The Effects of Hydroelectric Flooding on a Reservoir's Peripheral Forests and Newly Created Forested Islands

Yves Bégin, Luc Sirois, and Céline Meunier

1 Introduction

While research shows that large water bodies can produce significant micro- and meso-climatic effects, these effects are not well documented. The flooding of large areas transforms terrestrial environments into aquatic environments, with hills becoming islands and the flooded edges dynamic shorelines. In creating these reservoirs, we expose the new shoreline forests to processes and natural hazards pertaining to lacustrine environments. The environmental transformations caused by these processes are generally limited to the immediate edges of the reservoirs. In Russia, Vendrov and Malik (1965), D'yakonov and Reteyum (1965), and Butorin et al. (1973) have shown that the effects of reservoirs in the Volga are limited to their riparian edges. Wind controls the geomorphologic activity of waves and ice delineating the shore tree line. The wind also controls the distribution of snow at the edge of the water body during the long part of the year that is covered by ice. In New Zealand, Fitzharris (1979) reviewed the effects of the planned Upper Clutha Valley hydroelectric project. The study highlighted thermal effects, i.e., a decrease in daily thermal differences at the start of summer, a

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general warming in the middle of summer, and a lengthening of the warm season in autumn. A decade earlier, in Japan, Shirata (1969) found the same effects along the shores of Lake Inawashiro. In Canada, along the banks of the Canadian-American Great Lakes, earlier studies were synthesized by Eichenlaub (1979). The principal conclusions point to the fact that large water bodies increase the mean annual temperature, reduce daily and seasonal thermal variations, delay seasons by several weeks, amplify local winds, and decrease local precipitation while increasing evaporation. Lacking a dense network of meteorological stations, most of these studies were based on estimations and theoretical models (Therrien 1981; Mysak 1993; Gooseff et al. 2005; Stivari et al. 2005). Within this context, several authors have hypothesized that the creation of vast water bodies for hydroelectric projects can have an effect on local climate (Perrier et al. 1977; Sottile and Levesque 1989). Ecological indicators on the islands and edges of large lakes in northern Québec have led several authors to stipulate that these large water bodies, particularly when frozen, may create local climates colder and more humid than those above land. These local climates create an environmental risk of transforming the ecological conditions at the peripheries of the new water bodies, as well as on their islands. To what extent are these environments exposed to disturbances that did not exist before their flooding? The development of these reservoirs creates new conditions that may cause exacerbate the intensity of natural phenomena beyond certain thresholds thus resulting in a shift of the exposed shoreline environments from one ecological state to another.

To investigate the possibility of these “anthropogenically facilitated hazards”, we draw on the example of the climatic impacts resulting from the creation of large reservoirs in north eastern Canada. The creation of the La Grande hydroelectric complex in northern Québec inundated an area of 11,400 km^2, of which only 12% were previously wetlands or water bodies (Tamenasse 1980; SEBJ 1987; Fig. 1). In a study commissioned by Hydro-Québec, Météoglobe Canada (1992) estimated that the climatic effects of the reservoirs extended to a maximum of less than 25 km from their borders, a distance equivalent to the breeze created by the temperature contrast between the water body and adjacent land, that extends 1.5 times the radius of the basin according to Litynski et al. (1989). Météoglobe Canada expressed reservations about the validity of predictions of local climate effects based on models using temporally discontinuous and spatially sporadic data. We investigated the effects that the Robert-Bourassa Reservoir (also called LG-2) may have had on the forest environments of its periphery and the islands that were created by its flooding. We hypothesized that the reservoir would have a significant climatic influence on the forests, which would be observable using dendrochronological indicators. The Robert-Bourassa Reservoir (created in 1979–1980), with an area of 2,835 km^2 is the second largest reservoir in the La Grande complex after Caniapiscau (4,275 km^2). The time duration that the reservoir has been flooded (1979–1980) may be sufficient to observe how the change in climate is expressed within the regeneration, growth forms, and annual rings of new riparian trees.

