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# The impact of peatland afforestation on plant and bird diversity in southeastern Québec[1]

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*Abstract*: Forest expansion (afforestation) is one of the main vegetation changes currently observed in peatlands worldwide in response to natural and anthropogenic disturbances. We examined the relationships between plant and bird richness and frequency and extent of the forest cover in bogs of southeastern Québec to evaluate the impact of forest expansion on typical bog species. A total of 154 plant species and 36 bird species were recorded in the 16 peatlands studied (2-189 ha). Richness and frequency of ombrotrophic plant species were negatively associated with an increase in forest cover. Yet, minerotrophic and minerotrophic-ombrotrophic species did not appear to take advantage of this decline. Afforestation influenced bird species composition by altering the vegetation structure in all strata of the bogs (fewer mosses and shrubs, more trees) and by homogenizing the spatial distribution of plant communities (open patches progressively replaced by forested patches). Peatlands of southeastern Québec remain islands of boreal vegetation in a matrix of deciduous forests and agricultural fields, but afforestation appears to progressively reduce the diversity of peatland habitats. Afforestation does not imperil plant or bird species across their entire range, but it contributes to impoverishing regional biodiversity.
*Keywords*: afforestation, biodiversity, *Dendroica palmarum*, *Melospiza lincolnii*, ombrotrophic peatland, *Sphagnum fuscum*.

*Résumé* : L'augmentation du couvert forestier est l'un des principaux changements écologiques qui s'observent dans les tourbières sujettes à des perturbations naturelles et anthropiques. Nous avons étudié l'impact d'une augmentation du couvert forestier sur les différentes espèces d'oiseaux nicheurs et de plantes de tourbières du sud-est du Québec. Au total, 154 espèces végétales et 36 espèces d'oiseaux ont été recensées dans les 16 tourbières étudiées (2 à 189 ha). L'importance du couvert forestier est associée à une diminution de la richesse et de la fréquence d'apparition des espèces végétales ombrotrophes. Les espèces minérotrophes et minérotrophes-ombrotrophes ne semblent pas profiter du déclin des espèces ombrotrophes. L'augmentation du couvert forestier agit sur les espèces d'oiseaux en changeant la structure de la végétation des tourbières (moins de mousses et d'arbustes, davantage d'arbres) et en homogénéisant la répartition spatiale des communautés végétales (aires ouvertes progressivement remplacées par des zones boisées). Les tourbières du sud-est québécois demeurent des îlots de végétation boréale dans une matrice constituée de forêts décidues et de champs agricoles, mais l'augmentation du couvert forestier réduit graduellement la diversité des habitats qu'on y trouve. Cela ne met pas nécessairement en péril les espèces de plantes et d'oiseaux des tourbières, mais cela contribue néanmoins à l'appauvrissement de la diversité régionale.
*Mots-clés* : biodiversité, boisement, *Dendroica palmarum*, *Melospiza lincolnii*, *Sphagnum fuscum*, tourbière ombrotrophe.

*Nomenclature*: Stotler & Crandall-Stotler, 1977; Anderson, 1990; Anderson, Crum & Buck, 1990; Esslinger & Egan, 1995; Gauthier & Aubry, 1995; Hinds, 2000.

## Introduction

Ombrotrophic (bog) and minerotrophic (fen) peatlands are widespread ecosystems, covering about 3-4 × $10^6$ $km^2$ worldwide (Joosten & Clarke, 2002). Most peatlands are located in the boreal zone, between latitudes 50° and 70° N in Canada, Russia, Fennoscandia, and the northwestern part of Europe (O'Neill, 2000). Peat-accumulating ecosystems are one of the main terrestrial carbon sinks and have accumulated about 455 Gt of carbon over the past 10,000 y (Gorham, 1991). The biodiversity of bogs is low, but they have very distinctive flora and fauna, and many species groups can only be found in these ecosystems (Moore, 2002). This is especially true for southern bogs (Maltby, 1986). They exhibit an array of plant and animal species commonly found at more northern latitudes. Bogs can thus be considered as islands of boreal diversity in a temperate zone (Spitzer, Bezděk & Jaroš, 1999; Calmé, Desrochers & Savard, 2002). Consequently, any natural or anthropogenic disturbance altering the nature and distribution of plant and animal communities in bogs may seriously affect regional biodiversity.

Afforestation (increase in tree cover) is one of the main vegetation changes recently observed in peatlands in response to natural and/or anthropogenic disturbances. Raised bogs of western Chile have become increasingly forested near human establishments, probably due to drainage (Pisano, 1983). Large increases in tree cover have been observed in Swedish peatlands over the last 40 y, possibly caused by drainage (Linderholm & Leine, 2004). The proliferation of pine in raised bogs in the Jura Mountains (Switzerland) has also been linked to drainage and peat-cutting activities (Freléchoux *et al.,* 2000). In the last 50 y, many open bogs in the Bas-Saint-Laurent

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region, southeastern Québec (Canada), have undergone major changes in vegetation structure (Figure 1), including large tree cover increases (Pellerin & Lavoie, 2000; Pellerin, 2003b). A dry climatic period during the first part of the 20$^{th}$ century, drainage, and fire events seem to be the main causal factors of these vegetation changes (Pellerin, 2003b; Pellerin & Lavoie, 2003).

Afforestation is expected to be detrimental to peatland biodiversity. Forest expansion has been associated with habitat loss for *Sphagnum* and other moss species (Frankl & Schmeidl, 2000; Pellerin & Lavoie, 2000), and within temperate regions, several moss species are almost exclusively found in bogs. The influence of forest cover on species distribution in bogs has been studied for plants (Lachance & Lavoie, 2004) and insects (Spitzer, Bezdek & Jaros, 1999). However, to our knowledge, no study has investigated the specific influence of afforestation on bog plant and bird assemblages and its subsequent effect on regional biodiversity. Birds were included in this work because a considerable amount of information on the diversity and ecology of bog avian species has recently been collected in southern Québec (Calmé & Desrochers, 1999; 2000; Calmé, Desrochers & Savard, 2002). The objectives of this study were to examine the relationships between plant and bird richness and frequency and extent of the forest cover in bogs, and to evaluate the impact of forest expansion on typical bog species. We hypothesized that forest expansion is accompanied by significant changes in plant and bird assemblages and that, consequently, these changes are detrimental to regional biodiversity.

