# CRITERION 4.0

## Forest Ecosystem Contribution To Global Ecological Cycles

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> *"Global ecological cycles are a complex of self-regulating processes responsible for recycling the Earth's limited supplies of water, carbon, nitrogen and other life-sustaining elements. Understanding the role forests play in these cycles is essential for the development of sustainable forest practices."*
>
> *- CCFM (1997)*

# PREAMBLE

The Fundy Model Forest curtailed efforts to address Criterion 4.0 – Global Ecological Cycles, when it was realized that the issues regarding atmospheric influences were too complex and long-term for a FMF working group to deal with in an effective manner. The indicators included under this criterion are still of interest to the FMF partners due to the fact that one of the areas of high impact from atmospheric influences is in the vicinity of Fundy National Park at the upper part of the Bay of Fundy.

This section of the report addresses air quality trends and tree condition. As well, some additional information regarding climate change is included.

# Air Quality and Tree Condition Within the Fundy Model Forest

## Introduction

Air quality has been deteriorating in many forested regions of the world due to increasing emissions of primary air pollutants such as nitrogen oxides (NOx), sulfur oxides (mainly as sulfur dioxide or $SO_2$), fine particulate matter, heavy metals and persistent organic pollutants. The Bay of Fundy Region (FR) is situated downwind of the some of the largest stationary and most populous area emitters in North America , while its forests retain critical ecological, economic, aesthetic, and recreational values. Primary air pollutants emitted some distance from the region are transported, transformed and deposited via wet (rain, fog, cloud) and dry (gases, particulate, vapour) pathways onto eastern Canadian forests (EC, 1997).

McLaughlin and Percy (1999) reported on air pollution and forest health in North America. In their retrospective analysis, they focussed on four longer-term, coordinated and extensive case studies to report on state of science. They concluded, "...regional scale air pollutants are affecting the physiological processes of forest tree species within diverse, widely distributed, and regionally important forests. The processes affected and the stresses they produce are important to the way these forests grow and respond to biotic (ie insects, disease) and abiotic (ie drought, wind) stresses within their regional environments." Furthermore, they stated that "...ambient air pollution effects on carbohydrate allocation, root growth, water uptake and control, and soil Ca and N levels indicate that regional air pollution could significantly enhance the adverse effects of global warming in some areas."

It is not the intention of this article to review air pollution effects on forests, but rather: 1) to provide a summary of recent trends in air quality specific to the FR, and 2) to relate these trends to one commonly measured indicator of forest health at plots located within Fundy National Park (FNP) and the Fundy Model Forest (FMF). While there are a number of air pollutants of current or emerging concern to global forests (Percy *et al*., 2000), two have and will continue to be of concern to FR forests. Tropospheric, or ground-level ozone ($O_3$) is a secondary air pollutant formed from the photochemical oxidation in sunlight and at warm temperatures/low humidity of NOx and volatile organic compounds (VOC's) to form a host of secondary pollutants. The most prominent secondary product is $O_3$. The second is deposition of strong sulfurous and nitric acids, the majority of which (circa 70%) are deposited in rain, cloud and fog. Both $O_3$ and acid deposition are subject to long-range transport and approximately 70% received into the FR originates from outside the Atlantic Region (EC, 1997).

## Air Quality Trends

### *Ozone*

In 2000, Canada Wide Standards (CWS) for $O_3$ and fine particulate matter ($PM_{2.5}$) were promulgated (see http://www.ccme.ca/3e_priorities/3ea_harmonization/3ea2_cws). The CWS for $O_3$ is a 65 ppb, 8-hour averaging time by 2010, with achievement to be based on the 4th highest measurement annually, averaged over 3 consecutive years. Dann (2001) has spatially applied the CWS in eastern North America for 1996-1998 (Figure 35). As can be seen, eastern continental $O_3$ concentrations decrease northeast. However, much of the FR was in exceedance of the new CWS by up to 10 ppb. The well-documented $O_3$ scavenging influence of urban centres, like the St John area, was evident through lower concentrations (green zone) in and around St. John than in surrounding areas (yellow).

