UNIVERSITY OF NEW BRUNSWICK

Potential Effects of Climate Change on New Brunswick Freshwater and Terrestrial Ecosystems

An Overview

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3/18/2013

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1 Introduction

The Canadian province of New Brunswick (NB) is comprised of distinct landscapes with a vast array of ecological features. Coastal regions, river valleys, and highlands compose large portions of them. Within these areas are complex and intricate ecosystems with tightly woven relationships between biotic and abiotic elements. NB is also unique for being part of the site of periphery and overlap for the boreal and temperate ecosystems, commonly referred to as the Acadian Forest eco-region. Consequently, biotic assemblages with differing northern and southern ecological niches and requirements co-exist and compete in some areas of the province. How these relationships continue to evolve will be heavily influenced by climate change and the resulting fluctuations in climatic parameters, such as temperature and precipitation.

How climate change will affect the biota of terrestrial and freshwater ecosystems of NB continues to be a common theme for researchers in the province, and even a source of disagreement. While much scientific study has been completed to date on various biological groups, far more remains to be undertaken. Some of this research and the researchers conducting the science explicitly deal with elements of changing climate, but others do not. The importance of awareness and understanding of these effects is indisputable for policy and decision making by government, especially in a province such as NB with a high degree of economic and cultural reliance on natural systems by individuals, industry and government.

The purpose of this report is to describe the views and opinions of leading scholars, researchers, and scientifically trained managers regarding potential macro-level ecosystem effects and changes in the biota of terrestrial and freshwater ecosystems as a result of climate change. This report compiles the professional judgments of a range of biological experts regarding the most likely vectors of ecosystem change and the vulnerability of particular species and habitat types. Report findings include the speculation of biological experts whose current research addresses potential effects of global warming, and others who do not. This report is essentially a social science endeavor about science and more importantly the science policy interface. Ultimately our concern is with getting the best, most accurate information regarding potential climate change effects into the hands of decision-makers and policy-makers upon whom it is incumbent to assess the risks and allocate resources to deal with these problems.

2 Research Objectives

By surveying ecologists, biologists, and other experts of biota and in respect to the province of NB, the research objectives of the project are to:

- gather a macro level view of how climate change will affect ecosystems by 2050 and 2100;
- identify select species of flora and fauna that will decline as a direct or indirect result of climate change;
- identify select species of flora and fauna that will benefit as a direct or indirect result of climate change;
- summarize potential mitigation and adaption responses at the individual, community, and government levels; and
- assess the degree of consensus or divergence of opinion among natural resource managers and scholars regarding the medium and long-term impacts of climate change.

3 Literature Review

3.1 Background

In recent years, climate change has become a priority file for the NB Department of Environment and Local Government, and for Natural Resources Canada. At both levels of government, officials are working to identify means of mitigating climate change by reducing greenhouse gas emissions, and to prepare communities to deal with changing realities through adaptation strategies (NBDENV, no date; Vasseur & Catto, 2008). In both cases, sound science is necessary to inform and monitor progress. In NB, responses in ecosystem structure, function, and spatial distribution are expected as our winters become warmer and wetter and summers become warmer and, in some areas, drier. The extent and nature of these changes remain to be seen, but a number of researchers in NB and nearby jurisdictions have been working on this subject, with their findings and forecasts available in peer-reviewed journals and books, gray literature, and digital media.

This section of the report reviews the recent and current literature on ecosystem responses to changing climate in NB. This document presents research activities related to terrestrial and freshwater ecosystems and habitat; in particular, forests, biodiversity, and invasive species; in the context of downscaled global climate models depicting future climate scenarios in NB.

3.2 Predicting the Effects of Climate Change in NB

At least two groups of researchers have used statistical downscaling of global climate models to develop regional or local climate change scenarios, specifically in NB (Swansberg *et al*., 2004; ESDRC, 2009). These provide analyses of the potential effects of climate change on temperature patterns, and on our hydrologic regimes in three future time series: 2020s (2010-2039), 2050s (2040-2069), and 2080s (2070-2099). Additionally, a Natural Resources Canada report provides regional projections of climate change effects (Vasseur & Catto, 2008) and a number of publications include projections of regional downscaling of climate change effects to examine the potential implications for a variety of ecosystem characteristics (Huntington *et al,* 2009; Johnson et al., 2009; Rodenhouse *et al*., 2009; Dukes *et al*., 2009).

All scenarios indicate increases in temperature in all seasons in our region. According to Swansberg et al., in NB,

"Annually, minimum air temperature may increase by approximately 4 to 5° Celsius, while maximum temperature may increase by approximately 4° Celsius...Larger increases in air temperature are anticipated in central New Brunswick ...than in northern...or southern...regions of the province. Seasonally, the greatest increases are expected in maximum spring air temperature...and minimum winter air temperature." (Swansburg *et al*., 2004).

Other analyses yield similar results, but there are differences in the projections of temperature changes in the 21st century. In most cases, projections range from an increase of approximately 1.1 to 5.3° Celsius, based on anticipated carbon emissions; and most publications indicate that there will be a greater increase in winter low temperatures than in summer high temperatures, particularly in the early part of the century.

These are dramatic changes, which will have second order effects on parameters such as water availability, proportion of precipitation that falls as rain or snow, resultant snow pack, plant growth rates, net primary production, evapotranspiration rates, length of the growing season, and plant and animal phenology (Johnson, 2009).

In general, we can anticipate warmer wetter winters in NB, and warmer summers. Mean daily precipitation may increase significantly across the province between 2010 and 2099. The distribution of increases may vary, ranging from 9-14% in southern regions of NB to 25-50% in northern regions (Swansburg *et al*., 2004). Seasonal changes in precipitation in may also increase in northern and upper central areas, while in lower central and southern areas, no significant changes in precipitation are anticipated.

Some areas of the province may experience little change in water availability as a result of these shifts. However, the combination of increased temperature and precipitation patterns may result in dry conditions in summer in lower central NB: evapotranspiration will increase with increasing temperatures resulting in drier conditions despite minimal changes in summer rainfall. Additionally, altered temperature and precipitation patterns will affect the annual discharge of NB's rivers: there may be a 16-45% increase in annual discharge throughout the province, compared to current conditions. Both large and small rivers in northern and central NB may experience >40% increases in discharge. The increases in discharge are likely to be seen during winter and spring, while summer discharge rates may decrease significantly across the province (Swansburg *et al*., 2004; Huntington *et al*., 2009).

