Peatland fragments of southern Quebec: recent evolution of their vegetation structure

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Abstract: One of the main problems associated with small natural reserves is their progressive loss of ecological integrity owing to the influence of surrounding human activities. In southern Quebec (Bas-Saint-Laurent, Canada), peatlands are extensively mined to extract peat for the production of horticultural compost and are isolated within agricultural lands. Government environmental agencies have proposed that peat industries set aside 5–10% of a bog's area as a natural refuge for peatland plants and animals. Do these fragments constitute reliable refuges? Do they maintain their ecological characteristics over a long period? We studied the recent evolution of plant communities in peatland fragments using paleoecological techniques and a geographical information system. In the study area, some treeless fragments dominated by *Sphagnum* species have recently (since 1940) converted to forest sites. Macrofossil and dendrochronological analyses suggest that peat-mining activities were not the main factors responsible for the afforestation of peatland fragments. On the other hand, the isolation of the Bas-Saint-Laurent peatlands within an agricultural plain for more than 100 years may explain the afforestation process (drainage activities). Furthermore, fires may have accelerated afforestation by facilitating the spread of seeds of tree species with serotinous cones. Because most peatlands of the Bas-Saint-Laurent region are still affected by drainage and fires, it is probable that several open bog fragments will not maintain their treeless vegetation structure over a long period. Consequently, peatland fragments should not be considered as a solution to long-term conservation needs in southern Quebec, at least not for plant and animal species of open bogs. This study also shows that even ecosystems known to be resistant to invasions by exotic species (such as peatlands) can be strongly affected by fragmentation and by their surrounding environment on a long-term basis.

Key words: peatland, peat mining, fire, fragmentation, conservation, Quebec.

Résumé : Un des principaux problèmes associés aux petites réserves naturelles est la perte progressive de leur intégrité écologique, en raison de l'influence des activités anthropiques environnantes. Dans le sud du Québec (Bas-Saint-Laurent, Canada), bon nombre de tourbières sont exploitées à des fins horticoles et sont isolées au sein de terres agricoles. Les autorités gouvernementales suggèrent aux industriels de conserver de 5 à 10% de la surface d'une tourbière à l'état naturel comme refuge pour les plantes et les animaux. Est-ce que ces fragments sont de véritables refuges? Maintiennent-ils leurs caractéristiques écologiques sur une longue période de temps? Nous avons étudié l'évolution récente des communautés végétales de fragments de tourbières en utilisant des techniques paléoécologiques et un système d'information géographique. Dans la région d'étude, un certain nombre de fragments ouverts (sans arbre), dominés par les sphaignes, se sont récemment (depuis 1940) transformés en sites forestiers. Les analyses macrofossiles et dendrochronologiques suggèrent que les activités d'extraction de la tourbe ne sont pas entièrement responsables de l'afforestation des fragments tourbeux. Par contre, le processus d'afforestation pourrait s'expliquer par l'isolement des tourbières au sein d'une plaine agricole depuis plus de 100 ans (drainage). De plus, les feux ont pu accélérer le processus, en facilitant la dissémination des graines d'espèces arborescentes avec cônes sérotineux. Puisque la plupart des tourbières du Bas-Saint-Laurent sont toujours affectées par le drainage et les feux, il est probable que plusieurs tourbières ouvertes deviennent forestières à plus ou moins brève échéance. En conséquence, les fragments tourbeux ne devraient pas être considérés comme une solution aux problèmes de conservation des tourbières dans le sud du Québec, du moins pas pour les espèces colonisant des milieux ouverts. Cette étude montre également que des écosystèmes reconnus pour être résistants aux invasions biologiques (telles les tourbières) peuvent aussi être fortement affectés par leur fragmentation et leur environnement immédiat.

Mots clés : tourbière, extraction de la tourbe, feu, fragmentation, conservation, Québec.

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Introduction

In many regions, the conservation of large natural areas is not possible because the ecosystems are already highly fragmented. In those cases, small natural reserves may be the only conservation alternative (Forman 1995; Shafer 1995; Turner and Corlett 1996). They are often the last refuges for many native species (Magsalay et al. 1995), and they add a touch of heterogeneity to regional landscapes (Saunders et al. 1991; Forman 1995; Shafer 1995; Virolainen et al. 1998; Honnay et al. 1999). Furthermore, they may be used as "stepping stones" for the dispersion of animals and plants between large natural patches, which is important in maintaining the metapopulation dynamic of many species (Gibbs 1993; Hanski 1998; Semlitsch and Bodie 1998).

One problem associated with small natural reserves is their progressive loss of ecological integrity as a result of surrounding human activities (Newmark 1995). For example, the isolation of a 400-ha woodland park by urban development in the Boston, Massachusetts, area during a 100-year period contributed to the extinction of 155 vascular plant species and the introduction of 36 exotic species (Drayton and Primack 1996). In Singapore, a similar study conducted in a 4-ha fragment of humid tropical forest has shown that more than 50% of native plant species have been lost during the 20th century (Turner et al. 1996). Reconstruction of the temporal dynamic of isolated fragments is complex because historical data are scarce or too recent to estimate the long-term effects of fragmentation on the integrity of ecosystems. Furthermore, these data can give an indication of decline or expansion of populations but are of limited value for determining the causes of these changes. However, paleoecological techniques can be used to reconstruct the characteristics of natural environments before they were disturbed by humans (Birks 1996). These reconstructions are particularly easy in peatlands where the peat deposit contains reliable archives (pollen, plant, and animal macrofossils) that are useful for studying ecosystem dynamics (Jacobson et al. 1991; Barber 1993; Bunting et al. 1998).

In southern Quebec, Canada, peatlands are extensively mined to extract peat for the production of horticultural compost. Bogs are drained and peat is extracted over almost all of their area. In some regions (Bas-Saint-Laurent), only small fragments of unmined peatland remain. In other regions (Côte-Nord), undisturbed bogs are still widespread, but the peat industry is expanding (Fig. 1). Government environmental agencies propose that peat industries set aside 5–10% of a bog's area as a natural refuge for plants and animals during mining activities and to facilitate the natural regeneration of abandoned mined sites (Thibault 1998). Do these fragments constitute reliable refuges for bog plants and animals? Do they maintain their ecological characteristics over a long period? To address these questions, we studied the recent evolution of plant communities in some peatland fragments of the Bas-Saint-Laurent region using paleoecological techniques (macrofossil analysis, dendrochronology) and a geographical information system. In this region, some fragments have been isolated for more than 50 years; as such, they constitute ideal sites for evaluating the long-term consequences of such isolation. The main objectives of this study were to determine whether the evolution of plant communities in bog fragments is affected by surrounding human activities (peat mining, agriculture) and if these fragments act as refuges for peatland plants and animals. We hypothesized that peatland fragmentation and peat-mining activities rapidly (within a few decades) and strongly influence successional pathways of bog remnants.