## Methods

### STUDY AREA AND SAMPLING SITES

Ombrotrophic peatlands of the Bas-Saint-Laurent region, in southeastern Québec, Canada (Figure 2), offer a good opportunity to study the influence of forest expansion on species richness and diversity since all have experienced an increase in their forest cover over the past 50 y (Pellerin, 2003b). These peatlands 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$^2$) is a narrow strip of agricultural lands located between the cities of Rivière-du-Loup and L'Isle-Verte. Few settlers established in the study area prior to 1800 (Morin, 1993). The original forest cover of the plain was almost completely cleared during the first part of the 19$^{th}$ century, and by 1870 most of the area was used for agriculture (Fortin, 1993a). The peatlands were one of the last ecosystems without agricultural or industrial activities (Fortin,

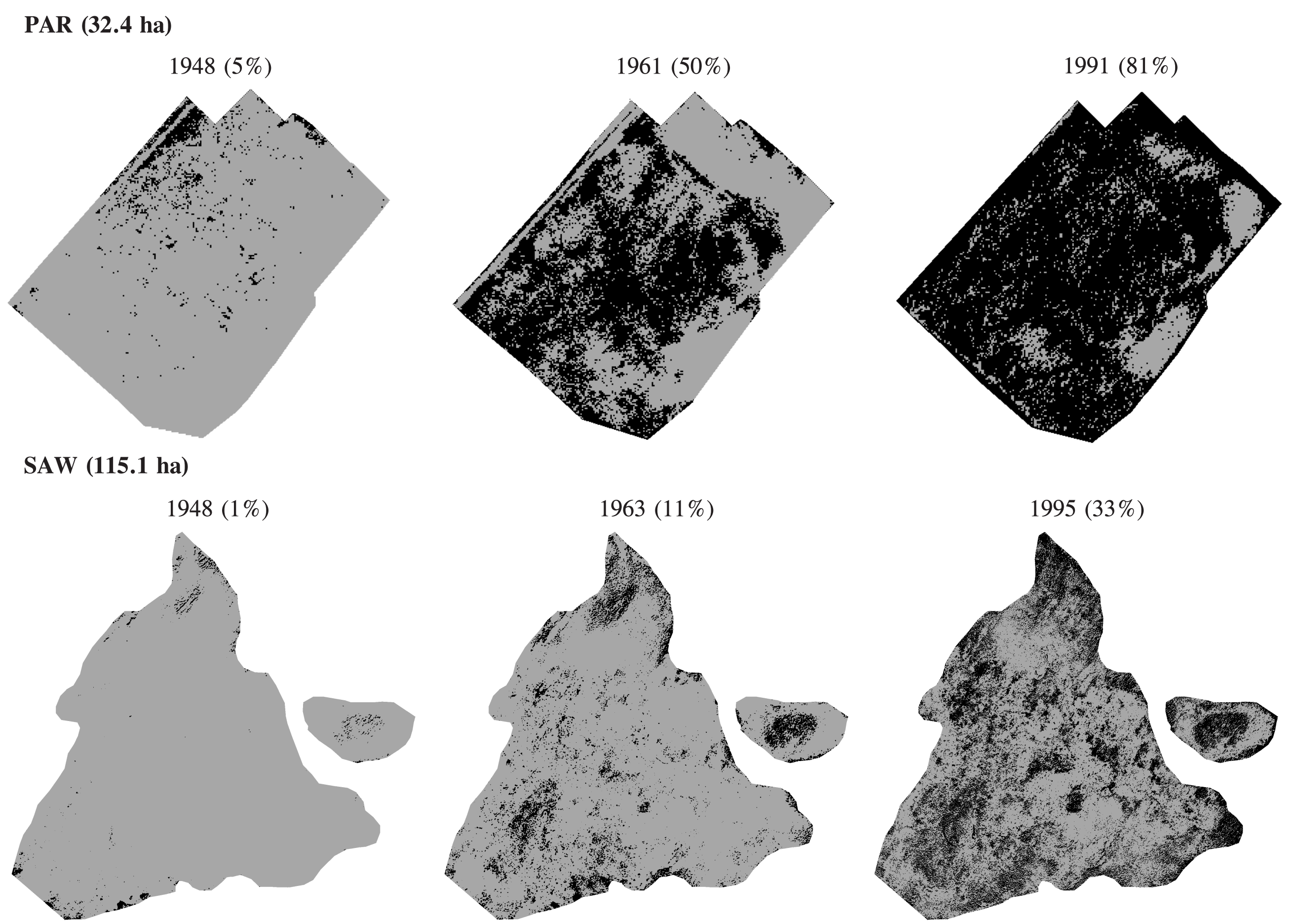


FIGURE 1. Spatio-temporal evolution of the forest cover (black areas) of LeParc (PAR) and Saint-Arsène West (SAW) bogs, Bas-Saint-Laurent region, southeastern Québec, reconstructed from aerial photographs. Percentage of the bog area covered by forest is indicated for each year (modified from Pellerin & Lavoie, 2003).


FIGURE 2. Study area, Bas-Saint-Laurent region, southeastern Québec, and spatial distribution of studied bogs, mined peatlands, and woodlots on well-drained sites. Data on woodlots are from Environnement Canada (1999). Peatlands that have been sampled: BDB: Bois-des-Bel; MIC: Michaud; PAR: LeParc; SAE: Saint-Arsène East; SAW: Saint-Arsène West; TUF: Coteau-du-Tuff; N1, N3, N4, N6, N7, N9, N10, N13, N19, and N22: unnamed peatlands.

1993b). Nevertheless, between 1929 and 2000, 62% of the total area covered by bogs was disturbed, by peat mining, logging, or farming activities (Pellerin, 2003a).

Today, the study area is mainly covered by agricultural fields, although woodlots on mesic and xeric sites still occupy about 15% (3,460 ha) of the total area (Figure 2). Woodlot vegetation is dominated by sugar maple (*Acer saccharum*), yellow birch (*Betula alleghaniensis*), and balsam fir (*Abies balsamea*) (Robitaille & Saucier, 1998). A total of 18 peatlands are present in the study area. Among those, seven bogs are presently used for the extraction of horticultural peat or are abandoned after decades of mining; mined surfaces occupy an area of 620 ha. Eleven unmined peatlands and five unmined fragments of large bogs are also present, occupying an area of 510 ha. These bogs or bog fragments were never subjected to peat mining, large-scale logging, or farming activities. They range in size from 2 to 189 ha. A mosaic of open and forested patches usually characterizes their vegetation. Dominant tree species include black spruce (*Picea mariana*), jack pine (*Pinus banksiana*), and tamarack (*Larix laricina*). Ericaceous shrubs, mainly *Chamaedaphne calyculata*, *Kalmia angustifolia*, *Rhododendron groenlandicum,* and *Vaccinium angustifolium* are widespread in all bogs. In open habitats, *Sphagnum* mosses, mainly *S. capillifolium*, *S. fuscum*, *S. magellanicum,* and *S. rubellum*, cover the ground layer, whereas *Pleurozium schreberi* dominates the ground layer of forested sites.