Due to the combined effects of changes in temperature, precipitation patterns and form (i.e. more rain and less snow), we can expect increasing temperatures in both surface and groundwater aquifers. Additionally, we can expect increased flooding due to elevated river discharge, particularly in the winter, and more intense storm events. Our seasonal weather patterns in general may become more "dramatic: winter cyclonic storms, summer heat and drought, early or late frost, winter rain/thaw, river ice jams and flooding." (CPAWS, 2009; Huntington *et al*., 2009).

Sea level rise, combined with increased frequency and intensity of storms and continental subsidence, will cause increasing incidence and magnitude of storm surges, in particular along NB's southeast coast. Experts estimate that sea level will rise 50-70 centimetres by 2100 (Environment Canada, 2006; Vasseur & Catto, 2008), which could cause what are currently 1 in 100 year storm surges to occur annually. Because this document focuses primarily on the effects of climate change on freshwater and upland ecosystems, sea level rise will not be treated in more detail below. It should be noted, however, that sea level rise can cause salt water intrusion into coastal groundwater aquifers, which could subject upland or inland ecosystems to additional environmental stress.

3.3 Freshwater Habitat

The potential effects of climate change on freshwater habitat are many and varied, including potentially dramatic changes in quantity and quality of water (Schindler, 2001). These are likely to be combined with continued and increased human pressures on freshwater systems. The net results may include reduction in habitat availability, in particular for cold-water fishes such as salmonids; altered fish migrations in some areas; reduction or destruction of native fisheries; restructuring of aquatic communities because of invasion of alien species of both plants and animals; increased eutrophication; and dramatic alteration of a variety of complex biogeochemical processes (Schindler, 2001).

In NB, although overall discharge in rivers may increase in a changing climate, the timing of the distribution of water may also change such that our normal summer flows are decreased dramatically, while winter flows increase (Swansburg *et al*., 2004; CPAWSc, 2009). This can cause second order effects such as elevated water temperatures, leading to increased biotic activity (e.g. algal blooms), which can subsequently exacerbate elevated water temperature as thermal capacity increases. Likewise, the change in penetration of sunlight into can cause shifts in the depths of thermoclines in lakes, as well as changes in primary productivity in all fresh water systems. The potential cascading effects of climate change on freshwater habitat are quite complex causing disturbances among populations of aquatic species of both plants and animals. In addition, the stress on native species of fish and other freshwater organisms may increase their vulnerability to parasites, pests, and predators, and reduce their ability to compete for territory or food with invasive species better adapted to new climatic conditions.

3.4 Forests

The seminal work regarding terrestrial ecosystem classification and forest species assemblages in NB is *Our Landscape Heritage: The Story of Ecological Land Classification in NB* (Zelazny *et al*., 2007). Forest species assemblages are associated with a particular suite of physical parameters, including soil characteristics, precipitation, and temperature. As temperature and moisture regimes in NB shift in a changing climate, we can expect that eco-regions will respond by either migrating (both laterally and vertically) or diminishing, depending upon the rate and magnitude of change and their ability to respond to it (CPAWS, 2009a). A variety of pressures will be placed on forests across Canada as our climate shifts: these include shifts in site factors, synchrony of phenology, physiological responses of trees, regeneration, migration, shifts in species ranges, adaptation pressure; and both abiotic and biotic disturbances (Johnson, 2009).

"Maladaptation occurs when the local environment to which species are adapted begins to change at a rate that is beyond the species' ability to accommodate" (Johnson, 2009). Trees are long-lived and unable to move, and as climate change affects site factors such as water availability and temperature, individual trees become increasing maladapted to fit their previously well-suited locations. Phenology, the timing of biotic activity such as "flowering, bud set, bud burst, growing season length, dormancy period, and availability of pollinators, etc." (Johnson, 2009), can also be affected by climate change, such that biological activity of individual plants can compromise its health (as when buds burst in response to warm temperatures, but are then compromised when the warmth is followed by freezing temperatures). In addition, asynchronous phenology among species dependent upon one another can occur, as when flowers bloom before pollinators are available – this can compromise both the plants and pollinators. Other physiological phenomena such as net primary productivity, dehydration postponement and tolerance, and regeneration success can also be markedly affected by climate change.

Many factors contribute to a tree species' ability to migrate, in particular the means of seed dispersal. In order to contend with changing temperature and moisture regimes in eastern Canada, tree species "would need to move several thousand metres per year." (Johnson, 2009). Most tree species can move no more than 100-200 metres per year. (Johnson, 2009). Johnson (2009) expects that by 2100, NB's climatic zones will shift 250-600 kilometres northward, up to 5000 metres per year; the impacts on our forest assemblages of such a rapid change would be dramatic. It is possible that our provincial tree, balsam fir (*Abies balsamea*), would be drastically reduced in numbers, and that we will see an advance of forest cover types now associated with New England in our province. These include hardwood [e.g. oak/maple (*Quercus* spp./*Acer* spp.) assemblages], spruce-fir (*Picea* spp.), mixed hardwood/spruce-fir, and mixed hardwood/pine (*Pinus* spp.) (Aber *et al*., 1995).

Other effects of climate change on our forest composition and spatial distribution in NB include out-competition by invasive species (Dukes *et al*., 2009), increased susceptibility to pests and insects (Dukes *et al*., 2009), and increased or decreased primary productivity due to increases in atmospheric concentrations of carbon (Johnson, 2009).

3.5 Terrestrial Fauna

The potential effects of climate change on our native species of fauna are also complex, involving first order effects (e.g. response to changes in temperatures) and second order effects (e.g. habitat loss or degradation due to forest response to climate change). Moose, for example, are adapted to live in cold climates, and suffer from heat stress in temperatures over 14 °Celsius in the summer and above -5.1 °Celsius in winter (Rodenhouse *et al*., 2009). They are likely to move northward, or to higher elevations, in order to find temperature ranges to which they are well-adapted. In general, we can anticipate that the normal ranges of our native fauna will migrate in a northeastern pattern. Less clear, however, is the relative success rate of these shifts, since forest assemblages are not able to migrate as readily or quickly as some of the animals that depend upon them for habitat or food. Likewise, some animals can migrate more easily than others: small animals (e.g. salamanders), or those inhabiting very specific, isolated, habitats (e.g. some species of butterflies) or able to withstand narrow ranges of temperatures are more likely to have trouble migrating than larger or winged animals adapted to more general conditions or a wider range of temperatures (Rodenhouse *et al.*, 2009).

