projects at Zackenberg have ranged widely from auroral geophysics to plant genetics. Many of the studies are correlated with research at other high latitude research stations.

ZERO provides unique and comprehensive "standard" or basic information on the arctic environment and its changes, against which the observations from other monitoring sites, circumpolar or around the planet, can be related. It is particularly valuable as an observatory to record changes in high arctic biological diversity against a comprehensive long-term background of data on the physical and chemical environment, in a location that is less affected by human perturbations than anywhere else in the northern hemisphere. Over the years it will become an even more valuable environmental reference.

With the current reorganization of the Danish Polar Center (2009), responsibilities for the ZERO activities will be carried by different Danish and Greenland government departments and institutions, but the basic monitoring and research program is continuing.

ZERO produces an annual report *ZERO*, and occasional summary volumes of its research. Monitoring data are available through its website. The results of the individual researches are reported in the open literature.

5.3 Toolik Field Station
www.uaf.edu/toolik/

The Toolik Field Station was established in 1975 on the shore of Toolik Lake in the northern foothills of the Brooks Range in northern Alaska. Its stated purpose was "to study the environmental and basic ecology of the tundra and associated freshwater ecosystems and their responses to climate change and disturbance." The station has developed as a facility to support research, rather than a research and monitoring program in itself. Managed and coordinated by the Institute of Arctic Biology of the University of Alaska Fairbanks, its basic activity and long term funding has been as the northernmost station of the Long Term Ecological Research (LTER) network of the US National Science Foundation. The present facility can support up to 80 researchers, including temporary satellite field camps. Most of the researchers are from universities. In recent years, 64 universities including twelve from outside the USA, and eight government scientific programs have made use of the facility.

The studies undertaken through Toolik were at first individual, mainly short-term. Many were directed to or needed as background for assessing the ecological disturbance of the newly constructed Dalton Highway and the oil pipeline that crosses the tundra from the Arctic Ocean coast to the Brooks Mountain Range. In the course of this work, the first careful comprehensive assessments of the biological diversity of the Arctic coastal plain and the arctic mountain region were obtained. Toolik then became a focus for the continuing Arctic System Science (ARCSS) Land/Ice/Atmosphere activities, and the US Department of Energy program on Response, Resistance, Resilience and Recovery from Disturbance (R4D), related to on-going and projected energy developments in northernmost America. Pure scientific research on biological and environmental topics however has remained the bulk of the scientific activities.

In 1996 a major review of the priorities for Arctic science and the needs for and role of the Toolik Field Station for the next 20 years recommended increasing integration of the disciplinary scientific studies, attention to process dynamics at landscape and regional scales, in order to evaluate the place of the Arctic in the total Earth system. Recommended topics of attention included:- global climate change and snow/ice albedo effects on the tundra energy budget; the dynamics of carbon dioxide and methane; terrestrial and aquatic ecosystem productivity and the role of carbon and nutrient storage; river runoff and effects on Arctic Ocean chemistry, nutrients, and circulation; herbivore and plant community dynamics, especially with respect to changes in biodiversity.

The current Science Mission Statement of the Toolik Field Station is to "support field research and education that will lead to greater understanding of the arctic region and its relationship to the global environment". Much of our scientific knowledge about diversity in the terrestrial high latitudes, its past changes, and the processes that link to climatic and human influences comes from research undertaken at or coordinated with Toolik Field Station over the past thirty years. In some subject areas, the Toolik Field Station has become the standard reference and working site both for purely scientific research and studies of the applied sciences for resource developments and environmental protection policies. These, too, must take knowledge of the effects of climate change into account. An example is the Global Hierarchical Observing Strategy (GHOST) which links a permafrost active layer mapping network with a meso-scale air temperature/precipitation network and temperature/depth profiles from boreholes to develop active layer thickness calculations, and in conjunction with ZERO studies in Greenland to provide regional estimates of the impacts of global change (Nelson and Brigham, 2003).

5.4 Global Change in Mountain Regions (GLOCHAMORE) mri.scnatweb.ch/glochamore/

The GLOCHAMORE research activity is an enterprise of coordinated research planning, organized under the UNESCO Man and the Biosphere Program (MAB) and coordinated through the Mountain Research Initiative (MRI) at Berne, Switzerland. Its purpose is to develop a state-of-the-art integrated and practical research strategy to improve understanding of the causes and consequences of global change in a selection of UNESCO MAB Biosphere Reserves in mountain regions around the world. The research in accordance with the strategy will serve as a basis for defining and implementing sustainable development policies and practices in Biosphere Reserves, which will then serve as models and examples for the respective mountain regions. The research activity builds in part on the GLORIA-WORLDWIDE (Global Observing Research Initiative in Alpine Environments) activity research themes (Grabherr, 2005) and the U.N. International Year of the Mountains (Martin and Hik, 2002).

Twenty-eight MAB Biosphere Reserves, in all the major mountain systems of the planet except in Antarctica, are participating in GLOCHAMORE. Six mountain Biosphere Reserves in the American Cordillera are taking part. The interest and objectives are not only on the "above the tree-line" aspects, but on the mountain Biosphere Reserves as a whole, including the lower slopes and valleys, the natural resources, and social and cultural issues. A number of international planning workshops have been held, addressing the drivers of global change, characteristics of changes in mountain environments and ecosystems, effects on the well-being of people, and issues of adaptation to change.

The first edition of the GLOCHAMORE Research Strategy was completed in 2005 (Gurung 2006). It contains ten sections, most of which have several sub-sections, and for each sub-section there is a research goal that has been drawn up after international discussion. The major section topics are, respectively: climate; land use change; the cryosphere; water systems; ecosystem functions and services; biodiversity; hazards; health determinants and outcomes affecting humans and livestock; mountain economics; and society and global change. Section 6, *Biodiversity,* lists the following sub-sections, each with a research goal:- biodiversity assessment and monitoring; biodiversity functioning; biodiversity management; alpine community change; key fauna and flora; mountain forest structure; culturally dependent species; and impacts of invasive species. An on-line database of GLOCHAMORE research projects is available through the MRI website.

The implementation of research programs in accordance with the Research Strategy is the responsibility of the Biosphere Reserves. In the Americas, an interesting development has been the concept of a *GLOCHAMORE American Cordillera Transect,* with potential to involve Biosphere Reserves from western Alaska to the southern Andes (there are 49 MAB Biosphere Reserves along this chain). An informal Cordilleran Network of Biosphere Reserves has been formed, and international working groups on topics of special interest are developing, including one on "Biodiversity".

UNESCO MAB, the United Nations body charged with applying Education, Science, and Culture to issues of humans and their relationship with the biosphere, has reaffirmed that its World Network of Biosphere Reserves should be major learning laboratories and demonstrations for sustainable development, appropriate to the circumstances in different parts of the world, under conditions of environmental and social change. The GLOCHAMORE studies and cooperative networks will advance this objective in the world's mountain regions. Investigation and understanding the nature and processes of climate change and their relationship to biological diversity are central to the studies.

5.5 International Polar Year (IPY)
www.ipy.org/prog/

The current International Polar Year 2007-08 is the fourth major international coordinated research program in the polar regions. The previous ones have been held in 1887-88, 1932-33, and 1957-58. Each of the former ones has had a profound and lasting influence on world science. The present IPY is the largest coordinated scientific enterprise yet undertaken in high latitudes. Sixty-five countries are taking part or have submitted proposals for research projects, at present numbering in excess of 1200. The activities currently underway involve in excess of 5000 scientists, including investigations in both north polar and south Polar Regions.

This is the first IPY to include biological science and education research. The following is a selected list of project proposals which, by their title or subject category, appear to be directly related to biodiversity and the effects of climate on northern regions. Project numbers are for reference only and indicate the order in which proposals were received at the international central office. Not all have been completed as originally proposed, and some have been combined or consolidated. Details of each can be obtained by following the leads through the website above.

PROPOSAL NO.	
202	Arctic freshwater biodiversity network
133	Biodiversity monitoring
390	Biodiversity of arctic spiders
246	Biosphere-atmosphere coupling in the Arctic
72	Biological diversity network
55	Ecological response to atmospheric change
408	Monitoring human-caribou migration
120	Northern disease variability
443	Tracers of climate change

Most of the identified IPY 2007-2008 field research projects terminated at the end of 2008, but several have extended life or have led to continuing studies. Working on the results and interpretations will take several years. A number of international follow-up and data organization workshops and conferences have already been held and will continue. As in previous IPYs, all data will be openly available once the individual research results have been published. Information on the progress and data availability may be obtained through the web sites noted above. In most countries in the Americas, the national IPY committees have arranged a continuing science management infrastructure, so that the IPY momentum will not be lost.

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PAPER 5

CLIMATE CHANGE AND BIODIVERSITY IN ST. VINCENT AND THE GRENADINES

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ABSTRACT: The paper will attempt to show the current status of climate change and biological diversity along with identifying the present and potential impacts to the forest biodiversity in St. Vincent and the Grenadines from global climate change including ENSO phenomenon, invasive species, hurricanes, forest fires and land degradation. The paper defines Climate Change and Biodiversity in addition to linking their relationships and effects on St. Vincent and the Grenadines. Furthermore, the current status of climate change and forest biodiversity monitoring, by including a list of endemic species in St. Vincent and the Grenadines, is provided. The Paper: (1) identifies the impacts on forest biodiversity from global climate change by indicating key issues of the recent Knowledge, Attitude, Practices (KAP) Survey 2007 done in Union Island, Bequia and Spring Village (communities in St. Vincent and the Grenadines); and state current and potential adverse impacts of climate change on Biodiversity such as changes in flowering of the forest species; migration/succession of forest types, vegetation and fauna; damage/destruction of habitat due to change in temperature and rainfall; and changes in predator/prey relationship, which in turn will affect agriculture and human health; (2) identifies research areas that will provide pertinent information; this is due to the lack of scientific evidence for implementing adaptation strategies aimed at providing environmental and socio-economic sustainability. Such research will focus on options, interactions and synergies between global climate change and forest biodiversity; and (3) provides present and future networks including the Second National Communications Project to the UNFCCC, which was launched in October 2006 and one of its main components being to conduct vulnerability and adaptation assessments of our major productive sectors, inclusive of forest biodiversity. The assessments start at the end of 2007 and are expected to be completed by 2008; and highlight existing regional agencies focusing on climate change and its adverse effects that will assist in giving technical and other support to regional countries on addressing climate change issues along with providing assistance to research projects. Preparing the paper was done using existing documents on the topic done locally, regionally and internationally. In addition, informal interviews were held with individuals from relevant government ministries and other agencies in St. Vincent and the Grenadines. Information in the paper focuses mainly on the effects of climate change and biodiversity on the terrestrial environment within St. Vincent with minimal comparative effects on the Grenadines. It will give information on five endemics. Also, the limited quantity of documented information and adequate research on the effects of climate change on biodiversity in SVG limits the information available. The paper lists the effects caused by the adverse impacts of climate change on forest biodiversity. It also shows the commonality in habitat loss, collateral damage and survival of the fittest of the species in the forest environment.

Keywords: climate change, biodiversity, Caribbean

1. Introduction

St. Vincent and the Grenadines is a multiple island nation consisting of 32 islands and cays located in the Eastern Caribbean. The total land area is approximately 389 square kilometers or 38.694 hectares. St. Vincent is the largest and main island with a size of 344 square kilometers or 34.462 hectares. The Grenadines consist of a number of privately and state-owned islands with Bequia, Mustique, Canouan, Mayreau, Union Island, Palm Island and Petit St. Vincent being inhabited. Four other islands make up the Tobago Cays Marine Park. St. Vincent and the Grenadines' human population is 100,747 from the last population census in 2005. The islands form part of the Windward Islands, and are located between St. Lucia to the north and Grenada to the south, and 100 miles west of Barbados. St. Vincent is very mountainous in nature with one of the world's largest active volcanoes (La Soufrière) – its highest point, rising to over 4,000 feet- and the second oldest Forest Reserve in the Western Hemisphere, the Kings Hill Forest Reserve established in 1791. The Grenadines in contrast, consist of low dry islands surrounded by extensive coral reefs. Average annual rainfall in St. Vincent ranges from 1,200 mm on the dry coast to 7,000 mm in the wet central mountains. In contrast, the Grenadines may experience as little as 460 mm per annum (Simmons and Associates *Inc.*, 2000).

St. Vincent and the Grenadines has a diverse collection of biological resources. It is very mountainous and fertile and has a significant tropical rainforest that provides the natural habitat for the St. Vincent Parrot (*Amazona guildingii*), the National Bird, and other wildlife. Collectively, more than 1,150 species of flowering plants, 163 species of ferns, 4 species of amphibians, one of which is endemic (Henderson *et al*, 2007), 14 species of reptiles, 111 species of birds and 15 species of mammals have been identified within St. Vincent and the Grenadines (Anthony, 1997). As on most West Indian Islands, threats to native species include pollution, habitat loss as a result of agriculture, urbanization, and development for tourism, and predation by, competition with, or habitat damage attributed to introduced species (especially mongooses, feral cats, rats, dogs, goats, and invasive reptiles and amphibians). The marine biodiversity has been given a lot of attention with the establishment of the Tobago Cays Marine Park, located in the Grenadines. Conservation programs fall under the Ministry of Agriculture, Forestry and Fisheries, with terrestrial systems primarily under the Department of Forestry. The St. Vincent Parrot Reserve, established for the protection of habitats also benefits other species that rely on intact mature forest.

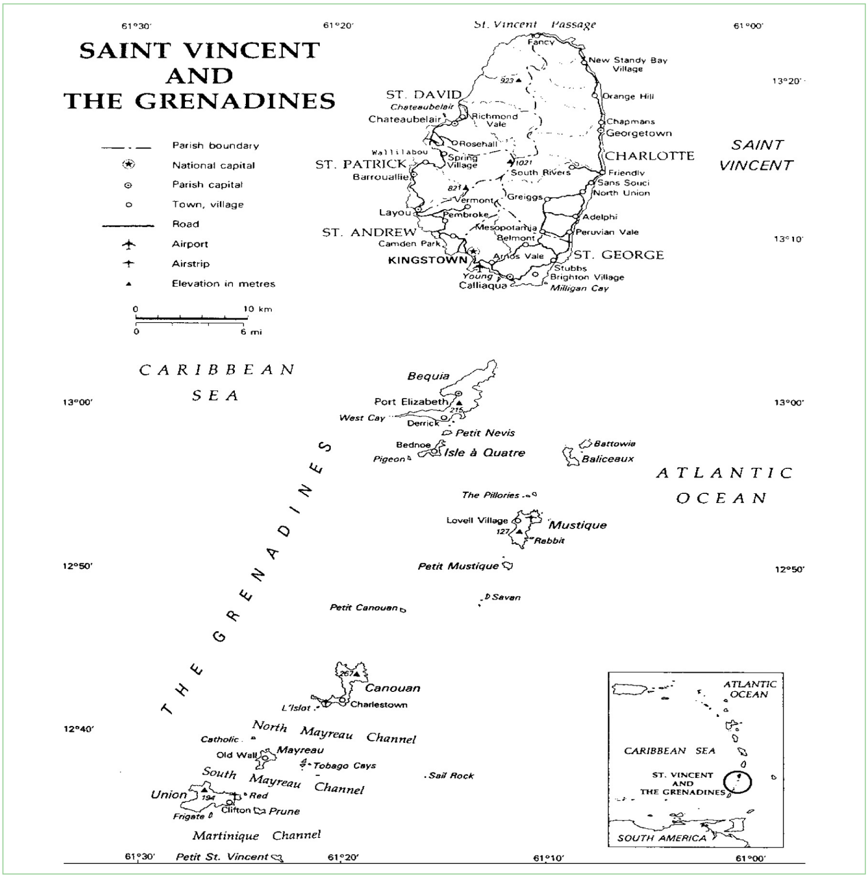


FIGURE 1
Country Map for St. Vincent and the Grenadines (Source: GSVG, 1986b. In CCA, 1990).

2. Climate Change and Biodiversity

According to the United Nations Framework Convention on Climate Change (UNFCCC), Climate Change is defined as: "*a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is observed, in addition to natural climate variability, over comparative time periods.*" Climate Change is projected to affect all aspects of biodiversity. The changes however, have to take into account the impacts from other past, present, and future human activities including increasing atmospheric concentrations of greenhouse gases especially carbon dioxide (CO_2) and natural systems. The ENSO phenomenon in a given year is associated with increase air temperatures when compared to a normal year (non-ENSO) or a La Niña year. This increase in air temperatures is most likely to lead to adverse effects on biological diversity. Such adverse effects include species migration, loss of micro and macro soil organisms, restrictions in species ability to adapt to excess heat, and ultimately species being endangered or death. An increase of global air temperature between 1.5 to 2.0 degrees Celsius can lead to adverse impacts such as an increase in evaporation losses, general increase in extreme events (droughts, floods, excessive rainfall, etc.), and decrease in the number of raindays while at the same time providing an increase in the quantity of rainfall at a national level (Joyette, 2007).

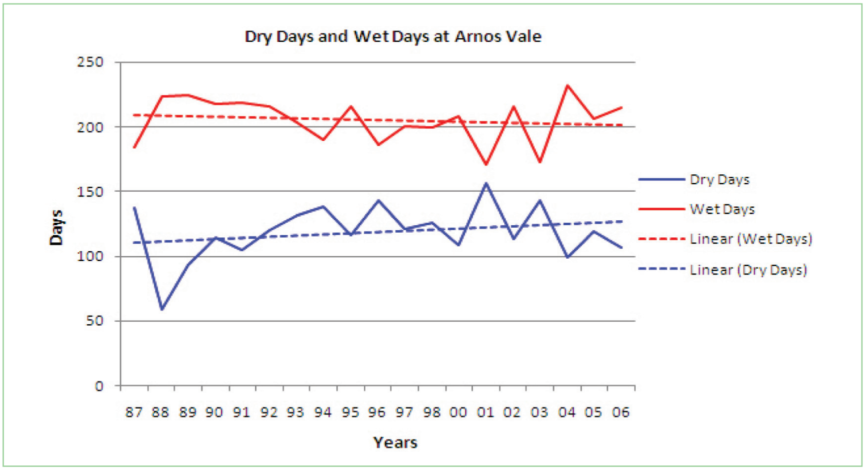


FIGURE 2
Annual Total Dry Days and Wet Days observed at Arnos Vale, St. Vincent and the Grenadines (Source: St. Vincent and the Grenadines Climate Assessment, 2007).

The islands climate features are notable by heavy convective downpours, seasonal tropical synoptic systems such as tropical waves and tropical cyclones and the Inter-Tropical Conversion Zone are among the most significant ones. These features have been known to produce widespread heavy rain, floods and landslides that have resulted in considerable damage and destructions to the environment and infrastructure, and to a lesser extent, humans. Joyette (2007) observed that within the last 10 years, there appears to be a growing trend of a wetter than normal dry season in St. Vincent and the Grenadines. The current loss of forest cover can be accelerated by climate change unless immediate action is taken vis-à-vis adaptation and mitigation measures.

Biodiversity defined by the United Nations Convention on Biological Diversity (UNCBD) is: "*the variability among living organism from all sources including inter alia, terrestrial, marine, and other aquatic ecosystems and the ecological complexes of which they are part.*"

Conservation of Biodiversity globally is enshrined in the Convention on Biological Diversity (CDB) initially signed by 154 nations at the United Nations Conference on Environment and Development (UNCED) in Rio de Janeiro in June 1992. The nation of St. Vincent and the Grenadines is a signatory to several multilateral environmental agreements and has other national legislation that are supportive of adaptation measures for climate change which in turn make provisions for the conservation and protection of biological diversity (*see Attachment 1*). St. Vincent and the Grenadines ratified the CBD and therefore became responsible for implementing the provisions of the Convention. A National Biodiversity Strategy and Action Plan was developed in 2000 for the protection and sustainable use of St. Vincent and the Grenadines' biodiversity in accordance with Article 6 of the CBD (*see Attachment 2*).

There are a number of legislative acts and regulations that incorporate the sustainable use of biodiversity. These include the Fisheries Act of 1986, Fisheries Regulations of 1987, Wildlife Protection Act (WPA) of 1987, Forest Resource Conservation Act (FRCA) of 1992, Town and Country Planning Act of 1992, The Marine Parks Act and Marine Parks Regulations of 1997 and 1998 respectively, and the National Parks Act of 2002, among others. The two pieces of legislation implemented by the Forestry Department within St. Vincent and the Grenadines supports the legal basis for managing its natural resources. The FRCA 1992 gives the Forestry Department the mandate for managing the nation's forests and watersheds. The WPA of 1987 provides for the protection and management of the Nation's wildlife and authorizes the establishment of wildlife reserves for that purpose. It is under this Act that the St. Vincent and the Grenadines's 24 wildlife reserves have been established. The Fisheries Act in turn provides for the management and development of fisheries as well as the protection of special areas designated as marine reserves. The implementation of measures for the conservation and sustainable use of biodiversity is incorporated into the work programmes, and operational, corporate, and management plans of the various government and non-governmental sectors and agencies. In the case of marine biodiversity, regional consultations took place in 2004 to develop a common Fisheries Policy and Regime which would include strategies to address Article 6 and 8 of the CBD.

In 1993, about 38% of the land area was covered by forest, about 5% of which was mature, mostly undisturbed primary forest. At that time, land above 305 meters sea level was reserved to conserve remaining forests (St. Vincent and the Grenadines Forestry Department, 1993). There is history of deforestation in St. Vincent and the Grenadines due to squatting and agricultural encroachment (Providence, 2000). Estimates of deforestation in some watershed areas were estimated to approach 60 – 70 acres/year (CCA. 1991). The national forest inventory of 1993 gave an average rate of deforestation as 17 ha/year, over the period 1986-1993. In 1984, Birdsey *et al.*, did an inventory of the forest in St. Vincent, which was based on photo interpretation. The map produced was an adaptation of Beard's 1949 study. The most recent inventory was done in 1993 where a National Inventory Report was produced. This inventory was based on the re-interpretation of the 1982 photographs and strip sampling points (the findings of this inventory are in Tables 1 and 2).

TABLE 1
Forest Land Classification and Areas by Inventory Year

Forest Types	Area in ha		
	1949	1984	1993
Rainforest	8218	9208	7759
Dry Scrub Woodland	1491	1326	2179
Elfin Woodland	207	952	457
Palm Brake	4122	1734	518
Regeneration			1776
Total Forest Area	**14,038**	**13,220**	**12,689**

TABLE 2
Areas of Rainforest Type

Forest Types	Area in ha
Primary Rainforest	4308
Secondary Rainforest	3451
Total Forest Area	**7759**

According to the 1993 National Inventory Report, a formal inventory has never been carried out for the Grenadines; however, visits were made for the GOSVG/CIDA forestry development project to ground-truth existing map information. An account of the flora of the Grenadines can be found in Howard's "Vegetation of the Grenadines" published in 1952 and cited in the Country Environmental Profile of St. Vincent and the Grenadines. Forests and sustainable forest management are not only important to the Vincentian government; they also play an important role in the lives and well being of the Vincentian population. Most of the forests in St. Vincent and the Grenadines are located on government lands. Management, therefore, is done primarily through the Forestry Department. Direct national spending on the forestry sector stands just over 2.1 million Eastern Caribbean dollars annually. The forests in St. Vincent and the Grenadines are of prime importance for the national economy through ecotourism, welfare of citizens (livelihoods), and environmental conservation and management. The awareness of its economic and social importance is increasing rapidly among Vincentians.

Forests within St. Vincent and the Grenadines play a special role in the conservation of biodiversity. Within its 150 square miles, it houses hundreds of the world's plants and animals; more than thirteen of which are known to be endemic to St. Vincent and the Grenadines. In tree species alone, forests are extremely diverse, often having more than 100 species per hectare. Forests cover approximately 28 percent of the island but contribute only 0.74 percent to the national GDP. The forests support 65 percent of the national biodiversity; protect the many steep slopes from erosion, and maintain the surface water flow on which the country depends for its potable water.

3. Adverse Impacts of Climate Change on Forestry in St. Vincent and the Grenadines

The potential impacts of climate change will likely be felt most strongly in coastal areas, through mechanisms such as saltwater intrusion, increased coastal erosion, and flooding or inundation. However, the country as a whole will be more susceptible to certain impacts, particularly increased intensity of tropical storms and hurricanes, which threaten biodiversity, human life and ecosystems, and have significant impacts on the national economy. There is evidence already in St. Vincent and the Grenadines of increased incidence of extreme events such as increased rainfall events and flooding, providing a strong indication that climate variability is already adversely affecting the country. Climate change will influence terrestrial ecosystems in varying ways. The projected changes in climate can have adverse effects on water resources, agriculture, natural ecosystems and human health. The main aspects of climate change that will affect the forest biodiversity of St. Vincent and the Grenadines include: increases in global air temperatures; increased rainfall; and sea level rise.

3.1 Increases in Global Air Temperatures

The increase in global air temperatures will lead to a number of adverse effects to the forest biodiversity within St. Vincent and the Grenadines. As a result of such global increases, there is evidence that national temperatures have increased both with regards to the maximum and minimum. According to Joyette (2007), annual minimum temperatures have increased from approximately 18.8°C to approximately 21.2°C and maximum temperature from 32.7°C to 33.2°C over the last 28 year period (Figure 3). This will result in the land heating up faster than usual and not cooling as quickly. This additional heat will adversely influence terrestrial ecosystems and ultimately the biological diversity that such ecosystems support. The additional heat will also result in increased soil moisture content loss, changed soil texture and properties, and increased transpiration rate of native flora. As a result of these adverse effects, there is a high incidence for flora and fauna migration in addition to floral succession.

As the earth's temperature rises, there will also be increased heat in certain wildlife habitats thus wildlife will move towards higher elevations or different locations to find suitable habitats. For agriculture, accelerated global warming will affect atmospheric carbon dioxide concentrations, temperatures, and precipitation patterns that can change relatively wet areas to dryer areas, or wet

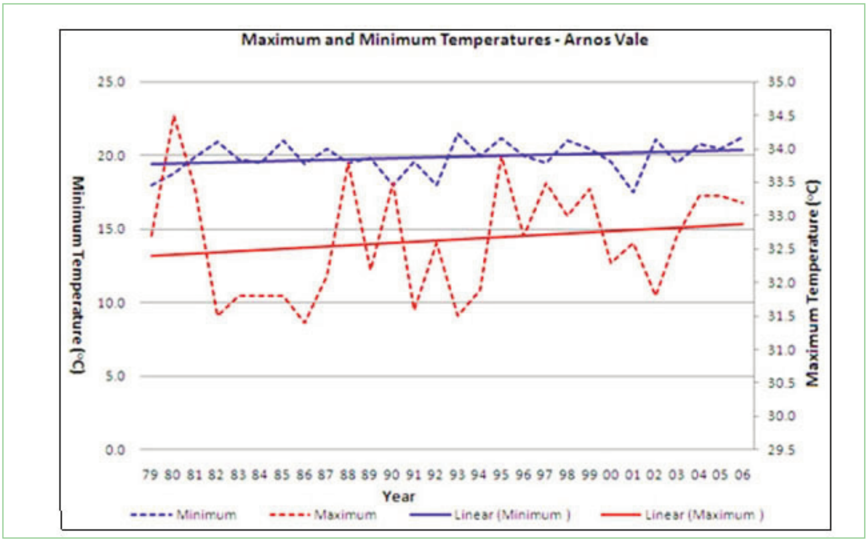


FIGURE 3
Maximum and Minimum Temperature, Arnos Vale, 1979 - 2006 (Source: St. Vincent and the Grenadines Climate Assessment, 2007).

areas to wetter areas, or dry areas to dryer areas with substantial impacts on agriculture. Therefore, higher temperatures will affect plant production which can compromise national food security. Also, due to the higher air temperatures, agriculture crops are most likely to face added stresses from increased and/or new pests and diseases, which result in other adverse effects associated with the increased use of herbicides and pesticides to control the increase in and/or new pests and diseases.

Native vegetation is expected to migrate owing to temperature change and increased precipitation, which may create problems in small island settings such as St. Vincent and the Grenadines. From a watershed perspective, there is a fluctuation in the rate of re-charge and discharge of water in the watersheds throughout St. Vincent and the Grenadines. This occurs as a result of increased air temperatures, which reduces soil moisture and increases the transpiration rate of the tree species. As a result the trees will increase their uptake of moisture from the soil and this will reduce the quantity of groundwater available to recharge the surface flow in the rivers. In addition, increases in evaporation of surface water will also cause a fluctuation in the discharge rate.

The forest biodiversity is under added pressure from resource competitors, predators, parasites, diseases and disturbances (such as fires or storms). For example, where fire is used to clear agricultural land, drier, warmer conditions will make an adjacent forest more susceptible to burning. In addition, disturbances such as fires, floods and pests are expected to become more frequent as a result of climate change. Increased rainfall events will cause increased soil erosion and soil leaching thus leading to less fertile land which will affect the production of food for daily consumption and livelihoods.

Increases in air temperature will give rise to a reduction in the incubation period of the *Aedes aegypti* mosquito by providing the environment (forested and non-forested areas) for this pest to flourish. This will cause the mosquito to mature in a shorter time thus increasing the quantity of mosquitoes, which in turn can lead to dengue fever outbreaks leading to human health issues. With the increase in temperatures, the vegetation zones are expected to move towards higher latitudes or high altitudes and in some cases depending on the rate of the temperature increase certain vegetation zones/types can become extinct. Changes in streamflow, floods, droughts, water temperature, and water quality have been observed and they have affected biodiversity and the goods and services that the ecosystems provide. Changes in rainfall frequency and intensity combined with landuse change in watershed areas have led to increased soil erosion and siltation in rivers.

The increase in global air temperature will also give rise to increase in sea surface temperatures. In coastal waters, increase in temperatures will lower the oxygen content and allow for growth of toxic algae and harmful bacteria that can destroy several species of fish. The inundation of shallow reefs and mangroves will result in loss of breeding grounds and ultimately the loss of some species. In addition, increase in sea surface temperatures is most likely to place added stress on certain species of coral reefs, which can lead to their deaths and possible extinction. Also, increase of sea surface temperatures will most likely result in a poleward shift of biological diversity especially fishes as they move to more conducive habitats.

3.2 Increased Rainfall

Joyette (2007) observed that within the last 10 years, there appears to be a growing trend of a wetter than normal dry season in St. Vincent and the Grenadines. From observation in St. Vincent and the Grenadines, the *Burgera simaruba* (gumbolimba) usually starts shedding its leaves and flowers in January, but for the past 5 years when there is continuous rainfall in January it sheds its leaves and puts out new shoots later, and when there is a dry spell in March/May it starts fruiting (Glasgow, 2007). In addition, at Argyle, along the east coast of St. Vincent, the *Coccoloba uvifera* (seaside grape), during an unusual weather system with an increase of rainfall also in January, there was a sudden flush of leaves reddish brown in color (Johnson *et al.*, 2007). According to the climate

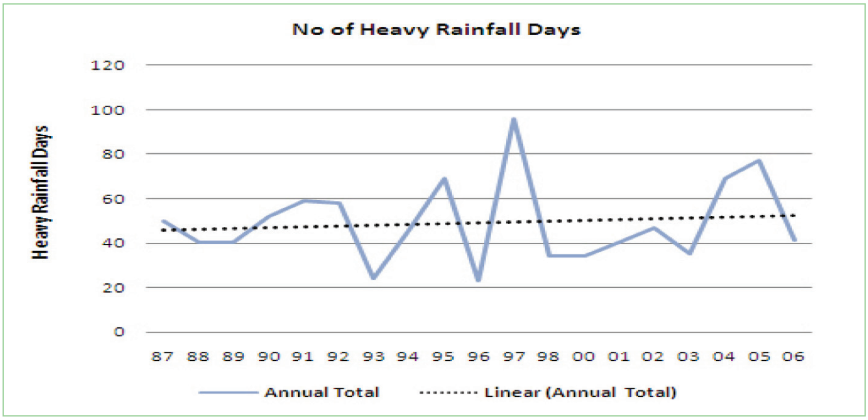
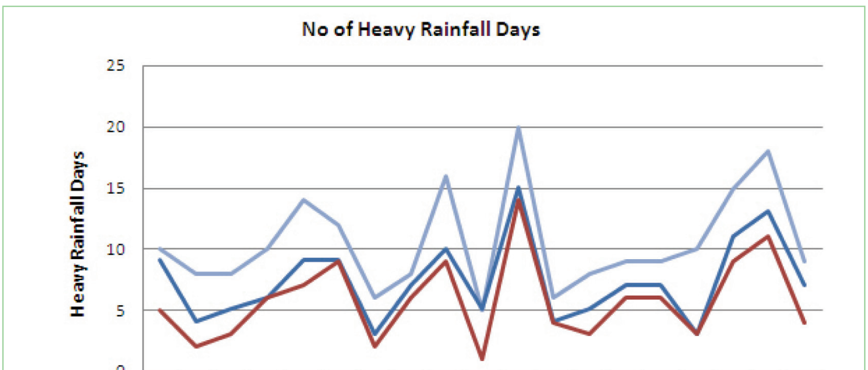


FIGURE 4
Annual total heavy rainfall days at Arnos Vale, St. Vincent and the Grenadines (Source: St. Vincent and the Grenadines Climate Assessment, 2007).

assessment of St. Vincent and the Grenadines done by Joyette (2007), the quantity of precipitation has increased while the number of raindays has decreased. This means that a larger quantity of rainfall falls in less days and this has serious implications with regards to increase surface run-off and flooding. Increased flooding events will cause damage, destruction, and dislocation of species. Frequent flooding in coastal areas is very likely to cause a change in vegetation and ultimately the flora and fauna biodiversity. Also, increase surface run-off will cause an increase in soil erosion, which in turn will lead to deposition of contaminants in fresh water and eventually this will most likely adversely affect aquatic biodiversity. With the increase in rainfall, this eventually leads to landslides and frequent flooding, seeds and other plant parts are removed and deposited in other areas starting a process of colonization of dominating species that are there. This can also be caused by wind due to more frequent storms/hurricanes. As a result, this will affect fauna behaviour in relation to food and nesting/breeding (Glasgow, 2007).



Rain \ Year	87	88	89	90	91	92	93	94	95	96	97	98	00	01	02	03	04	05	06
≥ 35mm	10	8	8	10	14	12	6	8	16	5	20	6	8	9	9	10	15	18	9
≥ 45mm	9	4	5	6	9	9	3	7	10	5	15	4	5	7	7	3	11	13	7
≥ 55mm	5	2	3	6	7	9	2	6	9	1	14	4	3	6	6	3	9	11	4

FIGURE 5

Number of heavy rainfall events at Arnos Vale, St. Vincent and the Grenadines (Source: St. Vincent and the Grenadines Climate Assessment 2007).

3.3 Sea Level Rise

As recently reported by the United Nations, the Antarctic ice/glaciers are melting twice as fast within the last 10 years, which will lead to rise in sea level. This will most likely result in a change in coastal vegetation, loss of species' habitats, loss of species, migration of wildlife especially migratory birds, dislocation of species, and disruption of the ecological balance of the coastal ecosystems. According to Johnson, there appear to be an influx of zenaida doves for the past four years seen in different parts of St. Vincent and the Grenadines. There was also an increase in the number of butterflies that however can also be attributed to the decrease in banana cultivation and less use of chemicals by the farmers.

4. Proposed Research

Due to the fact that there is a lack of scientific evidence to adequately implement adaptation strategies aimed at providing environmental and socio-economic sustainability, the following areas of research are identified:

1. Identify and describe the added stresses that the Cross Country Road (CCR) will have on the forest biodiversity bearing in mind the adverse impacts of climate change. This research will require conducting a comprehensive inventory of the biodiversity along and around the path of the CCR;
2. Research all endemic species to look at the impacts of climate change, how their habitats will be impacted, identify new threats, and determine actions (adaptation and mitigation strategies/measures) that will ensure these species survival;
3. Research introduced species such as the Armadillo (Tattoo), Agouti, etc. about the impact of climate change on them, their abilities to adapt, their continued importance to the people of St. Vincent and the Grenadines as food, livelihoods and contribution to the economy; and
4. Research on the introduction of the most appropriate species to meet local needs and demands in the face of the adverse effects to be faced as a result of climate change and environmental pollution.

It is imperative that the above research areas focus on options, interactions ad synergies between global climate change and forest biodiversity.

5. Present and Future Networks

The Environmental Services Unit in the Ministry of Health and the Environment is responsible for coordinating the various biodiversity reports and is the focal point for the CBD; however, actual biodiversity management rests with a number of agencies. The major agencies are the Forestry Department and the Fisheries Division in the Ministry of Agriculture, Forestry and Fisheries. The Ministry of

Agriculture, Forestry and Fisheries as a larger entity also consists of other departments and units which have responsibilities relating to biodiversity management. These include the Plant Protection Unit, the Agriculture Department/Extension Tree Crops and Gardening Services, the Animal Health and Production Unit, and the Research and Development Unit.

Another important agency responsible for biodiversity related matters is the Central Planning Unit in the Ministry of Finance and Economic Planning. This agency deals with land use management and spatial mapping of natural resources. It is also responsible for ensuring the enforcement of legislation relating to Environmental Impact Assessments (EIA) and environmental mitigation. There is also the recently formed (2003) National Parks, Rivers and Beaches Authority which operates under the Ministry of Tourism and Culture as well as the Tobago Cays National Marine Park which is managed by a board.

There are also various private corporations and statutory organisations involved in certain aspects of biodiversity management. These include the electrical company, St. Vincent Electricity Services Ltd. (VINLEC) and the Central Water and Sewage Authority (CWSA).

Since there is no single agency concerned with biodiversity management, the coordination of management efforts is particularly challenging. It is important to note that while biodiversity issues are dealt with as part of the work programs of the above-mentioned agencies, biodiversity as a separate concern is not given adequate attention. Thus the various work programmes outlined in the decisions made by the Conference of Parties are generally not deliberately tackled, but instead tend to coincide with strategies being implemented by the various agencies.

One exception, however, is the Environmental Services Unit in the Ministry of Health and the Environment. The work programme of this unit centers on a number of key environmental issues and the implementation of various international conventions, multilateral environmental agreements (MEAs), and regional initiatives including those related to biodiversity.

In 1990, St. Vincent and the Grenadines adopted the Specially Protected Areas and Wildlife (SPAW) Protocol, which became international law in 2001. This protocol was designed to regionalize global conventions such as the Convention on Biological Diversity (CBD), the International Coral Reef Initiative (ICRI) and its action component, the International Coral Reef Action Network (ICRAN), and the Global Coral Reef Monitoring Network (GCMN). *See Attachment 3* for more information on the SPAW Protocol. In 2003, a demonstration project was launched in St. Vincent and the Grenadines under the Caribbean Regional Environment Programme (CREP). The main objective of the project is "to enhance the contribution of natural areas of biodiversity and economic significance to the sustainable development of CARIFORUM[1] member states. The project is intended to help local people make a living while applying the principles of sustainable use. In 2001, St. Vincent and the Grenadines (SVG) signed the St. Georges Declaration of Principles for Environmental Sustainability in the Organisation of Eastern Caribbean States (OECS). This set of principles mandates actions specific to biodiversity conservation. *See Attachment 4* for detail.

At the 1994 Global Conference on the Sustainable Development of Small Island Developing States (SIDS) in Barbados, countries in the region, including St. Vincent and the Grenadines, adopted a Programme of Action for the Sustainable Development of SIDS, also known as the Barbados Programme of Action (BPOA). Chapter IX of this programme of action outlines a number of activities to be undertaken at the national level as it regards biodiversity conservation. These activities coincide with many of the articles in the CBD. *See Attachment 5* for more information.

Besides the various regional efforts, a number of local NGOs are involved in various biodiversity related projects. One outstanding NGO is the Bequia Sandwatch Group which is involved in the monitoring beach erosion, coral bleaching and other environmental hazards. Another group is the Mayreau Environmental Developmental Organisation (MEDO), based on the Grenadine Island of Mayreau, which collects and updates various checklists of biodiversity in St. Vincent and the Grenadines and which is involved in a number of conservation and sustainable use projects. This group is also engaged in a number of environmental education activities. In addition, the University of the West Indies Centre for Resources Management and Environmental Studies (CERMES) coordinated a project in the Grenadines that seeks to build the capacity of local communities to manage their biodiversity.

Acknowledgements

The authors of this paper will like to acknowledge the assistance given by the following institutions and individuals in preparing this report. The Ministry of Agriculture, Forestry and Fisheries and in particular the Director and Staff of the Forestry Department for their contribution, advise, guidance, patience and logistical support in preparing this report. The Ministry of Health and the Environment and in particular Mr. Edmund Jackson, Environmental Health Services Coordinator, for sharing information and reports related to the topic. The St. Vincent and the Grenadines National Trust especially Ms Rachel Moses for assistance and use of recent relevant reports. Mr. FitzGerald Providence, Project Manager of the Integrated Forest Management and Development Programme.

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ATTACHMENTS

Attachment 1

International Multilateral Environmental Agreements and National Legislations

The following agreements, singly or collectively, are supportive of adaptation measures for climate change which in turn make provisions for the conservation and protection of biological diversity and have all been signed by St. Vincent and the Grenadines:

- The ***United Nations Framework Convention on Climate Change (UNFCCC 1992):*** This convention and its protocol seek to control the emission of greenhouse gases. The Government of St. Vincent and the Grenadines and the private sector are taking measures to reduce greenhouse-gas emissions;
- The ***United Nations Convention on Biological Diversity (CBD 1992):*** This convention seeks to protect flora and fauna and their habitats from destruction by man. The Government of St. Vincent and the Grenadines has submitted three reports on biological diversity as part of this convention;
- The ***Basel Convention on the Control of Transboundary Movement of Hazardous Waste and their Disposal (1989):*** This Convention seeks to restrict the importation of hazardous waste;
- The ***Convention on Trade in Endangered Species (1989)*****:** The Convention attempts to regulate wildlife trade through worldwide system of import and export controls for species which are listed in three appendices. Appendix I of the Convention lists species which are threatened with extinction and for which commercial trade is prohibited; Appendix II lists species which may become extinct unless trade is strictly regulated; and Appendix III reports those species protected in their country for origin and for which the cooperation of other nations is required in order to enforce export restrictions;

- The ***Vienna Convention on the Protection of the Ozone Layer (1985):*** Protection of the ozone layer will reduce ultraviolet radiation. St. Vincent and the Grenadines has in place a programme to phase out the use of ozone-depleting substances under this convention;
- The ***United Nations Convention on the Law of the Sea (UNCLOS 1982):*** This convention prescribes jurisdictional rule for the protection of the marine environment. UNCLOS obligates coastal member states to "protect and preserve the marine environment". This convention provides the framework for the Exclusive Economic Zone;
- The ***International Convention for the Prevention of Pollution from Ships (MARPOL 1973):*** Enforcement of this convention will protect aspects of coastal resources against marine pollution;
- The ***Town and Country Planning Act (45 of 1992):*** This act makes provision to ensure orderly development of lands and the proper planning of town and country areas;
- The ***Forest Resource Conservation Act of 1992***, which makes provision for the management and protection of forested areas;
- The ***Fisheries Act of 1986***, which makes provision for the protection and management of fisheries and marine protected areas;
- The ***Beach Protection Act of 1981***, which makes provision for the control of sand mining and the general protection of beach areas; and
- The ***Central Water and Sewage Authority Act of 1992***, which permits the protection of water resources related to water-supply needs.

Attachment 2

Article 6 CBD: General Measures for Conservation and Sustainable Use

Each Contracting Party shall, in accordance with its particular conditions and capabilities:

(a) Develop national strategies, plans or programmes for the conservation and sustainable use of biological diversity or adapt for this purpose existing strategies, plans or programmes which shall reflect, inter alia, the measures set out in this Convention relevant to the Contracting Party concerned; and

(b) Integrate, as far as possible and as appropriate, the conservation and sustainable use of biological diversity into relevant sectoral or cross-sectoral plans, programmes and policies.

Attachment 3

The Specially Protected Areas and Wildlife (SPAW) Protocol

(Adapted from the Caribbean Environment Programme (CEP) website **www.cep.unep.org**).

The Convention for the Protection and Development of the Marine Environment of the Wider Caribbean Region (the Cartagena Convention) is the only legally binding environmental treaty for the Wider Caribbean. The Convention and its Protocols constitute a legal commitment by the participating governments to protect, develop and manage their common waters individually or jointly.

The SPAW Programme supports activities for the protection and management of sensitive and highly valuable natural marine resources. This Sub-Programme is responsible for the regionalization of global conventions and initiatives such as the Convention on Biological Diversity (CBD), the International Coral Reef Initiative (ICRI) and the Global Coral Reef Monitoring Network (GCRMN). A Memorandum of Cooperation exists between the CBD and UNEP-CAR/RCU to assist with the implementation of the CBD at the regional level.

The Protocol Concerning Specially Protected Areas and Wildlife (the SPAW Protocol) has been internationally recognized as the most comprehensive treaty of its kind. Adopted in Kingston, Jamaica by the member governments of the Caribbean Environment Programme on 18 January 1990, the SPAW Protocol preceded other international environmental agreements in utilizing an ecosystem approach to conservation. The Protocol acts as a vehicle to assist with regional implementation of the broader and more demanding global Convention on Biological Diversity (CBD).

The objectives of SPAW are:

- To significantly increase the number of and improve the management of national protected areas and species in the region, including the development of biosphere reserves, where appropriate.
- To develop a strong regional capability for the co-ordination of information exchange, training and technical assistance in support of national biodiversity conservation efforts.
- To coordinate activities with the Secretariat of the Convention on Biological Diversity, as well as other biodiversity-related treaties, such as the CITES, Ramsar, Bonn and Western Hemisphere Conventions.
- To assist the Governments of the region, upon their request, in the development of guidelines regarding the application of regulations and

economic steering instruments in the decision-making process toward the establishment and enforcement of measures necessary to prevent, reduce and control marine pollution and to provide them with the relevant information.

Advantages:

1. The only regional environmental legal agreement addressing biodiversity conservation issues of the Wider Caribbean.
2. Its provisions provide specific and concrete guidance for the implementation of the Convention on Biological Diversity (CBD), in particular regarding protected area establishment and management, as well as species and coastal ecosystems management and conservation. (The CBD is very demanding on those issues but does not provide guidance which SPAW does).
3. SPAW was developed *by* the governments of the region and *for* the region. In this way is more appropriate and specific to the Wider Caribbean than other global treaties.
4. It is supported by an operational programme, which is currently supporting for example: marine protected areas in the region, countries with coral reef conservation and management, countries in implementing sustainable tourism practices, etc.
5. It has no direct financial implications for the countries as the Trust Fund is independent from the Convention (Dominica has been paying to the Trust Fund anyway and they are not fully benefiting from SPAW as they have not become Parties).
6. Being a Party to SPAW sends a clear message to the region and donors about the commitment of a country (Dominica) towards biodiversity conservation. This could particularly relevant a Dominica develops as a "Green Globe" destination.
7. SPAW provides for the establishment of a Scientific and Technical Advisory Committee (STAC) to address issues and identify priorities. The STAC could be used by the region to address CBD issues and form consensus. The participation of the region in CBD meetings has been very poor and the STAC could be used as a mechanism to carry a unified voice from the region to CBD.
8. A Party to SPAW will benefit from the activities of the SPAW Programme and from regional cooperation opportunities in the management of coastal and marine resources.
9. A Party to SPAW will also benefit from the Memorandum of Cooperation which exists between CBD and SPAW Secretariats.
10. A Party to SPAW will benefit from technical assistance from the SPAW Regional Activity Centre to be established in 1999 in the National park of Guadeloupe.

Attachment 4

The OECS Environmental Management Strategy & the St. Georges Declaration of Principles for Environmental Sustainability in the OECS

(Adapted from the Development Gateway website)
http://topics.developmentgateway.org/oecsaid/rc/filedownload.do~itemId=270681
http://topics.developmentgateway.org/oecsaid/rc/filedownload.do~itemId=270681.

THE OECS ENVIRONMENTAL MANAGEMENT STRATEGY

"To protect, conserve and enhance or restore, where appropriate, the quality and value of the region's natural resources in order to sustain social and economic development for present and future generations."

Vision Statement to guide implementation of
The St George's Declaration Of Principles For
Environmental Sustainability In The OECS

At the Third Meeting of the Organisation of Eastern Caribbean States (OECS) Environment Policy Committee (September 1999) OECS Ministers of The Environment requested that the OECS Natural Resources Management Unit (NRMU) prepare an "OECS Charter for Environmental Management" and "a regional strategy...that will become the framework for environmental management" in the region. In accordance with the Ministers' request, OECS NRMU developed the *St. George's Declaration Of Principles For Environmental Sustainability In The OECS*, which was signed by Ministers in April 2001 and which sets out the broad framework to be pursued for environmental management in the OECS region.

The *St. George's Declaration of Principles for Environmental Sustainability in the OECS* comprises twenty one principles. They are:

Principle 1 **Foster Improvement in the Quality of Life**

Principle 2 **Integrate Social, Economic and Environmental Considerations into National Development Policies, Plans and Programmes**

Principle 3 **Improve on Legal and Institutional Frameworks**

Principle 4 **Ensure Meaningful Participation by Civil Society in Decision Making**

Principle 5	**Ensure Meaningful Participation By The Private Sector**
Principle 6	**Use Economic Instruments for Sustainable Environmental Management**
Principle 7	**Foster Broad-based Environmental Education, Training and Awareness**
Principle 8	**Address the Causes and Impacts of Climate Change**
Principle 9	**Prevent and Manage the Causes and Impacts of Disaster**
Principle 10	**Prevent and Control Pollution and Manage Waste**
Principle 11	**Ensure the Sustainable Use of Natural Resources**
Principle 12	**Protect Cultural and Natural Heritage**
Principle 13	**Protect and Conserve Biological Diversity**
Principle 14	**Recognise Relationships between Trade and Environment**
Principle 15	**Promote Cooperation in Science and Technology**
Principle 16	**Manage and Conserve Energy**
Principle 17	**Negotiate and Implement Multi-lateral Environmental Agreements**
Principle 18	**Coordinate Assistance from the International Community towards the Organisation of Eastern Caribbean States**
Principle 19	**Implementation and Monitoring**
Principle 20	**Obligations of Member States**
Principle 21	**Review**

Following is a description of some of the principles of the *St. George's Declaration for Environmental Sustainability in the OECS* that complement various elements of the Convention on Biodiversity (CBD).

PRINCIPLE 11

Ensure the Sustainable Use of Natural Resources

Each Member State agrees to:

(a) Manage terrestrial, marine and atmospheric resources, organisms and eco-systems in an appropriate manner to obtain the optimum sustainable productivity, while maintaining the integrity of natural and ecological processes and inter-relationships between such systems and processes;
(b) Design, promote and implement measures to prevent, mitigate and control degradation of aquatic, terrestrial and atmospheric environmental quality and processes conducive to desertification;
(c) Cooperate in the conservation, management and restoration of natural resources existing in areas under the jurisdiction of more than one State, or which may exist in areas that are fully or partially beyond the limits of its national jurisdiction;
(d) Work together, in collaboration with Civil Society, to promote and facilitate improved national and regional capability for the management of natural resources;
(e) Collaborate in the implementation of appropriate precautionary approaches aimed at managing and avoiding environmental degradation and over-exploitation of natural resources within the sub-region;
(f) Take all necessary measures within its legal and policy framework, including enactment of new legislation where appropriate, to ensure that conservation and management of natural resources are treated as an integral part of development planning at all stages and levels;
(g) Develop a schedule of development activities for which environmental impact assessment will be required as part of project definition and design, and the results of which will be considered in determining whether and how a project will proceed.

PRINCIPLE 13

Protect and Conserve Biological Diversity

Each Member State agrees to:

(a) Pursue appropriate measures to conserve and, where necessary, restore biological diversity, including species diversity, genetic diversity within species and ecosystem diversity;
(b) Manage biological resources to ensure their conservation, sustainable use and possible restoration;
(c) Establish appropriate legal and institutional structures to control and licence the prospecting for, or harvesting and export of cultural and ecological resources;
(d) Take necessary precautionary measures to avoid or minimize, the intentional or accidental introduction or escape, into or from the environment, of alien or modified organisms that are likely to impact adversely on other organisms or the environment;
(e) Take appropriate measures to control or eradicate alien or modified organisms having the potential to impact adversely on other organisms the environment or human health;
(f) Take appropriate measures to ensure that activities within its jurisdiction, do not damage the biological diversity and the environment of another State, within or beyond the limits of that other State's national jurisdiction.
(a) Assess and where appropriate, adopt new technologies, techniques and methodologies for achieving effective environmental management.

PRINCIPLE 15

Promote Cooperation in Science and Technology

Each Member State agrees to:

(b) Promote directly or through competent regional or other international agencies cooperation in the fields of science, technology and other research in support of sound and sustainable natural resource and environmental management , and the sustainable development of human resources;
(c) Promote scientific and technical cooperation in the field of environmental conservation and the sustainable use of natural resources;

(d) Cooperate to establish, adopt and implement comparable or standardized research techniques and harmonized methods to measure environmental parameters, and promoting widespread and effective participation of all States in establishing such methodologies;
(e) Assess and where appropriate, adopt new technologies, techniques and methodologies for achieving effective environmental management.

PRINCIPLE 17

Negotiate and Implement Multi-lateral Environmental Agreements

Each Member State agrees to:

(a) Endeavour to become and remain parties to multi-lateral environmental agreements relating to the subject-matter of this Declaration;
(b) Collaborate to establish or better utilise existing sub-regional negotiating mechanisms for multi-lateral environmental agreements;
(c) Cooperate to the degree feasible in formulating common positions in the negotiation and implementation of multi-lateral environmental agreements;
(d) Establish appropriate mechanisms to facilitate the exchange of information relating to the negotiation, implementation and compliance with multi-lateral environmental agreements;
(e) Ensure, to the extent feasible, that the Principles contained in this Declaration are fully integrated into the negotiation and implementation of multi-lateral environmental agreements;
(f) Reserve the right of Member States, whether individually or together, to adopt and implement measures, where necessary, beyond the provisions of multi-lateral agreements for the purpose of meeting the needs of this Declaration while maintaining compliance with the multi-lateral agreements to which they are signatories.

PRINCIPLE 19

Implementation and Monitoring

Each Member State agrees to:

(a) Ensure that all new national policies and programs are undertaken in a manner that is consistent with the principles contained in the Declaration;
(b) Cooperate in good faith with each other to achieve optimal results from their environmental policies and actions relating to the use of trans-boundary natural resources, and in the effective prevention or abatement of trans-boundary environmental problems;
(c) Work concertedly together to implement the Principles enunciated in this Declaration;
(d) Implement the commitments contained in Annex A to this agreement in a timely and expeditious manner, and with all due diligence, and report periodically on measures undertaken to satisfy this requirement;
(e) Work concertedly together to develop the OECS Environmental Management Strategy that will give effect to this Declaration;
(f) Undertake to apply minimum acceptable standards at all times in respect of addressing issues concerning the impact or adverse effects of trans-boundary natural resources on the environment;
(g) Develop a national environmental management strategy within two (2) years of the date this Declaration comes into force;
(h) Designate an entity comprised of each Member State to monitor and facilitate the compliance of each Member State with this Declaration, and to report on measures undertaken to implement this Agreement;
(i) Communicate timely and relevant information on all aspects of the St George's Declaration's Principles to other interested States.

Attachment 5

Programme of Action for the Sustainable Development of Small Island Developing States

(Selected Passage)

Adapted from the United Nations Department of Economic and Social Affairs website, from the Report of the Global Conference on the Sustainable Development of Small Island Developing States (Bridgetown, Barbados, 25 April-6 May 1994).

Full text available at **www.un.org/documents/ga/conf167/aconf167-9.htm**.

IX. BIODIVERSITY RESOURCES

Basis for action

41. Small island developing States are renowned for their species diversity and endemism. However, due to the small size, isolation and fragility of island ecosystems, their biological diversity is among the most threatened in the world. Deforestation, coral reef deterioration, habitat degradation and loss, and the introduction of certain non-indigenous species are the most significant causes of the loss of biodiversity in Small Island developing States.
42. In the past, there has been a strong emphasis on the collection of more information. In small island developing States where limited and biologically precious resources are being threatened, while the lack of sufficient information is often cited as a rationale for inaction, there is often enough information to identify areas requiring in situ conservation. Although more information will be required in order to develop appropriate management plans, information collection should no longer be a prior condition for in situ conservation projects.
43. The nature of traditional, often communal land and marine resource ownership in many island countries requires community support for the conservation effort. Without that local support and commitment and the opportunity to integrate sustainable income generation into the conservation effort, even the most highly studied and well planned conservation area will not be sustainable.

44. Some of the most precious biological resources for islanders, environmentally, economically and culturally, are marine and coastal rather than terrestrial. This requires a conservation focus that takes into account customary land and reef tenure systems and practices, which may differ from that usually found in the larger developed countries. Other considerations include the adequacy of basic institutional support for conservation efforts (staff, vehicles etc.) and access to financial resources to help start innovative projects.
45. A number of international and regional conventions exist concerning the conservation and sustainable utilization of biological resources, which are expected to provide a sound legal framework of potential benefit to the sustainable development of small island developing States.

A. National action, policies and measures

(i) Formulate and implement integrated strategies for the conservation and sustainable use of terrestrial and marine biodiversity, in particular endemic species, including protection from the introduction of certain non-indigenous species and the identification of sites of high biological significance for the conservation of biological diversity and/or for eco-tourism and other sustainable development opportunities, such as sustainable agriculture, training and research.

(ii) Ratify and implement the Convention on Biological Diversity, 10/ the Convention on International Trade in Endangered Species of Wild Fauna and Flora 11/ and other relevant international and regional conventions.

(iii) Promote community support for the conservation of biological diversity and the designation of protected areas by concentrating on educational strategies that increase awareness of the significance of biodiversity conservation, in particular the fundamental importance to resource-owning communities of a diverse biological resource base.

(iv) Generate and maintain buffer stocks or gene banks of biogenetic resources for reintroduction into their natural habitat, especially in the case of post-disaster restoration and rehabilitation.

(v) Develop or continue studies and research on biological resources, their management and their intrinsic socio-economic and cultural value, including biotechnology.

(vi) Conduct detailed inventories of existing flora, fauna and ecosystems to provide basic data needed for the preservation of biodiversity.

(vii) Ensure that the ownership of intellectual property rights is adequately and effectively protected. Ensure, subject to national legislation and policies, that the technology, knowledge, and customary and traditional practices of local and indigenous people, including resource owners and custodians, are adequately and effectively protected, and that they thereby benefit directly, on an equitable basis and on mutually agreed terms, from any utilization of such technologies, knowledge and practices, or from any technological development directly derived therefrom.

(viii) Support the involvement of non-governmental organizations, women, indigenous people and other major groups, as well as fishing communities and farmers, in the conservation and sustainable use of biodiversity and biotechnology.

B. Regional action

(i) Encourage countries to give priority to known, existing sites of biological significance - while recognizing that there are many important sites whose biological significance remains unknown and to build up community support for the protection of those areas including their protection from the introduction of non-indigenous species.

