Recent expansion of jack pine in peatlands of southeastern Québec: A paleoecological study

Stéphanie PELLERIN\textsuperscript{2} & Claude LAVOIE, Centre de recherche en aménagement et développement, Université Laval, Québec, Québec G1K 7P4, Canada, e-mail: pelleris@yahoo.ca

Abstract: Jack pine (\textit{Pinus banksiana}) colonization and expansion in ombrotrophic peatlands of the Bas-Saint-Laurent region, southeastern Québec, was analyzed using macrofossil and dendrochronological analyses. During the last 80 years, and mainly between 1920 and 1945, several open peatlands dominated by \textit{Sphagnum} species were invaded by jack pine following a fire event. This phenomenon appears to have no precedent over the last 8,900 years, at least in one of the study sites. Fires triggered the expansion by eliminating the \textit{Sphagnum} mat and spreading thousands of pine seeds released by a few individuals. While fires contributed to the expansion of pines in bogs, this phenomenon may have been facilitated by a drier-than-average climatic period during the first part of the 20\textsuperscript{th} century. The fact that dense jack pine stands are now growing on thick organic deposits indicates that this species has a wider ecological tolerance than previously known and/or that the Bas-Saint-Laurent peatlands have recently undergone major ecological and hydrological changes favouring the growth of non-bog species.

Keywords: fire, jack pine, peatland, \textit{Pinus banksiana}, vegetation dynamics, Québec.

Résumé : Nous avons analysé les patrons de colonisation et d’expansion du Pin gris (\textit{Pinus banksiana}) dans les tourbières du Bas-Saint-Laurent (sud-est du Québec) à l’aide d’analyses macrofossiles et dendrochronologiques. Au cours des 80 dernières années, et principalement entre 1920 et 1945, plusieurs tourbières ouvertes dominées par les sphaignes ont été envahies par le Pin gris à la suite d’un feu. Il s’agirait d’un événement sans précédent au cours des 8900 dernières années, du moins dans l’un des sites à l’étude. Le feu a favorisé l’expansion du Pin gris en éliminant le tapis de sphaignes et en permettant la dissémination des graines de pin. Une période climatique plus sèche que la normale au début du XX\textsuperscript{e} siècle a pu faciliter le phénomène. La présence de peuplements denses de Pin gris sur dépôt organique épais indique que cette espèce peut coloniser un éventail plus large d’habitats ou encore que les tourbières du Bas-Saint-Laurent ont subi récemment d’importants changements écologiques et hydrologiques favorisant la croissance d’espèces que l’on ne trouve pas habituellement dans les tourbières.


Introduction

The distribution of jack pine (\textit{Pinus banksiana}) in Canada roughly corresponds to the area occupied by the fire-prone boreal forest (Rudolph & Laidly, 1990). Its range extends from Nova Scotia to Alberta, and north to the Mackenzie River valley in the Northwest Territories (Majcen, Gagnon & Benzie, 1980; Farrar, 1996). Jack pine is well adapted to postfire regeneration because its serotinous cones enclose a large number of seeds, which are released after intense fire events (Beaufait, 1960; Cayford, Chrosiewicz & Sims, 1967; Rowe & Scotter, 1973; Cayford & McRae, 1983). Fire eliminates competitors and prepares a suitable seedbed by burning the organic soil layer and exposing mineral soil (Critchfield, 1985; Thomas & Wein, 1985; Chrosiewicz, 1990). Jack pine is primarily found on podzolic soils (Cayford, Chrosiewicz & Sims, 1967). It grows best on well-drained loamy sands, but it is also found on very dry sandy or gravelly soils (Kenkel, 1986; Rudolph & Laidly, 1990). This tree species grows poorly on waterlogged organic soils (Janssen, 1967; Rudolph & Laidly, 1990). However, recent vegetation surveys conducted in the Bas-Saint-Laurent region, southeastern Québec (Figure 1), have shown that dense jack pine stands (60 to 100\% dominance) are widespread in ombrotrophic peatlands (Pellerin, Lachance & Lavoie, unpubl. data).