3.6 Invasive Alien Species

There is tremendous concern among naturalists and natural resource managers that climate change will encourage the spread of invasive alien species of insect pests, pathogens, and plants. These concerns are well-grounded in the literature and, indeed, through casual observation of roadside flora in NB or Maine. The mechanisms of these invasions include characteristics of invasive species, and characteristics of the sites into which they move. Invasive species of insects and pests are often limited by the ability of host plants or animals to resist infection. In forests already stressed by high carbon dioxide concentrations, elevated temperature, drought, etc. the ability of individual trees to resist infection is diminished. Conversely, increased temperatures generally correspond with increased biological activity among insects. Thus, conditions which may compromise host species will actually cause insect pests to thrive (Dukes *et al*., 2009).

3.7 Biodiversity

We can anticipate both first and second order effects on biodiversity in NB in a changing climatic regime. As described above, a variety of stressors will cause some species of plants and animals to thrive and others to suffer. Those already under pressure from habitat loss, development, etc. may be extirpated altogether. The relative competitive advantage of pioneer or alien species may cause decline among our native species of plants and animals. The ability of plants and animals to adapt to changes in their environment is influenced by the rate of change in their habitat and environment, their genetic variability, the availability of new habitat into which they can migrate, and the availability of food sources (CPAWS, 2009b). Thus, it is likely that we can expect alterations in the composition of our native forests and other ecosystem types, as some species are more or less affected by changing temperatures and moisture regimes, and that we can expect new and different assemblages of plants and animals to mix into or replace native ecosystems across our landscapes as immigrant species also seek optimum conditions for growth and reproduction.

Our ecosystems will change dramatically in the coming decades. Native, iconic species of plants and animals may diminish or be lost altogether. New assemblages of plants and the animals for which they provide habitat will appear. Management strategies on the part of private landowners and public agencies can contribute to preservation of species and ecosystem assemblages native to NB, but this will be an uphill and ongoing battle. Assisted northward migration of forest types could be incorporated into our tree planting strategies.

Protection of cool-water refugia can help to protect our already compromised salmon populations. Monitoring and removal, and restrictions on the importation, of invasive species can help to slow their advance, thereby giving our native species an opportunity to establish themselves in new territories. Protecting iconic landscapes in perpetuity through a system of protected natural areas can also provide refugia for species assemblages and opportunities to carry out further research on the effects of climate change on our native ecosystems (CPAWS, 2009a, 2009b). However, despite these efforts, we should anticipate and prepare for some major shifts in our ecosystems in the coming century.

4 Methods

We initially contacted several climatologists and modellers in NB to recommend to us which climatic variables would be important to highlight and describe to biologists and ecologists. These were identified as mean annual temperature, mean annual precipitation, and mean annual growing degree days. The climatologists also elucidated to us how these variables would change by the years 2050 and 2100.

We compiled an initial list of approximately sixty-five biological and ecological experts working within the province as potential interviewees. Our targets due to time and budget constraints was to interview between twenty to thirty of such experts and hold three focus groups with an additional twelve to eighteen researchers. The contacts spanned a wide range of institutions: professors at both Fredericton and Saint John campuses of the University of NB, l'Université de Moncton, and Mount Allison University; employees of NB Department of Natural Resources; researchers from the Canadian Forest Service; and, several experts from private organizations. The list evolved during the course of the project as we removed some contacts due to lack of relevant information, and added other contacts as interviewed experts referred us to their colleagues.

When contacted for an interview, we explicitly asked participants to "speculate" on the effects of climate change on their biota of expertise, as their previous work may not have directly considered climate change. We also emphasized that the results of interviews and subsequent reports would remain anonymous. Experts were initially contacted for an interview by email; if the individual did not respond within forty-eight hours, the expert was then contacted by telephone. In total, forty-three individuals were contacted for interviews; we successfully interviewed twenty-eight of the experts, while seven individuals declined and eight individuals could not be reached.

Interviews were presented with a set list of questions; however, the format was intended to be semi-structured. That is, the questions served as a guide, but we planned to deviate from the set list or add relevant probing questions in response to the interest and expertise of the person being interviewed. During the interviews, we identified and presented to our respondents a set scenario regarding changes in the climatic variables of temperature, precipitation and growing degree days by the years 2050 and 2100 time and specifically asked for explanations of how they biota they study may be affected by these changes. The scenario we presented was based on both interviews with the climate modellers and the literature reviewed above. After approximately ten interviews, and a series of refusals to be interviewed, an additional question was added to the script, asking why the individual agreed to an interview. Interviews were audio-recorded for future reference and accuracy. On average the sessions had lasted around thirty minutes, with the shortest being approximately nineteen minutes, and the longest being just over an hour.

In addition to the individual interview process, we conducted three focus group sessions. Twenty-nine potential attendees were selected based on our perception of their area of expertise and willingness to partake in a group discussion. We contacted the individuals by email and subsequently sent reminder emails to non-responsive individuals. In total, nineteen individuals attended the three sessions, with one held in Moncton and the other two in Fredericton. Six of the focus group participants were previously interviewed individually. The focus groups included a broader range of members, including graduate students and environmental sociologists. Sessions were approximately two hours long, and both audio and notes were recorded during the process.

5 Results

One of the original inspirations for this work was the recent publication *Our Landscape Heritage*: *The Story of Ecological Land Classification in New Brunswick* (Zelazny *et al.*, 2007) which represented the culmination of years of work by Department of Natural Resources biologists, ecologists, with support and input from dozens of other similarly trained experts in the region. The book gives a detailed description ecoregion by ecoregion, of the enduring features and characteristics of each region, as well as ecodistricts and ecosites within them. The work is very detailed, but given the growing consensus in the scientific community regarding climate change, one cannot look at such a document and wonder, "For how long will this characterization of these regions be accurate and relevant?" We set out with the idea that we might come to the science community with that text in hand, at least as a prop to suggest to our interviewees, that we can document a great deal of detail in the present and past, but what might we say about the future? How dramatically will the lines on these maps change? Which ecoregions will shrink or disappear altogether and might new ones previously unknown to New Brunswick emerge in the future?