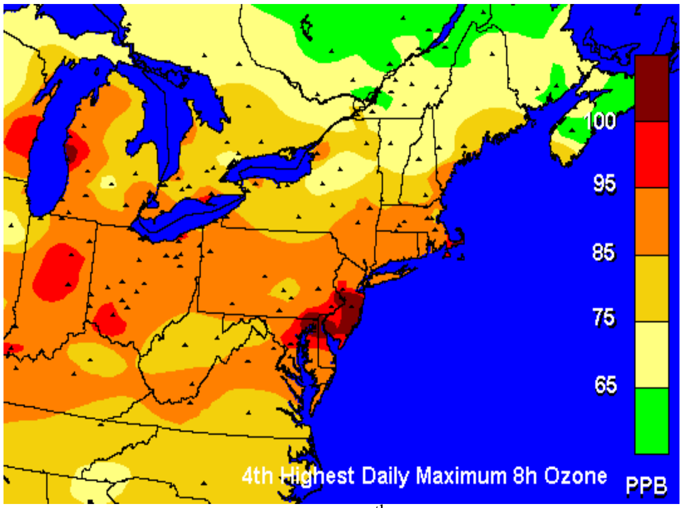

Figure 35. Regional levels of 4th highest daily maximum 8 hour ozone (1996-1998) (Dann, 2001)

Clearly then, when examining $O_3$ concentrations in forested areas, urban sites where the majority of ground-level $O_3$ stations are situated, must be excluded. In Figure 36, $O_3$ eleven-year (1989-1999) trend data collected at the station in FNP (Hastings Tower; Lat. 45 59, Long. 65 00) are compared with other coastal FR (Point Lepreau, main gate; Lat.45 07, Long. 66 45), inland FR (Norton, ball park; Lat. 45 64, Long. 65 71), Kejimkujik National Park (Lat. 44 44, Long. 65 21) and the Atlantic Region (n=6 sites) rural site average (four above-listed sites plus Blissville,N.B. (Lat. 45 61, Long. 66 56) and Cormac, Nfld (Lat. 49 32, Long. 57 40).

The CWS prescribes an $O_3$ threshold of 65 ppb, which is lower than the previous National Ambient Air Quality Objective (NAAQO) of 82 ppb over one hour, and close to the 60ppb threshold proposed during the 1996 Canadian NOx/VOC Science Assessment for protection of vegetation (Pearson and Percy, 1997). As can be seen, $O_3$ concentrations calculated using the CWS measured at FNP were in exceedance in 10 of 11 years during 1989-1999, the only exception being 1998 (58 ppb). While the CWS $O_3$ concentration decreased between 1992 (74 ppb) and 1998 (58 ppb), the calculated index for 1999 had increased again to 73 ppb. In 9 of 11 years, the FNP concentration was higher than the Atlantic Region rural site average (Figure 36).

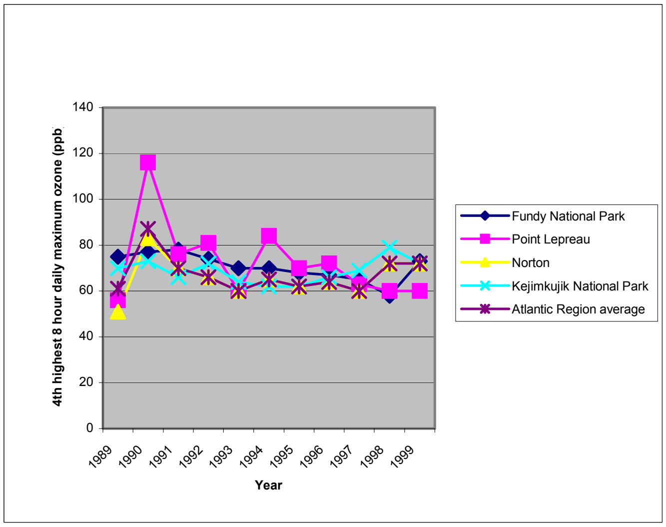

Figure 36. Regional trends in 4th highest daily maximum 8 hour ozone for selected “rural” sites (data source: EC-NAPS)