The presence of dense jack pine stands in ombrotrophic peatlands appears to be unusual, at least in Québec. Few botanists have mentioned its occurrence in such ecosystems (Lafond & Ladouceur, 1968; Gauthier & Grandtner, 1975; Lalier, 2000; Muller, 2001). Furthermore, neither paleoecological analyses conducted in the present range of the species in Québec (Garneau, 1987; Lavoie, Zimmermann & Pellerin, 2001; Muller, 2001) nor those conducted in its previous range (Larouche, 1979; Lavoie, Larouche & Richard, 1995; Lavoie & Richard, 2000a,b) have revealed a historical presence of jack pine stands in peatlands.

In this study, the historical pattern of jack pine colonization was analyzed in the peatlands of the Bas-Saint-Laurent region. Our objectives were to reconstruct the history of jack pine stands in peatlands and to determine which factors could have favoured their establishment and expansion. To achieve our objectives, we studied nine jack pine stands in six peatlands using plant macrofossil and dendrochronological analyses. We hypothesized that (i) the establishment of jack pine in the peatlands of the
Bas-Saint-Laurent region is a recent phenomenon (less than 100 years); (ii) fire accelerated the jack pine invasion process; and (iii) peat drainage induced by human activities facilitated the establishment and survival of jack pine.

**Methods**

**Study area**

The study area is a narrow (12 km), low-elevation (<170 m) strip of sand, silt, and clay surficial marine deposits (Fulton, 1995) located between the settlements of Rivière-du-Loup and L’Isle-Verte in the Bas-Saint-Laurent region, southeastern Québec, Canada (Figure 1a). It is an agricultural plain (245 km²) bordered on the northwest by the St. Lawrence River and on the southeast by the Rivière Verte. The region was deglaciated about 12,000 years BP, but was then submerged by the Goldthwait Sea (Dionne, 1977). The vegetation cover was established about 9,500 years BP, shortly after marine regression, and the modern vegetation developed after 8,000 years BP (Richard, Larouche & Lortie, 1992). On mesic and xeric sites, modern vegetation is characterized by sugar maple (Acer saccharum), yellow birch (Betula alleghaniensis), and balsam fir (Abies balsamea) forests (Grondin, 1996). Jack pine typically occurs as isolated clumps on open rocky sites (Blouin, 1970; Garneau, 1984). Large ombrotrophic peatlands are common in wet depressions and are dominated by black spruce (Picea mariana), ericaceous shrubs, and Sphagnum species (Gauthier & Grandtner, 1975).

The original forest cover of the study area was almost completely cleared during the 19th century. Until recently, peatlands were one of the last ecosystems undisturbed by human activities (Fortin, 1993). Nevertheless, between 1930 and 2000, 62% of the total area covered by bogs (4,829 ha) was reclaimed (Pellerin, unpubl. data). Peat extraction for horticultural use (84% of the disturbed area), logging (9%), and farming (4%) were the main anthropogenic activities in these peatlands.

The regional climate is wet and continental. Data from the meteorological station of Saint-Arsène, located in the study area, indicate that the mean annual temperature is 3°C. January is the coldest month (mean temperature: -12°C) and July, the warmest month (mean temperature: 18°C). The mean annual precipitation is 924 mm, 27% of which falls as snow (Environnement Canada, 1993).

**Field sampling**

To locate jack pine stands, we surveyed tree populations of all bogs (n=22) of the study area (Figure 1a). The most recent (1995) aerial photograph (1:15,000) covering each peatland was digitized, registered in space, and corrected to limit geometrical distortions using Geographic Transformer™ software (Blue Marble Geographics, Gardiner, Maine, U.S.A.). Corrected photographs were integrated in the geographic information system MapInfo Professional™ (MapInfo Corporation, Troy, New York, U.S.A.). The area of each peatland was delineated, and a grid of sampling stations located 50 m apart was then superimposed on the peatland polygon. The latitude and longitude of each sampling station were obtained with the geographic information system. Stations were located in the field during the summer of 1999 using a global positioning system. For each station, we visually described the vegetation (dominant tree species, vegetation structure, tree density) and noted whether there was any evidence of woodcutting or fire scars on the trees. For the large Rivière-du-Loup peatland (3,375 ha), we used a detailed vegetation cover map (Gauthier, 1967) to locate jack pine stands.

