

Conservation of bog plant species assemblages: Assessing the role of natural remnants in mined sites

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Abstract. Bogs, economically valuable wetlands, are subjected to exploitation in southern Canada. We addressed plant conservation within bogs mined for peat, in which small undisturbed remnants are left, mostly at the margins of the mined areas. The main goal of the study was to test whether these remnants act as refuges for plants which could recolonize areas that are planned for restoration after mining is completed.

Mosses, lichens and vascular plants were sampled in remnants of 24 mined bogs in southeastern Canada during the summer of 1997. The vegetation was also sampled at the margins and centres of 24 nearby natural bogs in plots similar in size to these remnants. Using similarity analysis and ordination techniques, we found that plant species assemblages in remnants of mined bogs differ from those near the margins of natural bogs, and that certain species are associated with the centre of natural bogs, due to the presence of pools. We also showed that water conditions of remnants are affected by drainage due to peat mining. *Sphagnum* moss showed itself to be a key indicator of mining effects on vegetation. Implications for peat resource management and bog conservation are discussed.

Keywords: Bog; Canonical Correspondence Analysis; Drainage; Peat mining; Peatland; Restoration; Similarity analysis; *Sphagnum*.

Nomenclature: Esslinger & Egan (1995) for lichens; Anderson et al. (1990) for mosses; Anderson (1990) for *Sphagnum* mosses; Stotler & Crandall-Stotler (1977) for liverworts and Scoggan (1978) for vascular plants.

Introduction

Peatlands are important features of Canadian landscapes, covering 17 % of the land (Gorham 1990). Most of them occur within the boreal zone and therefore escape industrial development due to their remoteness. By contrast, peatlands of southern parts of Canada, mostly bogs (ombrotrophic peatlands), face pressure from agriculture, urban expansion, forestry and peat mining industry. In contrast to urban development and, to a lesser extent, to agriculture, peat mining does not imply irreversible land conversion and therefore could

be less harmful to long-term peatland preservation if the peatlands could regenerate after peat extraction. However, abandoned mined bogs do not return readily to functional peat-accumulating systems characterized by the growth of *Sphagnum* mosses (Rochefort & Lavoie unpubl. 1996; Desrochers et al. 1998). They generally require restoration techniques such as those developed by the Peatland Ecology Research Group in eastern Canada (Rochefort & Campeau 1997).

Ecosystem remnants are important for ecological restoration as they could either serve to determine the indigenous vegetation of a particular degraded site (Allen & Wilson 1991; Moravec 1998), or serve as a source of propagules through soil (Brown & Bedford 1997) and vegetation transplantation or re-introduction (Ferland & Rochefort 1997; Quinty & Rochefort 1997), or through natural dispersal (Sarmiento 1997). Ecosystem remnants are also important for general vegetation conservation purposes (Webb & Vermaat 1990; Kirkpatrick & Gilfedder 1995; Prober & Thiele 1995; Brooker & Margules 1996). Monitoring the state of ecosystem remnants therefore becomes essential.

Within mined bogs, natural remnants may play the above-mentioned roles but their integrity could be at risk due to drainage practices used for peat exploitation. Indeed, *Sphagnum* mosses which are a major component of a bog's ground layer, are very sensitive to prevailing hydrological conditions (Andrus 1986; Sagot & Rochefort 1996). Nevertheless, experimental studies investigating drainage effects on bog vegetation have focused on trees because of their economic value (Wang et al. 1985; Lieffers & Rothwell 1987; Dang & Lieffers 1989; Prévost et al. 1997). Few studies have investigated the entire community response to drainage. To date, these studies have shown that changes in plant communities are usually small or slow in drained ombrotrophic sites (Laine & Vanha-Majamaa 1992; Laine et al. 1995). For example, the decrease of ground layer species is related to shading effects from trees and shrubs which benefit from drainage (Vasander 1982; Laine et al. 1995). However, patterns of

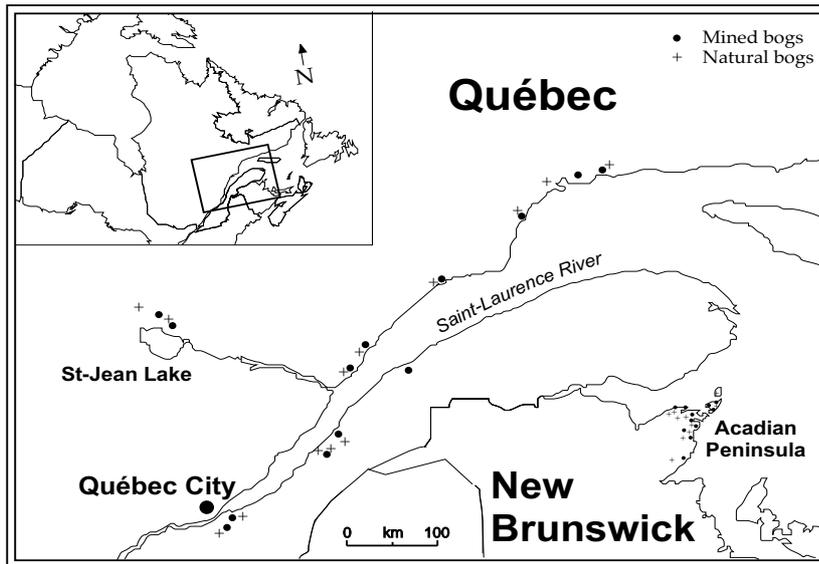


Fig. 1. Location of the study sites in eastern Canada.

microtopography can lead to a clear response to increasing dryness conditions as expressed by the disappearance of *Sphagnum majus* from hollows in a drained bog studied by Vasander (1982). Forest species like *Dicranum polysetum* and *Pleurozium schreberi* are favoured by dry conditions (Laine & Vanha-Majamaa 1992) and have been shown to be insensitive to acid conditions prevailing in bogs (Laine et al. 1995).