### VEGETATION SAMPLING

During the summer of 2000, vascular plants, mosses, liverworts, and lichens were sampled in the 16 unmined peatlands and unmined fragments of large bogs, 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 (Blue Marble Geographics, 1998). Corrected photographs were imported into a geographic information system (GIS), MapInfo Professional (MapInfo Corporation, 2001). In the GIS, a grid of sampling points located 50 m apart was superimposed on the 12 largest peatlands (6.3-189.2 ha). 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 ($n$ = 2,096) were obtained with the GIS and located in the field using a Global Positioning System receiver.

All plant species present within a 50- × 50-cm quadrat laid on the ground at each sampling point were identified. The presence of all species covering (at least partly) the vertical projection of the quadrat was also noted. Each plant species was associated with a particular trophic regime (minerotrophic, minerotrophic or ombrotrophic, ombrotrophic; see Appendix I) using the works of Gauthier (1967; 1980), Marie-Victorin (1995), Girard (2000), and Garneau (2001). Species restricted to bog ecosystems in the study area were identified using the work of Blouin and Grandtner (1971), who sampled vegetation communities in all habitat types of the Rivière-du-Loup county.

### BIRD SURVEYS

Bird populations were sampled in the 16 unmined peatlands and unmined fragments of large bogs from June 1 to 22, 2001. A grid of sampling stations was superimposed on all sites using the GIS. The stations were located 200 m apart and at least 100 m from the peatland border, except in the three smallest peatlands (2.0-3.3 ha), where a single sampling station was located at the centre of the bog. The latitude and longitude of each sampling station ($n$ = 135) were obtained with the GIS and located in the field using a Global Positioning System receiver. Nesting bird populations were sampled using fixed-radius point counts (Ralph *et al.,* 1993). Point counts were conducted using a 50-m radius and lasted 10 min, during which all birds that were heard were recorded. Point count stations were visited twice during the sampling period, by different observers and at different times between 0400 and 0900, on days without rain and with winds less than 30 $km \cdot h^{-1}$.

For analyses, we retained only 1) bird species breeding during the sampling period and using peatlands for breeding, according to Gauthier and Aubry (1995), 2) species for which the sampling method was appropriate, thus excluding bird species like purple finch (*Carpodacus purpureus*), whose large territories could induce us to sample the same individual more than once, and 3) species present in more than 5% of the sampling stations. Bog-specialist species were identified according to Calmé, Desrochers, and Savard (2002), who classified bird species sampled in 112 peatlands across the province of Québec (including peatlands of the Bas-Saint-Laurent region) according to their affinity with peatlands.

### FOREST COVER

Data from Pellerin and Lavoie (2003) were used to estimate the forest cover of the peatlands of the study area. The forest cover of each peatland was calculated using corrected aerial photographs taken in 1995 (the most recent photographs with the highest resolution level) and the EASI/PACE digital image processing software (PCI Remote Sensing Corp., 1997). Although field sampling (plants, birds) was conducted 5 or 6 y later, few changes in the tree cover were expected, since most of the forest cover increase in the Bas-Saint-Laurent peatlands occurred before the 1990s (Pellerin & Lavoie, 2003). A supervised classification approach with a maximum likelihood classifier was used (Campbell, 1996). On aerial photographs, the forested vegetation (trees of all heights, all species considered) could easily be distinguished from open vegetation (*i.e.,* with only small or no trees); hence, these two vegetation types were used to classify the photographs. Each photograph was classified separately to minimize between-image differences in brightness and contrast, and a mask for each bog was created to restrict the analysis to the area of interest. Thus, for each photograph, the area covered by each vegetation type was obtained.

### DATA ANALYSIS

Since peatlands are of variable sizes (2.0-189.2 ha) and sampling points and stations were established from regular grids, large peatlands would appear to have more species simply because much more effort was spent on sampling (Connor & McCoy, 1979). To correct plant species richness for sampling effort, a Monte Carlo procedure was applied (Sokal & Rohlf, 1981). One hundred samples of 30 randomly selected points were extracted from peatlands containing more than 30 sampling points. Relative richness was established for each of these peatlands by calculating the mean species richness from the extracted samples. A similar procedure was applied to correct bird species richness. However, since small peatlands had only one sampling station, relative richness for larger peatlands was simply the mean species richness of all sampling stations.

Species richness alone can be a misleading measure of biodiversity, since resistance to disturbances, primary productivity, and adequate functioning of an ecosystem depend not only on the number of species, but also on other factors, including species abundance or frequency (Magurran, 1988; Cardinale, Nelson & Palmer, 2000; McCann, 2000; Purvis & Hector, 2000; Tilman, 2000; Loreau *et al.,* 2001). To account for plant species frequency as well as the frequency of trophic groups (minerotrophic, minerotrophic-ombrotrophic, or ombrotrophic), an additional index was required. We took the number of sampling points where a species was found and divided it by the total number of sampling points in the peatland to correct for sampling effort and obtain the species' frequency. The same procedure was applied for trophic groups, albeit with the frequency calculated for all species belonging to a particular group. Thus, the relative frequency of a species ($F_{rs}$) and the relative frequency of a trophic group ($F_{rt}$) can be defined by two equations:

$$F_{rs} = \frac{N}{N_P} \quad [1]$$

where $N$ is the number of sampling points at which a given species was recorded in a particular peatland and $N_P$ is the total number of sampling points in the same peatland, and:

$$F_{rt} = \sum_{i=1}^{S_t} \frac{N_{it}}{N_P} \quad [2]$$

where $N_{it}$ is the number of sampling points at which the species $i$ of the trophic group $t$ was recorded in a particular peatland, $S_t$ is the number of species of the same trophic group recorded in the same peatland, and $N_P$ is the total number of sampling points used in this peatland. Thus, $F_{rs}$ and $F_{rt}$ are simple measures of relative frequency, calculated for each species and each trophic group.