We identified twelve large jack pine stands within nine peatlands. Three stands were rejected for sampling because they were too severely damaged by forestry practices. Therefore, we sampled nine stands located within six different peatlands (Table I and Figure 1b). The total area of individual peatlands ranged from 23 to 3,375 ha, but their undisturbed areas were much smaller, ranging from 1 to 1,250 ha (Figure 1b). Le Parc bog (PARC) was mined for the production of horticultural peat between 1962 and 1967, and Cacouna bog (CACO) from 1942 to 1975 and from 1983 to 1989, while the Rivière-du-Loup (RDL) and Saint-Arsène East (SAE) sites have been mined since 1939 and 1959, respectively (Lavoie & Saint-Louis, 1999). However, in the Rivière-du-Loup bog, only a small area located south of the RDL3 stand was mined before 1960. The mining activities near the three other stands began between 1961 and 1963 (Desaulniers, 2000). Logging was the main activity damaging Plourde (PLOU)
and Saint-Arsène West (SAW) bogs between 1932 and 1948 and between 1970 and 1986, respectively.

A 400-m² quadrat was delineated inside each jack pine stand (Le Parc bog was sampled in two different locations). We visually described the vegetation cover (tree species, presence of dead trees), counted all living jack pine individuals located inside the quadrat, and measured their diameter at breast height (DBH). We cored a maximum of 50 stems (randomly chosen) as close as possible to their collar using an increment borer. DBH values were used to calculate the basal area occupied by jack pine.

At each sampling station, peat thickness was estimated using an iron rod driven into the soil every 10 m along three transects (20 m long, 10 m apart). A peat monolith (15 cm × 15 cm wide, 20 cm to 35 cm deep) was extracted at the centre of each quadrat in order to reconstruct the recent history of jack pine stands using plant macrofossil analyses. In addition, to obtain a longer historical perspective on the presence of jack pine in peatlands, a peat core (394 cm long) was extracted from Le Parc bog (near PARC1 sampling station) using a side-wall peat corer (Jowsey, 1966). Le Parc bog was selected because it supports the largest jack pine stand and has the thickest peat deposit.

**Dendrochronological analyses**

Tree cores were dried and finely sanded, and the tree rings were counted under a low-power (50x) binocular microscope. On the cores without pith, we estimated the distance separating the innermost ring to the pith by fitting a circular template on the innermost ring and determining the diameter of the circle that best fitted the curvature of that ring (Conkey, Keifer & Lloyd, 1995). We then estimated the number of missing rings using an age-diameter relationship established with cores having pith. Only cores with the pith present or with fewer than five estimated missing rings were used to construct the age structure of each stand.

**Plant macrofossil analyses**

Surface peat monoliths were subsampled (100 cm³) at the 0-2 cm, 2-4 cm, 4-6 cm, and 6-10 cm levels (depths below the soil surface) and subsequently by contiguous 5-cm-thick slices along the peat section. Macrofossil analyses of the Le Parc peat core were conducted on 2-cm segments for the upper 20-cm section and then on 2.5-cm segments along the core. Subsamples were washed through a series of sieves (2-mm, 1-mm, and 0.5-mm meshes), and the remaining fractions were air-dried to prevent fungal contamination (Wohlfarth et al., 1998). Macroscopic remains (vascular plant, moss, and charcoal pieces) were sorted under a low-power (50x) binocular microscope. When macrofossil remains of a particular taxon were too numerous to be easily counted (n > 200), 0.5 g of the subsample was extracted. Fossil pieces were then counted, and the total number of pieces was estimated from the total weight of the subsample (Lavoie & Payette, 1995). Accelerator mass spectrometry dating was carried out on plant material extracted from subsamples 240-242.5 cm (fen-bog transition) and 390-394 cm (basal peat sample) of the Le Parc peat core.