In this paper, we assess whether remnants of mined bogs may act as representative refuges for plants and could eventually act as sources of colonists for active restoration of abandoned areas after mining. Surveys in southeastern Canada were conducted to compare plant species assemblages between the margins and centres of natural bogs to assess the possible loss in biodiversity in mined bogs where only margins remain after peat extraction. We also attempted to compare plant species assemblages and water conditions between remnants of mined bogs and margins of natural bogs to assess the drainage effect on plant species composition. Finally, we aimed to determine whether plant species composition in remnants constitutes a sufficient species pool for restoration purposes.

Study area

The study sites were located in the Low Boreal region, the Gulf Atlantic Boreal region and the Maritime Atlantic Boreal regions of Québec and New Brunswick provinces (Anon. 1988a), the main area for peat mining in southeastern Canada. Our study encompasses ombrotrophic peatlands only (domed and plateau bogs) since this is the type of peatland used by the peat mining industry.

Sampling

We chose 24 mined bogs from aerial photographs and field verification (Fig. 1). 15 out of these 24 mined bogs were paired with natural bogs located in the same region and with similar characteristics (surface area, shape). The remaining nine mined bogs were paired with the natural part of the same site when the mined area was less than half of the original bog's surface area and when the latter was greater than 1 km². Sampling was conducted from June to August 1997. In each mined bog, a remnant natural section at the periphery of the mined area was sampled (Fig. 2A). All sampled remnants were adjacent to an area mined during at least the two previous years. Margins and centres of natural bogs were sampled with plots of the same shape and surface area as for remnant plots (Fig. 2A). We considered only surfaces where the cover of trees taller than 1.5 m was less than 50%. The lagg (Gore 1983) or forested marshes at the bog margin were thus excluded from this study.

In each remnant, vegetation was sampled along three transects parallel to the exploited edge (Fig. 2B). The first two transects were set at 10 and 20 m from the mined area and the third one was set halfway between the second transect and the bog edge (60 m on average from the mined area). In each transect, presence and cover of all species were recorded in four 1-m² quadrats (Fig. 2B). In large remnants, we raised the number of quadrats per transect to six ($n=4$) and to eight ($n=1$). The quadrats in natural bogs were set up in the same way as for mined ones.

In order to assess plant response over a larger sampling area, we visually estimated vegetation cover by

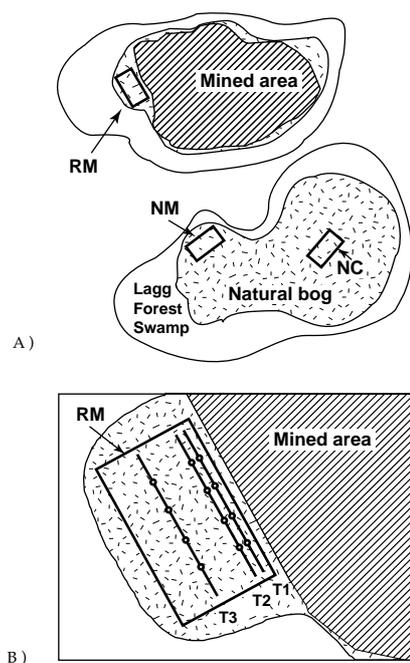


Fig. 2. A. Layout of plots within mined and natural bogs paired together in the same region (NC=Natural centre; NM=Natural margin; RM=Remnant margin). B. Position of transects and quadrats within a sampling plot neighbouring a mined area. The same disposition was used in plots within NM and NC. Not to scale.

strata when walking from one quadrat to the next. Observations were extended to 2.5 m outside each side of the transect. The nine strata were: *Sphagnum* mosses, mosses other than *Sphagnum*, lichens, litter, herbs, ericaceous shrubs, shrubs other than *Ericaceae*, trees, open water.

Vegetation cover for quadrats was estimated in the field to the nearest 1% while for the *strata* survey, vegetation cover was evaluated by classes as following: +: present; 1: < 1%; 2: 2-10%; 3: 11-25%; 4: 26-50%; 5: 51-100%.

In the middle of each transect, the water table depth was measured once and a peat sample was collected with a metal corer (840 cm³, depth of 11 cm) after the live mosses were cut off. The peat moisture content was estimated by a ratio of field weight minus dry weight (105 °C, 48 h) to initial volume. For each transect, the degree of decomposition of the peat was evaluated using the Von Post scale (Malterer et al. 1992). For each quadrat, we estimated the shade cover on the ground layer by summing the total percentage cover of tall species of ericaceous shrubs, shrubs other than *Ericaceae* and trees (App. 1). Paired natural and mined bogs were sampled within two days from each other.

Data analysis

Similarity of plant species assemblages between plot types

We tested whether there were any differences between plant species assemblages among the three different plot types (natural centres NC, natural margin NM and remnant margin in mined peatlands RM) with similarity indices using Mantel tests (Sokal & Rohlf 1995: 819). Mantel tests measure and test the association between elements of two similarity matrices. In this case, the observed similarity matrix was compared to a model similarity matrix, which was constructed with zeros for comparisons between plot types and ones for comparisons within plot types. When species similarity is greater within plot types than between plot types, there is a positive and significant association between the two matrices as denoted by the *r*-statistic (Manly 1997). Similarities were calculated with the Steinhaus index, which takes into account abundances and does not include species absent from the two sites compared (Legendre & Legendre 1984). Mantel tests were performed with 5000 permutations. One Mantel test was used to detect differences between natural centres and natural margins and another one to compare remnant margins to natural margins. We used a distance matrix as covariable since we detected a geographic effect of bog distribution on plant species assemblages (Mantel test, $r=0.31$, $P=0.0004$). Similarities were transformed into distances ($D=1-S$) before computing the Mantel tests (Legendre & Fortin 1989).

