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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.

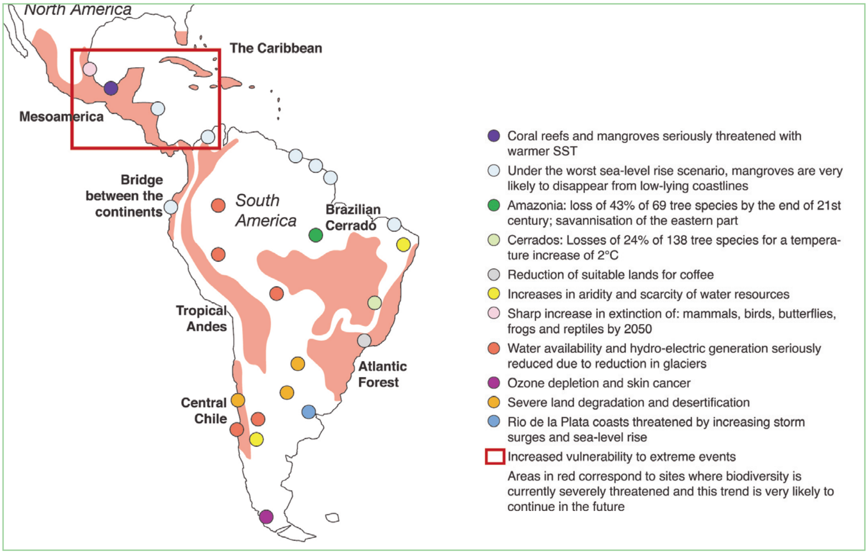

FIGURE 1
Key hotspots for Latin America (Magrin *et al.*, 2007).

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.

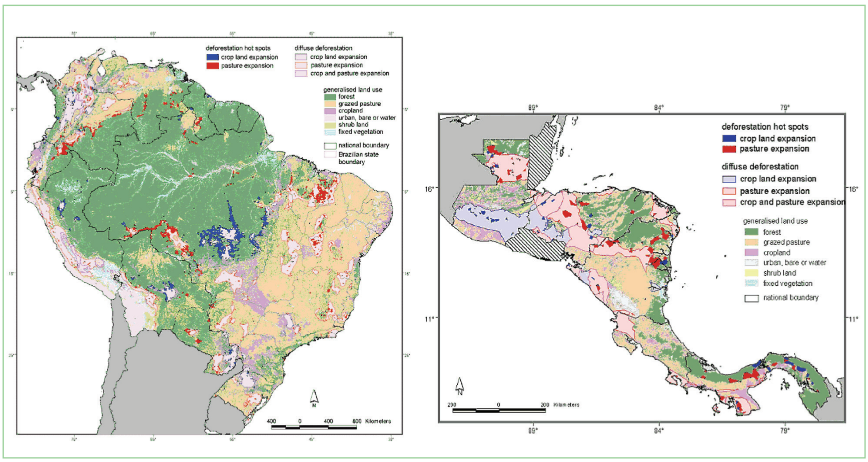

FIGURE 2

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.

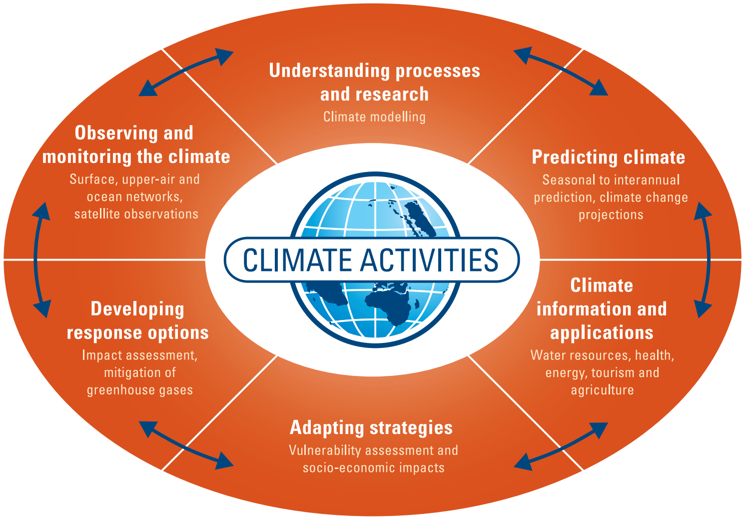

FIGURE 3
WMO implements a comprehensive and integrated for all aspects of international climate-related programmes.

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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