

# Vegetation of *Sphagnum* bogs in highly disturbed landscapes: relative influence of abiotic and anthropogenic factors

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## Abstract

**Question:** Has the vegetation of *Sphagnum* bogs been affected by more than 200 years of human activities?

**Location:** Bas-Saint-Laurent region, southeastern Québec, Canada.

**Methods:** Data (species assemblages, abiotic and spatio-historical variables) were collected in 16 bogs ranging from 2 to 189 ha, and incorporated in a geographical information system. Major gradients in vegetation composition were identified using DCA. CCA was used to relate vegetation gradients to abiotic and spatio-historical variables.

**Results:** A clear segregation of species assemblages was observed, from open and undisturbed bogs to forested and highly disturbed sites. Among abiotic factors, tree basal area, water table level and peat thickness had a significant influence on plant species composition. Among spatio-historical factors, disturbance level, area loss and fire were the most influential factors. Variance partitioning between these groups of factors suggests that spatio-historical factors had a major influence on peatlands, representing 22% of the variation observed in the plant species assemblages while abiotic factors represent only 17% of the variation.

**Conclusions:** The results highlight the influence of agricultural and other anthropogenic activities on plant assemblages and suggest that even wetlands apparently resistant to disturbances, such as peatlands, can be severely affected by anthropogenic factors. Plant species assemblages of ombrotrophic peatlands of the Bas-Saint-Laurent region were, and still are, largely influenced by human activities.

**Keywords:** Agricultural activity; CCA; Conservation; DCA; Peatland; Plant assemblage; Québec.

**Nomenclature:** Anderson et al. (1990) for mosses; Esslinger & Egan (1995) for lichens; Marie-Victorin (1995) for vascular plants.

**Abbreviation:** GIS = Geographical information system.

## Introduction

Most terrestrial ecosystems at temperate latitudes have been subjected to human use that has subdivided previously contiguous habitats into smaller patches and has isolated those patches within a highly disturbed matrix (Forman 1995). This continuing process of habitat fragmentation and isolation ultimately leads to a reduction in species richness and diversity at a regional scale (Simberloff 1988, 1998). The first impact of fragmentation is habitat destruction, which primarily affects population sizes and, consequently, extinction rates. A decline in species richness is usually observed in remaining patches (Gilpin & Soulé 1986; Wilcove et al. 1986; Collinge 1996). The second impact is isolation, which primarily affects dispersal and immigration rates (Haila & Hanski 1984; Wilcove et al. 1986; Saunders et al. 1991; Debinski & Holt 1999). It is now becoming increasingly clear that the impact of habitat fragmentation and isolation is driven by edge effects and by the nature and characteristics of the surrounding matrix (Gascon & Lovejoy 1998; Gilfedder & Kirkpatrick 1998; Ås 1999; Jules et al. 1999; Kemper et al. 1999; Jules & Shahani 2003).

Edge effects and the surrounding matrix also influence wetland ecosystems (Jean & Bouchard 1993; Findlay & Houlihan 1997), usually through drainage. For instance, Knutson et al. (1999) demonstrated that landscape metrics representing edge effects and surrounding matrices are strongly associated with frog and toad abundance in the marshes and swamps of Iowa and Wisconsin. However, it is not clear whether peatlands, which naturally occur in the landscape as separate and isolated patches within a matrix of upland habitats (Moore 1990), are affected by anthropogenic fragmentation and isolation. Ombrotrophic peatlands (bogs), in particular, develop in isolation from each other and the species that inhabit these ecosystems must colonize new locations from afar (Moore 2002). Furthermore, bogs are usually considered resistant: several studies suggest that *Sphagnum* dominated vegetation communities show little change through