For these analyses specifically comparing plant species assemblages between plot type, we used the mean abundance of each species per plot. Those two comparisons were conducted with all species used in the similarity index as well as with the non-vascular species only. Since there was little difference between the two analyses, we only present analyses using all species.

Influence of environmental variables on species and plot type patterns

An ordination approach was used to relate both species and plot type patterns to environmental gradients. The full data set was ordinated by partial Canonical Correspondence Analyses (pCCA) run with 10 environmental variables and three covariables (see Fig. 3 for variable definitions) (ter Braak 1987). This type of ordination enables the evaluation of the relative importance of the environmental variables of interest on the species patterns while controlling for other environmental variables.

We compared the pCCA with a Detrended Correspondence Analysis (DCA). This allowed us to see to what extent the variance in the data was better explained by theoretical variables (with DCA) than by measured environmental variables (with pCCA). Those ordinations (pCCA and DCA) were run with the mean percentage cover per transect for each species that occurred in more than seven samples. Since the first two axes of the pCCA could explain a comparable percentage of variance in the data as those of the DCA (14% for the pCCA compared to 18% for the DCA), we present only pCCA results.

Monte Carlo simulations with 99 unconstrained permutations were used to test the significance of environmental variables in pCCA (ter Braak 1987). The program CANOCO version 3.12 (ter Braak 1988) was used for ordination and Monte Carlo permutation procedures.

Drainage effects on conditions of remnant margins

Water table depth, peat moisture content and the degree of peat decomposition were analysed for remnant margin (RM) and natural margin (NM) plot types to detect any drainage effect from peat mining. Analyses of variance were carried out with a split-block design with 24 blocks (GLM procedure; Anon. 1988b). Plot types (RM, NM) were the main units and transects (1, 2, 3) were the subunits. *A priori* contrasts were used to detect differences between treatment levels. We tested the effect of plot type with qualitative contrasts and the transect distance with linear and quadratic contrasts after taking into account the unequal distances between transects. Then we tested if plant species assemblages were related to water conditions with two Mantel tests using a vegetation- and water conditions (water table depth or peat moisture content) similarity matrix (Steinhaus index; Legendre & Legendre 1984). This analysis allowed us to relate the drainage effect to vegetation on a transect basis. We compared remnant margin vegetation data to those of natural margins in this analysis and the abundance of each species was averaged per transect.

Vegetation strata cover among plot types

Vegetation strata data were analysed with split-block analyses of variance (24 blocks, GLM procedure, Anon. 1988). Plot types (RM, NM, NC) were the main units and transect (1,2,3) were the subunits. One analysis was carried out for each of the nine *strata*. All variables were log-transformed to stabilise variance. *T*-tests based on least-square means multiple comparisons were carried out to determine differences among treatments. The level of significance for comparisons was corrected for the dependence between comparisons using α/n (where $\alpha=0.05$ and n =number of comparisons).

Results

Similarity of plant species assemblages between plot types

Although remnants were small (sizes ranging from 0.4 to 8.4 ha with a mean surface area of 2.7 ha), a high diversity of species was recorded (126 species for all sites) (App. 1). However, half of the species had less than 10% occurrence. Excluding the 30 species detected only once, few species were restricted to only one plot type (ca. 6% for each type). 69 species, including 11 ericaceous shrub species, were found in all three plot types. However, when species abundances and composition are considered, plant species assemblages of remnants left by peat mining differed significantly from assemblages of natural margins (Mantel test, $r = 0.16$, $P = 0.0004$). We did not find any evidence of difference between plant species assemblages of centres and margins in natural bogs (Mantel test, $r = 0.02$, $P = 0.15$).

Influence of environmental variables on species and plot type patterns

The species distribution could be explained by two main gradients: moisture and microtopography (Fig. 3). Presence of a ditch, high shade cover, low water table and peat moisture content as well as the distance from the mined area influenced the first gradient. The second gradient was characterized by two contrasting microhabitats, Hummock/Hollow to Lawn/Carpet.

One group of wet habitat species such as *Drosera anglica*, *Cladopodiella fluitans*, *Utricularia cornuta*, *Carex trisperma*, *C. limosa* and *Sphagnum majus* were clearly associated with the lawn/carpet microhabitat (Fig. 3A). Lawn/carpet microhabitats occurred mainly in the centre of peatlands as shown by sample distribution on the pCCA biplot (Fig. 3B). A dry species group, although less distinct, occurred in the drier end of the water gradient (Fig. 3A). Species such as *Pleurozium schreberi*, *Cladonia cenotea*, *C. deformis*, *Dicranum polysetum* were more related to remnant margins than to margins and centres of natural bogs (Fig. 3B). No *Sphagnum* species occurred in the driest and most shaded areas (Fig. 3A).

Sample distribution on the pCCA biplot showed a u-shaped gradient (Fig. 3B). Natural centres were clearly associated with the lawn/carpet microhabitat and high moisture while the remnant margins were more related to the presence of a ditch, dryness and shade. Natural margins were overlapping the two other plot types. Even though the percentage of variance explained by the first and second axes of the pCCA ordination of the full data set was low (8.9% and 5.4% respectively) (Fig. 3A, B), species were significantly related to environmental variables (Monte Carlo permutation test, $P = 0.01$).