Methods

Study area and sampling sites

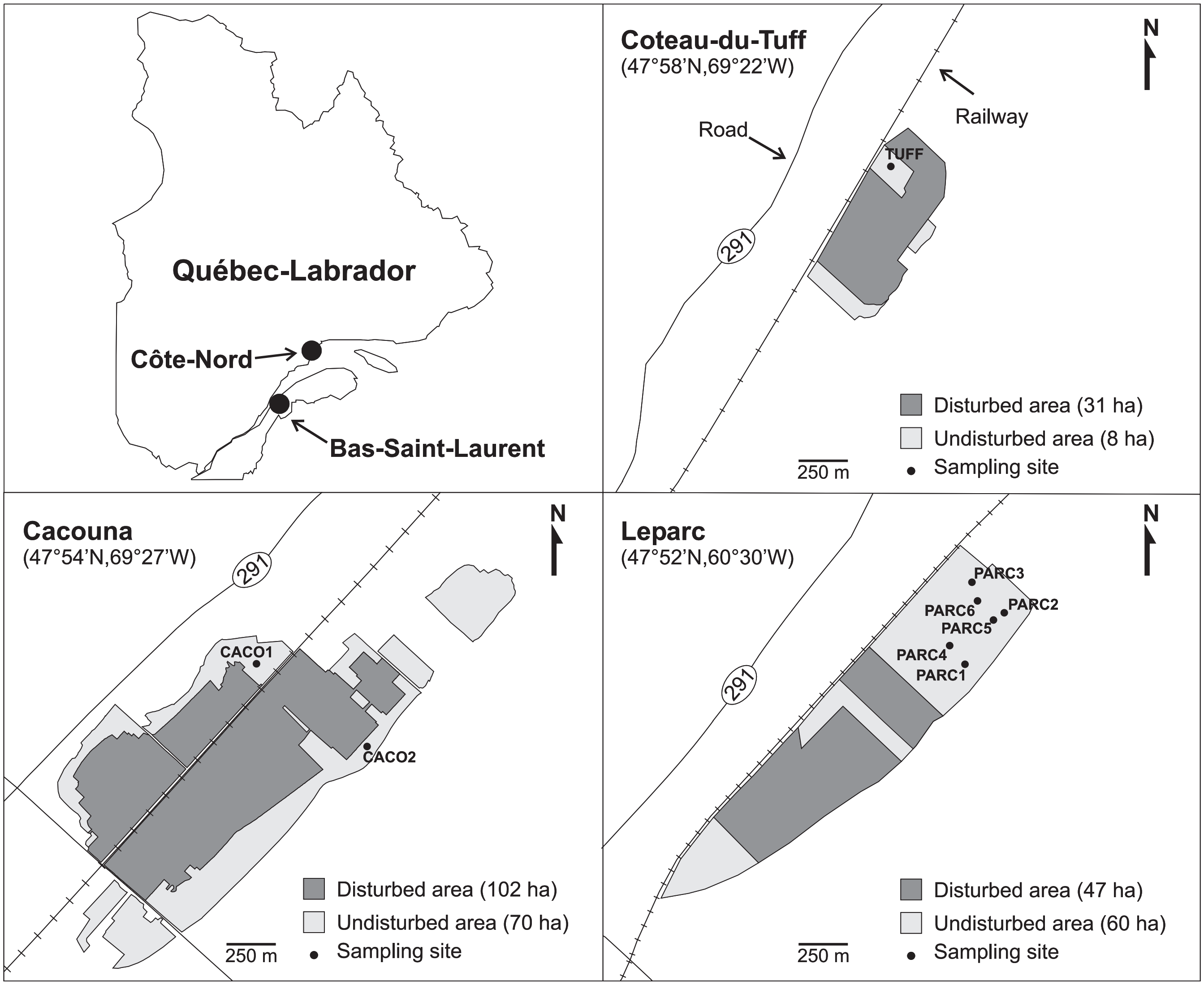
Ombrotrophic peatlands of the Bas-Saint-Laurent region are located in a 4 to 10 km wide agricultural plain bordering the south shore of the St. Lawrence River in Quebec. The original forest cover of this plain was almost completely removed during the 18th and 19th centuries (Laberge 1993) and, until recently, peatlands were the last natural areas in the region. Today, most of the peatlands either are being mined or were abandoned after decades of mining (Desrochers et al. 1998; Lavoie and Saint-Louis 1999). Small unmined bog fragments are still present at most sites because of the low horticultural potential of the underlying peat. However, the vegetation of most of these fragments was, before peat mining, representative of the original bog as a whole (Poulin et al. 1999).

We selected three bogs representative of most of the mined sites in the region (Lavoie and Rochefort 1996): the Cacouna, Coteau-du-Tuff, and Leparc peatlands (Fig. 1). The total area of each of these bogs is <200 ha, and all three were mined using the same manual method (block-cutting of peat) between 1942 and 1975 (Cacouna), 1948 and 1975 (Coteau-du-Tuff), and 1962 and 1967 (Leparc). Furthermore, all three bogs are adjacent to the same railroad track (built in 1876) and could have been affected by fire ignited by cinders from steam locomotives prior to about 1950 (Jacobson et al. 1991). To select sampling sites, we carefully examined 14 aerial photographs taken between 1932 and 1995. The sites were selected according to the recent evolution of their vegetation structure (open or forest vegetation). In the Cacouna bog, we chose a site that was afforested during the last 50 years (CACO1), and another that remained open during the same time period (CACO2). In the Coteau-du-Tuff bog, we selected a site (TUFF) in the middle of a small fragment (3 ha) surrounded by mined sectors. The vegetation structure of this fragment has not changed much during the last 50 years, according to aerial photographs. A mosaic of open and forest patches characterizes the main undisturbed fragment of the Leparc bog. We selected three sampling sites in each of the open patches of the fragment (PARC1, PARC2, and PARC3) which were associated with three forest sampling sites located nearby (PARC4, PARC5, and PARC6).

Description of sampling sites

During the summer of 1998, the vascular and nonvascular (moss, *Sphagnum*, liverwort, lichen) floras of the nine sampling sites were described inside a 20 × 20 m quadrat. The presence of all species covering a small point (diameter 1 cm) at 1-m intervals along 21 transects (20 m long, 1 m apart) was noted (Bonham 1989; Lavoie and Rochefort 1996). The richness and diversity of each site were calculated using the total number of species sampled and the Shannon diversity index (Magurran 1988). The thickness of the peat deposit was measured using an iron rod at 10-m intervals along three transects (20 m long, 10 m apart). A peat monolith (15 × 15 cm wide, 30–35 cm deep) was extracted at the centre of the quadrat for plant macrofossil analysis. The quadrat was then subdivided into four equal parts; two of these parts were randomly selected for tree sampling. The diameter at breast height (DBH) of all stems was measured, and the cross sections of a maximum of 50 tree trunks (randomly chosen, minimal height 1 m)

Fig. 1. Study area, showing selected peatland and sampling sites.



were taken using an increment borer as close as possible to the soil surface (collar).