(ii) Promote regional studies of the socio-economic and cultural value of biological resources, including genetic engineering, intellectual property rights and access to biotechnology, with the participation of existing or strengthened scientific institutions, relevant international agencies and non-governmental organizations.

(iii) Promote the establishment of regional gene-bank centres for research, seeking the development and introduction of more resistant and productive varieties of species, and provide the appropriate legal and technical procedures for the use of those biological resources.

(iv) Coordinate information exchange, training and technical assistance in support of national efforts to establish and manage conservation areas and for species conservation, including the identification and use of traditional knowledge and techniques for resource management that assist the conservation of biological resources and diversity.

(v) Promote and/or strengthen already existing regional scientific institutions that can operate as reference centres for problems related to the conservation and sustainable management of biodiversity.

(vi) Strengthen the capacity of regional organizations to provide technical support and coordination in the development of inventories of flora, fauna and ecosystems and, where feasible, to establish regional databases and gene banks.

(vii) Support the development of adequate and effective legal mechanisms for the protection of intellectual property rights.

C. International action

(i) Provide improved access to financial and technical resources for the conservation of biological diversity, including funds for basic institutional and logistic support for the conservation and management of biological diversity, with priority to be accorded to terrestrial as well as coastal and marine biodiversity, such as coral reef ecosystems.

(ii) Improve access to environmentally sound biotechnology, including know-how and delivery mechanisms.

(iii) Ensure that the activities of relevant international organizations, agencies and programmes of the United Nations as well as relevant non-governmental organizations are closely coordinated with and supportive of identified regional small island developing States centres or ongoing programmes in the conservation and sustainable use of biodiversity and biotechnology.

(iv) Make greater use of import restrictions under the Convention on International Trade in Endangered Species of Wild Fauna and Flora on products from endangered species endemic to small island developing States.

(v) Support national and regional actions for developing inventories of flora, fauna and ecosystems, including training and technical assistance.

(vi) Support strategies to protect small island developing States from the introduction of non-indigenous species.

(vii) Promote the full involvement of non-governmental organizations, women, indigenous people and other major groups, as well as fishing communities and farmers, in the conservation and sustainable use of biodiversity and biotechnology.

PAPER

6 ENVIRONMENT = MANAGEMENT X CLIMATE^2

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ABSTRACT: Einstein discovered a deep connection between energy and mass and represented it by the now famous equation $E=MC^2$. In this equation, the final variable is a very large number, the square of the speed of light. Moving beyond the physics, can we use the same intuitive approach when we look at the Environment where the final variable in this equation is the square of the climate or in other words, natural climate times human-induced climate. As we know, climate exerts a large influence on the environment, especially biodiversity, and we need to analyze the multiplier effects of the changing climate, not just the simple additive impacts. In this context, we know that biodiversity thresholds change radically when the impact of the multiplier climate is further accelerated by the lack of management actions. We have made significant progress in our understanding of the current and future changes in the climate system, but have we implemented biodiversity actions at the same magnitude and rate to maintain a sustainable environment?

Keywords: human-induced climate variability, multiplier climate, adaptive biodiversity management

1. Introduction

Human-induced climate variability and change is no longer a theoretical concept. It is a real driver of change that affects all human, biological and socio-economic activities. None are immune.

There are two real questions that now become apparent. First, are the cumulative effects of natural and human-induced changes in the climate an additive or a multiplier process? Second, can biodiversity management actions off-set this multiplier climate in order to maintain a sustainable environment?

In 2005, our article (MacIver and Wheaton, 2005) raised the overarching question if climate change were the "third outrage" on humanity. The first two were described by Freud when he observed that "humanity has in the course of time had to endure from science two great outrages upon its naive self love" – the first outrage when science discovered that the earth was not the centre of the universe and the second when biological science relegated humans to that of a descendent from the animal world (Gould, 1977). The Intergovernmental Panel on Climate Change has increasingly produced stronger language warning humanity that warming of the climate system is "unequivocal". In other words, science has already defined this "third outrage" on humanity, but has management heard the message.

2. The Multiplier Climate and Biodiversity Management

The debates have raged for years on the subject of natural versus human-induced climates. In reality, the environment cares very little about the word "versus" and is much more affected by the combined effects of both climates. So how do we deal with this changing climate? In keeping with the brevity of Einstein's equation, the following points bear consideration.

In the additive world of statistics, we could simply define the historical climate, its variabilities and extremes and add to it the projections of future climate change, making the assumption that the biological world will react in a similar linear and additive manner. By now, we know that this is not the case, and that the biological responses will be non-linear in space and time, hence the need for incrementally greater biodiversity management actions to off-set the multiplier effects of the changing climate.

But how do we illustrate this multiplier effect in a language that policy-makers and decision-makers can translate into adaptive management actions? We clearly understand the multiplier effects of a natural climate combined with an urban climate by defining pockets of urban heat islands and the increased adaptive responses that are required to protect human health in these sub-regions. Our experiences have demonstrated this same non-linearity at sub-regional and local scales in rural landscapes, demonstrating once again the multiplier effects of the combined natural and human-induced climate. Paleo-climate evidence also substantiates that atmospheric changes will be abrupt and step-wise and the need to re-define critical biological thresholds is urgent.

Have current biodiversity management practices kept pace and served as off-sets to this multiplier climate? Our experiences demonstrate that management is slow to respond to changes; reactive in its adaptation actions; incorrect in its assumptions that the biological community is a robust and resilient environment; and overall, management has difficulty custom-fitting adaptation actions to the appropriate scale. Instead, future adaptation actions need to recognize the urgency to adapt now; adopt a pro-active, anticipatory adaptation strategy; accelerate the planning and science solutions at the appropriate scales and engage communities, partners and the education sector. In other words, think much bigger in terms of planning; catastrophic in terms of threats; and implement solutions sooner, not later. The phrase "I told you so" brings little comfort to anyone after the event.

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MacIver, D.C. and E. Wheaton, 2005. Tomorrow's Forests: Adapting to a Changing Climate. *Climatic Change* 70: 273-282.

PAPER

7

BIODIVERSITY, GLOBAL CHANGE AND DEVELOPMENT - A DIALOGUE?

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ABSTRACT: Biodiversity is threatened by expanding human activities and development. For development decisions to take into account tradeoffs between development and biodiversity, a more quantitative understanding of biodiversity and its effects needs to be developed. In particular, expressing the benefits of greater biodiversity indiscriminately in terms of ecosystem services is fraught with problems because the relationships between diversity and services are not linear and do not only depend on diversity as such but also on the kinds of organisms present. In order to permit a more rational dialogue on biodiversity conservation and development, gaps in scientific knowledge need to be filled and results communicated in terms that permit the valuation of biodiversity relative to possibly forgone development benefits.

Keywords: climate change, biodiversity

The populations of a large number of organisms are threatened by human activities, and many ecosystems are degrading under human use. As societies grow and their impacts on natural environments expand, cumulative environmental effects result in global changes that raise concern about the sustainability of human activities. At the same time as sustainability is being questioned there is still a need for further development to reduce poverty and hunger in many countries. Human impacts on earth systems including biodiversity are therefore being discussed in both contexts of development and of conservation, two contexts that often are very far apart.

Biodiversity loss is a concern, but why and to whom? at what level of diversity does it become a concern? is it species diversity that counts, or assemblages of species in ecosystems? is it the diversity itself or a function of diversity that is valued? Answers to these questions are needed in order to address the balance between development and conservation. Both additional knowledge and a dialogue are needed on the value and valuation of biodiversity. The meaning of biodiversity and the relevance of different levels of biodiversity to the discourse on global change must become clearer. Too often, arguments in favour of biodiversity conservation are repeats of decades-old statements: bioprospecting (a new word for an old activity) is important for the development of medicines; human nutrition relies on a very narrow slice of biodiversity and additional genetic diversity is needed to safeguard this against future pest, diseases and environmental change; and most importantly - ecosystem services that are vital to humanity are supported by biodiversity. All of these arguments are valid but their repeated use does not shift the decision-making process towards greater consideration of biodiversity in the face of much more calculable economic interests in development.

A better quantification and presentation of the ecosystem services argument is particularly important in the context of development since it could show that reductions in biodiversity caused by development processes may directly undermine the development in question - a classic case of unsustainability. As a consequence, policies aiming at development must achieve a balance between impacts on biodiversity and ecosystem services on one hand and development outputs on the other. Achieving that balance requires understanding and knowledge. Some of the following examples indicate that gaps in scientific knowledge and in the communication of such knowledge are still significant impediments to rational decision making between development and biodiversity conservation.

Holling (1998) identified an "analytic approach" in ecology that expands existing knowledge by experimentation, and an "integrative approach" that brings together existing knowledge from different disciplines. Biodiversity research has probably done too little of the latter and communicated too little of an integrated knowledge base to allow differentiated judgments on the appropriate balance between conservation and development. In particular, the "value" of biodiversity needs to be assessed in order to advise policy. Increasingly "value" is associated with more or less quantifiable economic indicators.

In economic terms, the 'right' amount of conservation effort is one where the marginal economic benefits from conservation just equal the marginal costs of conservation. In applying this to biodiversity, it is difficult to put a value on the economic benefits, and even more so to quantify marginal benefits. In order to overcome this difficulty there is a common trend to evaluate ecosystem services instead and somehow attribute them to biodiversity. The G8, 2007 Potsdam initiative, rather than quantifying the benefits of biodiversity has asked to estimate the economic costs of global biodiversity loss. (Cor)relating visible and measurable loss to economic damage represents a "removal experiment" and may be easier than evaluating functional systems in which the relationships are unclear. The initiative shows, though, that we don't (yet) know the cost of degradation or the benefit of conservation.

The United Nations Development Program in its brief to the financial sector (UNEP, 2007) goes as far as coining the acronym BES for biodiversity-ecosystem-services, in order "to provide a simple and clear association between these two inter-related aspects of the natural world". But, even though biodiversity underpins many ecosystem services, the relationships are not linear. There are mutual non-linearities, not identities. As biodiversity increases, the marginal return in ecosystem services diminishes. In addition biodiversity cannot really be defined in incremental levels of diversity. There is no single measure (or even two or three measures taken together) that provides a comprehensive, systematic sense of biodiversity across scales. The ways in which biodiversity matters to ecosystem services depends on what organisms there are. (Diaz *et al.*, 2006).

This complexity adds up to confusion about what biodiversity is. The public perception is one of selected taxonomic diversity, or species richness often reduced to "charismatic mega fauna". Functional diversity is ill understood and often conflicts directly with the species perspective of threatened biodiversity since rare species are likely to have small effects.

The Convention on Biodiversity (CBD) defines biodiversity as the variability among organisms <u>and</u> the ecological complexes of which they are part. UNEP links this to ecosystem services which "are the goods and services that biodiversity provides" introducing the short-circuit between diversity and services that needs closer scrutiny.

What if biodiversity cannot simply be equated with ecosystem services and we cannot define a level of biodiversity or its loss that is safe? What then is the right amount of conservation? Agriculture relies on simplified ecosystems with managed landscapes, managed and selected biodiversity, well-defined benefits and largely known costs. This may help to show up some of the relationships between diversity and service. A typical "green" criticism of agriculture is that ecosystem functioning and stability are compromised by low diversity typical of managed ecosystems. But in reality there has always been a substitution of biological function by management inputs when ecosystems are used and goods extracted. In economic terms there is a problem in defining that balance of management input, ecosystem goods and services and the degradation associated with the use of land. To optimize land use change decisions expected benefits should equal or exceed expected costs (Pagiola *et al.*, 1998) based on accountable ecosystem services and accounted agricultural production. Too often the degradation costs are externalities to the accounting because information is lacking on how to include them. Ecosystem services may increasingly be taken into account, although down-stream services are often excluded. But, again, what if biodiversity can indeed not be equated to ecosystem services? and if we need to account for the value of biodiversity on a separate balance sheet? In many agricultural systems biodiversity *per se* has measurable values and is valued by land users: risk averse farmers use crop diversity to hedge income risk under variable climate and market conditions. In this use biodiversity represents an insurance value (Di Falco and Perrings, 2003). Managed increases in biodiversity by intercropping or agroforestry practices may achieve overyielding by providing extra yield due to low competition between the species chosen for association (such as combinations of deep and shallow rooting crops). Genetic resources from wild species and crop ancestors commonly are needed to manage pest and disease susceptibility. Genetic diversity has declined and still is declining among domesticated species (MEA, 2005) and this may imply quantifiable losses and additional risks.

Most societies have benefited from the conversion to managed ecosystems but losses in biodiversity and ecosystem services have reduced well-being, increased poverty and stifled development of some regions and groups. Does this recognition translate into sensible policy? Not really. Many developing countries discriminate against agriculture through overvalued exchange rates, protection of competing sectors, high direct taxation on production or even on potential production, and price controls that benefit the urban, voting poor. Such policies discourage investments to improve productivity and leave only area expansion to increase agricultural production. Yet the agricultural context offers clear conservation options: improve biodiversity in agricultural landscapes, retain ecological functionality through agroforestry, protect key areas such as corridors between remaining habitats or remnants of natural habitats. Under each case, society, rather than the individual producer must reconcile competition between protection and “forgone development opportunities”.

In the absence of a broad-based understanding of biodiversity and its benefits at different levels of diversity, biodiversity conservation is seen as a luxury of rich nations eager to preserve ”Nature”. Debt for Nature Swaps, although well-meaning reinforce this perception. Rich nations forgive debt for nature in poor nations that are therefore exempt from developing ”ownership” and stewardship of that nature. With a payment of at most, US$ 5 per ha for the ‘average’ swap (Ruitenbeek, 1992) biodiversity is valued quite lowly. Such low pricing is easily confirmed by a survey of logging license fees which can be less than US$ 1/ha even for highly diverse tropical forests. The conclusion that “the world does not care too much about the biodiversity capital and its bequests to future generations" by Pearce (2007) does therefore not surprise. It is affirmed by the ratio of actual global expenditures on ecosystem conservation which are only some US$$10^{10}$ compared to perhaps US$$10^{14}$ for economic subsidies (Pearce, 2007; James *et al.,* 2001). The UNEP financial sector briefing on BES shows that even some fundamental values are lacking in the balance between development and conservation: it includes advice to "commit to comply with BES laws" and "avoid protected areas". In other words, UNEP sees a need to admonish the financial sector to avoid aiding law breakers.

What already used to be difficult decisions based on complex relationships between biodiversity and resilience of ecosystems have become even more complicated under climate change and under human responses to climate change. In what ways does global change, and mitigation and adaptation efforts affect biodiversity and vice versa? Mitigation of CO_2 emissions by expansion of palm oil or sugar cane will cause biodiversity loss, yet a doubling in atmospheric carbon dioxide will also threaten the integrity of biodiversity-rich regions. Climate change and habitat loss interact in landscapes, and regional landscapes rather than individual ecosystems may have to be managed in the future. Sanctuaries may no longer work under climate change as climatic boundaries shift species out of protected areas or threaten their survival in protected zones undergoing permanent temperature or precipitation changes. Integrated approaches between climate, biological and human sciences will be needed to find answers to pressing questions of biodiversity use and conservation and, most importantly, science results must be communicated effectively and proposed actions justified to those who will foot the bill. Perhaps here the social sciences might serve as an example. Nobody would offer a single index and be content with a Shannon-Weaver index (a single number which expresses biodiversity of a community taking into account only the number of individuals in a community, the number of species, and the number of individuals in each species) like number to characterize a society under development. We are all used to multi-dimensional measures that consider such things as education, wealth distribution, mortality, demographics, infrastructure, access to water and other resources, energy use etc. to define "development". The complex interactions of the diversity of species, functional groups, water and nutrient cycles, ecosystems and their services, landscapes, and regions call for similarly multi-dimensional analysis communicated in terms that decision makers and voters understand.

To assist policy decisions and negotiation evaluation and accounting of ecosystem services must advance, and crucial knowledge gaps must be filled.

Studies of development and biodiversity must explore potential outcomes of decisions, explore links and tradeoffs between poverty alleviation (development) and biodiversity conservation. Most importantly, scientists must collaborate with policy makers from the beginning to identify questions and interventions of relevance to society (Agrawal and Redford, 2006). In this context, "collaborate" cannot mean a bottom-up approach to science steering since most stakeholders will have little systematic knowledge on the valuation of biodiversity; a dialogue is needed in which science knowledge combines with stakeholder concerns and analysis.

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CHAPTER

2

IMPACTS OF CLIMATE CHANGE ON BIODIVERSITY

PAPER

8

CLIMATE CHANGE IMPACTS ON FOREST BIODIVERSITY

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ABSTRACT: Forest ecosystems will be under severe stress over the next century by an unprecedented combination of climate change including increased threats of drought, wildfire, and pests and other issues such as land use change and over exploitation of resources. The assessment made by the Intergovernmental Panel on Climate Change (IPCC) shows that there will be major changes in the structure of forest ecosystems, the interactions between species, and the geographic range of many species resulting in mostly negative consequences for biodiversity and ecosystem resources. However, much is still unknown about the current year-to-year climate variability and its impact on forest ecosystems. For example, the relationships between physical mechanisms such as the El Nino/La Nina, Southern Oscillation and the North Atlantic Oscillation and the productivity of forest ecosystems are still being investigated and further research into these relationships is needed. Therefore, in order to sustainably manage current forest resources with respect to impacts of climate variability (droughts, wildfire) and to adequately address likely future climate change impacts, decision-makers at all levels need to be aware of all aspects of the climate system. The World Meteorological Organization (WMO), in collaboration with its Members comprising of a global network of National Meteorological and Hydrological Services (NMHSs) and other partners, plays an important role in weather and climate observation, monitoring, scientific understanding of climate processes, and the development of clear, precise and user-targeted information and climate predictions. It furthermore provides sector-specific climate services, including advice, tools and expertise, to meet the needs and requirements of climate-related adaptation strategies as well as decision-making. The climate system is so complex that the global network of scientific observations and research needs to be strengthened.

Keywords: climate change, biodiversity, forest ecosystems, climate variability, adaptation, WMO, drought, wildfires

1. Introduction

The Convention on Biological Diversity (1993) defines biological diversity as " … the variability among living organisms from all sources including, *inter alia,* terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part: this includes diversity within species, between species and of ecosystems." Forests play an important role in the world's ecology and biodiversity. About 30% of the total land area of the world is covered by forests (FAO, 2007). Forest ecosystems provide many invaluable goods and services to human society such as carbon sequestration, climate and water regulation, soil and water protection, disease and pest regulation, providing numerous commercial timber goods and non-timber forest products, and providing habitat for an increasing portion of biodiversity (Fischlin *et al.*, 2007). These non-timber products include food (game, roots, seeds, nuts, spices), medicinal, and cosmetic products. Scientists have examined records from the geological past which indicate that ecosystems have some capacity to adapt naturally to climate change but this resilience has never been challenged by the multiple demands from a large global human population (Parry *et al.*, 2007). All biological organisms react to environmental conditions and have evolved with specific climatic ranges in which they can survive, grow and reproduce. If these climatic conditions change beyond the tolerances of species, they will have the following responses: shifting the timing of life-cycle events; shifting range boundaries; changing morphology, reproduction, or genetics; and extinction (Rosenzweig *et al.*, 2007). Climate change is expected to have a large impact on forest ecosystems. In some cases, year-to-year climate variability can have as much impact on forest ecosystems as climate change. Therefore, in order to sustainably manage current forest resources with respect to impacts of climate variability (droughts, wildfire) and to adequately address likely future climate change impacts, decision-makers at all levels need to be aware of all aspects of the climate system.

This paper will first provide a brief overview of forest resources in the Americas. Next, it will focus on impacts of climate change on forest biodiversity in the Americas, after a brief overview of general impacts on biodiversity. The observed and future impacts are mainly distilled from Working Group II of the Fourth Assessment Report (AR4) of the World Meteorological Organization/United Nations Environment Programme Intergovernmental Panel on Climate Change (IPCC) released in 2007. The topic of climate variability and its impact on forest ecosystems will then be presented along with the role of the World Meteorological Organization (WMO) and other partners in providing useful climate information and services. Finally, some suggestions and recommendations will be discussed on strengthening the global network of scientific observations and research.

2. Overview of Forest Resources in the Americas

Forests cover about 37% of the total land area in all of the Americas, 26% in North and Central America and 51% in South America. The Americas have 37% of the world total of forested land with North and Central America and South America accounting for 14% and 23%, respectively (see Table 1). Within the two continents, Brazil (543 million hectares) makes for the largest forest land area in South America, with almost 10 times more forest than Peru (65 million hectares), which has the second largest forested area in the continent. In North and Central

America, Canada has slightly more forested area (244 million hectares) than the United States (225 million hectares). FAO (2007) also provides statistics on the change in total forest area from 1990-2000. The greatest decrease in forest area occurred in South America with a decrease of 37 million hectares or 4%. In the Amazon, the loss of total forested area was 41.5 Mha in 1990 and 58.7 Mha in 2000, an increase of deforestation of 17.2 Mha (Kaimowitz *et al.*, 2004). As a region, the Americas showed a decrease of 43 Mha or 2.5% of forested area. Most countries in the region showed a decrease in forest area. The United States showed an increase of 3.8 Mha of forest area or 1.8%. Canada reported no significant change, but Mexico showed a decrease of 6.3 Mha or 10%.

TABLE 1

Summary of regional and global forested area, percent of land area forested, and percent of world forested land. All figures as of 2000. (Source: FAO, 2007, Mha = million of hectares)

	Total Land Area (Mha)	Total Forested Area (Mha)	Change in Total Forest Area From 1990-2000 (Mha) and Percentage	Percent of Land Area Forested	Percent of World Forested Land
Americas	3,892	1,435	-43 (-2.9%)	36.9	37.1
North and Central America	2,136	549	-6 (-1.0%)	25.7	14.2
South America	1,755	886	-37 (-4.0%)	50.5	22.9
World	**13,064**	**3,869**	**-93 (-2.4%)**	**29.6**	

TABLE 2

Percentage of regional forest area by forest type (Source: FAO, 2007)

	Tropical	Subtropical	Temperate	Boreal/Polar
North and Central America	15%	16%	29%	40%
South America	96%	2%	1%	0
World	**52%**	**9%**	**13%**	**25%**

The types of forests varies greatly across the Americas. This is important when discussing the potential future climate change impacts. Most of South America has tropical forests while the forests in North and Central America are mostly temperate and boreal/polar (See Table 2). For the northern continent, this is due to the fact that Canada and United States account for 86% of forested land in North and Central America. According to the FAO individual country statistics, every country in Central America has 100% tropical forests. Seventy percent of Mexico's forested land is tropical and the remainder is subtropical.

3. Observed climate changes and impacts

In this section, the following was summarized from the IPCC AR4 WGII chapters on the Assessment of observed changes and responses in natural and managed systems (Chapter 1-Rosenzweig *et al.*, 2007), Latin America (Chapter 13 - Magrin *et al.*, 2007) and North America (Chapter 14 - Field *et al.*, 2007). In Latin America during the 20th century, there were significant observed increases in precipitation in southern Brazil, Paraguay, Uruguay, north-east Argentina and north-west Peru and Ecuador. On the other hand, there was a declining trend in precipitation in southern Chile, south-west Argentina and southern Peru. A number of regional studies for southern South America showed changes in the patterns of extremes consistent with a general warming, especially with more warm nights and fewer cold nights. There is also a positive tendency for intense rainfall events and consecutive dry days. One study identified positive linear trends in the frequency of very heavy rains over north-east Brazil and central Mexico. Due to increases in temperature, South American glaciers are in retreat, especially in Bolivia, Peru, Colombia, and Ecuador.

In North America, the annual mean air temperature increased during the period from 1955-2005, with the largest warming in Alaska and north-western Canada, substantial warming in the continental interior and modest warming in the south-eastern U.S. and eastern Canada. The spring and winter seasons showed the greatest changes in temperature and daily night-time temperatures have warmed more than daily daytime temperatures. As for the length of the growing season, it increased an average of 2 days per decade since 1950 in Canada and the conterminous U.S., with most of the increase due to earlier spring warming. This warming trend in North America during the last 50 years was most probably due to the combined effect of greenhouse gases, sulphate aerosols and natural external forcing. For most of North America, annual precipitation has increased with large increases in northern Canada, but decreases were observed in the southwest U.S., the Canadian Prairies and the eastern Arctic. The report notes that in the U.S. for the period from 1895-2000, the frequency of heavy precipitation events reached a minimum in the 1920s and 1930s, and increased in the 1990s. No consistent trends in extreme precipitation were found in Canada.

According to the IPCC AR4 WGII Chapter 1, there is a very high confidence that physical and biological systems on all continents and in most oceans are already being affected by recent climate changes (Rosenzweig *et al.*, 2007). Significantly, an assessment of observed changes at a global scale indicated that it is likely that over the last three decades, anthropogenic warming has had a discernible influence on many physical and biological systems. During the past 50 years, many animal and plant populations have been under pressure due to land-use changes and increased intensity of agriculture, causing many species to be in decline. Additionally, the fragmentation of habitat plays an important role, especially in species extinction. The AR4 notes that the vast majority of studies of terrestrial biological systems reveal notable impacts of global warming over the last 30-50 years such as: earlier spring and summer phenology and longer growing seasons in mid- and higher latitudes, production range expansions at higher elevations and latitudes, some evidence for population declines at lower elevational or latitudinal limits to species ranges, and vulnerability of species with restricted ranges, leading to local extinctions.

For Latin America (Magrin *et al.*, 2007), the report states that the tropical forests of Latin America, particularly those of the Amazon, are increasingly susceptible to fire due to increased El Niño-related droughts and to land-use changes. One study found that during the 2001 ENSO period, approximately one-third of the Amazon forests became susceptible to fire and this has the potential to generate large-scale forest fires due to the extended period without rain in the Amazon. The rates of deforestation of tropical forests have increased during the last 5 years with deforestation in Brazilian Amazon increased by 32% between the periods 1996-2000 and 2001- 2005. Latin America is currently responsible for 4.3% of global GHG emissions and 48.3% of these are due to deforestation and land use changes. The report highlights land use changes leading to habitat fragmentation and biodiversity loss. The majority of the endangered eco-regions are located in the northern and mid-Andes valleys and plateaux, the tropical Andes, in areas of cloud forest (for example, in Central America), in the South American steppes, and in the Cerrado and other dry forests located in the south of the Amazon Basin (see Figure 1). Deforestation and forest degradation through forest fires, selective logging, expansion of land for crops and livestock, infrastructure construction (dams and roads), and forest fragmentation are the dominant factors that threaten biodiversity in South America. AR4 points out that Latin America has 7 of the world's 25 most critical places with high species concentrations and these areas are undergoing habitat loss. Other studies have indicated that mangrove forests located in low-lying coastal areas are particularly vulnerable to sea-level rise, increased mean temperatures, and hurricane frequency and intensity especially in Mexico, Central America and the Caribbean.

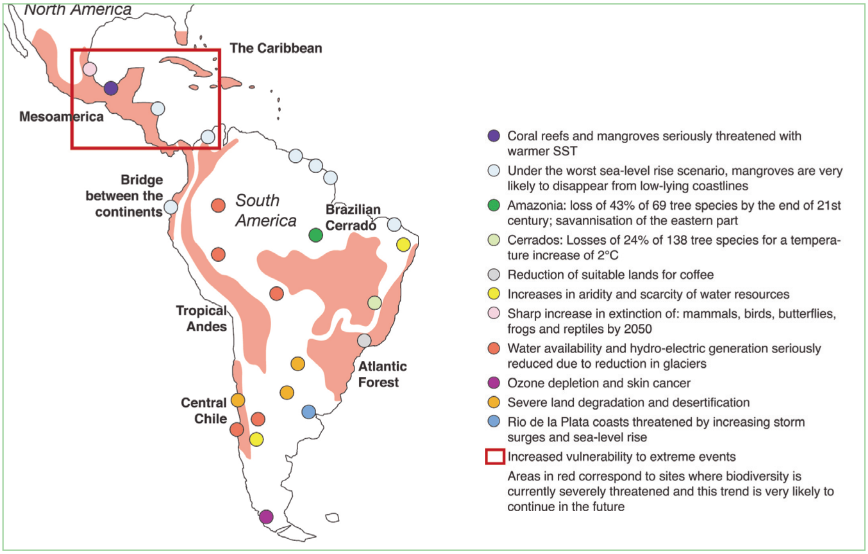

FIGURE 1
Key hotspots for Latin America (Magrin *et al.*, 2007).

For North America (Field *et al.*, 2007), there are three clear, observable connections between climate and terrestrial ecosystems: phenology; responses of plant growth or primary production; and the geographic distribution of species. Satellite observations indicate an earlier onset of greenness in the spring by 10-14 days, especially across temperate latitudes of the Northern Hemisphere. And this advancement in phenology is confirmed by field studies that show many plant species are flowering earlier. Studies indicate that the net primary production (NPP) in the continental U.S. has increased almost 10% from 1982-1998 and the largest increases have occurred in croplands and grasslands of the Central Plains. Several studies indicate that forest growth seems to be slowly accelerating in regions where growth has been limited by low temperatures and short growing seasons, but growth is slowing in areas subjected to drought. Many North American animal species were observed to have earlier spring breeding and migration cycles and have shifted their ranges, typically to the north or to higher elevations. An important issue cited by the AR4 is the interaction between the direct climate impacts on organisms with the indirect effects of ecological mechanisms (competition, plant consumption by animals, insects, disease) and disturbances such as wildfire, hurricanes, human activities. The report states for North America that the average area burned has increased during the last 20 to 30 years and earlier Spring snowmelt has led to longer growing seasons and drought, especially at higher elevations, where the increase in wildfire activity has been greatest. Insects and diseases are a natural part of ecosystems and periodic insect epidemics kill trees over large regions, providing dead, desiccated fuels for large wildfires. The report notes that these epidemics are related to aspects of insect life cycles that are climate sensitive in which many northern insects have a two-year life cycle and warmer winter temperatures allow a larger portion of overwintering larvae to survive. Examples of this include the spruce budworm in Alaska which completed its life cycle in one year and the mountain pine beetle has expanded its range in British Columbia into areas previously too cold.

4. Future Climate Changes and Impacts

The following future impacts of climate change were summarized related to forest ecosystems based on Chapter 4 on Ecosystems (Fischlin *et al.*, 2007) of the IPCC AR4 WG II. These include:

- There is high confidence that if greenhouse gas emissions and other changes continue at or above current rates, during the next 100 years the ability of many ecosystems to adapt naturally is likely to be exceeded by an unprecedented combination of climate change, associated disturbances such as flooding, drought, wildfire, and insects and other global change issues especially land-use change, pollution and over-exploitation of resources.
- There is a very high confidence that present and future land-use change and associated landscape fragmentation are very likely to impede the migration of species, thus impairing natural adaptation by geographical range shifts.
- There is high confidence that at current anthropogenic emission rates, the ongoing positive trends in the terrestrial carbon sink will peak before mid-century, then begin diminishing, even without accounting for tropical deforestation trends and biosphere feedback, tending strongly towards a net carbon source before 2100, assuming continued greenhouse gas emissions and land-use change trends at or above current rates.

- With medium confidence, the report states that approximately 20 to 30% of species currently assessed are likely to be at increasingly high risk of extinction as global mean temperatures exceed a warming of 2 to 3°C above pre-industrial levels. The report stresses that since global losses in biodiversity are irreversible, projected impacts on biodiversity are significant and relevant. With this level of warming, many species are at far greater risk of extinction than in the recent geological past.
- Substantial changes in structure and functioning of terrestrial ecosystems are very likely to occur with a global warming of more than 2 to 3°C above pre-industrial levels. Depending on the IPCC emission scenario, about 25% to 40% of ecosystems will show appreciable changes by 2100, with some positive impacts especially in Africa and the Southern Hemisphere arid regions, but there could be extensive forest and woodland decline in mid- to high latitudes and in the tropics, associated particularly with changes in disturbances such as wildfire and insects.
- With high confidence, the most vulnerable ecosystems include coral reefs, the sea-ice biome, high-latitude ecosystems such as boreal forests, mountain ecosystems, and mediterranean-climate ecosystems.

The following future impacts of climate change were summarized related to forest ecosystems from Chapter 13 on Latin America (Magrin *et al.*, 2007) of the IPCC AR4 WGII. The climate projections for Latin America up to the end of the 21st century indicate, with medium confidence, that mean temperature increases will range from 1 to 4°C to 2 to 6°C depending on the climate scenario. The frequency of weather and climate extremes is very likely to increase. For precipitation, most of the GCM projections indicate larger positive and negative rainfall anomalies than present for the tropical Latin America and smaller ones for extra-tropical South America. In addition, the frequency of weather and climate extremes is likely to increase in the future, as well as the frequency and intensity of hurricanes in the Caribbean Basin.

There is evidence that biomass-burning aerosols may change regional temperature and precipitation in the southern part of Amazonia. The report adds with high confidence that due to the synergy between land-use and climate changes there will be a substantial increase in fire risk for vegetation and there is a risk of significant extinction of species in many areas of tropical Latin America. Specifically, there will a replacement of tropical forest by savannas in eastern Amazonia and the tropical forests of central and southern Mexico. The report also indicates that over the next decades, inter-tropical glaciers in the Andes are very likely to disappear, reducing water availability and hydropower generation in Bolivia, Peru, Colombia and Ecuador.

There are estimates that by 2010 the forest areas in South America will be reduced by 18 Mha and by 1.2 Mha in Central America and that these deforested areas (see Figure 2) will be used for pasture and expanding livestock production. Several studies cited in AR4 indicate that in the Brazilian Amazon, if the 2002-2003 deforestation rate of 2.3 Mha/yr does not change, then 100 Mha of forest will have disappeared by the year 2020, while using a business-as-usual scenario, 270 Mha will be deforested by 2050. Using current trends, agricultural expansion could eliminate two-thirds of the forest cover of five major watersheds and ten eco-regions and cause the loss of more than 40% of 164 mammalian species habitats. One beneficial impact of climate change is a projected increase in soybean yields in the portions of South America. However, the future conversion of natural habitats to accommodate this soybean expansion is very likely to severely affect some forest ecosystems. The dry and humid Chaco forest (located in portions of Argentina, Paraguay, Bolivia and Brazil) and the Amazon transition forest and rainforest are likely to incur the greatest losses in area with losses also occurring in the Atlantic, Chiquitano (transition between Amazonian forest and Chaco forest) and Yungas forests.

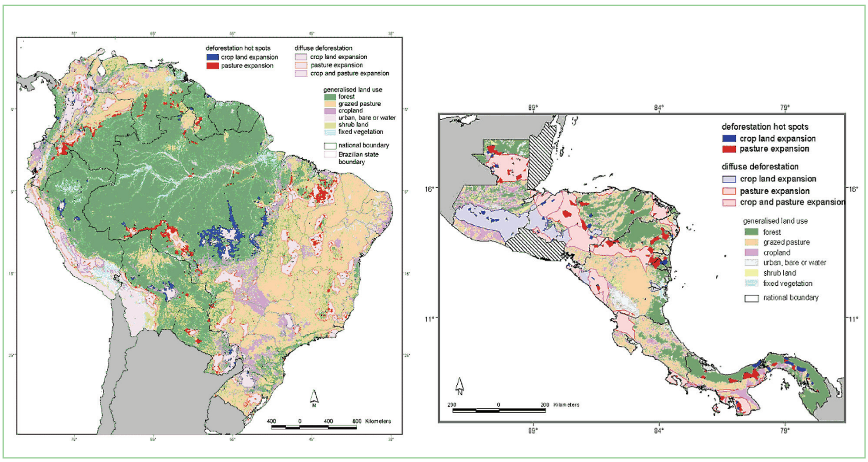

FIGURE 2

Predicted 2000-2010 South American and Central American deforestation hotspots and diffuse deforestation areas (Magrin *et al.*, 2007). Maps available at:
http://www.virtualcentre.org/ en/dec/neotropics/south_america.htm and
http://www.virtualcentre.org/en/dec/neotropics/ central_america.htm.

One concern of climate change in regards to forest ecosystems is that since biological systems respond slowly to relatively rapid climate change, tropical plant species may be sensitive to small variations of climate and this could lead to a decrease of species diversity. The report notes by the end of the century, 43% of 69 tree plant species studied could become extinct in the Amazon and that there will be larger impacts over northeast Amazon than over the western Amazon. With even slight precipitation reductions in the Amazon, it is likely that forests will be replaced by ecosystems such as tropical savannas that have more resistance to multiple stresses caused by temperature increase, droughts and fires. In the mountainous regions of Latin America, the tropical cloud forests will be threatened during the next 50 years if temperatures increase by 1°C to 2°C due to the increase in altitude of the cloud-base during the dry season.

The following future impacts of climate change were summarized related to forest ecosystems from Chapter 14 on North America (Field *et al.*, 2007) of the IPCC AR4 WGII. According to recent climate model simulations for the period from 2010-2039, annual temperatures across North America will be outside the range of present-day natural variability and will warm within a range from 1 to 3°C. By the end of the century, projected annual warming is likely to be 2 to 3°C across the western, southern, and eastern portions of the continent, but more than 5°C at high latitudes. The greatest projected warming is expected to be during the winter at high latitudes and in the summer in the southwest U.S. Across North America, extremes in warm temperatures are projected to become both more frequent and longer. A decrease in the annual mean precipitation is projected to occur in the southwestern U.S. but an increase is projected in the remainder of North America. In Canada, annual precipitation is projected to increase by about 20% and winter precipitation by 30%. For North America, studies indicate widespread increases in extreme precipitation, with greater risks of flooding from intense precipitation and droughts from greater temporal variability in precipitation. The projected changes in precipitation extremes are expected to be larger, in general, than changes in mean precipitation. The report states that future trends in hurricane frequency and intensity remain very uncertain but extra-tropical storms are likely to become more intense, but perhaps less frequent. Recent analyses indicate that there is no consistent future trend in El Niño amplitude or frequency.

With very high confidence, the IPCC AR4 states that for North America in general, wildfire and insect outbreaks are likely to intensify due to warmer temperatures with drier soils and longer growing seasons with an extended period of high fire risk and large increases in area burned. It should be noted that while climate model simulations indicate that precipitation will likely increase across portions of North America (see above paragraph), warmer temperatures and longer growing seasons will increase evapotranspiration and produce earlier Spring snowmelts, producing drier soils across forest ecosystems, especially in the Spring. Of course, future regional increases in Spring precipitation could counteract this, but the negative impacts on forest ecosystems due to earlier Spring snowmelt and longer growing seasons has already been observed in North America (see last paragraph in Section 3). Although recent climate trends have pointed to increased vegetation growth, increases in disturbances are likely to continue and will limit carbon storage, facilitate invasive species, and disrupt ecosystem services. By 2100 in Canada, warmer summer temperatures are expected to enlarge the annual window of high fire risk by 10-30%, and this could increase the area of forest burned by 74-118%. Over the 21st century, there will be pressure for species to shift northward and to higher elevations which will fundamentally rearrange North American ecosystems. The current ecosystems will have different capacities for shifts in the range of species and constraints from development, habitat fragmentation, invasive species, and broken ecological connections will alter the structure, function and services of ecosystems.

Over the 21st century, several simulations indicate that warming will lengthen growing seasons, sustaining forest carbon sinks in North America despite reducing some sink capacity due to increased water limitations in western forests and higher respiration in the tropics. The report notes that impacts on ecosystem structure and function may be increased by changes in extreme meteorological events and increased frequency of disturbances. These human induced or natural ecosystem disturbances could accelerate the loss of native species and invasion of non-native exotic species. Recent climate trends have increased ecosystem net primary production, and this trend is likely to continue for the next few decades. There are differing impacts on Net Primary Production (NPP) depending on latitude. At high latitudes, model simulations indicate increased NPP due to the expansion of forests into current tundra areas and longer growing seasons. Simulated changes in mid-latitude NPP are variable depending on whether precipitation will be sufficiently enhanced to offset increased evapotranspiration in a warmer climate.

The AR4 states that impacts of climate change on North America will not occur in isolation, but in the context of technological, economic, social and ecological changes such as effects of land-use change, air pollution, wildfires, changing biodiversity and competition with invasive species. Since the function of ecosystems have a strong dependence on moisture balance, the uncertainty about future regional precipitation patterns (amount, distribution, frequency) provides a large range of possible future North American ecosystems.

4. Climate variability

Climate variability can be defined as the deviation from long-tern climate averages over a certain period of time such as a month, season, or year. Examples of climate variations would include a stronger-than-normal monsoon, a more intense drought period (that is, the Southwestern US Drought), intense rainfall causing flooding or a stronger-than-normal tropical storm or extra-tropical storm season. There are several seasonal climate variations that are recurring and or part of the natural climate system. This would include the El Niño Southern Oscillation (ENSO), the North Atlantic Oscillation (NAO), the Pacific Decadal Oscillation (PDO), and the Indian Ocean Dipole. It is interesting to note that in many sections of the IPCC report, there is a discussion of various aspects of inter-annual climate variability such as fire activity in the south-western USA is correlated with ENSO positive phases (Field *et al.*, 2007); many biological responses are related with rising temperatures and it is challenging to distinguish the effects of climate change that are embedded in the natural variability of ENSO and the NAO (Rosenzweig *et al.*, 2007); many studies found connections between local ecological observations across birds, mammals, fish species and large-scale climate variations associated with the NAO, ENSO, and PDO (Rosenzweig *et al.*, 2007); several countries in Latin America are trying to implement some adaptation measures such as the use of climate forecasts in the agricultural and fisheries sector and early-warning flood systems (Magrin *et al.*, 2007). In some cases, these seasonal climate regimes can be as important as climate change and these climate variations exist whether the climate is changing or not and have an impact on forest biodiversity.

The issues of climate variability and climate change need to be integrated into resource use and development decisions. There is a need to optimally manage the different sectors with respect to today's natural climate variability and this requires a careful evaluation of the policies, practices and technologies currently in vogue. Decreasing the vulnerability of the different sectors such as biodiversity, forestry, agriculture, and energy to natural climate variability through a more informed choice of policies, practices and technologies will, in many cases, reduce the long-term vulnerability of these systems to climate change. Therefore, in order to sustainably manage current forest resources with respect to impacts of climate variability (droughts, wildfire) and to adequately address likely future climate change impacts, decision-makers at all levels need to be aware of all aspects of the climate system.

5. Role of WMO

The WMO is the specialized United Nations (UN) agency for weather, climate, hydrology and water resources and related environmental issues. The National Meteorological and Hydrological Services (NMHSs) of the 188 Members of the WMO have an essential role in adaptation to and mitigation of climate variability and change impacts. The most critical impacts are those potentially affecting human life and socioeconomic development, as well as those that disrupt food, water, transportation, and the various forms of biodiversity (marine, forest, agricultural). For example, prolonged drought periods can increase forest fire risk and weaken trees to be more suspectible to disease and pests. WMO has a vast reservoir of expertise, knowledge, data and tools among its Members, programmes and technical commissions, as well as through its partnerships. It can thus bring strong scientific and technical capability along with local, regional and global knowledge, providing authoritative and targeted analyses for the various user communities. The WMO will offer expert advice, guidelines, technical inputs and leadership in the implementation of some components of specific activities. The WMO Convention reaffirms the vital importance of the mission of NMHSs in observing and understanding weather and climate and in providing meteorological, hydrological and related services in support of national needs in areas such as:

- Protection of life and property;
- Safeguarding the environment;
- Contributing to sustainable development;
- Promoting long-term observation and collection of meteorological, hydrological and climatological data, including related environmental data;
- Promotion of capacity-building;
- Meeting international commitments; and
- Contributing to international cooperation.

WMO's ten major scientific and technical programmes continue to provide assistance and guidance to NMHSs in their contribution to curb the impacts of adverse weather situations on sustainable socio-economic development and help in the implementation of the Millennium Development Goals (MDGs). In addition, within WMO, eight Technical Commissions advise and guide the activities of the programmes, and six WMO Regional Associations are in charge of the implementation in a coordinated way.

The NMHSs have a long history of recording weather and hydrological observations, which when compiled over a long period of time provide the climatology of specific locations. They form an integral part of the WMO Global Observing System (GOS), which consists of a global network of observations over land, sea and in the atmosphere. Archived data by NMHSs have been used in the publication of world climatological statistics and a wide variety of climate diagnostics providing a deeper understanding of the climate variability and the associated processes. The NMHSs are national services that have been mandated duties for the collection, processing and archiving of systematic climate data, including the provision of access to data and related information. They are responsible for a network of observing systems whose data are exchanged among the international community using a well-coordinated and standardized communication system.

WMO's programmes related to monitoring the atmosphere, oceans and rivers provide the crucial time-sequenced information that underpins the forecasts and warnings of hydro-meteorological hazards. WMO's global network of Regional Specialised Meteorological Centres (RSMCs) and World Meteorological Centres (WMCs) provide critical data, analysis and forecasts that enable the NMHSs to provide early warning systems and guidelines for various natural hazards such as tornadoes, winter storms, tropical cyclones, cold and heat waves, floods and droughts. WMO focuses on optimizing its global infrastructure and integration of its core scientific capabilities and expertise into all relevant phases of disaster risk management decision-making at the international, regional and national level, particularly in relation to risk assessment and early warning systems. WMO and NMHSs have the capability to develop and deliver critical products and services to the entire disaster risk management decision process.

With regards to the issues of climate variability and change and adaptation to, and mitigation of, climate change impacts, there are many relevant aspects of the work of WMO, its members, and related organizations (WMO, 2007). In context of this paper, several of these aspects potentially relevant to forest biodiversity will be highlighted.

As discussed in the previous section, sustainable management of forest resources needs to take into account the impacts of climate variability such as droughts and wildfire and to address likely future climate change impacts, decision-makers at all levels need to be aware of all aspects of the climate system. For example, seasonal climate forecasts into management decisions can reduce the vulnerability of agriculture to floods and droughts caused by the

El Niño – Southern Oscillation (ENSO) phenomena. These same climate forecasts could also be used by decision-makers to allocate resources for fighting wildfires.

The development and application of these seasonal climate forecasts are done under the guidance of WMO's Climate Information and Prediction Services (CLIPS) within the World Climate Applications and Services Programme (WCASP). CLIPS was established in 1995 and builds on the rapidly developing atmospheric and oceanographic research as well as the wealth of data, experience and expertise within the NMHSs and related entities and provide a framework to deliver operational user-targeted climate services. CLIPS exists to take advantage of current databases, increasing climate knowledge and improved prediction capabilities to facilitate the development of relevant climate information and prediction products including their application in various socio-economic sectors to reduce the negative impacts to climate variations and to enhance planning activities based on the developing capacity of climate science. The CLIPS project can be an effective framework within which policies to address national and regional climate variability and change information and the associated adaptation issues can be integrated.

Specific institutional frameworks can be established, with appropriate stakeholders taking the lead, to address relevant climate change issues at the local and sector levels. In this context, the Regional Climate Outlook Forums (RCOFs) constitute an important vehicle in developing countries for providing advanced information on the future climate information for the next season and beyond, and for developing a consensus product from amongst the multiple available individual predictions. RCOFs stimulate the development of climate capacity in the NMHSs and facilitate end-user liaison to generate decisions and activities that mitigate the adverse impacts of climate variability and change and help communities to build appropriate adaptation strategies. There is a great potential for the regional climate activities that currently take place under RCOFs and through CLIPS training to expand the use of currently available tools to more countries and to include information on climate change scenarios assembled by the World Climate Research Programme (WCRP) such as climate projections created for the IPCC Fourth Assessment Report (AR4).

In the Americas, there are three RCOFS. The Western Coast of South America Climate Outlook Forum (WCSACOF) is coordinated by Centro Internacional para la Investigación del Fenómeno de El Niño (CIIFEN, International Research Centre on El Niño) based in Guayaquil, Ecuador. The countries participating in this RCOF are: Bolivia, Chile, Colombia, Ecuador, Perú and Venezuela. The Southeast of South America Climate Outlook Forum (SSACOF) is coordinated by each of the participant countries by rotation which include: Argentina, Brazil, Paraguay and Uruguay. The Climate Forum of Central America reviews and discusses the oceanic and atmospheric conditions latest forecasts of global models and their implications in the patterns of rainfall and temperature in Central America, as well as national-level analysis provided by each of Meteorological and Hydrological Services in the Region and develops a consensus seasonal climate outlook. The countries participating in this forum are: Belize, Guatemala, Honduras, El Salvador, Nicaragua, Costa Rica and Panamá. Links to these RCOF and others around the world can be found at **http://www.wmo.int/pages/prog/wcp/wcasp/clips/outlooks/climate_forecasts.html**.

There are many institutions that are involved in RCOFs that have a close connection with WMO in their formation. In response to several droughts in Africa, WMO, with the support of UNDP and other partners, have helped establish the Regional Centre for Agricultural Meteorology and Hydrology (AGRHYMET) in Niamey, Niger, and two Drought Monitoring Centres (DMCs) in Nairobi, Kenya and Harare, Zimbabwe (recently moved to Gaborone, Botswana). In 1993, WMO and the Economic Commission for Africa sponsored the establishment of the African Centre of Meteorological Applications for Development (ACMAD) in Niamey, Niger. In 1998, the International Research Center for the El Niño Phenomenon (CIIFEN), was established with the assistance of WMO and other partners (IRI, Permanent Commission for the South Pacific). CIIFEN aims to promote, complement and start scientific and application research projects to improve the comprehension and early warning of the El Niño Event, and climate variability at regional scale in order to contribute in the reduction of their social and economic impacts as well as generating a solid base to promote sustainable development policies when facing new climate scenarios. All of these regional institutions either host RCOFs with support from WMO and/or contribute their expertise and knowledge.

In addition to RCOFs and seasonal climate prediction, WMO plays a role in developing and highlighting the need for a comprehensive and integrated approach to more effectively monitor drought and provide early warning. The DMCs discussed previously were developed specifically for this purpose and new centres have recently been created. In 2006, WMO and the United Nations Convention to Combat Desertification (UNCCD) have established a Drought Management Centre for South-eastern Europe (DMCSEE) in Slovenia. The Center will integrate input from each participating country to develop a sub-regional drought management strategy, and implement an effective drought monitoring and early warning system. This process is also being explored by the several Central Asia countries in coordination with WMO and UNCCD. There are other regional examples such as the Australian National Agricultural Monitoring System (NAMS) and the US and North American Drought Monitor (WMO, 2006).

WMO is also facilitating the establishment of Regional Climate Centres (RCCs), as complementary and supportive entities of the NMHSs, to handle operational regional climate services, coordination, capacity building, data services as well as research and development. The functions and responsibilities of the RCCs are determined by the concerned NMHSs and are expected to address issues of particular regional significance by appropriate interpretations of global climate products.

The Global Climate Observing System (GCOS) has a role in ensuring the availability of adequate climate observations. As countries increasingly embrace the need to develop effective adaptation policies, the need for high-quality, long-term climate observations at all scales for adaptation needs has become obvious. Healthy observing systems at global, regional, and national levels are of fundamental importance for the development of user-driven climate services and effective climate risk management that will be required for adaptation to climate variability and change and for sustainable development generally. Through this Regional Workshop Programme GCOS has assisted NMHSs and other stakeholders in the development of Regional Action Plans (RAPs) that focus on addressing the highest priority observing system needs in each region. The Plans contain projects that, if implemented, would eliminate gaps and deficiencies in atmospheric, oceanic, and terrestrial climate observing networks and improve related data management and telecommunications functions.

Within the context of WMO, the Commission for Agricultural Meteorology (CAgM) is responsible for matters relating to applications of meteorology to agricultural cropping systems, forestry, and agricultural land use and livestock management, taking into account meteorological and agricultural developments both in the scientific and practical fields. The science of agrometeorology and its applications contributes to the development of operational knowledge to cope with new hazards such as increased effects of climate change and climate variability and their consequences. Information on recent past weather coupled with local knowledge can now be more widely used thereby allowing better planning of farming operations and of national agricultural policies. Drought and wildfires are the two natural hazards that the CAgM focuses on and that can impact forest biodiversity.

There has been recent concern about large fires, particularly those burning out of control and endangering human lives, property, and natural resources (California 2008, Spain and Greece, 2007 and Europe 2003). Fire has an influence on, and a response to, the changing global climate and, on a smaller scale, fire's effects on regional and local air quality and biodiversity have become international issues. To aid in determining the potential of fires starting in forests or grasslands, meteorologists have developed fire danger indices that use weather conditions and other information to determine the state of vegetative fuels on the ground. Meteorological data are also critical to forecasting behavior of fires once started.

WMO coordinates the Global Atmosphere Watch (GAW) Programme which is responsible for greenhouse gas measurements. In October 2006, GCOS and WMO established the WMO-GAW Global Atmospheric CO_2 and CH_4 Monitoring Network as a Comprehensive Network of GCOS. In March 2006, WMO released the first of a series of Annual Greenhouse Gas Bulletins. GAW is now working to register global monitoring activities within the GCOS framework for the essential climate variables, aerosols and ozone.

Fully coupled climate models are making rapid strides toward realistically simulating the climate and providing consistent projections of its future state at a global scale for various greenhouse gas emission scenarios. However, there is still considerable uncertainty in these projections associated with the inability of models to fully and accurately represent all the complex processes and interaction in the earth system. Under the coordination of the WCRP, concerted efforts are being made by some of the NMHSs and leading international climate modeling groups to develop Regional Climate Models capable of providing regional scale climate information for impact studies, to facilitate their use in developing countries, and to provide training as necessary While downscaling using regional climate models is valuable, there is also a need for higher-resolution global simulations to capture the global patterns that are an integral part of weather and climate. This will require the coordination of many scientists working together to build the next generation of climate prediction models.

All of these above WMO activities are relevant and can contribute to the work of the United Nations Framework Convention on Climate Change (UNFCCC). During the twelfth session of the UNFCCC Conference of the Parties (COP 12), the Programme on Impacts, Vulnerability and Adaptation to Climate Change, subsequently named the Nairobi Work Programme, was developed (UNFCCC, 2007). It comprises two thematic areas, namely 'understanding and assessment of impacts, vulnerability and adaptation' and 'practical adaptation actions and measures to respond to climate change', each with several sub-theme activities. Common threads in these activities are methodologies, data and modelling and integration into sustainable development. It was agreed to invite relevant organizations and other stakeholders to implement the activities of the programme of work in nine main areas:

- Methods and tools;
- Climate data and observations;
- Climate modelling, scenarios and downscaling;
- Climate-related risks and extreme events;
- Socio-economic information;
- Adaptation planning and practices;
- Research;
- Technologies for adaptation; and
- Economic diversification.

WMO has the competency and experience to contribute to the Nairobi Work Programme at international and regional levels and can play a role in the subject areas addressed by the specific activities undertaken by the Nairobi Work Programme. The NMHSs can actively contribute to the Nairobi Work Programme through the understanding and assessment of impacts, vulnerability and adaptation and practical adaptation actions and measures to respond to climate change.

In summary, the WMO and its partner organizations (GCOS, WRCP, etc.) provide an integrated framework of climate activities and information for various sectors such as agriculture, water resources, health, energy, and tourism (see Figure 3). This includes the activities of the RCOFs and seasonal climate prediction, drought, GAW, climate modeling, and the UNFCCC Nairobi Work Programme on Impacts, Vulnerability and Adaptation to Climate Change. In the context of ecosystems goods and services, several of these activities have potential application to sustainable management and use of forest goods and services. For example, knowledge of short-term climate variations such as El Niño or La Niña could aid in managing yields of local food crops. Also, better regional climate models can aid in long-term decision making in managing biodiversity.

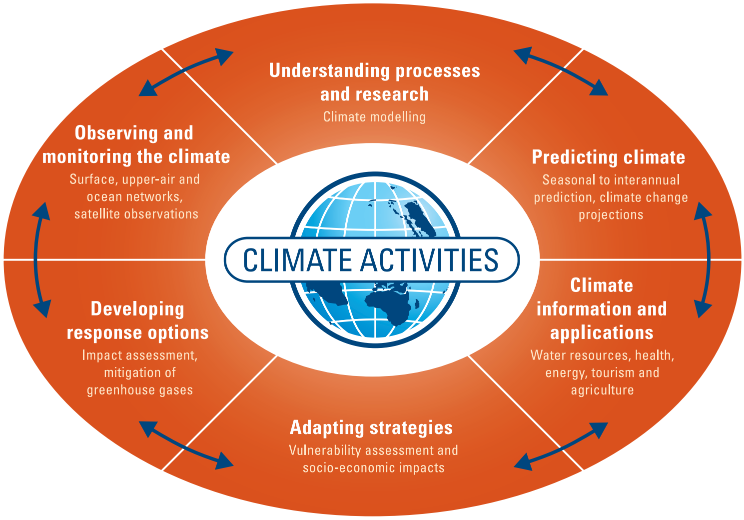

FIGURE 3
WMO implements a comprehensive and integrated for all aspects of international climate-related programmes.

6. Final Thoughts on Adaptation and Further Research

The AR4 does mention some current and potential options for adapting to climate change in the forestry sector such as fire management through altered stand layout, landscape planning, dead timber salvaging, clearing undergrowth, insect control through prescribed burning, and non-chemical pest control. Other adaptation measures to help protect ecosystems in the face of climate change are biological reserves and ecological corridors that have already been implemented (that is, Mesoamerican Biological Corridor), or planned for, which can maintain the biodiversity of natural ecosystems. (Magrin *et al.*, 2007). Other positive practices are oriented towards maintaining and restoring native ecosystems and protecting and enhancing ecosystem services such as carbon sequestration. Conservation of biodiversity and maintenance of ecosystem structure and function are important for climate-change adaptation strategies, due to the protection of genetically diverse populations and species-rich ecosystems (Field *et al.*, 2007). Climate change will likely increase risks of wildfire and there are programmes that promote wildfire safety in the U.S. and Canada. The greatest reduction in risk will occur in communities that take a comprehensive approach, managing forests with controlled burns and thinning, promoting or enforcing appropriate roofing materials, and maintaining defensible space around each building.

The AR4 report makes an important point that should be highlighted here. While there is significant evidence of observed changes in natural systems in every continent, the majority of studies come from mid- and high latitudes in the Northern Hemisphere and there is sparse documentation of observed changes in tropical regions and the Southern Hemisphere.

The lack of long-term records of daily temperature and rainfall in most of tropical South America does not allow for any conclusive evidence of trends in extreme events in regions such as Amazonia (Margin *et al.*, 2007). While there are some tools for estimating gradual change for most impacts of climate change, there are very few for assessing the conditions that lead to circumstances where a system changes or deteriorates rapidly. Most of the past research has addressed impacts on a single sector (for example, health, transportation, unmanaged ecosystems) and here have been very few studies that address the interacting responses of diverse sectors impacted by climate change, making it very difficult to evaluate the extent to which multi-sector responses limit options or create completely new outcomes (Field *et al.*, 2007).