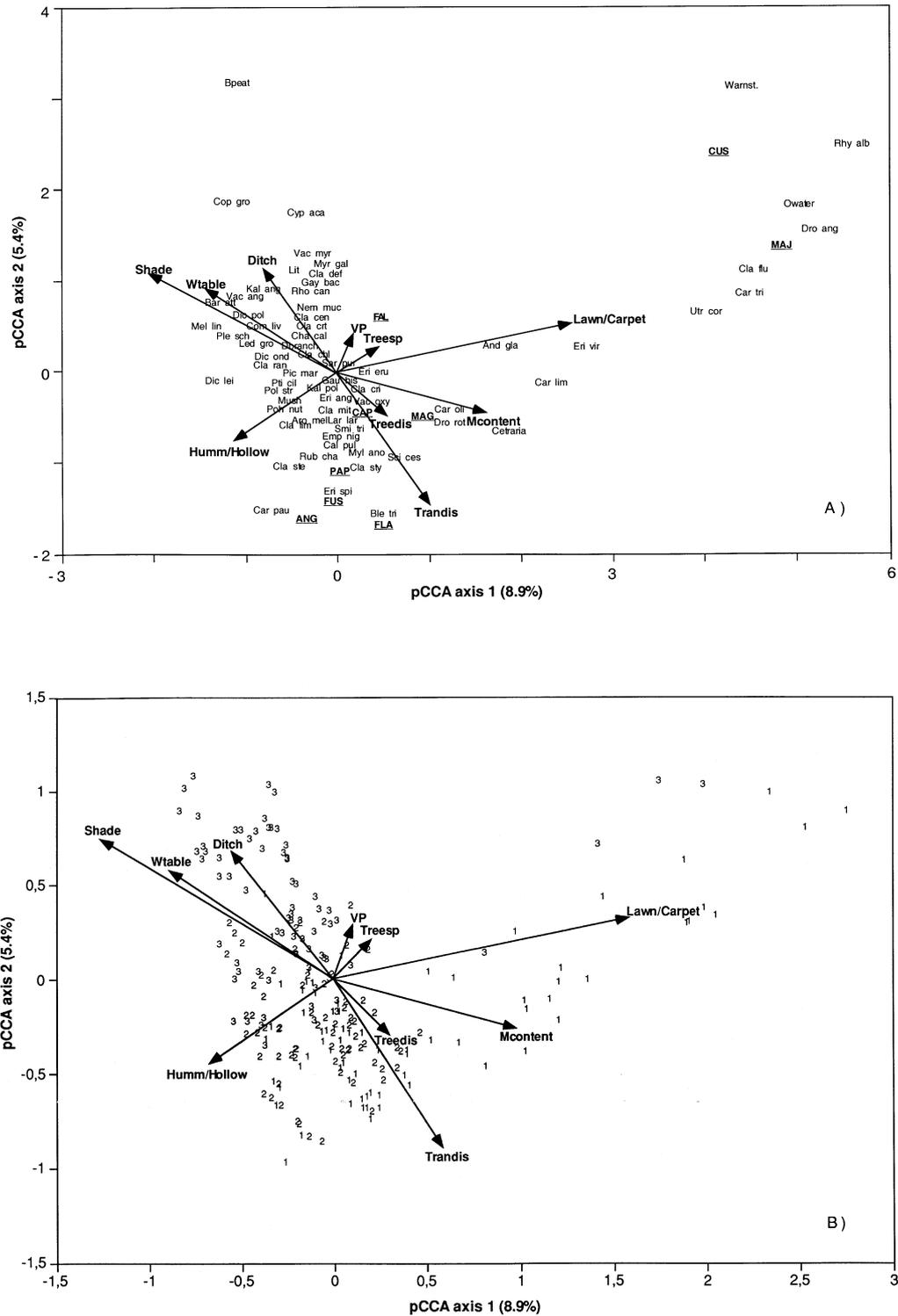


Fig. 3. Distribution of (A) species (*Sphagnum* species are underlined) (see App. 1 for codes); (B) samples for the three plot types – 1=Natural centre; 2=Natural margin; 3=Remnant margin – on pCCA ordination using three covariables (sampling date, bog latitude and longitude) and 10 environmental variables. Ditch=Presence of a ditch; Humm/Holl=Hummock/hollow microhabitat (%); Lawn/Carpet=Lawn/carpet microhabitat (%); Mcontent=Peat moisture content (% per volume); Shade=Shade cover on the ground layer (%); Trandis=Transect distance from the mined area (m); Treedis=Distance of the nearest tree from the sample quadrat (m); Treesp=Species of the nearest tree from the sample quadrat; VP=Degree of peat decomposition (Von Post scale), Wtable=Water table depth (cm).

Drainage effect on conditions of remnant margins

The water table decreased non-linearly from the bog edge to the mined area within remnant margins whereas there was no gradient in natural margins (Fig. 4A contrast 'type \times transect quadratic', $P = 0.02$). In general, the water table and peat moisture content were lower in remnant than in natural margins (Fig. 4A, B). For the water table depth, even the third transect, which was on average 60 m away from the mined area, was affected by the exploitation (Fig. 4A). The peat moisture content tended to increase linearly from the bog edge toward the centre in natural margins whereas it stayed constant within remnant margins. (Fig. 4B contrast 'type \times transect linear' was marginally significant, $P = 0.06$). The degree of peat decomposition increased non-linearly from the bog edge to the mined area within remnant margins whereas it decreased toward the centre in the natural margins (Fig. 4C contrast "type \times transect quadratic", $P = 0.02$).

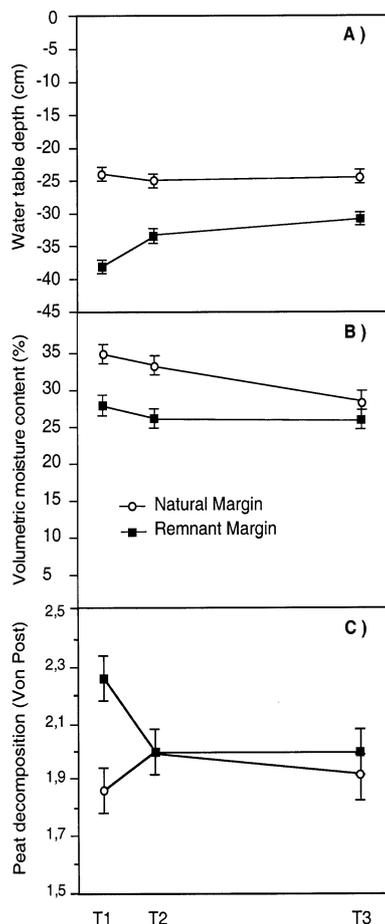


Fig. 4. Effect of plot type (natural or remnant margins) and transect distances from the mined edge (10, 20 and 60 m) on (A) water table depth, (B) peat moisture content and (C) the degree of peat decomposition (Von Post scale).