To determine whether the vegetation mosaic found in the Leparc fragment was influenced by peat thickness, we positioned 148 sampling stations along 18 transects, 30 m apart (oriented northwest to southeast), using a global positioning system. Sampling stations were located every 50 m along each transect. For each station, the thickness of the peat deposit was measured using an iron rod. Basal area occupied by each tree species was calculated using DBH of tree stems surrounding a sampling station and selected with a prism (Bitterlich 1984). Maps of peat thickness and tree basal area were created using Kriging's method of SURFER© (version 6.04) software (Golden Software Inc. 1996).

Dendrochronological and macrofossil analyses

Annual growth rings were counted on the finely sanded cross sections of trees. To conduct macrofossil analyses, 100-cm^3 subsamples were taken between 0 and 2, 2 and 4, 4 and 6, and 6 and 10 cm (depths below the surface) and subsequently by 5 cm thick slices along the peat section. Subsamples were washed through a series of screens (2, 1, and 0.5 mm meshes), and the remaining fractions were air-dried to prevent fungal contamination. Plant remains were sorted and identified from the dried peat material under a low-power (50×) binocular microscope. When moss and *Sphagnum* stems of a particular fraction were too numerous to be easily counted ($n > 200$), 0.5 g of the fraction was extracted; moss and *Sphagnum* stems were then counted, and the real number of stems was estimated for the total weight of the fraction (Lavoie and Payette 1995). Past fires in the peat profile were detected by extracting 10 cm^3 from the 1-mm fraction of each subsample and counting the charcoal pieces under a binocular microscope. Charcoal pieces from other fractions were not considered because they were too small to be easily counted (0.5 mm) or differed too much in size to be compared (2 mm), but their presence has nevertheless been noted. Charcoal count was adjusted for a total volume of 100 cm^3 of peat.

Aerial photograph analyses

The recent evolution of the Leparc bog vegetation structure (open, forest) was classified using nine aerial photographs (1948, 1961, 1970, 1979, 1983, 1986, 1990, 1991, and 1995), and the EASI/PACE (version 6.01) software (PCI Remote Sensing Corp. 1997). Each aerial photograph was first digitized, then registered in space, and then corrected to limit geometrical distortions. A group of control pixels was then used to define the spectral signature corresponding to forest or open vegetation. This signature was tested using another group of pixels (training sites). For each aerial photograph, forest or open-vegetation pixels were mapped, and a percentage of accurate pixel classification was obtained.

Results

Floristic and physical characteristics

Open sites (CACO2, PARC1, PARC2, PARC3, and TUFF) have a basal area of trees much lower (Table 1) than that of forest sites (CACO1, PARC4, PARC5, and PARC6). Forty-nine species of vascular and nonvascular plants were identified at the nine sampling sites. Six bog species (*Drosera rotundifolia* L., *Eriophorum vaginatum* L., *Sphagnum angustifolium* (C. Jens.) C. Jens., *Sphagnum fallax* (Klinggr.) Klinggr., *Sphagnum fuscum* (Schimp.) Klinggr., and *Sphagnum magellanicum* Brid.) were recorded only in open sites. Jack pine (*Pinus banksiana* Lamb.) was the main tree species of forest sites CACO1, PARC4, and PARC5. Black spruce (*Picea mariana* (Mill.) BSP.) dominated the forest cover of PARC6. Ericaceous shrubs (*Kalmia angustifolia* L., *Ledum groenlandicum* Oeder, *Chamaedaphne calyculata* (L.) Moench) were abundant at all open sites. At forest sites, *Vaccinium angustifolium* Ait. was the most frequently sampled shrub species. *Sphagnum* species and *Pleurozium schreberi* (Brid.) Mitt. dominated the moss cover of open and forest sites, respectively. Species richness was higher at the open (21–27) than at the forest (13–18) sites. More *Sphagnum* species were sampled at the open (4–5) than at the forest (0–1) sites. Shannon diversity index was also higher at the open (3.02–5.04) than at the forest (1.28–2.04) sites. The thickness of the peat deposit differed between sites (96–406 cm), but a thin or thick peat deposit was not necessarily associated with an open site (Table 1). However, at the Leparc bog, low values of the basal area of trees were located mainly at the edge of the fragment, i.e., where the peat deposit was thinner (Fig. 2).

Dendrochronological analyses

The age structure of black spruce and jack pine populations was reconstructed only at sampling sites where at least 10 individuals of the same species were sampled (Fig. 3). At PARC4 and PARC5, the first jack pine individuals were established between 1940 and 1944. The establishment of black spruce at PARC3, PARC5, and PARC6 occurred after 1945. At CACO1, the first jack pines were established between 1925 and 1929. However, most individuals were established between 1945 and 1949.

