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Peatland restoration in southern Québec (Canada): A paleoecological perspective[1]

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Abstract: We used macrofossil analyses to reconstruct the long-term development of plant assemblages and the history of fire events in a bog in southern Québec which was partly disturbed by peat mining activities and recently restored. Our main objectives were to (*i*) determine to what extent the present-day plant assemblage of an unmined sector of the bog resembles the plant assemblages that have been reconstructed for different periods of the ecosystem's development, (*ii*) establish the frequency of fire events and their impacts on plant assemblages, and (*iii*) interpret the results from the restoration experiment by considering the natural development of the peatland over recent millennia. Throughout the ombrotrophic stage of the peatland's development, plant assemblages have been stable and do not seem to differ strongly from those observed today in the unmined sector of the bog. Consequently, the present-day plant assemblage of the unmined sector could be considered a good reference to evaluate the restoration success of the mined area. The bog landscape was characterized by significant tree cover dominated by black spruce for almost its entire period of development. Consequently, a restoration experiment resulting in *Sphagnum*-dominated vegetation with a dense black spruce cover in the near future should not be considered a failure. Macrofossil analyses suggest that postfire vegetation succession occurring in the study site and elsewhere is similar to that resulting from restoration experiments conducted in eastern Canadian bogs. In both cases, the input of nutrients (biomass burning or artificial fertilization) strongly stimulates the growth of *Polytrichum strictum* colonies, which are rapidly overgrown by *Sphagnum* colonies in burned bogs. Therefore, it is possible that the restoration method used in eastern Canada will result in rapid vegetation succession culminating in a *Sphagnum*-dominated peatland. This case study shows that a detailed reconstruction of the history of a site is a valuable tool for clearly establishing the goals of a restoration program.
Keywords: fire, macrofossil analysis, paleoecology, peatland, Québec, restoration ecology.

Résumé : Nous avons reconstitué, à l'aide d'analyses macrofossiles, les assemblages floristiques et l'histoire des feux d'une tourbière du Québec méridional qui a été en partie perturbée par des activités d'extraction de la tourbe et récemment restaurée. Nos objectifs principaux étaient (*i*) de déterminer dans quelle mesure la flore du secteur non perturbé de la tourbière est similaire aux flores qui ont été reconstituées à différentes époques du développement de l'écosystème, (*ii*) de calculer la fréquence des feux et leurs impacts sur la flore, et (*iii*) d'interpréter les résultats de la restauration du site à la lumière du développement de la tourbière au cours des derniers millénaires. Pendant la période ombrotrophe de la tourbière, les assemblages floristiques ont peu varié; ils ne semblent pas différer beaucoup de ceux observés dans le secteur non perturbé de la tourbière de nos jours. En conséquence, la flore actuelle du secteur non perturbé peut être considérée comme un point de référence valable pour évaluer le succès de la restauration du secteur exploité. Le couvert forestier du site, dominé par l'Épinette noire, a été relativement dense au cours de la majeure partie de son histoire. En conséquence, si un couvert forestier dense devait se développer dans le secteur restauré, cela ne signifierait pas nécessairement que la restauration fut un échec. Les analyses macrofossiles suggèrent que la succession de la végétation qui s'est produite après-feu dans le site d'étude et dans d'autres tourbières est similaire à celle qui est initiée par les activités de restauration qui ont cours dans les tourbières de l'Est du Canada. Dans les deux cas, l'ajout d'éléments nutritifs (en provenance de la biomasse carbonisée ou de la fertilisation artificielle) stimule fortement la croissance des colonies de *Polytrichum strictum*, ces dernières étant rapidement remplacées par des colonies de sphaignes dans les tourbières incendiées. Il est donc possible que les méthodes de restauration utilisées dans l'Est du Canada favorisent l'établissement très rapide d'un couvert de sphaignes dans les tourbières exploitées. Cette étude de cas montre que la reconstitution historique détaillée d'un site peut être un outil fort utile pour établir de façon claire les objectifs d'un programme de restauration d'un écosysteme.
Mots-clés : analyse macrofossile, écologie de la restauration, feu, paléoécologie, Québec, tourbière.

Introduction

During the last decade, major progress has been made in restoring minerotrophic and ombrotrophic peatlands damaged by mining activities (extraction of horticultural peat), particularly in Europe (Wheeler *et al.*, 1995) and northeastern North America (Rochefort, 2000). The re-establishment of former hydrological characteristics in undisturbed fens and bogs, and the re-introduction of peat-forming plants (sedge or *Sphagnum* species) in mined peatlands have in many cases been highly successful (Ferland & Rochefort, 1997; Price, Rochefort & Quinty, 1998; Boudreau & Rochefort, 1999; Richert, 2000). This suggests that it is possible to rapidly recreate conditions favourable to the growth of typical peatland plants. However, few restoration programs have stated clear objectives as to what constitutes

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a restoration success, apart from general goals such as the restoration of a plant cover dominated by *Sphagnum* or brown mosses (Rochefort, 2000). No restoration program (to our knowledge) has systematically compared the biological and physical characteristics of the restored ecosystem to those of undisturbed bogs.

To fill these gaps, a multidisciplinary team of ecologists, hydrologists and biogeochemists (Groupe de recherche en écologie des tourbières: http://alpha.eru.ulaval.ca/gret-perg) pooled their expertise to conduct a long-term (> 10 years) whole-ecosystem bog restoration experiment. This team is presently restoring an 11-ha sector of an ombrotrophic peatland (Bois-des-Bel bog, southern Québec) that has been severely disturbed by peat mining activities. The objectives of this restoration experiment include restoration of the biodiversity (plants, amphibians, arthropods, birds) of the damaged site, and the eventual recreation of natural disturbance cycles (mainly fire). This does not mean that the restored plant and animal assemblages would be exactly the same as those present at the site before the beginning of mining activities (an impossible task), but rather that the composition of plant and animal assemblages in the restored ecosystem should stay within the natural range of variability characterizing such assemblages in undisturbed bog ecosystems. Defining the "natural range of variability" requires a large database for each taxonomic group. This database, a survey of plant and animal assemblages in bogs within the study area, is presently in development (Desrochers, Roche-fort & Savard, 1998; Lachance & Pellerin, unpubl. data), but since a biodiversity study is usually conducted over a one- or two-year period, it provides at best a snapshot picture of plant and animal assemblages. Since these ecosystems are necessarily dynamic entities, the study of the range of natural variability should incorporate a longer temporal perspective using historical and paleoecological tools.

