CLIMATE-BASED PREDICTIONS OF FOREST BIODIVERSITY USING SMITHSONIAN'S GLOBAL EARTH OBSERVING NETWORK

paper 7

MARIANNE KARSH[1], DON MacIVER[1],
ADAM FENECH[1] and HEATHER AULD[1]

[1]*Adaptation and Impacts Research Division, Environment Canada, Toronto, Ontario, Canada*

ABSTRACT: The conceptual relationship between temperature and forest family diversity has been developed by Rochefort and Woodward (1992) and is a useful concept to detect, examine and calibrate the climate-biodiversity relationship. The conceptual model assumes that the primary mechanisms that determine diversity include the capacity to survive the absolute minimum temperature of a site, and the ability to complete the life cycle in a given length and warmth of a growing season. This study presents the actual data, based on earth observing sites, as an effective diagnostic tool to identify areas where the biodiversity is or is not in equilibrium with the present climate, as well as developing the basis for predictions under climate change. This observing network is based on data from monitoring plots established in Canada and worldwide using protocols from the Smithsonian Institution's Measuring and Assessing Biodiversity (SI/MAB) program, as well as growing-degree data derived from climate observing sites.

Keywords: climate, biodiversity, Smithsonian Institution, forests

1. Introduction

Human population expansion, land-use conversions and atmospheric changes have dramatically altered ecosystems and species worldwide. The conservation of biological diversity is not single-species management and instead recognizes the functional ability or impairment of ecosystems to support many diverse species. Within this context, forest habitats support many diverse migratory and resident species, as well as serving as calibration and verification earth observing sites for remote sensing.

In 1992, the Smithsonian Institution (Dallmeier, 1992) initiated a global biodiversity observing programme under the auspices of UNESCO. This programme was unique and by using standardized plot sizes and measurement protocols for multi-taxa, the earth observing sites for biodiversity have grown to more than 500 sites worldwide. In Canada, for example, the number of sites exceeds 100 and are located largely in southern

ecosystems and monitored by community groups beginning with forest habitats and their respective diversity.

1.1 Scale dependency

Biodiversity is scale dependant. The relationship between spatial scales, plot sizes and biodiversity needs to be addressed from the onset of the project since there are significant differences in the species-area relationships of different habitats. In many cases, the relationship is "hump-shaped" where forest diversity peaks at areas approximately 1 hectare in size. For example, Figure 1 illustrates the scale dependency of forest biodiversity. Backus Woods and CARE sites in Ontario, Canada were compared to data from England, based on the work of Crawley and Harral (2001) where it was shown that maximum diversity for minimum area occurs around the 1 hectare size unit (Environment Canada, 2003). In the family diversity by area continuum, the Carolinian mixedwood forests of Backus Woods, located in one of our most biologically diverse areas in Canada, is very close to the peak of the curve indicating that a sample size of 1 hectare area is required to adequately
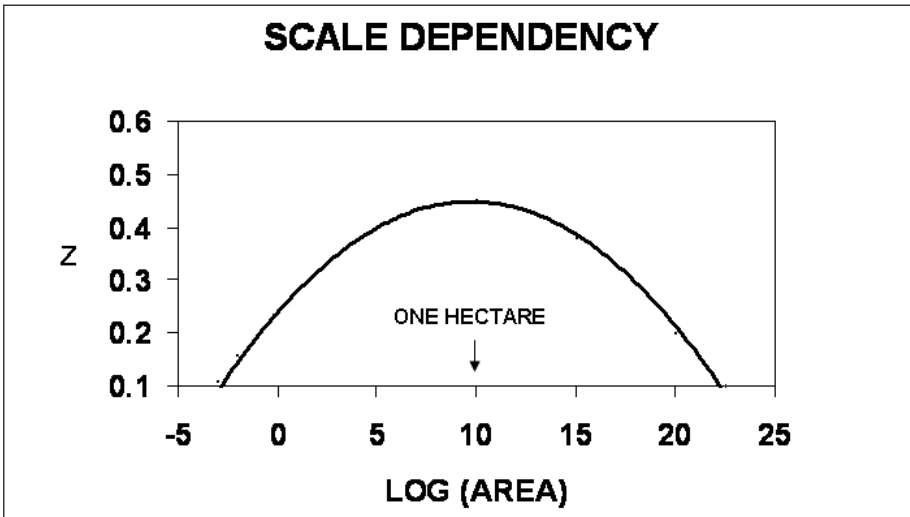
FIGURE 1

Scale dependence of the species-area relationship. The slope of the log species-log area curve, z, plotted against log (area).

sample the maximum forest species for the minimum area. Preliminary analysis shows that sampling an area smaller than 1 hectare at Backus Woods results in significantly less families and species (Environment Canada, 2003).