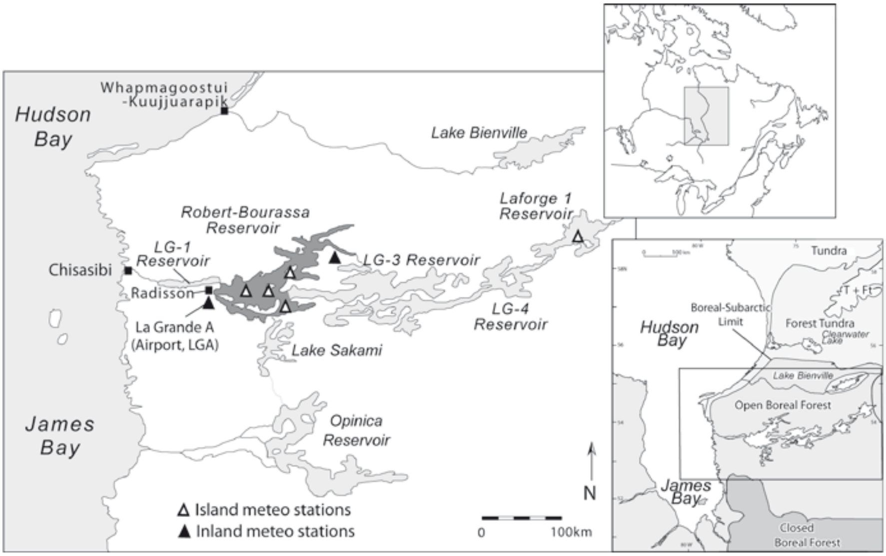

Fig. 1 Location of the Robert-Bourassa Reservoir within La Grande Rivière hydroelectric production zone in Northern Québec

2 Study Site

The drainage network of La Grande Rivière (La Grande) was, before the development of the hydroelectric complex, the fourth largest in Québec in terms of area (97,643 km^2). The Robert-Bourassa Reservoir is situated 117.5 km from the mouth of La Grande Rivière. It is the largest hydroelectric development in the world.

The study area is dominated by a cold continental climate. The influence of Hudson Bay and James Bay on the climate is very significant. During winter, the complete freezing of the bays and the gentle relief of the region allows colder conditions to develop. The mean minimum temperature in January is −23.2°C (Station LGA). In summer, warming is delayed by the presence of ice and cold currents from the peripheral seas. The mean maximum temperature for July is 13.4°C. The growing season for the region extends from mid-June to mid-September. The frost free period is very short (208 days) in the region. The annual precipitation is 679 mm, with 40% (271.6 mm) falling as snow. Snow precipitation at the start of winter is controlled by the duration of the freezing of James and Hudson Bays. The freezing of these interior seas begins towards the end of December or the beginning of January, resulting in a reduction in humidity and snow precipitation in the region. Despite the rigorous climate, winter is the sunny season of the year and the atmospheric conditions during this period are relatively stable. Snow is less abundant (~1.5 m) than in southern Québec (~2.5–3.5 m) and storms are also less frequent. Summer is short and autumn arrives early with frequent night frosts.

3 Methods

An assessment of the climate conditions over Robert-Bourassa Reservoir was made by the comparison of data collected simultaneously at four stations located on islands and at two other stations distant from the reservoir to the west and the east (Fig. 1). In order to determine the effects of temperature and wind on tree growth, a strategy was designed to sample trees on the reservoir's islands with site exposure being the principal factor considered. Results will be presented for the dominant species, namely black spruce (*Picea mariana*). Trees were selected from the shoreline forest edges of 16 islands; these are referred to as "exposed" trees and were sampled according to north, south, east, and west orientations (Fig. 2). At each island a minimum of 30 trees with diameters of less than 8 cm were sampled 30 cm from their base for a total of around 490 trees. The sampled trees were situated directly on the forest edge and thus had maximum exposure to lake effects. In addition, only trees that were isolated from neighboring trees were selected in order to avoid the influence of competition. Trees located at a distance from the forest edge were also selected and were considered as "sheltered" from the wind. These trees were sampled from band transects running perpendicular to the shore and are referred

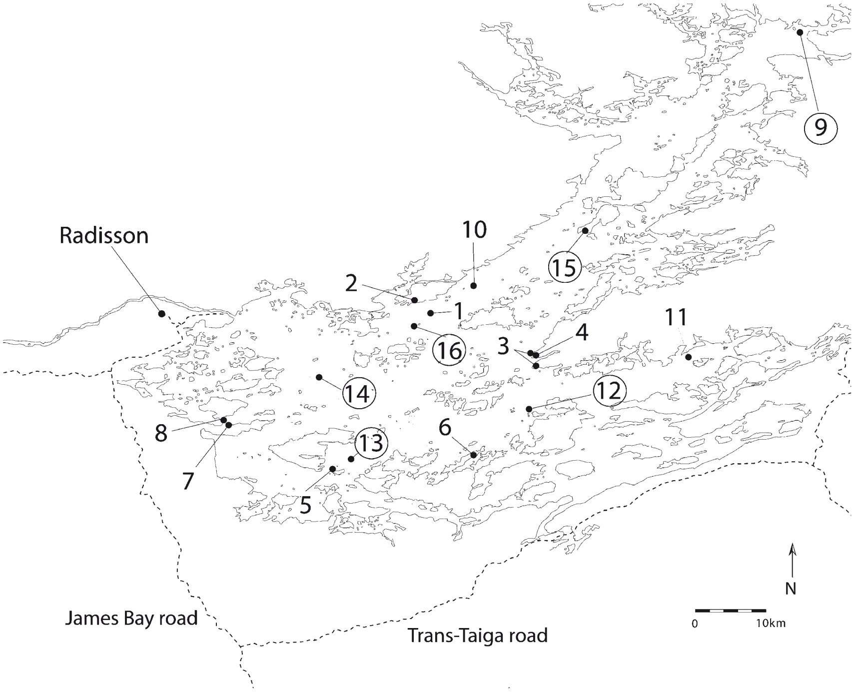

Fig. 2 Location of the sampling sites located on islands in the Robert-Bourassa Reservoir. *Circles* indicate islands where trees were sampled on hill tops for the analysis of reaction wood sequences