The vegetation of remnant and natural margins was associated with water conditions. Water table depth and peat moisture content were significantly correlated to plant species composition (Mantel tests, $r = 0.27$, $P = 0.001$ and $r = 0.19$, $P = 0.001$ respectively).

Vegetation strata cover among plot types

Plot types (NC, NM, RM) differed significantly in percent cover of lichens, mosses other than *Sphagnum*, ericaceous shrubs, herbs and open water ($P = 0.0001$ in all cases). Lichens were most abundant in natural centres, probably due to the influence of the Atlantic bog type which develops *Sphagnum*/lichens mosaics (Keys & Henderson 1987), and least abundant in natural margins (Fig. 5A). Moss cover was lower in natural margins although they covered little surface area in general (Fig. 5B). Herbs covered less surface area in remnant margins than in margins and centres of natural bogs (Fig. 5C). In contrast, ericaceous shrubs were the most abundant in remnant margins and the least abundant in natural centres (Fig. 5D). The percent cover of ericaceous shrubs was significantly higher in the third transect, the most peripheral one (Fig. 5E). There was more open water in natural centres than in the two other plot types owing to the presence of pools (Fig. 5F). The percentages of open water cover are low because we recorded open water cover only along transects that were 5 m wide and because transects were laid so as to avoid crossing deep pools. In our study, eight natural bogs (out of 24) had pools in their centre and very few pools extended towards the margins. Only one sampled remnant had pools which showed signs of drainage impacts as indicated by the aquatic species *Nuphar variegatum* growing on dry peat.

There was a significant interaction between the effect of transect and plot type on the percent cover of the other strata: *Sphagnum* mosses, litter, shrubs other than *Ericaceae* and trees ($0.0001 < P < 0.047$). *Sphagnum* mosses were markedly less abundant in remnant margins than in margins and centres of natural bogs (NC, NM) (Fig. 6A). Moreover, within remnant margins, *Sphagnum* cover was lower on the transect nearest to the mined area than on the other two transects. Litter had an opposite response, covering more surface area in remnant margins than in the natural bogs and, within remnant margins, being more abundant near the mined area (Fig. 6B). Shrubs other than *Ericaceae* were more abundant in the margins of either natural or remnant bogs compared to the centres and, within these margins, their cover was more important in the most peripheral transect (Fig. 6C). Trees showed a pattern similar to that of shrubs other than *Ericaceae* but there was no difference between natural centres and the first two transects in natural margins (Fig. 6D).

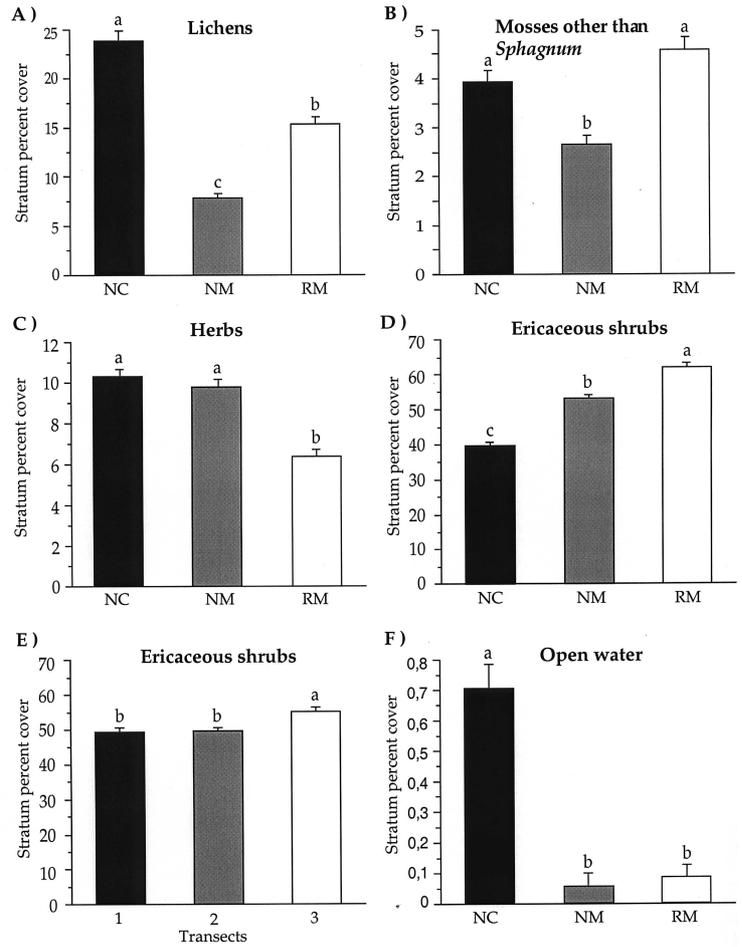


Fig. 5. Mean of strata percent cover for four vegetation strata (A - D) and one substratum (F) among plot types (NC = Natural centre; NM = Natural margin; RM = Remnant margin) and mean of strata percent cover for ericaceous shrubs among transects (E). Error bars are SE. Bars having dissimilar letters above them differ significantly. The level of significance was corrected for the number of comparisons.