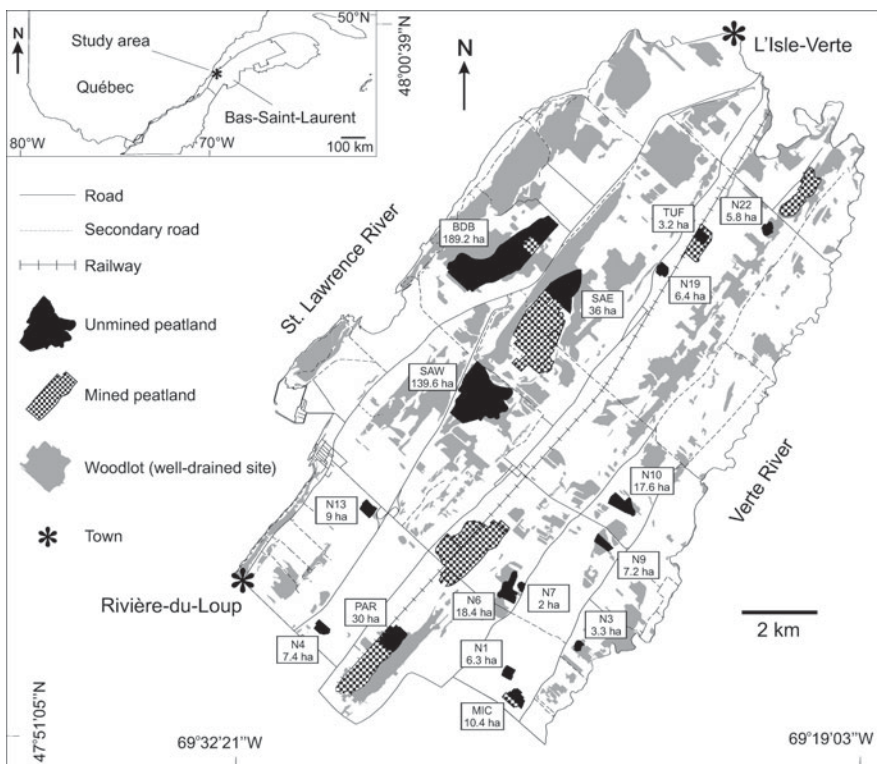
time despite anthropogenic or natural disturbances (Backéus 1972; Jasieniuk & Johnson 1982; Laine et al. 1995a; Gunnarsson et al. 2000). However, the scale (both in space and time) is important. Some events are disturbances at the vegetation level, but not necessarily at the unit (bog) level (e.g. fire). On the other hand, other disturbances may have no short-term effects at the vegetation level, but may have disastrous effects on the long-term functioning of the bog (e.g. drainage).

The objectives of this study were to (1) characterize plant assemblages present in a series of ombrotrophic peatlands located within a highly disturbed matrix and (2) evaluate the relative influence of abiotic and anthropogenic factors on the distribution of plant species. By using spatio-historical factors that describe human activities within and outside of the peatlands, including variables accounting for edge effects and the nature of the matrix, and abiotic factors that describe the actual conditions existing within these bogs, it would be possible to evaluate whether anthropogenic factors had an influence on the distribution of plant species. We hypothesized that the severity of the fragmentation and isolation processes strongly influences the abiotic environment of bog ecosystems, which explains their plant species assemblages. These peatlands can no longer be considered 'pristine' ecosystems.

## Methods

### Study area and sampling sites

Ombrotrophic peatlands of the Bas-Saint-Laurent region, in southeastern Québec, Canada (Fig. 1), offer a good opportunity for the study of the influence of anthropogenic fragmentation and isolation on natural bogs. These bogs are representative of ombrotrophic peatlands of eastern Canada, with their thick (> 1 m) peat deposit and plant communities largely dominated by *Sphagnum* species, at least before the beginning of the 19th century (Gauthier & Grandtner 1975; Pellerin & Lavoie 2003b). They have been fragmented and isolated into a matrix characterized by agriculture and peat extraction for the past 200 yr (Pellerin 2003a). Some sites are dissected by drainage ditches, and most of them have burned during the last century, probably due to human ignited fires (Pellerin & Lavoie 2003a, b; Pellerin 2003b). They are located in a 4 to 12 km wide agricultural plain bordering the south shore of the St. Lawrence River. The study area (176 km<sup>2</sup>) is a narrow strip of agricultural lands located between the cities of Rivière-du-Loup and L'Isle-Verte (Fig. 1). Few settlers established in the study area before 1800 (Morin 1993). The original forest cover of the plain was almost completely cleared during the first part of the 19th century, and most of the area was used



**Fig. 1.** Study area, Bas-Saint-Laurent region, southeastern Québec (Canada) and spatial distribution of studied bogs, surrounding woodlots and mined peatlands. Data on woodlots are from Environnement Canada (Anon. 1999b).

for agriculture by 1870 (Fortin 1993a). These peatlands were one of the last ecosystems without agricultural or industrial activities (Fortin 1993b). Nevertheless, between 1929 and 2000, 62% of the total area covered by bogs was disturbed, either by peat mining, logging or farming activities (Pellerin 2003a).