hereafter as north sheltered, east sheltered, etc. Only black spruce trees with a diameter of less than eight cm were sampled. Individual trees were sampled at 10 m intervals resulting in 29–31 trees per site. The maximum transect length was 300 m, with some being shorter in order to only sample sites that were homogenous in terms of topography, exposure, and forest structure and composition. In total, amongst over 900 trees sampled, 243 black spruce trees were retained for complete analysis. We systematically rejected trees that showed reaction wood sequences caused by wind destabilization. To assess the impacts of the changes in the eolian regime on the forest, we sampled mature trees situated in the open forests at the highest altitudinal points of six islands (around 15 trees per island for a total of 90 trees). These trees were the ones most exposed to the wind prior to the reservoir's creation and, by showing the development of reaction wood since its flooding, we suspected that their exposure to even stronger winds would have destabilized their original stature.

In the laboratory, in order to determine the effect of the reservoir's creation on black spruce growth, we identified and described abnormal rings (frost rings, incomplete rings, resin ducts, reaction wood), and measured the growth of annual rings using the methods of Schweingruber (1988). A densitometric analysis of a number of samples was also conducted using x-rays following the methods of Schweingruber et al. (1978). The density of earlywood, latewood, and the proportion of final wood were then analyzed for each annual ring. Finally, we investigated the effects of wind-blown snow on trees that showed intricate growth forms (Tremblay and Bégin 2005).

4 Results

4.1 *The Reservoir's Effects on the Temperature and Wind Regime*

The temperatures at reservoir locations differed than those outside its area of influence throughout all seasons, except winter. The mean temperature differed by 2.4°C in spring (April to June) and 0.8°C in summer. A reversal to warmer temperatures occurred in autumn, the reservoir being warmer than the hinterland (−1.5°C). No differences were observed in winter, the reservoir being covered by ice. The reservoir's continuous ice cover in winter possesses the same thermal properties as the surrounding lands. In light of these results, it is clear that the water body cools the local climate during spring and summer.

Growth degree days (GDD) were calculated as follows:

$$\sum_{i=1}^{n} (T_i \rangle 5) - 5 \tag{1}$$

where T was the mean daily temperature (°C) for each of the days of the year 'i' above 5°C and 'n' was the number of days. GDD were calculated using data from the stations for the year 1997, which serves as a reference, as it is considered an average year for the entire record. The calculation started on the 27th of June, as all stations were functioning at that time. Island stations showed a delay compared to hinterland ones, which suggests a cooling effect caused by the reservoir. For instance, the 300 GDD level was reached the 30th of July on a reservoir island, as compared to the 25th of July at La Grande airport situated inland (a delay of 5 days). This difference increased over the course of the season. The 700 GDD marker was attained on the 28th of September at reservoir stations in 1997, 19 days later than at inland stations (9th of September). The La Grande airport station possessed an advance of around 2 weeks up until mid-September when the effect of the reservoir seemed to reverse, i.e., its cooling effect was greatly reduced. GDD decreased along the distance to water edge (Sirois et al. 1999).

We also observed a delay in the first day of frost (i.e., the first day where the mean temperature is below 0°C). Freezing at insular stations occurred about 24 days later than the inland stations.

It seems clear that thermal effects are prevalent on the islands of the reservoir. However, these effects vary with seasons and the type of weather. Indeed, the average seasonal temperature differences between the two locations (island versus hinterland) was about 3°C in spring. This difference decreased as the year progressed (2°C in summer and null or inversed in autumn and winter). According to the isotherms of Québec (data available on Environnement Canada web site, www.ec.gc.ca), the conditions prevailing on the reservoir resemble those of Inukjuak, which is situated at the northern limit of the subarctic zone (530 km farther north). The start of the growing season is delayed under these conditions. In autumn, during windless conditions, the reservoir had a slight warming effect on the local climate, in contrast with spring and summer. However, the growing season, as indicated by the GDD, is not prolonged. In winter, the thermal climate of the region was homogenous and the continuous ice cover did influence the local thermal regime.