5.1 Flora

5.1.1 Forests

There was a high degree of consensus by forest researchers and practitioners that NB will see an alteration in tree species community structure as a result of climatic change. During interviews, forest researchers commonly noted that tree species are influenced by many parameters beyond temperature, precipitation and growing degree days; therefore, there is significant uncertainty about how species will be affected. Respondent 1 stated, "You cannot assume the past will look like the future". Overall, researchers agreed that tree species in the province at the southern extreme of their range will decline in abundance, while species present in the more northern peripheries of their range will benefit.

One forest researcher acknowledged that further understanding of what precisely causes a species' southern limit would be highly beneficial. As the individual explained, a tree species may be capable of growing well in a southern region; however, at this region, other competing species are favoured and may out-compete a given species, thus defining the southern limit of its range. In this case, competition is limiting a species, rather than climatic variables acting directly upon it. In fact, multiple forest researchers suggested that the scientific community's understanding of thresholds is still relatively limited. As respondent 2 stated, "there is still uncertainty about what determines southern limit and I would like to see that uncertainty reduced".

As one forester suggested, the Acadian forest type is a unique composition of boreal and temperate vegetation. Despite this inherent distinctiveness, both forest researchers and forest practitioners regularly highlighted that the current forests in the province are largely a legacy of historical human land use and harvesting practices. Agriculture and forestry have caused NB to be dominated by large-scale disturbance adapted species, which are generally more affiliated with northern climates, such as balsam fir, white spruce (*Picea glauca*), tamarack (*Larix laricina*), and white birch (*Betula papyrifera*). Consequently, the forests will be highly stressed by direct and indirect climatic effects. The stress affecting forests will be the result of a multitude of factors: diseases, insect infestation, fire outbreak, storm blow-down, and decreased habitat suitability. Southern-adapted small-scale disturbance species will benefit from the climatic changes; these species include white pine (*Pinus strobus*), red oak (*Quercus rubra*), and red spruce (*Picea rubens*).

One factor all forest researchers agreed would have vast implications on NB's forests is insects. Both forest researchers and entomologists also agreed that insect outbreak is one of the factors that we have the least ability to forecast; therefore, developing mitigation efforts is challenging. Respondant 3 explained: "Once you start changing the climate, you start changing the ranges and adaptive ranges of insects and pests… you're going to find things that maybe you've never had in your area before". Both forest researchers and entomologists explained that cold winter extremes in NB in previous years have limited the populations of some insect species that cause mass defoliation of trees. Therefore, with fewer or more infrequent extreme temperature lows to limit populations, outbreaks are predicted to increase in severity and be of longer duration, resulting in more defoliation than currently observed. Forest researchers expect increases in insects such as gypsy moth (*Lymantria dispar dispar*) and forest tent caterpillar (*Malacosoma disstria*), as a result of warming temperatures. Temperature changes will also allow species previously unknown to the province to establish. This potential for invasion of new species is the source of much uncertainty of how climate change will affect forests.

Forestry researchers discussed balsam fir extensively during the course of interviews. Overall, experts agreed that balsam fir in southern regions of the province is already experiencing some degree of stress as a direct or indirect result of climate change. One forest researcher predicted that by 2050, the extent of balsam far decline will extend to the Fredericton area, while the species will continue to flourish in northwestern areas of the province, such as Green River. The researcher highlighted that in northwestern NB at that point in time, balsam far may actually be improve with more growing degree days, and temperatures insufficient to promote stress. However, by the 2100 timeframe, balsam fir in northern NB will experience significant stress. Researchers cited one potential influential source of stress as outbreaks of insects such as balsam woolly algid (*Adelges piceae*), which is predicted to cause substantial damage across NB by 2100.

One forest researcher did not entirely agree with some climate change and forest simulation models. Some models have shown particular tree species to be at extraordinary risk for decline, such as balsam fir. In fact, some have predicted balsam fir to be extirpated from the province before 2100. The expert acknowledged that there may be significant reduction in the species; however, as several experts also agreed, the researcher did not realistically foresee any known tree species being extirpated completely by 2100.

Sugar maple (*Acer saccharum*) was another species that interviewees focused upon. Two forest researchers projected the species would benefit from the warming ecological conditions and supported increasing its abundance in NB. Another forest researcher stated that their research suggests that sugar maple will be negatively impacted in future decades. The researcher explained that Atlantic Canada's climate and the tree species located in the region are highly correlated with Atlantic Multidecadal Oscillation (AMO). The AMO is the measure of sea-surface temperature changes of the northern Atlantic Ocean, varying by several tenths of a degree Celsius (Kerr, 2000). In future decades, climatic changes as a result of the AMO will result in more frequent winter storms causing ice build-up on tree branches. Consequently, the structural integrity of trees such as sugar maple will be compromised due to ice-loading. Excessive physical damage will act as another source of stress for susceptible trees. Other species susceptible to structural damage from ice-storms are white birch and yellow birch (*Betula alleghaniensis*).

Two other forest researchers agreed that increased frequency of winter temperature variations will also impact these species. As temperatures warm to 2-3° Celsius above 0° Celsius and remain so for several days, tree sap begins flowing, buds begin opening, and the tree is no longer in a dormant phase. Subsequent drops in temperature to below freezing level damage branch tips and buds, and result in crown die-back. During spring and summer, the tree's energy is invested in reparation rather than growth and production. A series of winters with such events may lead to an overall decline in abundance.

Forest researchers agreed that climate change will likely increase the risk of forest fires in NB. While climate models predict that mean annual precipitation levels will rise, climatologists explained that warmer temperatures will increase the rate of evapotranspiration, making ecological conditions drier in some regions of the province than they currently are. Dry conditions may lead to increased incidents of forest fire, which will act as a source of stress and disturbance for forests. One forest researcher expressed concern about how susceptible NB may become to forest fires under drier conditions due to physical structure of stands. The researcher explained that much of NB's forests are in the form of managed stands, including young age plantations that are close to the ground and have tight crowns. Consequently, ground fires may spread to the tree crowns and subsequently spread through the stand, resulting in a large fire. Currently NB has a significant and effective firefighting infrastructure, in large part due to the value of the forest industry in NB, the province's small size and accessibility. Greater risk of fire may not result in more area burned, but there may be rising costs associated with maintaining NB's record of virtually eliminating large scale fires.