We chose 16 bogs, or bog remnants, within the study area. These had never been subjected to peat mining, large-scale logging or farming activities. They ranged from 2 to 189 ha (Fig. 1). Although most bogs have probably been influenced by surrounding human activities, previous studies indicated that the central parts of the two largest peatlands (140 and 189 ha) have not been disturbed, and can be considered as reference sites (Pellerin & Lavoie 2003b). Peatland vegetation is characterized by a mosaic of open and forested patches. Dominant tree species include *Picea mariana*, *Pinus banksiana* and *Larix laricina*. Ericaceous shrubs are widespread in all bogs. In open habitats, the ground layer is covered by *Sphagnum* mosses, whereas *Pleurozium schreberi* dominates the ground layer of forested sites.

#### Field sampling and laboratory analyses

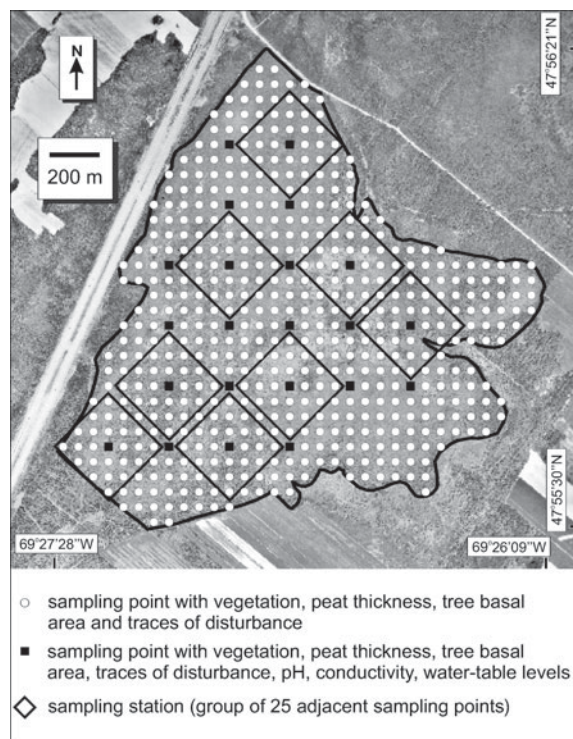
Vascular plants, mosses, liverworts and lichens were sampled in the 16 peatlands during summer 2000, using the following sampling scheme. The most recent (1995) aerial photograph (1 : 15 000) covering each bog was digitized, registered in space and corrected to limit geometrical distortions using Geographic Transformer software (Anon. 1998). Corrected photographs were imported into a geographical information system (GIS) (Anon. 1999a). In the GIS, a grid of sampling points located 50 m apart was superimposed on the 12 largest peatlands (6.3 - 189.2 ha; Fig. 2). The four smallest peatlands (2.0 - 5.8 ha) had a grid with points separated by a distance ranging from 25 to 40 m, in order to have a minimum of 30 sampling points in each bog. The latitude and longitude of each sampling point ( $N = 2096$ ) were obtained with the GIS and located in the field using a global positioning system receiver.

We identified all plant species present in a 50 cm × 50 cm quadrat laid on the ground at each sampling point. The presence of all species covering (at least partly) the vertical projection of the quadrat was also noted. Each plant species was ascribed to a particular habitat (ombrotrophic or minerotrophic peatland) using Scoggan (1978-1979), Gauthier (1980), Marie-Victorin (1995), Girard (2000) and Garneau (2001).

Near the sampling point, we measured the thickness of the peat deposit using an iron rod driven into the soil. We identified each tree stem selected with a prism to calculate tree basal area (Bitterlich 1984). Tree basal

area was used as an indicator of the importance of tree cover and shading. In the vicinity of each sampling point traces of disturbance, such as stumps or other woodcutting evidence, all terrain vehicle tracks, or walking or skiing trails were noted. Peat samples were taken at one out of every 25 sampling points following a regular grid (Fig. 2). They were obtained under the layer of living mosses, at 10 to 15 cm depth. Corrected conductivity and pH of peat samples were later determined in the laboratory, using methods described by Sjörs (1950) and Karam (1993). Highest and lowest water table levels were measured, again at one out of 25 sampling points, with the PVC tape discoloration method (Belyea 1999). Bamboo stakes with PVC tape were left *in situ* at sampling stations for three months, from early June to the end of August 2001.

To obtain abundance values for plant species, sampling points were grouped into sampling stations, i.e. groups of 25 contiguous points centred on the point where water table levels, pH and conductivity were measured (Fig. 2). Since sampling stations would overlap each other in large peatlands (> 18.4 ha), they were randomly chosen with a non-overlapping condition using the GIS (Fig. 2). Consequently, 44 sampling stations were created and other variables were calculated with the help of the GIS.