In this study, we reconstructed the long-term development of plant assemblages and the history of fire events in the Bois-des-Bel peatland using macrofossil analyses in the undisturbed and mined sectors of the bog. Our objectives were to (*i*) define plant assemblages according to each developmental stage of the peatland, (*ii*) determine to what extent the present-day plant assemblage of the Bois-des-Bel peatland is similar to those that have been reconstructed in the past, (*iii*) identify the past developmental stage of the peatland to which the peat deposit of the mined sector of the Bois-des-Bel site has regressed because of the extraction of a peat layer, (*iv*) establish the frequency of fire events and their impacts on plant assemblages, and finally (*v*) interpret the results from the restoration experiment by considering the natural development of the peatland over recent millennia. Other paleoecological studies have been conducted in restored peatlands to reconstruct the recent development of plant communities established after the end of mining activities (Smart, Wheeler & Willis, 1989; Joosten, 1995; Buttler *et al.*, 1996; Robert, Rochefort & Garneau, 1999). However, this case study is the first to our knowledge to use paleoecological analyses to clearly establish the goals of a peatland restoration program.

Material and methods

STUDY SITE

The Bois-des-Bel (BDB) peatland is located in the Bas-Saint-Laurent region (47° 58' N, 69° 26' W), on the south shore of the St. Lawrence River, eastern Québec, Canada (Figure 1). It is located in the agricultural plain near Rivière-du-Loup, bordered to the northwest by the St. Lawrence River and to the southeast by the Appalachian foothills. This plain is a narrow (16 km), low-altitude (0-250 m) strip of sand, silt and clay surficial marine deposits (Fulton, 1995). The region was deglaciated about 12 000 years BP, but was then submerged under the Goldthwait Sea (Dionne, 1977). The vegetation cover was established shortly after marine regression, about 9500 years BP. Pollen and macrofossil data indicate that modern vegetation developed after 8000 years BP (Richard, Larouche & Lortie, 1992). On mesic and xeric sites, this vegetation is mainly composed of sugar maple (*Acer saccharum*), yellow birch (*Betula alleghaniensis*) and balsam fir (*Abies balsamea*) forests (Grondin, 1996). 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 BDB bog covers an area of 202 ha, at a mean elevation of 15 m. Maximum peat thickness is 3.75 m (Girard, unpubl. data), and a basal peat sample has been dated to 6970 years BP (Lortie, 1983). The vegetation of the bog (Appendix I) is characterized by a mosaic of open and forest patches (tree basal area ranging from 0 to 42 m^2/ha) dominated by black spruce, ericaceous shrubs (mainly *Kalmia angustifolia*, *Ledum groenlandicum* and *Vaccinium angustifolium*) and mosses (mainly *Pleurozium schreberi*, *Sphagnum angustifolium* and *S. russowii*; Pellerin & Lavoie, 2000a). The BDB peatland is one of the last bogs in the Bas-Saint-Laurent region that has not been extensively mined for the production of horticultural peat. However, in 1972, a small sector (11 ha) was drained and cleared to extract peat using tractor-drawn vacuum machines (Figure 1). Mining of the site ended in 1980. In November 1999, the site was restored by spreading bog plant diaspores, covering the diaspores with a straw mulch, fertilizing with phosphorus, and blocking the drainage ditches (Price, Rochefort & Quinty, 1998; Rochefort, 2000).

PEAT SAMPLING AND TREATMENT

In September 1999, two peat cores were extracted from the BDB peatland: one from an unmined site, and the other from the adjacent mined sector. The exact location of the unmined coring site (unmined) was determined by consulting a previous survey of the peat deposit thickness in the peatland (Pellerin & Lavoie, 2000a). We selected a site very close to the mined sector, where the peat was thickest (Figure 1). The unmined site was located 15 m from the drainage ditch separating the unmined peatland from the mined sector. This is the minimal distance beyond which a drainage ditch is not expected to have strong effects on the hydrological characteristics of a *Sphagnum* peat deposit (Prévost, Belleau & Plamondon, 1997). The unmined coring site (unmined) was surrounded by scattered black spruce trees (tree basal area ranging from 7 to 12 m^2/ha) and by a

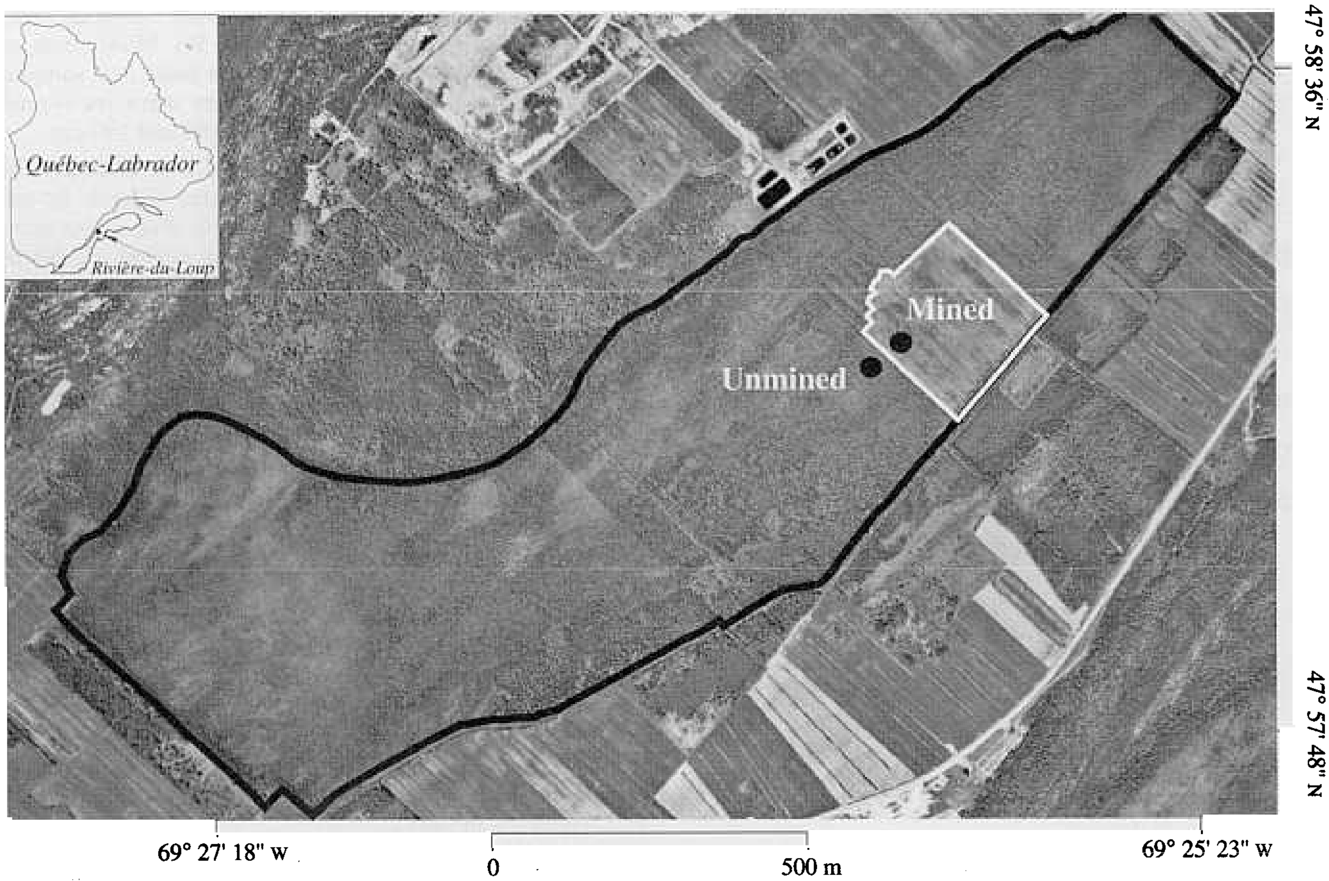

FIGURE 1: Aerial photograph of the Bois-des-Bel peatland, southern Québec. The black line delineates the peatland, and the white line delineates the mined sector of the bog. The unmined and mined coring sites are indicated by dots (photograph: courtesy of Hauts-Monts Inc., HMQ95118-89).