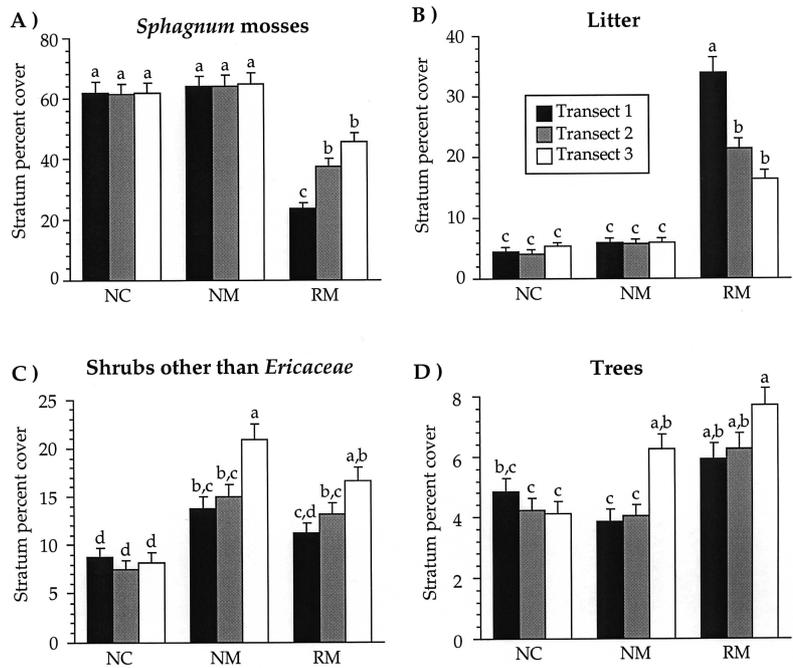


Fig. 6. Mean of strata percent cover for three vegetation strata (A, C, D) and one substratum (B) among plot types (NC=Natural centre; NM=Natural margin; RM = Remnant margin) for each transect (1, 2, 3). Error bars are SE. Bars having dissimilar letters above them differ significantly. The level of significance was corrected for the number of comparisons.

Discussion

Our study demonstrates that plant species assemblages of natural bog areas left by peat mining industry were different from the ones representative of an entire natural bog. Indeed, the location of the remnants and their susceptibility to drainage affected the preserved vegetation.

Species assemblages in natural bogs: centre vs. margins

Similarity analyses did not reveal any evidence of differences in plant assemblages between margins and centres of natural open bogs sampled. In contrast, many studies have found vegetation, hydrologic (Damman & Dowhan 1981; Bubier 1991) and/or chemical (Vitt & Bayley 1984) gradients from margins to centre in natural bogs. However, in these cases, sampling was not restricted to the open part of the natural bog and often included forested edges of the peatlands. Some studies even included the lagg zone (Bubier 1991). The peatland-margin to peatland-expanse gradient used in published studies was minimized in our study, which was limited to the open, exploitable part of the bog only.

Despite the plant assemblages response, some species were preferentially located in the bog centre. With statistical ordination, we discerned, at the species level, some responses that were undetectable at the plant assemblages level with similarity indices. According to the ordination biplot and to the strata sampling, the species group associated with the lawn/carpet microhabitat was found in bog centres where open water tended to occur. Even though few bogs developed pools, the high association of pools with specific plants contributed to local biodiversity. Peat mining leaves remnants which usually do not retain pools due to their peripheral location and thereby contributes to lower biodiversity within bogs.

Effect of peat mining on vegetation and water conditions

Plant species assemblages found aside the mined area of exploited bogs were markedly different of those of the natural bog habitat. Some species were favoured by dryness prevailing in remnant margins while *Sphagnum* mats were greatly reduced compared to natural margins, pointing out the dryer state of the remnants. Indeed, *Sphagnum* mosses are extremely sensitive to water availability (Wagner & Titus 1984; Rydin & McDonald 1985). The marked difference of *Sphagnum* cover between natural and remnant margins must have strongly influenced the value of the similarity index when comparing plant assemblages between those plot types as the similarity index used took abundances into

account. Within remnants, even the third transect, which was on average 60 m from the mined area, had less extensive *Sphagnum* mats than the corresponding transect in natural margins. According to the percent cover gradient from the mined area within remnant margins, *Sphagnum* mosses proved to be a key stratum indicator of mining effect on vegetation.

Vegetation differences found between remnants and natural margins were related to water conditions. Remnants were drier than natural margins. The overall peat moisture content of remnant margins was lower than in natural margins and, for any transect, the water table was lower in remnant margins than in natural margins. Many authors suggest that the water table is not affected more than 5 to 10 m away from the drainage ditch (Boelter 1972; Berry & Jeglum 1991). Nevertheless, Hillman (1992) reported that the level of the water table can be lowered by as much as 56 cm halfway between ditches spaced 50 m apart. Moreover, Boelter (1972) has shown that if the peat is fibric, the water table can be lowered more than 50 m away from a drainage ditch. In our study, the highest degree of peat decomposition was 3 on Von Post scale, indicating the susceptibility of peat to drainage.

Moreover, the water table gradient from the exploited edge within remnants suggests that their drier state was due to peat mining and not to intrinsic pre-mining conditions. In the latter case, we would either have expected no differences between transects or have predicted an inverse gradient (according to contrast with natural margins). The fact that peat moisture content did not follow the same trend as the water level within remnants could be due to higher peat compaction, which could have occurred toward the mined edge (Rothwell et al. 1996). Indeed, peat compaction increases bulk density and water retention capacity (Price 1997). Thus subsidence may have lessened the effect of a lower water table. The higher degree of decomposition of the first transect within remnant margins also suggests subsidence. Nevertheless, higher water retention of peat near the mined edge did not promote *Sphagnum* growth since this water is not readily available to *Sphagnum* mosses which have a weak capillary pull on water (Price 1997).