**Fig. 2.** Sampling design for the SAW peatland, Bas-Saint-Laurent region, Québec.

Distance separating the centroid of the sampling station from the nearest edge of the peatland was measured. A drainage index was calculated as the percentage of sampling points at a sampling station within 40 m of a drainage ditch. At shorter distances, a drainage ditch has an impact on the water level of peaty soils important enough to improve tree growth (Prévost et al. 2001). A disturbance index was calculated as the percentage of sampling points with traces of disturbance. The other spatio-historical variables were calculated for each peatland using the GIS and historical data of Pellerin (2003b) sampled in the same peatlands, and assigned to their respective sampling stations. Area was defined as the surface of the bog or bog fragment. Anthropogenic perimeter was the percentage of the peatland perimeter bordered by agricultural, peat mining and/or wood cutting activities, and/or by a road or a railway. Area loss, defined as the percentage of the area that has been lost during the last 50 yr because of peat mining or agricultural activities, and years elapsed since the last fire were obtained from Pellerin (2003b). It should be noted that most peatland area losses occurred during this period, mainly due to large-scale mining activities.

#### Data analysis

To conduct statistical analyses, we first constructed a vegetation matrix including the 44 sampling stations and the 136 plant species noted in these stations. Matrix cells contained the percentage of sampling points where a species was noted. We also constructed a data matrix for six abiotic variables characterizing each station and a data matrix for seven spatio-historical variables associated with each station (Table 1). Major gradients in vegetation composition were identified using Detrended

Correspondence Analysis (DCA). Canonical Correspondence Analysis (CCA) was then used to relate vegetation gradients to abiotic and spatio-historical variables. The combined use of DCA and CCA, detailed elsewhere (Økland 1990; Jean & Bouchard 1993; Anderson & Davis 1997; Girard et al. 2002), is appropriate for describing community structure (McCune 1997). For revealing the proportion of vegetation variability that could be accounted for by the abiotic and spatio-historical data sets, we used the four step procedure described by Borcard et al. (1992) and Jean & Bouchard (1993). Within each CCA, Monte Carlo permutation tests were performed to assess the significance of the trace statistics and of the first eigenvalue (ter Braak & Šmilauer 1998). All ordinations were carried out using CANOCO (ter Braak & Šmilauer 1998). To further distinguish species assemblages, a cluster analysis was also used. Clustering was made using Ward's method (Hair et al. 1987), which gave the clearest results. Cluster analysis was carried out using SPSS (Anon. 2000).

#### Results

##### Plant species assemblages

The DCA depicts patterns of variation in the plant species assemblages independent of the environmental variables (Fig. 3). Abiotic or spatio-historical variables can, nevertheless, be related to ordination axes with correlation coefficients. The percentages of species variance accounted for by the first two axes (calculated using eigenvalues and total inertia in Table 2) are 17 and 9%, respectively. The low percentage that is ex-

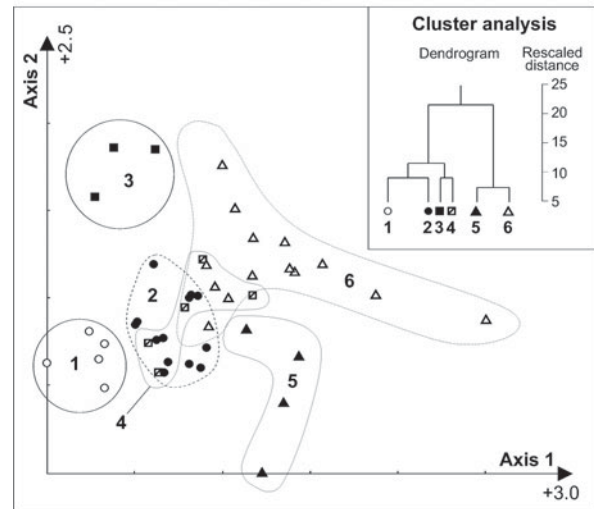
**Table 1.** Abiotic and spatio-historical variables collected for each sampling station in the 16 studied peatlands (Bas-Saint-Laurent region, Québec), and used in the DCA and CCA models (bold = variables considered by CANOCO as significant components of the models).