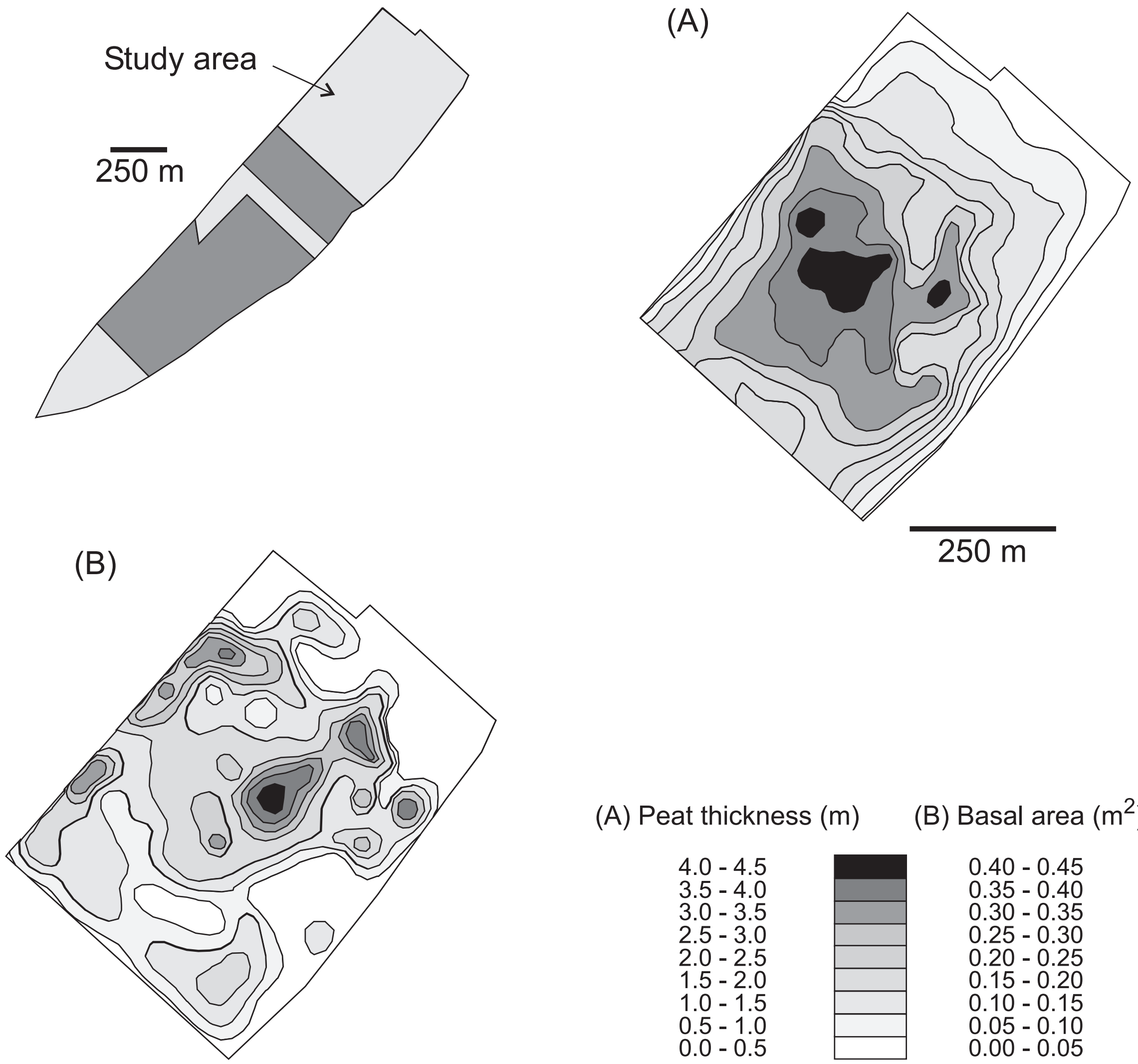
Macrofossil analyses

Macrofossil analyses have shown three recent evolution patterns of vegetation in bog fragments, some of them apparently influenced by fire (Fig. 4). At CACO1, PARC5, and PARC6, many more jack pine and black spruce macrofossils were present above the most recent charcoal layer than below. Furthermore, no *Sphagnum* remains were detected above this charcoal layer. The forest moss *Pleurozium schreberi* was also more abundant above the charcoal layer (PARC5 and PARC6). A similar phenomenon occurred at PARC4, but it was not possible to reconstruct the changes in the *Sphagnum* population because stems were too decomposed to be counted. At CACO2, the postfire succession was

Table 1. Characteristics of sampling stations of the Cacouna (CACO), Leparc (PARC), and Coteau-du-Tuff (TUFF) peatlands.

	1998 vegetation cover (%)								
Sampling site	Tree	Ericaceous shrub	*Sphagnum*	Moss	No. of species	No. of *Sphagnum* species	Shannon diversity index	Basal area of trees ($m^2/400\ m^2$)	Mean (±SD) peat thickness (cm; n = 9)
CACO1	78.2	33.1	0.5	31.7	17	1	1.98	3.18	207±6
CACO2	14.5	95.9	74.8	16.1	25	4	3.33	0.06	406±9
PARC1	11.3	94.8	81.2	10.2	24	5	3.02	0.02	375±13
PARC2	17.2	82.8	97.3	18.4	22	5	5.04	0.02	135±4
PARC3	61.0	1.2	57.6	13.4	21	5	3.98	0.16	96±2
PARC4	85.7	21.5	2.0	59.0	13	1	2.03	1.16	378±31
PARC5	76.6	10.9	1.1	73.0	18	1	2.04	1.16	176±62
PARC6	84.6	4.5	0.0	63.3	15	0	1.28	1.42	169±68
TUFF	7.0	81.4	75.1	26.8	27	4	4.32	0.01	271±37

Fig. 2. Spatial distribution of peat thickness (A) and total basal area of tree species (B) of the Leparc bog fragment.



different: *Sphagnum* remains were abundant on both sides of the charcoal layer, but black spruce remains almost completely disappeared above the charcoal layer, indicating the openness of the surrounding environment. Several tree stems have also been recovered at this site under the living *Sphagnum* mat. Finally, at TUFF, PARC1, PARC2, and PARC3, the most recent fire did not have a major impact on the vegetation structure. This structure remained open (<200 macrofossils of tree species at each stratigraphical unit) and dominated by *Sphagnum* species. However, remains of ericaceous shrub species were more abundant in the postfire environment.