Linear regressions were used to assess relationships between plant and bird species richness (after correction for sampling effort) $F_{rs}$ and $F_{rt}$, with forest cover. For birds, studying relationships between single bird species occurrences and forest cover leads to inconclusive results, since many bird species are uncommon. An alternative for studying such relationships is the use of logistic regression, where the dependent variable is categorical. Logistic regression was used to study the relationship between total species frequency (dependent variable, categorical) and forest cover (independent variable) while considering each species as a category (Tabachnick, 1996). Statistical analyses were conducted using SPSS software (SPSS, 2001), except for the logistic regression, which was computed using the CATMOD procedure in the SAS software (SAS Institute, 1999).

## Results

A total of 154 plant species were recorded in the peatlands (Appendix I). Of the 76 minerotrophic species, *Carex trisperma*, *Coptis trifolia*, and *Cornus canadensis* were the most abundant. *Dicranum polysetum*, *Nemopanthus mucronatus*, and *Pleurozium schreberi* were the most abundant of the 26 species that can be considered either minerotrophic or ombrotrophic. Finally, among the 38 ombrotrophic species, *Kalmia angustifolia*, *Picea mariana*, and *Vaccinium angustifolium* were the most abundant. Remaining plant species could not be classified in any group because of the lack of autecological information.

A total of 36 bird species were detected, but only 15 species were included in the analyses. Of these, eight are known as bog specialists at the regional level. The most frequent species were Nashville warbler (*Vermivora ruficapilla*), common yellowthroat (*Geothlypis trichas*), and magnolia warbler (*Dendroica magnolia*).

Linear regressions showed no significant relationship between forest cover and relative richness (Figure 3) except for ombrotrophic plant species, whose richness significantly dropped as forest cover increased. Relative frequency for ombrotrophic species was significantly and negatively correlated with forest cover (Figure 4). This result is noteworthy since forest cover increase was mainly associated with black spruce (Pellerin & Lavoie, 2003), classified in this study as an ombrotrophic species. It

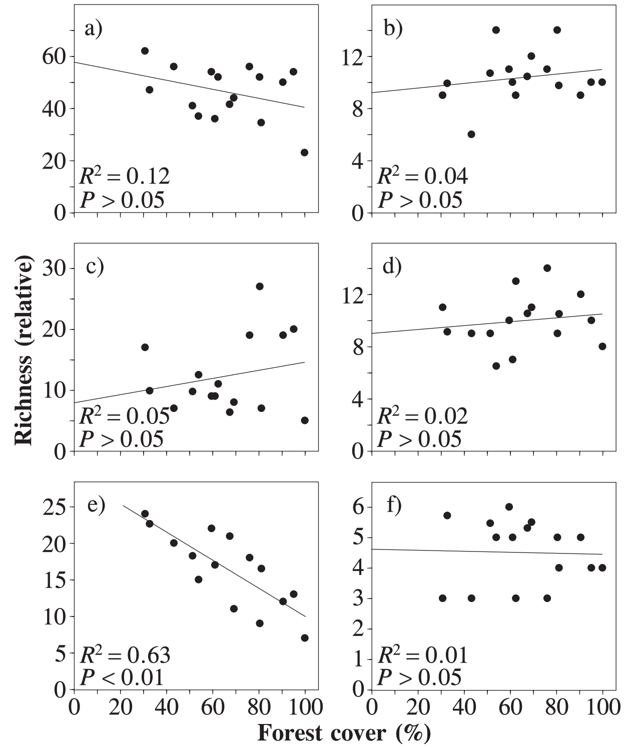


FIGURE 3. Effect of forest cover (percentage of the area of the peatland covered by trees in 1995) on relative richness of a) all plant species, b) all bird species, c) minerotrophic plant species, d) minerotrophic-ombrotrophic plant species, e) ombrotrophic plant species, and f) bog-specialist bird species sampled in bogs of the Bas-Saint-Laurent region, southeastern Québec.

strengthens the evidence of a loss of diversity for all other ombrotrophic species. The relative frequency of the minerotrophic and minerotrophic-ombrotrophic groups did not exhibit any significant relationship, but both trends were similar, *i.e.,* an increase in frequency with forest cover.

The relative frequency ($F_{rs}$) of 14 of the 38 ombrotrophic plant species was significantly correlated with forest cover (Table I). As expected, only *Picea mariana* was favoured by forest cover increase. Among the 13 species significantly impeded by forest expansion, five were restricted to ombrotrophic sites within the study area: *Kalmia polifolia*, *Mylia anomala*, *Rubus chamaemorus*, *Sphagnum fuscum*, and *Vaccinium oxycoccos*.

The occurrence of four of the 15 bird species analyzed was significantly correlated with forest cover (Table II). Among regional bog specialists, common yellowthroat and Lincoln's sparrow (*Melospiza lincolnii*) showed a significant decrease in occurrence in response to an increase in forest cover. In contrast, winter wren (*Troglodytes troglodytes*) and yellow-rumped warbler (*Dendroica coronata*) showed a significant increase in occurrence.

## Discussion

### AFFORESTATION AND PLANT DIVERSITY

Only the richness and frequency of ombrotrophic species were negatively associated with forest cover. Minerotrophic and minerotrophic-ombrotrophic species

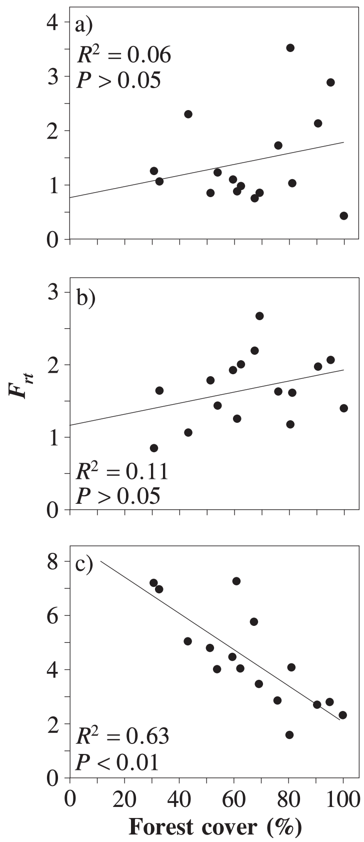


FIGURE 4. Effect of forest cover (percentage of the area of the peatland covered by trees in 1995) on the relative frequency ($F_{rt}$) for a) minerotrophic plant species, b) minerotrophic-ombrotrophic plant species, and c) ombrotrophic plant species sampled in bogs of the Bas-Saint-Laurent region, southeastern Québec.

did not appear to take advantage of this decline. The afforestation process that occurred during the last century influenced both shade and water table, two environmental parameters particularly important in determining the distribution of peatland plant species (Sjörs, 1950; Vitt *et al.,* 1990; Gignac, 1994; Lachance & Lavoie, 2004). Forest cover increase affects lower vegetation strata through alteration of light quality (increased shade), which influences the photosynthetic activities of plants. This may result in a decline of open-bog *Sphagnum* species (Gauthier, 1980), an increase in coverage of shade-tolerant mosses such as *Dicranum polysetum* and *Pleurozium schreberi* (Laine & Vanha-Majamaa, 1992), and a decrease in regional diversity as bog vegetation becomes similar to that of surrounding landscape dominated by coniferous forests (Laine, Vassander & Sallantaus, 1995).