Variable	Note
Abiotic	
pH	From a peat sample collected at the centre of each station
Conductivity ( $K_{\text{corr}}$ at 25°C)	From a peat sample collected at the centre of each station
<b>Tree basal area</b>	Mean of all sampling points in each station
<b>Peat thickness</b>	Mean of all sampling points in each station
Highest water-table level	At the centre of each station
<b>Lowest water-table level</b>	At the centre of each station
Spatio-historical	
Distance from the edge	Minimal distance between the centroid of the station and the closest edge of the peatland
<b>Disturbance index</b>	Percentage of sampling points in each station showing traces of disturbance, other than drainage ditches
<b>Area</b>	Total area of the peatland
Anthropogenic perimeter	Percentage of the peatland perimeter bordered by agricultural, peat extraction and/or wood-cutting activities and/or by a road or a railway
<b>Area loss</b>	Percentage of the peatland area lost between 1948 and 1995, i.e. during the period covered by aerial photographs
<b>Time elapsed since fire</b>	Years
Drainage index	Percentage of sampling points in each station close (< 40 m) to a drainage ditch

plained by the axes is not surprising due to the large number of rare species in the vegetation matrix (Gauch 1982). The station scores on the first axis are strongly correlated with tree basal area ( $r = 0.84$ ) and the disturbance index ( $r = 0.73$ ), as well as distance from the edge ( $r = -0.86$ ) and area ( $r = -0.76$ ). This axis therefore depicts a complex gradient from open, undisturbed stations located at the centre of large bogs to highly disturbed wooded stations usually close to the edge of peatlands. The second axis is mainly correlated with time elapsed since the last fire ( $-0.82$ ). This axis depicts the transition from stations undisturbed by fire during the last 200 yr to stations recently burned, i.e. during the last 80 yr.

The combined use of DCA and cluster analysis allows the delineation of six different plant species assemblages (Fig. 3), or clusters. Cluster 1 is composed of five stations with typical, open-bog vegetation characterized by carpets of *Sphagnum* species with ericaceous shrubs and scarce *P. mariana* copses. *Chamaedaphne calyculata* is found in 71% of sampling points, which is by far the highest abundance of this ericaceous shrub species in the six clusters. *Sphagnum fuscum*, present in 45% of sampling points, is the most abundant bryophyte. This plant species assemblage is also characterized in the field by a hummock-hollow pattern, typical of open-bog habitats. Cluster 2 shares many species with Cluster 1, but has a much higher *P. mariana* cover, with a lower abundance of *C. calyculata* (33% of sampling points) and *S. fuscum* (12%). Other characteristic species of Cluster 2 are *Nemopanthus mucronatus* (43% of sampling points) and *Dicranum polysetum* (24%). Cluster 3 has a plant assemblage very similar to that of Cluster 1 but with one marked difference, the presence of *P. banksiana*. Furthermore, lichens (*Cladina rangiferina*, *C. stellaris*, *C. mitis*) are abundant.

According to the DCA biplot, Clusters 2 and 4 appear similar in species composition, although cluster analysis located them a good distance from each other. This can be explained by the fact that the DCA biplot exhibits only the first two axes. The third axis is strongly correlated with area. Since Cluster 2 groups



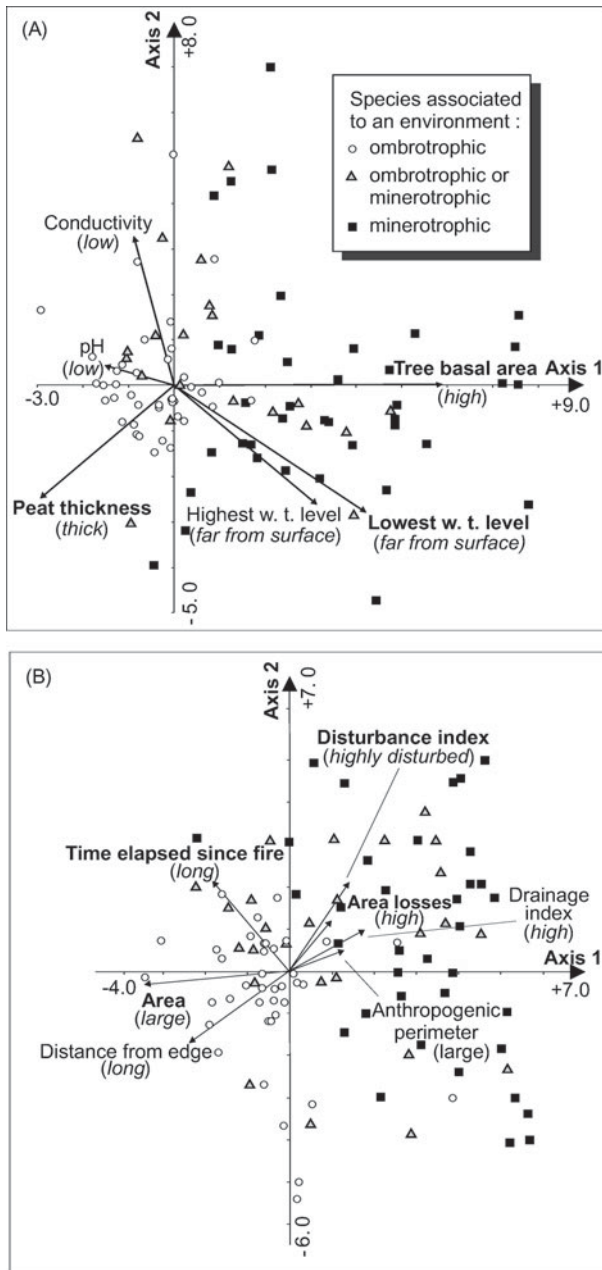
**Fig. 3.** DCA ordination applied to the 44 sampling stations extracted from the studied peatlands, Bas-Saint-Laurent region, Québec. Outlines circumscribe clusters. The dendrogram obtained by cluster analysis is also shown.