In most developing countries, climate is seen as a lesser priority compared to other current needs and relatively few resources may be allocated to climate activities at national levels.. In some developing countries, NMHSs are taking the lead in the establishment of national climate change committees and monitoring of UNFCCC activities, including advising policy and decision makers on matters relating to adaptation to impacts of future adverse climate conditions. Their detailed scientific knowledge under the guidance from WMO programmes on climate issues enhance their role, with the collaboration of other stakeholders, to prepare national greenhouse gas inventories and address impacts of climate change on vulnerable sectors of the economy such as agriculture, water resources, energy and coastal zones. WMO, with assistance from international and regional organizations, may guide and improve the capabilities of these national institutions' frameworks for implementation of adaptation activities. They can be provided with appropriate tools to take on work on developing GCMs at smaller scales to suit national needs. Research activities and systematic observations can be promoted to overcome constraints on data needs and to build capacity related to vulnerability and adaptation components of national communications. The climate system is so complex and the scientific and computational requirements for providing societally-beneficial regional climate forecasts are so enormous that the nations of the world should create international research and computational facilities dedicated to the huge challenge of climate prediction.

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PAPER

9

NOVEL TROPICAL FORESTS: THE NATURAL OUTCOME OF CLIMATE AND LAND COVER CHANGES

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ABSTRACT: The directional and irreversible change implied in climate and land cover change, modifies the ecological space of the biota and sets it in motion both ecologically and evolutionarily. The result of this change in conditions is the mixing and evolution of species, with consequences to species survival and community assembly. This paper proposes that the natural outcome of ecological end evolutionary changes induced by climate and land cover change is the formation of novel communities that will self-assemble, self-organize, and evolve in response to changing landscapes and prevailing environmental conditions. These communities and landscapes will be as or more diverse than current ones, function as those of today, but will be different in species composition, speed of ecological processes, and landscape structure. Understanding these future scenarios benefits from long-term, holistic, and comprehensive analyses. To solve conundrums, explain paradoxes, and minimize ecological surprises requires integrated consideration of species invasions, natural and anthropogenic disturbances, and ecological and evolutionary change. These events are responsible for sourcing, selecting, and maintaining genetic and ecological novelty in all environments, including urbanized landscapes.

Keywords: climate change, tropical forests, introduced species, novel communities, land cover change

Previous work has failed to adequately take into account mechanisms of persistence.
Botkin et al., 2007, p 228

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Botkin 2001, p 261[a]

1. Introduction

Recent climate change phenomena and anthropogenic activity involve and/or set in motion directional environmental change, as opposed to assumed cyclic changes in the pre-disturbance era, which modifies the ecological space under which organisms live and function. This directional change induces novel environmental conditions that the biota must adapt to or tolerate to assure survival. The simultaneous changes in biotic and abiotic settings complicate the interpretation of ecological phenomena because cannot predict with certainty

[a]For an alternative view see Lodge and Shrader-Frechette (2003)

the future conditions that the biota will face or the resulting biotic assemblages. However, it is safe to anticipate that continuing changes in environmental conditions will be the only constant for the future, even as the tropical conservation literature views change as generally detrimental to the future of tropical forests. I predict that the natural outcome of climate and land cover change in the tropics is the development of novel forest types within complex and diverse landscapes. I use land cover change as a surrogate for anthropogenic disturbances such as deforestation or urbanization. In support of my proposal I advocate a more holistic and balanced interpretation of the changes now taking place in the tropics and elsewhere on the planet.

To set the stage, I first examine several contemporary issues about tropical biodiversity that divide scientific opinion and prevent a consensus on the future outcome of climate and land cover change. Next, I highlight how current debates about the effects of climate change on biodiversity lead to the realization that we are entering a new era of conundrums, paradoxes, and ecological surprises. To better resolve these complex situations, it is necessary to understand the ecological consequences of disturbances, urbanization, and evolution, which I discuss sequentially. I end with a discussion of the natural outcomes of climate and land cover change.

2. Issues that Divide Scientific Consensus on Biodiversity

The common scenarios about the future of biodiversity in a world under the influence of climate and land cover change involve rampant species invasions, catastrophic levels of species extinction, homogenization of the biota, disruption of ecosystem services, and accelerated rates of tree turnover. How accurate are these predictions? I will discuss three of these in this section and address the other two later.

■ Tree Turnover in the Amazon

Tree data from long-term plots from throughout the Amazon basin reflect the following trends over a period of about 25 years (Phillips *et al.,* 2005):

- Trees $\geq$ 10 cm dbh recruit and die twice as fast on rich than on poor soils.
- Tree turnover rates have increased throughout the Amazon over the last two decades.
- Tree mortality and recruitment have increased in all regions except for mortality in eastern Amazonia.
- Tree recruitment rates have consistently exceeded tree mortality rates.
- Absolute increases in tree recruitment and mortality rates are greater in western Amazonia.

- Tree mortality appears to be lagging tree recruitment at regional scales.
- Tree biomass is increasing in these forests.

The question that these data raises is whether the observed patterns are, or are not, a reflection of global environmental change. Phillips *et al.* suggest that there are environmental change factors stimulating the growth and productivity of Amazon forests and thus the turnover rate of trees. Two such factors are the global increase in CO_2 concentration and increased nitrogen deposition. The authors might be correct in their suggestion for what these data mean, however, Chambers and Silver (2005) present a different point of view and raise important concerns regarding the mechanisms that would explain such environmental change effects. I believe there are five additional considerations that would limit how much these data can be used to show a global effect on these forests.

1. There is no established base pattern of stand development against which to evaluate these data. Before you can conclude that a temporal pattern represents an acceleration of normal stand dynamics, you need to have a base pattern for comparison. It is unfortunate that such a pattern is not known for Amazonian forests so that the changes over the past two decades can be compared against normal pre-climate change stand development. For Caribbean forests subjected to periodic hurricanes, stand development requires about 60 years and stages in patterns of structural development distinct in time can be detected, that is, period of rapid change (0 to 20 years), period of transition (20 to 45 years) and period of maturity (45 to 60 years). A similar pattern, but extending over 100 years, was documented for New England forests following timber harvesting (Bormann and Likens, 1981). During these distinct periods, mortality, recruitment, turnover, and biomass of trees change in magnitude and may even peak and change direction (Lugo *et al.,* 2000; Lugo, 2008). With long-term data, it is possible to evaluate future changes in stand development dynamics since frequency and intensity of hurricanes change. Is it possible that the tree data from the Amazon are reflecting normal rates of stand development along a temporal gradient that is unknown at this time?
2. The data set is too short. Obviously these data represent the longest record available to Phillips *et al.* (2005), but for forests that live for hundreds of years, 25 years is too short an interval to reach conclusions about long-term responses to subtle climatic change events (actually the mean length of plot monitoring was 10.1 yr). Are the study stands of the same age and stage of development? Do they all have the same history of disturbance?
3. The results appear to be normal values for the parameters being measured. For example, the corrected mean tree mortality rate (in percent per year) for various forest groupings in Phillips *et al.*'s Table 10.2 were 1.58, 1.91, 2.03, 2.59, 1.16,

1.27, 2.12, 2.55, 1.16, 1,41, 2.04, 2.86, 1.48, and 1.70. In a review of tropical forest tree mortality data, Lugo and Scatena (1996) found that normal background mortality for these forests averaged 1.6 percent per year with a few stands reaching 3 percent/yr. In Table 10.1 of Phillips *et al.* (2005), 5 (17 when measured rates are corrected) of 91 plots reach or exceed 3 percent per year turnover. Thus, the tree mortality results show no unusual levels that would lead you to believe there is an acceleration trend in the results.

4. The same is true of the tree biomass accumulation in Baker *et al.* (2005) who report a mean of 1.22 Mg/ha.yr for 59 sites. These values are lower than similar measurements in mature dry to wet forests in Puerto Rico (Lugo *et al.*, 2002), tropical forests in general (Figure 5 in Brown and Lugo, 1982), and world forests (Jordan, 1971). The values reported by Baker *et al.* (2005) reflect a normal carbon sink in mature tropical forests as predicted by Lugo and Brown (1986). Baker *et al.*, (2005) suggest their biomass accumulation values reflect a trend, when in fact they have a single rate determination for each plot. It is probably premature to predict trends from a single point in time but they base their suggestion on the tree turnover data of Phillips *et al.* (2005). However, there is no *a priori* ecological reasoning to expect a biomass accumulation trend in the same direction and in relation to a tree turnover trend. In fact, irrespective of forest stand dynamics, biomass accumulation in wood is similar worldwide (Jordan, 1971; Brown and Lugo, 1982) and Baker *et al.* (2005) have not shown that their results are different from the global average.
5. Only a few plots reflect the statistical trend reported for the combined number of plots, in fact, most plots show no trend at all through the period of measurement while some sites decrease in tree turnover (their Figure 10.2). Phillips *et al.* actually point this out, as their objective was not to analyze individual plots but to seek a landscape level pattern of change. Nevertheless, such a stance would be more convincing if a reasonable number of sites were actually showing an acceleration pattern of tree turnover. This leads you to wonder if the combination of plots used for the analysis reflected a difference in rates over a 20-year period not because of climate change but because the combined natural history of the plots lead them in a particular direction coincident with their particular histories of disturbance and development as suggested by Chambers and Silver (2005).

If these data were analyzed in the absence of a climate change debate, they would reflect a healthy and productive group of tropical forests behaving normally, growing, accumulating biomass, and showing regional differences, as do many other forests in the tropics and elsewhere. However, the authors are probably correct in the anticipation that biomass turnover rates would be expected to increase should the disturbance regime change and cause more frequent disruption of ecosystem structure. I predicted such a change in a climate change scenario that would increase the frequency of hurricanes over the Caribbean (Lugo, 2000). However, my prediction was based on increased mechanical disruption of forests by hurricane winds. The explanation of how a fertilization effect by CO_2 or nitrogen deposition can increase the tree turnover rate or biomass turnover is less clear as discussed by Chambers and Silver (2005). As cautioned by Phillips and Malhi (2005), the complexity of tropical forests limits our ability to generalize from small scale or single species experiments to whole ecosystem levels.

Prediction of Species Extinctions

The scientific community is also divided in predictions about the level of species extinctions expected in the tropics due to anthropogenic activity. For example, in the process of forecasting the effects of global warming on biodiversity, Botkin *et al.* (2007) noted what they called the Quaternary Conundrum: "While current empirical and theoretical ecological results suggest that many species could be at risk from global warming, during the recent ice ages surprisingly few species became extinct" (p. 227).

Recently, an article by Wright and Muller Landau (2006) caused a debate about these predictions. Many arguments were raised in an effort to demonstrate that the predictions were too low (Laurence, 2006). In my view, the Wright and Muller Landau paper contains a verifiable analysis of the species extinction issue because the assumptions it makes are explicitly stated and the study is based on empirical data. The paper also recognizes the limitations of the analysis and the uncertainties of the issue, unlike previous estimates by Myers (1979, 1982, 1983), Lovejoy (1981), Ehrlich and Ehrlich (1981), and Simberloff (1986) who made predictions with fewer data and undisclosed methods and/or assumptions. Over 10 years ago, a glossy document from the Smithsonian suggested that in 10 years it would be too late to do anything about the species extinction crisis. The ten years passed and what we have is a new discussion of the issue as if the previous exaggerated predictions were never made. The problem is the adequacy of the methods used to predict species extinction rates, the difficulty of achieving scientific consensus, and the potential loss of credibility given the visibility of the alarming rates forecasted compared to the actual loss and available data.

In spite of the strength of the analysis of Wright and Muller Landau, their work continues to depend on the species/area curve to estimate species extinction rates. Such a focus leaves out ecological considerations and real-world experience that would further reduce the estimate of the expected extinctions (Botkin *et al.,* 2007). The experience in Puerto Rico supports the assumptions of the model used by Wright and Muller Landau but not the predictions of the model.

The island of Puerto Rico, which lost 99 percent of its primary forests and 93 percent of its forest cover to agricultural activity, and has a high population density (>400 people/km^2) experienced much lower rates of species extinctions than predicted by the species/area method. Specifically, the extinction of species in Puerto Rico was no more than 10 percent of bird species, and 5 percent of plant species (Lugo, 1988). If anything, Puerto Rico shows that the species/area curve method for estimating species extinctions is not adequate for predictions because it ignores all the resilience mechanisms of nature that prevent massive species extinctions as a result of land use change and assumes that all species are lost when a parcel is deforested. The species/area method also ignores the role of humans in mitigating their effects (Lugo *et al.,* 1993; Lugo, 1997). In Puerto Rico, not only have native species been retained in higher-than-expected numbers, but also local species richness is now higher than at any known time because of an influx of new arrivals and their assembly in new plant communities (Lugo and Helmer, 2004) with higher species richness per unit area than the original forests (Lugo and Brandeis, 2005).

As the first quote at the beginning of this paper states, the problem with the predictions of extinctions of species is that we neglected aspects dealing with the persistence of species, focusing most of our attention on the negative aspects of the biodiversity equation. By doing so, we miss better than half of the biodiversity issue, which involves nature's response to anthropogenic activity and climate change and which contains the elements of potential solutions to the conservation issue. More balance is called for in the analysis of biodiversity issues. As we will see throughout this paper, the narrow focus on aspects of an issue rather than on its totality is a theme that repeats itself in many conservation issues. Sax and Gaines (2003) concluded that the loss of species at the global level exceeds the rate of species addition through evolution but evolution is responsible for species additions at rates faster than previously thought (below). Moreover, on islands worldwide, species invasions exceed species extinctions by a large margin, for example, doubling of plant species (Sax *et al.,* 2002). Therefore, while scientific attention is given to the implications of species loss, a greater challenge is to understand the implications of gains of species at local and regional scales.

Species Invasions

There is no debate about the pervasiveness of species invasions throughout the world and the biotic and abiotic change associated with such invasions. There is debate, however, on who is responsible for what when a species invades. Also, there is no question that when an introduced species becomes dominant in an ecosystem, rate processes, direction of succession, and interactions among populations change (examples in Gordon, 1998; Denslow and Hughes, 2004). However, there is debate on the implications of these changes to ecosystem function and the naturalness of the invasions (see second Botkin quote at the beginning of this paper). Moreover, the role of species invasions as causes of widespread extinctions is unproven, and evidence for supporting a general and primary role for invasive aliens in extinction remains limited (Gurevitch and Padilla, 2004). Vermeij (1996) called attention to evidence that led to the conclusion that invasions on oceanic islands and in lakes can cause extinction of species but rarely in the sea or on large landmasses. Nevertheless, Lodge and Shrader-Frechette (2003) believe there is no question of the fact that introduced species cause extinction of native species without consideration of the conditions under which the statement might apply. The three sources they use in support of their view provide no significant evidence that would lead one to believe their unqualified position (see Lugo and Brandeis, 2005). The assumption that introduced species are agents of change has been questioned experimentally (MacDougal and Turkington, 2005), who concluded invasive species were “passengers” of environmental change and noted that they have suppressive as well as facilitative effects on ecosystems (see also Didham *et al.*, 2005, 2007). However, there is strong evidence that under certain conditions introduced species change rates of ecosystem processes (such as productivity, nutrient cycling, biomass storage) (Vitousek *et al.,* 1987; Denslow and Hughes, 2004).

Mack *et al.* (2000) contains a more restrained assessment of biotic invasions, recognizing that not all invasive species are equally effective in the alteration of environmental conditions or in their effects on other species. Ricciardi and Cohen (2007) examined the literature and suggested that the term “invasive” should not be used to connote negative environmental impact. Paradoxically, invasive introduced species are proposed candidates to solve the energy crisis through biofuel biomass production (Raghu *et al.,* 2006). These plants have characteristics that make them successful invaders as well as excellent biomass producers. The same paradox applies to organisms introduced to control introduced organisms (Simberloff and Stiling, 1996), which essentially act to further homogenize ecosystems rather than maintain their differences.

Strayer *et al.* (2006) noted that the effects of invasive species such as evolution, shifts in species composition, accumulation of materials, and interactions with abiotic variables, all change over time when they can increase, decrease, or qualitatively change the impact of an invader through time. They thus require long-term study. However, most studies of species invasions are brief and they found that 40 percent of recent studies did not even state the time that had passed since the invasion. The short-term study of long-term phenomena is an important obstacle to scientific understanding and consensus on critical conservation issues. There is a need to focus research on a comprehensive and systematic approach to invasion biology (Vermeij, 1996).

A result of inadequate research on species invasions is the ease with which the invading species are held accountable for changes that those species had no part in promoting. Two examples illustrate the point. Amphibian decline in western North America was related to habitat changes that promoted the invasion of introduced species (*Rana catesbeiana*), but it was the habitat change (more permanent vs. ephemeral wetlands) that caused the decline in the native species (*Rana aurora*) and not the invasive species (Adams, 1999). Case (1996) reviewed the global bird literature and his analysis showed that: "Beginning in aboriginal times, the conversion of native habitats, particularly at lower elevations, to disturbed habitats simultaneously enhanced the success and persistence of introduced species, while decreasing population sizes and increasing extinction rates of native species. Thus habitat conversion and deterioration alone could produce a correlation between the number of extinct natives and the number of introduced species even without any direct cause or effect between birds in these two groups" (p. 85).

By not assessing the ecological situation properly, a "shoot first, ask questions later" approach to control of introduced species develops, but such an approach may have unintended ecological consequences as happened for decades in agricultural systems that used the same approach to control agricultural pests (Smith *et al.*, 2006). It turns out that indiscriminate eradication of weeds has negative as well as positive effects on crops and that through management, instead of eradication, crop production, as well as agroecosystem functioning, can be optimized. Zavaleta *et al.* (2001) suggested that because of the unforeseen aspects of invasive species removal, such activities should be coupled to ecosystem restoration goals and accompanied with sufficient monitoring to assure that the desired results are attained.

3. The Debate Turns Subjective

Laurance (2006) suggested that because results such as those in Wright and Muller Landau (2006) could be misused by sectors of society, scientists should be careful with what they conclude. Lewis *et al.* (2006), in response to Wright (2005) when he questioned the tree turnover data discussed above, suggested that Wright's approach "sends a worryingly ambivalent message about the future of tropical forests to students, scientists, policy makers and civil society as a whole" (p 174). Both of the arguments above are inappropriate in a scientific debate and deny the role of independent science in informing policy. The critiques aim to limit scientific freedom or at least force it to serve a particular point of view (advocacy science). The comments also ignore that scientific progress is made by falsifying assumptions and cannot be limited by fear of what others will do with the new information. In an essay entitled "What is wrong with exotic species?" Sagoff (1999) argued against ecology becoming a normative science, and pointed out the pitfalls of such an approach. Moreover, conservation is best served by scientific discovery and well-documented analysis.

In short, the lack of consensus on biodiversity conservation issues is partly due to lack of information, to the absence of a balanced approach, and the subjectivity of some arguments, which on the whole lead to a failure to address and resolve conundrums, paradoxes, and ecological surprises.

4. The Biotic Age of Conundrums, Paradoxes, and Ecological Surprises

Changes in the ecological space of organisms set them in motion both in ecological and evolutionary terms (below). Because the level of environmental change due to human activity is so pervasive at all scales of biotic organization (from cells to global), the magnitude of biotic response is also dramatic and unprecedented. The initial reaction of reasonable observers to this new level of biotic change is to consider all changes as detrimental to the established biotic order. Over time however, evidence accumulates to suggest that the observed changes in the biota are neither negative nor positive. Instead, they are adaptive. Carroll and Dingle (1996) postulated "...that invaders most likely to integrate successfully are those on which high levels of additive genetic variation are expressed in traits most likely to be adaptive in the new environment" (p 207).

The accumulation of examples of novel biotic interactions and species assemblages will be best described as paradoxes or ecological surprises (many leading to conundrums) for as long as biotic change to negative consequences. This is particularly plausible because for the past 100 years the study of biota from the point of view of a balanced system with predictable environmental conditions. Against that backdrop, the biotic turmoil induced by intense anthropogenic activity and directional climate change certainly appears paradoxical. I now present a few illustrative examples from different parts of the world.

A conundrum faced by the readers of the scientific literature is that on the one hand, introduced species can be held responsible for enormous changes in the environment and cost the human economy billions of dollars. On the other hand, introduced species are a natural component of the response of the biota to the massive changes taking place in the environment and they help sustain environmental services through periods of environmental turmoil. The economic cost of introduced species is greatest in agricultural systems and other intensively managed systems where a change in the biota represents potential losses or gains of money (Westbrooks, 1998). Ecologically, the same critical situation occurs in isolated oceanic islands such as the Hawaiian or Galapagos islands, where the native biota is recognized for its endemism and biotic value or perhaps in stream channels or other similarly confined environments such as lakes, where an unchecked introduced species can create ecological havoc with native species. These well-understood situations, and others that I don't mention, require dedicated management to assure the survival of the natural biotic values involved. However, in most of the landscape where the vastness of the scale constrains what can realistically be accomplished by management, it behooves ecologists to understand the processes at play before promoting expensive and many times unrealistic solutions for the suppression of change, particularly if it turns out that the species invasions are adaptive to new climatic and environmental conditions.

Fridley *et al.* (2007) described the invasion paradox based on observations at small scales (< 10 m^2) of a negative relation between the number of native species and the number of species or success of introduced species. However, at larger scales (> 1 km^2) there is a positive relationship between the number of native species and the number of introduced species. This paradox cannot be explained by a single theory, as it requires the consideration of as many as eight processes, or a pluralistic framework to explain the observed relationships.

The inbreeding paradox raises the question of how invaders of new territories with low numbers (inbreeding) become successful invaders. Pérez *et al.* (2006)

proposed new possibilities for explaining the paradox such as epigenetic adaptations (inheritable modification of gene function without changes in the base sequences of DNA) and adaptive (non-random) mutations, two types of genetic response that suggest that evolution might be hastened under stress. Roman and Darling (2007) resolved the paradox for aquatic plants through the effect of numerous introductions, which promote range expansion through genetic and demographic mechanisms. Other solutions to this paradox are described later.

If local adaptation is common and important, then why are introduced species so successful at outcompeting and replacing native species? This paradox has many explanations. Allendorf and Lundquist (2003) suggested that a lag time after the invasion was necessary for the invading species to develop adaptations to the novel habitat. Alternatively, if the novel habitat is also new to the native species, the competition between the invasive and the native takes place under conditions where either species could gain "a home" advantage. In this case, the outcome depends on a species' capacity to deal with the novel environment. In the long-term, large and infrequent disturbances (LIDS *sensu* Dale *et al.,* 1998) determine which species attain permanence on sites, as the LID might require a particular set of adaptations such as tolerance to wind, drought, fire, flood, etc. Thus, there is a short-term/long-term aspect to the success of invasions (Lugo, 2004b).

The literature is becoming replete with reports of new mutualistic relationships between native and introduced species as well as between introduced species. For example:

- In Hawaii, introduced birds have replaced the native seed-dispersing avian species because nearly all the native seed-dispersing species have been lost. These introduced frugivore birds disperse both native and introduced plant species and they contribute to the regeneration of native plants in the understory of forests dominated by introduced trees (Foster and Robinson, 2007). In their study, Foster and Robinson found that of the total seed dispersal work by introduced birds, 85 percent were native plant species. Most Hawaiian understory plants depend on introduced bird species for their dispersal.
- The introduced black spiny-tailed iguana (*Ctenosaura similis*), native to Mexico, and the introduced Brazilian pepper (*Schinus terebinthifolius*) established a mutualism in south Florida (Jackson and Jackson, 2007). Another example is the importance of the introduced Chinese privet (*Ligustrum sinense*) for sustaining the white tailed deer (*Odocoileus virginianus*) in the Fall and Winter in southeastern United States (Stromayer *et al.,* 1998).

- Gutiérrez *et al.* (2007) describes the conundrum of the spotted (*Strix occidentalis*) and barred (*S. varia*) owls where a native replaces another native perhaps mediated by natural or anthropogenic factors.
- The urban fire ant paradox involves native fire ants (*Solenopsis geminata*), which persist in an urban refuge, while invasive fire ants (*S. invicta*) dominate natural habitats (Plowes *et al.,* 2007). Old residential areas with low landscape disturbance in Austin, Texas, provided refuge to the native fire ant inside the city.
- Apparent competition (Meiners, 2007). The presence of an introduced shrub that shares seed predators with native trees increases predation of native tree seeds and reduces its regeneration.
- Facilitated pollination (Bjerknes *et al.,* 2007). Invasion by introduced plant species do not necessarily reduce pollination success in native plant species. Instead they may facilitate pollination by increasing the density of pollinators. The fact is that the interaction is complex, and requires longer and broader types of studies to unravel the outcome of the interaction.
- The germination requirements for the annual plant *Cardamine hirsuta* were different in its native range (Europe) than in Japan, where it was introduced and naturalized (Kudoh *et al.,* 2007). This shows that not all populations or strains of a species are equally invasive and that adaptive change is sometimes required for an invasive species to be successful in the new environment.
- Ashton *et al.* (2005) found that in mixed deciduous forests in Long Island, New York, the rate of litter decomposition and N release was accelerated both by invasive species relative to native ones and in invaded sites relative to sites not invaded.
- Forys and Allen (1999) were unable to anticipate the expected changes in vertebrate fauna in south Florida using current organisms, body mass data, species distribution and niche classification. Although it is clear that the fauna of the future will be different from that of today, it was impossible to anticipate the nature of the future fauna given the profound ecosystem changes taking place.
- The stoichiometry of a floodplain in New Zealand was affected by the phosphorus accumulation due to early dominance of an introduced shrub (*Buddleja davidii*), but this dominance was short-lived as the native shrub (*Coriaria arborea*) dominated the later stages of succession (Bellingham *et al.,* 2005). There was no immediate impact on forest species composition.

The few examples listed above show that the mixing of species now in progress worldwide involves much more than plant and animal species sharing geographic or ecological space. Instead, the newly mixed biota is reacting, changing, interacting, adjusting, and adapting to the new biotic and abiotic conditions (more on this below). This results in the assembly of novel communities with novel species to species and species to environment relationships that surprise many or appear paradoxical in the context of a non-changing world. Moyle and Light (1996) assumed the *Frankenstein Effect* as a firm rule for anticipating the community assembly rules due to species invasions: "New invasions are likely to have unexpected consequences" (p. 159).

Botkin (2001) summarized this new circumstance by describing a new conundrum. He stated that "one can either preserve a "natural" condition or one can preserve natural processes, but not both" (p. 261). This is so because the preservation of natural processes requires change in environmental conditions and the biota. By focusing on a particular natural condition, Botkin says, one would have to stop environmental and biotic change at a great cost to humans. This conundrum is at the crux of the issue facing us in the world of climate and land cover change. These two processes of environmental change appear irreversible and it is very difficult, if not impossible, to reverse them.

5. The Role of Disturbances

One of the most important advances in modern ecology is establishing how natural and anthropogenic disturbances influence ecosystem composition, structuring, and functioning. Because disturbances alter conditions in forests, they set in motion responses that last for a long time, well after the event, as will be shown below. Ecologists have made significant advances in understanding the role of natural disturbances on ecosystems and are now focusing attention on anthropogenic disturbances, which appear to have novel effects on the composition, structuring, and functioning of ecosystems. In this section I review literature that shows how anthropogenic disturbances determine the species composition of forests. This is a particularly important subject for our understanding of how forests might respond to climate and land cover change and it also integrates a large literature on invasion biology into the debate of the future of biodiversity in the tropics.

Many studies show that land use has a long-lasting influence on the species composition of forests established on deforested lands (for example, Foster and Aber, 2004; Balée and Erickson, 2006). In Puerto Rico, Thompson *et al.* (2002) found that land cover in 1936 influenced the contemporary forest species composition in spite of decades of forest succession and numerous passages of storms and hurricanes over the site. In France, Dambrine *et al.* (2007) showed that the effect of land use remains on the landscape over millennia after abandonment. Species richness patterns follow soil alteration and human activity some 1500 years ago, and they believe part of the explanation is the human effect on the biogeochemistry of sites. Dupouey *et al.* (2002) observed that species richness and plant communities vary according to the intensity of former agriculture. These variations are linked to long-term changes of chemical and structural properties of soils. The effects are historically irreversible. Vellend *et al.* (2007a) found legacies of human land use on species composition of forests in North America and Europe that last for centuries. Cramer and Hobbs (2007) assembled examples from throughout the world that show the long-term legacy of vegetation change after abandonment of agricultural activity.

Aplet *et al.* (1998) used a chronosequence approach on the lava flows of Mauna Loa, Hawaii, to study primary succession of vegetation on wet and dry sites along precipitation, substrate texture, time, and temperature gradients. Of the 124 species they encountered, 27 species were introduced and they mostly occurred on lowland dry sites. Although introduced species were found in 27 of 42 sites, their dominance in terms of biomass contribution (> 20 percent of the total biomass) was significant in eight sites. They also found that the presence of introduced species reflected past disturbances rather than primary succession. Repeated burning on dry sites appears to facilitate the presence of introduced grasses such as *Pennisetum setaceum*. Otherwise, the primary succession gradient was dominated by native species. Disturbance mediation is apparently required for the invasion and dominance of introduced species in Hawaii.

This was also the result of an analysis of the 180-year history of *Syzygium jambos* in the Luquillo Experimental Forest (Brown *et al.,* 2006). This tree was most abundant in locations that had been deforested or heavily impacted by human activity. However, its density in mature or primary forests was very low (Brown *et al.,* 2006; Thompson *et al.,* 2007). The tree has remained dominant on previously altered riparian areas, where it forms a novel forest type *sensu* Lugo and Helmer (2004).

The synergy between habitat fragmentation, grazing, and species invasions explains resulting communities with better insight than by classic fragment area approaches (Hobbs, 1991). Laurance and Williamson (2001) described a synergy or positive feedback between forest fragmentation, drought, and climate change in the Amazon. This feedback involved fire disturbances, deforestation, and logging as forcing functions that accelerated forest response to climate change. Hobbs and Mooney (1998) argued and provided illustrative examples showing that the effects of humans on biodiversity was much more than implied by the extinction of species debate. In fact humans add more species to landscapes than become extinct (Hobbs, 2001), but they also cause the local extinction of populations, reduce species ranges, greatly modify the habitats, promote species invasions, and thus the structure, functioning, and species composition of ecosystems. Hobbs (1991) examined the circumstances that favored the invasion of the most serious environmental weeds in Australia. In all cases, weed invasion was enhanced by anthropogenic disturbance. While all disturbances do not lead to invasions, invasions increased if the disturbance increased the availability of limiting resources and propagules were available. Natural disturbances maintained native species, but anthropogenic disturbances added new conditions to the disturbance regime that favored the invasion of introduced species. Combinations of disturbances act synergistically and make invasions more certain.

Simulation models for New England forests underscore the importance of disturbance to the outcomes of climate change or introduction of species scenarios (Loehle, 2003). Without disturbance, but a reduction in growth rate due to climate change, shade tolerant species or species with long life spans persist longer than light-adapted or short life span species. This slows down the invasion by introduced species. Disturbance events speed up displacement of species by allowing quicker turnover of species, thus facilitating the dominance of introduced species.

Corbin and D'Antonio (2004) found that unless land use, climate, or both changed, the conversion of native perennial grasses to annual introduced grasses was unlikely to occur by simply introducing propagules of the invasive grasses. However, if land use or climate or both changed, then propagules of introduced annual species have a greater opportunity to become established and slowly replace native perennial species in a California coastal prairie. After Hurricane Hugo in Puerto Rico, Chinea Rivera (1992) found that as the native forest recovered, the only sites available for regeneration of the introduced *Albizia procera* were roadsides and other anthropogenic-impacted areas.

The above Puerto Rican and Australian examples focused on the influence on species composition of disturbances. The Hawaii examples illustrated that introduced species gain a foothold because of anthropogenic disturbances, a principle confirmed through experiments in California (Corbin and D'Antonio, 2004), modeling in New England (Loehle, 2003), and experience in Australia and Puerto Rico. The effects of anthropogenic activity on species composition persist for a long time, perhaps influenced by the high level of synergy that occurs between natural and anthropogenic disturbances and the novel environments they create. However, not all anthropogenic disturbances have the same effects on ecosystems. Molina Colón and Lugo (2006) found that those disturbances that opened the forest canopy but left the soil intact had milder effects on subsequent forest succession than disturbances that both opened the canopy and altered soil conditions. Similarly, some anthropogenic disturbances associated with climate change such as increasing temperatures and CO_2 concentrations affect ecosystems physiologically, which involves a different set of ecosystem response mechanisms than those associated with agricultural activities. Urbanization is a general term for many types of anthropogenic activities that involve an equally diverse range of disturbance types. These vary from total conversion and replacement of forests to ecophysiological disturbances such as air or soil pollution. As we will see next, ecosystem responses to urbanization are also diverse.

6. The Role of Urbanization

Of all anthropogenic disturbances none is more dramatic than the urbanization process. This process transforms the land to a greater level than agricultural activity and it is a process whose intensity is on the rise, given the global movement of people to urban settings. Because of the increasing rate of expansion of cities, urbanization is believed to be one of the leading causes of species extinctions, as natural populations become fragmented, habitats are converted to other uses or degraded, and the biota is extirpated or homogenized (McKinney, 2006). Cities also contain new environments to which many native organisms are not adapted to colonize. Some of these environments are usually colonized by introduced species (Kühn and Klotz, 2006).

McKinney (2006) suggested that urbanization was a major cause of biotic homogenization. Cities homogenize the physical environment, are maintained for centuries under conditions different from the natural ones surrounding them, and they promote the same kinds of species adapted to city conditions. Thus, the expansion of cities promotes the expansion in numbers and area of these same kinds of species. Cities also can act as refugia for plant species that then expand their ranges into rural areas (Kühn and Klutz, 2006). As there are local disturbance gradients within cities, these induce gradients of homogenization from the core, where the global homogenizers are found, to the suburban and urban fringe where native species occur (McKinney, 2006). Paradoxically, the species richness of cities is higher than that of natural systems in the vicinity (McKinney, 2006; Kühn and Klotz, 2006).

Issues of comparability (area sampled, taxa included, life zone conditions included) and availability of data complicate the comparison of species richness or similarity data such that the predictions of homogenization do not always lead to the same conclusion. On a regional scale in Germany, urbanization is not unequivocally related to homogenization (Kühn and Klotz, 2006). Native species and introduced species before 1500 show signs of homogenization due to urbanization but all species and those species introduced after 1500 do not show a homogenization effect. McKinney (2006) found that introduced species have lower similarity among cities than native species, suggesting differentiation of the introduced flora instead of homogenizing it.The Jaccard Similarity Index is used to demonstrate homogenization among cities (McKinney, 2006). Generally, the index shows more similarity among cities than among natural areas. However, the pattern applies to cities such as New York, Boston, Philadelphia, Minneapolis, Washington DC, Detroit, and Saint Louis in similar latitudes and life zones *sensu* Holdridge (1967) compared with natural areas that span into western United States, where the life zones are considerably different (Lugo *et al.,* 1999). The Jaccard Similarity Index compares the species composition of different floras and indicates how similar the floras are based on the number of species they have in common. However, the Index does not include the relative quantitative presence of the species (Mueller Dombois and Ellenberg, 1974). The Jaccard Similarity Index weights all species equally and ignores the effects that the mixing of species has on the structuring and functioning of ecosystems. Two floras could be very similar floristically and, thus assumed to be homogenized, but they might not be similar ecologically because the distribution of species within each flora assembles into different types of communities.

There is no argument that a homogenized environment, be it in a city or under natural conditions, leads to a few species and high species dominance. And there is no argument that some species associated with human dwellings have global distributions and can occur in most cities or that the world is experiencing a loss of endemic taxa. Olden *et al.* (2004) discussed the ecological and evolutionary effects of homogenization, and like others raised important consequences of the process to displaced and vulnerable organisms. However, all their analysis is focused on the assumption of extinction and that the ecological and evolutionary change would lead to reductions in diversity. They do not consider the other side of the equation, namely the possibility of evolutionary and ecological change within the urbanized area that would lead to genetic diversity and ecological novelty in light of new environmental conditions. Cities are not globally homogeneous in their biota, as anyone who travels across latitudes or across life zones, instead of within latitudes or life zones, can attest. The San Juan Metropolitan Area has a flora much different from that of

Washington DC. The point is that cities do have an ecological cost as they displace natural ecosystems and local populations but they also diversify the landscape, are collectively diverse, and contribute to the formation of novel communities.

7. The Role of Evolution

The modern biological invasion is an unprecedented form of global change (Ricciardi, 2007). This is so in terms of temporal and spatial scales, novel species combinations, novel evolutionary pressures, and potential evolutionary consequences. Ecological and evolutionary insights can be gained from the study of species invasions (Sax *et al.,* 2007; Yoshida *et al.,* 2007). Vellend *et al.* (2007b) pointed out that invasions have positive values in terms of promoting evolutionary diversification such as establishing allopatric populations in new environments, altered ecological opportunities for native species, and new opportunities for hybridization between previously allopatric taxa. Cryptic species invasions, phenotypic plasticity, general-purpose genotype, non-additive genetic variation, hybridization, introgression, polyploidy, and trait genetic variation are examples of the evolutionary considerations with implications to invasion ecology (Yoshida *et al.,* 2007). Of these evolutionary events, introgression or genetic "swamping" is the focus of conservation concerns because of its negative consequences to the genetic purity of endemic and endangered species (Cox, 2004). This is a legitimate concern, but only one aspect of the evolutionary changes in progress today.

Hoffmeister *et al.* (2005) recognized the importance of evolutionary change as a result of the combined effects of species invasions, habitat fragmentation, and isolation. They argued that both ecological and evolutionary change require consideration if we are to understand the full effects of environmental change. Lambrinos (2004) showed with examples that invasion dynamics can be influenced by the interaction of ecological and evolutionary processes acting over similar time scales and at any stage of the invasion process (his Figure 1). Parker *et al.* (2003) recognized and discussed the relevance of evolutionary biology to the study and control of invasions.

Interspecific hybridization between a native and introduced species following plant invasions may sometimes lead to the rapid evolution of new plant taxa (Abbott, 1992). In Germany, 134 hybrids between 109 native and 81 introduced species have been anticipated, although 75 have been found (Bleeker *et al.,* 2007). Thirty-seven threatened native plant species hybridize with introduced species, of which 17 may suffer outbreeding depression when hybridizing with a more common introduced species. Introgression of alien genes may affect 8 of these threatened species. In the case of *Fallopia japonica*, a highly invasive species that was introduced in the 19th century to Europe, Bailey *et al.* (2007) documented how a single female plant that greatly spread by vegetative means, overcame its lack of genetic variability through hybridization and polyploidy. Some of the hybrids possessed novel genotypes with higher fitness than parents. These plants can switch from clonal dispersal to a home-produced hybrid and backcrosses, honed by natural selection that fits the particular ecological niches in which they happen to find themselves.

Dacus tryoni, the Queensland fruit fly dramatically increased its range over a hundred years not because there were more resources to support the expansion but because it overcame a physiological limitation to extreme temperature. Through adaptation by the mechanism of hybridization and introgression of genes from other fruit flies, the species acquired this physiological capability. Hybridization is an effective mechanism towards rapid evolution of organisms (Lewontin and Birch, 1966).

Invasions represent a novel selection process (Carroll, 2007). Contemporary evolution in response to anthropogenic change appears increasingly common. Native phytophagous insects in North America and Australia evolved substantially after colonizing introduced hosts. Evolving natives and introduced species may reconfigure contemporary and future communities. Adaptive evolution may also enhance native communities' capacity to control invasive populations. In support, Carroll gives examples of evolution in native prey to invasive predators in a few generations. Maron *et al.* (2004) conducted experiments with *Hypericum perforatum* (St. John's wort) to test the relative effects of contemporary evolution, phenotypic plasticity, and founder effects in affecting phenotypic variation among introduced plants. Multiple introductions add considerable genetic variation to the invading populations. Some genotypes were pre-adapted to conditions faced in the new range. Some genotypes were not, and these are the ones evolving to the new conditions they are facing. The rate is fast, as the plant has only undergone 12 to 15 generations over 150 years. The results suggest that introduced plants are evolving adaptations to broad-scale environmental conditions in their introduced range.

In short, evolutionary change is at play in novel environments created by anthropogenic activity. Much of this change appears critical to the maintenance of species and communities in rapidly changing conditions. When the genome of species keeps pace with environmental change, the likelihood of maintaining environmental services in novel environments is enhanced.

8. Novel Tropical Forests and Diverse Landscapes

At the outset I advocated a more holistic and balanced interpretation of the changes now taking place in the tropics and elsewhere on the planet and highlighted the problems with an excessive focus on the negative aspects of the effects of environmental change on biodiversity. To avoid the pitfalls of negativism (see the exchange between Orr, 2007; Nugent, 2007; and Knight, 2007), a holistic approach on biodiversity will:

- Focus research on the long-term behavior of complex tropical forests and the synergy within and between ecosystems and external disturbance forces;
- Be transparent in the analysis by stating assumptions;
- Focus on both the resilience, including the adaptability, and vulnerabilities of the biota;
- Distinguish between short and long-term system responses;
- Recognize the emerging system properties with changing levels of biotic organization, that is, the whole is greater than the sum of the parts;
- Practice inter- and trans-disciplinary approaches to the analysis of complex socioecologic problems; and
- Focus on all species and all environments.

Given the magnitude of anthropogenic activity on the world and the consequences of this activity, the biota is on the move, both ecologically and evolutionarily, as it has done over millennia as conditions on Earth change (Behrensmeyer *et al.,* 1992). Rich and Woodruff (1996) describe large-scale temporal changes in the vascular flora of England (1930 to 1988) that reflect changes in land use and human activity (that is, loss of species in converted habitats and gains of introduced species throughout). What will the eventual outcome of this large-scale biotic change be?

Allan (1936) argued that introduced and native plant species in New Zealand co-existed in different types of plant assemblages characterized by different levels of human intervention. Egler (1942) agreed from the point of view of Hawaii vegetation and underscored that the issue is to "...consider the ecological status of each species of the available flora, quite independently of whether the species has been introduced during recent years or arose there by evolution from pre-existing forms" (p. 15). Hatheway (1952) confirmed Egler's observations and both recognized the role of the introduced tree *Leucaena glauca* as a nurse crop for native vegetation.

Future scenarios under the influence of climate change have been described as "new species, new biotic communities, new ecosystems" p. 271 (Cox, 2004). Moreover, he explains that given climate and land cover change the question of what species are truly alien becomes nebulous because the range expansion within continental areas by many species involves hundreds of kilometers. The ecological and evolutionary adjustments by both introduced and native species mean that maintaining or restoring the original community composition of many areas is impossible, thus providing a clue to the solution of the conundrum of Botkin (2001, p. 261).

Clearly the tactics for the conservation of biodiversity need to account for new species combinations in small fragments of fragmented landscapes as argued by Kellman (1996). In addition to addressing the specialization aspect of species, more attention is needed on the ecological flexibility of species. In these new combinations of species never seen before, species will have to perform roles that may appear unnatural in a continuum of communities, but not in fragments. The number of small and different fragments is bound to increase in the future and they offer new scientific challenges.

Williams and Jackson (2007) discussed the concept of no-analogous communities and novel climates to refer to communities that are compositionally unlike those of today, but which occurred frequently in the past and will develop in the greenhouse world of the future. A no-analog community "consists of species that are extant today, but in combinations not found at present" (p. 477). Williams and Jackson assumed that species will move along gradients of ecological space in accordance to their tolerance and adaptations, because the species niche might only be partially described by modern climate. They were referring to climates that in modeling exercises appear in 2100 in tropical and subtropical regions. They see these climates as warmer than any present climate and see them globally with spatial variable shifts in precipitation and increased risk of species reshuffling into no-analog communities and ecological surprises.

The analysis of Sax *et al.* (2007) suggests that the notion of species migrating geographically in response to climate migration assumes that today's species distributions in relation to climate variability will enable predictions of future distributions. Consult Iverson *et al.* (1999) for an Atlas of how tree species distributions will change due to climate change in northeastern United States. However, assuming that today's species distributions enable predictions of tomorrow's species distributions might not always be true. Species with small native ranges but large naturalized distributions and species with large native ranges, but growing in naturalized ranges outside their predicted climate envelope, do not fit the models as they cause a climate envelop mismatch. What this means is that the experience with introduced species appears to change the rules of the game. Moreover, it is possible that the predictions for the next century of species movement in climatic space based on modeling exercises are already in progress in the world. These actual species movements are greatly accelerated by the movement of introduced species by anthropogenic vectors and the acceleration of novel climate formation by human activity.

Well before Williams and Jackson (2007), Allan (1936) recognized the formation of novel plant communities with combinations of introduced and native species. Also, Lugo and Helmer (2004) had already proposed the identical definition of no-analog communities when they described the new forests of Puerto Rico, whose parameters of anthropogenic activity place the island well into the Homogeocene (Lugo, 2004a). Similarly, Hobbs *et al.* (2006) used the same definition and provided examples from all over the world to illustrate the emergence of novel communities in response to the anthropogenic alteration of the biotic and abiotic environment. Thus, there is increasing support for recognizing the formation of novel communities in response to climate and land cover change. The process is already well underway in regions with heavy anthropogenic activity, which leaves three questions to complete the description of the potential outcome of climate and land cover change in the tropics.

1. **How will the novel communities develop?** The novel communities will self-assemble, self-organize, and evolve in response to prevailing environmental conditions. Self-organization is called upon to explain the non-random distribution of earthworms under novel environments (Barot *et al.,* 2007) and to explain the emergence of the novel communities and ecosystems (Odum, 1988). Egler (1942) described self-organization, but did not use these words when describing the emerging novel communities of Hawaii: "Out of chaos emerges a new order, and plant succession…, though novel, is beautifully orderly and comprehensible" (p 17).

   Because we are dealing with living entities, the introduction of species to the environment activates a plethora of biotic responses in the short- medium- and long-term both in the introduced species as in the species already in location. The induced responses also involve different sectors of the ecosystem as has been shown by Bohlen (2000) who observed that changes aboveground as a result of the introduction of species have effects on belowground processes and species composition as well, including belowground invasions. The fungal dimension of biological invasions also changes as a result of changes in the aboveground component of ecosystems (Desprez Loustau *et al.*, 2007).

The theory and experience of naturalists, ecologists, and evolutionary biologists clearly show that for as long as the biota has been scientifically observed natural, systems never remain still in space or time. The biota is forever adjusting to change and adapting to the ever-dynamic physical environment. There is no reason to expect this natural history to be suspended with the emergence of intense human activity. On the contrary, both the evolutionary and ecological literature briefly reviewed here shows that the adjustments of the biota in the face of climate and land cover change have accelerated, just as the extinction rates have also accelerated.

2. **How diverse will the novel forests and landscapes be?** The novel forest and the landscapes will be as diverse as the current forests and landscapes. The main difference will be the species composition and the relative importance of species in communities. The accelerated responses of the biota to human activity do not appear to lead to a homogenized world *sensu* McKinney and Lockwood (1999) because the resulting environments are not as pervasively homogeneous as anticipated. For example, Case (1996) found that the gain in the number of introduced bird species in the world was close to the number of bird species lost to extinction and the resulting new assemblages of bird populations were as diverse as before. Humans may in fact be increasing the diversity of environments in the world by introducing novel environments that the biota had not experienced before. And the human element is also active in the conservation and preservation of familiar natural environments and wilderness because it values such environments.

3. **Will we lose environmental services?** No. Ecological functioning is resilient and is maintained even as species composition changes, particularly if the novel community is adapted to prevailing environmental conditions. Energy, water, nutrients, and organisms will flow, cycle, and/or turnover in response to community development, environmental conditions, and disturbances. Rates can be faster, slower, or the same as those of previous communities as those rates respond to environmental conditions and available resources.

In summary, the literature reviewed here suggests that ecological and evolutionary processes will continue to play important roles in all environments, including anthropogenic-dominated environments. These changing environments will support novel ecosystems with different species assemblages than today but familiar functional attributes. Reviews of studies of ecological functioning of novel forests do not yield abnormalities in terms of primary productivity and nutrient cycling processes (Lugo, 1992; Silver *et al.,* 1996, 2004; Lugo and Helmer, 2004). In the last analysis, the equation that determines the future of tropical forests will hinge on an allocation of space for humans and wilderness. How much space will people allow for tropical forests and tropical wilderness where the forces of natural selection and self-organization can play out? Such a division of space will also change over time as it has in the past and as the proportion of space changes, so will the composition of the biota.

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PAPER

10 CLIMATE CHANGE IMPACTS ON COASTAL BIODIVERSITY

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ABSTRACT: The physical configuration of coastal ecosystems is determined by a combination of marine, terrestrial, and atmospheric processes that shape the land/ocean interface. As the world's present coastlines evolved over the past 7,000 years (a period when sea level was relatively stable) assemblages of organisms that represent the current biodiversity of the coastal margins of the Americas also emerged. Located along the narrow transition zone at the ocean edge of continents and islands, coastal ecosystems and their biodiversity are affected by changes in the processes that created and sustain them. They are intrinsically dynamic due to their exposure to alternate flooding and drying, winds, waves, tides, and storms. Organisms that inhabit coastal ecosystems are uniquely adapted to environmental conditions that occur along the energy, salinity, and moisture gradients that extend from the subtidal region of the coast to the inland boundaries of its wetlands, estuaries, and floodplains.

Impacts on coastal systems are among the most costly and most certain consequences of climate change. As temperature increases and rainfall patterns change, soil moisture and runoff to the coast are likely to be altered. As sea level rises, coastal shorelines will retreat and low-lying areas will tend to be inundated more frequently, if not permanently, by the advancing sea. The salinity of estuaries, coastal wetlands, and tidal rivers will increase, thereby restructuring coastal ecosystems and displacing them further inland. If tropical cyclones increase in intensity, as projected by many studies, shoreline retreat and wetland loss along the low-lying coastal margins will accelerate further. As temperature increases along polar coastlines, a combination of permafrost thawing, sea level rise, and sea ice retreat will cause coastal erosion and land loss. This chapter examines the known effects of these and other key climate change variables on coastal ecosystems and their biodiversity.

The vulnerability of coasts to atmospheric warming and the changing climate is enhanced by environmental stresses associated with human development of the coastline and adjacent watersheds. Coastal areas comprise some of the most heavily developed landscapes in the Americas. The autonomous adaptive capacity and sustainability of coastal ecosystems in North, Central, and South America will be challenged due to a combination of stressors at the ocean/land interface. Coastal river deltas, such as the Mississippi and Paraná, are particularly vulnerable due to their high sensitivity to relatively small changes in mean sea level and riverine sediment delivery. Many coastal states, provinces, and nations are planning coastal adaptation strategies but much of the current emphasis is on protection of the built environment. Some climate change adaptation options, such as flood protection levees and sea walls, can exacerbate the effects of climate change and sea level rise on coastal flora and fauna. By incorporating biodiversity considerations into adaptation planning, native fish, wildlife, and plant populations are more likely to be preserved as climate change intensifies in the 21st century.

Keywords: coastal, biodiversity, climate change, sea level rise, the Americas, deltas, barrier islands, marshes, seagrasses, estuaries, mangroves, adaptation

1. Introduction and Definitions

The United Nations Convention on Biological Diversity (UNCBD) defines biodiversity as the variability among living organisms from all sources, including the ecological complexes of which they are a part (UNCBD, 2000). The World Meteorological Organization and the Intergovernmental Panel on Climate change (IPCC) define "climate" as the average state of the weather over time with the period generally being 30 years (although for some marine climate parameters such as storminess, longer averages are required (Zhang *et al.,* 2000). Climate change is defined by the IPCC as "any change in *climate* over time, whether due to natural variability or as a result of human activity" (IPCC, 2007a, page 871). The IPCC emphasizes three levels of biodiversity in its reports – genetic, species, and ecosystem (IPCC 2001, 2007a). Under these broad definitions, biodiversity can be influenced by any change in climate that directly or indirectly affects organisms at any level of their organization.

Climate is a primary basis for many ecosystem, biome, and habitat classification schemes. The U.S. Forest Service (2008) defines "ecoregions", which comprise their basic management units, as "large areas of similar climate where ecosystems recur in predictable patterns." The four primary domains of the U.S. Forest Service's ecoregion classification are differentiated by precipitation and temperature: the polar domain, the humid temperate domain, the dry domain, and the humid tropical domain (Bailey, 1976, 1983). The ecoregion classification used by the government of British Columbia is based on a combination of climate, vegetation, and physiography (Demarchi, 1993, 1994). The widely used Köppen (1923) and Trewartha (1943) climatic zone classifications are based on the concept that native vegetation is the best expression of regional climate. Each of these commonly used classifications reflects an understanding and acknowledgement of the strong role that climate plays in biogeography.

Relationships between climate and the distribution of plants and animals in the Americas have long been recognized, described, and classified (Herbertson, 1905; Shelford, 1926; Holdridge, 1947, 1967). The role of climate change, however, is generally absent from the scientific literature that established the present-day biome and ecosystem classification maps of North, Central, and South America. Human understanding of decadal- and century-scale trends in climate and the effects of these changes on ecosystems have advanced rapidly over the past two decades, along with an exponential increase in literature published on the topic (Stanhill, 2001). Based on an analysis of roughly 30,000 datasets, the IPCC (2007a) concluded that 85% of the physical and biological changes in natural systems observed globally since 1970 were consistent with the responses that would be expected to accompany atmospheric warming.

However, our understanding of the relationship between biodiversity and climate change has not advanced as rapidly, and conservation land acquisition, coastal resource management programs, and endangered species protection programs are still based on the assumption of a static climate, even though there is evidence indicating that many species and entire ecosystems are moving, restructuring, or disappearing on every continent as a result of climate change (Parmesan and Yohe, 2003).

Ecosystems located along continental and island margins are intrinsically dynamic due to their exposure to alternate flooding and drying, winds, waves and currents, and changes in the elevation of the land or the ocean surface. Located along the narrow transition zone at the land/ocean boundary, coastal ecosystems and their biodiversity are affected by any changes in the processes that created and sustain them. Organisms that inhabit coastal ecosystems are uniquely adapted to the often extreme environmental conditions that occur along the energy, salinity, and moisture gradients that extend from the subtidal region of the coast to the inland boundaries of its wetlands, estuaries, and floodplains. In some coastal systems, such as rocky intertidal zones, the diversity of life forms is considered very high (and very sensitive to perturbation) (Raffaelli *et al.,* 1991) while in others, such as salt marshes and mangrove forests, single plant species can dominate in what can appear to be a monotonic assemblage of halophytes (Saenger, 2002). In contrast to terrestrial and ocean systems which have physical gradients that can stretch over 10s or 1000s of km, coastal ecosystem gradients can be as small as meters, particularly along steep rocky shores.

The structure of plant and animal communities in coastal regions is governed by the tolerances of species to environmental conditions such as light availability, temperature, moisture, disturbance (for example storms, fire), tides, water depth, salinity, and nutrient availability. All of these limiting factors can be affected by climate change — even light availability, which is influenced by the abundance of algae in surface waters and the density of the canopy in a coastal forest.

2. Key Climate Change Variables in the Coastal Zone

Human-induced climate change is likely to intensify during the coming decades and beyond due to increasing greenhouse gas composition and land use change (IPCC, 2007b). In its 2007 fourth assessment report, the IPCC identified six physical factors associated with climate change that can alter the structure and function of coastal ecosystems (Nicholls *et al.,* 2007) (Figure 1). Some of these variables are primary drivers that directly affect coastal biota, while others lead to higher-order effects that can be equally significant in terms of their potential for altering plant and animal community structure. This section describes the pathways by which these major climate change factors can impact biodiversity along the coasts of the Americas with examples for each.

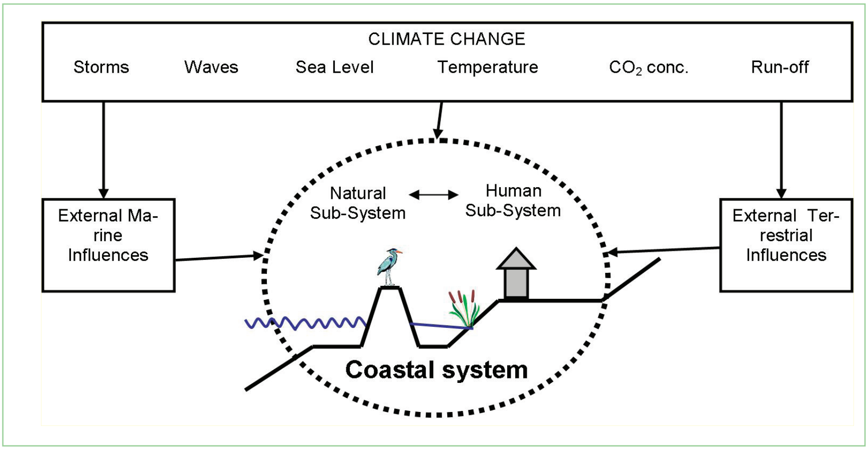

FIGURE 1
Major climate change factors in coastal regions (source: Nicholls *et al.*, 2007, reprinted with permission from IPCC).

3.1 Atmospheric and ocean water CO_2 enrichment

In addition to altering the climate, greenhouse gas emissions can independently impact coastal flora and fauna. The concentration of CO_2 in the Earth's atmosphere has increased by approximately 30% since the Industrial Era (from about 270 ppm in the mid-1800s to 379 ppm in 2005) (IPCC, 2007b). The IPCC attributes this increase to human emissions of greenhouse gases into the atmosphere and changes in land use, such as deforestation.

The increased availability of CO_2 directly affects the growth and metabolism of plants and many microorganisms. An increase in atmospheric CO_2 has a fertilizing effect on most herbaceous plants by enhancing photosynthesis and water-use efficiency (Acock *et al.*, 1985; Nijs *et al.*, 1989; Allen *et al.*, 1988, Rabbinge *et al.*, 1993; Anderson *et al.*, 2001). Growth in woody plants is also stimulated by increases in CO_2, but there is a wide range of responses among species (Eamus and Jarvis, 1989; NCASI, 1995). As CO_2 levels in the atmosphere increase, transpiration rates in plants tend to decrease because stomates are not open as long. This can have a positive effect on plant productivity and survival because it decreases plant water demand.

Differential responses among plants to the effects of rising atmospheric CO_2 can alter competition among plant species. (Bond and Midgley, 2000). Plants that use the C3 photosynthetic pathway (so called because carbon is initially fixed as a 3-carbon compound) generally respond more favorably than do C4 plants (Ainsworth and Long, 2005). Most trees and shrubs are C3 plants while most herbaceous plants use the C4 pathway. Several field and greenhouse studies confirm that growth rates of herbaceous wetland plants that use the C3 pathway are more likely to be enhanced than those with C4 systems (Drake *et al.,* 1996; Marsh, 1999). Warming, on the other hand, appears to favor C4 herbaceous types (Epstein *et al.,* 2002). Growth rates and biomass accumulation for each plant species can respond somewhat differently to the combination of CO_2 fertilization and warming (Burkett and Kusler, 2000), which could theoretically alter species interactions along coastal gradients, from seagrass beds to coastal grasslands and forests. Very few studies have been conducted that will help predict the net impacts of CO_2 enrichment on plant diversity in coastal environments. Some experiments, in short grass prairie for example, show no difference among photosynthetic responses under a combination of elevated CO_2 and warming (Morgan *et al.,* 2001).