A summary analysis of wind data comparing both sectors of the water body indicated differences that can be attributed to the reservoir. There were notable differences in the eolian regimes of the islands compared to the land. A meteo station located in the largest open water part of the reservoir recorded winds that were double the speed of those at inland stations throughout all the seasons. The acceleration of winds within the central basin also allows edge effects to penetrate more deeply into the interior of the islands' forests. Coupled with thermal effects, these factors may cause a phenological delay that extends for a greater distance from the water in the central basin than elsewhere. In winter, eolian stress may also affect wider forest fringes regardless of orientation within the central basin.

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effects, these factors may cause a phenological delay that extends for a greater distance from the water in the central basin than elsewhere. In winter, eolian stress may also affect wider forest fringes regardless of orientation within the central basin. Depending on the configuration of the islands, snow blown by the wind may also accumulate at various distances into the forest.

4.2 Effects of the Reservoir on Tree Growth and Ring Density

A large number of the trees sampled showed growth decreases coinciding with the filling of the reservoir. Growth decreases were less than 5 years in duration and rarely irreversible. In most cases, the decrease in growth occurred a few years (1985–1986) after the transitional period of 1979–1980 when the reservoir was filled. This reaction may be attributable to the progressive deterioration (foliar loss) of the protective forest edge. Based on the orientation, the reaction of the trees appeared to be the most pronounced on the western and northern exposures, with very few reactions being observed on the south facing side of the islands. Trees with drastic and irreversible reductions in annual ring growth were rare with most of them being situated in the northern section of the central basin of the reservoir, although some were also found to the east. In summary, although undeniable effects were observed in many trees, variations in the widths of annual growth rings does not always appear to be an infallible indicator of the climatic influence of the reservoir. For example, summer 1992 was particularly cold in the Canadian subarctic, following the Pinatubo eruption. The reservoir did not exacerbate such cooling and the island trees did not show any difference in their response to climate.

Patterns of latewood characteristics for the trees situated on the islands and edges of the reservoir may be more indicative of local climate than annual tree-ring widths. Although densitometric analysis is tedious, it does provide valuable details concerning the formation of wood at the start of the growing season (earlywood) and at the end of the season (latewood). Indeed, the exposed trees displayed a net change in their densitometry profile. In general, exposure favors the development of less dense latewood (maximum density) and dense earlywood (minimum density). This reaction characterized the trees occupying the wind exposed edges of the forest islands. The densitometric profiles of sheltered trees were more variable and appeared to be dependent on the forested environments (Fig. 3).

Despite the absence of meteorological data characterizing the contrasts in the forested environments of exposed versus sheltered sites, the general trend of a decrease in ring density and an increase in the proportion of latewood suggests a delay in the growing season that involves an increase in the average density of the earlywood and a longer late growing period that allows for a greater development of latewood. The late ending of tree dormancy caused by the thermal effect of the frozen water body, along with the late autumn caused by the mitigating effects of the water body, favors the formation of a large proportion of latewood cells. The triggers for the formation of latewood in trees are still unknown. However, we do know that they appear after the foliation period.