together stations extracted from large peatlands and Cluster 4 from small bogs, they strongly differ on the third axis, but appear similar on a biplot (two axes). Cluster 4 differs from Cluster 2 because of the presence of mosses typical of forested bogs, i.e. *Pleurozium schreberi*. Cluster 4 also has a higher richness of herbaceous species. Cluster 5 is composed of stations located at the edge of their respective peatlands and bordering agricultural fields. Consequently, this cluster exhibits an array of minerotrophic and/or opportunistic species, including *Betula* spp., *Carex* spp. and *Sphagnum* spp. (*S. fimbriatum* var. *fimbriatum*, *S. squarrosum* and *S. centrale*). Herbaceous species are abundant, especially *Cornus canadensis* (40% of sampling points). Finally, Cluster 6 delineates all the densely forested stations mainly located in residual peatland fragments and mostly with a high disturbance index ( $> 30\%$ ). Although several bog species are found in these stations, a wide array of forested and/or exotic species has also become established, including *Lythrum salicaria* and *Phragmites australis*. Species richness is

**Table 2.** Comparison of the ordination results by DCA, CCA and partial CCA. Eigenvalues ( $\lambda$ ), species-environment correlation coefficients ( $r$ ) for the first two axes and significance of first canonical axis,  $p(\lambda_1)$ , are shown. Constraining variables are indicated by parentheses, covariables by brackets.

Analysis	$\lambda_1$	$\lambda_2$	$r_1$	$r_2$	$p(\lambda_1)$
DCA with abiotic	0.25	0.13	0.75	0.60	-
DCA with spatio-historical	0.25	0.13	0.68	0.57	-
CCA (abiotic)	0.14	0.07	0.81	0.79	0.005
CCA (spatio-historical)	0.12	0.08	0.84	0.81	0.025
CCA (abiotic) [spatio-historical]	0.10	0.07	0.79	0.85	0.035
CCA (spatio-historical) [abiotic]	0.08	0.07	0.80	0.87	0.048

Total inertia : 1.495



**Fig. 4.** CCA ordinations of all plant species sampled in the studied peatlands (without covariables), Bas-Saint-Laurent region, Québec. Abiotic (A) and spatio-historical (B) variables are superimposed (w.t. = water table). The trophic regime associated with each species is indicated (bold = variables considered by CANOCO as significant components of the models).

high (107 species), but few (32) of the species are typical of ombrotrophic peatlands.

### Environmental gradients

CCA depicts patterns of variation in the vegetation assemblages dependent on environmental gradients and obtained using linear combinations of abiotic or spatio-historical variables. In the CCA carried out with plant species and abiotic factors (Fig. 4a), the percentages of the variance accounted for by the first two axes (calculated using eigenvalues and total inertia in Table 2) are 43 and 20%, respectively. Although McCune (1997) advised against community structure description using CCA, it is noteworthy that minerotrophic species seem to be associated with forested (high tree basal area) and dry (deep water table) stations (Fig. 4a). In the CCA carried out with plant species and spatio-historical factors (Fig. 4b), the percentages of the variance accounted for by the first two axes (calculated using eigenvalues and total inertia in Table 2) are 31 and 19%, respectively, indicating a lower fit than for abiotic factors. Despite this, the CCA biplot using spatio-historical factors produced a clear segregation of points. Ombrotrophic species are mainly located in the left side of the ordination, suggesting the positive influence of a large area and the absence of recent fires. On the other hand, minerotrophic species are apparently associated with disturbances (high disturbance index, major area loss, recent fire) and small bogs.