Interestingly, for a median year (1994) during that period, FNP had the highest annual mean $O_3$ concentration (34 ppb) of any site in Canada , including those in southern Ontario and Quebec (EC-EPS, 1997). CWS $O_3$ concentrations at Point Lepreau (Figure 36) were highly variable with high years (ie 1990) possibly reflecting long range transport into the FR from regions to the SW. The Norton trend indicates increasing $O_3$, as does Keji.

There is evidence for a gradient in increasing $O_3$ exposure moving NE within the FR. This is demonstrated by viewing a one-week period of cumulative $O_3$ dose collected by passive ozone monitors located in open, rural sites throughout SE NB (Figure 37). The exposure (16 ppm hours=16000 ppb hours) measured at FNP was among the highest in the FR during the August. Exposures in SW NB were significantly lower.

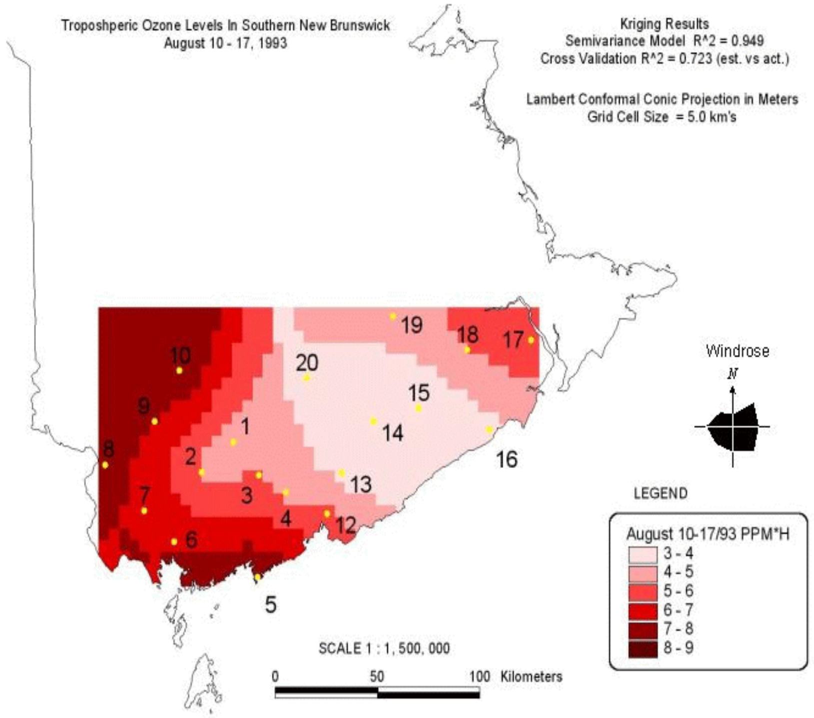

Figure 37. NE gradient in $O_3$ (expressed as ppm hours) as shown by rural passive ozone sampling during a one-week period (source: Cox et al., 2001)

### *Acid Deposition*

Acidic precipitation arises from the oxidation of $SO_2$ and $NO_2$ in the atmosphere to form sulphuric and nitric acids that are then deposited onto forests via precipitation, interception of fog and cloud, or dry (gases, vapour) deposited pathways. Human-caused emissions of $SO_2$ have declined 25% in North America and 48% in Europe since the early 1980's (Fowler *et al*., 1999). However, while emissions have been reduced in Canada by 40% (4,634 to 2,766 thousand tonnes $yr^{-1}$), those in the United States have declined only 21% (22,351 to 17,622 thousand tonnes $yr^{-1}$) (EMEP, 2000). In contrast, emissions of NOx have only been reduced by 2% (22,501 to 22,083 thousand tonnes $yr^{-1}$) during 1980-1998. In Canada, NOx emissions actually increased by 4% (1,959 to 2,051 thousand tonnes $yr^{-1}$) during the same period (EMEP, 2000).