As shallow coastal waters absorb more CO_2 from the atmosphere, an increase can be expected in dissolved CO_2 and dissolved inorganic carbon (DIC), both of which can affect estuarine biota. Shirayama and Thorton (2005) demonstrated that a 200 ppm increase in carbon dioxide adversely affects the growth of gastropods and sea urchins. Photosynthesis rates of submerged aquatic vegetation tend to increase when exposed to elevated CO_2 and DIC, but responses can diminish rapidly if temperature (or other thresholds) are reached (Short and Neckles, 1999; Harley *et al.,* 2006). Algal growth in estuaries may also respond positively to elevated DIC and CO_2 (Beer and Koch, 1996). An increase in epiphytic or suspended algae can decrease light available to submerged aquatic vegetation in coastal waters and large-scale algal blooms reduce oxygen available to fish and shellfish (Nicholls *et al.,* 2007). Hypoxia is often cited as the cause of declining fisheries productivity in mid-latitude and subtropical coastal waters and toxic algal blooms (red tides) can result in direct mortality to fish and benthos (Boesch *et al.,* 2001; Day *et al.,* 2003; Niemi *et al.,* 2004).

Another important consequence of increasing the uptake of CO_2 by estuaries is the lowering of the pH of the water because of the well documented reaction:

$CO_2 + H_20 + CO_3^{2-} = 2HCO_{3-}$ (Andersson *et al.,* 2003). This reaction leads to a lowering of the carbonate saturation state of the water because of the titration of the carbonate ion (CO_3^{2-}) by the invading CO_2. Coupled atmospheric-ocean models that simulate the effects of atmospheric CO_2 level on ocean pH suggest that the carbonate saturation state of both the global ocean and nearshore coastal waters will decrease significantly through this century (Mackenzie *et al.,* 2001; Caldiera and Wickett, 2005). Reductions in pH and carbonate saturation state have at least three implications for estuarine biota: a reduction in the ability of carbonate flora and fauna (such as shellfish, hard corals and diatoms) to calcify, changes in the dissolution of nutrients and carbonate minerals in sediments, and a reduction in the capacity of the ocean to function as a "biological pump" that removes CO_2 from the atmosphere (McLean *et al.,* 2001; Andersson *et al.,* 2003; The Royal Society, 2005; Turley *et al.,* 2006). Some studies suggest that there might be a 10-30% reduction in the skeletal growth of corals in response to a doubling of CO_2 (Kleypas *et al.,* 2001; Guinotte *et al.,* 2003) as well as a weakening and dissolution of coral skeletons (Marubini *et al.,* 2002; Hallock, 2005). Changes in pH need to be considered in relation to increases in sea surface temperature (SST), which result in increased calcification rate in massive *Porites* (Lough and Barnes, 2000; McNeil *et al.,* 2004). However, it is clear that coral response to SST is nonlinear, and SST increase beyond a key threshold is incontrovertibly linked to mass bleaching, and in many cases mortality (Kleypas *et al.,* 2005).

Several experiments involving exposure of plankton to elevated CO_2 concentrations have shown small effects (10% or less) on photosynthesis rates (Beardall and Raven, 2004; Schippers *et al.,* 2004; Giordano *et al.,* 2005). These small increases in productivity, however may cumulatively affect estuarine and ocean productivity. In its assessment of the effects of increased CO_2 and its effects on ocean pH, the Royal Society (2005) concludes that it is impossible to differentiate unequivocally between the effects of increased CO_2 and those of decreased pH in experiments on marine organisms, since there is significant co-variance of these environmental factors.

Even if they respond favorably to elevated CO_2 levels, organisms have a threshold at which further CO_2 enrichment will not continue to increase photosynthesis levels or decrease water use because of other limiting factors. The availability of soil nutrients, for example, in emergent coastal marshes and forests can limit the potential improvement in water-use efficiency due to suppressed transpiration. Temperature, disease, pests, pollutants, and light availability can also constrain the potential enhancement of plant growth by elevated CO_2. These limiting factors and their interactions with other natural and human-induced environmental change have not typically been accounted for in models that predict the impacts of climate change on coastal biomes. There remains considerable uncertainty about how mangroves will respond to elevated atmospheric CO_2. Mangroves may respond to increased levels of atmospheric CO_2 by reduction in stomatal conductance to minimize water loss without a concomitant increase in photosynthetic rates, but this may also lead to an increase in growth rate through improved plant water balance (Saenger, 2002). If stomatal conductance remains unchanged at higher CO_2 levels then mangrove photosynthesis rates and productivity are likely to increase (Cambers *et al.,* 2007).

Hence, a better understanding of the effects of rising CO_2 concentrations on coastal ecosystems is essential in order to predict future changes in mangroves and other coastal vegetation types.

3.2 Increased Air and Water Temperature

Temperature affects the growth, survival, reproduction, and distribution of plants and animals. Through its effects on basic metabolic processes such as respiration, photosynthesis, budburst, egg laying, and food availability, an increase in temperature could, in theory, alter biological diversity at every level in the food web.

As air and water temperature increase, species ranges will likely expand toward environments that are presently cooler (IPCC, 2007a; Parmesan and Yohe, 2003). If dispersal capabilities are limited or suitable habitat is not available, local extirpations and extinctions are likely to occur (Thomas *et al.,* 2004). For fishes, climate change may strongly influence distribution and abundance through changes in growth, survival, reproduction, or responses to changes at other trophic levels (Brander *et al.,* 2003; Reid, 2003). Further temperature rises are likely to have profound impacts on commercial fisheries through continued shifts in distribution and alteration in community interactions (Perry *et al.,* 2005). There is a lack of information on how tropical fish will respond to temperature increases (Cambers *et al.,* 2007).

Seasonally elevated water temperatures along the Caribbean, Gulf of Mexico, and Mid- and South Atlantic shorelines are often associated with extensive algal blooms that impact living resources, local economies, and public health (Day *et al.,* In Press; Cambers *et al.,* 2007). Impacts of harmful algal blooms include human illness and death from ingesting contaminated shellfishes or fish, mass mortalities of wild and farmed fish, loss of seagrasses by reduced light availability, and alterations of marine food chains through adverse effects on eggs, young, and adult marine invertebrates (for example corals, sponges), sea turtles, seabirds, and mammals. Recently, algal blooms have occurred in areas where they had not occurred in recent decades and new species have appeared (GEOHAB, 2001, 2005).

Increased temperatures in terrestrial habitats will reduce streamflow and alter water quality into deltas, estuaries and in coastal regions, causing addition change and/or degradation of coastal ecosystems.

A particularly insidious result of the increase in sea surface temperatures (SST) is the impact of coral bleaching on coral reefs. Bleaching occurs when SST rises to ~1° C above the monthly maximum, leading to expulsion of the symbiotic algae (zooxanthellae) and paling of the coral surface (Hoegh-Guldberg, 1999; Douglas, 2003). Corals may recover, but if SST remains at these high levels for prolonged periods combined with high solar radiation, or exceeds 2 °C above the threshold, coral mortality is likely (Lesser, 2004). In the Caribbean, there has been a widespread decline in coral cover as a result of the synergistic effects of multiple stresses such as disease, hurricane impact and dust input. The extent to which the thermal threshold at which corals bleach could increase through adaptation or acclimatision with ongoing global warming remains uncertain. According to one recent study (De'ath *et al.,* 2009) calcification of long-lived massive corals on the Great Barrier Reef has declined by 14.2% since 1990, largely through a decrease in extension rate. SST warming threatens repeated bleaching events and further reduction in both coral cover and diversity on reefs over the next few decades, and there is an urgent need for focused management to improve the ecological resilience of coral reefs (Hoegh-Guldberg, 2004).

While increasing SST is clearly affecting coral reef systems in the Caribbean region (Nicholls *et al.,* 2007), there is evidence that some coral species off of the coasts of the Americas are responding to increased SST by expanding their latitudinal ranges. Examples include the recent establishment of staghorn coral (*Acropora cervicornis*) off Fort Lauderdale in Broward County, Florida (Vargas-Angel *et al.,* 2003) and the expansion of range of staghorn and elkhorn coral (*Acropora palmata*) into the northern Gulf of Mexico, coincident with increasing sea temperatures (Precht and Aronson, 2004). In the face of continued global warming, the northernmost limit of this range expansion will ultimately be determined by a combination of temperature and other physical constraints, as well as interactions among species (Precht and Aronson, 2004).

3.3 Sea Level Rise

The IPCC global-mean sea-level rise scenarios are based on thermal expansion and ice melt: the best estimate shows an acceleration of up to 2.4 times compared to 20th Century values and a rise in the range 18 to 59 cm by the end of the 21st century (Meehl *et al.,* 2007). Superficially, these projections are smaller than Church *et al.* (2001), but this largely reflects differences in methodology and the IPCC (2007b) synthesis report emphasizes that the upper 95% range of the model predictions is not an absolute upper bound on global-mean sea-level rise during the 21st Century, with the contributions from the major ice sheets (Antarctica and Greenland) being a major uncertainty. Several recent papers support the view that a 1+ meter rise in sea level over the next century cannot be entirely discounted at present (Rahmstorf, 2007; Rahmstorf *et al.,* 2007; Rohling *et al.,* 2007). Further even with stringent climate mitigation (reduced greenhouse gas emissions) sea levels will continue to rise for centuries due to the thermal inertia of the oceans among other factors.

Importantly, local (or relative) changes in sea level depart from the global-mean trend due to regional variations in oceanic level change and geological uplift/subsidence: it is relative sea-level change that drives impacts and are of concern to coastal managers (Bird, 1993; Harvey, 2006). Regional sea-level change will depart significantly from global-mean trends: for the A1B scenario the spatial standard deviation by the 2080s is 0.08 m, with a larger rise than average in the Arctic (Meehl *et al.,* 2007). Hulme *et al.* (2002) suggested that impact analysis explore additional sea-level rise scenarios of +50% the amount of global-mean rise, plus uplift/subsidence, to assess the full range of possible change. Furthermore, coasts subsiding due to natural or human-induced causes will experience larger relative rises in sea level which must also be considered (Bird, 1993; Nicholls *et al.,* 2007; Syvitski, 2008). Increases of extreme sea levels due to the combination of rising sea levels and changes in storm characteristics are also of significant concern (Zhang *et al.,* 2000; Nicholls *et al.,* 2007; von Storch and Woth, 2008).

A report that summarizes the opinion of a group of 23 experts concerning the implications of climate change in the Intra-Americas Sea (Gulf of Mexico - Caribbean Sea - Bahamas - Bermuda - Guianas) indicates a wide range in response in coastal systems to a scenario of a 20 cm rise in mean sea level and 1.5 °C increase in mean temperature. For some ecosystems in the region, the effect of the increase in temperature will be much more important than an increase in mean sea level rise, and vice versa for others; for some neither is important; for others both are important. Of the 14 Central American ecosystems considered, the most heavily impacted are expected to be deltas and beaches, both because of sea level rise; neither is particularly vulnerable to a modest temperature rise (Maul, 1993).

Several studies have focused on the impacts of sea level rise on tropical mangrove forests (Field, 1994; Bacon, 1994; Lugo, 2002; Diop, 2003). Negative effects produced by the permanent or prolonged inundation on reproduction and viability of individual mangroves trees have been described (Yáñez-Arancibia, 1998). An assessment of the impacts of a 0.3 and 1 meter of sea level rise on Guacalillo mangroves in Costa Rica indicated that 65% of these mangroves would be lost due to flooding and erosion processes with a 1 meter increase in mean sea level (Piedra and Piedra, 2007). In South America, other ecosystems at risk due sea level rise are the wetlands in the San Borombom Bahia, which is a Ramsar site. This area also has the protected area "Campus del Tuyu", which is almost the last relict of Pampa ecoregions ecosystems. This area will be threatened trough sea level rise and associated changes in salinity and flooding patterns (Fundación Torcuato Di Tella, 2005).

Along the Patagonian coast in Argentina there are important sites for biodiversity that have large intertidal habitats and tidal sea level variations that reach 12 meters, particularly the Peninsula de Valdez wetlands y the Atlantic coast of Tierra del Fuego (Boltovskoy *et al.,* 2008). Sea turtles are among the vulnerable species along this coastal region. All seven species of marine turtle are listed as "threatened" or "endangered" under the U.S. Endangered Species Act. Accelerated sea level rise will decrease sea turtle nesting beaches and the availability of some of their food sources (Fish *et al.,* 2005).

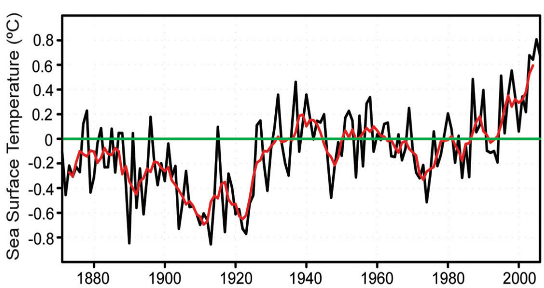

FIGURE 2

Sea surface temperature trend in the main hurricane development region of the North Atlantic during the past century. Red line shows the corresponding 5-yr running mean. Anomalies are departures from the 1971-2000 period monthly means. (Source: Bell *et al.*, 2007).

3.4 Changes in Storm intensity

The kinetic energy of tropical storms and hurricanes is fueled from heat exchange over warm tropical waters. Increased tropical storm activity is likely to accompany global warming as a function of higher SSTs, which have been observed globally (Webster *et al.,* 2005; IPCC 2007b). Sea surface temperature has increased significantly in the main hurricane development region of the North Atlantic during the past century (Bell *et al.,* 2007) (Figure 2) as well as in the Gulf of Mexico (Smith and Reynolds, 2004). Recent empirical evidence suggests a trend towards more intense hurricanes formed in the North Atlantic Basin, and this trend is likely to intensify during the next century (IPCC, 2007b).

In the Gulf of Mexico region, there is presently no compelling evidence to suggest that the number or paths of tropical storms have changed or are likely to change in the future (CCSP, 2008). Changes in other storm characteristics are less certain and the number of tropical and extra-tropical storms might even reduce (Meehl *et al.,* 2007). One recent analysis of hurricanes in the North Atlantic region suggests that an increase in intensity associated with global warming will be expressed in terms of increased windspeed and rainfall (Knutson *et al.,* 2008).

If tropical cyclones increase in intensity, coastal erosion and land loss are likely to increase along low-lying, sedimentary shorelines of the east coasts of Central and North America, with the exception of Panama. When hurricanes enter the Gulf of Mexico they veer northward away from the equator and Panama coast. Tropical cyclones in the southern hemisphere are also uncommon. Tropical cyclone Catarina in 2004 was the first recorded and subsequently struck southern with winds equivalent to Category 2 on the The coast of Argentina is vulnerable to high winds and coastal flooding during winter "sudestada", which are weather phenomena that appear to be associated with cyclogenesis (Escobar *et al.,* 2004), but the effects of climate change on these events, if any, have not been documented.

The greatest damages to coastal systems during hurricanes and other tropical storms are due mainly to storm surge, waves, and wind. If a strong hurricane makes landfall along the shallow Gulf of Mexico coastal margin when the tide is high and barometric pressure is low, the effects can be particularly severe. An increase in storm surge associated with hurricanes that make landfall in the Gulf coast region could affect the sustainability of some natural coastal systems and the species that depend upon them. Loss of beaches would affect bird rookeries and sea turtles nesting sites. Aquatic and terrestrial species limited to coastal areas (Alabama Beach Mouse, Okaloosa Darter) may be threatened throughout their range. Many small islands along the northern Gulf of Mexico coastline were lost to open water during the 2005 hurricane season. During Hurricane Katrina in 2005, approximately 388 km^2 of coastal marshes and barrier islands in coastal Louisiana were converted to open water (Barras, 2006).

3.5 Changes in Wave regime

Few studies have examined potential changes in prevailing wave heights in coastal regions as a consequence of climate change. In the Northern hemisphere, a multidecadal trend of increased wave height has been observed (Figure 3), but the cause is poorly understood (Guley and Hasse, 1999; McLean *et al.*, 2001; IPCC, 2007b), and if the time period is extended there is no evidence of any trends in the drivers of waves (winds and storminess) (WASA Group, 1998). The increasing North Atlantic wave height in recent decades has been attributed to the positive phase of the North Atlantic Oscillation, which appears to have intensified commensurate with the slow warming of the tropical ocean (Wolf, 2003). Increasing average summer wave heights along the Mid-Atlantic coastline of North America appear to be associated with a progressive increase in hurricane activity between 1975 and 2005 (Komar and Allan, 2007)

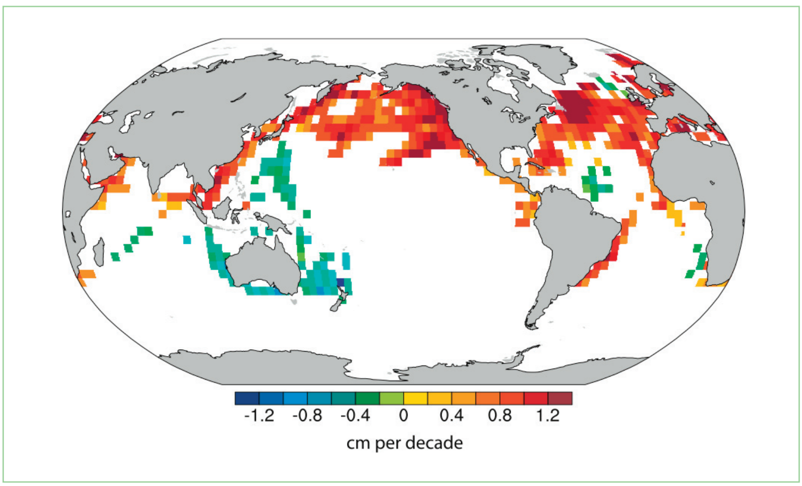

FIGURE 3
Linear trends in significant wave height (cm per decade) for regions along the major ship routes of the global ocean for 1950 to 2002. Adapted by IPCC (2007) from Gulev and Grigorieva (2004).

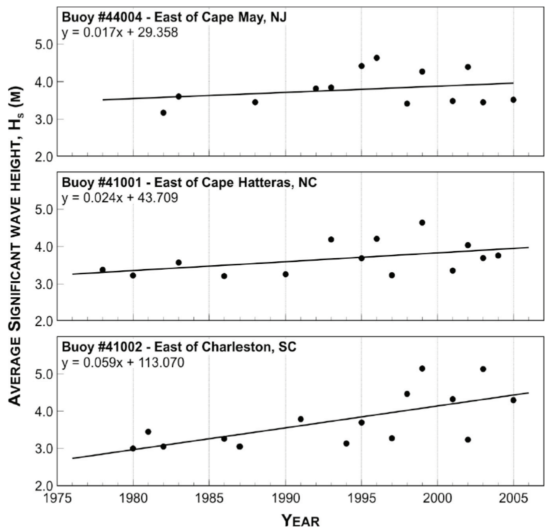

FIGURE 4
Trends in wave height at three locations along the Mid-Atlantic coast of North America (Komar and Allen, J. Coast. Res. 2008).

(Figure 4). Wave heights greater than 3 m increased by 0.7 m to 1.8 m during the three decades of study, with hourly averaged wave heights during major hurricanes increasing significantly from about 7 m to more than 10 m since 1995 (Komar and Allan, 2008). Peak and average wave heights have increased significantly during the winter months along the Pacific coast in the vicinity of Washington (Allan and Komar, 2006; CCSP, 2008).

Scenarios of future changes in seasonal wave heights constructed by using climate model projections for the northeastern Atlantic predicted increases in both winter and fall seasonal means in the 21st century under three forcing scenarios (Wang *et al.*, 2004). The IPCC (2007b) concludes that an increase in peak winds associated with hurricanes will accompany an increase in tropical storm intensity. If tropical storm windspeed increases as anticipated by the IPCC this will tend to have a positive effect on mean wave height during the coming decades. Wave heights in coastal bays and lagoons may also tend to the secondary effect of shoreline retreat and submergence increasing fetch – as already evidenced in subsiding coastal Louisiana (Stone *et al.*, 2003).

TABLE 1

Examples of adaptation options in coastal zones and potential impacts on biodiversity (modified from CBD 2005). [P] Protection, [A] Accommodation and [R] Retreat

Adaptation activity	Potential risk to biodiversity		Possible action for adaptive management
Sea walls, dikes and tidal barriers [P]	Adverse	High-Very High if concrete/ rock structures Low-medium if using mud walls and vegetation	Include biodiversity considerations in Environmental Impact Assessment (EIA)
Bridges to cross potentially inundated areas due to climate change [A]	Adverse	Medium-High depending on the location	Include terrestrial and aquatic biodiversity considerations in EIA
Elevate Buildings [A]	Adverse to neutral	Low if already in urban areas	Monitor for likely effects on biodiversity and include adaptive management
Regulating development in coastal areas	Adverse or positive	High-Very High if urbanization of high biodiversity areas; Low otherwise	Strategic environmental assessment should consider the impact on biodiversity and zone accordingly; allow for appropriate conservation areas for biodiversity
Migration of people from coastal areas and/or marginal lands (for example in semi-arid areas) [R]	Adverse or positive	Low if moving to urban areas although could place additional pressure on water and energy resources; High if moving to slightly less marginal areas	Educate the urban planners to minimise the exploitation of natural resources; effect of other migration may be hard to manage
Introduction of salt tolerant varieties of native plants and animals [A]	Positive to Neutral	Low	Monitor for likely effects on biodiversity and include adaptive management
Establishment of aquaculture or mariculture to compensate for climate-induced losses in food production [A]	Neutral to adverse	High if alien or GMOs fish or other aquatic including marine organisms escape eutrophication or harmful chemicals are released	Monitor for likely effects on biodiversity and include adaptive management
Beach nourishment and beneficial use of dredged material [P or A]	Positive or Adverse	Low if restoring natural sedimentation patterns; High if sediments are added in a manner that alters geomorphology to the point that native species are eliminated	Assess natural processes that maintain coastline; monitor coastal system and species response
Rehabilitation of ecosystems [A]	Positive	Generally Low unless invasive exotic species are used or damage to neighbouring areas	Monitor for likely effects on biodiversity and include adaptive management
Establishment of protected areas [P]	Positive or neutral	Medium-High	Monitor for likely effects on biodiversity and include adaptive management
Relocate highways and other infrastructure further inland [R]	Neutral or Negative	Potentially very high if natural coastal migration is impeded or runoff to the coast is obstructed	Elevate roads or design so that natural coastal processes can be maintained

3.6 Changes in Runoff to the Coast

Changes in precipitation and run-off patterns appear likely as climate change intensifies, but the uncertainties are large. Milly *et al.* (2005) showed increased discharges to coastal waters in the Arctic, in northern Argentina and southern Brazil, while reduced discharges to coastal waters are suggested in the western Gulf of Mexico, Venezuela and Guyana coastal zones. The additional effects of catchment management and water use also need to be considered as this may be a larger effect than climate change (Table 1).

Changes in freshwater runoff patterns can affect coastal and estuarine biota through several pathways. If freshwater flows to the coast decrease, the salinity of coastal wetlands and estuaries is likely to increase. The distribution of coastal biota is closely linked with salinity of water and soils. Few studies have documented the interactions between runoff, salinity, and species distribution.

Earlier and faster snowmelt due to increasing temperatures portend changes in freshwater and nutrient delivery to the coast from meltwater-dominated watersheds. Changes in the timing of freshwater runoff to estuaries could affect the productivity of many estuarine and marine fishery species (Nicholls *et al.*, 2007). Changes in runoff can also affect sediment delivery, which has important implications for the sustainability of deltas and other sedimentary landforms.

Freshwater inflows into estuaries influence water residence time, vertical stratification, salinity, control of phytoplankton growth rates, and the flushing of contaminants in estuaries. In estuaries with very short water residence times, phytoplankton are generally flushed from the system as fast as they can grow, reducing the estuary's susceptibility to eutrophication and harmful algal blooms.

4. Human Development Impacts on the Resilience of Coastal Systems

Coastal areas comprise some of the most heavily developed landscapes in the Americas. The autonomous adaptive capacity and sustainability of coastal ecosystems in North, Central, and South America could be challenged due to a combination of stressors at the ocean/land interface. Coastal river deltas, such as the Mississippi and Paraná, are particularly vulnerable due to their high sensitivity to relatively small changes in mean sea level and riverine sediment delivery. Coastal habitat losses portend lower resilience of wetland dependent fish and wildlife to the effects of climate change. In North America, approximately half of the coastal wetlands in the United States have been converted to other uses. In some coastal regions of North America, such as Louisiana, Florida and Alaska, the effects of climate change have already been linked with habitat loss and changes in plant and animal community distribution (IPCC, 2007b).

A study carried out by The Nature Conservancy, in collaboration with the governments and non-governmental institutions in Brazil, Chile, Colombia, Ecuador, Peru and Venezuela, identifies the top ten threats to coastal and marine environments in South America. Almost invariably, the top three threats to coastal and marine biodiversity are fishing, urban development and pollution (Chatwin, 2007). In some coastal areas, the expansion of the agricultural frontier is a growing threat, as for example the Paraná river delta wetlands, in Argentina, where the slashing and burning is increasing for cattle ranching (Donadille *et al.,* 2006) and the Atlantic Forest in Brazil when the coastal areas are used for sugar cane plantations that increase erosion of the coastal lands which results in an unnaturally high amount sediments being carried off to sea. The mangrove areas along the South American coast are highly prone to suffer impacts from shrimp farm development, such as deforestation and changes in water quality (MMA, 2002).

Coastal zones are becoming more populated and urbanized, but basic infrastructure is not keeping up. Considering the sources of pollution, the most common form of sewage management, when it exists, in South America is to pipe it directly into the marine environment (Chatwin, 2007). In Brazil, 80% percent of the urban population is not serviced by public sewage systems and 43% of urban homes do not even have septic tanks (MMA, 2002).

Because of the dependence on maritime transportation, some productive sectors of chemical, petrochemical and petroleum industries are located near or even directly on the shore. The environmental risks posed by these sectors, added to the risks already posed by port activities, shipbuilders, and processing plants for cellulose and a number of minerals for the export market, support the conclusion that there is a high potential of environmental risk and impact in Brazil's coastal zone (MMA, 2002).

A cartographic atlas of Environmentally Sensitive Areas of Argentine coast and sea (Boltovskoy *et al.,* 2008) identifies the coastal zones that are specially vulnerable and important for conservation. The fishing industry has been identified as a particularly important threat to biodiversity along Patagonian coast. Seabirds globally at risk are threatened as by-catch by long line fishing vessels (Favero *et al.,* 2003).

The expansion of the tourist industry is the main cause of the transformations in many coastal natural areas (Magrin *et al.,* 2007). Even the areas of low population density in the coastal zone -historically, the homes of traditional communities- are experiencing growing threats from unfettered development driven by tourism. Resort development and a growing demand for second homes are further threatening coastal habitat integrity. Along with this development, the lack of adequate licensing and enforcement results in inadequate land use, changes to the landscape, and harmful impacts to fragile ecosystems (MMA, 2002). The coastal habitat loss has been remarkable in several places in Central America, for example Cocos in Costa Rica, Tortuguero-Miskitos islands in Nicaragua and Gulf of Mexico (Magrin *et al.*, 2007).

While the Atlantic Ocean and Caribbean Sea are South America's most threatened, the Pacific Ocean clearly houses the least protected coastal and marine environment in South America. All of the ecoregions have less than 0.5% of their area within existing protected areas. Currently, only 3.4% of these coasts are represented within some type of protected area (Chatwin, 2007).

5. Interactive Effects Among Climate Drivers and Human Development Activities

Environmental conditions in coastal ecosystems are unique in that they are a derivative of the combined marine and terrestrial conditions prevalent at any one site. Often dynamic coastal systems do not respond in a deterministic way to forcing factors, but show complex non-linear or chaotic behavior partly dependent on antecedent conditions (Lee *et al.,* 2001). Plants and animals in coastal regions also respond to second- and higher-order effects of increasing global temperature and changes in precipitation patterns. In the coastal zone, for example, increased salinity will lead to a shift in species that are more salt tolerant. The increased salinity is a third-order effect of atmospheric warming that causes eustacy, which causes increased tidal exchange, increased intensity and frequency of storm surge, and increased mean water levels in coastal systems. Species that have greater tolerance of increased salinity will outcompete those with lower tolerance, leading to changes in the structure and functions of the coastal ecosystem. Changes in community structure can be episodic, and in some cases, ecosystems may be eliminated if thresholds are exceeded (Burkett *et al.,* 2005).

There is no single driver of coastal biodiversity impacts, rather a combination of stressors, including human development activities and their effects on coastal systems. A conceptual model of the physical drivers affecting the biodiversity in

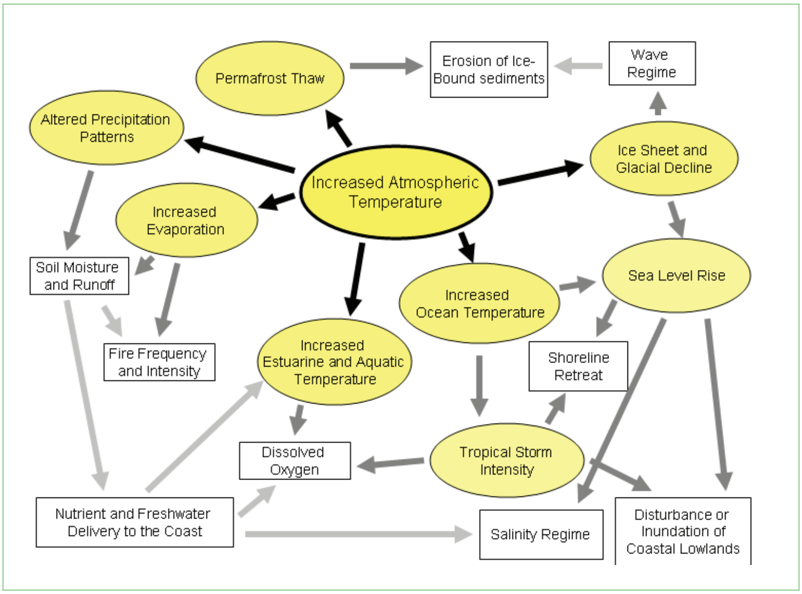

FIGURE 5
Interactions among the key physical factors associated with climate change and its impacts on coastal systems (Modified from SEI, 2007).

the coastal zones of the Americas is presented in Figure 5. Many of these feedbacks and interactions have been described but most are not quantified at scales that permit predictive modeling.

6. Incorporating Biodiversity Considerations in Coastal Adaptation Planning

Coastal adaptation approaches can be classified into three generic groups: 1) Protection, 2) Accommodation and 3) Retreat (Klein *et al.*, 2001; Nicholls *et al.*, 2007). The approaches include structural and non-structural measures. Structural measures refer to any physical (natural or artificial) construction to reduce or avoid possible impacts of hazards, which include engineering measures and construction of hazard-resistant and protective structures and infrastructures. Non-structural measures refer to policies, awareness, knowledge development, public commitment, and methods and operating practices, including participatory mechanisms and the provision of information, which can reduce risk and related impacts.

Protection involves the use of natural or artificial measures to protect landward development, attempt to hold the shoreline in its existing position and reduce hazard impacts. Traditionally, protection against coastal erosion, flooding, storm surge and tsunami inundation has been approached through mitigation or hard structural response. This has involved measures such as the construction of groins, seawalls, offshore breakwaters, and bulkheads. More recently, there has been a move to soft defences and the restoration of natural coastal storm buffers, such as barrier islands and mangrove forsest. Protection and especially, hard structural responses, may lead to significant adverse ecological impacts if migration is deliberately excluded.

Accommodation involves adjusting how people live and the way they develop land in response to coastal hazards. It includes the continued, but altered, use of land, market mechanisms and building and/or site design to reduce vulnerability to coastal hazards. Examples include elevating structures out of floodplains, on pilings or fill, elevated flood and cyclone shelters, changing crops to more flood/salt tolerant varieties, etc. Ecosystem migration is much less restricted than under protection.

Retreat, which in this context would mainly be managed or planned, means preventing future development in coastal hazard zones and progressively giving up threatened or vulnerable land by moving development away from coastal hazard areas as the opportunity arises or as individual assets come under imminent threat. This usually requires a number of measures to limit new or redevelopment and existing buildings and infrastructure may be relocated or abandoned. Ecosystem migration can occur to the maximum extent possible.

These policies have all been used in the Americas. Around major cities such as New York, hard defences have been extensively constructed and this approach has been termed the 'New Jerseyisation' of the coast (Nordstrom, 2000). Hardening of shorelines around estuaries such as the Chesapeake Bay is especially harmful to coastal ecosystems and their potential to migrate. Over the last 3 decades, soft protection beach nourishment has been extensive around the US coast (for example, Miami, FL and Ocean City, MD) and elsewhere in the Americas. Homes are also raised above the 100 year flood elevation using pilings in coastal areas subject to high velocities (breaking waves). Retreat and abandonment of coastal areas is also apparent and has been especially prevalent on islands on the U.S. East Coast, including both barrier islands and islands within the Chesapeake Bay (for example, Gibbons and Nicholls, 2006). These have allowed natural processes to run their course, and in one case (Poplar Island, MD) one of these bay islands has been recreated using beneficial use of dredge spoil.

Impacts on coastal systems are among the most costly and most certain consequences of climate change. For this reason, many coastal and island nations in the Americas are evaluating adaptation options and implementing strategies for reducing undesirable impacts. Many coastal communities are planning adaptation strategies but much of the current emphasis is on protection of the built environment.

Some adaptation options, such as restoring natural coastal hydrology, will tend to positively impact biodiversity. Other adaptation options, such as flood protection levees and sea walls, can exacerbate the effects of climate change and sea level rise on coastal flora and fauna. Retreat from coastal areas, such as the on-going relocation of native communities along the Beaufort and Chuckchi seacoasts of North America, may or may not adversely affect coastal biodiversity depending upon where these communities are relocated. By incorporating biodiversity considerations into adaptation planning, native fish, wildlife, and plant populations are more likely to be preserved as climate change intensifies in the 21st century.

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PAPER

11 TROPOSPHERIC OZONE AND ITS EFFECTS ON THE MAIN AGRICULTURAL CROPS OF CUBA

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ABSTRACT: Tropospheric ozone is the air pollutant that causes the most damage to forests, agricultural crops and vegetation in general. It is a major factor in the appearance of disease and illnesses in agricultural cultivations and forests. In addition to being an air pollutant, tropospheric ozone is also a major greenhouse gas - the third largest, in fact - having a direct influence on climate change. This paper reports on research conducted in agricultural areas of Mexico and Cuba showing the link between the long-range transport of air pollutants and the high levels of atmospheric ozone concentrations and their impact on forests and agricultural crops. The paper demonstrates the importance of an early warning system of projected high levels of atmospheric ozone so that farmers and government agencies can take appropriate response measures to protect vegetation.

Keywords: tropospheric ozone, foliar damage, synoptic meteorology, early warning systems

1. Introduction

Tropospheric ozone, the ozone at ground-level nearest the surface of the Earth, causes serious damage to human health and ecosystems. It impacts particularly on agricultural crops causing irreparable losses to the economies of every country with high levels of the pollutant. While initially attributed to highly industrialized countries, damage from tropospheric ozone now extends to less developed nations as in the case of Cuba and other smaller countries in the Americas.

There is a relationship between the industrial level reached by the different countries of the Americas and the level of responsibility for producing tropospheric ozone (Ramirez, 1998). The long-range transport of air pollutants plays a very important role in the Americas as it does for other geographical areas such as Europe. The European Union, through the United Nations' Economic Commission for Europe's (ECE) Convention on Long-Range Transboundary Air Pollution (LRTAP), recognizes the importance for reducing tropospheric ozone to protect human health and vegetation (Ashmore, 1987).

The majority of tropospheric ozone formation occurs when nitrogen oxides (NO_x), carbon monoxide (CO) and volatile organic compounds (VOCs) react in the atmosphere in the presence of sunlight. The main anthropogenic sources of these ozone precursors (NO_x and VOCs) come from motor vehicle exhaust, industrial emissions and chemical solvents. Although these precursors often originate in urban areas, winds can carry NO_x hundreds of kilometers, causing ozone formation to occur in less populated regions as well.

The United Nations' Framework Convention on Climate Change (UNFCCC) says that global agriculture will face many challenges over the coming decades (UNFCCC, 2008). Degrading soils and water resources will place enormous strains on achieving food security for growing populations, and these conditions may be worsened by climate change. Less developed nations will be most impacted because their economies are least able to adapt to climate change, and they depend fundamentally on agriculture.

The study of synoptic scale meteorology helps to interpret, with more precision, the origin of ozone-polluting air masses, usually from the big urbanized areas to the agricultural regions. This constitutes a fundamental tool for the diagnosis and forecast of tropospheric ozone levels to facilitate appropriate response measures protecting agricultural crops and their yields.

This paper presents work from two projects – "Paper on global changes in tropospheric ozone and its impact on main agricultural crops", and "Variations in the concentration of ozone in agricultural areas of the Metropolitan Area of the Valley of Mexico". Through both projects, it was possible to measure levels of ozone in different agricultural areas and link these with different meteorological phenomena at a synoptic scale.

2. Behaviour of tropospheric ozone in Cuba

The measurement of the tropospheric ozone that began in Cuba in 1974 provides observational evidence of two fundamental time periods - the first of higher ozone concentrations at mean values of 60 ppb from October to March, and the second from April to September of lower ozone values at 15 ppb. An example of the typical behaviour of the concentrations in Cuba can be found in Figure 1.

The period of maximum ozone concentrations is also characterized by the arrival of continental air masses transporting anthropogenic primary pollutants that are turned into ozone in the presence of solar radiation. This period presents ozone values considerably higher than the value of 40 ppb established in Cuba for the

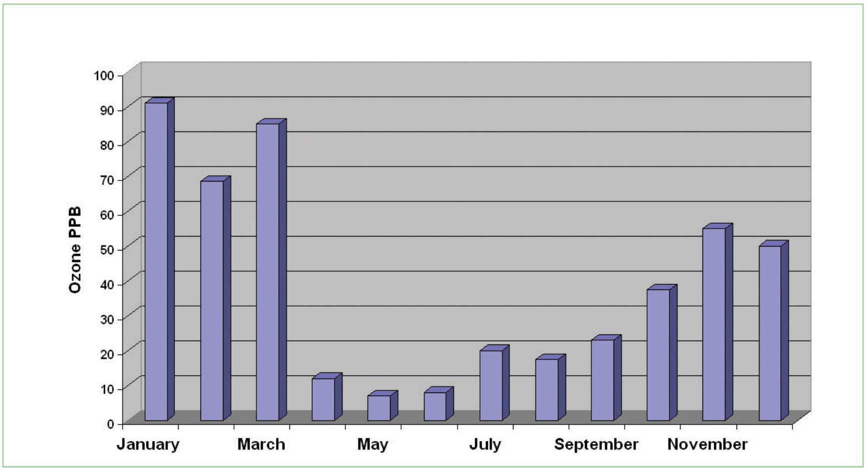

FIGURE 1
Monthly averages of tropospheric ozone in Cuba.

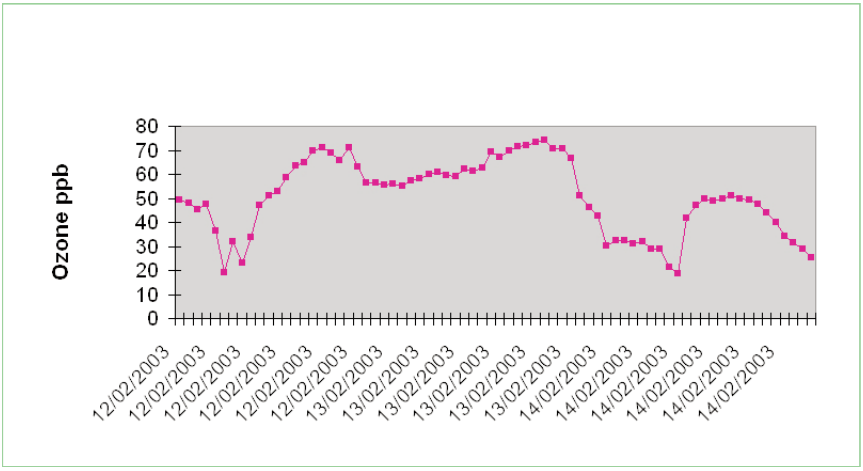

FIGURE 2
Variations in hourly measurements of tropospheric ozone in Cuba – February 12-14, 2003.

protection of agricultural cultivation. The timing of this period of higher ozone also coincides with the cultivation of agricultural crops key to the Cuban economy (Ramirez, 1998). The Cuban economy largely depends on the agricultural sector, mainly potato, tobacco, garlic, onion and vegetables - cultivations that are most susceptible to high levels of ozone.

After cold meteorological fronts, Cuba is influenced by continental air masses, sustained from one to four days, bringing ozone concentrations above the 40 ppb agricultural threshold (Figure 2). Other meteorological elements that influence the elevation of the ozone concentrations include:

- The thickness of the layer in the atmospheric levels of 1000 and 850 hPa;
- Trajectories of particles from continental source regions;
- Absolute humidity;
- Little presence of precipitation to influence of with discharges pressures; and
- High flow of solar radiation.

Figure 3 shows an example of the continental atmospheric influence on Cuba. The map shows the surface map with superior air at 5000 feet for 1800Z on

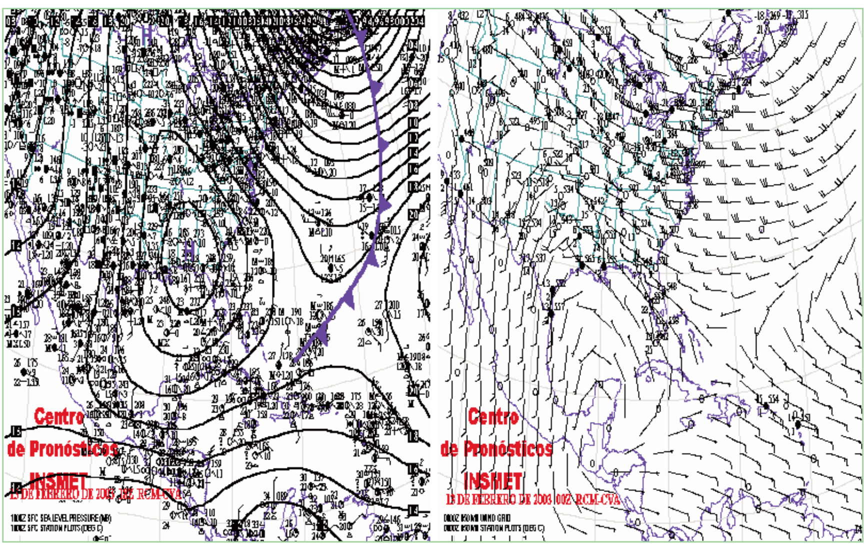

FIGURE 3
Continental atmospheric influence on Cuba, February 13, 2003.

February 13, 2003, where a centre of high pressure located in the southern United States moves toward the east. Atmospheric pollutants arrive in Cuba under these meteorological conditions as a direct result of long-range transport. These high levels of ozone represent between 30 to 40% of the total agricultural growing days in Cuba causing serious damage to crops and to vegetation in general.

One of the counties with many hectares dedicated to agricultural activity is Havana. Ozone is monitored at Santiago of the Vegas, an excellent location in the municipalities San Antonio of the Baños and Güira of Melena where potato, garlic, onion, tobacco, tomato and beans are cultivated. Figure 4 shows the variation of daily ozone maximum concentrations during the high ozone period for the year 2003. Ozone levels broke the threshold established for agricultural activity in Cuba for 55% of the days. All these days were associated with meteorological conditions of long-range transport of air pollutants.

In February 2003, extremely high levels of ozone were reached breaking the dangerous threshold of 100ppb, for 39% of the days. However, during the time of cold fronts when the continental air mass influence does not exist, ozone levels remained below the dangerous and agricultural protection thresholds (see Figure 5a for the ozone concentrations on February 15, 2003). The synoptic situation for this day shows flows of air masses from the Caribbean, conditions not favourable for ozone concentration increases like those observed in Figure 5b.

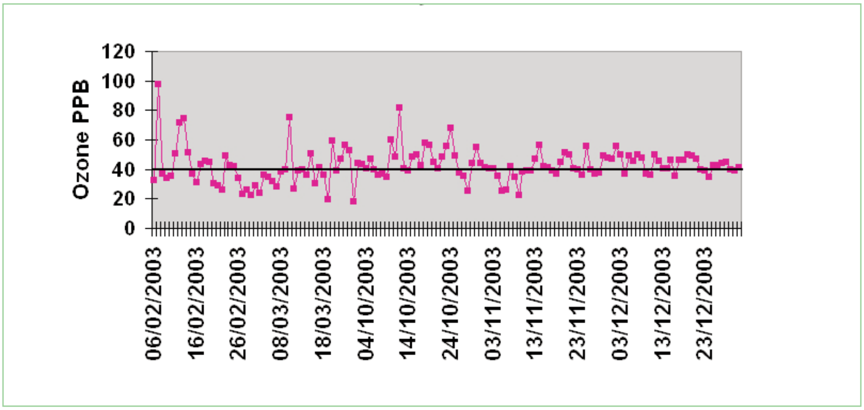

FIGURE 4
Variations in daily maximum tropospheric ozone in Cuba, 2003. Solid line represents 40 ppb value established to protect agricultural crops in Cuba.

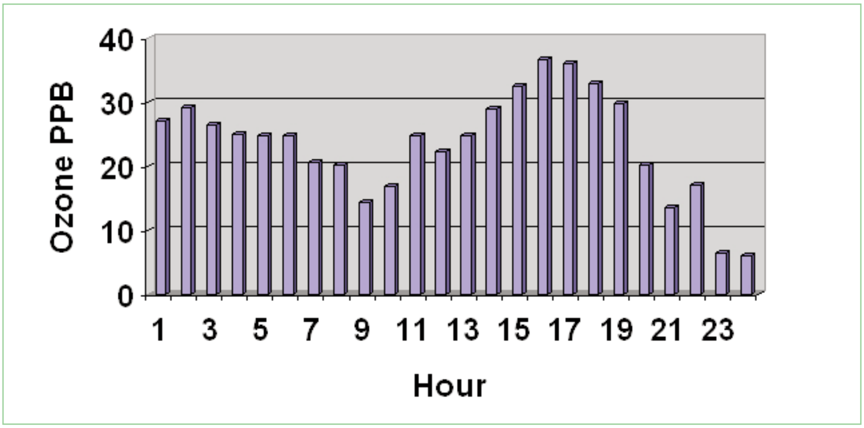

FIGURE 5A
Hourly tropospheric ozone concentration in Cuba for February 15, 2003.

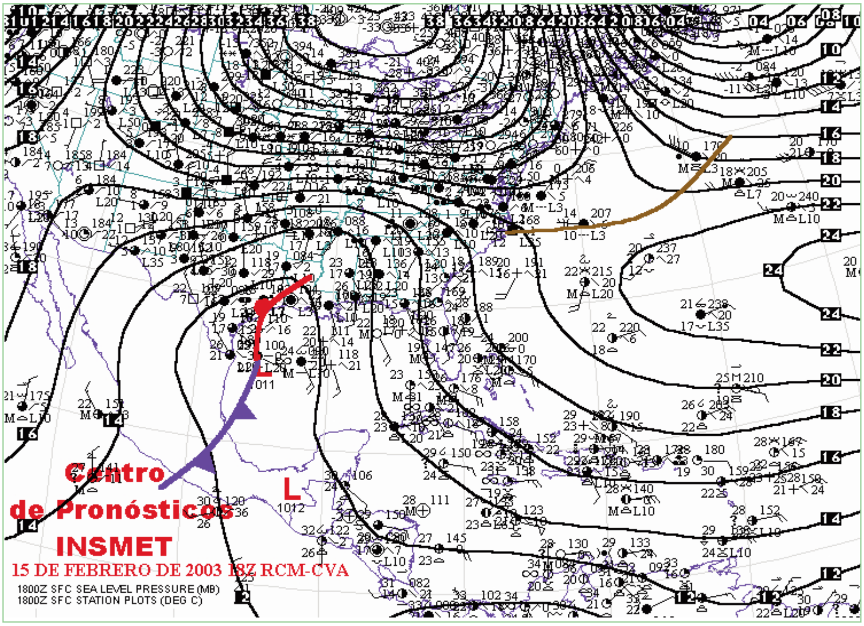

FIGURE 5B
Synoptic observations for Cuba, February 15, 2003.

3. Early warning system for the protection of agricultural activities

In agricultural areas of Cuba, the impacts of high atmospheric ozone concentrations have been observed and threaten the supply of food to the Cuban population. For example, in the year 1992, Cuba lost 73% of garlic crops due to ozone damage; and in the tobacco industry, one of the main economic sectors of the country, severe damages were observed in 2005 due to high ozone concentrations (Figure 6). In cultivations of tomato, cucumber, peppers and other crops, severe damage has also been observed caused by high ozone concentrations. It has been noted that those agricultural crops most affected by high ozone concentrations are also those most susceptible to the appearance of crop disease and illness (Ramirez, 1998).

During the 1990s, Cuba introduced an early warning system providing farmers and Cuban agricultural institutions with five days advance warning of high ozone concentrations. The Cuban agricultural agency uses this system to implement crop protection strategies before damage can have their effect from high ozone

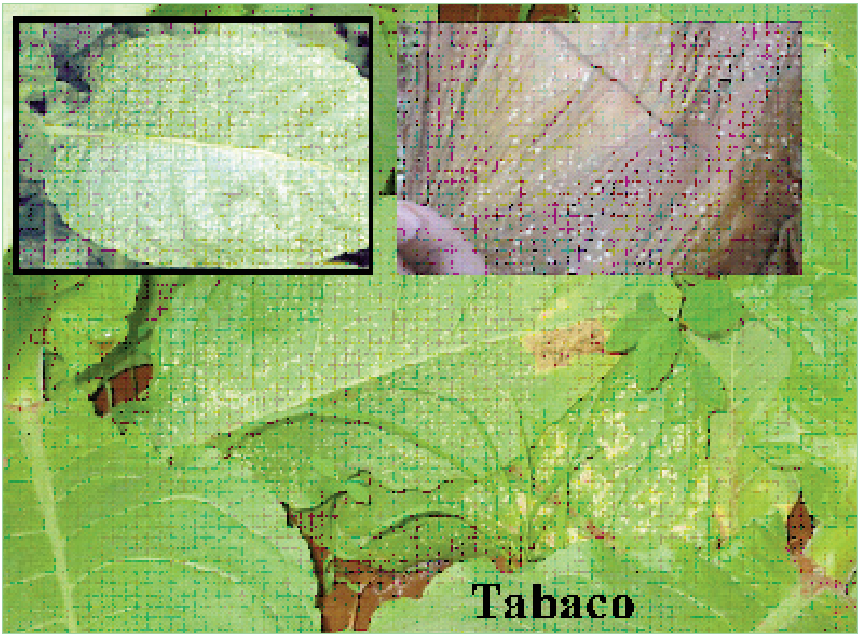

FIGURE 6
Tropospheric ozone damage to tobacco in Cuba.

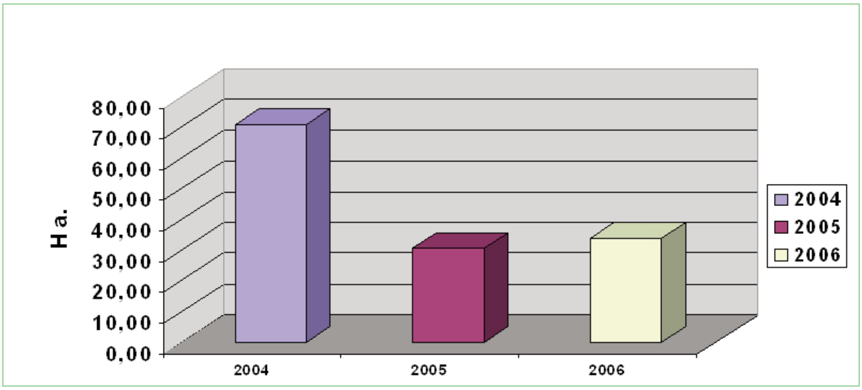

FIGURE 7
Damage to tobacco crops from tropospheric ozone in Havana, Cuba 2004-06.

concentrations. There is much evidence indicating the economic benefits that the early warning system provides and these are quantifiable. In 1992, when the early warning system of high ozone concentrations was not used, 73% of the garlic crop was lost due to ozone effects. Since 1997 with the introduction of the early warning system, only about 2% of the garlic crop is lost each year due to the high ozone concentrations. During the 1990s prior to the early warning system, damages to tobacco farms from high ozone concentrations was about 2500 hectares. And since 1997, although ozone concentration levels above damaging levels were experienced, damages to tobacco fields is limited to about 50 hectares due to crop protection strategies implemented as a result of the early warning system (Figure 7), such as spraying chemicals that close stomata to dangerous ozone concentrations.

The early warning system alerting to on-coming high concentrations of ozone can be considered to be an adaptation mechanism in the face of climate change.

4. Measurements of ozone in the Federal District of Mexico

A pilot project was implemented in 2002 to measure the levels of the tropospheric ozone and its link with synoptic scale meteorology in non urban areas of the southern Metropolitan Area of the Valley of Mexico (ZMVM). The project had two stages - the first measured ozone levels during August and September of 2002 at San Miguel of Topilejo in the Southwest, San Luís in the south and Tlahuac in the southeast. The ozone concentrations reached similar levels at all three places, often surpassing the threshold values at which ozone concentrations cause damage to agricultural crops. The second stage measured ozone concentrations in June and July of 2003 at the Commission of Natural Resources (CORENA) facilities in San Miguel of Topilejo.

In the Federal District area of Mexico, there are 33,800 hectares dedicated to agriculture representing 22.7% of the land surface area. The agricultural work focussed in the southern area at Milpa Alta, Tlalpan, Tláhuac and Xochimilco (INEGI, 1999) produces corn, grains and some other varieties of vegetables representing 19,857.5 tons (INEGI, 1999).

San Miguel of Topilejo is a town located to the Southwest in Mexico of 309 km^2 land area where oats, corn and potato farming is mixed with extensive forest area totalling 46% of the total land area. As shown in Figure 8, urban sprawl has extended to the agriculural area of 7,000 hectares that produces the economic sustenance for thousands of locals. The forests, once considered as conservation land to be the lungs of the City, are now under threat. It is necessary to find solutions so that the human population can live in harmony with the forests and also improve the agricultural production under threats from high atmospheric concentrations of ozone. The large increase in human population, the advance of urban sprawl and multiple industrial activities threaten this region with

FIGURE 8
San Miguel of Topilejo, Mexico.

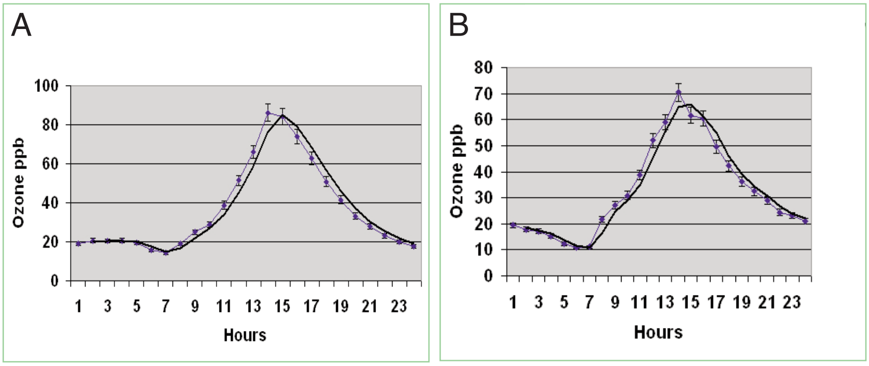

FIGURE 9
Hourly minimum tropospheric ozone concentrations in San Miguel of Topilejo, Mexico, June 2003.

deforestation, the destruction of agricultural crops and the appearance of different lung illnesses in the human population. Although rural areas of the Metropolitan Area of the Valley of Mexico, they do not escape the threats often associated with urban areas making it necessary to investigate levels of atmospheric ozone.

Figure 9 shows the minimum ozone concentration values (during the early morning hours) and the maximum values observed after noon around 1400 to 1500 hours for June (A) and July (B). Figure 10 shows the variation of daily ozone

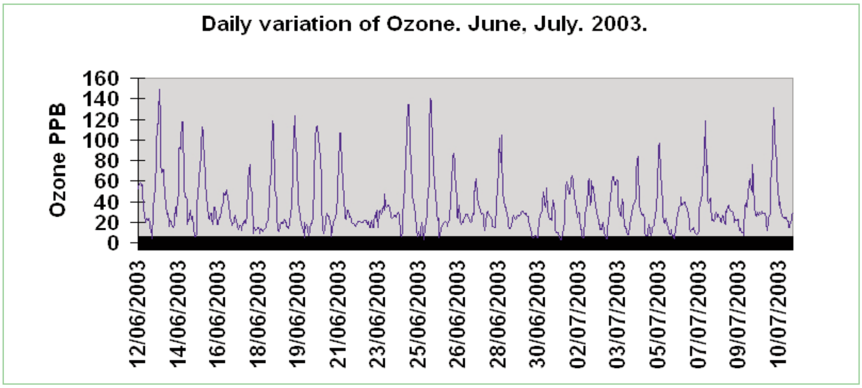

FIGURE 10
Daily tropospheric ozone levels in San Miguel of Topilejo, Mexico, June-July, 2003.

values during the whole period of measurement. More than 50% of the values break the threshold established for agricultural crop protection in Cuba (as well as Europe) of 40 ppb (Ramírez, 1998; Directiva/81/CE. Parlamento Europeo, 2001). Figure 10 also shows that 37% of the days have ozone levels higher than 110 ppb, a level set in Mexico as harmful to human health (Ramos, 2002). The month of June registers the highest ozone concentrations breaking the thresholds for human health and agricultural cultivation. These data indicate the necessity to continue investigating the ozone concentrations in these rural areas, and their effects on the vegetation and human health.

For the synoptic analysis, 87 daily atmospheric maps from the Department of Meteorology of the Government of the Federal District (G.D.F) in Mexico were examined for 1200Z (0700 Hours), in the atmospheric heights of 8,000, 9,000 and 10,000 feet. Figure 11 shows an example during the month of June, 2003. Examination of wind measurements indicate that, in the month of June, the largest mean ozone concentrations occur when the flow of the wind in the Valley of Mexico is from the North. However, in the month of July, the largest mean ozone concentrations are linked with the flow of wind from the South.