Among plant species affected by an increase in the forest cover, *Sphagnum fuscum* is one of the most important species because it is the dominant *Sphagnum* species in raised bogs of eastern Canada (Gauthier, 2001). Although this species can withstand a wide range of environmental conditions (Mulligan & Gignac, 2001), it does not tolerate shade (Gauthier, 2001). *Sphagnum fuscum* typically forms hummocks (Gauthier, 2001), which provide adequate habitats for a large variety of liverworts, mosses, and vascular plants like *Mylia anomala*, *Vaccinium oxycoccos*, *Polytrichum strictum,* and, to a lesser extent, *Pohlia nutans* (Gauthier, 1967; 1980; Jacquemart, 1997).

Most of the species affected by an increase in the forest cover but not associated with the microhabitat structure created by *Sphagnum fuscum* appear particularly light sensitive. *Chamaedaphne calyculata*, *Kalmia polifolia*, *Rubus chamaemorus*, and *Vaccinium angustifolium* have a strong association with open *Sphagnum* bogs (Gauthier, 1967; Hoefs & Shay, 1981; Lapointe & Rochefort, 1997; Dyck & Shay, 1999; Jean & Lapointe, 2001). Under controlled conditions, shading significantly reduces the growth of *Sphagnum capillifolium* (Hayward & Clymo, 1983).

TABLE I. Ombrotrophic plant species with a relative frequency ($F_{rs}$) significantly influenced by forest cover in peatlands of the Bas-Saint-Laurent region, southeastern Québec. Bold: species restricted to bogs in the study area (according to Blouin & Grandtner, 1971).

| Scientific name | $Z^1$ |
|---|---|
| *Chamaedaphne calyculata* | -3.59** |
| *Kalmia angustifolia* | -4.38** |
| *Kalmia polifolia* | -3.41** |
| *Maianthemum trifolium* | -2.46* |
| ***Mylia anomala*** | -4.61** |
| *Picea mariana* | 2.93* |
| *Pohlia nutans* | -3.93** |
| *Polytrichum strictum* | -4.19** |
| *Rhododendron groenlandicum* | -5.57** |
| ***Rubus chamaemorus*** | -2.36* |
| *Sphagnum capillifolium* | -2.75* |
| ***Sphagnum fuscum*** | -2.47* |
| *Vaccinium angustifolium* | -3.03** |
| ***Vaccinium oxycoccos*** | -5.29** |

** $P < 0.01$.

* $0.01 < P < 0.05$.

[1]A high value indicates a strong relationship with forest cover while the sign indicates the direction (+: species favoured by forest expansion; -: species impeded by forest expansion).

TABLE II. Most frequent nesting avian species sampled in 16 peatlands, Bas-Saint-Laurent region, southeastern Québec. Results of the logistic regression with the intensity and direction (*Z*-score) as well as the significance of the relationship between species frequency and forest cover are shown. Bold: species considered as bog specialists according to Calmé, Desrochers and Savard (2002). Species sorted by decreasing association with forest cover.

| English name | Scientific name | $Z^1$ | $P$ |
|---|---|---|---|
| Winter wren | *Troglodytes troglodytes* | 2.26 | 0.02 |
| Yellow-rumped warbler | *Dendroica coronata* | 2.13 | 0.03 |
| American goldfinch | *Carduelis tristis* | 1.47 | 0.14 |
| **Magnolia warbler** | *Dendroica magnolia* | 1.42 | 0.16 |
| **Ruby-crowned kinglet** | *Regulus calendula* | 1.09 | 0.27 |
| **Nashville warbler** | *Vermivora ruficapilla* | 0.54 | 0.59 |
| **Palm warbler** | *Dendroica palmarum* | 0.36 | 0.72 |
| Swainson's thrush | *Catharus ustulatus* | 0.10 | 0.92 |
| **Hermit thrush** | *Catharus guttatus* | 0.03 | 0.98 |
| Boreal chickadee | *Parus hudsonicus* | -0.01 | 0.99 |
| **Golden-crowned kinglet** | *Regulus satrapa* | -0.09 | 0.93 |
| American robin | *Turdus migratorius* | -0.70 | 0.48 |
| White-throated sparrow | *Zonotrichia albicollis* | -1.61 | 0.11 |
| Common yellowthroat | *Geothlypis trichas* | -2.07 | 0.04 |
| **Lincoln's sparrow** | *Melospiza lincolnii* | -4.93 | < 0.01 |

[1] A high value indicates a strong relationship with forest cover while the sign indicates the direction (+: species favoured by forest expansion; -: species impeded by forest expansion).

Afforestation probably influences *Kalmia angustifolia* and *Rhododendron groenlandicum* through a combination of effects. *Kalmia angustifolia* prefers dry habitats (Gauthier, 1967), but is more vigorous in open canopy black spruce forests (Mallik, 1994). Therefore, only a dense tree cover would significantly impede its growth. The fact that this species is affected by tree cover in this study indicates the intensity of the afforestation process. On the other hand, *Rhododendron groenlandicum* prefers a denser canopy and a wetter habitat than *Kalmia angustifolia* (Gauthier, 1967; Dyck & Shay, 1999). The negative influence of increasing black spruce cover on the frequency of *Rhododendron groenlandicum* suggests that the detrimental effect of water-table drawdown caused by a dense tree cover (Prévost, Plamondon & Roy, 2001; Van Seters & Price, 2001; 2002; Girard, Lavoie & Thériault, 2002) negates the positive influence of the canopy closure.