A cooperative effort between the New Brunswick Electric Power Corporation and the New Brunswick Department of the Environment reported on precipitation monitoring data for southern New Brunswick (NBDOE, 1999). One important innovation has been the reporting of precipitation chemistry data using a mass balance approach, so as to represent potential for acidification. This project calculated potential acid input (PA) as: PA= $SO_4$ dep + ($NO_3$ dep+$NH_4$ dep) -(Ca dep+Mg dep+K dep).

Unfortunately, the monitoring site in FNP (Alma gate) has been operating only since 1993 and represents the only network FMF data source. Although one cannot deduce trends from only four years of data, PA increased at FNP, from 0.25 kmoles $H^+$ $ha^{-1}$ $yr^{-1}$ in 1993 to 0.29 kmoles $H^+$ $ha^{-1}$ $yr^{-1}$ in 1996 (NBDOE, 1999) (Figure 38). In contrast, PA at Nictau (Lat. 47 13, Long. 67 19), Harcourt (Lat. 46 29, Long. 65 15) and Bonny River (Lat. 45 14, Long. 66 51) was larger in 1993 than in 1996. In 1995 and 1996, PA among the four sites was largest at FNP (0.30 and 0.29 respectively).

Fog interception is a prominent feature in coastal FR areas. These fogs are formed in the same chemical environment as the marine boundary layer bringing wet $SO_4$ and $SO_2$ from continental pollution sources, and, therefore, their chemical composition is expected to be similar (EC, 1997) and have at least twice the pollutant concentrations as rain. Estimation of PA input using rain chemistry-derived data alone, likely underestimates total acid deposition by at least 50% (Cox *et al*., 1996).

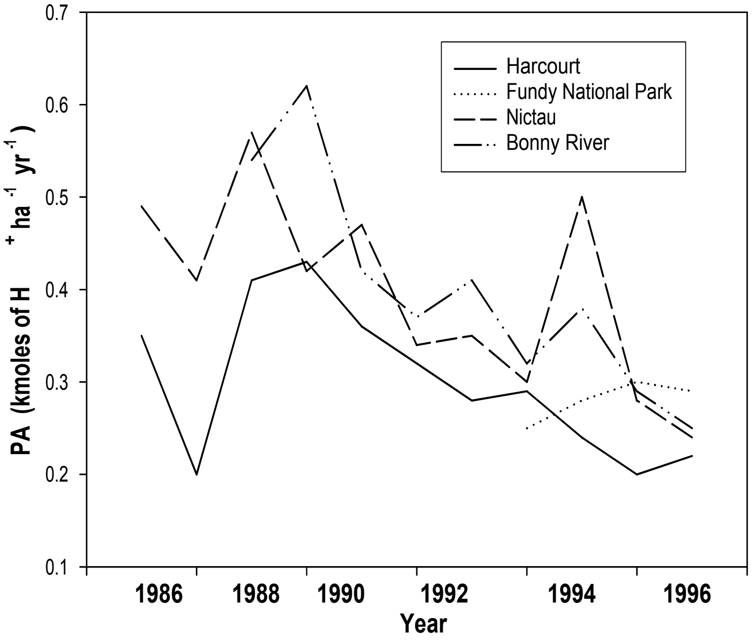

Figure 38. Potential acid input (PA) into eleven New Brunswick sites during an 11 year (1986-1996) period (source: NBDOE, 1999)

## Tree Condition Monitoring

The Canadian Forest Service has monitored the health of Atlantic Canadian forests as part of international, national and regional scale network programs. The Acid Rain National Early Warning System (ARNEWS, 1984-2000) was established in 1984 in response to widespread forest destruction in Europe and concern in North America. Its mandate was to monitor the condition and changes in the condition of the forest in order to detect early signs of acid rain damage. Previously, in 1982 eleven plots were established to monitor the observed deterioration of white birch along the Bay of Fundy first reported in 1979. Crown condition is an internationally used and commonly reported indicator of tree health and will provide the focus for this report.