dense cover of ericaceous shrubs and *Sphagnum* mosses (Pellerin & Lavoie, 2000a). The mined coring site (mined) was located in the mined sector at a distance of 30 m from the unmined site, *i.e.,* 15 m from the drainage ditch separating both sites (Figure 1). This 15-m distance was necessary to prevent possible misinterpretation of the paleoecological record resulting from soil disturbances created by digging of the drainage ditch.

At each coring site, a peat core was extracted using a side-wall peat corer (Jowsey, 1966). Subsamples of 50-100 cm^3 were taken in the field by cutting 5-cm thick slices along the core. In the laboratory, peat subsamples were kept frozen before processing to prevent fungal contamination (Wohlfarth *et al.,* 1998). Subsamples were washed through a series of screens (2-, 1- and 0.5-mm meshes), and the remaining fractions were air-dried, again to prevent fungal contamination (Wohlfarth *et al.,* 1998). Macroscopic remains (vascular plant, moss, fungus, and charcoal pieces) were sorted under a low-power (50x) binocular microscope. Identified specimens were mounted on micropaleontological slides with gum tragacanth. When macrofossil remains of a particular taxon were too numerous in a subsample to be easily counted ($n > 200$), 0.5 g of the subsample was extracted; fossil pieces were then counted, and the real number of pieces was estimated for the total weight of the subsample (Lavoie & Payette, 1995). Macrofossil number was adjusted for a total volume of 100 cm^3 of peat. Macrofossil zones were delineated according to changes observed in the relative abundance of taxa and species composition throughout the peat profiles. Finally, plant or charcoal remains were extracted from the subsamples for conventional (unmined : 55-60 and 105-110 cm) or accelerator mass spectrometry (unmined : 155-160 and 205-210 cm; mined : 90-95 and 175-180 cm) radiocarbon dating. Radiocarbon dates were calibrated (Stuiver *et al.,* 1998) and used to calculate the peat accumulation rate. This rate is essential for determining the macrofossil influx, or the number of macrofossil pieces that were deposited per 100 cm^2 per year (Birks & Birks, 1980). The macrofossil influx was calculated only for the unmined site where four plant or charcoal samples were dated.

Nomenclature follows (*i*) Scoggan (1978-79) for vascular plants, except Farrar (1996) for trees, (*ii*) Anderson (1990) and Anderson, Crum and Buck (1990) for mosses, (*iii*) Stotler and Crandall-Stotler (1977) for liverworts, (*iv*) Esslinger and Egan (1995) for lichens, and (*v*) Massicotte *et al.* (1992) for fungi.

Results

UNMINED SITE

PEAT ACCUMULATION RATE

Peat accumulation (Figure 2 and Table I) extended over a period of 6570 calendar years, *i.e.,* from *ca* 4570 years BC to present (*ca* 5700 years BP to present). A high peat accumulation rate (0.70 mm/year) was recorded in the basal peat

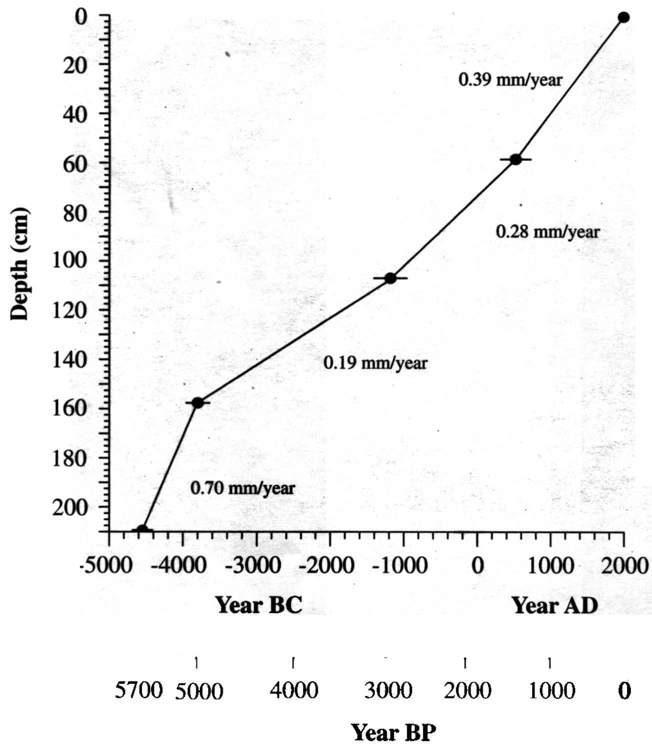

FIGURE 2: Peat accumulation rate (unmined site) for the Bois-des-Bel peatland. Horizontal bar: 2 sigma calibrated age range.

deposit (5710-5010 years BP). Between 5010 and 3010 years BP, the peat accumulation rate decreased strongly (0.19 mm/year), but then increased slightly (0.28 mm/year) between 3010 and 1500 years BP. The rate increased again after 1500 years BP (0.39 mm/year).

MACROFOSSIL ANALYSIS AND INFLUX

A total of 31 taxa of plants (vascular and nonvascular) and fungi were recovered from the peat core of the unmined site, 26 of them identified (some tentatively) to the species level. According to the changes observed in the relative abundance of taxa and species composition throughout the peat profile (Figures 3 and 4), four zones were delineated to reconstruct the history of the unmined site. Zone I corresponds to the beginning of peat accumulation in the site. The peat formed during this period (*ca* 5710-5010 years BP) was composed mainly of tree and sedge fragments. Tree remains (*Abies balsamea, Betula papyrifera, Larix laricina, Picea mariana*) were numerous, although birch and fir macrofossils were found almost exclusively in Subzone Ib. The dominant sedge species identified were *Carex* cf. *exilis* (Subzone Ia) or *C. trisperma* (Subzone Ib). Many seeds of *Viola* cf. *palustris* were recovered in the basal peat samples (200-210 cm). A few charcoal pieces were recovered between 160 and 165 cm, and between 185 and 190 cm.