The CARE site, with a fewer number of families, peaks at the same scale but its maximum value is less than the more diverse site at Backus Woods. This suggests that there might be a family of related curves illustrating the family diversity by area relationship with family diversity increasing with increasing area sampled up to the 1 hectare plot size. These sites form the benchmark to compare increasingly diverse sites across the Americas and also are valuable to detect departures from the expected responses due to management or other natural disturbance effects. In the single species forest there is much less dependency on the area sampled compared to the more diverse forests of southern Canada. An example of the single species forest is the site at Charlevoix which is exclusively a monoculture stand of black spruce, *Picea mariana*. Consequently, smaller sample sizes will show the same result in a traditional growth and yield plot area of 20 meters by 20 meters compared to the 1 hectare size area.

Since the productivity – diversity relationship is also scale-dependent, as Chase and Leibold (2002) observe, then the difference in species composition among localities within regions must increase with productivity. Chase and Leibold (2002) warn that unless protected, species adapted to live in habitats with low productivity could be permanently lost from the ecosystem. Understanding the scale dependence of forest biodiversity monitoring will be essential in order to predict and ameliorate the effects of humans and natural impacts on the earth's ecosystems.

1.2 Network of Forest Biodiversity Sites

The Forest Biodiversity Observing Network consists of more than 500 individual observing sites that allow for transect studies to interlink climate and biodiversity information together throughout the forests of the Americas (Figure 2). This network has the potential to provide an early warning prediction system of changes as a result of global change. The network connects over 20 countries in the Americas with their respective Smithsonian Institution biodiversity monitoring plots and creates transects that run from the single pine species sites of the Cree community of Oujebougamou, Quebec, Canada throughout North, Central and South America to return once again to the single pine species sites of Chile (Fenech *et al.*, 2005).
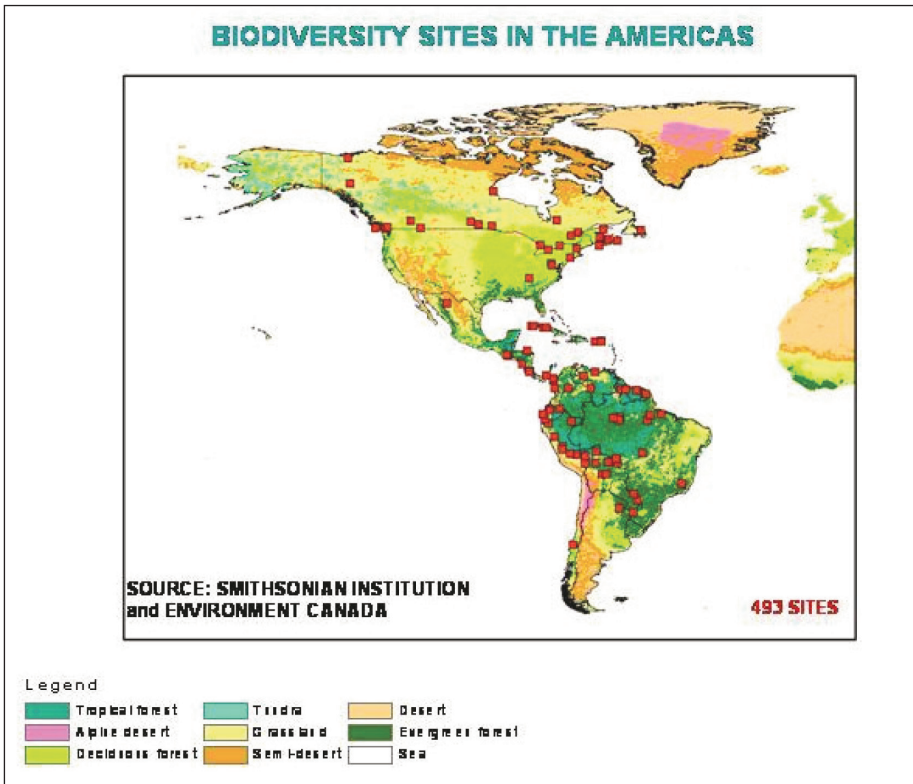
FIGURE 2

International SI/MAB Biodiversity Sites in the Americas.