### *White birch*

### *Condition on ARNEWS plots*

ARNEWS had two plots in the FMF, one near Martin Head (Lat. 45 30, Long. 65 00), Saint John County and the other at East Branch Trail (Lat.45 37, Long. 65 08) in FNP. In Figure 39, crown condition is summarized for white birch (*Betula papyrifera* Marsh.), the most common plot tree species at Martin Head.

Nearly 60% of white birch have died at Martin Head over the past 16 years (Figure 39). Significant stress induced by acid fog and $O_3$, have resulted in successive years of increasing dieback to the point that trees have died from the loss of living crown and from increasing, consequential incidence of secondary factors such as *Armillaria* root rot. Tree mortality has not increased since its maximum (56 %) in 1997. Significantly, between 1984 and 1999, the percentage of healthy trees had decreased from 83% to only 18%. Insects and disease as primary agents of decline have been ruled out (Magasi, 1985).

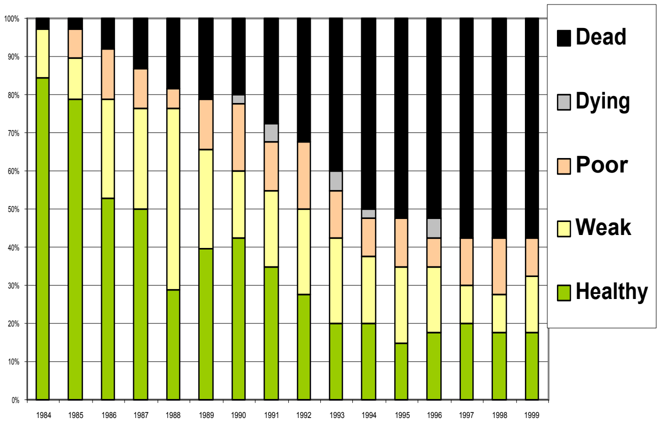

Figure 39. Trend in white birch crown condition at Martin Head (n=40 trees)

### *Condition on 11 Survey Plots*

Eleven white birch deterioration plots were established in 1982 in coastal areas of southern NB between Campobello Island and FNP. Figure 40 shows the 19-year trend in crown condition for the remaining seven of the original eleven-plot network. Though the symptoms of early foliage browning and leaf drop have been much less frequently observed since the 1980's, stands of white birch have not recovered to their 1985condition status. Then, almost half the trees were classed as healthy. Since 1985, there has been only one year (1991) when a minimum 20% of trees were healthy. For the other 13 years since

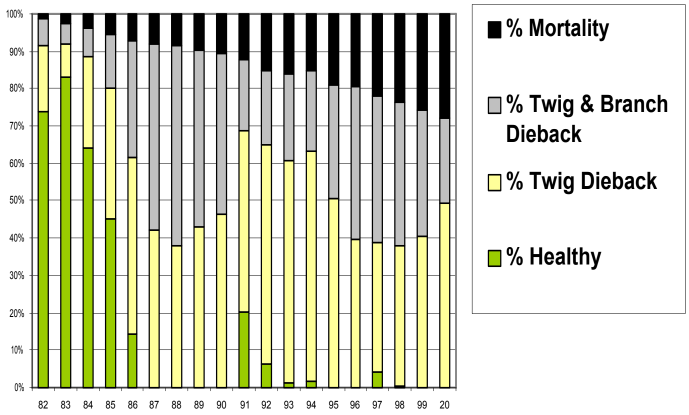

Figure 40. Nineteen-year (1982-2000) trend in crown condition at New Brunswick birch deterioration plots.

1986, the proportion of healthy trees never exceeded 5%. Total mortality has been increasing each year since 1982, and in 2000 was nearly 30%.