When we asked experts what strategies individuals, communities and governments could adopt to respond to climate change, we received a diversity of responses directed at institutional (government and industry) and individual levels. Several forest researchers explained that future forestry practices will substantially influence how climate change affects NB's forests. These scientists advocated that forestry policy and practices should be changed to better manage forests for climatic influences. One researcher stated that they are able to measure 60-80% tree growth by climatic variables only, depending upon species and location. Others advocated managing for species biodiversity. Both practitioners and researchers cited that integrating more southern-adapted species to enhance diversity and to avoid monocultures of northern-adapted species was crucial.

Respondent 4 stated, “I do not think you want to fight the loss of species that are becoming maladaptive”.

In the case of balsam fir, one researcher explained that forestry practices should begin now in southern NB to reduce the content of balsam fir and increase tolerant hardwood species. The researcher further explained that similar practices in northern New Brunswick will not be necessary until 25-50 years from now. Both forest researchers and practitioners also highlighted the value of creating and maintaining protected areas to act as refugia and a source of biota. Three forest researchers and one forest practitioner advocated greater policy focus on managing forests for carbon.

Forest researchers and practitioners expressed a need for government to set exemplary standards for climate change action. Respondent 5 acknowledged the associated challenges: “that's why forestry has always had problem with politics because politics is the epitome of short-term; forestry is the epitome of long-term”. Forest researchers and practitioners also insisted that government must introduce incentives to influence private woodlot management and education. Referring to woodlot management, respondent 6 stated, “There’s definitely a lot of need for knowledge. People may want to do this but may not know what the best practices may be for adaptation and mitigation.” Several experts agreed that while climate change is a global issue, woodlot owners may respond by encouraging biodiversity and southern-adapted species.

A forest researcher identified continuous monitoring as the best response action. The researcher advocated including climate change parameters into permanent sample plots to gather long-term data on climatic effects. The researcher also advocated the use of provenance trials and analysis of current species suitability in climates to which NB will be similar in future decades. One individual who is both a forester and forest researcher believed responding to climate change is a key responsibility of the forestry profession. The individual stated that foresters should not present themselves so much as people who maintain the forestry industry, but rather as professionals who are proficient in carbon management and other forestry-related environmental practices. All experts agreed that there will be both negative and positive effects of climate change on forests, but the degree to which they provide benefits or impose costs on forest stakeholders is a matter of perspective. Some experts were even hesitant to place value judgments on effects. Respondent 7 admitted, “I have a romantic attachment to present composition of our forests, so my view of change is skewed”.

5.1.2 Ground Vegetation

Few or our interviewees had much to say or much experience about ground vegetation communities. This is partly a legacy of where past research dollars have flowed, which is often toward resources that have commercial value. One researcher and one naturalist agree that climate change may indirectly affect groups of rare arctic alpine plants with limited-habitat located in southeastern NB in a protected natural area. The researcher explained that while the plants will likely tolerate the warming temperatures due to the high variability they experience in the microclimate, increased precipitation events may impact the structure of plants' habitat. Heavy precipitation events cause the brook associated with the site to rise and intensify erosion of the cliff face on which the plants live.

Bryophyte communities may be affected in NB as an indirect result of climate change. A researcher explained that the proportion of forests floor covered in bryophytes is highest under coniferous stands and lowest under deciduous stands; this is due to greater establishment of bryophytes in needle litter than leaf litter. The researcher stated that there may be less suitable habitat in microsites for bryophytes as a result of changes in forest composition.

5.2 Fauna

5.2.1 Mammals

White-tailed deer (*Odocoileus virginianus*) and moose (*Alces alces*), both charismatic megafauna, were two of the most commonly considered mammals during interviews. One wildlife biologist observed that NB is representative as both the northern boundary for white-tailed deer and the southern boundary for moose. The biologist also noted that both moose and deer could potentially act as bellwether species for climate change for the province.

Wildlife biologists and practitioners predict that moose will be affected by climate change in multiple ways. Moose is a species that thrives in colder temperatures. The northern range of moose is limited by the availability of food, while the southern range is limited by warm temperatures. One biologist explained that research has shown moose behavior to respond quickly and closely to changes in plant phenology. Consequently, if the number of annual degree days increases and quality vegetation is available earlier in the winter season, the species may benefit. Maternal nutrition, for example, may be augmented.

One wildlife biologist stated that moose cannot tolerate long periods of ambient summer temperatures above 28° Celsius due to their dark coats that absorb heat and direct solar radiation. Furthermore, thermal stress acts upon the physiology of moose at temperatures above 4° Celsius during winter. The biologist stated that the effects of warmer temperatures upon moose will be partly dependent upon the availability of microclimates for heat relief, such as riparian areas with access to food. The biologist commented that if by 2100, temperatures increase as much as models predict, moose will be unable to adapt and may no longer be present in the province. Respondent 8 added, "It won't be moose we'll be managing for". However, another wildlife biologist stated that despite predicted climatic changes, moose will remain in the province. The individual explained that a significant amount of moose habitat has been created by forestry harvesting practices in the province over the last 50 years.

Wildlife biologists and practitioners agreed that deer populations would most definitely benefit from warming temperatures. As deer habitat within the province is developed and deer expand into urbanized areas, biologists and practitioners believe that more social carrying capacity issues will develop. As is currently the case in the Sussex to Kennebecasis Valley and Saint John region, great numbers of deer are living and reproducing in urbanized areas. These areas offer protection from predators such as coyotes (*Canis latrans*), which are less prone to occupying metropolitan areas. Consequently, social issues arise, such as deer and car collisions and feeding on gardens and ornamental vegetation. Deer are also vectors for disease, such as infection by *Borrelia* spp., causing Lyme disease and transferred by blacklegged ticks (*Ixodes scapularis*). Both practitioners and biologists also agreed that human action to control deer population levels, such as increasing harvest rates, present many challenges and risks. As one biologist explained, capturing and relocating is highly expensive, is hazardous for the public when completed in the urban environment, and results in a high mortality rate for the moved deer.

One wildlife biologist pointed out that deer populations may suffer if heavy rainfall should occur during vulnerable parturition periods. Does do not remain with fawns during the first month after birth; therefore, fawns are more susceptible to hypothermia. Increased frequency of rain and freeze cycles in the winter could also harm deer populations. The biologist explained that rainfall and subsequent freezing temperatures create a layer of crust on snow that may not support the weight of deer; consequently, deer have more difficulty in pushing through the snow. Furthermore, the crust may support the weight of predators such as coyotes and bobcats (*Lynx rufus*), increasing predation on the less mobile, vulnerable deer. Wildlife biologists and practitioners also agreed that an issue that may arise if deer populations expand is infection of brainworm (*Parelaphostrongylus tenuis*), which is a parasite harmless in deer, but transferable and potentially fatal to moose.