**Recent fire and climate history**

No fire scar was found; recent fire events were detected by charcoal layers located less than 10 cm below the soil surface. Interviews were conducted with the owners of each site to estimate the year of the most recent fire event. In order to detect whether the climate could have had an influence on jack pine establishment in bogs, we carefully examined the climatic data available (1913-1995) from the La Pocatière meteorological station, located 60 km southwest of the Rivière-du-Loup bog (Environnement Canada, unpubl. data). Data from Saint-Arsène station were not used because the record was much shorter and incomplete. Only annual precipitation data are presented in this analysis.

**Results**

**Characteristics of jack pine stands**

The basal area and the density of jack pine stems varied greatly among the stands (Table I). The basal area ranged from 7.5 to 75.1 m² ha⁻¹ and the pine density from 1,125 to 3,275 stems ha⁻¹. No jack pine seedling or sapling (a tree smaller than 1.3 m) was found. The mean thickness of the peat deposit differed largely between sites (101-378 cm).

**Age structure of jack pine stands**

All pine stands were less than 80 years old. At Rivière-du-Loup bog, the first jack pines established between 1921 and 1944 (Figure 2). At RDL3, more than 80% of individuals appeared between 1945 and 1949. At...
PLANT MACROFOSSIL ANALYSES

Plant macrofossil analyses showed that a similar pattern of vegetation change recently occurred at each study site (Figure 3). Black spruce and especially jack pine macrofossils are much more abundant above than below the most recent charcoal layer: 98.6% of pine macrofossils were recovered above the charcoal layer. At RDL2, RDL3, RDL4, and SAW we found charred needles of jack pine in the most recent charcoal layer, indicating that there was at least one jack pine at those sites when fire events occurred. The sites hold few or no *Sphagnum* remains above the most recent charcoal layer. The decrease of *Sphagnum* macrofossils was not detected at PARC1 because the organic material was too decomposed to allow *Sphagnum* stems to be counted. The forest mosses *Pleurozium schreberi* (RDL2, RDL4, PLOU, PARC1, PARC2, SAW), *Ptilium crista-castrensis* (SAW) and *Rhytidiodelphus trigetus* (RDL1) were more abundant above than below the most recent charcoal layer. An increase in the number of macrofossils of ericaceous shrub species (*Kalmia angustifolia, Ledum groenlandicum, Rhododendron canadense, Vaccinium angustifolium*) was also found in the postfire environment at most sites. Leatherleaf (*Chamaedaphne calyculata*), a shade-intolerant species (Marie-Victorin, 1995), disappeared in the upper layers of the peat deposits at RDL1, RDL3, PLOU, SAE, and SAW. Interviews indicated that at PLOU and SAW peatlands, the most recent fire occurred around 1930 and 1940, respectively. The cause of the fires was unknown for all but one of the study sites: at SAW it was accidentally ignited by humans.

Peat accumulation at Le Parc bog initiated ca 8,890 years BP (Figure 4). Changes in the species composition in the peat profile indicate two main developmental stages. During Stage I, local conditions were minerotrophic, and the peat was mainly composed of remains of Cyperaceae, tamarack (*Larix laricina*), and *Drepanocladus aduncus*. At least three fire events occurred during this stage. The transition between Stage I and Stage II (6,610 years BP) is characterized by an increase of *Sphagnum* remains and a decrease of Cyperaceae and tamarack macrofossils. Local conditions became ombrotrophic. Stage II was subdivided into three substages: Substage IIa, dominated by black spruce and *Sphagnum* remains; Substage IIb, characterized by the scarcity of black spruce remains; and Substage IIc, characterized by a major increase of jack pine, black spruce, and *Pleurozium schreberi* remains, just above the most recent charcoal layer. Although occasionally present in some subsamples of macrofossil substages I, IIa, and IIb, jack pine remains were very rare below the most recent charcoal layer.