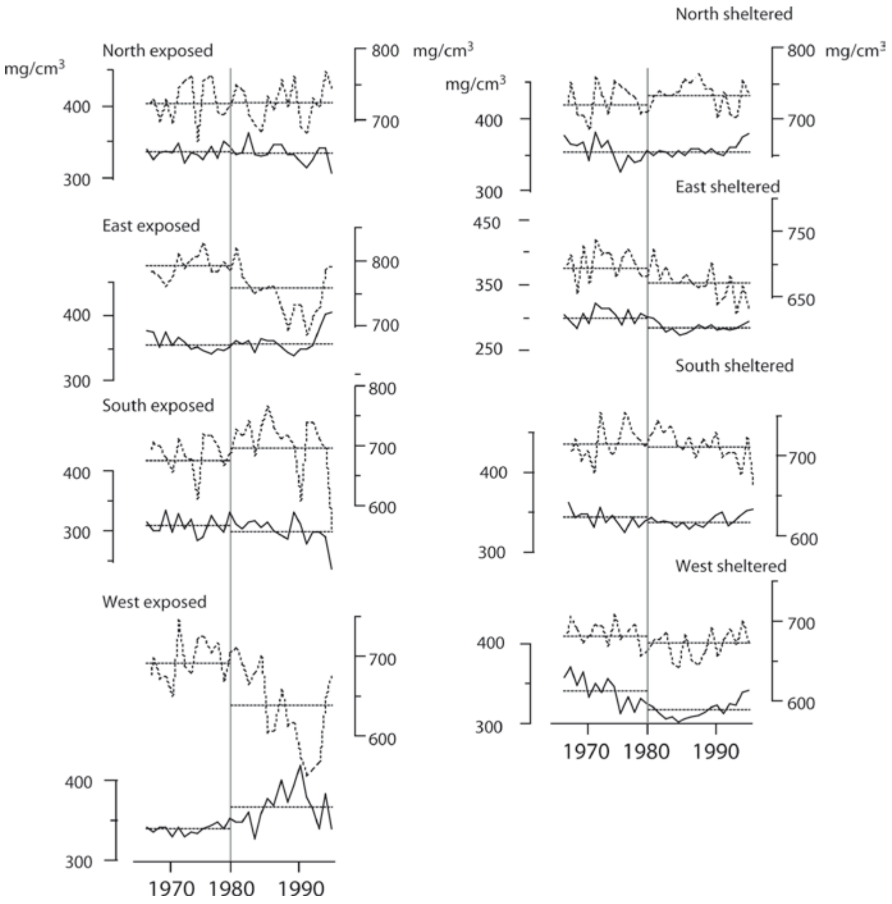

Fig. 3 Average minimum (*solid line*) and maximum (*dotted line*) densities of the tree-rings of spruce sampled on exposed and sheltered sites according to directional aspects on the 16 islands selected in the Robert-Bourassa Reservoir. Each line represents the average of about 30 trees. The vertical line refers to the year the reservoir was created

The large number of environmental factors compared to local climatic factors does not allow us to interpret the effects that the reservoir may have on different individual tree growth parameters. However, the edge effects observed around the lake shorelines and on the islands are clear. Indeed, the reduced foliar mass of the trees, their eroded growth forms, and physical damage were indicators of this influence. The study of climatic effects on the forest environment should therefore be refocused at the local scale. At the Robert-Bourassa Reservoir, the clearest border effects are related to the wind exposure of the forests and to the unequal distribution of snow cover. Similar to subarctic trees, the trees occupying the shores of the reservoir possess irregular growth forms that are indicators of hibernal erosion. This phenomenon is well documented in the literature, but its occurrence within the boreal zone is not typical. Indeed, the trees occupying the banks of large, natural lakes in the region possess symmetrical growth forms, while those of the reservoir possess numerous dead branches that lead to the development of eroded forms (Lavoie and Payette 1997). The regression of growth forms is associated with the loss of foliar mass that occurs due to winter wind events (removal of leaves and buds by wind-blown snow crystals). The effect is not solely a winter phenomenon. Indeed, the distance to water (or ice cover) delays the bud set period despite the occurrence of milder autumn conditions. Incomplete protection of buds and needles limit their survival and, as a result of harsh winters, reduces the potential for the reconstruction of the chlorophyll apparatus over the following summers. The large number of environmental factors compared to local climatic factors does not allow us to interpret the effects that the reservoir may have on different individual tree growth parameters. However, the edge effects observed around the lake shorelines and on the islands are clear. Indeed, the reduced foliar mass of the trees, their eroded growth forms, and physical damage were indicators of this influence. The study of climatic effects on the forest environment should therefore be refocused at the local scale. At the Robert-Bourassa reservoir, the clearest border effects are related to the wind exposure of the forests and to the unequal distribution of snow cover. Similar to subarctic trees, the trees occupying the shores of the reservoir possess irregular growth forms that are indicators of hibernal erosion. This phenomenon is well documented in the literature, but its occurrence within the boreal zone is not typical. Indeed, the trees occupying the banks of large, natural lakes in the region possess symmetrical growth forms, while those of the reservoir possess numerous dead branches that lead to the development of eroded forms (Lavoie and Payette 1997). The regression of growth forms is associated with the loss of foliar mass that occurs due to winter wind events (removal of leaves and buds by wind-blown snow crystals). The effect is not solely a winter phenomenon. Indeed, the distance to water (or ice cover) delays the bud set period despite the occurrence of milder autumn conditions. Incomplete protection of buds and needles limit their survival and, as a result of harsh winters, reduces the potential for the reconstruction of the chlorophyll apparatus over the following summers. This phenomenon also characterizes the shoreline trees of large natural water bodies in this region. The spruce trees that are located at the water's edge of these water bodies generally exhibit a krummholz growth form (Lavoie and Payette 1997). The trees that are located at the edge of the reservoir differ from the natural lake ones by having been established much earlier than the reservoir was created. Their degradation thus occurred after the flooding of the reservoir.