A transect across physical, chemical and ecological gradients allows for unique investigations into the cumulative impacts of global change on forest biodiversity that will increase our understanding of the impacts of climate change and help to further reduce the adaptation deficit of the Americas (Fenech *et al.,* 2005). The network, using the same measurement protocols, allows for comparative studies in forest biodiversity.

Considerable knowledge, information and data bases currently exist in Canada. For example, using global protocols for forest biodiversity monitoring, there are now approximately 104 SI/MAB sites in Canada located across climate, chemical and ecological gradients with over 25 sites located

within Southern Ontario that allow for more detailed bio-climate analysis (MacIver, 1998; Environment Canada, 2003).

The International Smithsonian biodiversity sites across climate, chemical and ecological gradients forms an integrated knowledge network and networking of scientists, educators, and public volunteers and provide the realistic framework for adaptive actions (MacIver and Dallmeier 2000). When the network of Smithsonian Institution sites is expanded to include Protected Areas (IUCN), World Biosphere Reserves (UNESCO), these sites provide an effective community-based platform to monitor changes in forest species, ecosystems and biodiversity under changing climatic conditions (MacIver and Wheaton, 2005).

With more than 400 Biosphere Reserves worldwide, and with each Biosphere Reserve having a conservation function, this ensures protection of some the earth's most important ecosystems. Some of the SI/MAB sites are located in these Biosphere Reserves and some are located in fragmented landscapes subject to numerous natural impacts and land-use changes. From an adaptation viewpoint, the Protected Areas, Biosphere Reserves and the Smithsonian Sites are well situated to become the Global Monitoring Network, linking together the human dimensions of development and natural conservation within an integrated abiotic, biotic and socio-economic framework (MacIver and Wheaton, 2005).

2. METHODS

2.1 Biodiversity Sites

A sub-sample of all of the sites were chosen for analysis which represent mixedwood, unmanaged conditions that could be compared with sites across the Americas. Biodiversity sites located in close proximity to marine environments, or which had been planted or treated with one or more forestry scenarios, such as prescribed burns, or sites exposed to natural or human caused impacts were not included in the analysis. In addition, sites with pure monocultures (>90 percent) of black spruce (*Picea mariana*), balsam fir (*Abies balsamea*) or sugar maple (*Acer saccharum*) were also not included in the analysis.

2.2 Climate Stations

Twenty Canadian climate stations were used in the analysis. The long-term 30 year climate normals (1970-2000) are available on-line through Environment Canada at: www.climate.weatheroffice.ec.gc.ca/climateData/canada_e.html

Estimates of growing degree days for Central and South America were retrieved from maps of the biosphere produced by New *et al.*(1999). The maps can be viewed at: www.sage.wisc.edu/atlas/

3. RESULTS

The heat unit-family diversity conceptual relationship devised by Rochefort and Woodward (1992) was a useful starting point to examine and calibrate the actual climate-biodiversity relationship. The long-term bioclimate data bases in Canada and the SI/MAB biodiversity sites were used to illustrate the further development of this relationship. In this paper we have chosen to continue the work of MacIver (1998) to construct and calibrate this climate-biodiversity baseline. Rochefort and Woodward's model assumes that the primary mechanisms determine diversity: the capacity to survive the absolute minimum temperature of the site and the ability to complete the life cycle in a given length and warmth of a growing season. The development of a family diversity index measured against heat units is a useful science-policy model to understand the anticipated effects of global climate change on biodiversity (MacIver, 1998).