Wildlife biologists and practitioners also discussed how climate change may impact furbearer species in NB. Overall, they agreed that climate change would not be detrimental to most species. One practitioner predicted that small mammals such as deer mouse (*Peromyscus maniculatus*) and red squirrel (*Tamiasciurus hudsonicus*) would likely abound due to the extended growing season, increasing cone crop and ground vegetation availability. Furbearers like the marten (*Martes Americana*), an umbrella species for old-growth habitat in NB, feed on small mammals and would likely benefit from the increased prey availability. However, the subnivean winter behavior of marten may change with reduced snow levels and cause the marten to chase down prey in trees, as they do during the other three seasons. As noted by a naturalist, this effect may also render small mammals more vulnerable to freezing during winter if there is a lack of subnivean habitat to insulate them.

A wildlife practitioner also noted that the quality of pelts from furbearers may change for trappers with warming temperatures. Temperature changes may affect furbearers and growing winter coats. Trappers in NB currently harvest furbearers in late fall to winter when their pelts are densest to achieve best value in Asian and European markets.

One wildlife practitioner acknowledged that some concern has been expressed over forest composition shift in NB and old-growth habitat species like marten. Marten have been characterized as requiring "old", northern-adapted conifer stands. However, the practitioner explained that recent research has shown that marten will occupy stands of large intolerant hardwoods, such as poplar (*Populus balsamifera*), trembling aspen (*Populus tremuloides*) and red maple (*Acer rubrum*). Consequently, the practitioner suggested forest composition shifts in NB may not be as detrimental to marten as some have suspected.

Both wildlife biologists and practitioners agreed that lynx (*Lynx Canadensis*) is a species that would likely be negatively impacted by climate change. Lynx have evolved for cold temperatures and high snow depths, and NB is within the southern limit of the species' range. Warming temperatures and reduced snow levels would not only affect lynx, but would also expand the range of bobcat into northern NB. Experts note that when bobcat and lynx ranges overlap, bobcat will out-compete lynx with its heavier body and more generalist behavior. Respondent 9 explained: "Lynx can run on the snow far easier than bobcat. Lynx have specialized to feed on hare, but bobcat is far more of a generalist. When conditions warm up and there are more favourable conditions for bobcat, bobcat expands into the new range. Lynx will lose out on that. It's definitely a function of snow".

We experienced consensus among experts that variations in climate would affect the utilization and management of some wildlife, possibly warranting policy reconsideration to appease the public. In the case of deer, hunters in northern NB have a culture of using a snow layer to track deer. Some trappers also employ a similar method to snare coyote and bobcat. The trapping of furbearers in aquatic habitat is timed to end shortly before temperatures remain below 0° Celsius and water bodies freeze. If warming temperatures and other climatic variables disrupt these social customs, government may have to consider adjusting the timing of hunting and trapping seasons.

5.2.2 Fishes

There was high congruence between ichthyologists and wildlife biologists on how fishes in NB may be affected. Two species of salmonids, Atlantic salmon (*Salmo salar*) and brook trout (*Salvelinus fontinalis*), were the key species discussed during interviews. Experts agreed they could be affected by climate change through a multitude of direct and indirect pathways. Both species have tight water temperature thresholds; consequently, they will not thrive in waters exceeding these thresholds. Increasing water temperatures also have implications on water chemistry, further adding potential stress to the fishes and increasing the complexity of understanding thresholds. These implications include reduced availability of dissolved oxygen, and fluctuations in pH level. The metabolic processes of fish may also be affected. Ultimately, the range of brook trout and salmon will recede, causing population decline in NB. One biologist cited this as a leading cause of the current reduction of brook trout in the province.

One biologist explicitly cited the high temperature regimes observed during summer of 2012 a result of climate change. The expert further explained that while such events of high water temperatures above 25° Celsius have been documented since at least the 1960s in the Miramichi River, the frequency of such events has increased. Precipitation is an integral part of the events, since water will only reach the extreme temperatures if water levels are low. Based on the last ten years, there is great likelihood that juvenile salmon in the main branches of the Miramichi River will see a high temperature stress event in their lifetimes. Such events cause fish to act against their natural instinct to seek areas of protection and, instead, seek areas of cold water refugia, resulting in large numbers of fish gathering at these areas. Such gathering events lead to additional stress, disease-spread and increased vulnerability to predation.

Ichthyologists and wildlife biologists also agreed that warmer water temperatures would facilitate the span of non-native warm water fishes into NB, and increase the range of warm water species already present, such as smallmouth bass (*Micropterus dolomieu*), muskellunge (*Esox masquinongy*), and chain pickerel (*Esox niger*). Warm winter species that were already somewhat tolerant of NB conditions could potentially flourish under new climatic conditions. Warm water species could naturally enter the province, or, as has occurred in the case of smallmouth bass, be introduced by individuals. Warm water invasive fishes may act not only as competitors to native fishes, but also as predators, potentially affecting population levels.

One biologist affirmed that a certain degree of security regarding invasive species will be lost as water temperatures increase. The individual explained that when people released non-native species in to the province's waters decades ago, there was minimal concern that the species would successfully colonize waters here due to unsuitable temperatures. Respondent 10 explained that as the climate changes, "the comfort of saying, 'it will never persist here' will erode in the future".

Four wildlife biologists stated that fish habitat may be physically altered as a result of climate change. Increased frequency of heavy precipitation events causes high water flow and flooding, ultimately mobilizing bed material, washing out streams and eroding stream banks. When water courses return to base flow levels in the widened stream beds, water levels are shallower, leading to warmer water temperatures.

All biologists and ichthyologists agreed that climate change undoubtedly results in increased stress level for fishes, either directly or indirectly. This stress renders fish more susceptible to parasites and diseases, many of which are latently present in NB waters and will establish under ideal conditions.

Biologists acknowledged that there are some actions that may be employed to respond to the changes. Individuals with riverside properties should avoid using phosphates and disturbing sedimentation to prevent hazardous algal blooms that may occur in warming water temperatures. Education will also have a valuable role in teaching the public about the implications of releasing non-native fishes in NB. The public may also learn about adjusting their recreational activities on rivers during high water temperature events, such as avoiding inflatable tubing down rivers and adding strain to already stressed fish populations.