### Afforestation and bird diversity

Afforestation influenced bird species by changing the vegetation structure of bogs (fewer mosses and shrubs, more trees) and by homogenizing the spatial distribution of plant communities (open patches progressively replaced by forested patches). Previous studies have shown the importance of both factors for bird distribution (Rotenberry, 1985; Stockwell, 1994; Calmé & Desrochers, 2000). In bogs of the Bas-Saint-Laurent region, recent changes in the spatial distribution of open and forested patches probably explain the main patterns in bird distribution, since the distributions of three of the four bird species significantly affected by afforestation (common yellowthroat, Lincoln's sparrow, and winter wren) apparently relate to ecotones. Common yellowthroat and Lincoln's sparrow were negatively affected by an increase in the forest cover because, in peatlands, they usually nest in copses of black spruce localized in transition areas (ecotones) between forested edges and open areas (Gauthier & Aubry, 1995; Desrochers, 2001). A decrease in the extent of open areas therefore affects those birds since it reduces the area occupied by ecotones. On the other hand, yellow-rumped warbler and winter wren, two coniferous forest species (Gauthier & Aubry, 1995; Anthony *et al.,* 1996), benefit from an increase in the forest cover. However, the positive influence of afforestation may only be a temporary situation for winter wren since in our study sites this bird species mainly prefers young copses of black spruce.

During the nesting period, palm warbler is strongly and almost exclusively associated with peatlands, at least in temperate regions where coniferous forests are scarce and mainly restricted to bogs (Wilson, Zierzow & Savage, 1998; Calmé & Desrochers, 1999; Desrochers, 2001). This species is usually associated with small copses of black spruce surrounded by open areas, a situation that is somewhat intermediate between open and closed canopy. Palm warbler typically nests on the ground and uses the tallest tree of the copse for surveillance and as a song post (Welsh, 1971). Therefore, it is somewhat puzzling that palm warbler is not significantly affected by an increase in the forest cover. It is hypothesized that an increase in the number of black spruce copses in open areas temporarily compensates for the loss of area occupied by open patches and that the palm warbler will eventually find itself impeded by forest expansion.

### Afforestation as a threat to regional biodiversity

Among ombrotrophic plant species significantly affected by an increase in the forest cover, five are exclusively restricted to bogs in the Bas-Saint-Laurent region (Blouin & Grandtner, 1971). These five species are also associated with plant communities typical of pristine open bogs (Lachance & Lavoie, 2004). However, considering that 154 plant species were found in the 16 bogs that were studied, the loss of only five species (3% of the total) may appear negligible, especially because none of these species is rare in Québec. Furthermore, it is likely that some open patches will remain in the next decades, especially in larger, less disturbed bogs. Such patches will constitute refuges for typical bog species.

Afforestation is mainly due to black spruce expansion, and peatlands will remain coniferous islands providing appropriate habitats for many passerine bird species like yellow-rumped warbler, magnolia warbler, and hermit thrush. However, it is unlikely that peatlands will remain refuges for specialist birds in the near future. It is indeed doubtful that species like Lincoln's sparrow and palm warbler will maintain viable populations in the region, since these birds require large open bog areas that are slowly disappearing.

In summary, there is a clear trend toward a homogenization of the landscape. There are fewer and fewer bogs in the Bas-Saint-Laurent region because of industrial (peat extraction) and agricultural activities, and remaining sites are being progressively transformed into forested stands with a vegetation structure very different from that of typical, pristine open bogs. Peatlands of the Bas-Saint-Laurent region remain islands of boreal vegetation in a matrix of deciduous forests and agricultural fields, but the diversity of their habitats is progressively reduced because of the afforestation process. This phenomenon does not imperil plant or bird species across their entire range, but it does contribute to the impoverishing the regional diversity. Protecting the remaining bogs in this region, especially the largest ones, from anthropogenic disturbances (Lachance & Lavoie, 2004) would probably slow the afforestation process and ensure that at least some refuges will remain available for typical bog plant and bird species.

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## Literature cited


Anderson, L. E., 1990. A checklist of *Sphagnum* in North America north of Mexico. Bryologist, 93: 500-501.

Anderson, L. E., H. A. Crum & W. R. Buck, 1990. List of the mosses of North America north of Mexico. Bryologist, 93: 448-499.

Anthony, R. G., G. A. Green, E. D. Forsman & S. K. Nelson, 1996. Avian abundance in riparian zones of three forest types in the Cascade Mountains, Oregon. Wilson Bulletin, 108: 280-291.

Blouin, J.-L. & M. M. Grandtner, 1971. Étude écologique et cartographie de la végétation du comté de Rivière-du-Loup. Service de la recherche, Ministère des Terres et Forêts du Québec, Québec, Québec.

Blue Marble Geographics, 1998. Geographic Transformer 3.1. Geographic Software Component Company, Gardiner, Maine.

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

Calmé, S. & A. Desrochers, 2000. Biogeographic aspects of the distribution of bird species breeding in Québec's peatlands. Journal of Biogeography, 27: 725-732.

Calmé, S., A. Desrochers & J.-P. L. Savard, 2002. Regional significance of peatlands for avifaunal diversity in southern Québec. Biological Conservation, 107: 273-281.

Campbell, J. B., 1996. Introduction to Remote Sensing. 2nd Edition. The Guilford Press, New York, New York.

Cardinale, B. J., K. Nelson & M. A. Palmer, 2000. Linking species diversity to the functioning of ecosystems: On the importance of environmental context. Oikos, 91: 175-183.

Connor, E. F. & E. D. McCoy, 1979. The statistics and biology of the species-area relationship. American Naturalist, 113: 791-833.

Desrochers, A., 2001. Les oiseaux : diversité et répartition. Pages 159-173 *in* S. Payette & L. Rochefort (eds.). Écologie des tourbières du Québec-Labrador. Presses de l'Université Laval, Saint-Nicolas, Québec.

Dyck, B. S. & J. M. Shay, 1999. Biomass and carbon pool of two bogs in the Experimental Lakes Area, northwestern Ontario. Canadian Journal of Botany, 77: 291-304.

Esslinger, T. L. & R. S. Egan, 1995. A sixth checklist of the lichen-forming, lichenicolous, and allied fungi of the continental United States and Canada. Bryologist, 98: 467-549.

Environnement Canada, 1999. Atlas de conservation des boisés en paysage agricole. [URL] http://www.qc.ec.gc.ca/faune/atlas/atlas.html

Fortin, J.-C., 1993a. La population du littoral et celle du plateau. Pages 349-383 *in* J.-C. Fortin & A. Lechasseur (eds.). Histoire du Bas-Saint-Laurent. Institut québécois de recherche sur la culture, Québec, Québec.

Fortin, J.-C. 1993b. Colonisation et commercialisation de l'agriculture. Pages 429-472 *in* J.-C. Fortin & A. Lechasseur (eds.). Histoire du Bas-Saint-Laurent. Institut québécois de recherche sur la culture, Québec, Québec.