CLIMATE HISTORY

While the climate of the La Pocatière area during the last 80 years was characterized by dry and wet periods, no long-term trends in the precipitation record were noticeable (Figure 5). Drier-than-average climatic periods were recorded from 1913 to 1935, in the 1960s, and in the 1980s. Wetter periods occurred around 1940, at the beginning of the 1950s, and during the 1970s. The establishment of jack pine at RDL1, RDL2, PLOU, and SAE occurred during drier climatic periods (1913-1935 and 1960-1970), while at RDL3, RDL4, PARC1, PARC2, SAW, and CACO, the establishment coincided with a wetter climatic period (beginning of 1940s).
Figure 3. Macrofossil diagrams (selected taxa) from jack pine stands in bogs of the Bas-Saint-Laurent region, southeastern Québec. Angl, Andromeda glaucophylla; Kaan, Kalmia angustifolia; Kapo, Kalmia polifolia; Legr, Ledum groenlandicum; Vaan, Vaccinium angustifolium. Macrofossil pieces: linear scale, except for Sphagnum (logarithmic scale); *, one piece only. Arrow and dotted line indicate the beginning of the massive establishment of jack pine during the 20th century. See Figure 2 for site name’s code.
FIGURE 3. Continued.
Discussion

JACK PINE STAND CHARACTERISTICS AND ESTABLISHMENT

Compared to other jack pine populations located in the southern (Conkey, Keifer & Lloyd, 1995), central (Béland & Bergeron, 1993), and northern (Desponts & Payette, 1992) part of the species range in eastern North America, the jack pine stands of the Bas-Saint-Laurent peatlands are rather dense with a high basal area. The establishment of large jack pine stands in ombrotrophic peatlands of the Bas-Saint-Laurent region is a recent phenomenon, initiated during the 20th century. Macrofossil and dendrochronological analyses showed that during the last 80 years, and mainly between 1920 and 1945, open peatlands dominated by Sphagnum species were invaded by jack pine following the most recent fire event. A close examination of aerial photographs taken in 1929 supports this interpretation, since no evidence of a dense forest cover was detectable at the location of sampling stations. The presence of a dense jack pine stand appears to be a unique event in the ca 8,900-year history of the Le Parc bog. However, the presence of charred pine needles in several peat sections indicates that some jack pine individuals were growing in the peatlands when these fires occurred, suggesting that the present-day population originated from seeds released by a few individuals.

CAUSES OF THE RECENT JACK PINE EXPANSION

FIRE

Our macrofossil data indicate that jack pine invaded the bogs following the most recent fire that burned these ecosystems. Several studies have shown that fire has usually few long-term impacts on the vegetation and habitat structure of ombrotrophic peatlands (Damman, 1977; Jasieniuk & Johnson, 1982; Foster & Glaser, 1986; Kuhry, 1994; Lavoie, Zimmermann & Pellerin, 2001). In Canada, the most important change reported in a bog after a fire event is a slight increase in the cover of some mosses (e.g., Polytrichum strictum) and ericaceous shrubs (Jasieniuk & Johnson, 1982; Foster & Glaser, 1986;
Kuhry, 1994). Although fires are not essential to maintain a treeless environment in ombrotrophic peatlands (Klinger, 1996), fires in bogs kill trees, which results in a higher water table favouring the growth of *Sphagnum* mosses (Damman, 1977; Chambers, 1997). Tree seedlings established in a *Sphagnum*-dominated environment have little chance of surviving because they are rapidly overgrown by *Sphagnum* mosses (Gauthier, 1980; Ohlson & Zackrisson, 1992; Gunnarsson & Rydin, 1998, Ohlson et al., 2001). Although fires have certainly accelerated the afforestation process in the Bas-Saint-Laurent peatlands by facilitating the spread of jack pine seeds and preparing a seedbed favourable for seed germination and seedling establishment, it is unlikely that fire alone can explain the recent jack pine expansion. For instance, in the Le Parc bog several fires were recorded during its 8,900-year history, but none, except the most recent one, was followed by a massive establishment of jack pine.

**DRAINAGE**

In Europe and North America, the recent afforestation of peatlands is often associated with human activities (Jacobson, Almquist-Jacobson & Winne, 1991; Bunting et al., 1998; Frankl & Schmeidl, 2000; Freléchoux et al., 2000). For example, Freléchoux et al. (2000) linked the recent development of pinewoods in bogs of the Jura Mountains (Switzerland) to drainage associated with the peat-cutting industry. Drainage lowers the water table, which improves the aeration of the upper peat layers and increases soil temperature and nutrient availability (Hillman, 1992; Pakarinen, 1994; Silins & Rothwell, 1999). Those changes in edaphic conditions facilitate the survival and the growth of trees in peatlands (Lees, 1972; Lieffers & Rothwell, 1986; Macdonald & Yin, 1999).