Partial canonical ordinations were carried out, and the trace and sum of all canonical eigenvalues were calculated for each. In total, 44% of the variation can be explained. Abiotic and spatio-historical variables explain 16.7 and 21.9% of the species data, respectively. The interaction between these two sets of explanatory variables explains 5.4% of the variation in the species data. Finally, 56% of the variation cannot be explained by the two explanatory data sets, probably owing to lack of fit of data to the response model (Økland 1999). Permutation tests on the trace value showed that the available explanatory variables explain a significant part ( $P < 0.01$ ) of the variation in the species data.

### Discussion

Two facts suggest a strong influence of spatio-historical variables on species distribution in peatlands. Of the four variables most strongly correlated with Axis 1 of the DCA, only one is an abiotic variable (tree basal area as a shade indicator). In addition, only one variable is highly correlated with Axis 2 (time elapsed since fire), and it is spatio-historical in nature. The overall distribution of sampling stations can be easily summarized: undisturbed stations of large peatlands are usually near the centre of the biplot; as stations are increasingly

disturbed by human activities (short distance from the edge, high disturbance index, short time since fire), they fan out toward the higher values of the two axes.

CCA of all species and abiotic variables produced a similar ordination, with typical ombrotrophic species near the centre of the biplot while minerotrophic species are located toward the right edge. Tree basal area, water table level and peat thickness are abiotic variables strongly influencing the species distribution in the 16 ombrotrophic peatlands studied. This is not surprising since several other quantitative studies conducted in boreal peatlands have illustrated the single or combined influence of these variables on plant assemblages (Jeglum 1971; Jasienuk & Johnson 1982; Økland 1990; Brown et al. 1993; Jean & Bouchard 1993; Jeglum & He 1995; Anderson & Davis 1997). CCA of all species and spatio-historical variables produced an ordination similar to that of related to abiotic variables, with ombrotrophic species near the centre of the biplot and minerotrophic species located toward the right edge.

Agricultural activities have had a small impact on the area occupied by peatlands in the Bas-Saint-Laurent region during the last 50 yr, compared with peat mining (Pellerin 2003a). However, it is likely that the influence of farmers on plant assemblages of bog remnants is substantial. First, most disturbance traces that have been found are from wood cutting activities. In the Bas-Saint-Laurent region, wood cutting is a small-scale activity conducted by farmers (Pellerin 2003a). Few tree stems are removed, and the impact of such removal on the water table level is probably weak, but the creation of gaps and the resulting modification of the light regime may have a major, although local, impact on species assemblages (Vitt et al. 1990; Anderson et al. 1995). Small bogs (< 20 ha) are also more susceptible to disturbance by farmers. Most small sites are owned by farmers (cf. large sites owned by peat mining companies), they are more accessible and the task of slowly transforming those peatlands into viable agricultural fields is easier. This may partly explain why small bogs have different plant species assemblages compared to large peatlands and why area is such a strong structuring variable. Finally, Pellerin & Lavoie (2003a) have shown that fire occurred more frequently in the Bas-Saint-Laurent peatlands during the last 200 yr than during the remainder of the Holocene. This suggests that recent fires are consequences of an increasing human influence on peatland ecosystems. There is some evidence that farmers were responsible for this increased frequency, but this assertion remains to be substantiated.

Other variables that were considered as non-significant, such as drainage, also are of interest. Drainage is generally considered as having a major impact on peatland species distribution through its effect on water

table level (Price 2001). It should be noted that the drainage index used does not take into account the size, length, depth or inclination of the various drainage ditches, but only their presence; consequently, the drainage index is an imperfect indicator of the impact of drainage ditches. Furthermore, a typical replacement of species assemblages caused by drainage can take as long as 30 yr in ombrotrophic bogs (Laine et al. 1995b). Since most drainage ditches present in the 16 studied peatlands have been dug during the last 50 yr (Pellerin & Lavoie 2003b), the current vegetation would not reflect the actual hydrological conditions. Moreover, Pellerin & Lavoie (2003a, b) suggested that major changes in vegetation structure in the ombrotrophic peatlands of the Bas-Saint-Laurent region require the combined influence of drainage and/or drought and fire. Dry conditions induced by drainage or drought would maintain a bog in a precarious state where the vegetation is able to maintain itself, until an additional disturbance (fire) appears and causes a major shift in species assemblages. Drainage alone would have, at least in the short term, a negligible effect on species distribution. Consequently, bogs that have recently been drained but not burned have probably been less affected by drainage than others.