In many parts of Canada, the family tree diversity is expected to be in equilibrium with the present climate. For example, given the heat units at Kejimikujik National Park, 8 tree families were observed in the 1 hectare SI/MAB unmanaged mixedwood sites. In comparison, in Southern Ontario, an area that has experienced substantial human and atmospheric-induced change, the tree families are usually found at the 12-13 family diversity level or less.

Figures 3 and 4 show the actual forest biodiversity using individual SI/MAB results along the Climate Family Diversity baseline versus heat units, defined as growing degree-days above 5 degrees Celsius. This baseline could be used as an effective diagnostic tool to identify areas where the biodiversity is not in equilibrium with the present climate (MacIver 1998) and as a predictive tool under climate change.
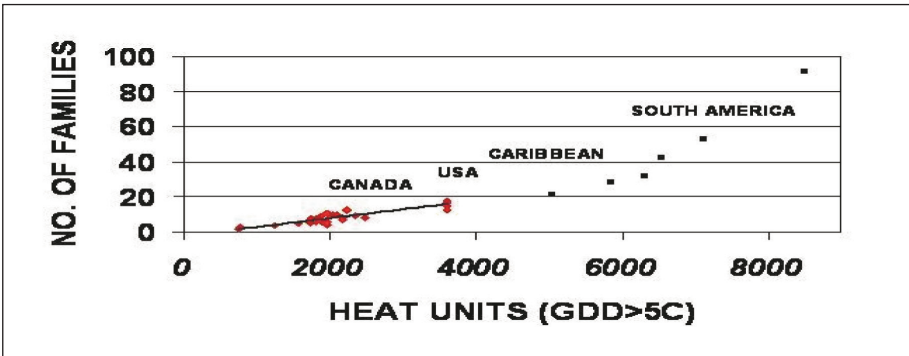
FIGURE 3

Number of families as related to heat units in Canada (16 sites) compared to reference sites in the U.S.A, Caribbean and South America.
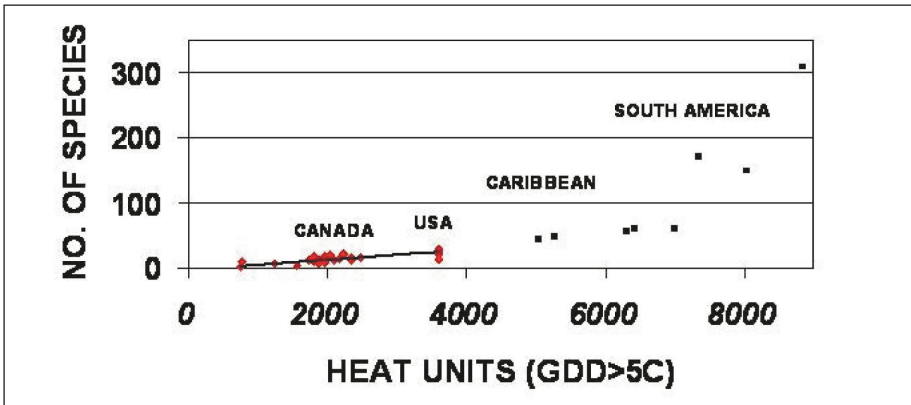
FIGURE 4

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

Evidence suggests that the biodiversity is not always in equilibrium with the present climate. Examples of this are managed forest stands or stands that have been exposed to human and natural impacts. For example, the prescribed burn or management techniques at Long Point, Ontario reduced the family tree biodiversity to 4 or 5 families, a reduction of close to

70 percent. Allowing heavy human impact through the forest at the Toronto Zoo site reduced biodiversity to 7 families; with only 4 of these families having 5 or more stems, a reduction of at least 50 percent.

Both managed and impacted sites show considerable departures from the Climate-Biodiversity baseline. Understandably, there are numerous reasons for these imbalances. Southern Ontario is an area where historical depletions of the Carolinian forest have resulted in highly fragmented small woodlots surrounded by intensive agriculture or urban development. It is also an area where all of the atmospheric stressors impact the biodiversity (MacIver, 1998). Similarly, sites dominated by a single species or sites located in marine areas also show considerable departures from the Climate-Biodiversity baseline. This preliminary research suggests that with sufficient data a separate set of curves could be produced for pure single species sites, managed or impacted sites, and sites directly influenced by large bodies of water.