Are the Bas-Saint-Laurent peatlands affected by drainage resulting from human activities? There is little doubt that their hydrology has been altered (Van Seters & Price, 2001), since most bogs are either mined or crossed by drainage ditches. However, peat mining activities, which are responsible for the development of drainage ditch networks in most of the bogs studied, started after the beginning of the pine invasion at RDL1, RDL2, RDL4, PARC1, and PARC2. At CACO, the establishment of the pine stand occurred at approximately the same time as the beginning of mining activities, but the drainage ditches present at that time were located far from the stand studied in this paper. Furthermore, the SAW and PLOU sites have never been mined. In 1929 and 1948 (years corresponding to the oldest aerial photographs in the study area), all study sites were located 70 to 500 m from the closest drainage ditch. Since most of the drying effect associated with a drainage ditch occurs within 25 m (Hillman, 1992; Rothwell, Silins & Hillman, 1996; Prévost, Belleau & Plamondon, 1997; Silins & Rothwell, 1999), drainage ditches should have had only a minor impact on the hydrology of the study sites when jack pine established (before 1945 at all sites, except SAE).

**CLIMATE**

In Europe, Scots pine (*Pinus sylvestris*) colonization in peatlands during the Holocene epoch was ascribed to warmer and/or drier climatic periods (Birks, 1975; Pears, 1975; Bridge, Haggart & Lowe, 1990; Gear & Huntley, 1991; Pilcher et al., 1995). Dry climatic conditions lowered the water table and enabled pine seedlings to colonize peat surfaces. Pine colonization usually stopped after bog-surface moisture increased (Chambers, 1997).

The relationship between pine colonization and climate is unclear in the Bas-Saint-Laurent region. Some stands established during drier periods, while others established during wetter periods. However, it should be noted that eight of the nine pine stands established before 1945, thus during or just after a long climatic period (from ca 1913 to 1935) with precipitation lower than average. Furthermore, tree ring counts at ground level usually underestimate the year of establishment of the tree stands due to missing or partially formed growth rings, and because the real tree collars are often buried in the peat or misidentified (DesRochers & Gagnon, 1997; Parent, Morin & Messier, 2000). Consequently, it is likely that the establishment of the five pine stands estimated to have occurred between 1940 and 1944 actually occurred earlier, i.e., during the 1913-1935 climatic period. Additional sampling of 254 trees at Le Parc bog (Lavoie, unpubl. data) revealed that some jack pines are older (1925-1940: cored at breast height) than those sampled in PARC1 and PARC2 quadrats, supporting this assertion.
Although we have no historical data on the hydrology of the Bas-Saint-Laurent peatlands, it is possible that a long-term water input deficit (1913-1935) may have dried the peat surface, thereby simultaneously impeding postfire re-establishment of a thick Sphagnum mat and favouring the survival of pine seedlings. While precipitation was only slightly lower than average during most of the 1913-1935 period, even a slight (a few centimetres) lowering of the water table can promote pine colonization in bogs (Frankl & Schmeidl, 2000; Frélouchoux et al., 2000). A very dry climatic period would be detrimental to pine survival and growth, because trees growing on organic soils have root systems that are mainly confined to the unsaturated surface peat layers (Lieffers & Rothwell, 1987). A major lowering of the water table exposes trees, especially seedlings, to water stress (Dang & Lieffers, 1989; Malmer, Svensson & Wallén, 1994; Gunnarsson & Rydin, 1998) and negates any benefits generated by low ground-water levels (Pepin, Plamondon & Britel, 2002).