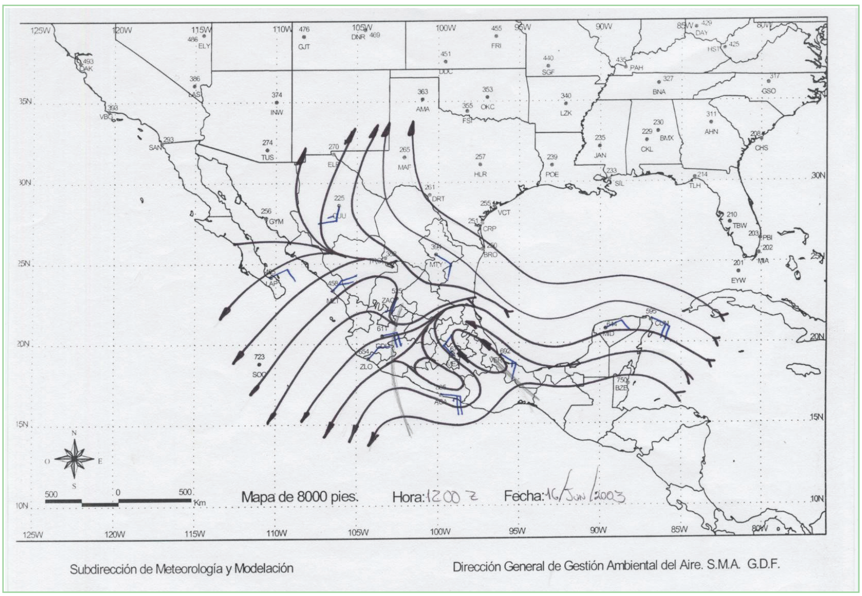

FIGURE 11
Synoptic analysis of tropospheric ozone concentrations in Mexico at 8,000 feet on June 16, 2003.

5. Conclusions

The effects of high levels of atmospheric ozone pollution on human health and agricultural crops can now be observed in non-urban areas of less developed countries such as Cuba and Mexico – effects initially limited to countries of more economic and industrial development.

The high levels of ozone concentrations in the atmosphere that were observed as part of this study threaten the food security of both countries.

The application of an early warning system to alert farmers and government agencies about projected high ozone concentrations can alleviate the current damage and maintain agricultural crop yields.

A next step to the investigation could be to extend monitoring ozone concentrations to non-urban areas of other countries in the Caribbean region that present similar problems as Cuba and Mexico.

Acknowledgments

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CHAPTER

3

TOOLS AND APPLICATIONS FOR MANAGING CLIMATE CHANGE AND BIODIVERSITY

PAPER

12 CARIBBEAN CLIMATE SCENARIOS FOR THE CARIBBEAN: LIMITATIONS AND NEEDS FOR BIODIVERSITY STUDIES

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ABSTRACT: The extent of climate baseline data, climate information and climate scenarios which are readily available for related biodiversity studies and the capacity for undertaking these studies in the Caribbean were investigated. A list of the databases available is given. Although adequate capacity and some information exist, there are gaps to be filled. Information is inadequate because of the limited baseline data, the course resolution of the global and even the regional models. Steps to fill the gaps are discussed. Information for biodiversity studies includes knowledge of climate threshold values, geographical distribution. Some of this information can be provided by statistical downscaling but the process requires daily data of good quality and long duration. These however infrequently exist. The material for this paper comes from the Implementation of the Climate Change and Biodiversity in the Insular Caribbean (CCBIC) Project which is being conducted by the Caribbean Natural Resources Institute (CANARI).

Keywords: climate change, biodiversity, Caribbean, modeling

1. Introduction

> "At the global level, human activities have caused and will continue to cause a loss in biodiversity through, *inter alia,* land-use and land-cover change; soil and water pollution and degradation (including desertification), and air pollution; diversion of water to intensively managed ecosystems and urban systems; habitat fragmentation; selective exploitation of species; the introduction of non-native species; and stratospheric ozone depletion. The current rate of biodiversity loss is greater than the natural background rate of extinction. A critical question … is how much might climate change (natural or human-induced) enhance or inhibit these losses in biodiversity?" (Gitay *et al.,* 2002).

This question is being addressed by implementation of the *Climate Change and Biodiversity in the Insular Caribbean (CCBIC) Project.* The project is executed by The Caribbean Natural Resources Institute (CANARI). One of the first steps, recognized by the CCBIC Steering Committee at its inaugural meeting in Trinidad in March 2007, was the establishment of Scenario and Modelling Working Group (WG I). The task of WGI was to provide "a summary of the state of knowledge and expertise for the development of climate change scenarios and models in support of the identification and assessment of expected impacts of global climate change on Caribbean coastal and marine biodiversity, identifying the gaps in our knowledge, expertise, and capacities, and the measures that must be undertaken to fill these gaps" (CCBIC Guidance to Working Group Leaders).

To address the task of WGI, 5 key problems were considered:

1. What baseline climate information and existing climate databases do we have for the Caribbean? This is a necessary starting point in any climate study.

2. What research has been done on climate variability and climate change in the Caribbean, and what has been learned? How are climate change scenarios developed and what are the climate change scenarios for the Caribbean? To generate scenarios of future climate, it is necessary to know the climate processes at work and processes that change climate. Models that simulate climate and climate change have to be evaluated to determine if they capture actual climate processes and changes. This will assist in determining the validity of the scenarios generated.

3. What is our present manpower and equipment capacity? This will determine the manpower and equipment needs.

4. What more do we need to know about climate change, especially as it relates to biodiversity and how can these needs be achieved?

5. What climate models are best suited for addressing climate change and biodiversity?

These problems are the subject of the following 5 sections, sections 2 to 6. Section 7 contains concluding remarks.

2. Baseline Data and Climate

The focus of this section was to summarize the baseline climate information and databases for the Caribbean region. Note that particular emphasis was paid to the English-speaking Caribbean and Cuba. Several sources of climate data [for example, precipitation (intensity and duration), temperature (daily maximum and minimum), wind speed, direction, radiation, relative humidity among others] exist for the Caribbean region. The climate parameters contained in these datasets vary with some datasets containing more parameters than others. In addition, some data sets contain unprocessed data whereas other datasets contain processed data. These datasets and their availability are summarized below.

Caribbean Institute for Meteorology & Hydrology (CIMH)

CIMH maintains a climatology database that contains data recorded at stations maintained by National Meteorological Services (NMS) that are members of the Caribbean Meteorological Organization (CMO) [Anguilla, Antigua & Barbuda, Barbados, St. Lucia, St. Vincent & the Grenadines, Dominica, Guyana, Grenada, Trinidad & Tobago, Jamaica, St. Kitts & Nevis, Belize, the British Virgin Islands, the Cayman Islands, Montserrat, and the Turks and Caicos Islands] as well as other stations in these countries deemed to provide data of good quality that meets WMO specified standards. CIMH performs quality assurance checks on the data prior to making it available to the public.

Parameters contained in the CIMH database include daily temperature, pressure, relative humidity, precipitation, cloud, and wind speed and direction. In several cases, the data sets are incomplete due to instrument failure and failure of the NHS to forward the data to CIMH. In some cases, the NMSs have a more comprehensive data base than CIMH, however, much of this data is in notebooks and has not been converted to electronic form. A proposal to support rescuing much of the hard copy data from the various NMSs has been circulated to various funding agencies. Data contained in the database is available at no cost for academic applications; however, there is a charge to commercial customers. Data contained in the CIMH monthly summaries is available directly from CIMH in hard copy form (1972-2004). These datasets are currently being scanned and posted to the CIMH webpage (**http://www.cimh.edu.bb**). A list of stations currently stored at CIMH is available at **http://www.cimh.edu.bb/datainv.htm**. In addition, data can be obtained directly from NMSs who may have data for stations not present in the CIMH data base. Electronic data at most NMSs in the Caribbean are stored in CLICOM and/or CLIDATA.

Caribbean Climate Interactive Database (CCID)

The CCID database consists of daily and monthly station data for various Caribbean islands in the period 1935 to 2000. The variables available are minimum temperature, maximum temperature and precipitation. The raw data or time series of monthly averages, climatologies, standard deviations, and anomalies may be viewed and saved. In addition correlations and scatterplots of variables may also be obtained. The data is available free of cost and can be obtained by sending a request to Dr. Michael Taylor in the Department of Physics, University of the West Indies, Mona at **michael.taylor@uwimona.edu.jm**.

■ Universidad Nacional Autonoma de Mexico (UNAM)

UNAM provides monthly temperature (maximum and minimum) and precipitation data on a 0.5° x 0.5° grid that extends from 140° to 59° Longitude W and from 4.75° to 45.25° Latitude N. The data time series extends from 1901 to 2002. Sources of the data used to develop the gridded dataset are daily station precipitation and temperature from CLICOM (for Mexico) and the Global Historical Climatology Network (GHCN). Given the sizes of the islands of the eastern Caribbean, the grid resolution is quite coarse. In addition, the quality of the gridded data relies on the spatial locations of the sources of data, the interpolation methods used to develop the grid, and the quality assurance methods employed at the measurement locations. More information is available at **http://iridl.ldeo.columbia.edu/SOURCES/.UNAM/.gridded/.monthly/.v0705/.dataset_documentation.html**.

■ Climate Research Unit (CRU)

The Climate Research Unit (CRU) at the University of East Anglia is one of the most popular sources of global climatic data and is often cited in major publications on climate. The CRU provides monthly data at several grid resolutions with the highest resolution being on a 0.5° x 0.5° grid that includes the Caribbean. The data time series extends from 1901 to 2000.

Climate parameters available from CRU include temperature (maximum, minimum, mean, and range), precipitation, wet days, water vapour, and cloud. More information on CRU is available at **http://www.cru.uea.ac.uk/**.

■ Climate Prediction Center (CPC) Global Climate Data and Maps

The Climate Prediction Center Global Climate Data and Maps contains maps and time series for precipitation and surface temperatures for Africa, Asia, Europe, South and Central America, Mexico, Caribbean, Australia, and New Zealand. CPC monitors weather and climate in real time with the aid of satellite animations, conventional rain gauge observations and global analyses of the atmospheric state. CPC also has available time series of accumulated actual daily precipitation and accumulated normal precipitation both of which are available on a daily basis and can be viewed on 5° x 5° grids over the Americas. CPC also provides weekly maps of total precipitation and temperature (maximum and minimum) as well as departures from the norm. Monthly and 3-month maps are also available. CPC provides observed precipitation time series showing observed versus actual for selected cities around the world for the last 30, 90 and 365 days. CPC provides observed temperature time series showing observed versus actual for selected cities around the world for the last 30, 90 and 365 days. More information on CPC is available from **http://www.cpc.noaa.gov/products/monitoring_and_data/restworld.shtml**.

■ International Research Institute for Climate and Society (IRI)

IRI/LDEO Climate Data Library has available over 300 datasets from a range of earth science disciplines and climate related topics. The data includes the NCEP reanalysis database, outputs from IPCC assessment models, NCEP Climate Forecast System, and NCEP CPC constructed analog sea surface temperature forecasts among others. Information summarizing the contents of the IRI/LDEO Climate Library is available at **http://iridl.ldeo.columbia.edu** and **http://iridl.ldeo.columbia.edu/SOURCES**.

■ National Centers for Environmental Protection (NECP) Operational Analysis

NCEP provides a range of climate data products to the public. The global products dataset includes precipitation and temperature which are updated twice daily. In addition to these products, NCEP also provides reanalysis data 4 times per day for a range of meteorology parameters. For more information go to **http://www.cdc.noaa.gov/cdc/data.ncep.reanalysis2.html**.

■ Global Climate Observation System (GCOS)

GCOS is intended to be a long-term operational system. GCOS addresses the total climate system including physical, chemical and biological properties as well as its atmospheric, oceanic, terrestrial, hydrologic, and cryospheric components. GCOS provides comprehensive operations required for monitoring the climate system, detecting and attributing climate change, assessing inputs of, and supporting adaptation to, climate variability and change, applications to national economic development, research to improve understanding, modeling and prediction of the climate system. More information on GCOS is available at **http://www.wmo.ch/pages/prog/ gcos/index.php**.

■ Cuba's Climate Data

A database of precipitation, maximum and minimum temperature, relative humidity and wind speed and direction exists for 68 stations on Cuba. These stations have in general at least 30 years of daily and tri-hourly data with some stations having time series that go back 100 years. (See the Attachment for an illustration of precipitation and temperature anomalies over approximately 100

years). Most stations have not been moved from their original location and those that were moved have had correction factors applied to the data to account for the relocation. All of the meteorological data for Cuba has been digitized and a quality control process implemented to minimize errors. In addition to the measurement of standard meteorological parameters, specialized meteorological stations exist that provide solar radiation, upper-air agro-meteorological, air quality and pollution data. The Center of Climate is in charge of storing and processing all the climate data and has the necessary software and hardware resources to deal with this task efficiently. More information on climate data and climate studies in Cuba can be obtained at **http://www.met.int.inf.cu**.

3. Average Behaviour or Climatology

The Caribbean climate has been concisely described by Taylor and Alfaro (2005). It can be broadly characterized as dry winter/wet summer with orography and elevation being significant modifiers on the sub regional scale. The dominant synoptic influence is the North Atlantic subtropical high (NAH). During the winter the NAH is southernmost with strong easterly trades on its equatorial flank. Coupled with a strong trade inversion, a cold sea surface temperature (SST) and reduced atmospheric humidity, the region generally is at its driest during the winter. Precipitation during this period is due to the passage of mid-latitude cold fronts. With the onset of the spring, the NAH moves northward, the trade wind intensity decreases, the sea becomes warmer and the southern flank of the NAH becomes convergent. Concurrently easterly waves traverse the Atlantic from the coast of Africa into the Caribbean. Easterly waves frequently mature into storms and hurricanes under warm sea surface temperatures and low vertical wind shear generally within a 10°N-20°N latitudinal band referred to as the *main development region*. They represent the primary rainfall source and their onset in June and demise in November roughly coincides with the mean Caribbean rainy season. Around July a temporary retreat of the NAH equatorward is associated with diminished rainfall known as the mid-summer drought. Enhanced precipitation follows the return of the NAH and the passage of the Inter Tropical Convergent Zone (ITCZ) northward. The passage of cold fronts from mid-latitudes is responsible for much of the rainfall in the dry season (December to March). Air temperature tends to follow the sun, or more precisely the variation in solar insolation. Below about 15°N, this variation results in a bi-modal temperature peak. The timing of the processes are illustrated graphically for Jamaica in Figure 1, and for Trinidad and Tobago in Figure 2.

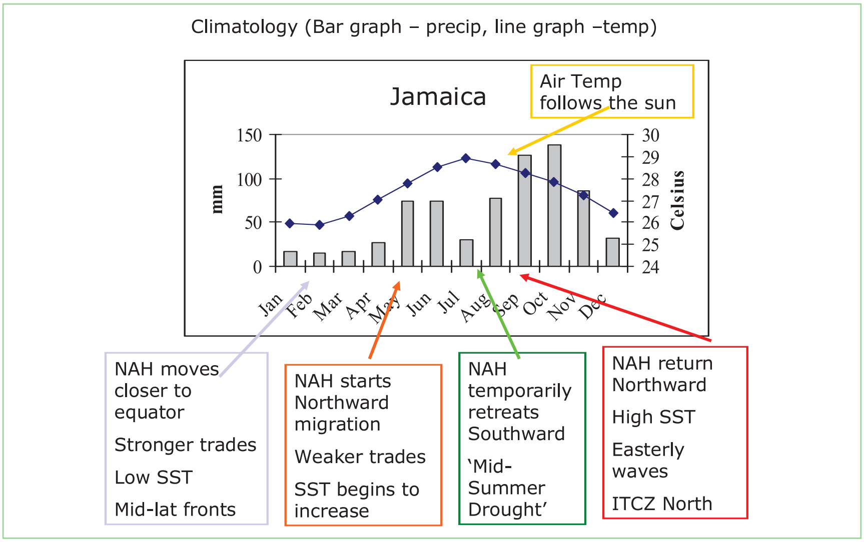

FIGURE 1

The timing of climatology processes for Jamaica (NAH refers to North Atlantic High pressure system; SST, Sea Surface Temperature; ITCZ, Inter-tropical Convergence Zone)

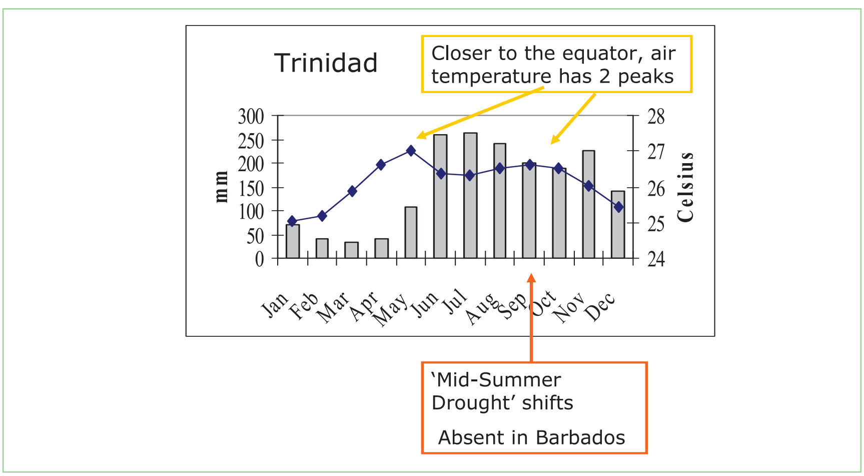

FIGURE 2

The climatology for Trinidad, same as for Jamaica but the Mid-Summer Drought occurs later and 2 peaks in air temperature are evident

For small islands, differences in size, shape, topography and orientation with respect to the trade wind influence the amount of rainfall received by the various islands. Cuba, Jamaica, Hispaniola and Puerto Rico, the larger and more mountainous islands of the Greater Antilles, receive heavier rainfall at higher elevations, with a rain-shadow effect on their southern coasts that are distinctively arid. The smaller islands to the East tend to receive less rainfall, with Barbados and Trinidad in the South receiving more rainfall than the rest. The dry belt of the Caribbean is found over the south-western islands of the Netherlands Antilles.

4. Climate Variability and Climate Change

4.1 Climate Trends

■ Temperature and Precipitation

Global temperatures have increased by about 0.74°C (0.56°C to 0.92°C) since the 19th century (IPCC, 2007). There has been a warming trend globally with minimum temperatures increasing at a higher rate than maximum from 1950-2001 (Alexander *et al.*, 2006). An increasing trend in both variables is also observed for the Caribbean region by Peterson *et al.* (2002). They used ten global climate indices to examine changes in extremes in Caribbean climate from 1950 to 2000. They found that the difference between the highest and lowest temperature for the year is decreasing but is not significant at the 10% significance level. Temperatures falling at or above the 90th percentile are increasing while those at or below the 10th percentile are decreasing (both significant at the 1% significance level). These results indicate that the region has experienced some warming over the past fifty years. Thus there is a general warming trend with the number of very warm days and nights increasing, while the number of very cool days and nights has been steadily decreasing over the same time period.

Two of the precipitation indices used by Peterson *et al.* (2002) showed significant changes, the greatest 5 days rainfall total is increasing (10% significance level) while the number of consecutive dry days has decreased (1% significant level). However the results may not take into account differing behaviour in precipitation in the North and South Caribbean. Using several observed data sets, Neelin *et al.* (2008) noted a modest but statistically significant drying trend for the Caribbean's summer period in recent decades.

Studies carried out in Cuba have demonstrated the existence of important climate variations in the country and in the region (Naranjo and Centella ,1998; Lapinel *et al.,* 2002 and Álvarez, 2006). Major trends in the increase of annual mean temperature of 0.5°C and an increase in the frequency of impact of extreme climate events, such as, intense rains and severe local storms, characterize the climate of the second half of the 20th century in Cuba. The frequency of drought events has also increased significantly, while the hurricanes that affect Cuba show a secular tendency to reduction. It has been demonstrated that these variations are consistent with the increase in the atmospheric circulation in the region and with the increase in the influence of El Niño Southern Oscillation (ENSO) event, which plays an important role as a forcing element of climate variability in Cuba. Cuba's climate behaviour during the last 4 decades is consistent and suggests the existence of an important variation since the 1970s.

Hurricanes

Analysis of observed Tropical cyclones in the Caribbean and wider north Atlantic Basin show a dramatic increase since 1995. This increase however has been attributed to the region being in the positive (warm) phase of a multidecadal signal and not necessarily due to global warming (Goldenburg *et al.*, 2001). Results per year obtained from Goldenburg *et al.* have shown that during the negative (cold) phase of the oscillation the average number of hurricanes in the Caribbean Sea was 0.5 per year with a dramatic increase to 1.7 per year during the positive phase. While attempts have been made to link warmer SSTs with this increase in numbers, these have proven to be inconclusive, (Peilke *et al.*, 2005). In a study to further examine the proposed link between global warming and tropical cyclone frequency, Webster *et al.*, (2005) found that while SSTs in tropical oceans have increased by approximately 0.5°C between 1970 and 2004 only the North Atlantic Ocean (NATL) shows a statistically significant increase in the total number of hurricanes experienced since 1995. In an analysis of the frequency and duration for the same time period no significant trends were noted for ocean basins except for the NATL which showed an increasing trend significant at the 99% confidence level. Webster *et al.*, (2005) also noted an almost doubling of the Category 4 and 5 hurricanes in the same time period for all ocean basins. While the number of intense hurricanes has been rising, the maximum intensity of hurricanes has remained fairly constant over the 35 year period examined.

4.2 Future Climate Scenarios - IPCC Projections

Temperature and Precipitation

IPCC Scenarios of temperature change and percentage precipitation change between 1980 to 1999 and 2080 to 2099 for the Caribbean are based on the coordinated set of climate model simulations archived at the Program for Climate Model Diagnosis and Intercomparison (see http://www-pcmdi.llnl.gov/) PCMDI; subsequently called the multi-model dataset or MMD (Christensen *et al.*, 2007). The results of the analysis using A1B Special Report Emission Scenario - SRES (Nakićenović and Swart, 2000) are summarised in Table 1 (Christensen *et* *al.*, 2007). A small value of T (column 8 for temperature and column 14 for precipitation) implies a large signal-to-noise ratio and it can be seen that, in general, the signal-to-noise ratio is greater for temperature than for precipitation change, so that the temperature results are more significant. The probability of extreme warm seasons is 100% (column 15) in all cases and the scenarios of warming are all very significant by the end of the century.

TABLE 1

Regional average of Caribbean (CAR) temperature and precipitation projections from a set of 21 global models in the MMD for the A1B scenario. The mean temperature and precipitation responses are first averaged for each model over all available realisations of the 1980 to 1999 period from the 20th Century Climate in Coupled Models (20C3M) simulations and the 2080 to 2099 period of A1B. Computing the difference between these two periods, the table shows the minimum, maximum, median (50%), and 25 and 75% quartile values among the 21 models, for temperature (°C) and precipitation (%) change. Regions in which the middle half (25-75%) of this distribution is all of the same sign in the precipitation response are coloured light brown for decreasing precipitation. T years (yrs) are measures of the signal-to-noise ratios for these 20-year mean responses. They are estimates of the times for emergence of a clearly discernible signal. The frequency (%) of extremely warm, wet and dry seasons, averaged over the models, is also presented. Values are only shown when at least 14 out of the 21 models agree on an increase (bold) or a decrease in the extremes. A value of 5% indicates no change, as this is the nominal value for the control period by construction (from Christensen *et al.*, 2007).

	Temperature Response (°C)							Precipitation Response (%)						Extreme Seasons (%)		
Region[a]	Season	Min	25	50	75	Max	T yrs	Min	25	50	75	Max	T yrs	Warm	Wet	Dry
CAR	DJF	1.4	1.8	2.1	2.4	3.2	10	-21	-11	-6	0	10		100	2	
	MAM	1.3	1.8	2.2	2.4	3.2	10	-28	-20	-13	-6	6	>100	100	3	18
10N,85W	JJA	1.3	1.8	2.0	2.4	3.2	10	-57	-35	-20	-6	8	60	100	2	40
to	SON	1.6	1.9	2.0	2.5	3.4	10	-38	-18	-6	1	19		100		22
25N,60W	Annual	1.4	1.8	2.0	2.4	3.2	10	-39	-19	-12	-3	11	60	100	3	39

Table 1 shows that the MMD-simulated annual temperature increases at the end of the 21st century range from 1.4°C to 3.2°C with a median of 2.0°C, somewhat below the global average. Fifty percent of the models give values differing from the median by only ±0.4°C. There were no noticeable differences in monthly changes. According to Table 1, most models project decreases in annual precipitation and a few increases, varying from –39 to +11%, with a median of –12%. Figure 3 (Christensen *et al.*, 2007) shows that the annual mean decrease is spread across the entire region (left panels). In December, January and February (DJF), some areas of increases are noted (middle panels) and in June, July and August (JJA), the region-wide decrease is enhanced, especially in the region of the Greater Antilles, where the model consensus is also strong (right panels).

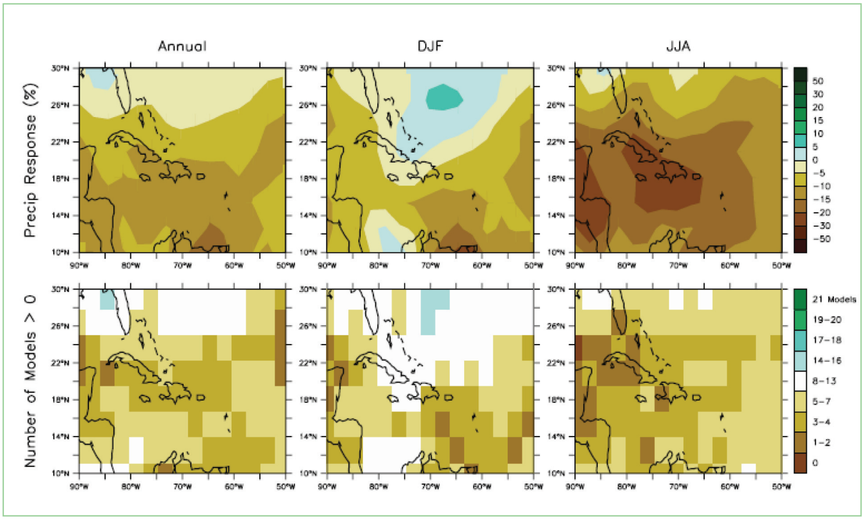

FIGURE 3
Precipitation changes over the Caribbean from the MMD-A1B simulations.
Top row: Annual mean, DJF and JJA fractional precipitation change between 1980 to 1999 and 2080 to 2099, averaged over 21 models. Bottom row: number of models out of 21 that project increases in precipitation (From Christensen *et al.*, 2007).

Sea Level Rise

Global sea level is projected to rise between the present (1980–1999) and the end of this century (2090–2099) by 0.35 m (0.23 to 0.47 m) for the A1B scenario (IPCC, 2007). Due to ocean density and circulation changes, the distribution will not be uniform. However, large deviations among models make estimates of distribution across the Caribbean uncertain. The range of uncertainty cannot be reliably quantified due to the limited set of models addressing the problem . The changes in the Caribbean are expected to be near the global mean. This is in agreement with observed trends in sea level rise from 1950 to 2000, when the rise in the Caribbean appeared to be near the global mean (Church *et al.*, 2004),

Hurricanes

In an experiment with a high resolution global 20-km grid atmospheric model, Oouchi *et al.*, (2006). was able to generate tropical cyclones that begin to approximate real storms. The model was run in time slice experiments for a present-day 10-year period and a 10-year period at the end of the 21st century for the A1B scenario to examine changes in tropical cyclones. In that study, tropical cyclone frequency decreased 30% globally, but increased about 34% in the North Atlantic. The strongest tropical cyclones with extreme surface winds increased in number while weaker storms decreased. The tracks were not appreciably altered, and maximum peak wind speeds in future simulated tropical cyclones increased by about 14% in that model, although statistically significant increases were not found in all basins (Meehl *et al.*, 2007). However, these regional changes are largely dependent on the spatial pattern of future simulated SST changes (Yoshimura *et al.*, 2006) which are uncertain.

4.3 IPCC 4th Assessment Summary

The summary below (Christensen *et al.*, 2007) is based on the SRES A1B scenario which gives an average global increase in temperature of 2.8° C over the present century. If all developed countries were to cut greenhouse gas emissions at the rate now proposed by the United Kingdom and France (approximately 50% by 2050 and 80% thereafter), then the global temperature increase would be limited to just under 2° C.

> "Sea levels are likely[1] to continue to rise on average during the century around the small islands of the Caribbean Sea …. Models indicate that the rise will not be geographically uniform but large deviations among models make regional estimates across the Caribbean … uncertain. Note: Based on the personal judgement of the CANARI Working Group I, the increase will probably follow the global average. All Caribbean … islands are very likely to warm during this century. The warming is likely to be somewhat smaller than the global annual mean warming in all seasons. Summer rainfall in the Caribbean is likely to decrease in the vicinity of the Greater Antilles but changes elsewhere and in winter are uncertain. Note: On-going analysis of precipitation changes by the Climate Studies Group Mona warrants upgrading the 'likely' decrease of precipitation in the greater Antilles to 'very likely'. It is likely that intense tropical cyclone activity will increase (but tracks and the global distribution are uncertain)."

[1] In the IPCC Summary for Policymakers, the following terms have been used to indicate the assessed likelihood, using expert judgement, of an outcome or a result: Virtually certain > 99% probability of occurrence, Extremely likely > 95%, Very likely > 90%, Likely > 66%, More likely than not > 50%, Unlikely < 33%, Very unlikely < 10%, Extremely unlikely < 5%

5. Present Capacity

This section deals mainly with the manpower and equipment capacity of three institutions, Caribbean Institute of Meteorolgoy and Hydrology (CIMH), Climate Studies Group Mona (CSGM) and Instituto de Meteorologia (INSMET). Other institutions involved in climate change research in the regions are the Caribbean Community Climate Change Centre (CCCCC) and the Joint Institute for Caribbean Climate Studies (JICCS). CSGM has been collaborating on climate variability and climate change projects with CIMH since 1995, and with ISMET since 2000. Collaboration on climate change has strengthened with CCCCC as the facilitator. Taken together there is a core group of researchers and technical staff, backed up by research students capable of conducting climate change research in the region. However since these institutions deal mainly with atmospheric modeling, there is a need for expertise in ocean and land surface interaction.

6. Gaps and Bridging Them

6.1 Gaps

Significant strides have been made with respect to gaining an understanding of Caribbean climate variability and change, and efforts have begun with respect to generating region specific scenarios of future climate. Yet, gaps still remain which must be bridged, particularly if interdisciplinary efforts are to materialize. Some of the gaps are as identified below.

■ The Data Deficit

Determining the mechanisms that control Caribbean climate whether through statistical analyses or modelling requires good quality climate data of significant temporal length, and from all territories across the Caribbean region. For example, statistical downscaling – a technique well suited for the development of scenarios for the biodiversity sector – requires long time series of daily station data for the location being studied. The summary of Section 2 suggests that datasets and data reserves exist for and within the Caribbean region. However there a number of deficits, including:

- The need to increase the density of stations for which quality controlled historical data is available.
- The need for daily station data of sufficient temporal length (30 years or more) to enable scenario generation via statistical means.
- The need to expand the number of climatic variables captured by the historical data. The current emphasis is on a minimum dataset of precipitation,

maximum and minimum temperature. This may not be sufficient for the generation of scenarios of relevance to other sectors for example, the biodiversity sector.
- The need to ensure easy access to the existing data stores, for legitimate users for example, researchers.
- The need to ensure that data currently being recorded meet adopted global and regional standards so that the identified data deficiencies with respect to present day historical data are not the deficiencies of the future generation.
- The need to capture secondary or derived information (for example, climate indices or data ranges or deviations) for storage alongside the primary data.
- The need to expand data offerings to include SST and variables such as soil moisture, concentration of atmospheric constituents, etc.

Whereas some territories, for example Cuba, have been successful at amassing reasonably long time series of station data for multiple variables and multiple stations this is not the case throughout the entire region. In many territories additional data exist which could supplement existing databases, but in non-traditional archives (for example, records of sugar plantations, agricultural and hydrological bodies) and in non-digitized forms, and are therefore yet to be captured. There is at present no coordinated region-wide data capture effort in spite of a growing sense of urgency about the deterioration of the media on which some the data is currently captured.

6.2 Capacity Constraints

Human Capacity

The Caribbean region is not devoid of the human capacity to undertake the tasks associated with generating climate change scenarios. Highly qualified meteorologists, and climate researchers with sufficient knowledge of methodologies to assess and produce relevant analyses exist within the region at institutions such as the CIMH, at a few meteorological offices and at regional and local universities. The number of interdisciplinary and multinational research projects carried out at these institutions and others within the region attest to this capacity. Yet there are constraints. In particular, the very recent interdisciplinary emphasis of climate change research means that the pool of professionals who can either straddle the disciplines being combined (for example, meteorology and the biosciences), or with skills to effectively assess and/or examine vulnerability or adaptation, is small (though growing). Consequently there is often a need to hire consultants from outside the region to do such evaluations and assessments. Unfortunately, the experience of the region is that such experts leave their results but not their methodologies, and therefore do not facilitate a transfer of knowledge. It is also to be noted that an aging cadre of professionals in the meteorological institutions of the region remains a problem.

Technical Constraints

Technical capacity varies across the region. The infrastructure to support meteorological measurements, climatic analysis, dynamical modeling, and scenario generation exists throughout the region, though not necessarily uniformly so. Institutions such as CIMH, IMSMET, UWI and UPR- Mayaguez are noteworthy for their technical infrastructure which, though not adequate, is sufficient for many tasks. Yet a survey of the region suggests some common constraints. In spite of a growing awareness about the importance of data collection, the high cost of purchase, maintenance and calibration of meteorological instruments has resulted in a gradual deterioration of the meteorological network. When replacement instruments do not exist, or must wait on grant or government funding to be obtained, or inappropriate substitutions are made in the absence of the genuine instrument, the climate database suffers. Additionally, the use that modern meteorology makes of new computer resources means that the meteorological services and institutions conducting related meteorological activities, as well as research entities exploring climate variability and change, require high performance computers and massive data storage systems. These are necessary to generate useful and high quality information for forecasting purposes and for the research community. At this moment, most territories benefit from useful meteorological information from a variety of sources, including regional weather forecasting and some detailed mesoscale information. Outside of a few territories, however, (for example, Puerto Rico) it is impossible to give a detailed local forecast using currently installed capacity.

6.3 Knowledge Needs

Finally, as previously suggested, Sections 3 and 4 point to a vastly improved understanding of regional dynamics and a growing understanding of climate change and its likely manifestation in the Caribbean region. Yet the increased understanding highlights some knowledge gaps - pointing to areas that require better understanding. These include a need for:

- Further understanding of Caribbean climate variability, particularly on the sub-seasonal, seasonal, interannual (outside of El Niño variations) and decadal scales. Phenomena such as the low level jet, dry season dynamics, easterly wave dynamics and interactions require further examination. This is needed to provide context for examining future change within the region;

- Investigation of local or sub-regional climates and climate gradations within individual territories and how these will likely be altered by climate change;
- Further application of regional modelling techniques (dynamical and statistical), particularly with respect to downscaling climate change results for sub-regions, territories, cities, towns, and station sites;
- Dialogue between climate researchers and scientists within the biodiversity sector (for example) in order to jointly set foci, priorities, and an agenda of needs and deliverables. This would include the quantifying of climatic variables, scales, and thresholds which would be needed for analysis of the impact of climate change on the sector. For example, measurement of changes in oxygen levels in the water, or in the composition of gases in the atmosphere (ozone, methane) seem necessary for biodiversity studies but are not currently routinely done;
- Better understanding of sea level rise estimations due to global warming and the implications this will have for Caribbean coastlines especially during extreme events;
- More region specific information/studies on deforestation, flooding, and the role of climate in determining such things as human settlements and international commerce; and
- Clearer understanding of the usefulness of the various types of climate data currently being archived for modelling biodiversity impacts, as well as the limitations and boundaries within which the data can/should be used.

Admittedly, some of this knowledge may already be in existence, particularly in the archives of governmental and non-governmental organizations, in the form of consultancy reports and commissioned studies done over the years. Their inaccessibility, the lack of knowledge about their whereabouts or existence, and the absence of central bibliographic databases do nothing to fill the knowledge needs of the region.

6.4 Filling the Gaps

The following represent steps which could/should be taken to fill the identified gaps. In some cases the steps represent major efforts which would involve multi-national collaboration, while in other cases the steps could be undertaken by a single territory or institution. Identification of funding to carry out the proposed solutions remains a vexing issue for the region as a whole. Recommendations for each section include:

Data

1. Putting in place mechanisms (protocols and agreements for sharing, online facilities, etc.) to facilitate the sharing of data located in existing archives and databases scattered throughout the Caribbean.
2. Putting in place structures/programs to capture data that is not yet digitized and not yet available for use by researchers.
3. Putting in place programmes, infrastructure, and instrumentation to enable and/or support the capture of new data.
4. Subjecting existing data to rigorous quality control techniques in order to build a climate database for use by other sectors.
5. Acquiring useful datasets from sources outside the Caribbean, for example, detailed bathymetric maps of the Caribbean region.
6. Creating additional databases (where possible) of variables deemed necessary for interdisciplinary work, for example, soil moisture, SST, etc.

Capacity – Human and Technical

7. Investing in postgraduate training with an emphasis on Caribbean climate variability and change, numerical modelling of climate, and the modeling of climate change impact on various sectors including biodiversity, agriculture, tourism, water and coastal zones.
8. Supporting student exchanges within and outside of the region.
9. Support for staff education and training (especially for existing staff at meteorological services) in numeric and impact modelling, interpretation of results, analysis methods for climate change etc.
10. Acquiring equipment and software to support climate research at existing organizations and institutions with track records for doing the same. This would include massive storage devices, beowolf clusters (for numerical model runs), high speed intranet, radar networks, satellite images, software licenses and professional packages (for example, Fortran, Matlab, GIS and professional Linux), high speed intranet, radar networks, satellite images, licenses and professional packages.
11. Updating meteorological infrastructure to ensure recording of quality data. This would include acquisition of automatic stations and calibration equipment for basic meteorological instruments for example thermometers, barometers, etc. as well as the acquisition of specific meteorological instruments, for example, buoys, mareographs, and gradient towers to study the turbulent layer and the wind properties near the ground level, solar radiometers and UV sensors, to study the solar potential of our region, etc.

Knowledge

12. Developing online mechanisms for storing and disseminating information for example, a web-page compendium for use as a clearing house document for information.
13. Developing a Caribbean climate atlas.
14. Facilitating dialogue between climate researchers and scientists of other sectors such as biodiversity, in order to establish priorities, needs and deliverables for climate change studies.
15. Supporting graduate student research and cross disciplinary training.

7. Climate Models, Generation of Climate Scenarios

Scenarios can be generated using Atmospheric Global Climate Models (GCM), Coupled Atmospheric-Ocean Global Climate Models (AOGCM) which give coarse results over a large grid (~ 4° latitude x 4° longitute), and Regional Models, which have a smaller scale of approximately 50km. These models are referred to as dynamic models since they utilize the dynamic processes that affect climate. Current temperature, pressure, relative humidity and winds are used as inputs into these models and many atmospheric parameters, computed and stepped forward in time, are produced as outputs. Another technique used for generating the scenarios is called statistical downscaling. The aim of statistical downscaling is to generate the climate scenarios for a small region or even a point such as a weather station, using the output of a dynamic model for a larger region; hence the term downscaling. The process consists of generating and validating regression equations that relate the climate parameters to be downscaled for the small region, called predictands, with climate predictors, such as surface temperatures, pressure and vertical velocity, which are available from data sets, such as the National Centre for Environmental Prediction (NCEP) re-analysis dataset (Kalnay *et al.*, 1996). These regression equations are then employed to find scenarios of future climate for the small region by using future values of the predictors generated by the dynamic model (reproduced from Chen *et al.*, 2006). All models must be validated by comparing their simulation of current or past climate with current or past climate data.

General Circulation models can be used to study climate change in the Caribbean region as a whole. For finer resolution, for example, studying an individual island, a regional model with resolutions of 25 to 50 km would be required. For studies of smaller areas, for example, biodiversity around a station, statistical downscaling would have to be used. The statistical method however requires an input of a long time series of daily data, preferably of at least 30 years duration, but it has been know to be used with as short as 15 years of data.

Because information for biodiversity studies includes knowledge of climate threshold values and geographical distribution, statistical downscaling may be a method of choice due to its site specific nature. This method is versatile in terms of the parameterization and generation of future climate. Say, for example, that vegetation growth rate was related to relative humidity. In the first place, independent of generating scenarios, a long time series would allow for better correlation between vegetation and relative humidity. Then by statistical downscaling, scenarios of a time series of relative humidity could be obtained for sometime in the future, and this in turn could be used to develop scenarios of growth rate.

In addition, for purposes of downscaling a properly designed statistical method may in actuality be more reliable than a regional method using a single model. This is because the convention in obtaining the most reliable scenario from dynamic models is to use the average scenario from a number of models. So if the values of future predictors to be used in a statistical downscaling model could be obtained by averaging these values from outputs of several GCM's, the scenario generated by the statistical model would be more reliable than that obtained by a single regional model using inputs from a single GCM. The main limitation would be the uncertainty that the regression equations developed between the predictors and predicted in the present climate would remain the same in the future climate. However the likelihood of this is quite good since we know most of the atmospheric physics and chemistry involved, and there is not much room left for surprises.

8. Concluding Remarks

This report has established that, although Caribbean Institutions are able to analyze and generate climate change scenarios, gaps in our ability to do so exist. Section 5 lists the needs and suggests pathways for bridging the gaps. Some solutions are not expensive, such as inter-disciplinary collaboration, exchange of personnel and training. Others require more funding, notably in computer accessories. Invariably the question will be asked whether or not the efforts to bridge the gaps are worthwhile. The scenarios generated by more affluent countries are global (and regional for their own needs). It will inevitably be the task of Caribbean countries to produce their own regional scenarios, and the quality of the scenarios generated will depend on the capability, so that efforts must be made to increase it. There are questions that need to be answered concerning changes in Caribbean biodiversity, as reported by the other 2 working groups in the *CCBIC* project, which require more data gathering and model runs.

The question will also be asked 'What if global warming can be limited and eventually reversed will efforts be in vain?' In the first place, the world is already committed to increases (less than 2°C) over the century due to the long life time of greenhouse gases in the atmosphere and the 'long' memory of the ocean even if GHG emission conditions were stabilized. In the second place there are many advantages to be gained, outside of global warming concerns. Increased capacity in climate studies will lead to better forecasting of daily weather and of seasonal changes, such as drought and floods. Crop models and climate models could be combined to predict crop yields. Again, models could be run to determine the effects of deforestation, or better yet, the effects for re-forestation. So that filling the gaps in our capability to study and generate future climate will not be in vain.

Acknowledgements

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Attachment

Precipitation and Temperature at Casablanca station, Cuba, 1909 - 2000/2

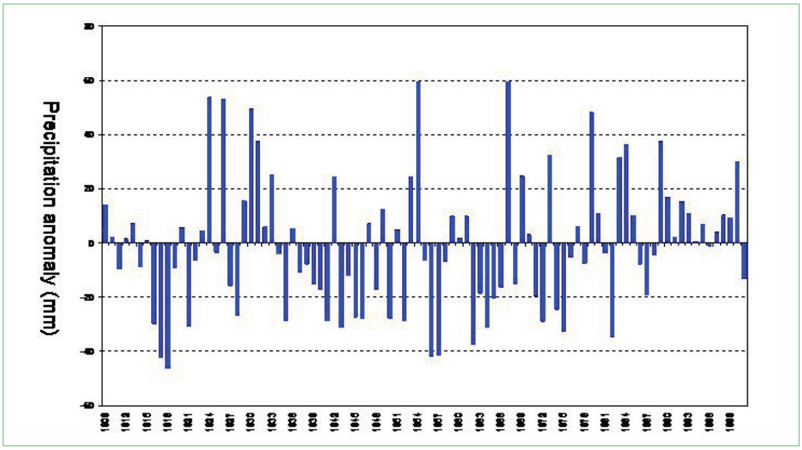

FIGURE A1

Precipitation anomaly at Casablanca station, Cuba, 1909 - 2000.

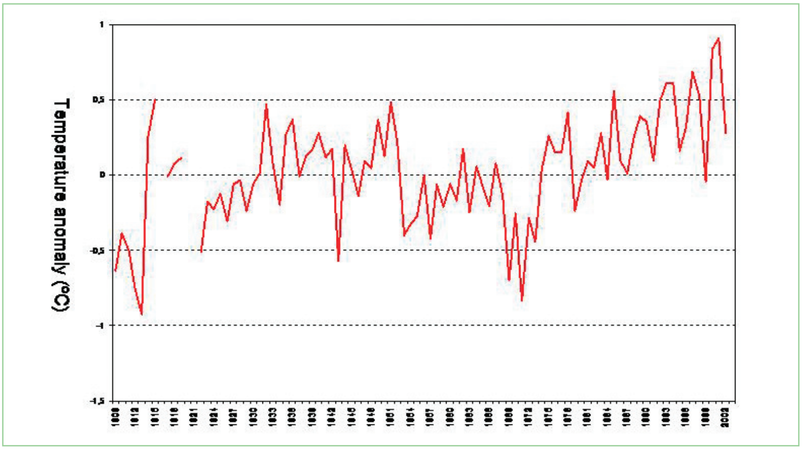

FIGURE A2

Temperature anomaly at Casablanca station, Cuba, 1909 - 2002.

PAPER

13 CLIMATE CHANGE AND ADAPTIVE RESOURCE MANAGEMENT IN THE SOUTHWEST NOVA BIOSPHERE RESERVE

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ABSTRACT: Recognition of the global phenomenon of climate change is stimulating government response internationally and nationally. However, there is a need to better define regional climate change impacts, and develop strategies to enhance ecological and socioeconomic resilience at the community level. This paper describes several selected research and monitoring activities being carried out to define impacts from climate change in southwestern Nova Scotia, Canada, followed by strategies being developed by government, industry and community colleges in response to potential climate change impact. Research and monitoring projects conducted in the Southwest Nova Biosphere Reserve region include ecosystem process and biodiversity monitoring in Kejimkujik National Park and National Historic Site; analysis of Blanding's turtles growth rings as indicators of climate dynamics; monitoring of microclimate and sea level change modeling using LIDAR technology; and assessment of wetland and aquatic system changes. Climate change response initiatives described include strategic planning by the Government of Nova Scotia; response strategies of Nova Scotia Power Company; use of climate data for agricultural planning by the Applied Geomatics Research Group of the Nova Scotia Community College (NSCC); NSCC Lunenburg Campus forestry training initiatives; and collaborative community based public education initiatives by the Mersey Tobeatic Research Institution and the Southwest Nova Biosphere Reserve Association.

Keywords: climate change, ecological and socioeconomic resilience, impacts, biodiversity, monitoring, microclimate, response initiatives

1. Introduction

While the scientific community has increasingly become aware of the measurement challenges, facts and interrelationships associated with the climate change phenomena over the past few decades, the global public at large has only much more recently begun to be informed. As risk of significant environmental impact due to anthropogenic causes increases, democratic societies must understand and support regulation while making personal choices to reduce the pollutants contributing to the problem. In industrialized nations, this represents a huge challenge. Many economies that were developed in the 20th century depend on large and often inefficient use of coal and petroleum products. Hence, there are major socioeconomic implications associated with addressing the climate change threat in developed countries. Acknowledging that most governments in the world have now recognized the threat and reality of climate change, the process has begun to address the challenge of change. While climate change discussions associated with the Kyoto Protocol, and more recently in Bali, have been advanced at the national level, there is a growing recognition that resiliency strategies also have to be developed and implemented at the regional and community level.

Climate change impacts can vary widely across geographic regions. The ecology, including hydrology, soils, vegetation, and socioeconomic characteristics will affect the nature the responses to problems in a given area. In a socioeconomic context, climate change impacts can directly affect economic health in a specific region, or indirectly as a consequence of impact elsewhere. For example, it has been suggested that the high rate of climate related mountain pine beetle (Dendroctonus ponderosae) range extension, and subsequent salvage tree harvest in western Canada, has impacted the economic viability of sawmills in eastern Canada.

The following paper discusses some methods by which climate change is being studied in the UNESCO Southwest Nova Biosphere Reserve in Nova Scotia, Canada, and examines some of the adaptive response approaches being developed in the region.

2. Discussion area

The area to be discussed forms the southwestern portion of the peninsular Province of Nova Scotia, in eastern Canada. The region is bounded on its north shore by the Bay of Fundy, with the world's highest tides, and on the eastern coast by the North Atlantic Ocean. The areas' terrestrial land base has been designated the UNESCO Southwest Nova Biosphere Reserve and is comprised of 5 municipal counties; Annapolis, Digby, Queens, Shelburne and Yarmouth (13,770 km^2) with a population of approximately 100,000 people. The core protected area of the Biosphere Reserve is comprised of Kejimkujik National Park and National Historic Site (381 sq km), and the Tobeatic Wilderness Area

(1038 km^2). The bedrock of southwestern Nova Scotia is primarily igneous, with some metamorphic and sedimentary elements. Forest soils tend to be thin and acidic. The landscape shows the effects of previous glaciation, and features a large number of shallow lakes, rivers and other wetlands. The climate is strongly influenced by the sea and weather systems originating over continental North America. Surface fresh waters in the region tend to be acidic and nutrient poor, with low mineral content and buffering capacity (Kerekes, 1973a). Nova Scotia's geographic positioning downwind from North America's industrial heartland results in high levels of acidic precipitation from air pollution on the continent.

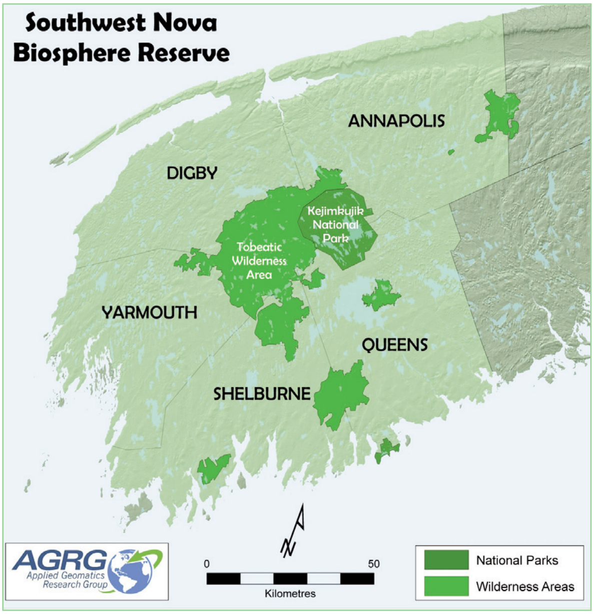

FIGURE 1

The Southwest Nova Biosphere Reserve region.

2.1 Terrestrial Biodiversity

Forests in the Southwest Nova Biosphere Reserve area are classified as part of the Acadian Forest region, one of eight forest types in Canada (Rowe, 1972). Tree species include red spruce (*Picea rubens*), white spruce (*Picea glauca*), white pine (*Pinus strobes*), eastern hemlock (*Tsuga canadensis*), and larch (*Larix laricina*) interspersed with red maple (*Acer rubrum*), red oak (*Quercus borealis*), sugar maple (*Acer saccharum*), white birch (*Betula papyrifera*) and white ash (*Fraxinus* *americana*) in the complexity of the landscape. Harvesting, fire, insects and storms play a role in influencing succession. While much of the biodiversity is typical of the boreal/mixedwood forest, areas with warmer microclimate may account for some of the southern originating coastal plain flora and fauna including the water-pennywort (*Hydrocotyle umbellata*), Blanding's turtle (*Emydoidea blandingii*), northern ribbon snake (*Thamnophis sauritus septentrionalis*), and southern flying squirrel (*Glaucomys volans*).

2.2 Human use in the Southwest Nova Biosphere Reserve region

Use of the area began with aboriginal activity more than 4500 years ago. The Mi'kmaq traversed the region and utilized both forest and coastal resources. European presence started in the 17th century and primary industry initially included forest harvest for ships timbers, and the fishery. Nova Scotia ports were also considered important as strategic military bases. The Annapolis valley rose in importance for agriculture beginning in the 18th century. Currently, southwestern Nova Scotia socioeconomic fabric has diversified, as reflected in the nature of the towns, businesses and transportation in the region. Forestry, the fishery and agriculture remain as important industries, despite increased global competition and fish harvest decline. Tourism, based on the picturesque landscape, is an important contributor to the economy. The people in the region are hard working and progressive. The Southwest Nova Biosphere Reserve, beginning 100 Km west of the provinces' capital Halifax, is comprised of smaller coastal and inland communities that depend on natural resources to sustain their populations.

A large protected area complex, including Kejimkujik National Park and National Historic Site and the Tobeatic Wilderness Area in the core of the Biosphere Reserve, feature a high standard of biodiversity protection and visitor experience. The National Park has served as an important national monitoring site for long range transported air pollutants and there is strong collaboration among land users, local and regional educational institutions for environmental research and monitoring. Modern communities in southwestern Nova Scotia struggle with the economic, social and ecological challenges typical of many northern hemisphere countries. However indicators of climate change are beginning to raise concerns in an environmental and socioeconomic context.

2.3 Modeling climate change

While monitoring for climate change can simply be a function of weather documentation and assessment at a given site, the projection of climate trends and impacts for a specific geographic region, using current information and understanding of global processes, is a far more complex modeling process.

Climate can be thought of as an average of the weather over a period of years or decades. It describes the characteristic weather conditions to be expected in a region at a given time of year, based on long-term experience. By international convention, weather observations are commonly averaged over a period of 30 years to produce the statistics that describe the climate "normals". These averages are helpful for providing "average" temperatures and precipitation, or when comparing one location to another, but they do not provide the necessary information to assist communities in planning for climate change adaptation (Fenech and Liu, 2007).

Climate change monitoring and assessment in southwestern Nova Scotia is being carried out as a consequence of a number of Environment Canada programmes. The Atmospheric Environment Service continues to monitor weather and air pollutants at the Kejimkujik site. Parks Canada has collaborated with the Adaptation and Impacts Research Group to apply General Circulation Models (GCM) to project climate change impacts in Kejimkujik, and other national parks across Canada (Scott and Suffling, 2000). The projections for Kejimkujik inland and at Kejimkujik Seaside could be considered representative for southwestern Nova Scotia. Based on a 100 year projection for doubling of atmospheric CO_2 projections (Shaw *et al.*, 1998), sea level rise around the coast of Nova Scotia increase by 0.5m, with resultant altered marine terrestrial interface, intercoastal erosion and salt water intrusion. Changes in currents are projected to occur as a result of cooling coastal waters resulting in more fog.

Air temperatures is projected to increase by 3.4°C in winter and 3.9°C in summer (Scott and Suffling 2000). Rainfall is projected to increase in the spring and fall, but decrease by 3-5% in the summer. Storm frequency is projected to increase. Clair (1998) has suggested that peak run-off would change from May to April, with minimum flow changing from September to August, with decreased summer water levels. These climate changes could increase forest fire frequency and intensity, insect pest distribution and subsequently forest succession. Red maple and poplar would likely show a positive response to the change in climate, while red spruce, sugar maple, hemlock, beech and white ash may show a negative response.

2.4 Climate change validation studies

To observe manifestations of climate change, it is desirable to assess a number of indicators which can help with impact and trend determination. The following 11 sections are selected examples of climate change effects studies in southwestern Nova Scotia.

3. Sea level change modeling using LIDAR technology; Coastal Flooding Analysis Tools

■ Project purpose

A model was required that would first help accurately determine land elevations, and flood elevations from past storms. Second, a model was required that would help determine flood frequencies, that is, probabilities, for different flood levels, including climate change impacts on flood levels. LIDAR with Water Modeler was chosen for the study, which was then tested in Annapolis Royal, Nova Scotia, the coastal flooding test community.

■ How the Model Works

LIDAR (Light Detection and Ranging), is used for collecting elevation data from an aircraft using a laser. It has emerged in the last 5-10 years as the most accurate means of topographic mapping. The result of a LIDAR survey is a dense set of elevation points (on the order of cm or m spacing) that include the earth's surface as well as features such as trees and buildings. The points can be brought into a geographical information system (GIS) and used to build surfaces that represent the earth's topography. The level of detail and the accuracy of the elevation maps, known as digital elevation models (DEMs) are far superior to traditional methods and provide the ideal map to determine flood risk.

■ Modeling software development

Applied Geomatics Research Group (Nova Scotia Community College), with partners in the private sector under the leadership of Roger Mosher has developed tools to facilitate the analysis of coastal areas vulnerability to flooding from storm surges. Tools that were developed include a software package known as the "Water Modeler" that allows observed water level records to be analyzed and probabilities and return periods to be calculated based on observed water levels. The approach taken calculates empirical annual probabilities of accedence of a given water level, and allows a model to be constructed for the prediction of probabilities with relative sea-level changes incorporated, to simulate possible climate change effects. The method is based on the "Gumbel extreme value distribution".

■ Model testing and historical analysis

In order to ascertain historic flood levels, past floods were examined and ground-truthed with interviews of Annapolis Royal businesses and residents located near the boundaries of these floods. The flood that occurred on February 2, 1976 (known as the Groundhog Day storm) was the highest historical flood for which accurate records were available. Thus, this became the primary flood for analysis of future impacts of climate change.

The 1976 flood extent was mapped with LIDAR, and using GIS the stages of the flood in terms of when dikes and levees were breached was determined. The storm surge at St. John, NB was modeled on top of the elevation of the predicted high tide to calculate the still flood water level. Wind records were used with a bathymetric and land elevation model to simulate the waves during the storm. These data provided the inundation area but did not address the frequency of this flood, that is, what the return period, or probability was of it occurring in any given year.

■ Bernier Model

In order to help determine the probability of such a flood as the 1976 occurring, a sea level rise and storm surge model developed by Bernier (2005) was used. The model analyzed water level records from various tide gauges around the region for the last 40 years to calculate return periods of storm surge water levels and how they might change under climate change scenarios. The storm surge model was driven by historical wind records reported at every 6 hours, thus the observed water levels were averaged from hourly to every 6 hours, resulting in underestimating some short lived storm events.

■ Water Modeler

Concurrent with the Bernier (2005) study, Water Modeler was being developed and was compared to the results of Bernier (2005). Water Modeler was used to analyze the hourly tide level data, recorded by the Department of Fisheries and Ocean, for Saint John, New Brunswick. The water levels were then translated from St. John to Annapolis Royal across the Bay of Fundy. Testing showed that translation was sufficiently accurate so that the extent of the 1976 flood could be mapped. The long time series of water levels at St. John were compared with a shorter time series at Digby west of Annapolis Royal. The difference in storm surge magnitudes between St. John and Digby was on average 1 cm with a standard deviation of 30 cm. Thus the water level predictions for Digby and Annapolis Royal were expected to be accurate within 40 cm (for example, 1 standard deviation). Climate change factors were incorporated as follows.

■ Climate Change

The cumulative flood probabilities were plotted for the Groundhog Day storm in St. John (4.95 m orthometric) using the current relative sea level rise rate of 22 cm per century and the projected climate change potential rate of 80 cm per century. The flood level-return period graphs constructed demonstrate how any water level return period can be extracted, with or without sea level rise from climate change.