4.3 Frost Rings and the Phenological Delay of Tree Growth on the Islands

Frost rings (Glerum and Farrar 1966) form while wood cells are still living, i.e., around 40–50 days after their development. They are formed when air temperatures drop below 0°C for 1–5 days, which causes the contents of the cells to freeze and the consequent bursting of the cells. The broken cells are sometimes sealed by resin from the resin canals of the woody rays. The affected area in the ring is clearly visible at the macroscopic level (deformed wood cells). Frost rings may be simple (unique/singular) or double depending on the number of frost events that have affected a tree during the same growing season. They can also be continuous or discontinuous (only affecting part of the tree circumference). We observed a scarcity of frost rings after the reservoir creation. While they were frequent before 1980, they have subsequently become rare and less defined anatomically (Fig. 4). The sampled black spruce trees were all considered to be less than 50 years of age – the maximum cambial age after which frost rings cannot develop due to the protection provided by the development of thick bark. A delay in the ending of dormancy may also protect trees in the reservoir's environment from frost damage. The absence of frost rings after 1980 in the western sector is striking. This phenomenon could be related to the more pronounced cooling effects within the central basin of the reservoir.

Traumatic rings with a proliferation of resin canals have become more frequent along the reservoir islands since its flooding, even at some distance from shoreline. While the factors responsible for the development of these rings are not fully known, the most likely hypothesis is that they are a response to massive foliar loss. They are common in black spruce and their abundance is not dependent on tree age.

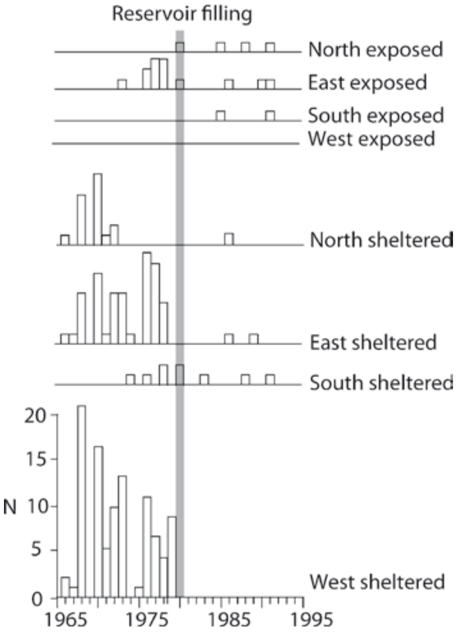

Fig. 4 Frost ring chronologies (number of frost rings amongst the sampled trees) on the islands of the Robert-Bourassa Reservoir. The *gray bar* indicates the year of flooding. The four *upper diagrams* indicate trees at the shoreline edge (exposed to the north, east, etc.); the *lower diagrams* correspond to trees sheltered from the wind (trees selected along a band transect towards the inner part of the island)

4.4 Trees Destabilized by the Wind

Although the trees occupied windy positions on the hilltops before the reservoir's flooding, their current situation on the islands that formed after flooding likely exposes them to greater winds. However, wind destabilized trees were found primarily on the shorelines and in open forests. At shoreline sites, we avoided sampling trees with leaning stems to avoid reaction wood, particularly for the densitometric analysis. Reaction wood is over-lignified wood that appears as a reaction to changes in mechanical tension that occur when a stem is destabilized (Scurfield 1973). Lignin gives wood an amber color and makes reaction wood readily identifiable. The majority of the trees showed the start of reaction wood sequences in 1980 (Fig. 5). This observation confirms that an increase in local wind force has occurred, as suggested by other work conducted on the edges of reservoirs (Arritt 1987). The presence of reaction wood and its orientation in the stems (it develops on the side where the tree is bent) are important indicators that allow wind events to be dated and delineated spatially.

4.5 The New Insular Nival Regime and Mechanical Damage to Pre-established Trees

By creating a barrier to the wind, forest edges capture powdered snow and contribute to the modification of local snow conditions. Indeed, one of the most important impacts of the reservoir was the creation of large ice surfaces over which the wind blows to create new distribution patterns of snow on the ground. Once the ice cover of the reservoir is consolidated in December, snow collected and blown by the wind

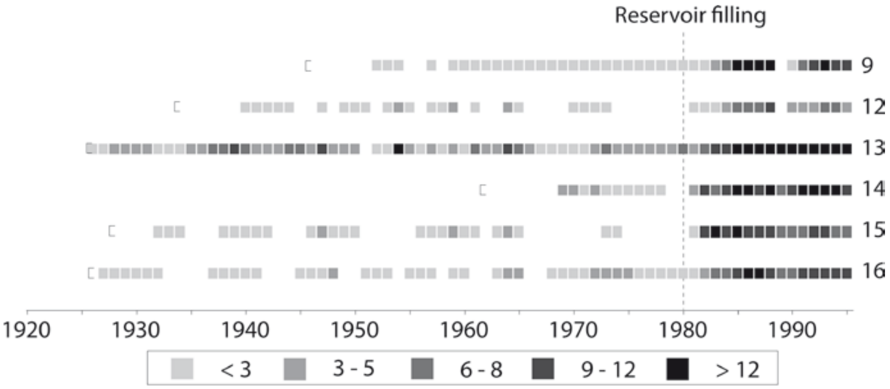

Fig. 5 Proportion of trees (in classes of three) located at the tops of islands and possessing reaction wood sequences due to destabilization by the wind before and after the reservoir's creation. Numbers on the right refer to sampling sites (Fig. 2)