Recent evolution of the vegetation structure of the Leparc peatland

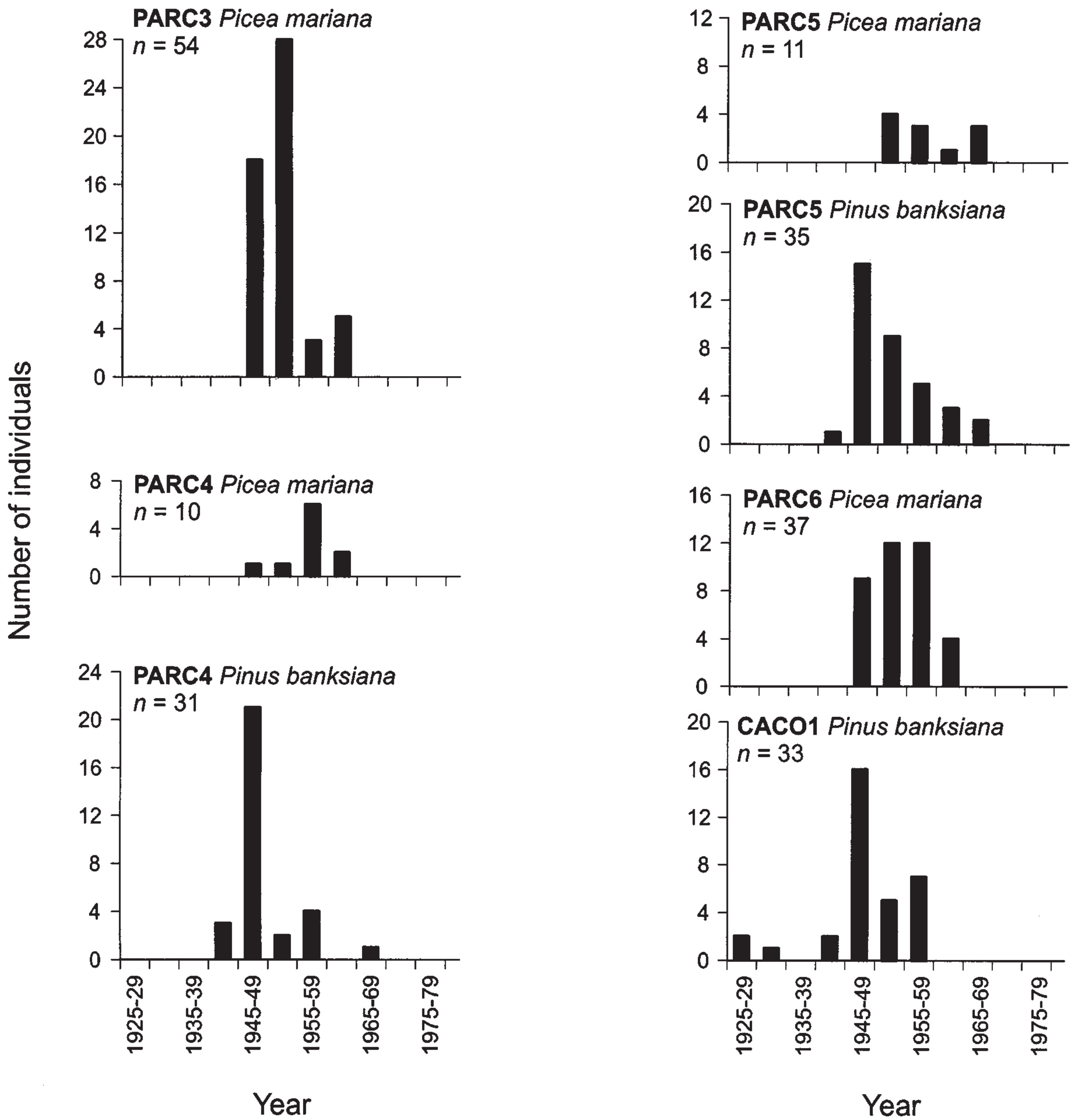
The accuracy of the aerial photograph classification covering the Leparc fragment was over 91% in all cases except that for 1995 (74%). This photograph was not included in the analysis. The classification showed a gradual afforestation of the fragment after 1948 (Fig. 5). In 1948, only 5% of the fragment was covered by a forest. More than 80% of the remnant had a forest vegetation structure in 1991. Consequently, 30 ha of open bog have been converted into forest bog since 1948, mainly between 1948 and 1961.

Discussion

Peatland fragments are dynamic ecosystems where vegetation communities are likely to change rapidly in a very short time period. In the Bas-Saint-Laurent region, many treeless fragments dominated by *Sphagnum* species have recently converted to forest sites with few *Sphagnum* species. This phenomenon occurred in the Cacouna and Leparc peatlands and seems widespread in the study area. Jack pine and black spruce are the main tree species contributing to the afforestation process. Macrofossil analyses have shown that these species, well adapted to postfire regeneration, invaded the bogs following the most recent fire that burned these ecosystems. According to the population structure of trees (Desponts and Payette 1992; Desrochers and Gagnon 1997), these fires occurred in the 1940s in forest sampling sites (CACO1, PARC4, PARC5, and PARC6).

Macrofossil and dendrochronological analyses suggest that peat-mining activities were not the main factor responsible

Fig. 3. Age structure (5-year classes) of jack pine and black spruce populations at PARC3, PARC4, PARC5, PARC6, and CACO1 sampling sites.



for the afforestation of peatland fragments. This phenomenon is particularly obvious at the Leparc bog where afforestation was initiated (1940–1944) well before the beginning of peat-mining activities (1962). On the other hand, the isolation of the Bas-Saint-Laurent peatlands within an agricultural plain for more than 100 years may explain the afforestation process. Drainage of agricultural lands surrounding peatlands has probably had an impact on the water content of surface peat, especially at the edge of bogs where most fragments are located. The drying effect of a drainage ditch can be detected >60 m from the ditch (Poulin et al. 1999). A lowering of the water table increases the aeration of peat near the soil surface, which facilitates tree colonization (Boggie 1977; Pakarinen 1994; Laine et al. 1995*a*). Fires, possibly ignited by cinders from steam locomotives, may have accelerated the afforestation process by facilitating the spread of seeds of tree species with serotinous cones (black spruce, jack pine), populations of which are abundant in the Bas-Saint-Laurent peatlands (Gauthier and Grandtner 1975).

Not all fragments were converted into forest sites during recent decades. The small bog remnant of the Coteau-du-Tuff peatland remained open, although it is surrounded by drainage ditches and was disturbed by fire in the recent past. At CACO2, the site is more open today than it was before the most recent fire. Drainage and fire did not change the vegetation structure of the PARC1, PARC2, and PARC3 sampling sites. Why were these sites not recently invaded by trees? Data collected in this study do not give any indication about factors preventing tree invasion, but it is possible that

Fig. 4. Macrofossil diagrams, selected taxa only (●, one piece only). Date of charcoal layers was estimated using tree population structures only at sampling sites where at least 10 individuals of the same species were sampled (see text for details).