5.2.3 Birds

Wildlife biologists and naturalists established that NB will likely have a bird species composition shift as the climate changes, possibly increasing species richness. Bird species of a more southern range will move into the province, while species in the province that are associated with coniferous habitat and cooler temperatures may recede. However, experts emphasize that species are dependent upon vegetation and invertebrates. Consequently, species range will be heavily determined by the changes in the distribution of these organisms. Two ornithologists and one naturalist agreed that birds such as Bicknell's thrush (*Catharus bicknelli*) with breeding habitat of high-elevation, dense conifer stands may be at risk. The naturalist also cited Gray Jay (*Perisoreus canadensis*) as another northern species that may be decline with climatic changes, as it caches food for winter consumption. The naturalist suggested that warming temperatures may cause the food caches to perish and affect the bird's success.

A naturalist has observed that some species appear to be over-wintering better in the province in the past twenty-five years than they did in the past. Some of these observed species include mourning doves (*Zenaida macroura*), northern cardinal (*Cardinalis cardinalis*), turkey vulture (*Cathartes aura*), pine warbler (*Setophaga pinus*), northern mockingbird (*Mimus polyglottos*), and red-bellied woodpecker (*Melanerpes carolinus*). The cause of this change in behaviour is unclear, but the naturalist suggested that warming temperatures and changing climatic temperatures may be a cause. The naturalist also suggested that more frequent sleet events may affect birds of prey. The hard layer of snow crust that forms as a result of sleet events increases the difficulty of catching small mammals for birds of prey, as they have to penetrate the crust layer of snow.

Ornithologists suggested that climate change may cause migratory birds to become decoupled from the insectivorous food sources they rely upon during breeding season. Research has shown that this has occurred in Europe. The experts believed that responses from bird physiology and insectivorous prey to warming temperatures would be different. With warmer temperatures, birds may migrate earlier or faster than before and not coincide with peak invertebrate abundance for nestlings, as explained by one expert. Another ornithologist explained that warmer temperatures may cause insects to reach peak abundance before migratory birds have arrived in the province. Both scenarios result in inadequate resources; consequently, bird breeding success will be lowered.

Increased precipitation may cause nestling mortality if it should occur during late June when nestlings are vulnerable to hypothermia. One ornithologist viewed this effect with high concern; another ornithologist agreed, but added that if the precipitation was not continuous throughout the breeding season, birds can successfully re-nest. The second individual's research has found no major costs of doing so.

One ornithologist noted that birds are already dealing with other stressors, such as contamination or habitat degradation. The effects of climate change on species will be another stressor to cope with. Respondent 11 stated, "Climate change could be the straw that breaks the camel's back". When asked what responsive actions should be taken in regards to birds, one ornithologist explained that maintaining forest cover was key in the case of songbirds. Closed canopies will reduce the effects of increased heat and provide vital habitat for the species.

6 Discussion

Initially, we intended to present our interview respondents with a "moderate" and "severe" scenario and then ask them about two future time periods, 2050 and 2100. That would have resulted in 4 potential future outcomes and ultimately seemed too complex to implement. When we consulted the climatologists on the most likely scenario, they advised us that current carbon emission levels already exceed the predictions of the severe climate change scenario. Even if ambitious global emission reductions are made there will be latency effects in the system that almost guarantee some degree of change, particularly for the 2100 time period. Consequently, we based our changes in climatic variables on the severe scenario and chose to consider the originally proposed points of time in the future.

One deficiency in the project was the lack of representation of Francophone biological expertise. We did not deem our team proficiently fluent in French biological terminology to adequately converse with experts; therefore, we contacted only English-speaking biologists for the one-on-one interviews. We did conduct a focus group at the Université de Moncton. While we had an excellent conversation there with nine participants, we had a difficult time recruiting biologists and ecologists to that meeting. Rather, we had a more eclectic group that included three environmental chemists, two sociologists, a law student, a member of the education faculty and one ecologist. Interestingly, an overarching concern that we heard there was the potential negative effects of sea level rise, which no one really identified as critical to ecological changes in either of the focus groups held in Fredericton. This underscores the idea that local effects may be quite varied, and therefore local perceptions of what adaptation and mitigation efforts might be appropriate will likely vary as well.

As previously described, there was some disagreement between experts on how particular organisms may be affected. When this occurred, the cause of the disagreement was generally which parameters of the organism the expert was taking into consideration. Different theoretical parameters acting in isolation may have differing results on organisms; furthermore, parameters when considered collectively may produce different results than individually.

Every biologist, ecologist, forester and practitioner emphasized to some degree or another during the course of interviews that ecosystems are complex, intricate structures; therefore, speculating on how ecosystems or the organisms within them may be affected by climate change is highly challenging. Most experts were hesitant to respond to our questions in the level of detail we had hoped. We identified and presented to them changes in climatic variables of temperature, precipitation and growing degree days at the 2050 and 2100 timeframes with the optimism that experts may identify ranges of species that would be affected and how. Experts, however, rarely were comfortable speaking with anything near the level of specificity for which we were hoping. Effects were also not associated with the particular dates we identified. Most experts disregarded the 2100 timeframe entirely and predicted that the 2100 timeframe would see a continuation and exaggeration of changes described for the 2050 timeframe.

When experts were asked what individuals, communities, and governments may do to mitigate the effects of climate change, the vast majority of individuals acknowledged that action should be directed toward the root of the problem. This tended to be the initial reaction of experts, regardless of biological expertise. Respondent 12 stated that in the past when presented with this question, that it was, "just an excuse to not deal with the causal effects." In fact, when presented with this question, most experts immediately referenced the importance of dealing with climate rather than describing micro-scale actions aimed directly at the biota. Reducing consumption and carbon emissions and appealing to politicians to become adamant about implementing policies to reduce emissions were common responses.

As previously stated, seven experts declined to participate in an interview. Four of these individuals were from academic institutions, two from government, and one from a private organization. Overall, four of the individuals who declined explained that they viewed their own research and knowledge as too limited in scope or relevance to adequately consider climatic effects to offer insight. However, three of these four individuals were encouraging of the project nonetheless and suggested names of colleagues whom they thought would be more conversant on the subject to interview. The other three individuals who declined to speak with us were reluctant to do so because of the notion of speculation. One individual remarked that his contribution would only consist of "speculative arm-waving". Another individual explained that they did not see value in speculation on species changes due to climate change, regardless of a specialist's level of expertise. The third individual stated that they are a researcher and professor, and do not partake in speculative deliberations.