The transition between Zones I and II is characterized by the disappearance of almost all remains of birch, fir and tamarack (*Larix laricina*), and by a major drop in the number of spruce needles. Throughout this period (*ca* 5010-4200 years BP), the tree macrofossil influx was close to zero. *Carex trisperma* was well represented in Zone II with numerous seeds. Sclerotia of *Cenococcum geophilum* became very abundant from 5010 years BP. A few charcoal pieces were recovered between 145 and 150 cm.

The main characteristic of Zone III (*ca* 4200-500 years BP) is the presence of abundant remains of *Sphagnum* species, particularly in Subzone IIIb. Almost all *Sphagnum* remains were stems, and very few leaves were recovered. Black spruce was by far the main tree species in this zone, although numerous fir remains were also present about 3000 years BP. At the end of Subzone IIIa (70-75 cm), the tree macrofossil influx was higher than in Zone I. However, in Subzone IIIb, the tree macrofossil influx was close to zero. Some macrofossils of ericaceous shrubs (*Chamaedaphne calyculata, Kalmia angustifolia, Kalmia polifolia, Ledum groenlandicum*) and numerous sclerotia of *Cenococcum geophilum* were noted throughout Zone III. Numerous remains of the mosses *Pohlia nutans* and *Polytrichum strictum* were also recovered at the beginning of Subzone IIIa (130-135 cm). Six charcoal layers were detected in this zone. The charcoal influx was particularly high for four of these layers.

Zone IV (*ca* 500 years BP to present) is characterized by (*i*) the infrequency of tree remains, (*ii*) an increase in the number of ericaceous shrub macrofossils, (*iii*) the presence of several seeds of *Carex trisperma*, (*iv*) the highest frequency of *Sphagnum* stems, (*v*) an increase in the number of *Drepanocladus* spp., *Pohlia nutans* and *Polytrichum strictum* remains, and (*vi*) an abrupt decline in the number of *Cenococcum geophilum* sclerotia.

MINED SITE

MACROFOSSIL ANALYSIS

A total of 31 taxa of plants (vascular and nonvascular) and fungi were recovered from the peat core of the mined site, 26 of them identified (some tentatively) to the species level. Only two zones were delineated to reconstruct the history of the mined site (Figure 5). Zone A corresponds to

TABLE Radiocarbon dates from the Bois-des-Bel peatland, southern Québec.

Laboratory number	Core depth (cm)	Radiocarbon date (years BP ± σ)	Calibrated age (years AD or BC)[a]	2 sigma age range (calibrated years)	Dated material
UL-2190	UNMINED: 55-60	1500 ± 90	AD 534	381 - 688 AD	Charcoal
UL-2191	UNMINED: 105-110	3010 ± 90	1220 BC	1443 - 997 BC	Wood
Beta-144854	UNMINED: 155-160	5010 ± 40	3818 BC	3940 - 3695 BC	Wood
Beta-144855	UNMINED: 205-210	5710 ± 40	4568 BC	4675 - 4460 BC	Wood
Beta-146981	MINED: 90-95	4720 ± 50	3505 BC	3640 -3370 BC	Wood
Beta-146980	MINED: 175-180	6610 ± 50	5555 BC	5630 - 5480 BC	Wood

[a]Median value of 2 sigma calibrated age range.

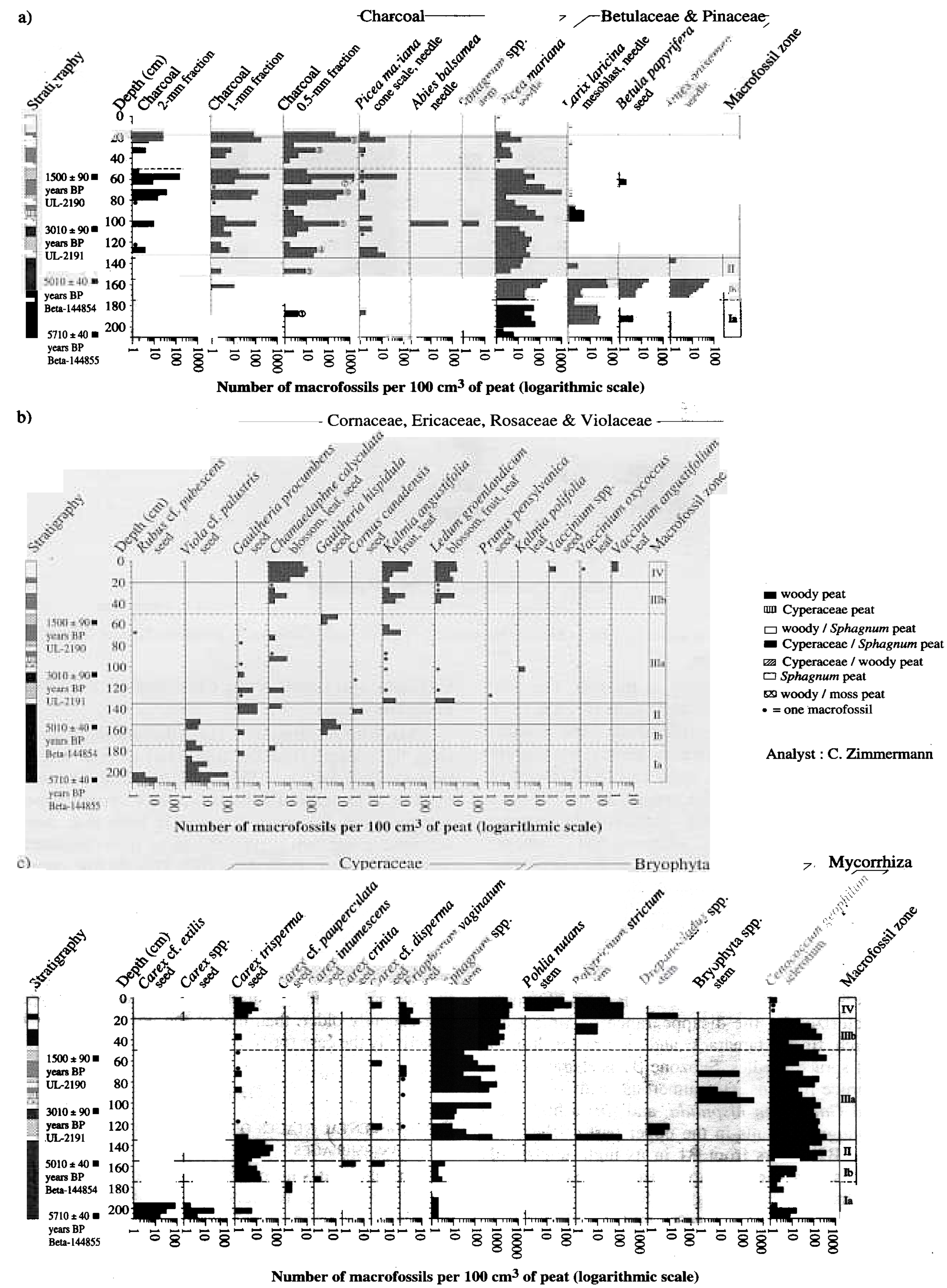

FIGURE 3: Macrofossil diagram (unmined site) for the Bois-des-Bel peatland (a: charcoal, Betulaceae and Pinaceae; b: Cornaceae, Ericaceae, Rosaceae and Violaceae; c: Cyperaceae, Bryophyta and Mycorrhiza). Each fire event is indicated by a number (charcoal: 0.5-mm fraction).