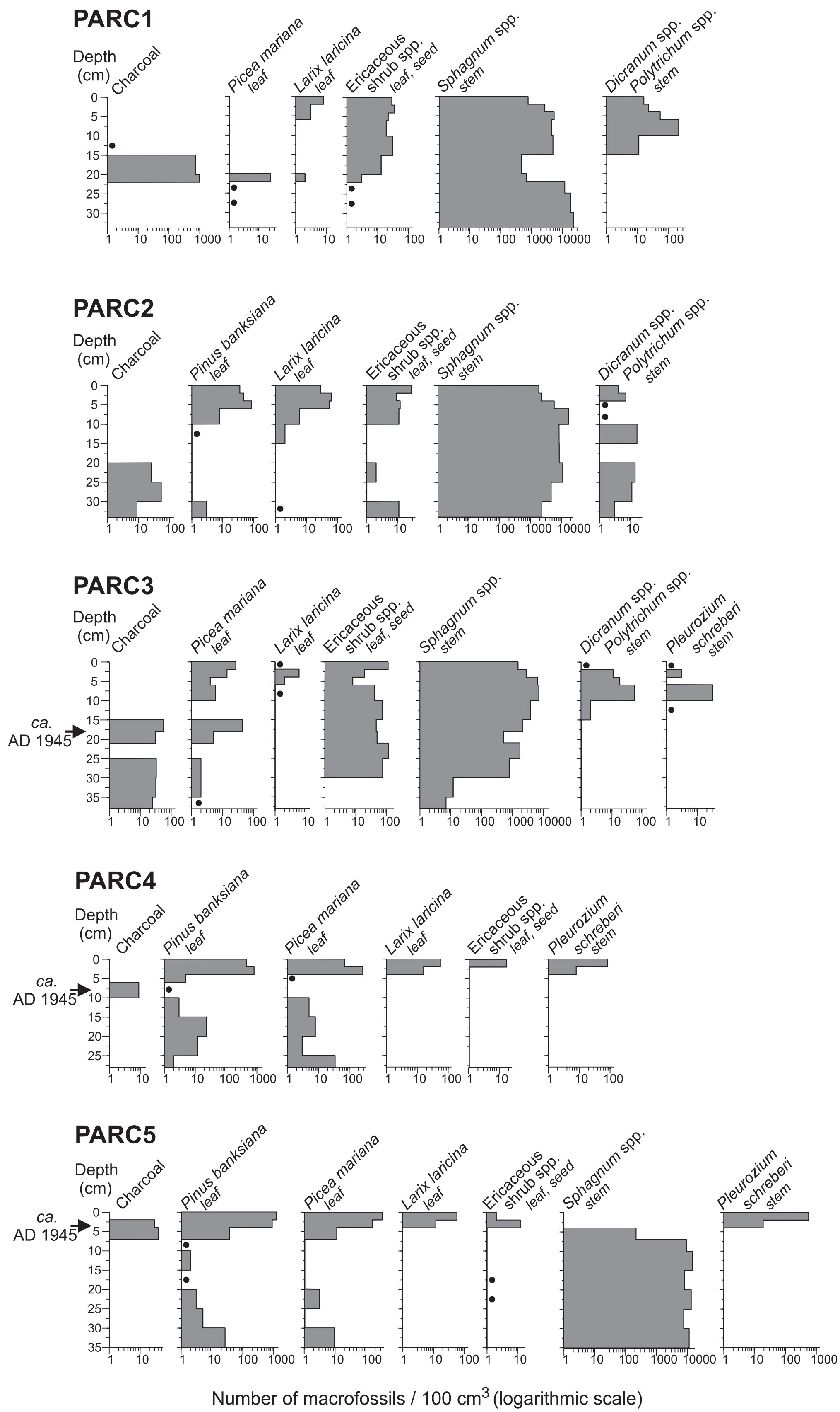
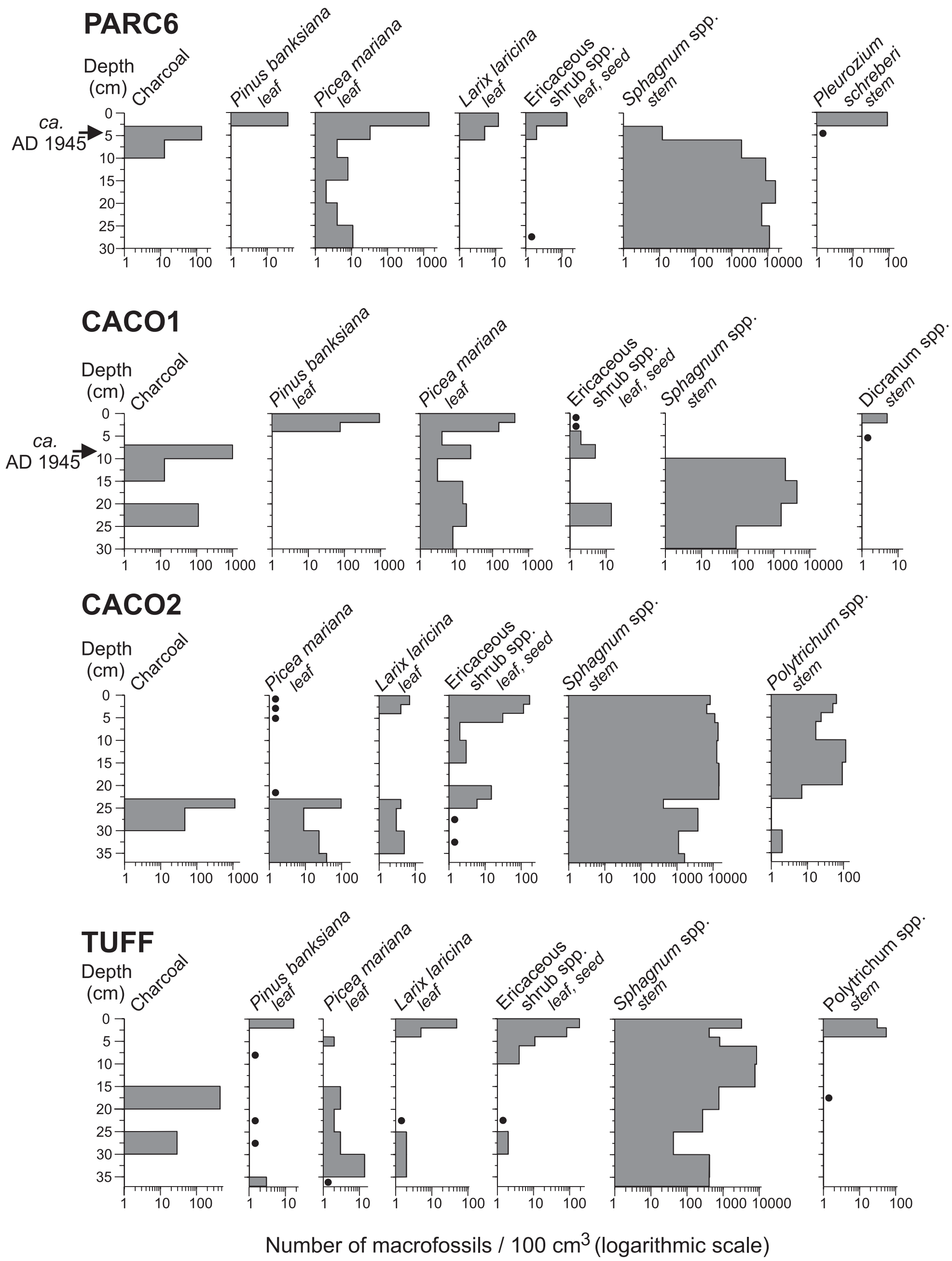