The majority of experts who agreed to an interview also exhibited some degree of reluctance to "speculate". Multiple experts acknowledged this disinclination to speculate for two main reasons, explicitly stated during interviews: speculation is not the role of scientists, as that contradicts the very nature of science. One expert further explained that making predictions based on climatic models is challenging because if the climate models are inaccurate, the predictions for biota are also wrong. Respondent 12 explained, "It's like a straw man that will fall apart when the model is wrong". The second reason, as we also observed in experts who declined to speak, was that many of them initially doubted the significance of their own knowledge to make predictions of climatic effects on biota. This, however, was part of the project's intent to gather information from not only experts who had researched climate change in relevance to their biota of expertise, but also experts who had not yet done so.

When we asked experts why they were willing to speak with us despite initial hesitation, they provided us with a few reoccurring explanations: while they were uncomfortable with speculating, they recognized that their conjectures will be reported anonymously. They also appreciated that the report will present results precisely as conjectures and informed opinions, and not as scientifically tested facts. Many experts also explained that they view climate change as a real and pressing issue. Respondent 11 stated, "It's the most important issue that faces the planet - I think it dwarfs everything else." Respondent 13 made a similar remark: "Everything we do in the future will be done against the backdrop of climate change."

A few researchers also expressed concern over what would occur if scientists did not discuss climate change. Respondent 14 explained: "If we do not, other people who have no knowledge are quite willing to speculate. And then that becomes the dominant message." A few researchers and practitioners also reported that they have experienced climate change firsthand in their work, be it through an indirect effect on the biota they study. For these experts, climate change and its effects are undeniable and increasingly consequential, and it is their role to draw attention to this.

We expected that experts would be less willing to deliberate and speculate about climate change effects in focus groups composed of their peers than they would be during individual interviews. We suspected this would be partly because the anonymity we maintained during interviews could not be preserved during focus group sessions to other members present. Ultimately, our assumption proved incorrect. During focus group sessions, we observed that experts were willing to hypothesize about effects and they were very interested in hearing what their colleagues had to say. In some instances they began asking questions of their colleagues. We purposely comprised the focus groups to consist of people with little overlap in their expertise (e.g. we did not have two ornithologists, two plant biologists, or two insect ecologists to the same focus group). So with the encouragement and curiosity of their peers and colleagues, they were more willing, not less, to speculate about system dynamics if not actual likely outcomes that may result from global warming. Overall, focus group sessions were productive and provided a platform for discussion on climate change between individuals of varying institutions, backgrounds and expertise. Given the interesting dynamics in the focus groups (one of which was also attended by one Department of Environment staff member, one Department of Natural Resources staff member and a city employee, in addition to four scientists) it seems as though convening future conversations like this perhaps including senior department staff (Deputy and Assistant Deputy Ministers or Section Leaders) and elected officials may be something that the Department of Environment might consider. It would be an efficient way for decision-makers to informally but directly tap into the considerable expertise that exists in the province for helping determine the best courses of action to address global warming.

Another common theme heard in the vast majority of individual interviews was skepticism regarding the accuracy of climate change models and predictions. Interviewees frequently expressed their distrust in models prior to making predictions. Multiple individuals alluded to the notion that meteorologists do not succeed in predicting tomorrow's weather; therefore, it is unrealistic to expect climatologists and modellers to be able to accurately predict climate decades into the future. Three individuals blatantly stated that they severely doubted the magnitude and reality of climate change, and felt no reason for concern. Two experts also expressed disbelief that climate change is the result of anthropogenic activities and believe it is a natural cycle previously experienced. They both acknowledged that human activity has facilitated the process, but not been the sole cause of it.

All but one expert described overall effects of climate change on biota in terms of trends rather than processes resulting from breeches of ecological thresholds. When pressed for specific thresholds, experts acknowledged that some do exist, but are very complex, since no one isolated parameter is solely acting upon biota. As explained in the case of fishes and water temperature, lethal temperatures do exist for cold water salmonids; however, water temperature is also influencing other vital parameters such as dissolved oxygen and pH balance. Consequently, experts were reluctant to identify thresholds and make predictions based solely upon them.

7 Summary

The province of NB is a distinctive eco-region where the temperate and boreal climate types intersect. As a result, the associated biota of these climates thrives and competes within the same areas and, commonly, at the same habitat sites. Terrestrial and freshwater ecosystems will be vastly affected as climate change influences, both directly and indirectly, the ecological parameters that present limitations or favourable conditions for specific organisms. Trends and variations will occur across a range of spatial and temporal scales. At the macro-level, the success of individuals of northern-adapted trees species such as balsam fir and white spruce may decline, eventually leading to stand-level decline, and potentially population reduction in the province. Southern-adapted species such as red spruce and red oak will likely improve under the climate conditions and increase their distribution across NB. These variations at the forest stand level may have implications for species at micro-sites, such as bryophyte communities.

Mammal population levels may also be influenced in the case of Canada lynx and white-tailed deer. Decreased snow levels will not only affect the success of lynx as predators and be out-competed by bobcat, but decrease their range within the province. Deer, however, will thrive under warming temperatures and reduced snow levels, likely leading to increased social interactions in urban environments. These interactions may lead communities to pressure government for increased population management.

Two cold-water salmonid fish species, Atlantic salmon and brook trout, are also predicted to be decline in NB waters as a result of direct and indirect climatic changes. Warm-water fish populations currently in the province will likely grow and increase their range. Other warm-water species currently not established in the province are also predicted to invade with warming temperatures.

Similar to tree species, bird species composition will likely shift as southern-adapted species expand their range in or into NB, and northern-adapted ones recede. The de-coupling of migratory bird movements from peak insect abundance levels will also affect population success.

Biological experts have highlighted various responsive actions to climate change. Nearly all experts agreed that addressing the actual cause of global warming is key, rather than only acting upon its effects and influences. Experts have cited various ways individuals may employ adaptive and mitigating action; however, most emphasis was placed on governmental response. Nearly all experts advocated that changing policy for forestry practices and wildlife management in the face of climate change is crucial.

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