### *Condition in the SW FR*

At a more southerly site near Point Lepreau, foliar browning was greatest in the mid 1980's. Browning was statistically correlated with fog acidity, and $NO_3$ concentrations in fog. Foliar browning decreased following 1987, and tree condition has improved coincident with historical lows in fog frequency (Cox *et al.*, 1996). It is also clear that a concomitant improvement in fog chemistry between 1987 and 1996 occured (Figure 41). Concentrations of the two major acid anions, sulphate ($SO_4$) and nitrate ($NO_3$) have decreased significantly between 1988 and 1996, leading to a decrease in fog hydrogen ion concentration, or in other words, fog acidity.

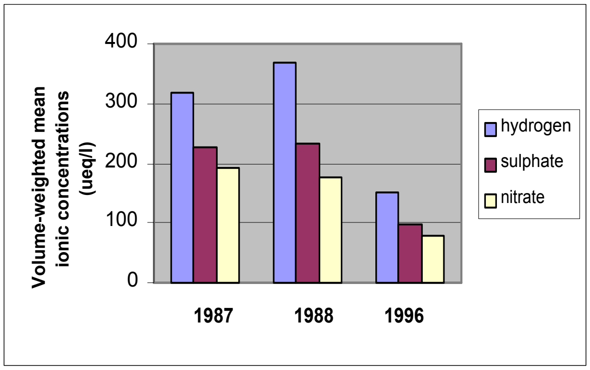

Figure 41. Comparative Point Lepreau fog chemistries for three years.

### *Red spruce*

Red spruce is a common tree species in the FMF and was equally represented in the Martin Head (est. 1984) and FNP (est. 1993) ARNEWS plots. The combined plot histogram (n=27 trees) of red spruce crown condition is summarized in Figure 42. Though a few trees demonstrated slight crown condition deterioration in 1997, they have showed improvement since (Figure 42). There was no red spruce mortality on either plot since establishment. There is, however, a considerable scientific literature on the sensitivity of red spruce (cf. McLaughlin and Percy, 1999) to acid deposition, and the species has experienced acid fog-induced decline in the mid Gulf of Maine (Jagels *et al*., 1989) area, immediately south of the FR. Red spruce decline at higher elevations in the Appalachians has also been attributed to acid deposition (cf. McLaughlin and Percy, 1999).

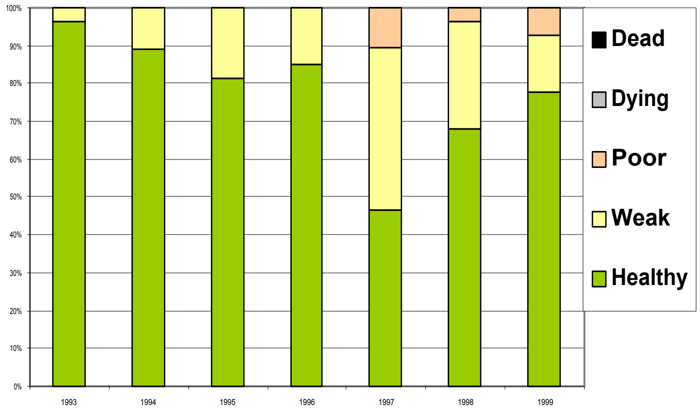

Figure 42. Trend in crown condition at Martin Head and Fundy National Park ARNEWS plots.

## Summary

The FMF is situated in an area that regularly receives significant regional-scale loading of long-range transported acids (EC. 1997). Ozone concentrations calculated using the CWS remain in exceedance.

Ozone is expected to become a greater threat to global, national and regional forest health, given the relatively small reductions (US), or increases (Canada) in precursor NOx emissions. The combined impact of a deterioration in air quality and predicted climate warming may exacerbate the impact (Percy *et al.*, 2000).