■ Model Results

The use of LIDAR, with the adaptation of Water Modeler to our site, proved to be an excellent method of determining probabilities for floods of different levels. The resulting flood elevations we obtained using LIDAR and Water Modeler together allowed the modeling of many different actual and hypothetical flood elevations for the test site of Annapolis Royal (Figure 2). Also, this combination of tools provided a probability factor for the 1976 Groundhog Day storm: 1 in 121 years. These results were used in Annapolis Royal coastal flooding analysis,

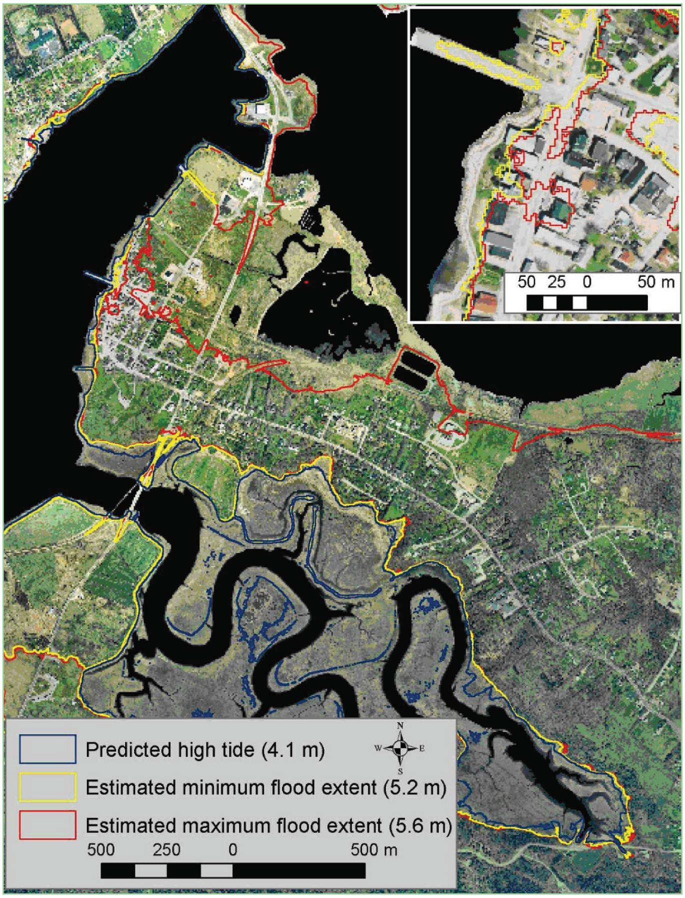

FIGURE 2

GIS mapping of Annapolis Royal showing estimated flood extent.

which in turn, was used in the GIS mapping analyses. The blue line in Figure 2 represents the predicted high tide level and the yellow and red lines represent the predicted flood levels of the Groundhog Day Storm. The yellow line represents a level of 5.2 m, representing the minimum flood extent, and the red line represents a level of 5.6 m, representing the maximum extent of the flooding, considering the precision of the method used.

Conclusions for Land Use Planning

Accurate coastal flood risk mapping, with climate change factored in, will become increasingly important to land use planning. This is an issue in most of Atlantic Canada, and will become increasingly important as existing development in the floodplain is flooded more frequently, and new development threatens coastal shores. As demonstrated in this study, a difference in water level of 40 cm can have a significant impact of flood extent. Many costal communities have vulnerable infrastructure to such events that are expected to increase in the future as a result of climate change.

4. Biodiversity and climate monitoring studies in Kejimkujik National Park and National Historic Site

Kejimkujik National Park and National Historic Site has been the focus of significant Environment Canada research and monitoring activity beginning in 1978 with the Long Range Transport of Air Pollutants study programme (LRTAP). Information gathered at Kejimkujik contributed to international agreements to reduce acid rain producing pollutants. It is also a participant in the Environment Canada Ecological Monitoring and Assessment Network (EMAN). One hectare SI/MAB study plots have been used at Kejimkujik to study multi-taxa forest biodiversity (Drysdale and Howell, 1998), exotic species occurrence, and forest insect defoliation impact. While Environment Canada continues to collect climate and airborne pollution data on site, Parks Canada Agency scientists have continued to develop strategies to understand ecosystem stressors and their implications for maintenance or restoration of park ecosystem integrity.

Currently, Parks Canada is developing a monitoring strategy incorporating a bioregional perspective for a variety of measures. With the participation of other national parks in eastern Canada, this approach is intended to facilitate efficient use of study resources, and provide documentation of environmental change over a large geographic area. Standardized protocols are used and results are being recorded in a national databank, as well as being stored and updated on site. Exceeded thresholds will be linked to specific management responses to ensure maintenance of protected area ecological integrity.

At Kejimkujik, forest plot scale monitoring will document changes in vegetation community composition, tree recruitment, tree growth and mortality, arboreal lichen diversity, occurrence of exotics, changing soil moisture, and decay rates. Monitoring birds, white-tailed deer and salamanders will also contribute to knowledge associated with forest ecosystem dynamics. At a landscape scale, change in forest composition, net primary productivity, change in successional pathways, larger scale disturbance tracking, including insects, fire, and blow down will be documented using geomatics tools. In aquatic ecosystems, changes to fish populations due to loss of quality coldwater habitat and invertebrate change will be monitored. Water quality, lake freeze and thaw dates, wetland wells and sea level changes will also be documented.

Continuing work on species at risk recovery including Blanding's turtle, northern ribbon snake and piping plover will also incorporate consideration for potential climate change effects.

Recent research has shown a change appears to be occurring in lake cold water temperatures. Kejimkujik has very few lake refugia that can develop thermoclines and trap cold water required for brook trout survival in summer.

In 2002, a native forest insect largely unknown to science became a major player in forest dynamics. The Pale-winged gray (*Iridopsis ephyraria*) had affected some hemlock stands in the region. In some stands it destroyed up to 90% of mature tree needles within the first year, and eliminated most understory growth. Forest insects such as the gypsy moth (*Lymantria dispar),* the oak leaf roller (*Tortrix viridana*), chain-spotted geometer (*Cingilia catenaria*), and jack pine budworm (*Choristoneura pinis*) have defoliated forest stands in the park within the last five years. (Pers Con. Chris McCarthy, Kejimkujik National Park and National Historic Site, Maitland Bridge, Nova Scotia).

Increasing numbers of invasive exotic vegetation species are being identified and removed from the park to maintain ecosystem integrity. Monitoring continues to safeguard against invasive exotic fish from neighboring waters.

5. Assessment of wetland changes

From 2004-2007 stratigraphic and paleobotanical (pollen) studies have been conducted on sediment cores from the Pleasant River Fen in southwestern Nova Scotia to determine how climate change may have influenced the wetland (Martin *et al.*, 2005). Wetlands constitute an important terrestrial sink for carbon. A decrease in productivity or change in groundwater regime will affect this sink and a net release of greenhouse gases could result. Wetlands in Nova Scotia also provide habitat for several rare, disjunct species, most notably the Blanding's Turtle. The survival of these species may be dependent on the stability of these environments.

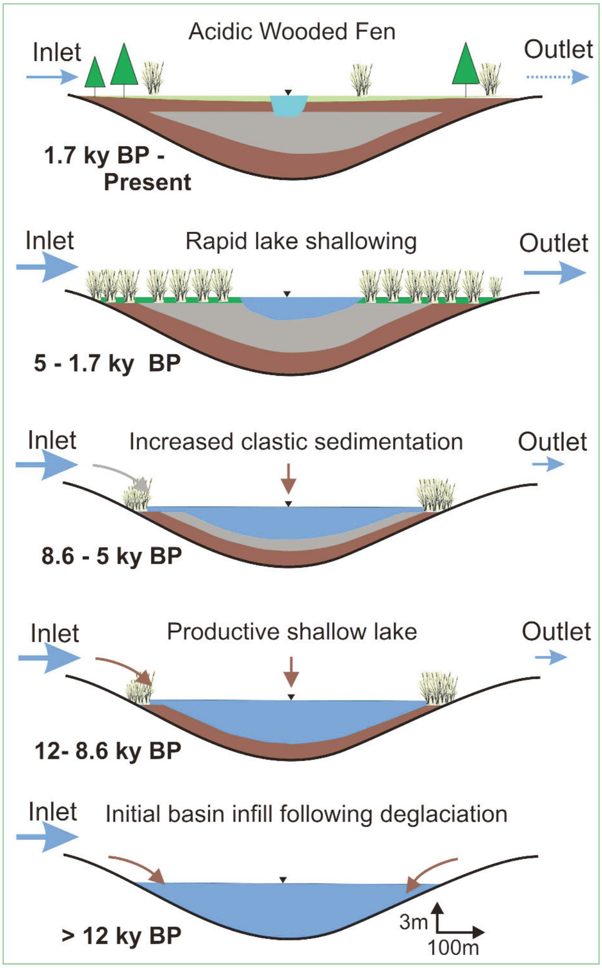

FIGURE 3
Cartoon indicating how the Pleasant River Fen has evolved since deglaciation.The fen has been strongly influenced by climate driven changes in groundwater levels as well as the natural evolution of the wetland environment.

Vibracoring, sonar mapping and dating of wood recovered in sediment cores indicated that over 5 m of dominantly organic sediment has been deposited since deglaciation (~12000 ^{14}C yr BP). Transitions in the abiotic properties of the bog sediment indicate that the water table was likely much lower than at present during the middle Holocene (8000 – 3000 ^{14}C yr BP) and that the region was dominated by a forest assemblage consistent with drier and slightly warmer than present conditions. A transition in the pollen and sediment record at about 3000 ^{14}C yr BP is coincident with the onset of modern moist cool climate in the region, and a significant rise in the water table. The upper 40 cm of the core (300 BP – Present) exhibits much lithostratigraphic variability which appears related to human activity (fire, water level management) in the region. The results of this study indicate the Pleasant River Fen (Figure 3) has evolved significantly in response to past climate change. Future climate change has the potential to further modify this environment.

6. Assessment of aquatic system changes

A major objective of the Mersey Tobeatic Research Institute/Parks Canada project to advance understanding of water quality and habitat connectivity, is to assess the status and quality of aquatic ecosystems in the upper Mersey River watershed. With respect to cold water fish species, such as brook trout (*Salvelinus fontinalis)*, a major limiting factor is the presence of summer refugia having cold water and adequate dissolved oxygen. Information on the locality and status of cold water lake habitats within the Mersey River watershed is important for development of conservation and protection efforts intended to preserve these important habitats. Increasing pressure is also being placed on many lakes in Nova Scotia as a result of forestry and agricultural activities and the increase in lakeshore cottage and residential home development that is evident in many areas of the Province.

The research team approach adopted to meet these objectives was to initially identify lakes within the upper Mersey watershed likely to contain cold water habitat based on information contained in the FINS database (The FINS database is maintained by the Nova Scotia Department of Agriculture and Fisheries and contains all of the data collected as part of the Province's Lake Survey Program) and the extensive database developed on lakes within Kejimkujik National Park by Kerekes (1973a), and Kerekes and Schwinghamer (1973b). The primary condition for selection was that the maximum depth of the lake had to be >6 m to ensure sufficient hypolimnetic volume to serve as cold-water habitat. A secondary selection condition, necessary to assess the degree of change in cold water habitat, was the availability of historical survey data collected during either July or August, the time when water column stratification is strongest and hypolimnion dissolved oxygen concentrations are the lowest. A total of 45 lakes met these conditions. Of the 45 lakes identified, five were selected for survey during August 2005.

The five lakes within the upper Mersey watershed were surveyed to determine if they contained suitable cold water habitat during summer. Of the five lakes surveyed, four lacked suitable cold water habitat during August, and the remaining lake only contained suitable cold water habitat within the lower portion of the metalimnion (Figures 4 ad 5). In 2006 an additional six lakes located within the Mersey watershed were surveyed. All but one lacked suitable cold water habitat during August, and the remaining lake only contained suitable cold water habitat within a small area of the thermocline. When compared to surveys carried out two to three decades earlier, all of the lakes except one exhibited a significant decrease in cold water habitat. This decrease was due to reduced levels of dissolved oxygen rather than elevated water temperatures.

These results are similar to those obtained by Brylinsky (2002) in a similar survey of 20 lakes located throughout Nova Scotia. In that study it was suggested that the differences observed over time could be a result of either a change in the trophic status of the lakes, or to a difference in the length of the growing seasons between survey years. In that study it was also determined that there was very little difference between the degree of temperature stratification and hypolimnetic dissolved oxygen concentration measured during July and August.

Because of the lack of data on trophic state for the early surveys, it is not possible to determine if the decrease in cold water habitat may be related to changes in trophic status. However, the majority of lakes surveyed do not appear to have been subjected to conditions that would result in nutrient over-enrichment leading to eutrophication. It is thus possible that the change observed in cold water habitat is a result of a shorter ice-free period and a corresponding longer growing season which would result in a longer period of time for depressed hypolimnetic dissolved oxygen concentration to develop.

7. Analysis of Blanding's turtles growth rings as indicators of climate dynamics associated with species at risk recovery

Richard (2007) used digital plastron scan images to measure growth ring sizes of immature Blanding's turtles and attribute temperature and precipitation variables to growth ring size in the endangered south western Nova Scotia population. A new methodology was developed for standardizing measurements of plastral growth rings by adapting dendrochronological techniques such as the statistical software tools COFECHA, ARSTAN and PRECON.

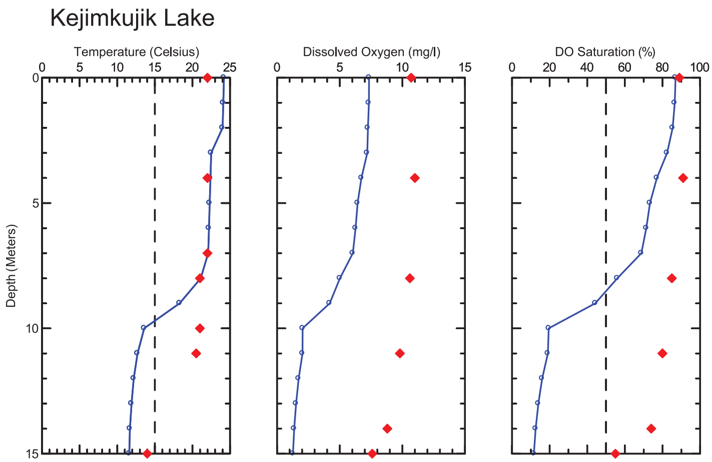

FIGURE 4

Temperature, dissolved oxygen and percent dissolved oxygen profiles for Kejimkujik Lake collected on 23 August 2005 (diamonds) and 3 August 1971 (circles). (dashed lines represent approximate upper temperature and lower percent dissolved oxygen limits for cold water salmonids).

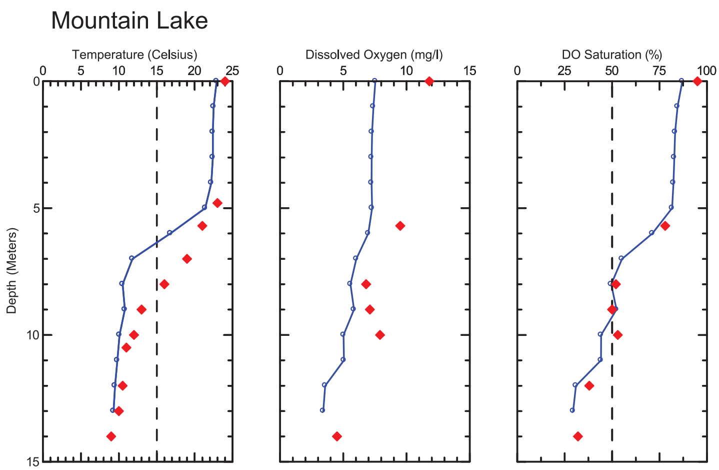

FIGURE 5

Temperature, dissolved oxygen and percent dissolved oxygen profiles for Mountain Lake collected on 24 August 2005 (diamonds) and 5 August 1971 (circles). (dashed lines represent approximate upper temperature and lower percent dissolved oxygen limits for cold water salmonids).

COFECHA was used to verify that the growth ring series for each individual turtle cross-dated across the entire sample size (N=116). A total of 56 individual chronologies cross-dated (series intercorrelation = 0.443) with each other, the remainder were mostly very young in age (< 10 years). COFECHA also allowed the correction of aging errors within individual chronologies. ARSTAN was used to remove the age variable (detrend) in the cross-dated series (N=56) and create one "master chronology" for the data set (N=30 years) using growth index as scale, where a growth index value of 1 indicates an average year of growth while >1 indicates above average and <1 indicates below average. PRECON was designed for tree ring studies and longer data sets and requires 39 years of data to run its analysis. Richard added 9 years of average growth (growth index = 1) to the master chronology to explore its use on a turtle chronology. PRECON was used to estimate the R-square value of mean monthly temperature and precipitation response functions for the master chronology (R square = 0.51).

Because of PRECON's limitations, Richard conducted a series of calibration/verification linear regression models using MINITAB on the master chronology (N=30), mean monthly precipitation and temperature, previous mean monthly precipitation and temperature and previous year's growth ring index in order to strengthen the climate response analysis. The model chosen (60% calibration/ 40% verification) had an R Square value of 0.81 and corresponded to response variables outlined from the PRECON analysis (positive response to current September temperature, current March temperature and current June precipitation). The model was then used to hindcast and forecast Blanding's turtle growth using climate data from the third generation coupled Global Climate Models made available through Environment Canada's Canadian Centre for Climate Modeling and Analysis.

Tree ring data from five softwood species (larch, eastern hemlock, red spruce, white pine, balsam fir) adjacent to Blanding's turtle habitat and collected by the Mount Allison University Dendrochronology Lab did not significantly correlate with the Blanding's turtle master chronology. Because Blanding's turtle growth is closely linked to climate, climate change impacts could be numerous. Larger females lay larger clutches (McNeil, 2002; Congdon and van Loben Sels, 1991), thus an increase in growth could lead to larger clutch sizes and consequent greater fitness and turtle abundance throughout Nova Scotia if evolutionary forces are maintained. However, change in climate could also result in a change in mean nesting dates, habitat and food availability changes, skewed sex ratios (due to temperature sex determination in the nest) and other unknown behavioral and physiological responses.

The y axis represents growth index is as described above (1 = year of average growth, <1 below average growth, >above average); x axis is years. The master chronology from ARSTAN is in green (N=30). Two models using the Canadian Centre for Climate Modeling and Analysis data are in red and blue, red representing no stabilization of CO_2 emissions, blue if emissions are stabilized to 550 ppm. The hindcast model (model of what happened in the past) is represented in grey.

8. Climate Change Adaptation Through Learning (ATL): Using past and future climate extremes science for policy and decision-making

Communities need information on extremes of climate so that they can determine how they adapted in the past to these extremes, and subsequently how to best plan for the future. This approach is known as Adaptation Through Learning (Fenech and Liu, 2007), and applies in a preliminary way to the Southwest Nova Biosphere Reserve. In order to provide for community-based climate change adaptation planning, a history of climate extremes (hot-cold,

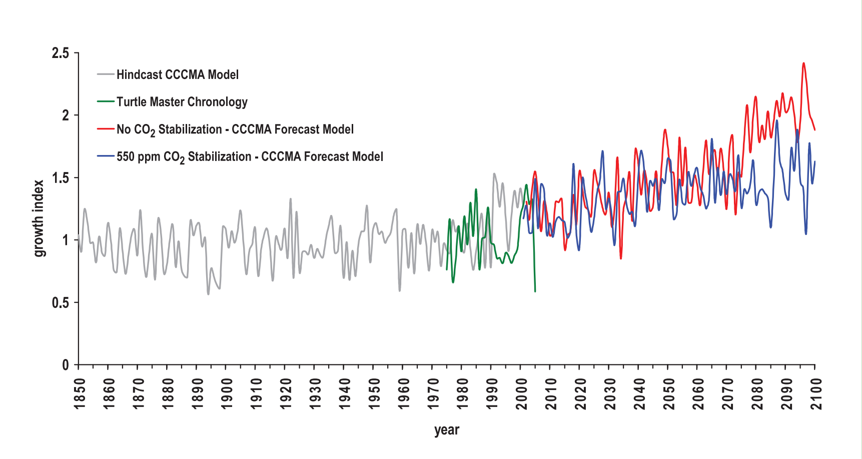

FIGURE 6
Blanding's turtle plastral growth ring hindcast and forecast linear regression models (60/40 calibration/verification).

wet-dry) is required for the Southwest Nova Biosphere Reserve located in Nova Scotia, Canada. Figure 7 shows mean daily temperature that be modified to show annual extreme hot days (Figure 8).

What lessons does the community learn from past climate events that can be useful in the future? Climate records document a year of extreme hot days just 15 years ago (Figure 8). This extreme year may have required intervention to save agricultural crops, or ensure a supply of potable water for communities. Similarly, civic preparedness for extreme storm events benefit from assessment of the past. Hence, this information becomes invaluable for response planning to address challenges associated with climate change.

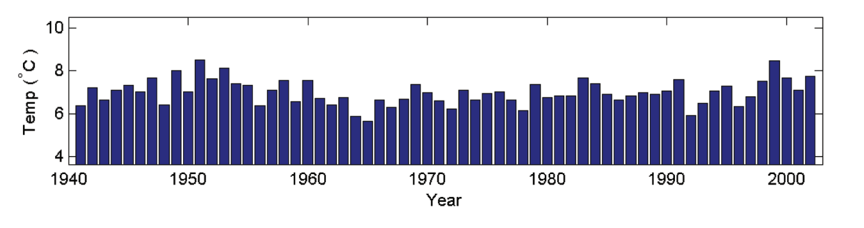

FIGURE 7
Mean Daily Temperature of Yarmouth Station A (8206500) from 1941-2002.

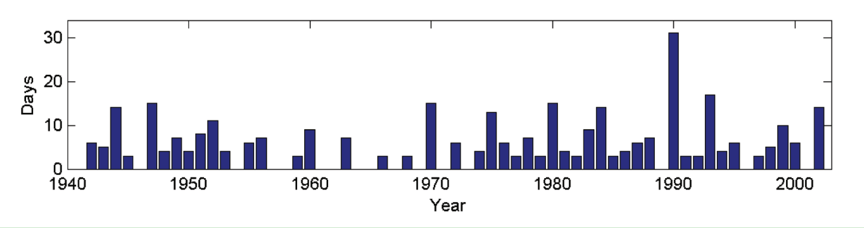

FIGURE 8
Annual Extreme Hot Days at Yarmouth Station A (8206500) from 1941-2002.

9. Examples of resilience planning and response

Development of resilience strategies must include an adaptive approach based on modeling, risk assessment, and precise observations of the land, sea and atmosphere. The following is an example of response strategies for climate change submitted by a variety of contributors for this discussion. They describe initiatives taken at the policy level by governments, energy industry, educational institutions, and actions taken in Southwest Nova Biosphere Reserve communities.

■ Province of Nova Scotia strategic planning and response

In general, the government of Nova Scotia is including impacts and adaptation considerations in various plans and strategies. Nova Scotia outlined its key environmental economic goals in the Environmental Goals and Sustainable Prosperity Act (EGSPA June 2007), including commitments to reducing greenhouse gases (GHG) and to protecting biodiversity. Reducing GHGs to ten percent (10%) below 1990 levels is a significant commitment for Nova Scotia. The Province of Nova Scotia remains one of the few provinces in Canada to have legislated GHG targets. With regards to biodiversity, the EGSPA commitment is to develop strategies by 2010 to ensure sustainability of forestry, mining, parks and biodiversity. (Pers com. Andrew Murphy, Manager, Air Quality Branch Department of Environment and Labour, Halifax Nova Scotia).

■ The Nova Scotia Department of Energy perspective

Climate change will have economic, environmental and social repercussions for virtually all sectors and regions of Nova Scotia. As a coastal province Nova Scotia is particularly vulnerable to the effects of sea-level rise and storm surge from more frequent and extreme weather events. Adapting to climate change is about taking proactive steps *now* to manage the risks and take advantage of any opportunities from climate change. It is recognized that it is far more cost effective to prepare now than to react later.

The NS Department of Energy has been the lead on climate change adaptation since 2001. It worked closely with provincial, municipal and federal departments to address the issue and support adaptation research and policy responses. The department has partnered with a number of other provincial agencies, has supported and developed research work, information guides, policy tools and a comprehensive public issues paper that discusses potential impacts, responses and departmental responsibility. As of April 1, 2008, the new Department of Environment will be taking the lead role on climate change adaptation.

In recognition of the need to better coordinate and mainstream adaptation responses across the government, the Department of Environment will work closely with other agencies and municipalities to try and develop a provincial strategy for adaptation, to be included in the Climate Change Action Plan, to be released later in 2008. The intent is to have the strategy prioritize and focus adaptation work, coordinate responsibility across departments, and enhance access to local information on climate risks and possible policy responses.

Already many departments have begun to take climate change impacts and adaptation options into consideration when developing their operational strategies. The NS Department of Environment and Labour is examining the impact of climate change on water supplies for their Water Strategy, while the NS Department of Natural Resources is looking at how climate change will affect parks, recreation, minerals and biodiversity in their Natural Resources Strategy. The NS Department of Fisheries and Aquaculture is also exploring the issue of coastal management.

10. Nova Scotia Power initiatives

Over the past eighty years, the province's main electricity supplier, Nova Scotia Power, and its predecessor utilities were designed and built to use indigenous fuels such as hydro power and coal. Now, Nova Scotia Power is diversifying by adding cleaner sources of energy such as natural gas and rapidly expanding its portfolio of renewable energy sources. Approximately 11 percent of the electricity consumed in Nova Scotia comes from cleaner, greener energy sources such as hydro, wind, biomass and tidal power. That number will grow to around 20 percent by 2013.

(Photo courtesy of OpenHydro)

FIGURE 9
In stream tidal power generation.

Nova Scotia has more installed wind power for domestic consumption than any other Atlantic province - 40 turbines rated at 60 megawatts. Nova Scotia Power is in the process of issuing contracts for an additional 240 megawatts of electricity from wind power. New wind farms are scheduled to be up and running in 2010. Nova Scotia Power is partnering with OpenHydro of Ireland to develop in-stream tidal power technology. A demonstration unit will be tested in a new provincial test facility in the Minas Passage of the Bay of Fundy, beginning in 2009 (Figure 9).

In recent years the company has reduced sulphur dioxide emissions from existing coal fired plants by 25 percent. Nitrogen oxides will be reduced by 40 percent. Greenhouse gases pose a significant challenge. Nova Scotia Power believes all options are on the table including looking outside Nova Scotia for electricity imports free of GHGs. The company is exploring the importation of nuclear power from New Brunswick and/or hydro power from Newfoundland. NSPI is a member of the Canadian Clean Power Coalition and is working with Dalhousie University to undertake research into new technologies such as carbon sequestration.

Recent customer surveys show that Nova Scotian's support a strategy that includes adding more renewables and cleaner energy choices and measures that save energy in their homes and businesses. Nova Scotia Power is working with stakeholders to develop a comprehensive demand side management program that will offer new energy conservation incentives and assistance for all customer classes: residential, commercial and large industry, with specific programs designed for low income households.

Hurricane Juan landed in Nova Scotia in 2003 and post tropical storm Noel caused damage in 2007 (Figure 10). To combat stronger storms Nova Scotia Power is spending more on vegetation management, cutting trees back from transmission line corridors and power lines. The goal is to reduce the opportunity for trees and tree limbs, combined with high winds, to cause power outages.

11. Annapolis Valley Temperature Mapping Study

To better understand the environmental landscape of the Annapolis Valley region the Applied Geomatics Research Group (AGRG) at the Centre of Geographic Sciences (COGS) has for years compiled numerous geospatial data layers of the Valley region. Landsat TM, Ikonos, and high-resolution digital aerial photography have been used to map over two decades of land cover change throughout the region. Since 2000 the AGRG began mapping the entire valley area using both CASI and LiDAR.

AGRG has also deployed meteorological monitoring equipment in association with AgraPoint International and the Grape Growers Association of Nova Scotia (GGANS). To date 16 Campbell Scientific meteorological stations and 75 Hobo temperature data loggers have been installed. While the 75 loggers record temperature, the meteorological stations record a full suite of parameters including wind speed, direction, solar radiation, air temperature, relative humidity, barometric pressure, rainfall, soil temperature and moisture.

All of the meteorological stations are wirelessly accessible via 1xRTT digital modems and a server set up at the AGRG lab. Automated processes summarize the data collected, and post the results, including monthly minimums, maximum, and mean temperatures, along with the monthly total heat accumulation (that is, Growing Degree Days base 10°C) on the AGRG website in near real-time.

This information, as well as the number of days making up the frost free growing season and the minimum winter temperatures, provides the grape growers with information that is useful when deciding on the variety of grape suitable for their vineyards.

Additionally, the AGRG is integrating the data collected from these in-situ sensors with other geospatial layers to analyze the meteorological conditions of the Annapolis Valley region. This provides an opportunity to understand the


(Photo courtesy of NS Power)

FIGURE 10
Effects of post tropical storm Noel in 2007.

relationships that exist between the temperature and physical measurements of the topographic landscape (that is, elevation, slope, aspect, proximity to the coast, and land cover). This will lead to a much more comprehensive understanding of the temperature/climate conditions throughout the entire Annapolis Valley region, and provide insight into global climate change and the implications for the future of Nova Scotia's agricultural industry.

12. Training initiatives by the Lunenburg Campus of the Nova Scotia Community Colleges (NSCC) to advance sustainable forest management

The NSCC Lunenburg Campus Natural Resources Natural Resources Environmental Technology training programme focuses on forest management in theory and practice in the region. The programme has evolved over the years to include course segments on biology, forest dynamics, forest ecosystem management, wildlife, and riparian zone management, in context with sustainable forestry. Climate change is discussed in context with implications and possible solutions for the Acadian forest typical southwestern Nova Scotia. We discuss forest species shifting from their natural ranges, increased exotic insect/disease attacks, remedies for these attacks, and consideration that increased annual temperature could lengthen the growing season. Students learn about the visual signs of trees under stress or dying.

Forestry dynamics are examined including carbon storage and carbon sinks in context with implications for industry and small woodlot owners. Long term management of growing forests must consider whether trees planted today will be healthy 50 years from now.

Students develop case studies and presentations on various resource management challenges including silviculture projects for Region of Queens Municipality, the Nova Scotia Department of Natural Resources, forest companies and private landowners. Similarly, wildlife habitat improvement, riparian zone management, uneven forest management and Acadian Forest restoration techniques, and the use of prescribed burning in Kejimkujik National Park and National Historic Site are addressed.

Students spend 4 weeks on an on the job placement, at the end of their course. Placements vary with the student's desire however some continue their careers as silviculture specialist.

13. A community-based response to local science information needs: The Mersey Tobeatic Research Institution Cooperative

The non profit Mersey Tobeatic Research Institute Cooperative was established as a community-based response to advance the use of science for decision-making on working landscapes and protected areas. Its registered mandate is to educate and increase public understanding of biodiversity conservation and sustainable resource management, while conducting ecological research associated with land use, species at risk, climate change and biodiversity assessment. MTRI functions in collaboration with the Southwest Nova Biosphere Reserve Association, as well as with universities, colleges, government agencies, communities and businesses in the region.

MTRI's multi-disciplinary board of directors includes scientists, administrators, educators, land owners and interested community members. Research and monitoring, education and communication, building, planning, and finance committees facilitate programme operations. The cooperative employs a project scientist and other staff to support project implementation, and field station operation at Kempt in the Region of Queens Municipality.

The MTRI field station provides office and lab workspace, basic accommodation and a venue for public presentations and training.

MTRI has undertaken a range of habitat connectivity, species at risk planning, research, monitoring and education projects.

14. The Southwest Nova Biosphere Reserve: A region wide approach to advance sustainable development and public education

The designation of the UNESCO Southwest Nova Biosphere Reserve in 2001 has facilitated significant collaboration among government, business, science and communities to advance sustainable resource management, biodiversity protection and associated public understanding in southwestern Nova Scotia.

A number of education initiatives have been implemented, and the public profile of the Biosphere Reserve continues to grow. The organization is exploring new opportunities to support operational staff, and enhance collaboration with participating municipalities, provincial and federal governments, and industry partners.

The Southwest Nova Biosphere Reserve provides important regional coordination function to facilitate understanding of environmental and socioeconomic issues such as climate change, while encouraging cooperative response and associated educational initiatives.

15. Conclusions

The general nature of this paper precludes definitive assessment of the full range of climate change studies and response planning in Nova Scotia. However, it appears that there are a variety of collaborative programmes being implemented by government agencies, educational institutions, sectors of the energy industry, and at the community level, in the South West Nova Biosphere Reserve.

While the terrestrial Biosphere Reserve area is well studied, there is a need for continuing research, monitoring, and analysis to understand the processes and implications for biodiversity, forests, watersheds, agriculture and marine fisheries in the region. There is a need to engage the public and enhance education associated with the climate change challenge and its implications for all sectors of society in Nova Scotia. Public understanding of the consequences of inefficient use of fossil fuels, and of greenhouse gas emission impact will help in the formulation of effective public policy in Canada.

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PAPER 14

CLIMATE CHANGE ADAPTATION THROUGH LEARNING (ATL): USING PAST AND FUTURE CLIMATE EXTREMES SCIENCE FOR POLICY AND DECISION-MAKING

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ABSTRACT: Climate can be thought of as an average of the weather over a period of years or decades. It describes the characteristic weather conditions to be expected in a region at a given time of year, based on long-term experience. By international convention, weather observations are commonly averaged over a period of 30 years to produce the statistics that describe the climate "normals". These averages are helpful for providing "average" temperatures and precipitation, or when comparing one location to another, but they do not provide the necessary information to assist communities in planning for climate change adaptation. Communities need climate information on extremes of climate so that they can determine how they have adapted in the past to these extremes, and how to best plan for these in the future. By showing the community how the climate has changed in the past, the question can be asked as to how they have adapted to these changes. Years of climate extremes may have required intervention from the community to save agricultural crops, preserve endangered species habitat, or ensure the quality of groundwater. This knowledge, taken together with scenarios of future climate change showing similar extreme hot or dry years in the future (that is, changed return periods), can identify some adaptation measures that might be taken to ensure that an adaptation infrastructure is in place, or that alternative management of the biosphere reserve occurs. In other words, what lessons did the community learn from the last event that can be drawn on with advanced knowledge about the future to minimize the negative impacts and maximize the benefits from climate change? The authors title this approach Adaptation Through Learning (ATL), and the paper provides an example from Canada.

Keywords: climate, climate change, adaptation, extremes, learning, Biosphere Reserves

1. Introduction

Climate can be thought of as an average of the weather over a period of years or decades. It describes the characteristic weather conditions to be expected in a region at a given time of year, based on long-term experience. By international convention, weather observations are commonly averaged over a period of 30 years to produce the statistics that describe the climate "normals" (see Phillips and McCulloch, 1972; Gates, 1973; Watson, 1974; Janz and Storr, 1977; Wahl *et al,* 1987; Auld *et al,* 1990). These averages are helpful for providing "average" temperatures and precipitation, or when comparing one location to another, but they do not provide the necessary information to assist communities in planning for climate change adaptation.

For example, as part of the Canadian Biosphere Reserves Association (CBRA) Climate Change Initiative (CCI) designed to present climate change information to Biosphere Reserve communities to allow local organizations to understand climate change and adapt to potential impacts, Hamilton *et al.* (2001) examined instrumental climate records from Biosphere Reserves across Canada including Waterton Lakes, Riding Mountain, Niagara Escarpment, Long Point, and Kejimkujik (a candidate Biosphere Reserve that was designated as the Southwest Nova Biosphere Reserve in 2001). Annual average temperature and precipitation series were generated from daily temperature and precipitation values. Long term trends were identified over the period of the instrumental record leading to the following results.

In general, data from the interval 1900 to 1998 show cooler temperatures in the 1920's, warming from the early 1940's into the early 1950's, cooling into the 1970's, and subsequent warming. At many stations, 1998 was the warmest in the instrumental record. The 20th century warming was shown as approximately 1.0 degree Celsius in the Riding Mountain area and 0.6 degrees Celsius at Long Point, Niagara Escarpment (see Figure 1 for example), and Waterton Lakes. There was a slight cooling in the Kejimkujik area over the past half century. Precipitation data showed increasing trends in the Kejimkujik. Long Point, Niagara Escarpment, and Waterton Lakes areas with no long term trend in the Riding Mountain area.

Managers at the Biosphere Reserves in Canada were perplexed when presented with this data and information. How, they asked, was such information on climate normals and trends supposed to assist them in preparing for future climate change, and the necessary adaptations that might follow?

This paper presents how the needs of environmental managers at Canada's Biosphere Reserves have dictated the development of an approach to community-based adaptation strategies to climate change that the authors title *adaptation through learning: using past and future climate extremes science for policy and decision-making.*

2. Biosphere Reserves in Canada

Biosphere Reserves are ecosystems around the world, regionally representative of the biosphere, and recognized internationally by UNESCO's Man and the Biosphere (MAB) Programme as part of a global network of 459 Biosphere Reserves in 97 countries (UNESCO, 2007). Biosphere Reserves are used to share

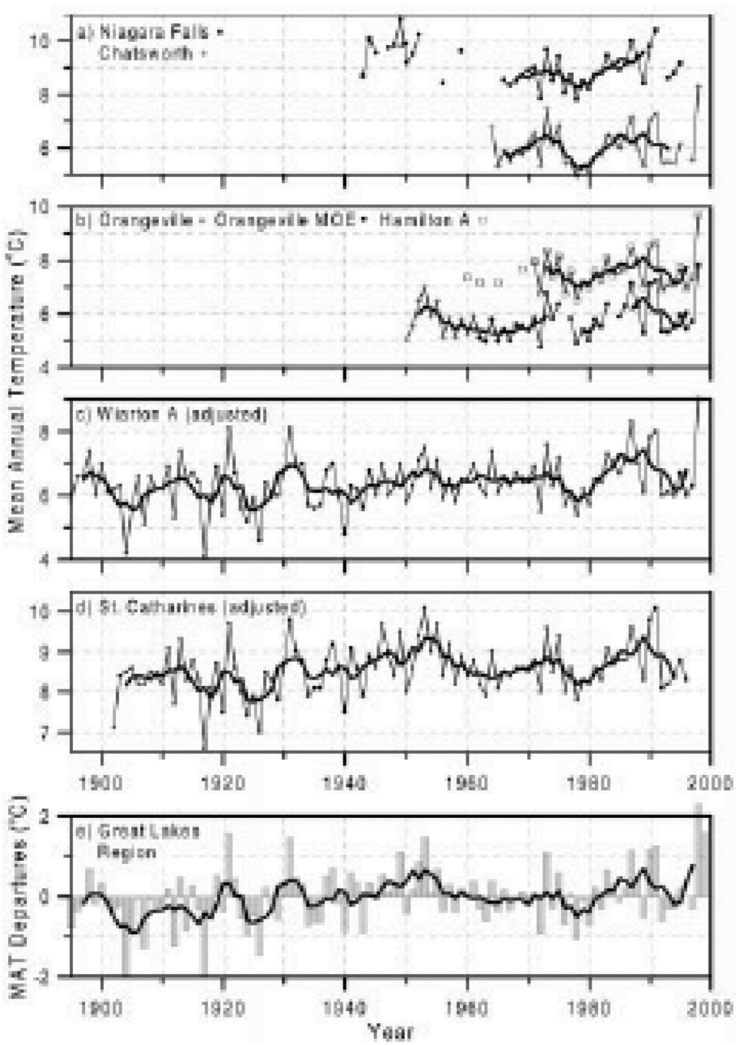

FIGURE 1

Mean annual temperature for stations representing Niagara Escarpment Biosphere Reserve, and departures for the Great Lakes Region. (Source: Hamilton *et al.*, 2001).

knowledge on how to manage natural resources in a sustainable way; to co-operate in solving natural resource issues; to conserve biological diversity; to maintain healthy ecosystems; to learn about natural systems and how they are changing; and to learn about traditional forms of land-use. Biosphere reserves are test areas for demonstrating ideas, tools, concepts, knowledge, etc. of resource conservation, sustainable development as well as climate change. It is the role of the biosphere reserve to serve as a mechanism for enhancing local, regional, and multi-jurisdictional cooperation that is most needed in the area (Ravindra, 2001).

These objectives are met through each Biosphere Reserve's management structure, or "round table" of local communities (ranging from local indigenous communities to rural societies), farmers, foresters, fishermen, research scientists, government decision-makers, and other agency representatives. What make these "round tables" unique are their connection to a national network of Biosphere Reserve communities and the links to the World Network promoting areas where sustainable development is an applied concept.

Since 1972, UNESCO has designated 15 biosphere reserves in Canada (see Figure 2): Mont St. Hilaire (Quebec, 1978); Waterton (Alberta, 1979); Long Point (Ontario, 1986); Riding Mountain (Manitoba, 1986); Charlevoix (Quebec, 1989); Niagara Escarpment (Ontario, 1990); Clayoquot Sound (British Columbia, 2000); Redberry Lake (Saskatchewan, 2000); Lac St. Pierre (Quebec, 2000); Mount Arrowsmith (British Columbia, 2000); South West Nova (Nova Scotia, 2001); Thousand Islands – Frontenac Arch (Ontario, 2002).

3. Adaptation to Climate Change

According to Smit *et al.* (2000), adaptation to climate change is the process of adjusting in response to, or in anticipation of, changed conditions. In the climate change context, more specifically, it is adjustment in ecological, social or economic systems in response to actual or expected climate stimuli and their effects or impacts. Adaptation is not a new concept (Burton, 2004) as it has been employed traditionally by ecologists to refer to the evolutionary process by which living organisms mould into a new environment. Observers have broadened the scale of reference by using the concept of adaptation to describe how systems, both natural and human, evolve over time when faced with environmental changes.

Adaptation can take the form of autonomous, reactive, or anticipatory action (Abramovitz *et al.*, 2002). *Autonomous adaptation* to climate change is

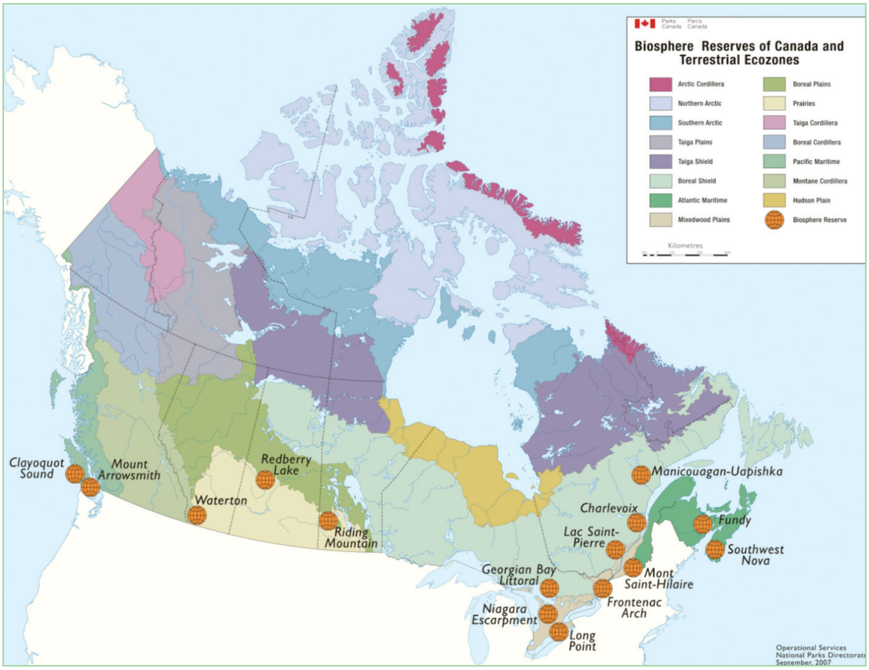

FIGURE 2
Map of Canada's Biosphere Reserves
Source: Canadian Biosphere Reserve Association, 2008.

essentially an unconscious process of system-wide coping, most commonly understood in terms of ecosystem adjustments. *Reactive adaptation*, as the name implies, involves a deliberate response to a climatic shock or impact, in order to recover and prevent similar impacts in the future. *Anticipatory adaptation* involves planned action, in advance of climate change, to prepare for and minimize its potential impacts. Such actions can aim at enhancing the buffering capacities of natural systems in the face of climate extremes.

The most recent literature in the climate change adaptation field revolves around concepts of building adaptive capacity (see Fenech *et al.*, 2004), adaptive capacity and development (Smith *et al.*, 2003), the adaptation deficit (Burton, 2004), and knowledge translation (Fenech and Murphy, 2006). Most relevant to this paper is the concept of knowledge translation – a concept used in the health care field that can be applied to climate change adaptation. Knowledge translation can be defined as the effective and timely incorporation of evidence-based information into the practices of health professionals in such a way as to affect optimal health care outcomes and maximize the potential of the health system. This same concept can be applied to the climate change adaptation field. Traditional methods of reading printed educational materials and attending didactic educational meetings are often not very effective in changing behavior (Grimshaw, 1998). To change behaviour and sustain a willingness to adapt to climate change will require, at a minimum, a catalyst for change, an understanding of the barriers to change, ongoing activities and communications to reinforce new behaviours, and recognition for taking the action (Fenech *et al.*, 2005). This paper presents an approach to providing past and future climate information, merged with experience and understanding of changes required, as a means of attempting to bring about climate change adaptation.

4. The Approach

Informal discussions were conducted with environmental managers at Biosphere Reserves in Canada and China – these being those responsible for local agriculture, local tourism, park management, or biodiversity conservation. The question was asked: "How do you make preparations about the threats from future climate (climate change)?" Most viewed the threat of climate change, or their own vulnerability, was to climate extremes – extreme hot, cold, wet and dry. They also felt that they had good experience with extreme weather over the past decades that they could learn from how they adapted in the past (if reminded of the specific years). The unknown was when and how often extreme weather was going to occur. The authors leave the answer to "when" to the *Farmer's Almanac*, but there is some science available to provide guidance on answering the question of "how often." It was clear from the discussions that communities such as Biosphere Reserves need climate information on extremes of climate so that they can determine how they have adapted in the past to these extremes, and how to best plan for these in the future.

4.1 Indices of Climate Extremes

An index of climate extremes summarizes and presents a complex set of multivariate and multidimensional climate changes so that the results can be easily understood and used in policy decisions made by nonspecialists in the field. Many have developed their own indices of climate extremes (see World Meteorological Organization (WMO) Commission on Climatology (CCl) (Karl *et al.*, 1999); European Climate Assessment, 2006; Stardex, 2006; *et al.)* totaling over 400, yet for the application of indices of climate extremes to Canada, the authors considered Gachon (2005) who identified 18 indices for extreme temperature and precipitation for Canadian regions.

Gachon considered four criteria in choosing indices: the indices must represent Nordic climate conditions such as found in Canada; the indices must be relevant to climate change impact studies; extreme indices are relatively moderate (for example, using 10th and 90th percentiles as opposed to the 5th and 95th); and indices are adapted to the main characteristics of climate conditions at the regional scale. Gachon (2005) concludes that the 18 indices presented in Table 1 "provide a good mix of information – precipitation indices characterize the frequency, intensity, length of dry spells, magnitude and occurrence of wet

TABLE 1

Gachon Indices of Climate Extremes for Impact Studies of Climate

DEFINITION		UNIT	TIME SCALE
Precipitation *Indices*			
Frequency	Percentage of wet days (Threshold=1 mm)	% days	Season
Intensity	Simple daily intensity index : sum of daily precip/ number of wet days	mm/wet d	Season
Extremes	Maximum number of consecutive dry days (<1 mm)	days	Season
Magnitude	Maximum 3-days precipitation total	mm	Season
and	90th percentile of rainday amount (Threshold=1 mm)	mm/days	Season
Occurrence	Percentage of days Prec>90th percentile (61-90 based period)	% days	Season
Temperature *Indices*			
Daily variability	Mean of diurnal temperature range	°C	Season
	Percentage of days with freeze and thaw cycle (Tmax>0°C, Tmin<0°C)	% days	Month
Season length	Frost season length :Tday<0°C more than 5 d.and Tday>0°C more than 5 d.	days	Year
	Growing season length :Tday>5°C more than 5 d.and Tday<5°C more than 5 d.	days	Year
Extremes	Sum of sequences > 3 days where Tmin< daily Tmin normal - 5°C	days	Winter
Cold & Hot	Sum of sequences > 3 days where Tmax> daily Tmax normal + 3°C	days	Summer
Extremes	10th percentile of daily Tmax	°C	Season
Magnitude	90th percentile of daily Tmax	°C	Season
and	10th percentile of daily Tmin	°C	Season
	90th percentile of daily Tmin	°C	Season
Occurrence	Percentage of days Tmax>90th percentile (61-90 based period)	% days	Season
	Percentage of days Tmin<10th percentile (61-90 based period)	% days	Season

extremes while temperature indices refer to variability, season lengths and cold and warm extremes in terms of magnitude, occurrence and duration."

These indices provide climate information as "easily understood and used in policy decisions made by nonspecialists in the field."

4.2 Climate Observational Data for Past Climate Extremes

The Gachon Indices of Climate Extremes (GICE), used to present to communities across temperate regions on understanding climate changes, are based on the two most common meteorological observations - temperature and precipitation. For the indices to be useful in understanding extremes, observations of the maximum and minimum temperatures as well as precipitation should be available on a daily basis, with a record length of at least thirty years of data. Basic climate observations of temperature and precipitation are taken around the world using common methodologies and standards established by the World Meteorological Organization (WMO). Temperature and precipitation observations are recorded across Canada by automatic weather stations, and volunteer climate observers.

An automatic weather station is a cluster of climate sensors connected to a data logger. Sensors are usually positioned by international standards and protocols on a two meter mast, and the station powered by a solar panel and battery. Sensors often used on automatic weather stations include: air temperature; relative humidity; rainfall; solar radiation; wind speed and direction; and barometric pressure. These stations can be designed as automated bioclimate monitoring stations (see Figure 3) adding sensors to measure meterological variables throughout the forest canopy and into the soil.

A network of more than two thousand volunteer climate observers from every province and territory in Canada records maximum and minimum temperature readings and precipitation readings twice daily. Every morning before eight o'clock, and every evening after five, these dedicated individuals head out into their backyards, schoolyards, churchyards or farmyards to observe using a rain gauge, a ruler and a thermometer housed in a louvred wooden box called a Stephenson screen. These measurements are reported to Environment Canada using an automated telephone entry system, and since 2000, via the Internet. The new system has resulted in a reduction in expenses (for manual data entry, postage and handling), automated quality assurance and data availability from observation to archive in minutes rather than months. The Canadian National Climate Archive in Toronto, Ontario, now houses more than seven billion

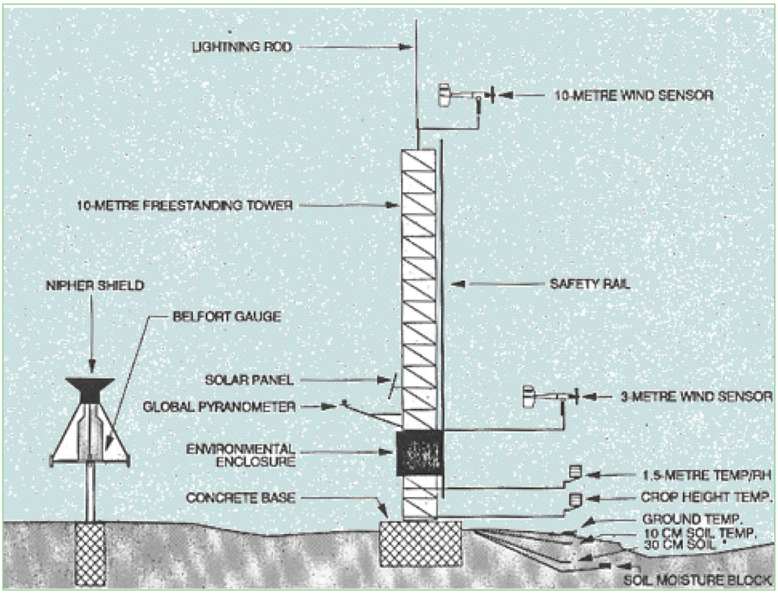

FIGURE 3
Bioclimate instrumentation to measure a profile of temperature, humidity, wind, precipitation and solar radiation throughout the forest canopy and temperature into the soil. (Source: Fenech *et al.*, 1995).

observations collected across Canada over the past century and a half, many of which are from volunteer climate observers.

To monitor and detect climate change reliably, the indices should contain variations that are caused by climate processes only. There are two aspects to consider when constructing these indices (Zhang, 2004). First, the original daily data should be homogeneous, that is, be free of not-climate-related variation. Secondly, the method for constructing the indices should not introduce any additional variation (function of use of calendar years that need to be overcome – see Zhang *et al,* 2005). A climate dataset contains climate information at the observation sites, as well as other non-climate related factors such as the environment of the observation station, and information about the instruments and observation procedures under which the records were taken. An assumption is made that the station records are representative of climate conditions over a region when the data are used in climate analysis. This is, unfortunately, not always the case. Zhang (2004) provides two excellent examples:

For example, if an observing station is moved from a hill top location to the valley floor 300 meters lower in elevation, analysis of its temperature data will likely show an abrupt warming at the time of the station relocation. This artificial jump would not be representative of temperature change in the region. Also, consider a station located in the garden of a competent and conscientious observer for 50 years, and suppose a tree was planted west of the garden at the time the observation station was established. The instruments are maintained in good condition and the observer accurately records the temperature in the garden. The tree slowly grows up and shades the observing site during the late afternoon when the daily maximum temperature is observed. As a result, the recorded daily maximum temperature would gradually become lower than that over the surrounding area not shaded by the tree. Thus the station would gradually become less representative of the surrounding area.

A real life example of a Canadian site being moved has been shown by Vincent (1998). It is therefore important to remove the non-climate factors from the data as much as possible, before the climate data can be used reliably for climate change studies. A great deal of effort has been made to develop methods to identify and remove non-climatic inhomogeneities (see Peterson *et al.*, 1998) and the WMO has developed a set of practical guidelines on how to deal with inhomogeneity problems depending on the circumstances under which inhomogeneity occurs (see WMO, 2007).

4.3 Modeling Future Scenarios of Climate Extremes

Our present understanding of the climate system and how it is likely to respond to increasing concentrations of greenhouse gases in the atmosphere would be impossible without the use of global climate models (GCMs). GCMs are powerful computer programs that use physical processes to replicate, as accurately as possible, the functioning of the global climate system (Environment Canada, 2002).

GCMs use mathematical models to simulate the functioning of the global climate system in three spatial dimensions and in time. Modern climate models, such as Canada's GCM, include coupled atmosphere, ocean, sea-ice and land-surface components. Constraints on the availability of computing resources dictate that coupled models, such as Canada's GCM, must operate at modest resolutions.

For example, the atmospheric component of the Canadian model is a 3-dimensional grid with a horizontal spacing of about 300 km and 10 layers in the vertical. The model simulates atmospheric temperature, pressure, winds and humidity at each grid point. The ocean has considerably higher resolution, using 29 layers of grid points with a horizontal resolution of about 150 km. The model simulates the density, salinity and velocity of the ocean water at each grid point. The land-surface component has one layer, uses the same horizontal grid as the atmosphere, and simulates the temperature and moisture content of the soil. The sea-ice component, which also has one layer, uses the horizontal grid of the atmosphere and simulates the temperature and thickness of the ice pack.

Detailed projections of local climate impacts cannot be made with modest resolution GCMs. Climate impact studies usually require detailed information on present and future climate with high resolution and accuracy. In most cases, detailed information is needed with spatial resolutions of the order of 100 km or less, and with high accuracy concerning the tails of statistical distributions (in particular the frequency and intensity of rare events). At the lowest end of the spatial resolution, with scales of one or a few grid distances, the global climate models have little or no skill.

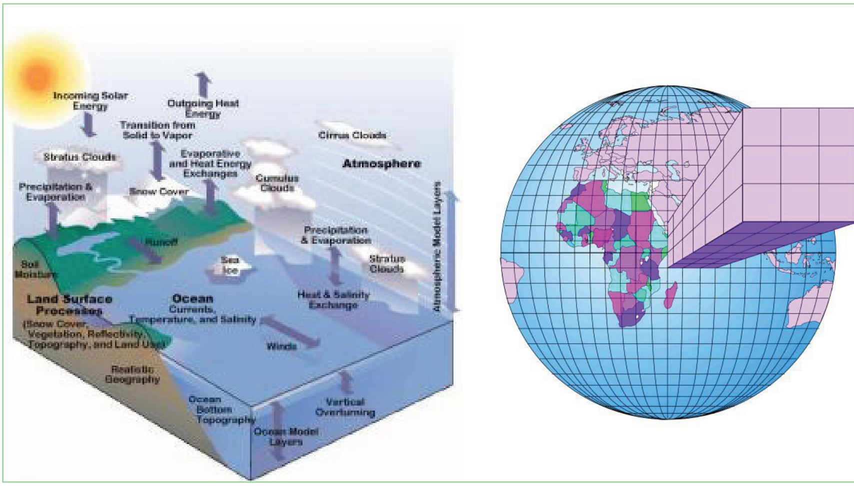

FIGURE 4
On left, climate system to be modeled by Global Climate Model (GCM); on right, gridded horizontal and vertical layers of a GCM.

A method often used to refine results from global models is to nest a regional climate model (RCM) within a GCM. In this approach, information from the global model is used to drive a higher resolution limited area model at its boundaries. The RCM in turn simulates climate features and physical processes in much greater detail within its limited area domain. The success of the nested approach depends on the accuracy of the large scale model (at the scales that it represents) and on the quality of the regional model. Scenarios of future climate change have become available from the Canadian Regional Climate Model (Caya *et al.,* 1995) recently (see CRCM website), yet no assessments have been made of their usefulness in local climate impact studies.

A number of methodologies have been developed for deriving more detailed regional and site scenarios of climate change for impacts studies. These downscaling techniques are generally based on GCM output and have been designed to bridge the gap between the information that the climate modelling community can currently provide and that required by the impacts research community (Wilby and Wigley, 1997). The literature presents downscaling techniques as generally divided into spatial (deriving local scenarios from regional scenarios) and temporal (deriving daily data scenarios from monthly or seasonal information) classes (Giorgi and Mearns, 1991).

Spatial downscaling refers to the techniques used to derive finer resolution climate information from coarser resolution GCM output. The fundamental bases of spatial downscaling are the assumptions that it will be possible to determine significant relationships between local and large-scale climate (thus allowing meaningful site-scale information to be determined from large-scale information alone) and that these relationships will remain valid under future climate conditions. There are three main classes of spatial downscaling:

- Transfer functions - statistical relationships are calculated between large-area and site-specific surface climate, or between large-scale upper air data and local surface climate.
- Weather typing - statistical relationships are determined between particular atmospheric circulation types (for example, anticyclonic or cyclonic conditions) and local weather.
- Stochastic weather generators - these statistical models may be conditioned on the large-scale state in order to derive site-specific weather.

Each has its own advantages and disadvantages, but what is most important is which method is able to most accurately take CGCM or CRCM data and statistically downscale it to areas the size of Canadian communities such as

Biosphere Reserves. No evaluation has been made as to the accuracy and appropriateness of the various methods – CGCM, CRCM, transfer downscale, weather typing, stochastic weather generator – for providing future climate scenarios for areas the size of Canadian communities.