Frankl, R. & H. Schmeidl, 2000. Vegetation change in a South German raised bog: Ecosystem engineering by plant species, vegetation switch or ecosystem level feedback mechanisms? Flora, 195: 267-276.

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

Garneau, M., 2001. Statut trophique des taxons préférentiels et des taxons fréquents mais non préférentiels des tourbières naturelles du Québec-Labrador. Pages 523-531 *in* S. Payette & L. Rochefort (eds.). Écologie des tourbières du Québec-Labrador. Presses de l'Université Laval, Saint-Nicolas, Québec.

Gauthier, J. & Y. Aubry (eds.), 1995. Atlas des oiseaux nicheurs du Québec méridional. Association québécoise des groupes d'ornithologues, Société québécoise de protection des oiseaux and Service canadien de la faune, Environnement Canada (région du Québec), Montréal, Québec.

Gauthier, R., 1967. Étude écologique de cinq tourbières du Bas Saint-Laurent. M.Sc. thesis, Université Laval, Québec, Québec.

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

Gauthier, R., 2001. Les sphaignes. Pages 91-127 *in* S. Payette & L. Rochefort (eds.). Écologie des tourbières du Québec-Labrador. Presses de l'Université Laval, Saint-Nicolas, Québec.

Gignac, L. D., 1994. Peatland species preferences: An overview of our current knowledge base. Wetlands, 14: 216-222.

Girard, M., 2000. La régénération naturelle d'écosystèmes fortement perturbés: le cas d'une tourbière exploitée du Bas-Saint-Laurent (Québec). M.A. thesis, Université Laval, Québec, Québec.

Girard, M., C. Lavoie & M. Thériault, 2002. The regeneration of a highly disturbed ecosystem: A mined peatland in southern Québec. Ecosystems, 5: 274-288.

Gorham, E., 1991. Northern peatlands: Role in the carbon cycle and probable responses to climatic warming. Ecological Applications, 1: 182-195.

Hayward, P. M. & R. S. Clymo, 1983. The growth of *Sphagnum*: Experiments on, and simulation of, some effects of light flux and water-table depth. Journal of Ecology, 71: 845-863.

Hinds, H. R., 2000. Flora of New Brunswick. 2nd Edition. University of New Brunswick, Fredericton, New Brunswick.

Hoefs, M. E. G. & J. M. Shay, 1981. The effects of shade on shoot growth of *Vaccinium angustifolium* Ait. after fire pruning in southeastern Manitoba. Canadian Journal of Botany, 59: 166-174.

Jacquemart, A.-L., 1997. *Vaccinium oxycoccos* L. (*Oxycoccus palustris* Pers.) and *Vaccinium microcarpum* (Turcz. ex Rupr.) Schmalh. (*Oxycoccus microcarpus* Turcz. ex Rupr.). Journal of Ecology, 85: 381-396.

Jean, D. & L. Lapointe, 2001. Limited carbohydrate availability as a potential cause of fruit abortion in *Rubus chamaemorus*. Physiologia Plantarum, 112: 379-387.

Joosten, H. & D. Clarke, 2002. Wise Use of Mires and Peatlands. International Mire Conservation Group & International Peat Society, Totnes.

Lachance, D. & C. Lavoie, 2004. Vegetation of *Sphagnum* bogs in highly disturbed landscapes: Relative influence of abiotic and anthropogenic factors. Applied Vegetation Science, 7: 183-192.

Laine, J. & I. Vanha-Majamaa, 1992. Vegetation ecology along a trophic gradient on drained pine mires in southern Finland. Annales Botanici Fennici, 29: 213-233.

Laine, J., H. Vasander & T. Sallantaus, 1995. Ecological effects of peatland drainage for forestry. Environmental Reviews, 3: 286-303.

Lapointe, L. & L. Rochefort, 1997. Le développement d'une nouvelle agriculture au Québec : le petit fruit de *Rubus chamaemorus* appelé chicouté. Conseil de recherches en pêche et en agroalimentaire du Québec, Québec, Québec.

Linderholm, H. W. & M. Leine, 2004. An assessment of twentieth century tree-cover changes on a southern Swedish peatland combining dendrochronology and aerial photograph analysis. Wetlands, 24: 357-363.

Loreau, M., S. Naeem, P. Inchausti, J. Bengtsson, J. P. Grime, A. Hector, D. U. Hooper, M. A. Huston, D. Raffaelli, B. Schmid, D. Tilman & D. A. Wardle, 2001. Biodiversity and ecosystem functioning: Current knowledge and future challenges. Science, 294: 804-808.

Magurran, A. A., 1988. Ecological Diversity and Its Measurement. Princeton University Press, Princeton, New Jersey.

Mallik, A. U., 1994. Autecological response of *Kalmia angustifolia* to forest types and disturbance regimes. Forest Ecology and Management, 65: 231-249.

Maltby, E., 1986. Waterlogged Wealth. Earthscan, London.

MapInfo Corporation, 2001. MapInfo Professional 6.5. MapInfo Corporation, Troy, New York.

Marie-Victorin, F., 1995. Flore laurentienne. 3e édition. Presses de l'Université de Montréal, Montréal, Québec.

McCann, K. S., 2000. The diversity-stability debate. Nature, 405: 228-233.

Moore, P. D., 2002. The future of cool temperate bogs. Environmental Conservation, 29: 3-20.

Morin, Y., 1993. Une nouvelle région de colonisation au Québec, 1790-1830. Pages 133-172 *in* J.-C. Fortin & A. Lechasseur (eds.). Histoire du Bas-Saint-Laurent. Institut québécois de recherche sur la culture, Québec, Québec.

Mulligan, R. C. & L. D. Gignac, 2001. Bryophyte community structure in a boreal poor fen: Reciprocal transplants. Canadian Journal of Botany, 79: 404-411.

O'Neill, K. P., 2000. Role of bryophyte-dominated ecosystems in the global carbon budget. Pages 344-368 *in* A. J. Shaw & B. Goffinet (eds.). Bryophyte Biology. Cambridge University Press, Cambridge.

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

Pellerin, S., 2003a. Des tourbières et des hommes. L'utilisation des tourbières dans la région de Rivière-du-Loup – L'Isle-Verte. Naturaliste canadien, 127: 18-23.

Pellerin, S., 2003b. La dynamique récente des tourbières du Bas-Saint-Laurent: une analyse historique et paléoécologique. Ph.D. thesis, Université Laval, Québec, Québec.