The continuing accumulation of global SI/MAB observing site results along with on-site climate observations, provide an important monitoring opportunity to construct, assess and calibrate the Atmospheric-Biodiversity change baseline. For example, when results from the Smithsonian Sites in Virginia are plotted (Figure 3), preliminary observations might suggest that the Family Diversity axis may not be linear, but either logarithmic or exponential approaching equatorial regions (MacIver, 1998). The preliminary research also seems to suggest this relationship when some additional sample sites in Central and South America were plotted (Figures 3 and 4).

The predictions equations have been tested against independent biodiversity observing sites and perform accurately in Canada. More importantly, under CGCM2 climate change scenarios, the family biodiversity has the potential to increase 60 percent by 2050 in the Toronto region of Canada, similar to that experienced currently in the Washington D.C. area.

Studies have shown that the urban climate of the City of Toronto has already warmed, equivalent to the expected 2050 climate. More than five years ago, a one-hectare climate change experimental site was established at the Humber Arboretum in Toronto to evaluate native and "Washington-type" forest and shrub biodiversity performance, using replicated plot designs and continues to be measured annually.

While additional sites from the equatorial to polar Climate-Biodiversity transects, standardized monitoring and global modeling would be useful to further calibrate this curve, there is also a significant opportunity to use the earth observing sites to calibrate and verify remote sensing imagery in order to fill spatial gaps, globally.

4. Conclusions

Forest biodiversity, at all taxa levels, has become an increasingly important issue to support detailed modeling of global carbon sinks and sources under climate change (MacIver and Wheaton, 2005). Biodiversity conservation is not single-species management but, instead, recognizes the functional ability or impairment of ecosystems to support many diverse species. In Canada, examples include the virtual elimination of the Carolinian forest in Southern Ontario; reductions in the old-growth forests in British Columbia and elsewhere; declines in waterfowl on the Canadian Prairies; decreasing forest health in Eastern Canada; increasing greenhouse gases and other atmosphere pollutants; and changes in fish stocks on all three coasts. Canadian ecosystems are limited and lack the species richness of more southerly climates. Canada can ill-afford to lose even one species or ecosystem (MacIver, 1998).

Biodiversity is a strong cross-cutting issue that links many disciplines and scientists. The forest biodiversity site networks would benefit greatly from being connected using GIS, remote sensing type technologies. Additional monitoring sites need to cross biological boundaries and atmospheric gradients from equator to poles in order to understand relative change, adaptation potentials and international policy directions (MacIver, 1998). Biodiversity issues and related science agendas would benefit from greater international collaboration and exchanges (MacIver, 1998). The sharing of biodiversity information data is crucial to the sustainability of the biodiversity and its rate of loss, globally.

Ecological predictions require the integration of weather and climate variability predictions, remote sensing of the biosphere and ecological models to project future changes in ecological states. Sustaining productive ecosystems, and restoring damaged ones, depends on our ability to understand and predict the impacts of human activities and natural processes

on those systems – in other words, to forecast change. In terrestrial ecosystems, many changes of biodiversity within the next 100 years will probably be due to land-use changes (Waldhardt *et al.,* 2004) and climate change. We need to anticipate how ecosystems will respond to natural and human stresses.

Ecological forecasts cannot be produced without reliable information about the current and historical condition of ecosystems and the network of forest biodiversity monitoring sites are crucial to this understanding. Likewise, the success of decisions made in response to specific forecasts cannot be evaluated without ongoing monitoring of change. New observation, modeling, and data management tools are needed to deal with gathering, integrating, and interpreting complex biological and chemical data, and making them available (Clutter, 2005).

A capacity to make predictions (Figures 3 and 4) can give policy makers and regional planning groups some confidence to move forward, implement or change current policy instruments, identify critical thresholds of climate for important biomes, develop and test key indicators of change, and highlight iconic species or communities or communities under immediate threat (Chilcott *et al.,* 2003).

Biodiversity is scale-dependent, multi-taxa and changing in response to land-use and climate changes. Climate-based predictions using Smithsonian's global observing network have provided valuable insights into fundamental atmosphere-biodiversity couplings and will strengthen the synergies between climate and biodiversity issues, both nationally and globally.

Acknowledgements

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