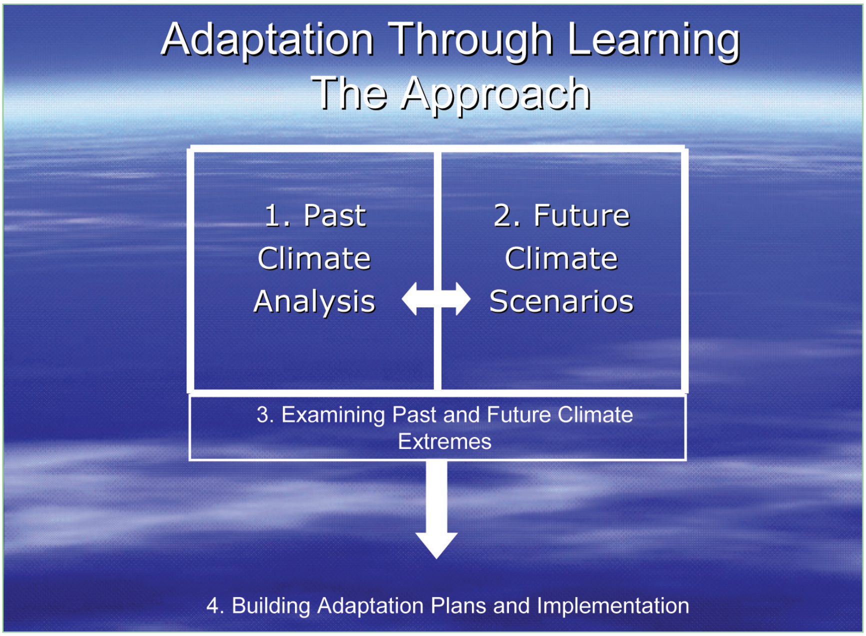

FIGURE 5
The Approach of Adaptation through Learning: Using Past and Future Climate Extremes Science for Policy and Decision-Making.

5. Applying the Approach as an Example

As shown above, in order to provide for community-based climate change adaptation planning, a history of climate extremes (hot-cold, wet-dry) should be built for the community – in this example, the Southwest Nova Biosphere Reserve located in Nova Scotia, Canada. Observational data from several climate stations are available for this Biosphere Reserve (see Figure 6 for example of climate stations around Southwest Nova Biosphere Reserve). However, a station from Canada's Climate Reference Network close to Southwest Nova Biosphere Reserves was selected to ensure the length and completeness of climate records

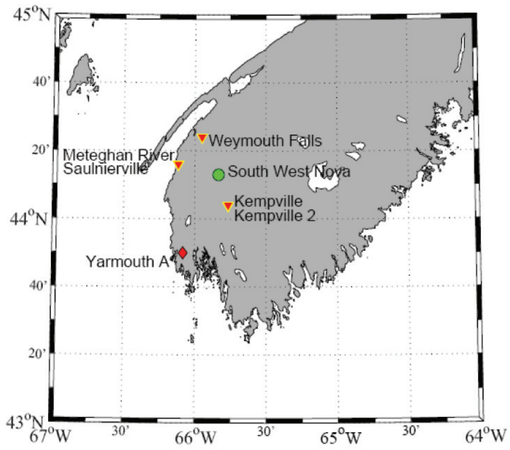

FIGURE 6
Climate Stations around Southwest Nova Biosphere Reserve in Nova Scotia, Canada.

available. There are 302 Reference Climate Stations in Canada for climate change studies, as well as other climate research (Plummer *et al.*, 2003).

At least seventy years of climate data are available for each of Canada's stations in the Climate Reference Network used in this study. The daily maximum, minimum and mean temperatures and precipitation amounts were checked for homogeneity using an R-based toolkit RHTest that uses a two-phase regression technique (Wang, 2003) for the detection and adjustment of inhomogeneity. The homogenized climate data for Southwest Nova Biosphere Reserve was then run through the 18 indices for climate change detection as identified by Gachon (2005). Based on seasonal reporting of indices, this produced a series of over 100 graphs and charts. A history is now being built that selects the most informative of the graphs to tell a story of when (year and/or season) the Biosphere Reserve experienced climate extremes. The process of graph selection is being documented for each of the 13 Biosphere Reserves, and an overall "approach" to building a history will be formulated.

Using the Southwest Nova Biosphere Reserve as an example, Figure 7 shows the mean temperature from 1941 to 2002 where no discernable trend of increasing or decreasing temperature is apparent.

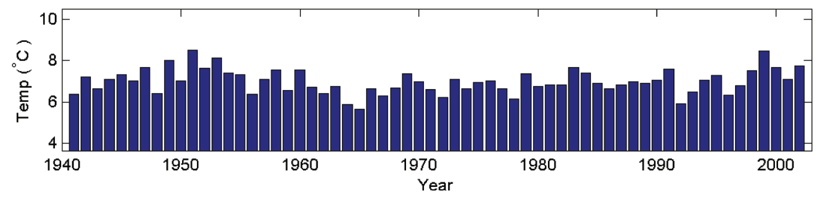

FIGURE 7
Mean Daily Temperature of Yarmouth Station A (8206500) from 1941-2002.

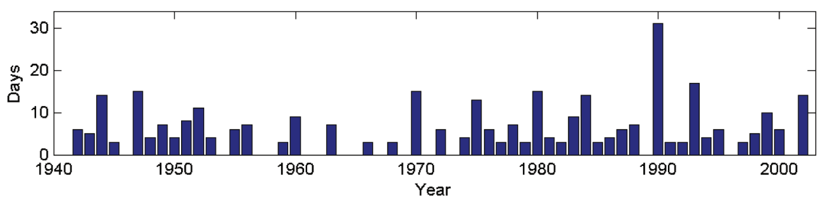

FIGURE 8
Annual Extreme Hot Days at Yarmouth Station A (8206500) from 1941-2002.

Examining extremes, however, provides an opportunity to focus on particular years. Figure 8 shows the extreme hot days (3 consecutive days where maximum temperature is greater than the daily normal maximum temperature plus 3 degrees Celsius) at Southwest Nova Biosphere Reserve. It is obvious that 1990 was a year of extreme hot days doubling any other year prior or following over the observation period.

Figure 9 shows a similar graph for precipitation – the number of consecutive dry days in the autumn when precipitation was less than 1 millimeter. The autumn of 1979 stands out as a particularly dry season, similar only to the autumns of 1964 or 1947.

The community's experience and natural knowledge bases are built using a participatory integrated assessment, a collaborative interdisciplinary research effort which is based on developing a partnership between researchers and stakeholders (Cohen, 2004). This is meant to create an exercise in shared

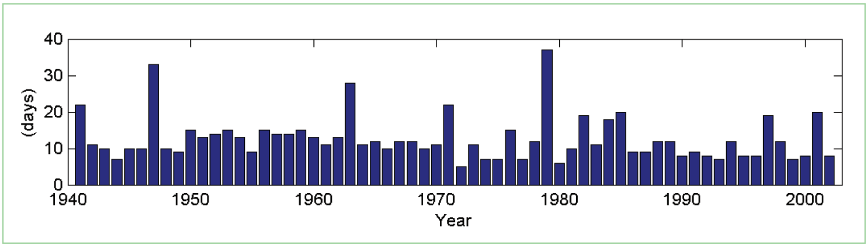

FIGURE 9

Consecutive Dry Days (precipitation less than 1 mm) in Autumn at Yarmouth Station A (8206500) from 1941-2002.

learning. Dialogue processes are critical to this process, extending beyond simply performing an outreach function. In this approach, dialogue contributes important information on how adaptation options may be considered by governments, private enterprises, and community groups.

By showing the community how the climate has changed in the past, the question can be asked as to how they have adapted to these changes. In this example, the past climate highlights a year of extreme hot days just 15 years ago, and 25 years ago for an extremely dry season, within the memory of many Biosphere Reserve managers. This extreme year may have required intervention from Biosphere Reserve managers to save agricultural crops, preserve endangered species habitat, or ensure the quality of groundwater. For example, the year 1990 was followed at Southwest Nova Biosphere Reserve by significant increases in the growth rates of the Blanding's Turtle, one of Nova Scotia's endangered species (see Drysdale, this volume). This knowledge, taken together with scenarios of future climate change showing similar extreme hot or dry years in the future (that is, changed return periods), can identify some adaptation measures that might be taken to ensure that an adaptation infrastructure is in place, or that alternative management of the biosphere reserve occurs. In other words, what lessons did the community learn from the last event that can be drawn on with advanced knowledge about the future to minimize the negative impacts and maximize the benefits from climate change?

6. Conclusions

Human communities, such as those in Biosphere Reserves, cannot gain much direction for future climate change adaptation planning using common methods of climate data presentation such as "climate normals" or "climate averages."

What is needed, and asked for by the community, is information on climate extremes, how these have been dealt with by the community in the past, and the expected frequency and increase in magnitudes expected to be dealt with in the future. This paper has presented an approach to feeding these needs; what the authors title Adaptation Through Learning. Adaptation Through Learning can be described as providing communities with information on past and future extremes of climate so that they can determine how they themselves have adapted in the past to these extremes, and how to best plan for these in the future. The tools available from climatologists for this approach include the Gachon Indices of Climate Extremes (GICE) to provide results from climate changes over time that can be easily understood and used in policy decisions made by nonspecialists in the field; observational climate data on temperature and precipitation from automated and volunteer weather stations to feed the indices for past climate; and climate data on temperature and precipitation from models of future climate scenarios, including Global Climate Models, Regional Climate Models, and several downscaling techniques for understanding future climate extremes.

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PAPER

15 CLIMATE CHANGE: ENVIRONMENTAL EFFECTS AND MANAGEMENT ADAPTATIONS

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ABSTRACT: Species, natural communities, and ecological systems have evolved over time in response to changing and dynamic environments. The natural variation of the physical environment and biotic interactions within that environment create a dynamic template that shapes how species evolve and what species may (or may not) be able to persist in any given area. Rapidly changing climate has potentially profound implications for nature conservation and threatened and endangered species management. Predictions include dramatic shifts in species populations and their distributions with potentially increased extinction risk for those species with restricted ranges, limited distribution, or mobility. For example, the rate of future climate change will likely exceed the migration rates of most plant species. Given likely future climate scenarios, conservation planners need to develop and use objective-driven learning-based adaptive strategies.

Keywords: global change, climate change, adaptive management strategies, adaptation, adaptive capacity, multiple scales

1. Introduction

The impact of human actions on the rate and direction of global environmental change is already being felt on biodiversity around the globe (Millennium Ecosystem Assessment, 2005). Present evidence suggests strong and persistent effects of such change on both plants and animals as evidenced by substantial changes to the phenology and distribution of many taxa (Parmesan and Yohe, 2003; Root and Schneider, 1995, 2003). For example, the onset of bird nesting, budburst, and migrant arrivals has markedly shifted over the last few decades and many species (for example, birds and butterflies) have extended their ranges further northward (Parmesan *et al.*, 1999; Walther *et al.*, 2002).

Some of the most pronounced ecological responses to climatic warming are expected in polar marine regions, where temperature increases have been the greatest and sea ice serves as a sensitive indicator of changes in climatic conditions and effects on ice dependent species (Regehr *et al.*, 2007). Terrestrial Arctic animals will be vulnerable to warmer and drier summers, climatic changes that interfere with migration routes and staging areas, altered snow and ice conditions and freeze-thaw cycles in winter, climate-induced disruption of the seasonal timing of reproduction and development, and influx of new competitors, predators, parasites and diseases (Callaghan *et al.*, 2004). One of the most striking examples is the concern over declines in Arctic sea ice and its effects on the long-term conservation of polar bears (*Ursus maritimus*). Recent changes in temperature and atmospheric circulation have led to marked declines in the thickness, extent, and duration of sea ice in many parts of the Arctic (Rigor and Wallace, 2004; Belchansky *et al.*, 2005; Stroeve *et al.*, 2005; Holland *et al.*, 2006). At the southern limit of polar bear range, a progressive change toward earlier breakup of sea ice has been shown to negatively influence body condition, reproductive rates and survival of bears (Stirling *et al.*, 1999; Obbard 2006; Regehr 2007b). Most recently, Regehr *et al.* (2007a) and Hunter *et al.* (2007) have shown that both survival rates and total population size of the Southern Beaufort Sea polar bear population appears to be in decline and are also significantly correlated with changes in ice distribution and the duration of the open water season. Projected changes in future sea ice conditions, if realized, will result in the loss of approximately 2/3 of the world's current polar bear population by the mid 21st century. Because models of melting Arctic sea ice are likely to have grossly underestimated the rate of projected melting the current assessment of future polar bear status may be overly optimistic (Amos, 2007; Whelan *et al.*, 2007).

Other areas where climate change influence is pronounced are in various mountain regions where climate-induced vegetation change has been well documented (Walther *et al.*, 2001) and for high-alpine assemblages in particular (Keller *et al.*, 2000; Theurillat and Guisan, 2001; Korner, 2003). Holzinger *et al.* (2008) found an increased number of vascular plant species of as many as three species per decade within the last 120 years on high alpine summits in Switzerland. They noted upward migration rates were within the range of several meters per decade, which is similar to results of in other studies (Grabherr *et al.*, 1994). These changes seem to be connected to temperature increases over the past century (Grabherr *et al.*, 2001; Walther *et al.*, 2005).

The process of adaptation by species or ecosystems to climate occurs in a variety of ways under many circumstances and is not likely to affect all species in the same way (Millennium Ecosystem Assessment, 2005). The process depends on many factors, including who or what adapts, what they adapt to, how they adapt, what resources are used and how, and the effects of adaptation within and across ecosystems, species and genetic levels (MacIver and Wheaton, 2005). Some species or communities will be more prone to extinction than others due to the direct or underlying effects of such climate change, and the risk of extinction will increase particularly for those species that are already on the verge of extinction. Vulnerable species often have limited climatic ranges, restricted habitat requirements, reduced mobility, or isolated or small populations (Millennium Ecosystem Assessment, 2005).

From a conservation perspective, adapting to changing climate poses a daunting task. Oftentimes managers develop plans for specific parts of the landscape using past conditions as a guide to judge future outcomes. But what if future conditions differ greatly from those in the past? Does it make sense to manage for outcomes that are probably impossible to achieve? Does it make sense to manage areas as if they were islands? Can we make decisions requiring an interlocking cascade of actions across broad landscapes? Does it matter if a species exists in a particular location or is it more important to ensure that it exists somewhere? Such questions make adapting to changing climate regimes much more complicated than the conservation approaches used up until now. Conservation becomes a moving target in a climatically changing environment, and although current reserve systems are a starting point, there is no clear end point (Von Maltitz *et al.*, 2006).

2. Climate Influences on Ecosystem Disturbances

Climate change, which contributes to habitat change, is becoming the dominant driver of changes in habitat condition, particularly for vulnerable species and habitats such as endemic montane, island, and peninsula species and coastal habitats such as mangroves, coral reefs, and coastal wetlands (Millennium Ecosystem Assessment, 2005). Both recent empirical evidence and predictive modeling studies suggest that climate change will increase population losses in many areas. Although there may be an increase in some regions in local biodiversity (usually as a result of species introductions), the long-term consequences of these increases are hard to foresee.

A review of how disturbances are influenced by climate and might be exacerbated by climate change provides a background for examining ways to deal with the impacts of climate change upon ecosystems and their services (Dale *et al.*, 2001). The effect of each individual disturbance is partly tempered by prior adaptations to previous disturbances as well as by current conditions, which are a function of past management practices. Assessments and decisions based mainly on global modeling efforts would likely overlook the potentially large ecological, social and economic impact that may occur at regional and local scales (Higgins and Vellinga, 2004). This highlights the importance of scale in assessing ecosystem responses and in scaling global models to regional and local levels. Effects of climate extremes on forests can have both short-term and long-term implications for standing biomass, tree health and species composition (Dale *et al.*, 2001; Bush *et al.*, 2004), and similar effects apply to semi-natural grasslands (Grime *et al.*, 1994). In addition, by creating forest gaps, disturbances can provide places where species better suited to new prevailing climate regimes can become established. Specific disturbances that affect and are affected by climate change are fire, drought, floods, insect and pathogen outbreaks, invasive species, hurricanes, ice storms, landslides, sea level rise and interactions among these disturbances.

FIRE: In 2003, large fires in southeastern Australia, western Canada, Mediterranean Europe, and southern California drew considerable public and political attention to fire as a phenomenon through which ecological and human dynamics collide (Lavorel *et al.*, 2007). The frequency, size, intensity, seasonality, and type of fires depend on interactions among climate, vegetation structure, and land use on local to regional scales (Dale *et al.*, 2001, Lavorel *et al.*, 2007). Fire initiation, propagation and spread depend on the amount and frequency of precipitation, the presence of ignition agents, and conditions (for example, lightning, fuel availability and distribution, topography, temperature, relative humidity, and wind velocity). Fires and their effects on terrestrial ecosystems are highly sensitive to climate change and can have dramatic impacts in the structure and functioning of ecosystems (Lavorel *et al.*, 2007). For example, the projected climatic changes for the next century (IPCC, 2007a) are faster and more profound than any experienced in the last 40,000 years (Bush *et al.*, 2004), and probably in the last 100,000 years. The simplification of ecological structure in Amazonia from complex forest to the simplicity of agriculture coupled with the increased probability of human-set fires and complex ecological interactions mediated by climate takes us into unknown bioclimatic territory (Bush and Lovejoy, 2007). Especially as it is now known that the hydrological cycle (rain coming from moisture from the ocean that is transpired by plants), which produces a significant fraction of Amazon rainfall, is also responsible for 40% of the rain south of the forest in Brazil and northern Argentina. With 20% of the Brazilian Amazon deforested, the point at which an irreversible drying trend is triggered cannot be far away. The immediate consequence of that alteration to the modern hydrological cycle, forest fragmentation, and human activity is the increased probability of Amazonian wildfire (Bush and Lovejoy, 2007).

DROUGHT: Droughts can occur in nearly all ecosystems (Dale *et al.*, 2001). Drought effects are influenced by soil texture and depth; length and severity of exposure; and species present and life stage. Ecosystem responses likely will include feedbacks to the climate system with some potentially significant positive feedbacks occurring in biotic responses to changes in the hydrological cycle (Higgins and Vellinga, 2004). These responses will likely amplify the hydrologic impacts of climate change as regions with decreases (increases) in precipitation shift to vegetation with lower (higher) leaf area and smaller (larger) root systems (Higgins and Vellinga, 2004). These changes are likely to lead to decreased (increased) atmospheric moisture through reduced (increased) transpiration (Higgins and Vellinga, 2004). These types of positive feedbacks from vegetation are implicated in persistence of the drought in the Sahel through a reduction in atmospheric moisture and a resulting shift to a self-sustaining dry equilibrium (Wang and Eltahir, 2000).

FLOODS: Evidence is growing that, as a result of global climate change, severe weather events such as heavy precipitation during winter could become more frequent. The likely result is an increased risk of large-scale flooding and loss of topsoil due to erosion (Fuhrer *et al.*, 2006). Large uncertainty in projections of the hydrological cycle make predictions about the magnitude and location of ecosystem perturbations also uncertain, limiting the potential for impact assessment and adaptation (Higgins and Vellinga, 2004).

INSECT AND PATHOGEN OUTBREAKS: Climate influences the survival and spread of insects and pathogens directly, as well as the susceptibility of their hosts and associated ecosystems (Dale *et al.*, 2001). Changes in temperature and precipitation affect herbivore and pathogen survival, reproduction, dispersal, and distribution. Indirect consequences of disturbance from herbivores and pathogens include elimination of nesting trees for birds and negative effects on mycorrhizal fungi (Gehring *et al.*, 1997; Ayres and Lombardero, 2000). Other indirect effects include the impacts of climate on competitors and natural enemies that regulate the abundance of potential pests and pathogens.

INVASIVE SPECIES: Invasive species can affect ecosystems through herbivory, predation, habitat change, competition, alteration of gene pools via hybridization with natives, fire frequency and severity, and disease (as either pathogens or vectors) (Dale *et al.*, 2001). The effects of invasive species should be considered concurrently with changes in native species distribution and abundance that occur as a consequence of climate change (Hansen *et al.*, 2001). The impact of introduced species on ecosystems is influenced by such climatic factors as temperature, drought, and cloud cover (Ayres, 1993). Invasion biology is not yet adept at forecasting impacts of invasions (Williamson, 1999). The complex interactions among introduced species, native communities, managed ecosystems, and climate change compound this forecasting problem (Simberloff, 2000).

HURRICANES: Historical observations suggest that the active hurricane seasons of 2004 and 2005 may be part of a natural cycle in Earth's climate system related to changes in mean sea-surface temperature (SST) in the North Atlantic Ocean (Poore *et al.*, 2007). Hurricanes are well-documented to disturb ecosystems of the eastern and southern coastlines of the United States, as well as those of the Caribbean islands and the Atlantic coast of Central America (Dale *et al.*, 2001). Ocean temperatures and regional climate events influence the tracks, size, frequency, and intensity of hurricanes (Emanuel, 1987). An average of two hurricanes make land every 3 years in the United States (Hebert *et al.*, 1996). Estimates are that the Florida Everglades have been impacted by 38 storms since 1886 (Doyle and Girod, 1997). Mangrove forests, and the fish and wildlife species dependant on them, rely on the interplay of a variety of physical factors for their existence, including salinity of the water, the amount of oxygen in the soil, soil type, nutrient availability, inundation by tides, and air and water temperature, to name a few (Tomlinson, 1986; Smith, 1992). Because of the complex interactions among these factors, wide-scale damage caused by hurricanes may have unforeseen consequences that cascade throughout the ecosystem (Ward and Smith, 2007). Another example is the catastrophic destruction of the floodplain forests of the Pearl River in Louisiana after Hurricane Katrina will have both short- and long-term consequences with the immediate structural changes having significant impacts on migratory birds (Faulkner *et al.*, 2007). Migratory birds are likely to encounter increasingly altered landscapes along their migration paths in part because of projected changes in habitats caused by such disturbances (Barrow *et al.*, 2007). Continued global warming may accelerate the hydrologic cycle by evaporating more water, transporting that water vapor to higher latitudes, and producing more intense and possibly more frequent storms (Emanuel, 1987; Walsh and Pittock, 1998).

WINDSTORMS: Small-scale wind events are products of mesoscale climatic circumstances and thus may be affected by climate change (Dale *et al.*, 2001). However the type and amount of alteration in windstorm characteristics cannot be predicted because these smaller-scale events are below the resolution of today's climate change models. For example, the more humid, warmer weather patterns predicted for the future in the Arctic are expected to increase the windthrow risk of trees through reduced tree anchorage due to a decrease in soil freezing between late autumn and early spring, that is, during the most windy months of the year. (Peltola *et al.*, 1999). Yet, tornadoes, downbursts, and derechos (a widespread and long lived windstorm that is associated with a band of rapidly moving showers or thunderstorms) are probably the most important agents of abiotic disturbance to eastern deciduous forests (Peterson, 2000).

These disturbances can create very large patches of damage and may trigger advanced regeneration, seed germination, and accelerated seedling growth which can change successional patterns, gap dynamics, and other ecosystem-level processes (Peterson and Pickett, 1995).

ICE STORMS: Ice storms are caused by rain falling through subfreezing air masses close to the ground, which super-cool the raindrops and cause them to freeze on impact (Dale *et al.*, 2001). Ice storms have been increasing in frequency over the last 50 years and may be affected by climate change. The 52-year average annual number of severe ice storms in the United States was 1.3. However, the average for 1949–1976 was 1.1 per year, increasing to 1.6 during the 1977–2000 period (Changnon and Changnon, 2002). These storms can be catastrophic disturbance events with potential impacts on carbon sequestration and ecosystem recovery (McCarthy *et al.*, 2006). Ice storms are important disturbances affecting forests over a surprisingly large portion of the USA extending from east Texas to New England (Irland, 2000). In the areas most affected, icing events are a factor that shapes stand composition, structure, and condition over wide areas. Impacts of individual storms are highly patchy and variable, and depend on the nature of the storm.

LANDSLIDES: Climate is an important forcing factor of landslide activity, especially as it effects precipitation and temperature as inputs into the landslide system (Schmidt and Dehn, 2003). Either increases or decreases in landslide activity can occur depending on the direction of change of precipitation and temperature. For example, increasing winter temperature and reduced snow storage has been shown to decrease landslide activity (Schmidt and Dehn, 2003). Both slow and rapid movements of soil, rock, and associated vegetation are triggered directly by climate factors and by climate-influenced processes (for example, stream-bank erosion) (Dale *et al.*, 2001). Triggering climatic events include snowmelt and intense rainfall. Landslide frequency and extent are also influenced by snow accumulation, distribution, and melt rate. Vegetation influences the likelihood of sliding through the soil stabilizing effects of root systems and the effects of vegetation structure and composition on hydrology. Landslides in forest landscapes can damage aquatic resources and threaten public safety but they are also important natural processes contributing to the maintenance of needed structures in stream courses for fish populations.

SEA-LEVEL RISE: Global average sea level rose at an average rate of 1.8 [1.3 to 2.3] mm per year over 1961 to 2003 (IPCC, 2007b). The rate was faster over 1993 to 2003. As sea level rises as a result of global climate change, storm surge floods will become more frequent and larger areas will become inundated (Barros, 2005). For example, in the Coastal Areas of the Río de la Plata, Argentina, the major impact of climate change regarding coastal flooding will be in the increasing frequency of floods caused by storm surges (Barros, 2005). Impacts of sea-level rise will include increased coastal erosion, higher storm-surge flooding, inhibition of primary production processes, more extensive coastal inundation, changes in surface water quality and groundwater characteristics, increased loss of property and coastal habitats, increased flood risk and potential loss of life, loss of nonmonetary cultural resources and values, impacts on agriculture and aquaculture through decline in soil and water quality, and loss of tourism, recreation, and transportation functions (IPCC, 2001b).

INTERACTIONS AMONG DISTURBANCES: Many disturbances are cascading with each successive disturbance building on previous events (Dale *et al.*, 2001). Warming temperatures across western North America, coupled with increased drought, are expected to exacerbate disturbance regimes, particularly wildfires, insect outbreaks, drought, windstorms, and invasions of exotic species (Bachelet *et al.*, 2007; McKenzie and Allen, 2007). Drought often weakens tree vigor, leading to insect infestations, disease, or fire. Insect infestations and disease promote future fires by increasing fuel loads, and fires promote future infestations by compromising tree defenses. Increased fire intensity or extent could also enhance the potential for landslides. One way invasive species can affect native ecosystems is by changing fuel properties, which in turn can affect fire behavior and alter fire regime characteristics such as frequency, intensity, extent, type, and seasonality of fire (Brooks *et al.*, 2004). Hurricanes generally contribute to increased species richness and diversity in coastal forests (Battaglia and Sharitz, 2005) but after Hurricane Katrina and Rita along the Gulf Coast of the United States the invasion of the Chinese tallow tree (Triadica sebifera) became a particular concern (Faulker *et al.*, 2007). Bigler *et al.* (2005) demonstrated the relative importance and the combined effects of fire and beetle outbreak, vegetation, and topography on fire severity during extreme drought in Rocky Mountain subalpine forests. Many ecologists and resource managers expect ecosystems to change more rapidly from disturbance effects than from the direct effects of a changing climate by itself (McKenzie and Allen, 2007).

3. Adapting To Climate Change

Existing climate data and models have highlighted general changes to global climate (English Nature *et al.*, 2003). However, uncertainties remain about the rate and severity of change at the regional and local level. Global change does not mean the same amount of warming everywhere. Some places may even become cooler. The challenge is less about dealing with projected impacts, than it is about developing strategies to manage the uncertainties created by climate change. A precautionary approach is needed that reduces current risk, accounts for the potential movement of species, and keeps future management options open. Developing techniques that allow species and ecosystem resources to be adequately conserved and managed in the face of climate variability will require addressing many challenges.

Climate change will result in both long-term changes in mean temperature and/or precipitation, as well as increases in the frequency of extreme climatic events (UNDP and GEF, 2008). Adaptation responses that focus on dealing with year-to-year risks (for example, forests fires, hurricanes, floods) may not be adequate for coping with long-term climate change impacts (for example, sea-level rise, earlier snow melts, temperature increase). The temporal dimension of climate change effects is therefore an important consideration in the development of effective adaptation strategies (IPCC, 2001a; Niang-Diop and Bosch, 2005). Developing such a strategy is not a simple one-time activity but instead is an iterative, continuous learning process. To ensure effectiveness, strategy development should incorporate the principles of an adaptive management process, including the dynamic reassessment of objectives, actions, monitoring, and implementation as environmental conditions change (Williams *et al.*, 2007).

As a result, conservation planners, managers, and policy makers need to become better informed about the potential consequences of climate change on the resources with which they work (Price and Root, 2004). Given the anticipated impacts of climate change over the next 50 to 200 years, many species will have to move from their current locations to other areas with suitable climates (Von Maltitz *et al.*, 2006). To facilitate this process and minimize species loss, a multitude of strategies are needed. Key elements of these strategies will include creating an environment permeable to species migrations through realignment of reserves, and incorporating land use outside of reserves in the conservation framework.

Among other things, this will require consideration of the placement of conservation areas on a north-south axis or along altitudinal gradients to enhance movements of habitats and wildlife by providing migration corridors or stepping stones. Any management plan needs to be flexible enough to adjust to ongoing and future change (English Nature *et al.*, 2003). This means going beyond a static management plan and moving towards a dynamic approach that tests assumptions, monitors results and adapts management actions accordingly. Such management should aim to enhance current biodiversity and learn how to accommodate the alterations in species range, distribution and population density being triggered by climate change.

When such measures do not meet conservation objectives, other more active approaches may need to be considered. For example, where species are unable to move on their own, facilitated translocations will need to be considered. As a last resort, it may be necessary to engage in ex-situ conservation for species with no possible future habitats (for example, polar bears and sea ice) (Von Maltitz *et al.*, 2006).

Implementing these concepts calls for much more robust conservation thinking and planning. Plans for specific sites must be viewed in the context of potential change. Should plans continue to be retrospective in nature where decisions are based on the range of historical variability? Or should planners ask questions about what species and ecosystems they should manage based on those which will likely persist at that site in the future? This kind of planning cannot be effective at a single site. Rather, an interlinked strategy among sites placed in a broader landscape will allow managers to manage for particular species and ecosystems somewhere in that landscape. Many species will persist, but not necessarily in the same locations.

In addition, there is a need to consider how people will adapt to climate changes and how their changing behavior will affect ecological systems. For example, as the temperatures in Florida increase and severe hurricanes become more prevalent, many Floridians are moving to the eastern Tennessee and western North Carolina. This migration may become more prevalent with sea level rise. The resulting development pressures are occurring in the forested areas of high biodiversity. At the same time, climate changes are resulting in an alteration in the places, seasons, and ways that people recreate that can add new pressures to ecological systems (Hall and Higham, 2005; Richardson and Loomis, 2004). Comprehensive strategies to cope with climate change will need to consider both natural and socio-political impacts.

Finally, changes will be needed not only in management concepts but also in legal constraints and opportunities. In particular, managing for threatened and endangered species will be problematic. The concepts of critical habitat and viable species populations are often tied to particular places or areas. But what if habitat for a threatened or endangered species migrates further upslope or northward as climate conditions change? Should a manager be held accountable for declines in habitats or species that can no longer exist in that particular place or area because of changes in the environment (warmer or cooler; wetter or drier) and not as a result of management action? Conservation has always been challenging, but now it is even more so in this era of dynamic climate change and conservation.

A learning-based approach to decision making seems especially well suited for meeting these challenges (Williams *et al.*, 2007). A prominent example is adaptive management, which applies to resource systems that are dynamic and influenced by evolving environmental conditions and management strategies. In particular, adaptive management is applicable to systems that are subject to uncertainties about environmental and management impacts which limit effective adaptation. From the above, it is clear that temporal variation and uncertainty are key attributes of ecosystems that must be managed in the face of climate change. An adaptive approach to climate change recognizes uncertainty, and the need to learn about climate impacts and adaptation through time. It must involve stakeholders in scoping and scaling adaptation strategy, as well as the monitoring and assessment of impacts. Finally, it builds directly on learning, to produce improved adaptive strategy based on what is learned. It is through such an objective driven, science-based approach that opportunities for adaptation can best be recognized and implemented, and threats from climate change can be ameliorated.

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PAPER

16 CLIMATE CHANGE, BIODIVERSITY CONSERVATION, DEFORESTATION AND ITS POLICY RESPONSES IN BOLIVIA UNDER THE CURRENT POLITICAL CONTEXT: WHAT SCOPE FOR SYNERGIES AND INTERACTIONS?

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ABSTRACT: Biodiversity conservation is an economic, environmental and social process. It is also a political and cultural process in developing nations, characterised by being the richest regions in biodiversity but also the poorest economically. Paradoxically, while biodiversity and forest management provide substantial socio-economic and environmental benefits, local people have not often received benefits resulting from these processes. Thus ecosystem degradation and deforestation has increased. This would be the case of Bolivia, considered among the richest countries in biodiversity, especially within the Tropical Andes Hotspot, recognised as the global epicentre of biodiversity. However, the country is one of the poorest nations in Latin America with indigenous communities among the most vulnerable groups. Despite some progress and advances during the last decade in biodiversity conservation and climate change, these efforts have been mainly promoted by the international cooperation. Therefore, political arguments and economic policies are asking new questions on the effectiveness of these initiatives for conservation and sustainable development, including climate change and the discussion of emerging trade-offs as part of new development approaches to reduce poverty. Furthermore, new threats arise to the sustainability of these processes related to increasing deforestation rates. Hence, the current national agenda is recognising the need for improved roles and synergies in the management and ownership of renewable natural resources, including recent legal and policy frameworks that are integrated into national development plans.

Keywords: Climate change, deforestation, policy-making, biodiversity conservation, CO_2 emissions

1. Introduction

Evidence produced by several studies since the early 1990s suggested that large-scale conversion of tropical forests into pastures or annual crops could lead to changes in the climate (Nobre *et al.,* 1991). Hence, it has been documented that land-use change impacts regional and global climate through the surface-energy budget as well as through the carbon cycle (Pielke *et al.,* 2002). As well as influencing local long-term weather conditions, regional-scale land-cover change can impact on the global climate system (Avissar, 1995; Pielke, 2001; Claussen, 2002). These aspects of human influence on climate were not accounted for under the Kyoto Protocol. The neglect of land-use effects lead to inaccurate quantification of contributions to climate change. Thus the role of tropical forests may be significant in this process. Apart from their role as reservoirs, sinks and sources of carbon, tropical forests provide numerous additional ecosystem services. Many of the ecosystem services directly or indirectly influence climate, including the maintenance of elevated soil moisture and surface air humidity, reduced sunlight penetration, weaker near-surface winds and the inhibition of anaerobic soil conditions. Such an environment maintains the productivity of tropical ecosystems (Betts, 1999). Nevertheless, deforestation is rapidly progressing in Amazonia, with estimates suggesting that if deforestation were to continue at the present rate, a significant reduction of Amazonian tropical forests would occur in less than 100 years (Nobre *et al.,* 1991, Killeen, 2007).

Academic and policy literature has directly linked deforestation rates with structural adjustment programmes (SAP) implemented in many South American countries, which promoted the expansion of timber and soy exports. In the case of Bolivia, deforestation has increased dramatically since the mid-1990s. A number of studies suggest that structural adjustment contributed to large-scale forest clearing for soybean production for export and, to a lesser extent, forest degradation by lumber companies particularly because Bolivia was amongst the first Latin American countries to initiate a far-reaching and relatively orthodox SAP, which did greatly contribute to forest clearing for soybean exports and to higher timber exports (Kaimowitz *et al,* 1999). Therefore, deforestation in tropical areas of South America and particularly in the Amazon is contributing to CO_2 emissions. Although, it has been considered that deforestation and tropical forests fires contribute globally with about 20 per cent of the total emissions, the major impact is related to the rapid loss of forest ecosystems and biodiversity. Accordingly, recent debates and positions are calling for action on the role of tropical forests and the role of deforestation in developing countries, including new visions and conceptions in developing countries based on current interest of policy-makers in considering schemes for income generation and responsibilities of developed countries.

This paper analyzes the opportunities to integrate climate change policies and biodiversity conservation into national development agendas, the impacts of climate change in Bolivia, the role of deforestation and the root causes for carbon emissions in the country. It also explores resulting policy connotations and approaches under a new administration, which present dissimilar conceptions of development, the role of the State and sustainable development, and the relationship between local and global impacts and responsibilities on climate change, deforestation and biodiversity conservation. Therefore, the research identifies the challenges of policy-making in the existing climate change and forest processes under the new administration of Evo Morales by providing up-to-date empirical evidence and conclusive analysis of the policy responses of the Bolivian government to climate change, forest management and biodiversity conservation.

2. Bolivia: Biodiversity, Forests and Protected Areas

Bolivia is a landlocked country comprising an area of 1,098,581 square kilometres, distributed in different eco-regions, containing more than fifty per cent of lowland areas (see Figure 1). In contrast to what is commonly assumed, a large portion of the country is covered by forest vegetation. The country's total forest area is 534,000 sq. km. which represents 48.60 per cent of the total surface. More than 80 per cent of the total forest area occurs in the Bolivian lowlands whereas the remaining 20 per cent is spread out in the highlands and the inter-Andean valleys.

FIGURE 1
Bolivia, its lowlands and its place in South America.

From the 80 per cent of forest area, four major zones have been identified: i) the humid and evergreen forest of the Amazonian lowland located in northern Bolivia; ii) the Beni plains, characterised by natural savannas and small patches of gallery forests, much of which are seasonally flooded; iii) the Chiquitania region, whose semi-deciduous forests are typical of slightly drier areas; and iv) the semi-arid Chaco region, with lower and less productive forests adapted to dry climates (MDSMA, 1995).

According to Pacheco (2006), the condition of Bolivia's lowland forests is the result, to a large extent, of the dynamics of occupation of forestlands and their intervention for timber extraction. Government plans and policies to develop the lowland region in the mid-1950s included road construction, colonisation projects, saw-pits and low credit for agricultural production. Therefore, the most intervened forests have been those located in the department of Santa Cruz. Since the early stages of frontier occupation there were close interactions between agricultural frontier and forest frontier expansion, though the latter was focused on the extraction of the most valuable species, such as mahogany. The exhaustion of mahogany tress in the forest frontiers of Santa Cruz motivated a migration of the timber companies to the southwest of Beni and the north of La Paz in the early 1980s (Pacheco, 2006). In many cases, these contracts overlapped with private properties, indigenous territories or protected areas.

Nonetheless, protected areas in Bolivia play a role not only in conservation but in support of local livelihoods and social participation as well. The Bolivian government estimates that around 60,000 people live inside protected areas and some 200,000 people live in surrounding areas (see Figure 2 for protected areas

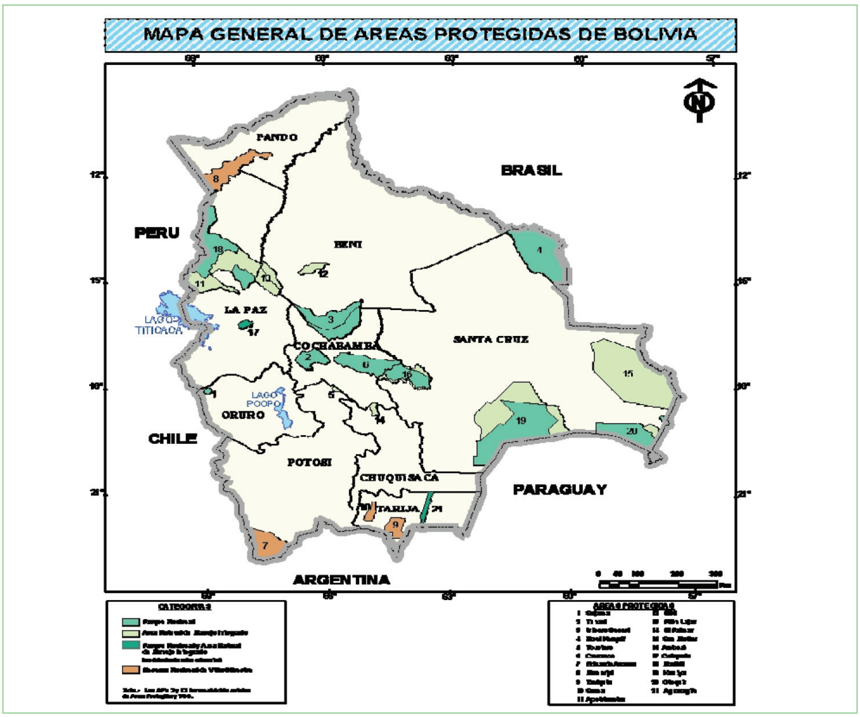

FIGURE 2
Official Protected Areas Map of Bolivia (in Spanish).

of Bolivia, and Figure 3 for how the percentage of land designated as protected areas has grown in Bolivia). Different management categories were created in order to adapt to local contexts. One of the most successful initiatives was the creation of Management Committees, composed by indigenous peoples authorities jointly with Park officials and government representatives, which are the main instruments used to obtain support for park protection. Through the committees, park administrators developed local agreements for a set of rules for resource use to make protection possible. In some parks, where local people have come to value the economic potential of wildlife and ecotourism, communities themselves identify and sanction violators.

As the World Bank (2002) reported, the ownership of the conservation ethic by some local communities is so strong that they are effectively functioning as *de facto* park wardens. Local people also use committees to address their needs, as communities, local organizations, and municipalities worked together to pool resources and undertake development activities that would not had been possible otherwise. Consequently, involving local communities in national park affairs and the parks promises of development benefits has helped increase their interest in conservation by adapting local and national realities towards a recognized acceptance of the importance of protected areas for sustainable livelihoods and biodiversity management and conservation.

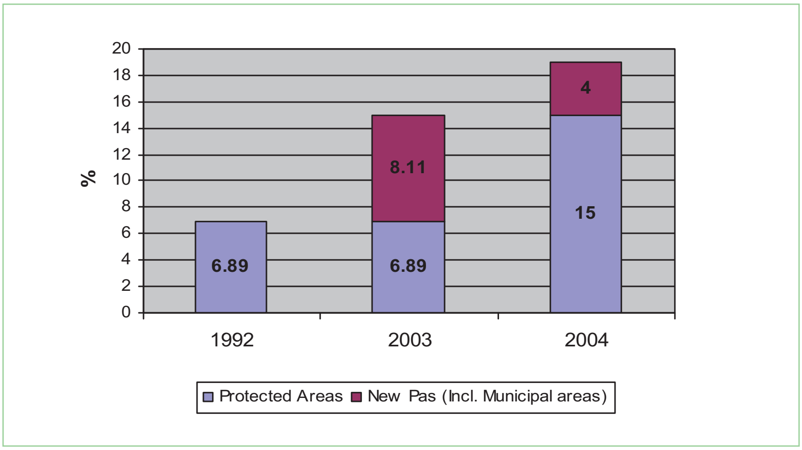

FIGURE 3
Percentage of Bolivia covered by Protected Areas.

In this sense, new protected areas were created in the last decade, which included different categories and a significant amount of natural areas for integrated management. This approach allows local and indigenous peoples to continue living in buffer zones and develop sustainable management practices of natural resources and biodiversity. Accordingly, the National Service of Protected Areas developed the framework of "Parks with People" in 2005, considering the importance and role of protected areas for sustainable livelihoods, poverty alleviation and sustainable development in rural areas, including a significant role on ecosystem services provision (Peredo, 2005). As part of this process, which is currently evolving into a national policy of "shared management" under the new government administration, not only national areas were represented in the national system of protected areas, but municipal protected areas and neighbouring declared indigenous territories are also areas for biodiversity conservation. Based on international support and funding, the percentage of national territory covered by protected areas in Bolivia increased in the last decade covering approximately 19 per cent of the total surface with representation throughout different ecosystems in the country (ABDES, 2005).

Several national parks are still having constraints in enforcing conservation measures and there is a persistence of conflicts for access to natural resources by several actors as the synthesis of rural conflicts. The root cause is related to the overlapping of territories containing vast natural resources, including minerals, hydrocarbons, timber, wildlife and land resources. The institution in charge to safeguard the biological diversity in Bolivia is living in permanent conflict. Although such conflicts remain widespread, the role of protected areas has been acknowledged and recognised under the new State Constitution, which defined them as part of the natural and cultural heritage of the country, undertaking environmental, cultural, social and economic functions (Republica de Bolivia, 2007). One of the reasons for this significant increase in conservation efforts is because Bolivia has been included within the 15 countries with the highest biodiversity rates in the world, due to its geographical location, the existence of several ecosystems and species richness and endemism, particularly in the so-called Tropical Andes Hotspot, which promoted a number of landscape initiatives regionally (see Table 1).

Extraordinarily high levels of species richness and endemism characterize the Bolivian portion of this hotspot, defined as the Madidi-Amboro Landscape. Few other areas in the world can compare with its biodiversity. For example, there are more than 5,000 plant species in Madidi National Park alone, which makes it the protected area with the highest plant diversity of the continent. Yungas

TABLE 1

Species richness in Bolivia (Source: Ibisch *et al.*, 2003)

Taxonomic Group	Number of Species	Number of endemic Species	Number of Threatened Species
Mammals	356	17	78
Birds	1.398	16	69
Fish	635	>10	76
Amphibians	204	41	3
Reptiles	267	27	24
Total	**2.730**	**80**	**250**

humid montane forests are a centre of diversity for Neotropical orchids, and 5% of all known orchids are found in the Amboro National Park and neighbouring areas (Conservation International, 2005). The Madidi-Amboro landscape plays an essential role in the regulation of ecosystem function at a regional level. In this context, this landscape includes upper Amazon Basin river systems, areas of heavy rainfall and watersheds that regulate seasonal flooding. Despite these impressive efforts and benefits arising from biodiversity and ecosystem services, threats to natural resources, biodiversity and sustainability still continue and have increased in the last ten years. Deforestation is greater than before affecting several regions in lowlands and the Bolivian Amazon, which worryingly resulted in high deforestation rates during the last decade.

3. Deforestation in Bolivia: Persistence of Threats and Underlying Causes

Most of the academic literature on deforestation suggests the importance of understanding its underlying causes and their relation to political and economic policies in developing countries, especially under structural adjustment programmes (SAPs), which rarely include considerations of long-term environmental consequences in tropical forests in particular. Structural adjustment policy had tended to liberalise the internal markets of labour, capital and goods, and to open them to international markets in order to adjust macroeconomic variables. It reduced fiscal expenses by reducing public employment and eliminating subsidised programmes. It aimed at restructuring the productive sectors by favouring tradable sectors through devaluing national currencies, established export incentives and removed agricultural import restrictions. Therefore, governmental policies have a decisive role in deforestation, as they can influence directly the land-use decisions (Reed, 1996).

Deforestation intensifies when agents make a profit from forest-competing land-uses and, therefore, when the profit that agents obtain from an economic activity is higher than the costs that such activity demands (Pacheco, 2006). The goal of SAP in Bolivia was to transform the state-dominated economy to a market-based production based on exports and foreign direct investment. The implementation of SAP based on fiscal and commercial policies stimulated the expansion of the agricultural frontier at rates of growth never before experienced.

Up until the late 1980s, deforestation rates in Bolivia were among the lowest in Latin America, based on key determinants which included a weak domestic demand for agricultural products and lack of infrastructure (Kaimowitz, 1997). Two national inventories of forest resources concluded that deforestation increased dramatically during the 1990s (Steiniger *et al.*, 2000; Camacho *et al*, 2001), especially after the implementation of the structural reforms during the same decade (Kaimowitz *et al.*, 1999). In this context, Camacho (2001) estimated that more than 3 million hectares of lowland forests in Bolivia have been cleared, with 1.4 million hectares (46.7 per cent) deforested in the department of Santa Cruz between 1993 and 2000. Consequently, deforestation rates have quadrupled during this time after the structural reforms and policies introduced in 1993, as Table 2 shows.

TABLE 2

Estimates of deforestation in the department of Santa Cruz

Dept.	Total Area	Forest Cover 1986 (ha)	Forest Cover 1993 (ha)	Forest Cover 2000 (ha)	Deforestation (ha)	
					1986-1992	1993-2000
Santa Cruz	35,643,850	34,465,013	33,890,513	32,431,848	574,500	1,458,665

These estimates led to several proposals and studies suggesting that structural adjustment have contributed to increase deforestation rates for soy and timber exports, by applying economic instruments and policies that removed price controls on soybeans, devalued the Bolivian currency, promoted investments in physical infrastructure such as roads and telecommunications, and introduced tax breaks and fiscal incentives for exporters (Kaimowitz *et al.*, 1998). These studies argue that the increasing deforestation rates in Bolivia as a whole are indicative of the general weakness of the government in the forestry and environmental sectors. Moreover, municipal governments have been largely ineffective in preventing deforestation (Hecht, 2001; Davies *et al.*, 2000; Camacho *et al.*, 2001;

Contreras and Vargas, 2001). These reasons are also encapsulated in the notion that structural adjustment reduced the role and capacities of government.

Following on Pacheco (2006), the estimates of deforestation (Table 3 and Table 4) that are available for the country as a whole are based on four datasets from the following institutions: i) The department of Geography from the University of Maryland (UMD), which shows the annual deforestation rates from 1984-87 to 1992-94. According to Steininger *et al.* (2000), it is the most serious estimate of forest-cover change because it is based in a wall-to-wall analysis of digital satellite data MSS and TM; ii) The estimates of the former Ministry of Sustainable Development and the Environment (MDSMA) for the period 1979-1993; iii) FAO's deforestation assessment for the decade of 1990 published in 2001, and iv) estimates for the period 1993-2000 of the Bolivian Forestry Project (BOLFOR), which promotes sustainable forestry in Bolivia.

The amount of deforestation that has taken place in Bolivia has been relatively low compared to other countries with tropical forests, but this trend has been reversed dramatically in the last years. The deforestation rate during the last decade, according to most of the estimates, is becoming closer to one of the Amazonian countries as a whole, but it is undoubtedly higher when considered on a per-capita basis.

TABLE 3
Estimates of deforestation in Bolivia (thousand hectares)

Sources	Years	Forest Cover	Deforestation in the period	Annual deforestation	Deforestation rate (%)
ERTS (1) MDSMA (2)	1975 1993	56,400 53,400	3,024	168	0.29
ERTS (1) Agrarian Superint. (3)	1978 2001	56,468 53,960	2,508	109	0.19
UMD (4) UMD (4)	1987 1993	44,707 43,790	2,470	153	0.34
FAO (5) FAO (5)	1990 2000	54,678 53,068	1,610	161	0.29
MDSMA (6) BOLFOR (6)	1993 2000	53,400 51,383	2,017	270	0.50

Notes: 1) GEOBOL, 1987; 2) MDSMA, 1995; 3) Agrarian Superintendence, 2001; 4) Steininger *et al*, 2000; 5) FAO, 2001; 6) Rojas *et al*, 2003. Based on Pacheco (2006) and ABDES (2006).

According to Kaimowitz *et al.* (1999), Pacheco (2006) and the sources of deforestation analysed, there is a clear relationship of deforestation caused by medium and large companies and producers in the soy and timber production for exports, as the following data shows based on data from the Department of Agricultural Statistics, Ministry of Agriculture and compiled by Pacheco (2006).

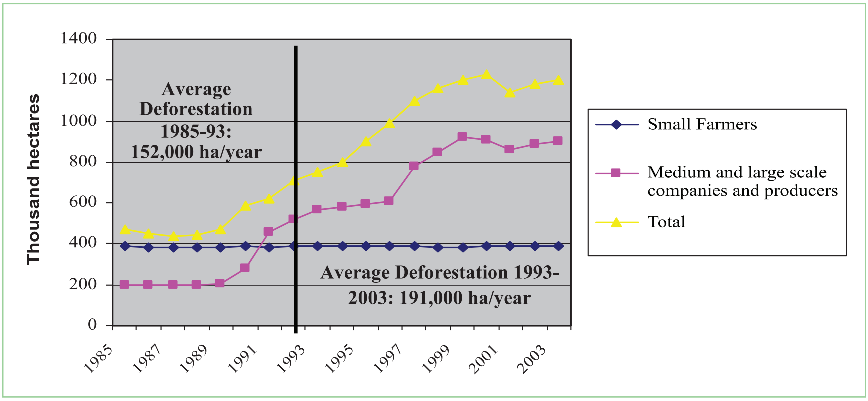

FIGURE 4
Deforestation in the Bolivian lowlands since the structural adjustment programme.

The extensive deforestation resulting from the implementation of SAP policies was not an unexpected side effect but would be more accurately described as a calculated cost that had been taken into account when the policy instruments were designed (Anderson, 2002).

The type of model adopted for soy exports, based on medium and large companies and producers, was the problem. It was thought that big producers were more efficient and they could provide more economic benefits. This model only included small producers in the productive chain in a marginal perspective. Therefore, the model promoted larger rates of deforestation (Pacheco, Pers. Comm., 2007).

In national terms, deforestation increased from an average of 152,000 hectares per year in the period 1985-1993 to an average of 191,000 in the following ten-year period of 1993-2003. Deforestation continued the following years from

TABLE 4

Estimates of Deforestation by Type of Factors

Type	Annual deforestation (thousand ha/year)		Deforestation Rate (%)		Participation with respect to total (%)	
	Mid 1980s to mid 1990s	Mid 1990s to 2000	Mid 1980s to mid 1990s	Mid 1990s to 2000	Mid 1980s to mid 1990s	Mid 1990s to 2000
Medium to large-scale	54.0	105.2	2.28	–	35.6	55.1
Predominantly colonists	62.4	41.7	1.19	0.86	41.1	21.8
Cattle ranching	6.8	13.6	0.33	0.67	4.5	7.1
No identified	28.6	30.4	0.08	0.09	18.8	15.9
Total	**151.9**	**190.9**	**0.34**	**0.43**	**100.0**	**100.0**

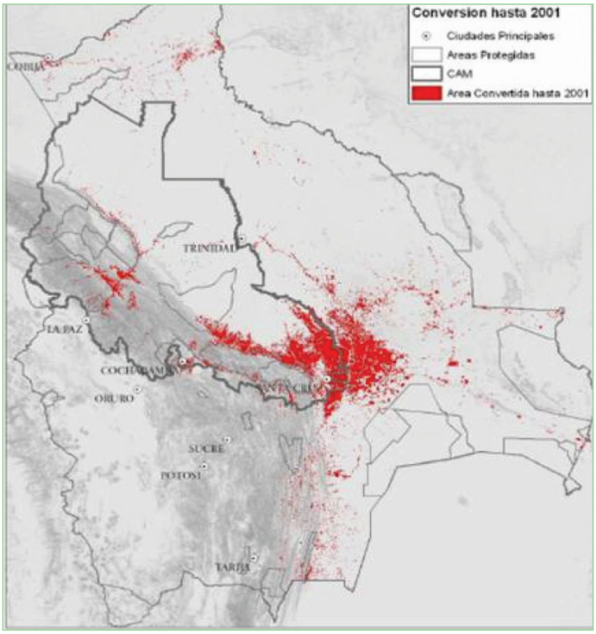

FIGURE 5

Land conversion until 2001 (Source: PNUD (2005) based on Ledezma and Painter (2005) and Killeen *et al.* (2005).

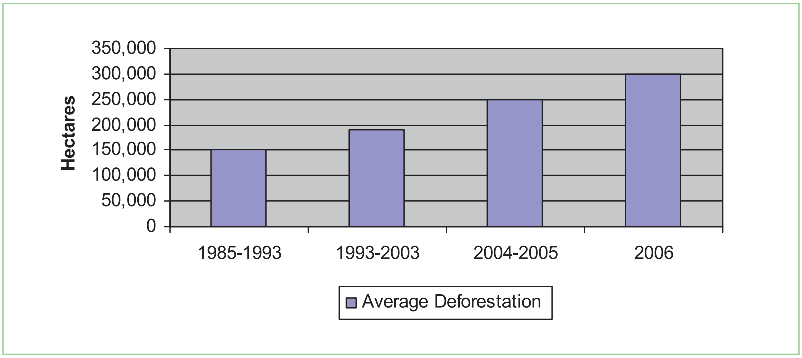

FIGURE 6
Evolution of Deforestation Rates in Bolivia 1985 to 2006.

250,000 hectares/year in 2005-2006 and reached approximately 300,000 hectares per year in 2006, according to the Forestry Superintendence (2007).

From 2005 and onwards, the presence of forest fires has increased to almost 90 thousand fires throughout the country but particularly in tropical regions, which represent almost double than in the period 2001-2006. Most of these fires have been attributed by the Ministry of Rural Development to large land-owners related to soy, cattle and timber economic activities. However, there may also be an increasing contribution of colonists in land conversion, which jointly causes an expansion of the agricultural frontier.

These fires reached the peak value in September 2007, which represented almost 50 per cent of the total fires of that year. This caused disruption and airports closure in capital cities in the eastern part of Bolivia, as well as health problems by producing and affecting respiratory issues both in rural and urban areas, predominantly in the department of Santa Cruz. An underlying factor for the increase of forest fires is the interest in accomplishing the social and economic function of the land, promoted and legally enacted by the new administration under the Land and Agrarian Reform Law of 2006. The main goal is to achieve social redistribution of land for productive purposes and social and political issues as well.

This legal framework may bring further impacts on deforestation, in order to comply with this legal requirement, particularly by large and medium land-owners, but by colonists groups and landless movements as well. Accordingly, it is estimated that conversion and land-use change will increase. The government is also promoting the development of infrastructure projects in the Bolivian lowlands, which are thought to increase environmental degradation. These mega-projects are particularly related to extensive road construction and improvement in the northern Amazon, known as the "March to the North". Other national and regional projects also include dams and sugar factories and oil exploitation in the north of La Paz.

4. CO_2 Emissions in Bolivia: The Role of Deforestation

The second national report of sustainability for the accomplishment of the Millennium Development Goals in Bolivia estimated that national emissions of CO_2 were likely 63K Gg. for 2002 (ABDES, 2005). The official inventories indicate that the dominant cause of CO_2 emissions is land-use change (NPCC, 2003). The widespread practice of slash-and-burn and the conversion of land for agro-industry and cattle-stock eliminate vegetation and burn biomass, which

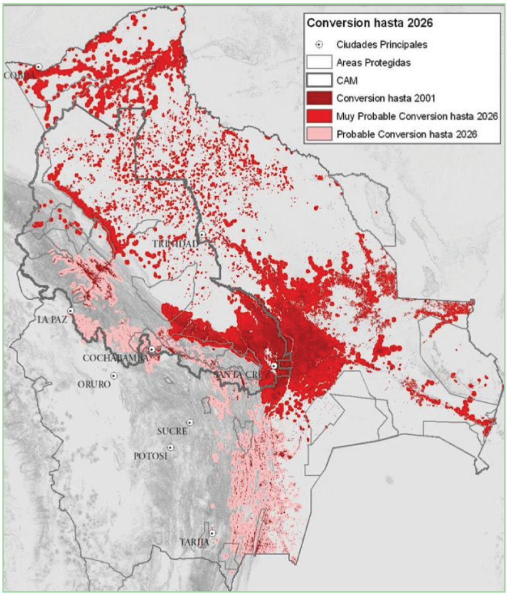

FIGURE 7
Land conversion until 2026 (Source: Ledezma (2005) ; Andersen (2005)).

represent the major cause for deforestation, biodiversity loss and CO_2 emissions. These emissions are distributed in three main sectors. Around 89 per cent of emissions are based on land-use change, followed by 10.5 per cent of emissions related to the energy sector and only 0.46 per cent to the industrial process produced by cement factories (ABDES, 2005).