Conclusion

The jack pine expansion in the ombrotrophic peatlands of the Bas-Saint-Laurent region is a recent phenomenon (<100 years), possibly unique in the last 8,900 years. Fires triggered the expansion by eliminating the Sphagnum mat and spreading thousands of pine seeds released by a few individuals. During the last two centuries, fire probably occurred more frequently in the Bas-Saint-Laurent peatlands than during the remainder of the Holocene epoch. Pollen and macrofossil analyses of 17 peatlands located in the study area indicate that at least one fire has occurred at thirteen sites since the beginning of European settlement (ca 1800), seven of which occurred after 1900. Fires ignited by humans have burned three Bas-Saint-Laurent bogs since 1992 (Pellerin, unpubl. data). Yet, frequent fires appear to be unusual, since fire intervals calculated for the Bas-Saint-Laurent peatlands range from 760 to 2,500 years. Fires triggered the expansion by eliminating the Sphagnum mat and favouring the survival of pine seedlings. Whereas other similar climatic periods may have occurred in the Bas-Saint-Laurent region during the Holocene, the rarity of fires would have prevented the establishment of pines. Furthermore, drainage induced by human activities during the last decades has probably further facilitated the growth of pines already established.

The fact that dense jack pine stands are now growing on thick organic deposits indicates that this species has a wider ecological tolerance than previously known and/or that the Bas-Saint-Laurent peatlands have undergone major ecological and hydrological changes favouring the growth of non-bog species. Whatever the causes of the recent expansion of jack pine in the Bas-Saint-Laurent peatlands, this phenomenon is expected to cause profound changes in bog ecosystems, such as altering hydrological conditions and increasing the above-ground accumulation of litter (Ohlson et al., 2001).

Acknowledgements

This research was financially supported (grants to C. Lavoie) by the Natural Sciences and Engineering Research Council of Canada (NSERC). The Fonds pour la Formation de chercheurs et l’aide à la recherche du Québec (FCAR) and NSERC provided doctoral fellowships to S. Pellerin. We are grateful to Premier Horticulture for allowing us to work in Rivièrev-Du-Loup and Saint-Arsène peatlands. We thank M. Garneau and C. Roy for their help with macrofossil and moss identification, J. Bussières, N. Hamel, C. Huot, D. Lachance, K. Marcoux, A. Saint-Louis, and C. Zimmermann for field and laboratory assistance and D. Arseneault, R. Anderson, C. Carcailliet, M. Lavoie, L. Sirois, and an anonymous reviewer for comments on an earlier draft.

Literature cited


Damman, A. W. H., 1977. Geographical changes in the vegeta-
tion pattern of raised bogs in the Bay of Fundy region of

Dang, Q. L. & V. J. Lieffers, 1989. Climate and annual ring

Desaulniers, A.-S., 2000. La fragmentation des tourbières: son
impact sur l’évolution des communautés végétales. M.
ATDR thesis, Université Laval, Québec, Québec.

Desponts, M. & S. Payette, 1992. Recent dynamics of jack pine
at its northern distribution limit in northern Québec.
Canadian Journal of Botany, 70: 1157-1167.

level a good estimation of black spruce age? Canadian

Dionne, J.-C., 1977. La mer de Goldthwait au Québec.
Géographie physique et Quaternaire, 31: 61-80.

Service de l'environnement atmosphérique, Environnement
Canada, Ottawa, Ontario.

canadien des forêts, Saint-Laurent, Québec.

Pages 349-384 in J.-C. Fortin & A. Lechasseur (ed.).
Histoire du Bas-Saint-Laurent. Institut québécois de
recherche sur la culture, Québec, Québec.

Foster, D. R. & P. H. Glaser, 1986. The raised bogs of south-
estern Labrador, Canada: Classification, distribution, vege-

Frankl, R. & H. Schmeidl, 2000. Vegetation change in a south
German raised bog: Ecosystem engineering by plant species,
vegetation switch or ecosystem level feedback mechanisms?

Freléchoux, F., A. Buttler, F. H. Schweingruber & J.-M.
Gobat, 2000. Stand structure, invasion, and growth dynamics
of bog pine (Pinus uncinata var. rotundata) in relation to
peat cutting and drainage in the Jura Mountains, Switzerland.
Canadian Journal of Forest Research, 30: 1114-1126.