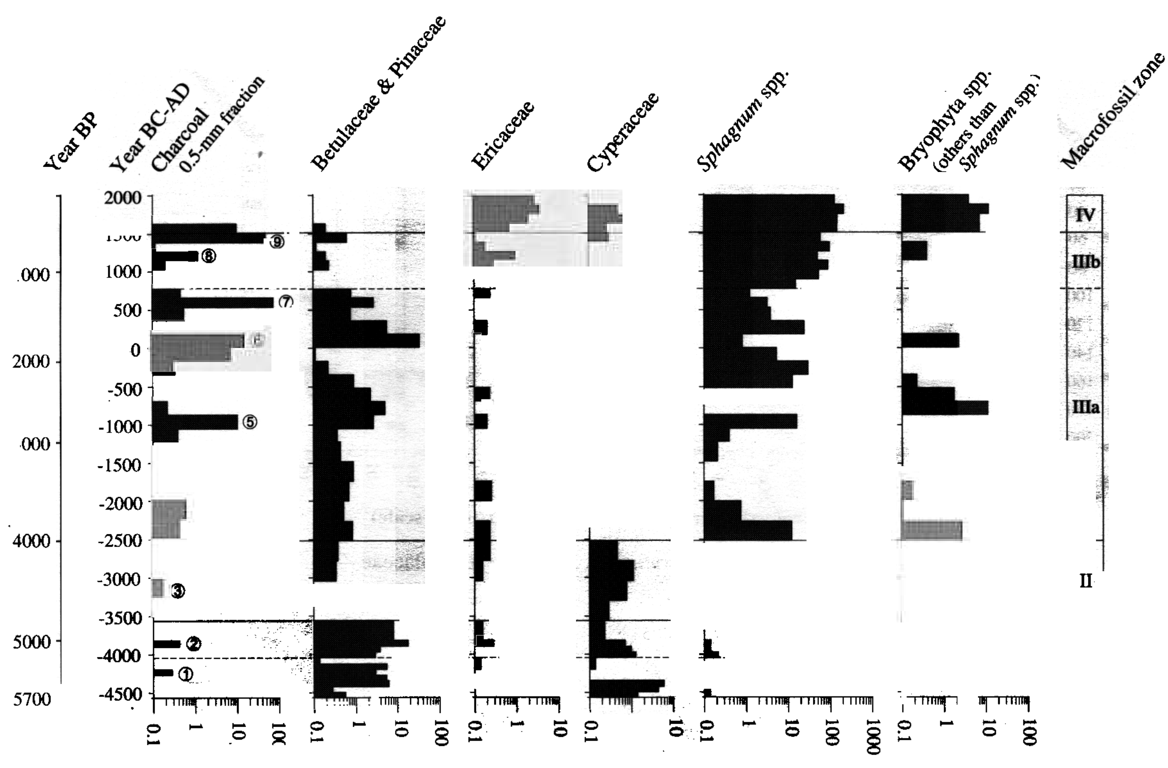

FIGURE 4: Macrofossil influx diagram (unmined site) for the Bois-des-Bel peatland. Each fire event is indicated by a number (charcoal: 0.5-mm fraction).

the beginning of peat accumulation in the site. The peat formed during this period (*ca* 6610-4720 years BP) was composed mainly of tree and sedge fragments. Tree remains (birch, fir, spruce, tamarack) were numerous, but mainly found in Subzone A1 and in the upper part (90-115 cm) of Subzone A2. The dominant sedge species identified were *Carex* cf. *exilis*, *C.* cf. *paupercula*, *C. rostrata* and *C. trisperma* (Subzone A1) or *C. crinata*, *C. disperma* and *C. trisperma* (Subzone A2). Many seeds of *Viola* cf. *palustris* were recovered in the major part of Zone A. Several remains of aquatic plant species (*Calla palustris*, *Hippuris vulgaris*) were also recovered in Subzone A1. Sclerotia of *Cenococcum geophilum* became very abundant from 120 cm. Only one charcoal layer was detected between 100 and 105 cm.

The transition between Zones A and B (*ca* 4720 years BP) is characterized by the disappearance of almost all remains of birch, fir and tamarack, and by a major drop in the number of spruce needles. Subzone B1 is characterized by (*i*) few spruce remains, (*ii*) numerous seeds of *Carex trisperma* and *Gaultheria hispidula*, and (*iii*) a high frequency of *Sphagnum* stems in the upper part of the subzone. Subzone B2 differs from B1 in its high number of spruce needles and the disappearance of *Sphagnum* remains. The main characteristics of Subzone B3 are an increase in the number of *Sphagnum* remains and the presence of some ericaceous shrub macrofossils. Charcoal remains were abundant in Zone B, but distinct charcoal layers were recovered only between 35 and 40 cm, and between 50 and 55 cm. Charred remains were numerous throughout Subzone B3.

UNMINED AND MINED SITES: COMPARISON OF MACROFOSSIL DIAGRAMS

Macrofossil diagrams from the unmined and mined sites have been visually compared to find similarities between both analyses (Figure 6). An abrupt decline in the number of remains of balsam fir, black spruce, paper birch and tamarack has been detected in both peat cores, and occurred at approximatively the same time (unmined: 5010 years BP; mined: 4720 years BP). This decline represents a reliable chronological marker for comparing the analyses. Once the position of the macrofossil diagrams are adjusted relative to each other using the decline of tree remains as a marker, it appears that the upper 65 cm of peat is missing in the mined peat core. Furthermore, the comparison suggests that the basal peat deposit of the mined site was deeper, and consequently older, than that of the unmined site, which is effectively the case (6610 *versus* 5710 years BP).