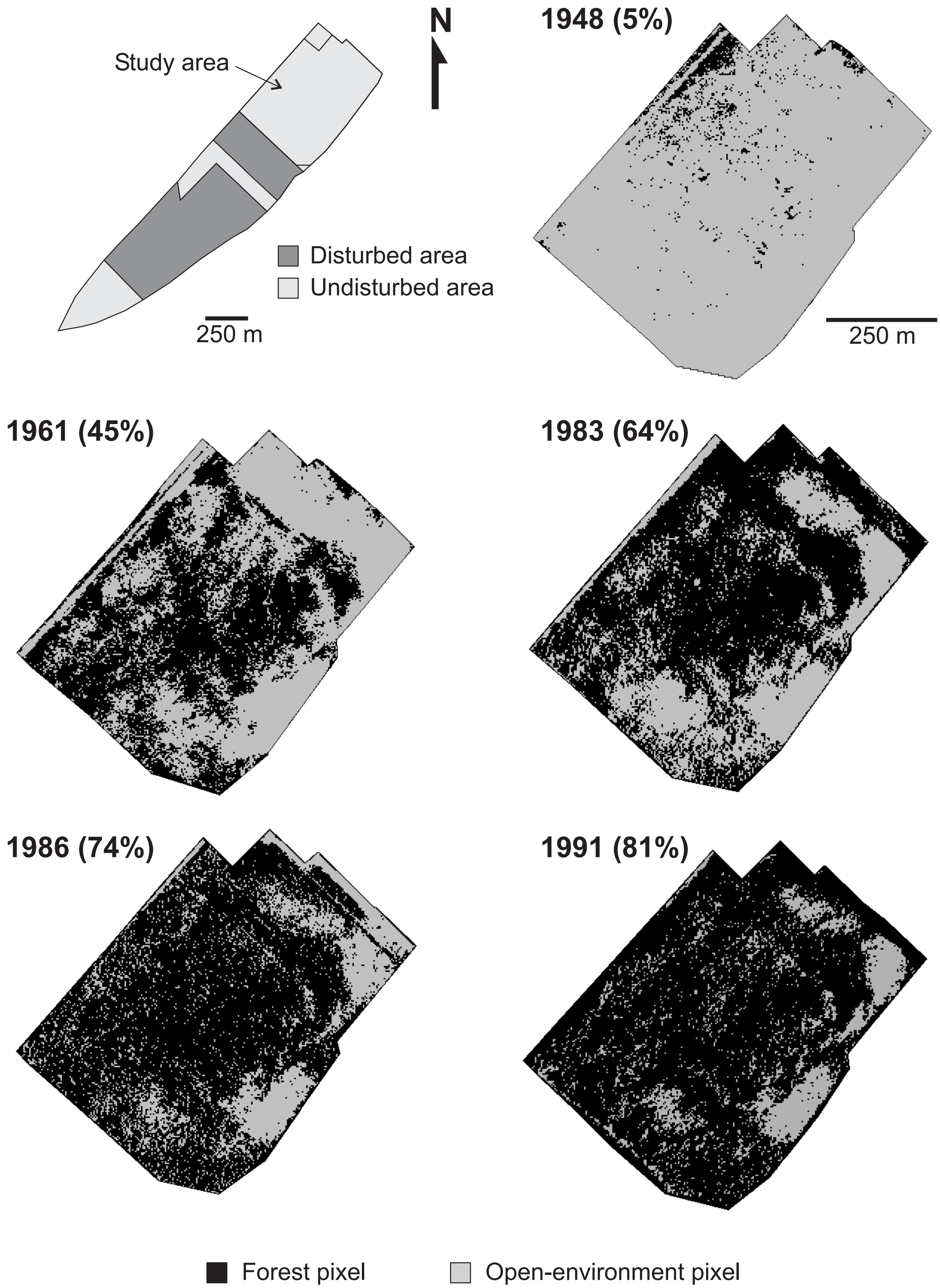
Fig. 4 (*concluded*).



these sites were more humid than the others. A high peat water content facilitates postfire *Sphagnum* regrowth and significantly reduces the establishment and the growth of trees (Gauthier 1980; Gunnarsson and Rydin 1998). Further studies on hydrological characteristics of bog remnants and of unmined, control sites are required to test this hypothesis.

Whatever the causes of the structural changes observed in bog remnants, our study shows that it is difficult to predict the evolution of their vegetation structure. Moreover, an open fragment may be rapidly converted into a forest bog without a *Sphagnum* cover. Open bogs are of particular interest for conservation because they are the first to be mined by the peat industry (higher peat quality, easier mining activities). For example, in the Rivière-du-Loup peatland (2 km south of Leparc bog), only 23% of the 1000 ha of open bog remained unmined after only 60 years of peat-mining activities (A.-S. Desaulniers and C. Lavoie, unpublished data). Open bogs have higher plant species diversity than forest bogs. They also have more typical bog animal species and microhabitats favorable to insects than forest peatlands (Laine et al. 1995*b*; Calmé and Desrochers 1999; Lavoie 2000). Finally, they contain diaspores (*Sphagnum* stems) essential for mined bog restoration programs (Quinty and Rochefort 1997). Because most peatlands of the Bas-Saint-Laurent region are still affected by drainage and fires (M. Vachon, personal communication), it is probable that several open bog fragments will not maintain their treeless vegetation structure over a long period. Consequently, peatland

Fig. 5. Spatiotemporal evolution of the forest cover of the Leparc bog fragment. Except for 1948, only years in which an increase of forest cover ≤1% between the year of the aerial photograph and that of the previous photograph are shown. Percentage of forest pixels for each photograph is indicated.



fragments should not be considered as a solution to long-term conservation needs in southern Quebec, at least not for plant and animal species of open bogs.

In the Bas-Saint-Laurent region where only small peatland fragments remain, bog remnants should nevertheless be conserved because they are the last examples of large ecosystems that were not mined in the recent past. However, in regions where the peat-mining industry is expanding, the conservation of some large (>200 ha), unmined sites would be preferable to scattered bog fragments (the current conservation measure). Large unmined peatlands are more likely to conserve their ecological integrity over a long period than bog remnants (Virolainen et al. 1998; Poulin et al. 1999). Finally, this study shows that even ecosystems known to be resistant to invasions by exotic species (such as peatlands; Lavoie and Rochefort 1996) can be strongly affected by fragmentation and by their surrounding environment on a long-term basis. This implies that conservation programs should be planned with both a spatial and a temporal perspective in mind.

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References

Barber, K.E. 1993. Peatlands as scientific archives of past biodiversity. Biodivers. Conserv. **2**: 474–489.

Birks, H.J.B. 1996. Contributions of Quaternary palaeoecology to nature conservation. J. Veg. Sci. **7**: 89–98.

Bitterlich, W. 1984. The relascope idea: relative measurements in forestry. Commonwealth Agricultural Bureau, Slough, U.K.

Boggie, R. 1977. Water-table depth and oxygen content of deep peat in relation to root growth of *Pinus contorta*. Plant Soil, **48**: 447–454.