Survey of Canada. Map 1880A. Geological Survey of
Canada, Ottawa, Ontario.

Garneau, M., 1984. Cartographie et phyto-écologie du territoire
côtier Cacouna – Île-Verte. M.Sc. thesis, Université Laval,
Québec, Québec.

Garneau, M., 1987. Reconstitution paléoécologique d’une tour-
bière liitorale de l’estuaire du Saint-Laurent: analyse macro-
fossile et sporopollinique. Géographie physique et Quaternaire,
41: 109-125.

Gauthier, R., 1967. Étude écologique de cinq tourbières du Bas-

Gauthier, R., 1980. Les sphaignes et la végétation des tour-
bières du parc des Laurentides, Québec. Ph.D. thesis,
Université Laval, Québec, Québec.

Gauthier, R. & M. M. Grandtner, 1975. Étude phytosoci-
ologique des tourbières du Bas-Saint-Laurent, Québec.


Pages 183-196 in J. A. Bérard & M. Côté (ed.). Manuel de
foresterie. Presses de l’Université Laval & Ordre des ingénieurs
forestiers du Québec, Québec.

Gunnarsson, U. & H. Rydin, 1998. Demography and recruit-
ment of Scots pine on raised bogs in eastern Sweden and
relationships to microhabitat differentiation. Wetlands, 18:
133-141.

Hillman, G. R., 1992. Some hydrological effects of peatland
drainage in Alberta’s boreal forest. Canadian Journal of Forest Research, 22: 1588-1596.

Jacobson, G. L., Jr., H. Almquist-Jacobson & J. C. Winne,
1991. Conservation of rare plant habitat: Insights from the
recent history of vegetation and fire at Crystal Fen, northern

Janssen, C. R., 1967. A floristic study of forests and bog vege-

organization and dynamics in the western subarctic,
Northwest Territories, Canada. Canadian Journal of Botany,
60: 2581-2593.

Phytologist, 65: 245-248.

Kartesz, J. T., 1994. A synonymized checklist of the vascular
flora of the United States, Canada, and Greenland. 2nd edi-

Kenkel, N. C., 1986. Structure and dynamics of jack pine
stands near Elk Lake, Ontario: A multivariate approach.
Canadian Journal of Botany, 64: 486-497.

Klinger, L. F., 1996. The myth of the classic hydrosere model

Kuhry, P., 1994. The role of fire in the development of
Sphagnum-dominated peatlands in western boreal Canada.

physiographiques de l’Abitibi. Service de la recherche forestière,
Ministère des Terres et des Forêts, Québec.

conifères en Jämésie, Québec nordique. M.Sc. thesis,
Université Laval, Québec, Québec.

Larouche, A., 1979. Histoire paléoglacière comparée de la végé-
tation à Sainte-Foy et au mont des Éboulements, Québec,
par l’analyse macrofossile et l’analyse pollinique. M.Sc. thesis,
Université Laval, Québec, Québec.

Lavoie, C. & S. Payette, 1995. Analyse macrofossile d’une
palse subarctique (Québec nordique). Canadian Journal of
Botany, 73: 527-537.

Lavoie, C. & A. Saint-Louis, 1999. The spread of gray birch
(Betula populifolia) in eastern Québec: Landscape and histori-

restoration in southern Québec (Canada): A paleoecological
perspective. Écoscience, 8: 247-258.

Conditions du développement de la tourbière de Farnham,
Québec. Géographie physique et Quaternaire, 49: 305-316.

Lavoie, M. & P. J. H. Richard, 2000a. The role of climate on
the developmental history of Frontenac Peatland, southern

tourbière du lac Malbaie, dans le massif des Laurentides
(Québec): évaluation du rôle du climat sur l’accumulation de

Lees, J. C., 1972. Soil aeration and Sittka spruce seedling

Lieffers, V. J. & R. L. Rothwell, 1986. Effects of depth of
water table and substrate temperature on root and top growth
of Picea mariana and Larix laricina seedlings. Canadian


Recent expansion of jack pine in peatland of southeastern Québec: A paleoecological study

Published in volume 10 (2), 2003