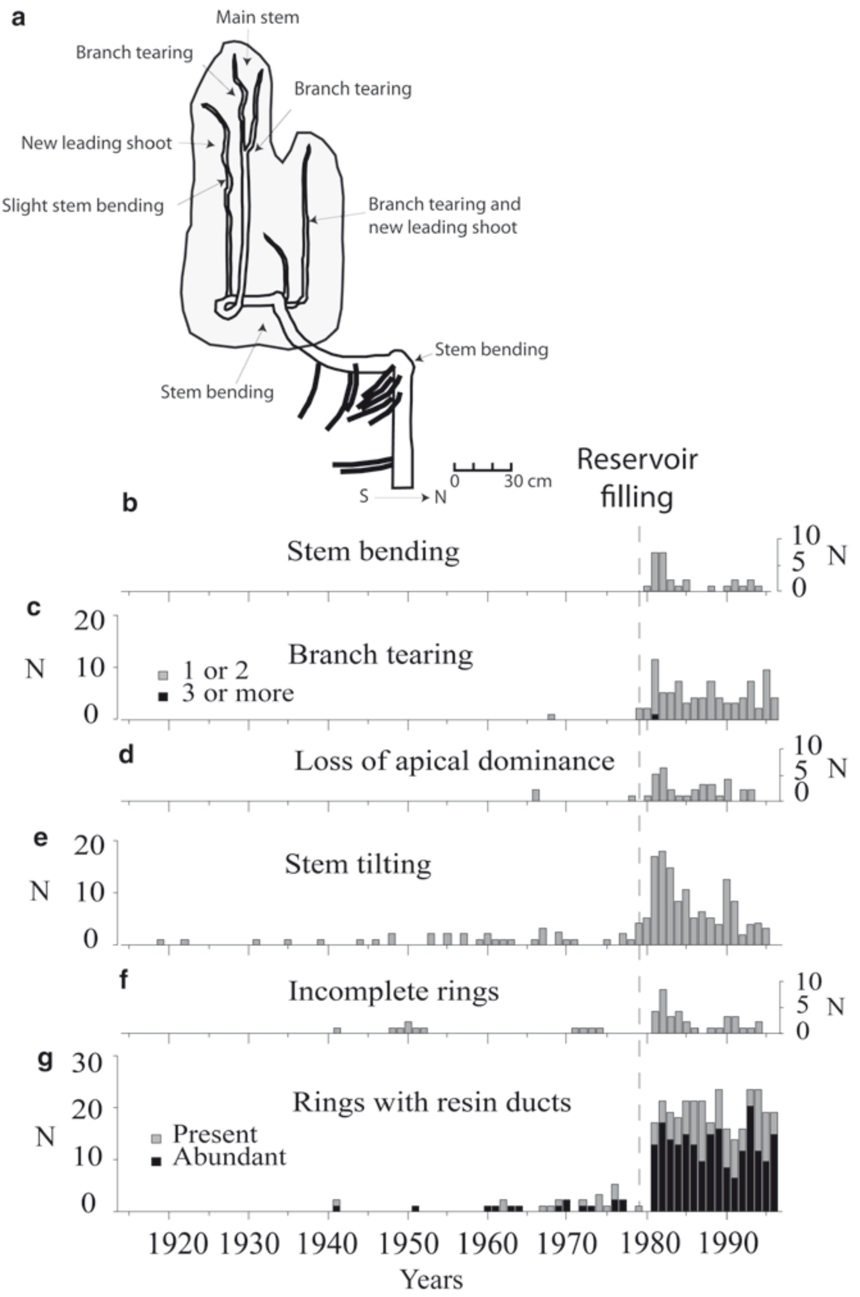

Fig. 6 (**a**) Schematic representation of a tree having experienced severe disturbances due to the over accumulation of snow on an island. (**b–g**) Frequency of damage to trees. The number of trees studied = 46. (**b**) Stem bending dated by the beginning of compression wood sequences and plowing scars. (**c**) Frequency of branch tearing scars. (**d**) Death of apical axis and development of a new leading stem. (**e**) Start of compression wood sequences (at least five consecutive rings) indicating stem tilting. (**f**) Incomplete rings. (**g**) Traumatic rings with alignments of resin ducts (Tremblay and Bégin 2005)