Discussion

DEVELOPMENTAL STAGES OF THE PEATLAND AND ASSOCIATED PLANT ASSEMBLAGES

At the BDB site, peat began to accumulate quite late during the Holocene period (*ca* 5710-6970 years BP) compared to other peatlands in the study area (Lortie, 1983; Van Seters, 1999). For example, peat accumulation began 9520 years BP in the Rivière-du-Loup bog (mean elevation: 100 m), 8730 years BP in the Cacouna bog (mean elevation: 83 m) and 8320 years BP in the Saint-Arsène bog (mean elevation: 53 m). The younger age of the basal peat deposit

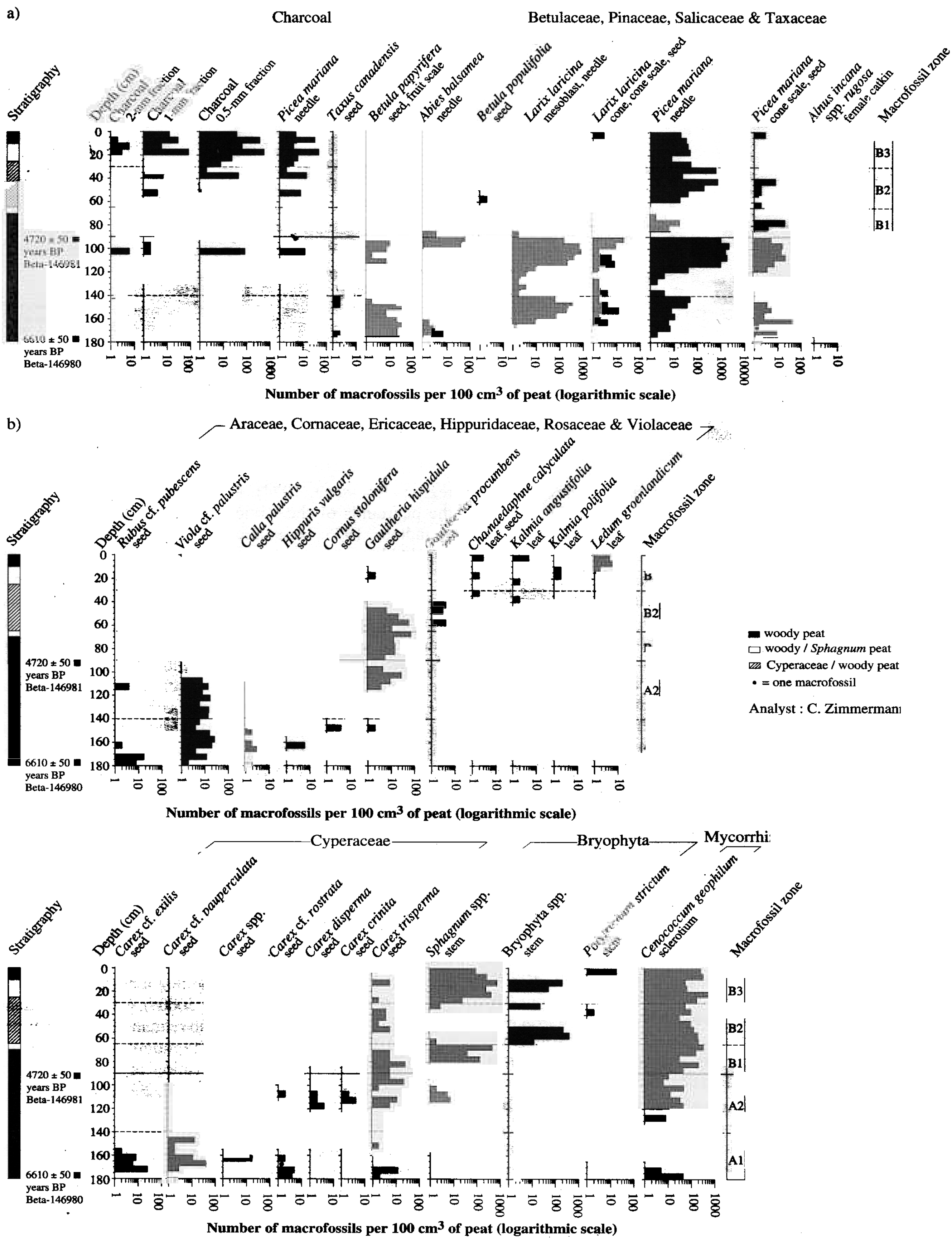

FIGURE 5: Macrofossil diagram (mined site) for the Bois-des-Bel peatland (a: charcoal, Betulaceae, Pinaceae, Salicaceae and Taxaceae; b: Araceae, Cornaceae, Ericaceae, Hippuridaceae, Rosaceae and Violaceae; c: Cyperaceae, Bryophyta and Mycorrhiza).

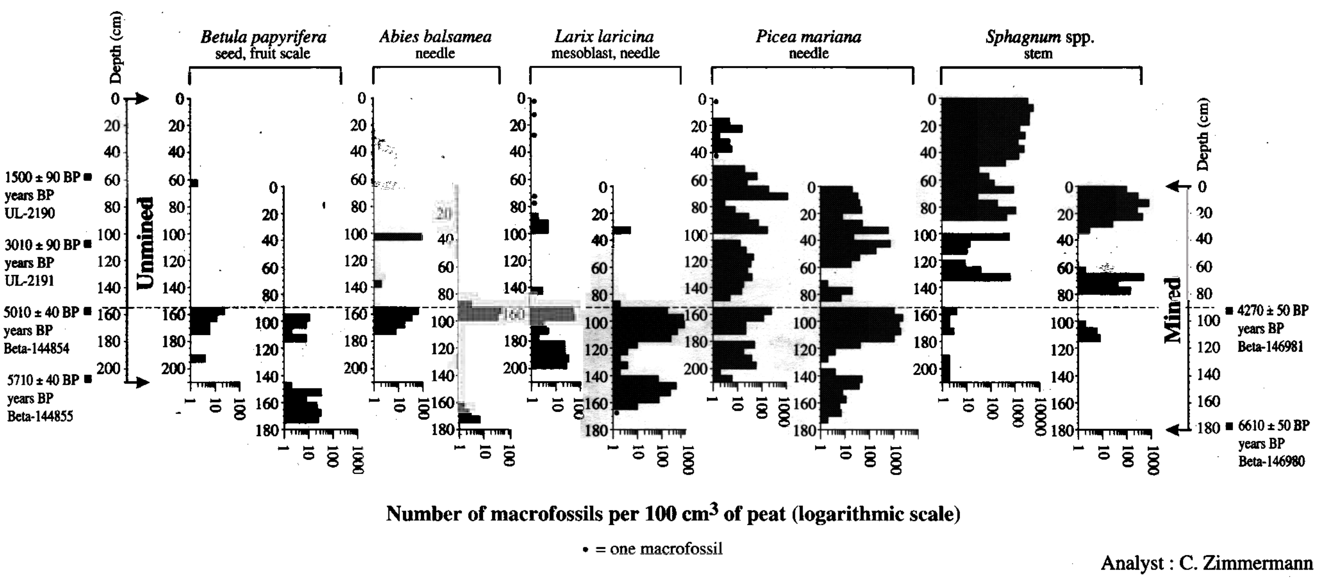

FIGURE 6: Comparison of macrofossil diagrams from the unmined and mined sites of the Bois-des-Bel peatland (selected taxa only). Macrofossil diagrams have been adjusted relative to each other using the abrupt decline of tree remains occurring *ca* 5000-4700 years BP as a marker (dotted line).

in the BDB bog could be explained by the low elevation of the site (15 m); it is possible that this site was submerged under the Goldthwait Sea as late as 7000 years BP (Dionne, 1977).