Available data on CO_2 emissions as a result of slash-and-burn practices shows a discrepancy between the official data provided by the National Programme of Climate change and those provided by San Andres University (UMSA). The official estimates by the NPCC were 0.044 GT of CO_2 for 1998 (NPCC, 2003), while the emissions estimated by the university shows 0.36 GT of CO_2 (Gutierrez and Palenque, 2000). These scenarios were based on the vulnerability assessment of ecosystems undertaken by the National Programme of Climate Change (NPCC, 2000b) and supported by different models accepted internationally, such as UKHI, HADCM2, GISSEQ, MAGICC, and the meteorological data available for the country. It is clear that the major source of CO_2 emissions is produced by land conversion and slash-and-burn practices accounting for more than 82 per cent of total emissions, and may be increasing as deforestation rates and forest fires are also increasing.

Such a high share of emissions from a land use changes and deforestation are second only to Indonesia and almost a similar value with Malaysia (Clabbers, 2004). Bolivia and many other Latin American countries are currently undergoing an economic and development transformation, including a steep upward trend of its greenhouse gas emissions primarily as a result of deforestation and energy (Silva-Chavez, 2005).

TABLE 5

LULUCF Emissions as share of total GHG emission (Source: in Silva (2005))

Argentina	19%
Bolivia	82%
Brazil	69%
Indonesia	86%
Malaysia	82%
Mexico	16%

In terms of the energy sector that represents the second largest source of Bolivia CO_2 emissions, the Clean Development Office has been developing a project portfolio aimed at achieving emission reductions of 5.8 million tons of $CO_{2,}$ in seven years under a CDM framework.

TABLE 6

CDM Project Portfolio in the energy sector (Source: Trujillo, R 2006 in NPCC Informative Bulletin No. 3)

PROJECTS	MW	CO_2 emissions reduction (annual tons)	CO_2 emissions reduction (7 years/ tons)
ENERGY INDUSTRY			
Hydroelectricity projects	204,3	0.39	2,72
Wind energy projects	20,6	0.0011	0.0077
Geothermal projects	1,5	0.0044	0.031
Biomass Projects	18,7	0.095	0.66
Energy efficiency and generation projects	80	0.34	2,38
Industrial projects	0	0	--
Fuel substitution	5,3	0.0018	0.0013
TOTAL	**330,4**	**0.83**	**5,81 MT**
WASTE MANAGEMENT			
Capture of landfill methane emissions	0	0.422	2,9 MT

It is clear that the highest CO_2 emissions in Bolivia are related directly to deforestation and slash-and-burn practices both in forests and savannas in the lowlands region, which are annually undertaken in order to expand the agricultural frontier for cultivation and cattle ranching. Nevertheless, these CO_2 emissions in the country are relatively low compared to other regions in a per capita basis. In Bolivia, they reach only 1.4 mT capita, while in Latin-American and the Caribbean as a whole these carbon emissions reached 2.5 t per capita. In contrast, emissions in the United States are about 19.7 mT per capita (World Bank, 2003). According to several interviews with former and current policy-makers, there is the perception that climate change has been produced by developed economies, and these countries should be responsible for adopting mitigation, adaptation and compensation measures.

These perceptions were enhanced after the unfortunate flooding of January and February 2008 in which more than 47 municipalities were affected, particularly at the Amazonian department of Beni. These floodings caused the death of more than 50 people and left more than 45,000 people affected. Although this event is not directly linked to climate change, there is the perception that there is an increasing role which provokes traditional events to have more severe impacts. It is also considered that developing countries shall not reduce their economic growth because of climate change as this is generally a clear responsibility of developed economies in the first instance. The following graph based on data from the World Bank clearly shows such economic and emission inequalities.

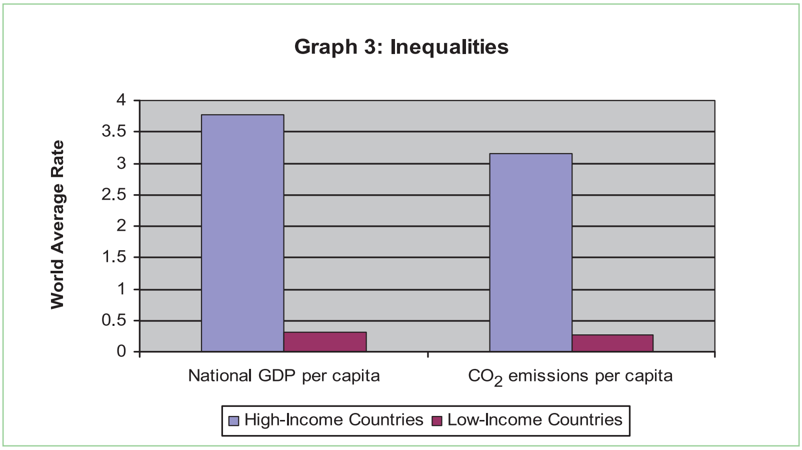

FIGURE 8

Inequalities of income and CO_2 emissions between high and low income countries.

Greenhouse emissions in terms of CO_2 in Bolivia are only 0.097% of the total global emissions. However, climate change impacts may affect in different ways and have been increasing in the last decade in many regions of the developing world. In Bolivia these climate alterations brought droughts in the Andean region, including glaciers retraction such as Chacaltaya (Figure 9) and Tuni-Condoriri (Figure 10) in the Bolivian highlands and flooding in lowlands and the Amazon. Hence, vulnerability to climate impacts are high in the country affecting natural ecosystems, water resources, food security, health and loss of infrastructure (NPCC, 2006). Based on political, economic and policy perspectives, the role of Bolivia and South American countries, with the only exception of Brazil as part of the BRIC (Brazil, Russia, India and China), is almost insignificant in global carbon emissions as North American, European and Asian nations are the primary sources of emissions. The graph in Figure 11 based on available data for 1999 presented by McKibbin and Wilcoxen (2002) clearly illustrates such differences.

Several political positions claim the need to tackle these inequalities and that South American developing countries have their own right to develop by using their natural resources. This position has been widely presented and supported

FIGURE 9
Chacaltaya Glacier Retraction in the Andean Region: Left shows the glacier in 1940 (Source: UMSA Archives – IHH – IRD) and right shows glacier in 2007 (Source: Ivy Beltran).

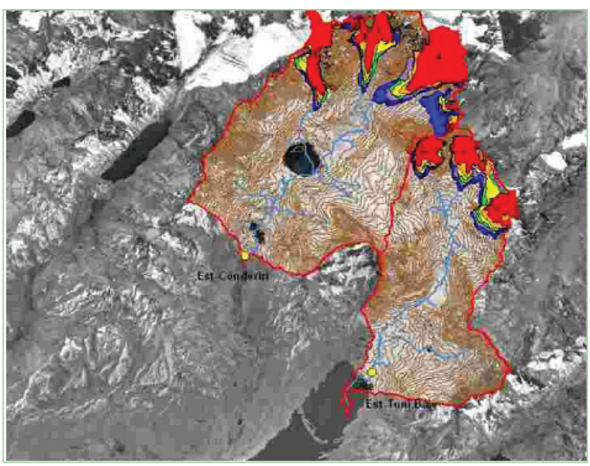

FIGURE 10
The Tuni Condoriri Glacier and water supply (Source: IPQ Project / LP /01037. NPCC – UMSA – IHH –IRD).

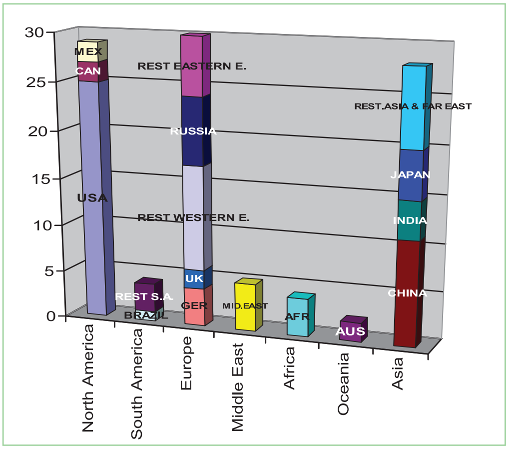

FIGURE 11
Global Carbon Emissions (% by region and country).

by Morales' administration, which have promoted the role of the State as a major political and economic change towards better redistribution of benefits, management of natural resources and participation of local and indigenous communities. In terms of climate change, there is the wide perception that although Bolivia is not a country producing carbon emissions, the impacts of climate change will be suffered throughout the country.

5. Bolivia and Climate Change: Potential Impacts

Maximum temperature increases are predicted to occur in the high mountains of Andean countries. If the models are correct, the changes will have important consequences for mountain glaciers and for communities that rely on glacier-fed water supplies (Bradley *et al.*, 2006). Bolivia is a country with a high vulnerability to climate change for several reasons: the population density in fragile mountain ecosystems, the expansion of arid zones, the existence of several regions exposed to periodic flooding, particularly in lowlands and the valleys, and the increasing deforestation rate and high poverty levels (Palenque, 2005).

These socioeconomic and environmental conditions mean the country is not very tolerant to climate change. Furthermore, the minimal infrastructure for natural disasters poses additional challenges. Based on that, the level of vulnerability for rural areas and poor people are severe, considering that these sectors will be more exposed and impacted seriously from climate change. One of the most notorious impacts of global warming is the slow disappearance of Andean glaciers. The Andean Range in Bolivia is one of the examples of tropical glaciers that have been affected by an increase in temperatures in the last decade. Accordingly, 1990, 1998 and 2000 were recognised as the highest temperatures in the historical record (Lozan *et al.,* 2001). Studies along the Tropical Andes indicate a temperature increase of 0.11°C/decade, compared with the global average of 0.06°C/decade between 1939 and 1998. Eight of the twelve warmest years were recorded in the last 16 years of this period (Vuille *et al.,* 2003). High-altitude mountain regions are then strongly affected by rising temperatures, as ice masses are declining rapidly (Ramirez *et al.,* 2001; Francou *et al.,* 2003: Kaser *et al.,* 2005).

According to Hoffmann (2005), Bolivian glaciers represent around 20 per cent of the world's tropical glacier area. Several small glaciers are located in the country, which are more sensitive to climate, and in turn, retreat at higher rates than larger glaciers. Impacts of glacier retreat are most likely to be mainly local. The supply of potable water for the growing urban areas in the La Paz and El Alto metropolitan regions is probably the main area of concern for shrinking glaciers in Bolivia. Although an increase in glacier melting initially increases runoff, the disappearance of glaciers will cause abrupt changes in stream-flow, because of the lack of a glacial buffer during the dry season. This will affect the availability of drinking water, and of water for agriculture and hydropower production (Bradley *et al.,* 2006). The highest percentage of glaciers in the country are located in the Andean Range, which because of its location and characteristics, provide water resources for: i) human consumption in the cities of La Paz and El Alto; ii) irrigation in northern highlands, high valleys, and cattle-stock on the shores of Lake Titicaca; and iii) energy generation through hydroelectricity (Gutierrez, 2007).

There is evidence that the contraction of Andean glaciers has been rapidly evolving. Based on research undertaken during the last 20 years, estimates predict that at the current rate, the glacier of Chacaltaya will completely disappear in no more than 10 years (Ramirez *et al.,* 2003). The glaciers balances of Zongo and Chacaltaya determine a significant risk for water supplies in La Paz and El Alto (Mendoza and Francou, 2000), which are amongst the most important cities in the country.

In terms of water supply for human consumption, the Tuni-Condoriri water system would have a serious impact with social and economic implications, as this system is directly linked as the major source of water supply for the city of El

Alto and peri-urban areas of La Paz, known as *laderas* or hillsides. Studies undertaken by the GRANT Project quantified the reduction in the glacier surface of the Tuni-Condoriri showing that under current conditions, the glacier of the Condoriri watershed would disappear by the year 2045, while the glaciers from the Tuni watershed would not last longer than 2025 (NPCC, 2006). Therefore, potable water supply from this system in El Alto would receive 35 per cent less in water resources, seriously affecting the normal distribution for both El Alto and several urban and peri-urban regions of La Paz. This scenario would cause rationalisation and reduction in water supply.

If water-resource buffers shrink further and some watersheds disappear completely, alternative water supplies may become very expensive or impractical in the face of increased demand as population and per-capita consumption rise. As water resources are affected by reductions in seasonal runoff in Andean countries, where hydropower is the major source of energy for electricity generation, there would be the need to shift to other energy sources, resulting in higher costs and most probably, an increased reliance on fossil fuels (Bradley *et al.,* 2005). Disappearance of these glaciers would not only affect water supply but will also have an important impact on electricity generation, as the region of Zongo is the most important provider of hydroelectricity for the capital city. These impacts are estimated to be direct consequences of climate change.

Irrigation in highlands and high valleys located in the region of Palca would also be affected with serious consequences for agricultural and cattle activities in rural areas. PRAA – The Andean Regional Project for Adaptation to Climate Change suggests an alarming loss rate of glacier surface, from 10 per cent to 90 per cent in the period between 1987 and 2004. This reduction of water availability would impact agricultural activities by reducing agricultural productivity, loss of cultivation fields, increases in costs for agricultural inputs and reduction in cattle production. Most of these products are commercialised in neighbouring regions and cities and, therefore, it would mean a decrease in food supplies. Furthermore, it is considered that these situations would cause social impacts as a supply reduction of basic food would be felt in local markets, increasing migration rates from highlands to urban areas. Estimates of climate change impacts on tropical ecosystems suggest there will be important changes in lowlands and tropical areas located in the East and North of the country in relatively short periods of time. In addition, it is estimated that dry forests in the region of Santa Cruz would get drier and the Chaco region in the south would suffer a total desertification, having a direct impact in the loss of endemic species of reptiles (ABDES, 2005).

There will be additional impacts on human health, particularly because of changes produced in the savannas of Beni and the alteration of the humid forest to tropical dry forest, which will increase the habitat for *Anopheles darlingi*, which is the main vector for malaria in the country (NPCC, 2000c). There may be increases in *leshmaniasis*, endemic of tropical regions in the country.

Additional studies suggest that the influence of climate change in the cities may be higher because of the effect of urban pollution of the atmosphere, water and soils. The level of pollutants such as nitrogen dioxide are above the limits in the cities of Cochabamba (Bascope, 2003), La Paz and El Alto, limits that would increase with further changes in the climate (Guisbert, 2003; Rocha and Palenque, 2003).

6. Policy Responses and Perspectives

Bolivia has ratified the Kyoto Protocol through the enactment of Law 1988 of July 22, 1999. This ratification was conditioned according to the principles of sustainable development, as the country had a specific policy and mandate to achieve sustainable development. One of the reasons for this ratification, behind the broad ratification made by most countries, was the interest in accessing incentives and economic benefits around clean development mechanisms. Furthermore, a proposal for a Carbon Law was presented in past years by the National Programme of Climate Change, which promoted the creation and development of a series of mechanisms for the certification of initiatives in terms of carbon sequestration and emissions avoidance. After several consultation workshops, it has been considered that there are very remote possibilities to establish a carbon market, with very few experiences. In this sense, these proposals have been put in stand-by if not rejected. However, on June 24, 2005, the Supreme Decree 28218 was enacted, declaring the implementation of projects and activities for climate change mitigation in forestry and energy sector as a national priority, in order to apply to CDM and other trade emissions schemes. This Decree shows the importance of projects and activities and the interest of policy-makers in these schemes as a way of generating short and long-term income.

Climate change mitigation in both sectors in this legal framework included the following areas: forestation and afforestation, fossil fuels substitution using natural gas, natural gas supply for residential, commercial and industrial consumption, renewable energies, energy efficiency, biogas, the efficient use of biomass and other project that reduce, capture, store and avoid greenhouse gases emissions. In December 2005, the historical election of Evo Morales and his Movement towards Socialism party (*Movimiento Al Socialismo* in Spanish) with more than 54 per cent of the votes, initiated a series of reforms and different visions on natural resources particularly, under the so-called process of change. These reforms involve a series of structural changes based on the elimination of the neoliberal era, both politically and economically, and the dismissal of sustainable development as a national policy. The proposal of the current administration claims for a different role of the State and the nationalisation of natural resources, both renewable and non-renewable, which was accomplished in the first place with hydrocarbons and later with protected areas.

This process considers an active participation of the State for sustainable use and management of biodiversity and forest resources, (considered as strategic resources for income generation) both for primary production and for industrialisation in order to improve life conditions of the Bolivia population, particularly indigenous communities. These principles aim to re-establish the balance between nature conservation and economic needs for national development, under the concept of "Living Well". Under this framework, the current administration considers to strengthen the regulatory participation and promotion of the State for the exploitation of natural resources towards guaranteeing a sustainable management of natural resources and a fair distribution of benefits resulting in that use. The new government considers indispensable to consolidate the ownership by the State over natural resources and genetic variability. Through this vision, natural resources will not be able to become subjects of commercial exploitation. National policies are focused under the implementation of a holistic vision that takes from nature what is needed for the development of the country, but, at the same time, protecting it (PND, 2006).

Forests and its resources are being considered now as an entire property of the State, where the State commands and controls forestry resources even if these forests are located on private lands or are part of concessions to private actors, designated for management, use and exploitation. The National Development Plan presented by the government of Evo Morales in 2006 is the major instrument of public policies that would lead the road in this process of change.

In terms of climate change, a significant background for carbon sequestration has increased based on the results of the Climate Action Project conducted in the Noel Kempff Mercado National Park, which is located in the department of Santa Cruz. This project has been conducted for the last ten years, having generated more than one million tons of CO_2 in certified carbon credits. Nevertheless, there are political positions claiming that these markets and market-based mechanisms for ecosystem services will provide the basis for these services to be sold as commodities, including the sensitive issue of water, with social and environmental impacts. These ideological conceptions are creating some increasing opposition for the implementation of projects on payments for environmental services, which are considered as part of a market-based mechanism and neoliberal approach.

According to the National Development Plan (NDP), carbon sequestration and certified emissions reduction (CERs) of greenhouse gases represent an important opportunity for income generation at a national level. This opportunity is based in the emerging international markets through clean development mechanisms, and the framework on climate change and environmental services. The national development plan has declared a specific policy on the reduction of greenhouse gases and carbon sequestration as part of the national development policies on environmental resources. In this policy, it has been designed that the State participates as the owner of natural resources in the generation of economic surplus through certification, international negotiation, sale and fair distribution of benefits produced by the commercialisation of carbon bonds in international markets. This plan conceives the strategy of income generation by carbon sequestration and CERs through forestation, reforestation and conservation, as part of environmental services. Three programmes have been proposed to implement this strategy:

a) CERs, carbon sequestration and conservation towards the promotion of clean development strategies and mechanisms for international markets, aiming at generating higher income for the country and local communities based on a fair distribution of benefits. This programme promotes investments of CDMs and other relevant schemes.

The main project is related to forestation and reforestation of 10 thousand hectares in tropical valleys in the department of Cochabamba aiming at sequestering CO_2 through production of biomass in forestry plantations and community agro-forestry systems in a 30-year period. The government aims to commercialise CERs from this project, as well as achieving rehabilitation of degraded lands of this region through the integration of native ecosystems with appropriate forestry and agro-forestry systems, which are incorporated to local traditions and uses. Carbon sequestration and potential income generated by the commercialisation of environmental services represent an important incentive for local communities. Effective and permanent participation of local communities, municipalities, national authorities and the private sector has been considered as a key factor in this process. Nevertheless, the participation of the private sector in general may have been restricted because of changes introduced by the government and a very unfavourable investment climate which resulted in having the lowest private and foreign direct investment rates in the country since 20 years.

b) National Programme of Carbon Sequestration. According to the National Development Plan, this programme aims to reduce deforestation rates in protected areas and buffer zones, which are threatened by human intervention, by avoiding illegal logging in protected areas and surrounding buffer zones. It aims to promote the certification, negotiation and commercialisation of carbon credits based on the experience of the Climate Action Project in the Noel Kempff Mercado National Park. This project runs from 1997 to 2025 and is estimated to produce CERs for more than 990 t CO_2 during the project life cycle (Ulloa, 2006). The project has the participation of local communities and two key components: i) To stop industrial timber harvesting by avoiding further timber extraction and damage to vegetation; and ii) Avoiding slash-and-burn agriculture through community development programmes. It is expected that similar schemes will be created and replicated in other protected areas based on regional and local projects.

c) Transformation and Change of the Energetic Matrix for CERs: This programme is based on the proposal to change the energy matrix and energy efficiency to obtain CERs through the implementation of related projects. This is part of the major component of the new government, which aims at strengthening the domestic demand of energy for social benefits. This policy framework was supported and strengthened by the participatory construction of an official proposal on climate change presented in September 2006 by the National Programme on Climate Change. This proposal was prepared and discussed with the participation of more than twenty institutions, including the academia, national agencies and municipal governments, as well as NGOs and local organisations from the forestry, environmental and climate change sectors. The proposal, which was presented in September 2006 and coordinated with other developing countries, acknowledged and promoted the clear need to include avoided deforestation as a recognised mechanism for emissions reduction. This is because there is a lack of an international agreements taking place under the Kyoto Protocol to address this important source of carbon emissions and valid alternatives to tackle these causes.

A key factor in terms of policy responses is that there are few specific policies (outside of protected areas) and measures in the National Development Plan and other sector-related policies in order to reduce deforestation, particularly in the Bolivian lowlands and the Amazon. This scenario represents a major challenge for biodiversity and sustainability.

7. Concluding Thoughts

Bolivia will benefit from the CDM in a meaningful way only if forest protection and reforestation projects are eligible under this scheme. Activities related to land-use change and forestry issues are responsible for more than 83 per cent of CO_2 emissions in Bolivia by 2001 (NPCC, 2001), which have increased to around 89 per cent by 2006. Moreover, around 97.7 per cent of Bolivia's CO_2 abatement potential is in this sector, which is equivalent to 903 million tons of CO_2, according to the national strategy study prepared in 2001 for the participation of Bolivia in the CDM. This study identifies a mitigation potential for land use, land-use change and in forestry projects of 73.5 million tons of CO_2 per year on average. The average potential in the energy sector is 1.8 million tons of CO_2 per year, even making CO_2 conservative assumptions for both of these estimates.

A number of potential CDM projects in the forestry sector have been proposed, presenting an assortment of mitigation options, and whose CO_2 mitigation effects could be demonstrated as being measurable and sustainable in the long-term. These projects would not only reduce emissions at very competitive costs, but also would be able to produce numerous collateral and value-added benefits for environmental conservation, local communities and biodiversity. Projects of this sort are related to the introduction of sustainable agro-forestry production methods, alternatives for rural population to shift away from traditional slash-and-burn agriculture, and the introduction of low-impact logging, all of which will aim for more efficient protection of protected areas, and provide economic incentives for local populations.

Despite the significant potential in the forestry sectors, Bolivia could also offer a variety of mitigation options in the energy sector (for residential, commercial, industrial and transportation sectors). Even considering that gas fired plants and hydroelectricity produce a major part of electricity in Bolivia, a potential for greenhouse gases emissions reduction also exists in the power generation sector (NPCC, 2001). Switching from diesel and gasoline to compressed natural gas, especially under the official decisions and policies of this administration to prioritise domestic use and demand of natural gas, is also a very interesting mitigation option in the Bolivian transport sector, which has great potential of GHG emissions reduction.

Mitigation options exist as well in rural areas and emissions reductions can be achieved in this context. In such areas, dispersed populations are not connected to the grid and electricity is usually and commonly produced by diesel power generators, -particularly in the Bolivian Amazon, which can be replaced by small hydroelectric plants. There exists an interesting hydroelectric potential not yet developed in the country, as well as wind and solar energy. However, current policies in terms of hydroelectricity still focus on old-fashioned megaprojects, instead of providing the appropriate support and investment for small and mini plants that would cause less environmental impacts while producing social benefits and opportunities for CDM projects. This is the case of the San Miguel del Bala hydroelectric dam, located in the northern part of La Paz, in the Madidi National Park buffer zone. This project was initially conceived in the late 1950s, reconsidered and rejected in the decade of 1990s, and officially supported again by the current administration through the enactment of the Supreme Decree No. 29191 of July 2007.

It is clear that the highest CO_2 emissions in Bolivia are directly related to deforestation and slash-and-burn practices both in forests and savannas in the lowlands region, which are undertaken annually in order to expand the agricultural frontier for cultivation and cattle ranching. In contrast, land-use GHG emissions in 2000 at a global scale represented only 18 per cent, according to the Stern Review. Avoided deforestation has been promoted for both specific-related sectors because of the deficiencies in the absence of a global climate agreement that values forests. With the recent outcomes of Bali, of critical significance is the decision that governments decided to encourage actions to reduce emissions from deforestation, and agreed to consider how to reward those countries who take immediate action. With this encouragement, tropical-forest governments could feel confident that efforts undertaken now could build the institutional and technical capacity needed. In addition, it was also acknowledged to consider efforts that not only reduce emissions from deforestation and degradation, but options to encourage the maintenance of carbon stocks found in countries with large intact tropical forests, such in the case of Bolivia, in order to prevent future emissions. It is expected that under these recent outcomes, the consideration of the role of indigenous and local communities will be moved forward to ensure that forest-dependant communities and those most directly connected to forests are not negatively impacted or undermined.

Three key areas would push the climate change agenda forward locally: economics, the media and political issues. In terms of economics, there is interest not only in the costs and impact of climate change but the opportunities for income generation through CDM schemes, and more significantly, by implementing deforestation avoidance and similar proposals. The media has gained a great space nationally and internationally since the release of *An Inconvenient Truth* and, currently, climate change is an unavoidable subject on the news. There is ground for political support based on the increasing outcomes and interest in both areas. In the case of Bolivia, political interest is framed under the policy framework which recognises the importance of climate change for future impacts and, especially, for the potential opportunities for income generation. Nonetheless, unless avoided deforestation and other similar schemes are put in place, deforestation will continue with high probabilities of not reducing current rates. On the contrary, deforestation rates may increase. Actions on such schemes are not only related to economic benefits and income generation, although there is enormous interest in those schemes based on the resulting economic benefits, but the need to include social and environmental benefits and the participation of rural and indigenous communities that could be most negatively affected. These impacts were clearly seen in the recent flooding of February 2008, particularly in the province of Beni. Otherwise, deforestation will undoubtedly continue to represent the major source of CO_2 emissions with significant values at the national level, although not on a global scale. Nevertheless, the main impact will result in a continue loss of habitat and biodiversity, which would have irreversible consequences.

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PAPER

17 CASE STUDY ON THE UPPER ESSEQUIBO CONSERVATION CONCESSION (UECC) - AS AN INNOVATIVE LEGAL MECHANISM FOR BIODIVERSITY CONSERVATION AND A VIABLE OPTION FOR AVOIDING FOREST DEGRADATION/DEFORESTATION

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ABSTRACT: Deforestation/forest degradation due to logging and agricultural clearing is one of the main causes of increased emissions of atmospheric carbon. Many developing countries (including Guyana) are traditionally dependent on commercial timber production for national economic development. As such, these countries continued to harvest their timber resources but without generating any significant economic benefits. Until recently, few alternatives have existed that would allow countries to benefit from their forests other than through the extraction of timber. One such alternative is the conservation concession- an approach that offers a sustainable and cost effective alternative for developing countries to achieve forest based economic development without incurring forest degradation. The Upper Essequibo Conservation Concession (UECC) is approximately 200,000 acres of relatively pristine tropical rainforests in a watershed area of the Upper Essequibo River within Guyana's Forestry Zone. The site is being managed by CI-Guyana for biodiversity conservation rather than timber production. Though this innovative mechanism of forestry management operates under the principles of a standard timber concession, the difference is rather than log the trees, CI-Guyana pays the Government of Guyana (GOG) royalty and fees equivalent to those of a logging concession to keep the trees intact. Additionally, a Voluntary Community Investment Fund was established to ensure nearby stakeholder communities receive tangible socio-economic benefits for choosing to forego logging of their forests for the achievement of biodiversity conservation and the prevention of forest degradation. The UECC has successfully proven that there are markets for conservation and it provides an excellent strategy for avoiding forest degradation while providing economic development without the need for new legislation or giving up of national sovereignty.

Keywords: conservation, concession, forest degradation, adaptation to climate change

1. Introduction

Deforestation, forest degradation and land clearing for agriculture are among the leading man-induced causes of global climate change and destroy about 9 million hectares of tropical rainforests annually (Niesten and Rice, 2004). Currently, it is estimated that approximately 20%-25% of global discharge of greenhouse gases emerge from land use changes in tropical rainforests. Though deforestation is apparently negligible in Guyana, there are conspicuous signs of forest degradation within the forestry sector. It is estimated that the country's timber industry destroys approximately 49,000 hectares of forests annually – a figure that does not include forest destruction due to road expansion and the mining (gold and diamond) industry. Due to the country's traditional dependence upon natural resources extraction (for example, timber and mineral mining) for national economic development, the rates of forest degradation in Guyana are therefore likely to accelerate and consequently, result in the destruction of biodiversity and the plundering of crucial environmental services (for example, clean air, carbon sequestration and climate regulation) associated with standing tropical rainforests.

Despite years of international efforts to increase global awareness on the effects of environmental destruction and to develop national policies and institutions for sustainable forest management, many developing countries are still inadequately equipped to avoid deforestation/forest degradation. Furthermore, these developing countries lack mechanisms to capture and commercialize environmental services, which possess the characteristics of public goods but have yet to receive an economic value in the market place. This economic conundrum results in wasteful forest destruction and contributes significantly to global emissions of GHG, due to logging. Therefore the provision of incentives for developing countries to conserve their rainforest, its biodiversity and environmental services will allow for compensation of the opportunity costs for forgoing logging and will also present cost effective and sustainable options to adapt forestry management to avoid deforestation and/or degradation and mitigate against climate change.

To create market mechanisms for conservation and to institutionalize conservation incentives, Conservation International (CI) developed and introduced the concept of a "conservation concession," an innovative approach that utilizes the principles of a standard timber concession to achieve biodiversity conservation outcomes, but also provides an option for the avoidance of deforestation/forest degradation, while pursuing forest-based national economic development. To implement this novel conservation approach, CI through its Field Office in Guyana (CI-Guyana) applied to the Guyana Forestry Commission (GFC) for a concession Lease License, held widespread consultations to garner informed consensus of stakeholders, built the required capacity, and formulated and implemented a Forest Resources Management Plan (FRMP). This participatory and transparent approach empowered stakeholders for their direct involvement in collaborative management of the site.

Concept description

The concept of a *conservation concession* refers to the idea of choosing not to exercise the rights acquired to the forests, biodiversity or other forms of natural resources. A conservation concession may take several forms, but the UECC is modeled after a standard timber concession where the logging concessionaire pays the Government of Guyana (GOG) for the right to extract timber from an area within the State's Forest Zone and other areas of country. The difference is that while the logging concessionaire will log the area, the conservation concessionaire pays the GOG for the forest to remain intact. In other words, rather than paying duties, acreage fees, royalty, etc for the extraction of timber within the State's Forest, CI-Guyana is paying similar fees to the GOG through the Guyana Forestry Commission (GFC) to keep the trees standing.

Though a conservation concession is currently not recognized as an official protected area in Guyana, it nevertheless functions like a standard protected area by safeguarding the forests and its resources from the pressures of extractive economic development. In Guyana, the UECC serves the additional function of buying time for the protection of an area of intact and biologically important rainforests until it becomes a legally declared protected area. This mechanism therefore not only offers an alternative to logging in countries endowed with large areas of intact high biodiversity forests of importance to conservation, but also provides a vehicle for establishing "anchors" for biodiversity conservation corridors.

2. The Problem

Logging is one of the root causes of deforestation and forest degradation in Latin America. Guyana and nearby countries are endowed with large expanses of relatively untouched tropical rainforests, but have traditionally focused on extraction of its timber resources for economic development. However, low prices on the domestic and global timber markets, low yields per hectare and relatively high production costs, have contributed to a poor financial performance within the timber industry. In spite of this, parcels of State Forests continue to be allocated to logging companies that remove the most valuable timber species, without any generation of significant profits. Simultaneously, there has been an increasing willingness to pay for conservation in the international community. Unfortunately, prior to the UECC, the international donors did not have a clear market mechanism that could allow them to directly invest financial resources for biodiversity conservation. As such, the GFC did not have any alternative to the allocation of the State Forests for commercial timber production. The UECC therefore provided an innovative and creative way to harness market forces to achieve biodiversity conservation and presented itself as an option to avoid forest degradation within Guyana's Forestry Sector.

3. Project Implementation

At the time of project implementation, conservation concessions and perhaps, biodiversity conservation as a whole were relatively new concepts to Guyana.

The GFC had just adopted and implemented the principle of Sustainable Forest Management (SFM) and incorporated it into the National Forest Policy. Simultaneously, Dr. Richard Rice and a group of researchers from CI's Centre for Applied Biodiversity Sciences (CI-CABS) were on a visit and recognized that SFM in Guyana will at best allow for long-term timber supply but with limited economic and ecological benefits. To address this problem, they proposed the idea of conservation concession to the Government and it was accepted. This led to a series of actions as described below:

- **Initial Consultation with all stakeholders to evaluate the feasibility of the idea**

After garnering the required policy support to initiate activities, CI-Guyana consulted with a wide range of potential stakeholders to ascertain the acceptability of the idea of a conservation concession. Through this comprehensive stakeholder management strategy, CI-Guyana was able to identify, inform and receive feedback from a wide range of national, regional and local stakeholders (including communities, Government organizations, NGOs, etc). Discussions were held with the Guyana Geology and Mines Commission (GGMC), the Guyana Environmental Protection Agency (EPA), Fisheries Department and the Ministry of Agriculture. This was needed because though the Concession focuses mainly on trees and non-timber forest products (NTFP) it contains a wide range of resources (for example, wildlife and minerals) that are of interest to these State Sector Agencies and are not covered by rights under the Forestry Regulations. Consultations with the Regional Advisory Committee (RAC) of the Region Nine (Upper Takatu – Upper Essequibo) Administration Unit guided the selection of Apoteri, Rewa and CrashWater (hereafter referred to as ARC communities) as the key stakeholder communities. The sixteen communities (including the ARC communities) in the North Rupununi Region are all represented by an umbrella community-based NGO registered as the North Rupununi District Development Board (NRDDB). Hence, the NRDDB automatically became the principal regional stakeholder.

For each stage of project development, CI-Guyana sought and gained the informed consensus of the principal stakeholders through the combination of consultation meetings (Figure 1) with education and awareness programmes. Upon garnering of the support framework for project implementation, a Guyanese Lawyer was hired to determine the compatibility of the project with existing national legislations on natural resource management.

FIGURE 1
Community-based stakeholder consultation meeting.

Applied to GFC for a State Forest Exploratory Permit

As is required under the national Forest Regulations, an application made to the GFC for a State Forest Exploratory Permit (SFEP) in May 2000 was accepted five months later, but only one-fifth (approximately 200,000 acres) of the area applied for was received. This permit allows a prospective timber concessionaire to execute feasibility studies and baseline analyses, all of which must be completed within three years in order to receive the lease agreement – Timber Sales Agreement (TSA).

Established formal partnerships with Government Agencies

CI-Guyana entered into a formal Memorandum of Understanding with the GOG for the sharing and wide distribution of any information that may be generated from research activities undertaken at the site. A commitment for a closer work relationship was also formalized though a MOU with the University of Guyana (UG).

Baseline Analyses

A Social Impact Assessment (SIA) was conducted in the ARC communities to determine socio-economic impacts of the concession. Because the project is not intended to have any negative environmental affects, the Guyana Environmental Protection Agency (EPA) waived the need for an Environmental Impacts Assessment (EIA). The draft SIA report was submitted to EPA and the communities for feedback before being finalized. Upon approval of the report, copies were widely distributed among all stakeholders and partners.

Other initial analyses conducted were:

- A preliminary reconnaissance and geo-referencing of the proposed site; and
- A vegetation classification based on video graphic surveys.

Built local capacity for co-management

Management of the UECC required active participation of the stakeholder communities, including a core team for long-term monitoring. To build the relevant local capacity CI-Guyana entered into an Agreement with the Iwokrama Centre for Research and Training (ICRT) to train four residents of the ARC communities for two years. Under the Agreement CI-Guyana was both a sponsor (contributing one-third of total cost of training programme) and client to the Ranger Training Programme.

Preparation of a FRMP for first five years of management

Data emerging from the baseline analyses and from regional and community consultations were used to guide the development of the first five-year FRMP. The draft FRMP was presented for feedback at national, regional and local consultation meetings. Many of the State Sector Agencies, NGOs and other partners including the EPA were also asked to review and comment on its contents. After receipt of widespread feedback, the final draft was presented at another National Consultation Workshop in the capital city of Georgetown. GFC's approval of the FRMP was received in 2002 March and discussed with the ARC communities a few weeks later.

Applied to GFC for a Timber Sales Agreement (TSA) and the EPA for an Environmental Permit

Application to the GFC for the TSA was made in March 2002 and soon after, negotiations commenced on the types and magnitude of payments to be made for the UECC. CI-Guyana and the GFC reached a negotiated agreement on the annual royalty fees, but as stipulated in the national forestry Regulations - the acreage fees remained at 0.15 USD per acre. The GFC also requested a one-off payment of a Performance Bond. Additionally, the EPA requested an annual Environmental Permit Fee as a safeguard for the project.

On the 17th July 2002, CI-Guyana and the GOG signed the Lease Agreement for approximately 200,000 acres of relatively pristine rainforest thereby establishing the world's first conservation concession. The TSA provides CI-Guyana with a 30-year lease to a portion of State Forest within a watershed area of the upper Essequibo River for conservation management rather than timber production. This historic signing ceremony occurred at the Office of the President and signaled the implementation of an innovative mechanism for forest management that will not only allow for biodiversity conservation and socio-economic development, but will also avoid forest degradation and contribute to the reduction of climate change.

- **Conducted an inventory of timber stocks in the concession**

Soon after receipt of the TSA, an inventory of the commercial timber species was conducted at the site. The aims of the inventory were to upgrade the national forest resources map and to receive information required to guide the development of a valuation model to achieve a more realistic value of the timber resources at the site. At that time, the development of a valuation model to accurately determine royalty payments was being considered, but as stated in the previous paragraph, CI-Guyana and the GFC opted for negotiated and mutually agreed royalty payments.

The fact that royalty payments were negotiated, it infers that the GFC is probably receiving more than the actual value of standing timber at the UECC.

- **Implemented a Voluntary Community Investment Fund (VCIF)**

In 2002 August, a Voluntary Community Investment Fund (VCIF) was implemented to provide for socio-economic development to the ARC communities for forgoing employment and other benefits that might have existed if logging was being done at the site. Because the NRDDB represents the interest of the stakeholder communities, an MOU was signed between CI-Guyana and the NRDDB for co-management of the VCIF.

4. Results

The experience so far provided by the UECC has confirmed that the idea of using "conservation concession" as an option to avoid forest degradation/ deforestation is quite viable. The UECC provides the GOG with a win-win opportunity to retain sovereignty of its forests and exercise a national responsibility to conserve its natural resources, while at the same time generating financial benefits to support national development programmes. The UECC is also another demonstration of Guyana's commitment to the Convention of Biological Diversity (CBD) for the promotion of biodiversity conservation. This is a significant achievement for the country, which is still in the process of developing legislation for a national protected areas system. Therefore, in the absence of national legal mechanisms for protected areas, the UECC resulted in structured and effective conservation of 200,000 acres of intact (Figure 2) and biological important rainforest.

Photo ©Save Your World LLC.

FIGURE 2
Aerial view of section of UECC.

Through the UECC a platform is now created for Guyana to become a beneficiary of carbon credits and/or other payment schemes for the provision of ecological goods and services such as clean air, quality freshwater and climate regulation. While countries (like Guyana) with negligible rates of deforestation and intact high biodiversity-value rainforests wait upon the proposed modifications to the Kyoto Protocol, the conservation concession presents opportunities for benefits from other forms of conservation incentive schemes. The remote location and management regime allowed the UECC to provide niche refugia for many species shy of the more accessible and impacted places. Though the biodiversity of the UECC is not yet fully understood, many species either endemic to Guyana or globally endangered are supported by the site, for example, the giant river otter (*Pteronura brasiliensis*), giant armadillo (*Priodontes maximus*), black caiman (*Melanosuchus niger*), jaguar (*Panthera onca*), and giant anteater (*Myrmecophaga tridactyla*). There is also a unique reef of the endemic greenheart (*Cholorcardium rodiei*) - Guyana's most valuable commercial timber species. According to the GFC, this reef is probably the limits of the greenheart distribution in Guyana.

Through the UECC the image of Guyana's forestry sector has also been enhanced. In fact, the GFC globally advertises the project to illustrate its commitment to SFM and to demonstrate that economic and ecological gains can be accrued through the avoidance of destructive forest development. At present, the UECC allows Guyana (through the GFC) to receive a steady flow of revenue for the protection of standing forests rather than from the extraction of trees for lumber.

The local communities have also demonstrated strong support for the UECC - mainly because of their dependence on its resources for their livelihoods and their desire to secure their nearby forests from the perils of destructive development and still receive socio-economic benefits. Since implementation, the local communities have expressed satisfaction with the project, which allows them to keep the trees standing rather than being logged, conserve their food resources, maintain traditional practices and still receive employment, training and community development. To date, funds disbursed under VCIF have contributed significantly to their welfare and livelihoods. For instance, a vibrant sheep and mutton production project was established at Apoteri, eco-lodges were constructed for Rewa (Figure 3) and CrashWater received a sewing and craft centre. These communities collaborated with the NRDDB to identify and conduct feasibility analyses of the projects prior to submission of proposals to the VCIF Steering Committee. In addition to employment received through the VCIF, the communities also benefit annually from temporary sources of employment (on average 20 persons per year) for the implementation of on-site project activities. The four graduated Rangers (who are residents of the ARC

Photo ©CI-Guyana

FIGURE 3
Edward's Eco-lodges at Rewa Village.

communities) are permanently employed by CI-Guyana. Collectively, they manage the Field Base at Apoteri and routinely monitor the site to ensure its biological integrity is not being jeopardized.

Since its implementation, the UECC has influenced similar initiatives in other countries such as Peru, Guatemala, Democratic Republic of Congo and Sierra Leone.

5. Conclusion

The UECC has successfully proven that conservation concessions could be modeled after standard timber concessions to safeguard pristine high biodiversity value rainforest from forest degradation and deforestation. Thus, it is an excellent strategy to achieve biodiversity conservation, avoid forest degradation and promote economic development at both national and local levels. It presents a win-win opportunity for the GOG to enter into transactions with a willing buyer of forest conservation without the need to alter existing legislation or surrender sovereignty over the country's natural resources.

Successful implementation was due to a well structured stakeholder management strategy that included the combination of conservation education and awareness programmes with consultation meetings. This approach allowed for transparency and total participation thereby giving all stakeholders a direct stake in conservation management of the site

At present a few limitations/constraints to Guyana's model of a conservation concession are as follows:

- The current national Forest Act under which the UECC was allocated only provides the concessionaire rights to "forest produce," that is, timber and other botanical non-timber forest products. So far, CI-Guyana has received the assurance and support of these State Institutions to withdraw any interest in land uses that are incompatible to the goals and objectives of the UECC;
- Due to an unexpected decrease in the availability of funds for project management CI as a not-for-profit NGO was compelled to aggressively fundraise to sustain the payments of annual acreage fees and royalty. To date, the UECC has been financed by the Global Conservation Fund and Save Your World, an American-based company that specializes in organic cosmetics and donates a percentage of each product sold to finance the concession fees;
- The current global principles of the Kyoto Protocol inhibit the UECC from receiving real cash benefits for reduced emissions of carbon due to avoided

deforestation/forest degradation (RED/D). To counter, CI has adopted and institutionalized a policy on climate change that includes avoided deforestation. Simultaneously, CI through CI-Guyana is collaborating with the GOG on global policy initiatives to ensure that the UECC and Guyana as a whole benefit from carbon trading through the avoidance of forest degradation.

Though there are constraints, the benefits of the UECC outweigh the limitations. In conclusion, the project allows conservation outcomes to be achieved, provides an option for the avoidance of forest degradation to reduce emissions of atmospheric carbon, promotes socio-economic development and will ultimately contribute to the prevention of global climate change.

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APPENDIX

PANAMA STATEMENT

from the
Climate Change and Biodiversity Symposium in the Americas
Panama City, Panama • February, 2008

Biodiversity

Biodiversity means the variability among all living organisms, including diversity within species, between species and of ecosystems. This diversity is the result of four billion years of evolution.

Biodiversity supports human societies ecologically, economically, culturally and spiritually. Despite its importance, ecosystems are being degraded and species and genetic diversity are declining at an alarming rate. This is due to the impact of a number of forcing agents, including a changing climate, growing human populations and increasing resource consumption.

The decline in biodiversity is now recognized as one of the most serious environmental issues facing humanity. A global goal has been defined – to reduce the rate of loss of biodiversity by 2010 (**www.biodiv.be/convention/2010target/links/lnk-world/int-conv/cbd/2010_target**).

Advice and Guidance

1. Support the establishment of a climate change and biodiversity monitoring and information network throughout the Americas. This network will provide:

   (a) a transect of scientific expertise and/or on-the-ground monitoring across chemical, climate and ecological gradients to allow for unique investigations into the impacts of climate change on forest biodiversity and improve our understanding of its adaptive capacity;
   (b) mechanisms for the sharing and communicating of information, data and science on climate change and biodiversity;
   (c) training on monitoring tools and methodologies, analysis techniques, data management and verification tools needed to support adaptation options and decision-making; and
   (d) a network secretariat, located at the Smithsonian Institution, for overall coordination of the monitoring network.

2. Support the establishment of a climate change and biodiversity research network throughout the Americas. This network will provide:

   (a) integrated research on climate change and biodiversity, including new global and regional climate change models, hazards and extremes, and other human pressures impacting forest biodiversity;
   (b) expert scientific advice on adaptation options and opportunities to reduce the impacts of climate change on biodiversity;
   (c) an exchange of scientists, environmental managers and community leaders to increase the scientific capacity, training and development of new study methods and monitoring techniques for both climate change and biodiversity; and
   (d) interlinking of research groups, such as Environment Canada's Adaptation and Impacts Research Division and the Smithsonian Institution, by taking advantage of new scientific developments (e.g., **www.cccsn.ca**, **www.hazards.ca**) to support the next generation of model development, transfer functions and adaptation science for effective decision-making.

3. Support the development of research activities as indicated in a recent UK Royal Society report (**http://royalsociety.org/**) on climate change and biodiversity. The chief aim of this research would be to improve our understanding of biodiversity in underpinning ecosystem structure and function, in climate regulation, and in human livelihoods. The interrelationships between biodiversity and climate change require further research and evaluation by the scientific community. In particular, the hypothesis that systems with high biological diversity are more resilient to global change than less diverse systems requires testing.

4. Support the development of scenarios for impacts on biodiversity and ecosystem services under different levels of climate change. Such scenarios are urgently needed now to identify adaptive management priorities and potentially dangerous levels of biodiversity loss.

5. Support the articulation of the benefits, needs and applications of seasonal climate forecasts for adaptation to reduce the effects of climate change and biodiversity losses, in preparation for the World Climate Conference (WCC-3) in Geneva in 2009 (**www.wmo.int/pages/world_climate_conference/index_en.html**).

The United Nations Convention on Biological Diversity

www.cbd.int/

In response to this crisis of present and impending loss of biodiversity, the United Nations in 1993 brought into force the United Nations Convention on Biological Diversity (CBD). The three objectives of the Biodiversity Convention are:

- The conservation of Biodiversity;
- The sustainable use of Biological Resources; and
- The fair and equitable sharing of the benefits that result from the use of Genetic Resources.

Scientific studies now make it clear that the climate is changing at regional and global levels and that many ecosystems are already being impacted by these changes. Climate change has been described as one of the major challenges of the 21st century to

conserving biodiversity, combating desertification and ensuring the sustainable use of natural resources – particularly since the rate of global climate change projected for this century is more rapid than any change that has occurred in the last 10,000 years. Its threats to ecosystems and to the spread of desertification are further compounded by the fact that humans have altered the structure of many of the world's ecosystems through habitat fragmentation, land degradation, pollution, and other disturbances, making ecosystems more vulnerable to further changes. Responses to deal with these threats will require improved scientific understanding of the linkages between the climate, biodiversity and the processes of desertification, along with an enhanced environmental forecasting capability to predict potential biodiversity and land use changes that may occur.

A summary of some anticipated effects of climate change on biodiversity is provided in Table 1. It should be remembered that in a region as vast as the Americas, there are significant differences over short distances and time-scales in the changing climate, its variabilities and extremes. Given the number of scientific studies that point to the differing localized rates of species and ecosystems adapting or maladapting to the changing climate, it is clear that the Americas can ill-afford the loss of even one species.

The Millennium Ecosystem Assessment

http://www.millenniumassessment.org/en/index.aspx

The global Millennium Ecosystem Assessment (MEA) (2005) further clarified the impacts on biological diversity and emphasized that protecting biodiversity is in the self-interest of all humans and their societies. Biological resources are the pillars upon which civilizations are built. Loss of biodiversity threatens essential ecosystem goods and services, while also interfering with the earth's hydrological, weather and climate systems. The various goods and services provided by ecosystems include:

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

The UN Framework Convention on Climate Change

http://unfccc.int/2860.php

The UN Framework Convention on Climate Change (UNFCCC) seeks to stabilize greenhouse gas (GHG) concentrations in the atmosphere at a level that will avoid dangerous human interference with the climate system. Because the climate of the future will eventually respond to all of the GHGs collected in the atmosphere over time, even cutting future GHG emissions to zero will not stop most changes. Hence, ecosystems and communities will need to adapt to climate change even if anthropogenic emissions are reduced to near zero.

Climate change is likely to have significant impacts on most or all ecosystems, since the distribution patterns of many species and communities are determined to a large extent by climate. However, ecosystems and biodiversity responses to changes in regional climate are rarely simple. At the most basic level, changing patterns of climate will alter the natural distribution limits for species or biological communities. In some cases, it may be possible for species or communities to migrate in response to changing conditions if there are no significant barriers to migration. Rates of climate change will also be critical, and these will vary at regional and even local levels. The maximum rates of

TABLE 1

Examples of Projected Impacts of Climate Change on Biodiversity

(Adapted from CBD Information Report,
Annex 1: Biodiversity and Climate Change, 2007. UNEP/CBD/SBSTTA/12/7)

The Changing Climate	Projected Climate Impacts	Impacts on biodiversity
Increased air temperatures	Increased number of hot days	■ Increased heat stress on biodiversity, loss of sensitive species and possible extinctions ■ Increased exposure to pests and diseases ■ Increased drying of wetlands and waterways ■ Invasion by more heat-tolerant species
	Increased water temperature	■ Decreased dissolved oxygen ■ Increase in instances of disease among fish ■ Loss of cold- and cool-water fish species ■ Increased vulnerability to invasive alien species ■ Reduced productivity of marine systems (coral reefs and seagrass beds) and possible extinctions
	Sea level rise	■ Salt water intrusion in coastal wetlands and other inland waters (islands especially vulnerable) ■ Inundation of lowlands and coastal wetlands ■ Increased mortality and disturbance of critical habitat ■ Increased erosion (beaches/coastal cliffs)
	Melting permafrost	■ Changes in nutrient cycling and soil biodiversity ■ Reduced access to food sources as a result of repeated freeze-thaw cycles ■ Loss of cryosoil-based ecosystems and species ■ Land instability, increased sedimentation and erosion ■ Drainage of lowland Arctic tundra
	Decreased ice cover (later freeze and earlier breakup)	■ Reduced winterkills ■ Changes in deposition of sediments in floodplains, affecting aquatic life
	Glacial retreat and decreased snow cover	■ Changing hydrological regimes ■ Changes in seasonal cues for mountain biodiversity ■ Increased predation ■ Disruptions in hibernation patterns ■ Reduced insulating protection from snow ■ Loss of snow bed ecosystems and species

TABLE 1

Examples of Projected Impacts of Climate Change on Biodiversity

(Adapted from CBD Information Report,
Annex 1: Biodiversity and Climate Change, 2007. UNEP/CBD/SBSTTA/12/7)

The Changing Climate	Projected Climate Impacts	Impacts on biodiversity
Changes in precipitation regimes	Increased instances of drought	■ Loss of ground cover leading to desertification and loss of soil biodiversity ■ Increased water stress on biological communities ■ Reduced availability of food and fodder ■ Salinization, compaction, cementation of soils ■ Increased risk of fire ■ Changes in natural flow regimes of rivers and streams ■ Changes of alpine grassland to steppe
	Increased flooding	■ Increased erosion of soil biodiversity ■ Increased land degradation ■ Increased threats from water-borne disease ■ Increased habitat destruction from flooding ■ Changes in natural flow regimes of rivers and streams
	Decreased freshwater availability in lakes and coastal zones	■ Decline of water levels and availability in freshwater lakes ■ Significant impacts on near-shore coastal biodiversity (e.g. bird and aquatic species) ■ Disappearance of coastal wetlands ■ Emergence of new land and property ownership issues
Increased frequency of extreme climatic events	Disruption in growth and reproduction	■ Changes in biodiversity, biomass and productivity ■ Changes in fires, insects and disease regimes ■ Increased mortality ■ Damage to forest structure, alteration of succession patterns and landscapes
	Heightened storm surges	■ Increased mortality of ecosystems and disturbance of critical habitat ■ Habitat loss (especially mangroves, reefs, sandbars and beaches) ■ Increased erosion and sediment damage

spread for some sedentary species, including large tree-species, may be slower than the predicted rates of change in climatic conditions.

The most vulnerable ecosystems 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, for example, Arctic, mountain and island ecosystems. Tools and guidance in the form of scientific predictions of ecological states are essential to pinpoint priority ecosystems and to guide climate change response options.

Organisms and ecosystems have a natural but limited ability to adjust to climate change. It is clear that as the climate has cooled and warmed over the past hundreds of thousands of years, the various major ecotypes and the animal communities that inhabit them have shifted cyclically to the north and south. Projected climate change, primarily driven by human-induced causes, is faster and more profound than anything in the past 40,000 years, and probably the last 100,000 years (IPCC, 2007). The UN Intergovernmental Panel on Climate Change (IPCC) Working Group II report suggests that 20 to 30 percent of global plant and animal species are likely to be at increased risk of extinction if increases in global average temperature exceeds 1.5 to 2.5 degrees Celsius.

The UN Convention to Combat Desertification

http://www.unccd.int/

The UN Convention to Combat Desertification (UNCCD) promotes an innovative approach to managing dryland ecosystems and arid regions and recognizes that desertification is caused by climate variability and human land management activities. Desertification is defined by the UNCCD as “land degradation in arid, semiarid and dry sub-humid areas resulting from various factors, including climatic variations and human activities” (Millennium Ecosystem Assessment, 2005). Desertification involves the loss of biological and economic productivity, as well as complexity in croplands, pastures, and woodlands.

The UNCCD recognizes that combating desertification is necessary to improve conditions in developing countries, particularly the least developed. To combat desertification and mitigate its effects in countries experiencing serious drought and/or desertification, the UNCCD outlines long-term integrated strategies that focus simultaneously on improved productivity of land and the rehabilitation, conservation and sustainable management of land and water resources. Its chief mechanism for implementing them is through the development of action programs to manage dryland ecosystems and arid regions (UNEP, 1996).

Addressing the underlying causes of desertification and drought and identifying measures to prevent and reverse them, action programs have been detailed for Africa, Asia, Latin America and the Caribbean, and the Northern Mediterranean (UNEP, 1996). The UNCCD also recognizes that the implementation of the UNFCCC, the CBD and related environmental conventions will play a significant role in combating desertification.

Examples of Climate Change Adaptation Options for Biodiversity

Adaptation options can be classified under many general thematic approaches, which include the following:

i. Adaptation Strategies:

- Ensure options are of the do-no-harm variety
- Improve predictions or plausible scenarios of future climate change
- Develop National Adaptation Plans that include biodiversity
- Undertake Adaptive Capacity Studies
- Prioritize intact or relatively unaffected habitats for protection
- Engage local people in planning and implementing mitigation and protection strategies
- Design reserves to protect vulnerable life stages
- Respond to changes already inherent in the system
- Improve integrated monitoring and detection programs

ii. Planned Adaptation

- Build corridors
- Reintroduce species, with great care
- Assist species regeneration
- Employ ex-situ conservation if extinction is imminent
- Manage for disturbances to the ecosystem
- Account for projected effects of climate change when designing new protected areas
- Track and manage invasives (e.g., control or eradicate invasive species)

iii. Building Ecological Resilience

- Reduce fragmentation
- Protect space, functional groups, climate refugia and multiple microhabitats in replicated areas
- Maintain a natural diversity of species, ages, genetic diversity and ecosystem health
- Provide buffer zones and flexibility of land uses
- Ensure connectivity of habitats along gradients
- Reduce other related and cumulative stressors

iv. Technological Adaptation Solutions

- Efficient management of rain/snow water availability
- Changes in timing/type of irrigation and fertilization
- Inoculate with soil biota important to plant vigor
- Establishment of aquaculture
- Diversion of fresh water
- Seawalls, dykes and tidal barriers
- Bridges to cross inundated areas
- Increase density and reliability of climate monitoring

v. Behavioral Adaptation Solutions

- Early-Warning Climate Alert and Response Programs for Biodiversity
- Prediction of climate extremes and hazards for emergency preparedness and disaster management of critical biodiversity
- Risk management assessments and priority setting of behavioral-based action plans to reduce the impacts of a changing climate on the functioning of biodiversity
- Redefinition of critical biodiversity thresholds to the new multiplier climate

vi. Regulatory/Policy Adaptation Actions

- Re-zone coastal areas
- Establish protected areas
- Natural forest regeneration or avoided deforestation
- Decrease nutrient enhanced run-off
- Non-chemical control of pest/disease outbreaks
- Establish no-take zones
- Landscape scale management of water availability and quality
- Change trade policies

vii. Economic Adaptation approaches

- Changes in grazing management and water management
- Apply modifications in agricultural land base and incentives for more sustainable agriculture and forestry
- Offer incentives to control the spread of invasive species
- Eliminate incentives that accelerate habitat loss
- Adopt energy efficient technologies for both adaptation and mitigation benefits

viii. Adaptation Science

- Model the buffering capacity of forest habitat for biodiversity in a changing climate, especially in urban parks and school yards
- Reduce other pressures/threats
- Introduce species tolerant to salt, drought, pests or higher temperatures
- Rehabilitate damaged ecosystems
- Multi-cropping, mixed farming, low-tillage cropping or low-intensive forestry
- Apply integrated models for climate and biodiversity prediction
- Improve the understanding of extremes/hazards and cumulative events

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