over large distance accumulates at the obstacles that are situated on the exposed southwestern banks. The islands, which were formerly hilltops that had little snow in winter due to winds, are now effective snow traps that collect up to 4 m of snow (in the past they only accumulated 1 m). The distribution pattern of snow depends on the orientation of the bank, the size and height of the island, and the forest structures present. The small islands have little effect on the wind as they are not obstacles. Their ability to accumulate snow is limited. Tall islands and those with large forest structures capture lots of snow. However, snow accumulation in the forests is highly dependent on the effectiveness of the barrier created by the foliage and branches of the first fringe of exposed trees. The progressive degradation of this fringe and/or the modification of its growth forms results in the accumulation of snow deeper and deeper within the forest to the point where damage caused by the over-accumulation of snow becomes common. This phenomenon has previously only been observed on large lakes within the subarctic zone (Boivin and Bégin 1997). Thus, it appears that the creation of the Robert-Bourassa Reservoir allows for the expression of phenomena that are generally found in the subarctic and not yet reported from lakes further south.

In order to determine the dendrochronological indicators regarding changes in the snow accumulation regime for an island in the Robert-Bourassa Reservoir, Tremblay and Bégin (2005) examined trees damaged by excessive snow. Changes in their growth forms recorded the history of damage that they experienced since the reservoir's flooding (Fig. 6a). The study revealed a gradual change in the local snow accumulation regime that corresponded with the degradation of the forest due to wind exposure. Beyond the riparian forest border that acts as an obstacle to the wind, snow accumulates towards the center of the island. Since the creation of the reservoir, trees in the shoreline forest have been subjected to various types of visible damage including stem bending, knocking over of stems, and tearing off of branches due to heavy snow loads (Fig. 6b–e). Damage to trees resulted in growth anomalies that spontaneously appeared within 3 years of the injury (Fig. 6f–g). Changes in tree growth patterns documented the degradation processes of the forest's margin. Abundant incomplete rings and traumatic rings with resin canals were found within the exposed trees at the periphery of the island, while trees situated in the interior possessed numerous scars that developed following mechanical damage related to excess snow. Damage abundance is related not only to the quantity of precipitation, but also to the reservoir's level in winter.

5 Discussion and Conclusions

The application of dendrochronology in this study relies on several fundamental principles. Firstly, although the reservoir has existed since 1980, it is possible that manifestations of the climatic effects may depend on certain events or a combination of conditions that have not yet occurred to leave obvious traces in the environment. However, the likelihood that stressful events have not occurred has been minimized by choosing the oldest reservoir in the La Grande complex. It has already been reported that visible manifestations of the influence of large subarctic lakes only occur on their immediate edges and on their islands. By analog, we have formulated the hypothesis that the effects of the reservoir on the forest will also be restricted to the reservoir's edges and islands. Knowledge of the regional dendroclimatic signal is required to test this hypothesis. Furthermore, the temporal dichotomy offered by the key year of 1980, corresponding to when the reservoir was flooded, allows for the calibration of the dendrochronological indicators representing the reservoir's microclimatic effects with data concerning previous growth conditions.

Secondly, variations in the growth of trees that are affected by the climatic effects of large water bodies only provide an indirect and minimal measure of this influence. Trees only react to stress once a threshold has been passed and the thresholds vary according to species, tree status within the stand, age, abundance of foliage, and state of health. It is possible that the climatic influence of a lake on its surrounding environments may only affect a few sensitive individuals or cause different reactions amongst individuals. The analysis of these reactions and a clear understanding of the biological and ecological characteristics of the tree species in question are therefore fundamental. Manifestations of climatic stress, as shown by abnormal tree growth forms, only allow minimal assessments of the affected riparian strip, beyond which timber productivity and reproductive efforts can be affected by distance from the water body and exposure to the dominant westerly winds.

Thirdly, tree growth is subject to numerous ecological factors that must be distinguished from the influence of climate. Although trees can record some punctual climatic stress events (frost events during the growth season), tree rings more typically provide a signal representing the cumulative events that describe the interannual trends of the region's climatic fluctuations. Through the careful selection of trees, according to their environmental conditions and physical characteristics, these factors can become a well-controlled variable in the analysis (Fritts 1976). Finally, the microclimatic effect of the reservoir may increase or decrease through the action of macro climatic events, which, under certain conditions, favor or limit the expression of the exposed trees' reactions. We propose a third hypothesis that the expression of climate is a result of the specific ambient conditions existing at strategic moments of a tree's life and according to temporal variations in its growth and the growth season. For example, at the edge of the reservoir, the duration of the ice cover would delay and slow growth, delay the development of reproductive structures, and lead to growth anomalies. Analyzing these growth characteristics would allow the effect of the local climate to be delimited for particular moments of the year.

The creation of large reservoirs is a good example of the type of major development projects that humans are capable of constructing. While we may not have the ability to control natural hazards, we do have the ability to exacerbate them. In the context of current climate change, of which we are a cause, these vast reservoirs constitute areas where mankind's footprint will last forever.

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