Management recommendations, conservation and restoration implications

For metapopulation dynamics, whole bog conservation is probably more important than remnants within exploited sites. Nevertheless, on a shorter time scale, bog remnants beside mined areas may function as refuges for plant communities during peat extraction, and as a source of colonists for restoration once peat mining is abandoned. Until now, establishment of a *Sphagnum* carpet has been the main focus of restoration in eastern Canada

(Campeau & Rochefort 1996; Quinty & Rochefort 1997; Rochefort & Campeau 1997). Remnants studied here included the main *Sphagnum* species used for active reintroduction in restoration processes: *S. fuscum*, *S. angustifolium*, *S. capillifolium*, *S. magellanicum*, *S. flavicomans* (Campeau & Rochefort 1996; Rochefort et al. 1997). Nevertheless, sampling by strata showed that the *Sphagnum* carpet expanse in remnant sites was reduced. Moreover, some *Sphagnum* species (those of the lawn/carpet microhabitat in particular) were absent or rarely found in remnant sites. For *Carex* species and ericaceous shrubs, which were recently subjected to restoration experiments (Boudreau & Rochefort 1998), only the latter were well represented in studied remnants.

Significant differences in plant species assemblages and water conditions between remnants and natural bogs suggest that current peat mining practices reduce the ecological integrity of remnants. Exploitation management which usually leaves remnants at the bog margins for economic or logistical reasons, should favour the conservation of fewer, larger remnants. As *Sphagnum* mosses and water conditions were still affected at 60 m on average from the mined area, a vegetated strip wider than 120 m is likely to be required in order to counteract influences from ecosystems adjacent to bogs. This should help to preserve natural bog refuges from drainage effects, both from the mined area and the surrounding ecosystem. Moreover, due to their associated plant species, peatlands with pool systems in their centre should be managed differently. They should be excluded from peat mining development and conserved intact. A less constrained conservation option would be to preserve a big natural section beside the exploited area when pools are numerous and extend towards the margins. This big remnant should have a shape that maximises the area to perimeter ratio so as to counteract drainage and peat blowing effects.

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App. 1. List of all species recorded with their percent occurrence for each plot type (out of 24 for each type) (NC=natural centre; NM=Natural margin; RM=Remnant margin). Species with a ♣ symbol are considered shading over the ground layer and build the environmental variable named shade (see Fig. 3). ♦ According to Fernald (1950).

Code		NC (24)	NM (24)	RM (24)	Total (72)
Sphagnum mosses					
ANG	<i>Sphagnum angustifolium</i>	13	54	29	32
AUS	<i>S. austinii</i>	13	0	4	6
CAP	<i>S. capillifolium</i>	100	100	96	99
CUS	<i>S. cuspidatum</i>	29	4	8	14
FAL	<i>S. fallax</i>	8	21	8	13
FLA	<i>S. flavicomans</i>	21	17	21	19
FUS	<i>S. fuscum</i>	96	88	88	90
MAG	<i>S. magellanicum</i>	92	83	88	88
MAJ	<i>S. majus</i>	25	4	8	13
PAP	<i>S. papillosum</i>	8	4	4	6
PUL	<i>S. pulchrum</i>	8	0	4	4
RUS	<i>S. russowii</i>	4	0	8	4
TEN	<i>S. tenellum</i>	21	0	4	8
RIP	<i>S. riparium</i>	4	0	0	1
Mosses other than Sphagnum					
Aul pal	<i>Aulacomnium palustre</i>	4	13	4	7
Cal str	<i>Calliergon stramineum</i>	4	0	0	1
Dic cer	<i>Dicranella cerviculata</i>	0	0	4	1
Dic lei	<i>Dicranum leioneuron</i>	8	0	25	11
Dic mon	<i>D. montanum</i>	4	8	8	7
Dic pol	<i>D. polysetum</i>	21	46	67	44
Dic sco	<i>D. scoparium</i>	8	4	8	7
Dic spa	<i>D. spadiceum</i>	4	4	4	4
Dic ond	<i>D. undulatum</i>	50	46	75	57
Ple sch	<i>Pleurozium schreberi</i>	29	63	58	50
Poh nut	<i>Pohlia nutans</i>	67	67	75	69
Pol str	<i>Polytrichum strictum</i>	79	83	88	83
Ste ser	<i>Steerecleus serrulatus</i>	4	0	0	1
Warnst.	<i>Warnstorfia exannulata</i>	4	0	0	1
Warnst.	<i>W. fluitans</i>	13	4	4	7
Warnst.	<i>W. spec.</i>	4	0	0	1
Liverworts					
Bar att	<i>Barbilophozia attenuata</i>	8	13	8	10
Baz tri	<i>Bazzania trilobata</i>	4	21	17	14
Ble tri	<i>Blepharostoma trichophyllum</i>	38	25	8	24
Cep sp.	<i>Cephalozia spec.</i>	13	0	0	4
Cal mue	<i>Calypogeja muelleriana</i>	0	13	0	4
Cla flu	<i>Cladopodiella fluitans</i>	42	13	13	22
Myl ano	<i>Mylia anomala</i>	96	83	83	88
Lichens					
Cetraria	<i>Cetraria islandica ssp. crispiformis</i>	13	4	0	6
Cetraria	<i>C. islandica ssp. islandica</i>	21	17	8	15
Cet del	<i>Cetrariella delisei</i>	4	0	0	1
Cla mit	<i>Cladina mitis</i>	63	63	79	68
Cla ran	<i>C. rangiferina</i>	71	75	88	78
Cla ste	<i>C. stellaris</i>	54	42	42	46
Cla sty	<i>C. stygia</i>	33	25	17	25
Cla amo	<i>Cladonia amaurocraea</i>	4	0	0	1
Cla bac	<i>C. bacillaris</i>	0	0	4	1
Cla bot	<i>C. botrytes</i>	0	0	4	1
Cla cen	<i>C. cenotea</i>	4	4	21	10
Cla chl	<i>C. chlorophaea</i>	8	21	21	17
Cla cer	<i>C. cervicornis ssp. verticillata</i>	4	0	0	1
Cla con	<i>C. conista</i>	0	0	4	1
Cla cri	<i>C. crispata</i>	17	25	33	25
Cla crt	<i>C. cristatella</i>	4	13	17	11
Cla dec	<i>C. decorticata</i>	0	0	4	1
Cla def	<i>C. deformis</i>	8	17	42	22
Cla fim	<i>C. fimbriata</i>	8	25	21	18
Cla max	<i>C. maxima</i>	0	8	0	3
Cla phy	<i>C. phyllophora</i>	0	0	4	1
Cla ple	<i>C. pleurota</i>	4	0	4	3
Cla squ	<i>C. squamosa</i>	8	8	8	8
Mic mel	<i>Micarea melaena</i>	0	0	4	1
Par hyp	<i>Parmeliopsis hyperopta</i>	0	4	0	1
Herbs					
Are bul	<i>Arethusa bulbosa</i>	0	4	0	1
Cal pul	<i>Calopogon pulchellus</i>	13	13	17	14

App. 1, cont.