Bonham, C.D. 1989. Measurements for terrestrial vegetation. John Wiley & Sons, New York.

Bunting, M.J., Morgan, C.R., Van Bakel, M., and Warner, B.G. 1998. Pre-European settlement conditions and human disturbance of a coniferous swamp in southern Ontario. Can. J. Bot. **76**: 1770–1779.

Calmé, S., and Desrochers, A. 1999. Nested bird and micro-habitat assemblages in a peatland archipelago. Oecologia, **118**: 361–370.

Desponts, M., and Payette, S. 1992. Recent dynamics of jack pine at its northern distribution limit in northern Quebec. Can. J. Bot. **70**: 1157–1167.

Desrochers, A., and Gagnon, R. 1997. Is ring count at ground level a good estimation of black spruce age? Can. J. For. Res. **27**: 1263–1267.

Desrochers, A., Rochefort, L., and Savard, J.-P.L. 1998. Avian recolonization of eastern Canadian bogs after peat mining. Can. J. Zool. **76**: 989–997.

Drayton, B., and Primack, R.B. 1996. Plant species lost in an isolated conservation area in metropolitan Boston from 1894 to 1993. Conserv. Biol. **10**: 30–39.

Forman, R.T.T. 1995. Land mosaics: the ecology of landscapes and regions. Cambridge University Press, Cambridge, U.K.

Gauthier, R. 1980. Les sphaignes et la végétation des tourbières du parc des Laurentides, Québec. Ph.D. thesis, Department of Forestry, Université Laval, Sainte-Foy, Que.

Gauthier, R., and Grandtner, M.M. 1975. Étude phytosociologique des tourbières du Bas-Saint-Laurent, Québec. Nat. Can. (Que.), **102**: 109–153.

Gibbs, J.P. 1993. Importance of small wetlands for the persistence of local populations of wetland-associated animals. Wetlands, **13**: 25–31.

Golden Software Inc. 1996. SURFER, version 6.04. Golden Software Inc., Golden, Colo.

Gunnarsson, U., and Rydin, H. 1998. Demography and recruitment of Scots pine on raised bogs in eastern Sweden and relationships to microhabitat differentiation. Wetlands, **18**: 133–141.

Hanski, I. 1998. Metapopulation dynamics. Nature (London), **396**: 41–49.

Honnay, O., Hermy, M., and Coppin, P. 1999. Effects of area, age and diversity of forest patches in Belgium on plant species richness, and implications for conservation and reforestation. Biol. Conserv. **87**: 73–84.

Jacobson, G.L., Jr., Almquist-Jacobson, H., and Winne, J.C. 1991. Conservation of rare plant habitat: insights from the recent history of vegetation and fire at Crystal Fen, northern Maine, USA. Biol. Conserv. **57**: 287–314.

Laberge, A. 1993. D'un territoire inoccupé à un espace saturé. *In* Histoire de la Côte-du-Sud. *Edited by* A. Laberge. Institut québécois de recherche sur la culture, Québec, Que. pp. 53–84.

Laine, J., Vasander, H., and Laiho, R. 1995*a*. Long-term effects of water level drawdown on the vegetation of drained pine mires in southern Finland. J. Appl. Ecol. **32**: 785–802.

Laine, J., Vasander, H., and Sallantaus, T. 1995*b*. Ecological effects of peatland drainage for forestry. Environ. Rev. **3**: 286–303.

Lavoie, C. 2000. Les arthropodes des tourbières. *In* Écologie des tourbières: une perspective nord-est américaine. *Edited by* S. Payette. Presses de l'Université Laval, Sainte-Foy, Que. In press.

Lavoie, C., and Payette, S. 1995. Analyse macrofossile d'une palse subarctique (Québec nordique). Can. J. Bot. **73**: 527–537.

Lavoie, C., and Rochefort, L. 1996. The natural revegetation of a harvested peatland in southern Quebec: a spatial and dendroecological analysis. Écoscience, **3**: 101–111.

Lavoie, C., and Saint-Louis, A. 1999. The spread of gray birch (*Betula populifolia* Marsh.) in eastern Quebec: landscape and historical considerations. Can. J. Bot. **77**: 859–868.

Magsalay, P., Brooks, T., Dutson, G., and Timmins, R. 1995. Extinction and conservation on Cebu. Nature (London), **373**: 294.

Magurran, A.E. 1988. Ecological diversity and its measurement. Princeton University Press, Princeton, N.J.

Newmark, W.D. 1995. Extinction of mammal populations in Western North American national parks. Conserv. Biol. **9**: 512–526.

Pakarinen, P. 1994. Impacts of drainage on Finnish peatlands and their vegetation. Int. J. Ecol. Environ. Sci. **20**: 173–183.

PCI Remote Sensing Corp. 1997. EASI/PACE, version 6.01. PCI Remote Sensing Corp., Arlington, Va.

Poulin, M., Rochefort, L., and Desrochers, A. 1999. Conservation of bog plant species assemblages: assessing the role of natural remnants in mined sites. Appl. Veg. Sci. **2**: 169–180.

Quinty, F., and Rochefort, L. 1997. Plant reintroduction on a harvested peat bog. *In* Northern forested wetlands: ecology and management. *Edited by* C.C. Trettin, M.F. Jurgensen, D.F. Grigal, M.R. Gale, and J.K. Jeglum. Lewis Publishers, Boca Raton, Fla. pp. 133–145.

Saunders, D.A., Hobbs, R.J., and Margules, C.R. 1991. Biological consequences of ecosystem fragmentation: a review. Conserv. Biol. **5**: 18–32.

Semlitsch, R.D., and Bodie, J.R. 1998. Are small, isolated wetlands expendable? Conserv. Biol. **12**: 1129–1133.

Shafer, C.L. 1995. Values and shortcomings of small reserves. BioScience, **45**: 80–88.

Thibault, J.J. 1998. Lignes directrices sur l'exploitation des tourbières au Nouveau-Brunswick. Division des ressources minières et de l'énergie, Ministère des Ressources naturelles et de l'énergie du Nouveau-Brunswick, Fredericton, Open file 98-7.

Turner, I.M., and Corlett, R.T. 1996. The conservation value of small, isolated fragments of lowland tropical rain forest. Trends Ecol. & Evol. **11**: 330–333.

Turner, I.M., Chua, K.S., Ong, J.S.Y., Soong, B.C., and Tan, H.T.W. 1996. A century of plant species loss from an isolated fragment of lowland tropical rain forest. Conserv. Biol. **10**: 1229–1244.

Virolainen, K.M., Suomi, T., Suhonen, J., and Kuitunen, M. 1998. Conservation of vascular plants in single large and several small mires: species richness, rarity and taxonomic diversity. J. Appl. Ecol. **35**: 700–707.