Significant differences in species assemblages have been observed between peatlands, differences mainly explained by spatio-historical factors associated with human activities. However, our variables describing edge effects and the nature of the surrounding matrix (distance from the edge, anthropogenic perimeter) are non-significant. It then appears that bogs, as other ecosystems, are affected by fragmentation and isolation in a human modified landscape, but that their impacts may not be measured adequately by popular spatial variables. This fact should incite ecologists to be careful when drawing conclusions about edge and matrix effects. Had we limited ourselves to distance from the edge and anthropogenic perimeter as spatio-historical variables we would have wrongly concluded that bogs are not affected by anthropogenic disturbances.

The reliable historical data of Pellerin (2003b) and the extensive database used in this study allow us to infer significant changes in the species assemblages of bogs during recent decades. Undisturbed stations have extensive bryophyte mats consisting of various *Sphagnum* species (*S. fuscum*, *S. magellanicum*, *S. rubellum* and *S. capillifolium*), *Polytrichum strictum*, *Pohlia nutans* and some liverworts, especially *Mylia anomala*. They are dominated by ericaceous shrubs such as *Kalmia angustifolia*, *Rhododendron groenlandicum*, *Chamaedaphne calyculata* and *Vaccinium angustifolium*, and tree cover is low with scarce copses of *P. mariana*. Some species, such as *Sphagnum rubellum* and *Drosera rotundifolia*, deserve attention. These species are almost

exclusively restricted to Cluster 1 and, consequently, may be considered as indicative of undisturbed conditions in ombrotrophic peatlands. As stations become disturbed, bryophytes and liverworts gradually disappear. The tree cover expands, and forest bryophytes such as *Pleurozium schreberi* and *Dicranum polysetum* gain dominance. Ericaceous shrubs usually become more dominant, especially in stations where the canopy is not completely closed. *Chamaedaphne calyculata* is replaced by *Rhododendron canadense*. There is also a diversification of tree species. *P. mariana* remains dominant, but *Betula papyrifera*, *B. populifolia*, *Larix laricina* and *Thuja occidentalis* are also present. Nearby agricultural activities seem to favour the introduction of various herbaceous species, especially *Cornus canadensis* and sedge species. Recent fire coupled with drainage favour the establishment of *Pinus banksiana* and of a stratum of ericaceous shrubs under which *Cladina rangiferina* is mainly found.

## Conclusion

Plant species assemblages of ombrotrophic peatlands of the Bas-Saint-Laurent region are largely influenced by human activities. This fact is clearly illustrated by partial CCA showing that spatio-historical variables related to anthropogenic activities are as efficient as abiotic variables in representing species variation. Palaeo-ecological data strongly suggest that only two centuries ago, most bogs had species assemblages typical of open ombrotrophic ecosystems as shown in Cluster 1 (Pellerin & Lavoie 2000, 2003b). Today, only five out of 44 sampling stations still exhibit vegetation typical of undisturbed peatlands (Gauthier 1980; Campbell & Rochefort 2001). Once habitats have been disturbed, typical and well established ombrotrophic species such as *Chamaedaphne calyculata* and *Sphagnum fuscum* are replaced by *Rhododendron canadense* and other vascular plants.

This study highlights the influence of agricultural activities on peatland integrity, an influence often underestimated when compared to large-scale industrial operations, such as peat extraction. The individual impact of each farmer is small, but in the long-term, their additive impacts can inflict significant damage on peatlands. This study supports the need for precise historical data and extensive vegetation databases to detect subtle, but increasing, changes in species assemblages in ecosystems.

All these elements highlight the need for conservation. Only 0.4% of Québec's peatlands have been preserved (Poulin & Pellerin 2001). Conservation of the Bas-Saint-Laurent region peatlands represents a major

challenge, not only because few stations still exhibit undisturbed vegetation, but also because these particular stations are parts of larger bogs that would need to be preserved in their entirety to ensure that valuable stations would have maximal chances to remain in their current conditions. Such bogs can also be considered as islands of northern vegetation in a southern environment. These large peatlands are refuges for plant and bird species that would otherwise be restricted to northern latitudes (Calmé et al. 2002). By supporting plant and animal populations at the southern edge of their distribution, ombrotrophic peatlands, despite being disturbed, prove to be legitimate conservation candidates as important as pristine boreal peatlands.

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