Code		NC (24)	NM (24)	RM (24)	Total (72)
Car exi	<i>Carex exilis</i>	0	4	0	1
Car int	<i>C. interior</i>	0	4	0	1
Car lim	<i>C. limosa</i>	21	17	4	14
Car oli	<i>C. oligosperma</i>	8	17	21	15
Car pau	<i>C. pauciflora</i>	0	21	8	10
Car tri	<i>C. trisperma</i>	4	21	0	8
Com liv	<i>Comandra livida</i>	8	33	33	25
Cop gro	<i>Coptis groenlandica</i>	4	8	8	7
Cyp aca	<i>Cypripedium acaule</i>	0	4	17	7
Dro ang	<i>Drosera anglica</i>	17	0	0	6
Dro rot	<i>D. rotundifolia</i>	96	75	75	82
Eri ang	<i>E. angustifolium</i>	17	63	46	42
Eri cam	<i>E. chamissonis</i>	8	0	4	4
Eri spi	<i>E. vaginatum</i> ssp. <i>spissum</i>	71	67	63	67
Eri eru	<i>E. vaginatum</i> ssp. <i>spissum</i> f. <i>erubescens</i> ♦	13	17	8	13
Eri vir	<i>E. virginicum</i>	33	17	25	25
Hab ble	<i>Habenaria blephariglottis</i>	0	4	0	1
Mai can	<i>Maianthemum canadense</i>	0	0	4	1
Mel lin	<i>Melampyrum lineare</i>	8	25	25	19
Nup var	<i>Nuphar variegatum</i>	21	0	4	8
Osm cin♣	<i>Osmunda cinnamomea</i>	0	4	0	1
Rhy alb	<i>Rhynchospora alba</i>	25	0	8	11
Rub cha♣	<i>Rubus chamaemorus</i>	79	75	88	81
Sar pur	<i>Sarracenia purpurea</i>	71	75	79	75
Sch pal	<i>Scheuchzeria palustris</i>	4	4	8	6
Sci ces	<i>Scirpus caespitosus</i>	50	50	42	47
Sis mon	<i>Sisyrinchium montanum</i>	4	0	0	1
Smi triß	<i>Smilacina trifolia</i>	25	46	33	35
Tri bor	<i>Trientalis borealis</i>	0	0	4	1
Utr cor	<i>Utricularia cornuta</i>	21	0	0	7
Xyr car	<i>Xyris caroliniana</i>	4	0	0	1
Xyr mon	<i>X. montana</i>	4	0	0	1
Ericaceous shrubs					
And glaß	<i>Andromeda glaucophylla</i>	58	29	50	46
Cha calß	<i>Chamaedaphne calyculata</i>	100	100	100	100
Gau his	<i>Gaultheria hispida</i>	21	25	21	22
Gau pro	<i>G. procumbens</i>	4	4	8	6
Gay bac♣	<i>Gaylussacia baccata</i>	33	29	29	31
Kal ang♣	<i>Kalmia angustifolia</i>	100	100	100	100
Kal pol♣	<i>K. polifolia</i>	100	92	100	97
Led gro♣	<i>Ledum groenlandicum</i>	92	100	100	97
Oxy mac♣	<i>Oxycoccus macrocarpus</i>	8	0	4	4
Oxy ova	<i>O. ovalifolius</i>	100	96	92	96
Rho can♣	<i>Rhododendron canadense</i>	50	46	58	51
Vac ang♣	<i>Vaccinium angustifolium</i>	58	71	71	67
Vac myr♣	<i>V. myrtilloides</i>	8	0	13	7
Vac hyb♣	<i>V. angustifolium</i> x <i>myrtilloides</i>	0	0	4	1
Shrubs other than Ericaceae					
Aro mel♣	<i>Aronia melanocarpa</i>	13	8	8	10
Emp nig♣	<i>Empetrum nigrum</i>	50	46	58	51
Nem muc♣	<i>Nemopanthus mucronata</i>	8	33	25	22
Sal dis♣	<i>Salix discolor</i>	0	4	0	1
Myr gal♣	<i>Myrica gale</i>	13	8	21	14
Trees					
Abi bal♣	<i>Abies balsamea</i>	0	4	0	1
Ace ru♣	<i>Acer rubrum</i>	0	8	4	4
Bet pap♣	<i>Betula papyrifera</i>	4	0	4	3
Bet pop♣	<i>B. populifolia</i>	0	0	13	4
Bet pum♣	<i>B. pumila</i>	4	4	0	3
Cor can♣	<i>Cornus canadensis</i>	0	8	4	4
Lar lar♣	<i>Larix laricina</i>	54	46	58	53
Pic mar♣	<i>Picea mariana</i>	67	92	83	81
Pin div♣	<i>Pinus divaricata</i>	4	8	0	4
Vib cas♣	<i>Viburnum cassinoides</i>	0	13	0	4
Others					
Bpeat	Bare peat	0	0	33	11
DBranch♣	Death Branch	21	33	33	29
Lit	Litter	92	96	100	96
Mush	Mushroom spp.	8	25	21	18
Owater	Open water	33	17	4	18