A healthy forest is one which retains "the capacity to supply and allocate water, nutrients and energy in ways that increase or maintain productivity while maintaining resistance to biotic and abiotic stress" (McLaughlin and Percy, 1999). Clearly, there are no purpose-designed studies that have set out to examine essential cycles in the FMF in the context of the atmospheric environment in which the forests are growing. Hence, two prominent tree species sensitive to acid deposition (red spruce, white birch) and ozone (white birch) and one indicator of change, crown condition, have been used as an indicator system for the purposes of this very brief assessment.

Empirical evidence exists for a direct causal relationship between deteriorating air quality (increased $O_3$ concentrations, increased acid loading) and increased white birch mortality. There are also monitoring data which suggest a secondary, pre-disposing influence of acid fog on white birch disease performance. At present, however, the risk to FMF health and sustainability posed by air pollutants such as $O_3$ and acid deposition remains un-quantified.

## Climate Change – Long-Term Considerations For The Fundy Model Forest

In proceedings of a climate change workshop held in Halifax (1997), Cox suggests that potential climate warming as a result of greenhouse gas emissions could result in seasonal changes, variable climate, and more extreme weather events which would have a greater effect on the forests of Atlantic Canada than would a small increase in temperature. This instability could result in a more active hydrological cycle and result in more large-scale blow downs in forests in this region. Some changes, which may occur in the forests of Atlantic Canada, are:

- Growth rates may increase due to longer growing seasons and warmer soil conditions. At risk however might be some hardwood species if there is a refreezing after buds and roots have initially thawed.
- Changes in growth rates, which could result in changes in timing of development of plant parts, could effect competition among plants and thus change plant populations and ecological relationships.
- Carbon sink-source relationships

Carbon loss in the mature forest may result from increased decomposition rates in the soil and forest disturbance. The young forest may not be an effective carbon sink due to air pollution, and acid precipitation.

Carbon storage may be compromised by higher harvest rates due to increased forest productivity. This might be mitigated through strategies to ensure carbon storage through both a continued supply of standing timber and also forest products. These strategies would need to address the possibilities of increased forest disturbance (from severe weather events) and any salvage operations that would take place. Particular attention would need to be given to carbon production through growth of the young forest.

- Species composition

The forest composition could be expected to change toward less boreal and more mixed forest with an increase in warming conditions. This will depend on species adaptability to new climate conditions. Current research (Cox, *et al*) is being undertaken to investigate conditions for drought tolerance of black spruce, response of sugar maple roots to frost penetration, and response of birches to winter thaw. Modelling for the maintenance and conservation of habitats and rare species for maintaining biodiversity is also being investigated.

### *Disturbance Regimes*

Fire – There is uncertainty in the modelling process for fire activity in the Maritimes. The fire weather index (FWI) uncertainty will be increased by changes that may occur in the forest due to other disturbances such as blow-downs from severe weather and increased insect infestations. These parameters will affect the amount of fuel in the forest.

Insect Outbreaks – Higher temperatures due to climate warming would mean greater survival of insects at the northern edge of their ranges. Greater survival would mean more damage to the forests.

Climate-related Decline – With a warmer climate, winter thaws could be expected to last longer. This would provide more time for dehardening of roots and therefore greater damage to those roots at time of refreezing. The result of this would be forest decline and dieback especially in hardwood species.

Storms and Large-scale Blow-downs – The loss of carbon storage from the forest due to increased storm damage and blow-downs can be avoided through salvage harvesting, which has become the practice in recent times. Proper management of the young forest will ensure a carbon sink. Factors affecting a possible increase in forest disturbances include more severe weather events associated with climate warming, and an increase of shallow-rooted species found in softwood plantations.

Browser Populations – Greater numbers of deer will survive because of less severe winter conditions. This will result in greater impact on the regenerating forests where deer browse, and lower species diversity.

There is much uncertainty in predicting climate change and its related effects. Investigation needs to address issues such as tree tolerance to drought, nutrient deficiency, blow-down and winter thaw duration on hardwoods. Species mobility and migration as well as the movements of people over the landscape will also impact the forests in the future.

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