There are two developmental stages in the BDB peatland: one associated with a minerotrophic peatland (Zones I, II and A), and the other with an ombrotrophic peatland (Zones III, IV and B). Between *ca* 6610 and 5010-4720 years BP, the peatland environment was characterized by a damp forest of birch, fir, spruce and tamarack. The high moisture level at the soil surface is reflected by the presence of vascular plants typical of wet and rich fens, such as *Calla palustris*, *Carex* cf. *exilis*, *C.* cf. *paupercula* and *Rubus* cf. *pubescens*. However, the only evidence for the presence of shallow water ponds is indicated by the presence of seeds of *Hippuris vulgaris* (Rousseau, 1974; Scoggan, 1978-79; Porsild & Cody, 1980; Boivin, 1992).

The abrupt decline in the number of tree remains *ca* 5000-4700 years BP is associated with a transitional stage from rich fen to bog. The site was not able to support tree species such as balsam fir, paper birch and tamarack, probably because the peat deposit was too thick (55-90 cm), and consequently, tree roots no longer had access to the underlying mineral soil (Montague & Givnish, 1996). Although few black spruce remains were recovered in Zone II, the presence of *Carex trisperma* and *Gaultheria procumbens*, species associated with conifer forests (Rousseau, 1974; Boivin, 1992), suggests that the peatland environment was a poor fen with scattered spruce trees.

The last stage of the peatland was initiated about 4200 years BP. This stage is characterized by a plant assemblage typical of the ombrotrophic peatlands of the Bas-Saint-Laurent region (Gauthier & Grandtner, 1975). The main tree species was black spruce, associated with ericaceous vascular plants (*Chamaedaphne calyculata*, *Gaultheria hispidula*, *G. procumbens*, *K. angustifolia*, *L. groenlandicum*) and *Sphagnum* mosses. It is noteworthy that *G. procumbens* is very rare today in the Bas-Saint-Laurent region (Rousseau, 1974), and has never been sampled in the peatlands of the Rivière-du-Loup area (Gauthier & Grandtner, 1975; Desaulniers, 2000; Lachance & Pellerin, unpubl. data).

During the last 4600 calendar years, the importance of the black spruce cover varied, but spruce trees were probably major components of the bog landscape throughout the ombrotrophic period, as reflected by the number of spruce needles recovered. Another indication of the continuous presence of black spruce is the numerous sclerotia of *Cenococcum geophilum* that have also been recovered throughout the peat profile, from *ca* 5010 to 500 years BP (unmined). This ectomycorrhizal fungus is commonly found on most black spruce roots in bogs and on roots of some other woody plants (Thormann, Currah & Bayley, 1999). The quasi-absence of sclerotia in the upper peat layer (0-20 cm) is probably related to the rarity of roots in this layer. The macrofossil influx data suggest that there was at least one short period (70-75 cm; *ca* 2000 years BP) during which the peatland was massively colonized by spruce. Macrofossil data suggest that the spruce cover has decreased since this forest period. This phenomenon is possibly still in progress, since a large number of dead or declining black spruce individuals have been reported in the bog area surrounding the mined sector (Pellerin & Lavoie, 2000a). On the other hand, the abundance of ericaceous shrub remains in the upper peat layer (0-20 cm) is probably a taphonomic phenomenon associated with the poor preservation of these remains in older peat samples (Pellerin & Lavoie, 2000b).

FIRE EVENTS

Nine distinct charcoal layers were detected in the unmined peat core, six of them during the ombrotrophic stage of the peatland (Zones III and IV). It was more difficult to reconstruct fire events in the mined core because the surface peat layer was lost, and the stratigraphy of the residual peat deposit has probably been disturbed near the surface by both peat mining and subsidence (Price &

Schlotzhauer, 1999). During the ombrotrophic stage, macroscopic charcoal layers indicated that one local surface fire burned in the vicinity of the unmined coring site every 766 calendar years. This interval is much longer than that calculated for the Pointe-Escuminac bog (New Brunswick), the only other ombrotrophic peatland in eastern Canada with a detailed fire chronology (one fire every 260 calendar years; Robichaud, 2000). However, macroscopic charcoal was detected in the Pointe-Escuminac bog using a finer macrofossil analysis (sampling 1-cm thick slices along the peat core), allowing detection of two or three distinct fire events within a 5-cm interval. Nevertheless, if we correct the fire interval calculated for the Pointe-Escuminac bog by combining multiple fires detected inside 5-cm intervals that would not have been differentiated using our own method, the mean interval between two consecutive fires remains short at 312 years. It has not been possible to precisely date the last fire disturbing the site (unmined core: 15-25 cm). However, palynological studies conducted in peatlands in the study area suggest that the uppermost 20-25 cm of an undisturbed peat soil correspond to the European colonization period (the last 200 years). Indeed, an abundance of *Ambrosia* and Gramineae spp. pollen, associated with agricultural fields, is detected in this surface peat layer (Pellerin, unpubl. data). This suggests that the last fire at the BDB site probably occurred 100-200 years ago.

The impacts of fire on the development of vegetation in the BDB peatland were minor, and restricted to a short period following the fire. The most obvious impact was an increase in the number of *Pohlia nutans* and *Polytrichum strictum* remains (unmined core: 0-20 and 130-135 cm), a phenomenon observed in many other *Sphagnum*-dominated Canadian peatlands (Jasieniuk & Johnson, 1982; Foster & Glaser, 1986; Kuhry, 1994; Pellerin & Lavoie, 2000b). The release of nutrients from the burning of plant tissues is probably the main reason for the sudden growth of *Polytrichum strictum* populations in fire-disturbed bogs. However, this nutrient supply rapidly ran out, and 20-40 years after the fire, *P. strictum* colonies were overgrown by *Sphagnum* colonies (Jasieniuk & Johnson, 1982; Kuhry, 1994). It is noteworthy that the postfire vegetation succession reconstructed at BDB differs strongly from that observed in other bogs in the Bas-Saint-Laurent region during the twentieth century. In many of these peatlands, the open *Sphagnum*-dominated vegetation has been replaced by a dense black spruce or jack pine (*Pinus banksiana*) forest (Pellerin & Lavoie, 2000b; Lavoie & Pellerin, unpubl. data). Pellerin and Lavoie (2000b) have suggested that drainage of peatlands and adjacent agricultural fields, as well as fires caused by agricultural and peat mining activities, may favour the massive invasion of trees in small bogs (< 100 ha). Drier peat soils may have facilitated the establishment and growth of trees, and fires accelerated the afforestation process by spreading spruce and pine seeds. However, more data are needed to support this assertion.

RESTORATION IMPLICATIONS

The development of the BDB peatland followed the classic hydroseral succession of rich fen to poor fen to bog found in other peatlands of northeastern North America (Hu & Davis, 1995; Lavoie, Larouche & Richard, 1995; Bhiry & Filion, 1996; Lavoie & Richard, 2000; Robichaud, 2000; Zimmermann & Lavoie, 2001). The ombrotrophic stage has influenced the vegetation development of the bog for the last 4600 calendar years. During this period, plant assemblages have been quite stable, and do not seem to differ strongly from those observed today at the BDB site (Appendix I) or elsewhere in the Bas-Saint-Laurent region (Gauthier & Grandtner, 1975; Desaulniers, 2000; Pellerin & Lavoie, 2000a). Furthermore, the loss of a *ca* 65-cm peat layer in the mined sector due to mining, oxidation and wind erosion (McNeil *et al.,* 2000) was not significant enough to return the site to the minerotrophic stage. Consequently, the natural range of variability characterizing the present-day plant assemblages of the BDB bog could be considered a good reference for comparing the biodiversity of the unmined and restored sectors.

The general objective of most peatland restoration attempts in eastern Canada is the re-establishment of vegetation communities dominated by *Sphagnum* mosses (Rochefort, 2000). The re-establishment of an open (treeless) vegetation structure has also seemed important from a conservation point of view. In some regions, open bogs are now rare because they are the first to be mined by the peat industry (due to their higher quality peat and easier mining operations). For example, in the Rivière-du-Loup peatland, only 23% of 1000 ha of open bog remains unmined after only 60 years of peat mining (Desaulniers, 2000). However, the BDB landscape was characterized by significant tree cover dominated by black spruce for almost its entire period of development, at least near the mined sector. Consequently, a restoration experiment resulting in *Sphagnum*-dominated vegetation with a dense black spruce cover (basal area of trees = 42 m^2/ha) in the near future should not be considered a failure, but simply the restoration of a plant assemblage that characterized the bog during most of its existence.

Although a finer macrofossil analysis should be conducted in the BDB site to precisely calculate its fire interval, macroscopic charcoal data suggest that the fire interval in the BDB peatland is quite long, *i.e., ca* 700-800 years. Whatever the exact fire interval, fires are rare events in the BDB bog. If the maintainance of a natural fire cycle is desired, great care should be taken to avoid accidentally igniting fires in the bog. This is especially important because fires of human origin were particularly numerous in bogs in the study area during the twentieth century (Pellerin & Lavoie 2000b, Lavoie & Pellerin, unpubl. data), and because the response of bog vegetation to cumulative fire events occurring over a short time period is unknown.

It is interesting to compare the vegetation succession in burned bogs to that produced by restoration experiments conducted in eastern Canada. In both cases, the release (biomass burning) or input (fertilization) of nutrients strongly stimulates the growth of *Polytrichum strictum.* This phenomenon is particularly obvious at BDB, only one year after the restoration of the site (C. Lavoie, pers. observ.). In mined bogs, *P. strictum* helps stabilize the soil surface, prevents wind erosion and frost heaving, and seems to favour the subsequent establishment of *Sphagnum* colonies (Rochefort, 2000). Therefore, it is possible that the restoration method applied at BDB and elsewhere (Price, Rochefort & Quinty, 1998; Rochefort, 2000) will rapidly result in vegetation succession culminating in a *Sphagnum*-dominated peatland.

Conclusion

The paleoecological analysis of the BDB peatland is an example of the contribution of Quaternary paleoecology to nature conservation and restoration (Birks, 1996). It shows that a detailed reconstruction of the history of a site is a valuable tool in clearly establishing the goals of a restoration program. Without this historical perspective, it would be difficult to take into account the dynamic aspects of an ecosystem in restoration planning. Furthermore, and particularly in regions highly transformed by anthropogenic activities, paleoecological analyses are essential to determine the "naturalness" of sites that are used as references to compare the biodiversity and disturbance cycles of restored areas. Recently, some paleoecologists (Buckland, 1993; Buckland, Eversham & Warburton, 2000) sharply criticized bog restoration attempts in England because the main peat-forming plant species have changed radically in the last 1000 years; some species, like *Sphagnum imbricatum*, are now regionally extinct (Mauquoy & Barber, 1999). Furthermore, it is possible that present-day climatic conditions not favourable to the development of bogs, especially at their southern distribution limit. However, the North American context is different (no plant extinction, most bogs located at boreal latitudes), and peatland restoration techniques seem promising from a paleoecological point of view.

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APPENDIX I. Percentage of sampling quadrats (N = 161) having a given plant, moss, liverwort or lichen species in the Bois-des-Bel peatland, southern Québec. Quadrats (50 × 50 cm) have been systematically positionned every 100 m in the peatland (unmined sector) and sampled (presence/absence of species) during summer 1999 (Pellerin & Lavoie, 2000a).

Species	Quadrats with the species (%)
TREES	
Abies balsamea	0.6
Acer rubrum	0.6
Alnus incana	0.6
Betula papyrifera	1.2
Larix laricina	23.0
Picea mariana	89.4
Thuja occidentalis	2.5
ERICACEAE	
Chamaedaphne calyculata	49.7
Gaultheria hispidula	3.1
Kalmia angustifolia	79.5
Kalmia polifolia	14.3
Ledum groenlandicum	72.0
Rhododendron canadense	11.2
Vaccinium angustifolium	59.6
Vaccinium cassinoides	6.2
Vaccinium oxycoccos	26.7
OTHER VASCULAR PLANTS	
Amelanchier bartramiana	2.5
Carex trisperma	6.2
Clintonia borealis	1.2
Coptis trifolia	1.9
Cornus canadensis	9.3
Drosera rotundifolia	6.2
Empetrum nigrum	1.9
Epilobium angustifolium	0.6
Eriophorum vaginatum	13.0
Maianthemum canadense	1.2
Melampyrum lineare	0.6
Myrica gale	1.2
Nemopanthus mucronata	34.2
Osmunda claytoniana	0.6
Pyrus arbutifolia	1.2
Rubus chamaemorus	8.7
Smilacina trifolia	12.4
Spiraea alba	0.6
Trientalis borealis	1.2
SPHAGNA	
Sphagnum angustifolium	34.2
Sphagnum capillifolium	17.4
Sphagnum centrale	1.9
Sphagnum fallax	3.1
Sphagnum fuscum	11.8
Sphagnum magellanicum	24.2
Sphagnum rubellum	17.4
Sphagnum russowii	29.2
OTHER MOSSES, LIVERWORTS	
Aulacomnium palustre	5.0
Bazzania trilobata	1.9
Cephalozia lunulifolia	1.2
Cladopodiella fluitans	1.2
Dicranum fuscescens	2.5
Dicranum majus	6.8
Dicranum polysetum	16.1
Dicranum scoparium	1.2
Dicranum undulatum	5.6
Limprichtia revolvens	13.7
Mylia anomala	14.3
Pleurozium schreberi	50.3
Pohlia nutans	13.0
Polytrichum strictum	21.7
Ptilidium ciliare	9.9
Ptilium crista-castrensis	1.9
LICHENS	
Cladina mitis	8.7
Cladina stellaris	0.6
Cladonia cristatella	0.6