Pellerin, S. & C. Lavoie, 2000. Peatland fragments of southern Québec: Recent evolution of their vegetation structure. Canadian Journal of Botany, 78: 255-265.

Pellerin, S. & C. Lavoie, 2003. Reconstructing the recent dynamics of mires using a multitechnique approach. Journal of Ecology, 91: 1008-1021.

Pisano, E., 1983. The magellanic tundra complex. Pages 295-329 *in* A. J. P. Gore (ed.). Mires: Swamp, Bog, Fen and Moor. Regional Studies. Elsevier, Amsterdam.

Prévost, M., A. Plamondon & V. Roy, 2001. La production forestière. Pages 423-447 *in* S. Payette & L. Rochefort (eds.). Écologie des tourbières du Québec-Labrador. Presses de l'Université Laval, Saint-Nicolas, Québec.

Purvis, A. & A. Hector, 2000. Getting the measure of biodiversity. Nature, 405: 212-219.

Ralph, C. J., G. R. Geupel, P. Pyle, T. E. Martin & D. F. DeSante, 1993. Handbook of Field Methods for Monitoring Landbirds. USDA Forest Service, Albany, California.

Robitaille, A. & J.-P. Saucier, 1998. Paysages régionaux du Québec méridional. Les publications du Québec, Québec, Québec.

Rotenberry, J. T., 1985. The role of habitat in avian community composition: Physiognomy or floristics? Oecologia, 67: 213-217.

SAS Institute, 1999. SAS 8.0. SAS Institute Inc., Cary, North Carolina.

Sjörs, H., 1950. On the relation between vegetation and electrolytes in north Swedish mire waters. Oikos, 2: 241-258.

Sokal, R. R. & F. J. Rohlf, 1981. Biometry. 2nd Edition. W. H. Freeman, New York, New York.

Spitzer, K., A. Bezděk & J. Jaroš, 1999. Ecological succession of a relict Central European peat bog and variability of its insect biodiversity. Journal of Insect Conservation, 3: 97-106.

SPSS, 2001. SPSS for Windows 10.0.0. SPSS Inc., Chicago, Illinois.

Stockwell, S. S., 1994. Habitat selection and community organization of birds in eight peatlands of Maine. Ph.D. thesis, University of Maine, Orono, Maine.

Stotler, R. & B. Crandall-Stotler, 1977. A checklist of the liverworts and hornworts of North America. Bryologist, 80: 405-428.

Tabachnick, B. G., 1996. Using Multivariate Statistics. HarperCollins College Publishers, New York, New York.

Tilman, D., 2000. Causes, consequences and ethics of biodiversity. Nature, 405: 208-211.

Van Seters, T. E. & J. S. Price, 2001. The impact of peat harvesting and natural regeneration on the water balance of an abandoned cutover bog, Québec. Hydrological Processes, 15: 233-248.

Van Seters, T. E. & J. S. Price, 2002. Towards a conceptual model of hydrological change on an abandoned cutover bog, Québec. Hydrological Processes, 16: 1965-1981.

Vitt, D. H., D. G. Horton, N. G. Slack & N. Malmer, 1990. *Sphagnum*-dominated peatlands of the hyperoceanic British Columbia coast: Patterns in surface water chemistry and vegetation. Canadian Journal of Forest Research, 20: 696-711.

Welsh, D. A., 1971. Breeding and territoriality of the Palm Warbler in a Nova Scotia bog. Canadian Field-Naturalist, 85: 31-37.

Wilson, W. H., Jr., R. E. Zierzow & A. R. Savage, 1998. Habitat selection by peatland birds in a central Maine bog: The effects of scale and year. Journal of Field Ornithology, 69: 540-548.

APPENDIX I. Trophic regime of plant species sampled in 16 peatlands of the Bas-Saint-Laurent region, southeastern Québec: m: minerotrophic; m-o: minerotrophic-ombrotrophic; o: ombrotrophic.

| Species | Family | Trophic regime |
|---|---|---|
| MOSSES | | |
| *Aulacomnium androgynum* | Aulacomniaceae | unknown |
| *Aulacomnium palustre* | Aulacomniaceae | o |
| *Brachythecium reflexum* | Brachytheciaceae | m |
| *Brachythecium salebrosum* | Brachytheciaceae | unknown |
| *Callicladium haldanianum* | Hypnaceae | unknown |
| *Campylium chrysophyllum* | Amblystegiaceae | unknown |
| *Campylium stellatum* | Amblystegiaceae | m |
| *Dicranum fuscescens* | Dicranaceae | m |
| *Dicranum majus* | Dicranaceae | m-o |
| *Dicranum montanum* | Dicranaceae | m |
| *Dicranum polysetum* | Dicranaceae | m-o |
| *Dicranum scoparium* | Dicranaceae | m-o |
| *Dicranum undulatum* | Dicranaceae | o |
| *Funaria hygrometrica* | Fumariaceae | unknown |
| *Herzogiella turfacea* | Hypnaceae | unknown |
| *Hylocomium splendens* | Hylocomiaceae | o |
| *Hypnum fertile* | Hypnaceae | unknown |
| *Hypnum pallescens* | Hypnaceae | unknown |
| *Isopterygiopsis pulchella* | Plagiotheciaceae | unknown |
| *Limprichtia revolvens* | Amblystegiaceae | m-o |
| *Plagiothecium cavifolium* | Plagiotheciaceae | unknown |
| *Pleurozium schreberi* | Hylocomiaceae | m-o |
| *Pohlia nutans* | Bryaceae | o |
| *Polytrichum commune* | Polytrichaceae | m-o |
| *Polytrichum strictum* | Polytrichaceae | o |
| *Pseudotaxiphyllum elegans* | Plagiotheciaceae | unknown |
| *Ptilium crista-castrensis* | Hypnaceae | m |
| *Sanionia uncinata* | Amblystegiaceae | m-o |
| *Sphagnum angustifolium* | Sphagnaceae | o |
| *Sphagnum capillifolium* | Sphagnaceae | o |
| *Sphagnum centrale* | Sphagnaceae | m |
| *Sphagnum fallax* | Sphagnaceae | m-o |
| *Sphagnum fimbriatum* | Sphagnaceae | m |
| *Sphagnum fuscum* | Sphagnaceae | o |
| *Sphagnum girgensohnii* | Sphagnaceae | m |
| *Sphagnum magellanicum* | Sphagnaceae | o |
| *Sphagnum papillosum* | Sphagnaceae | m |
| *Sphagnum rubellum* | Sphagnaceae | o |
| *Sphagnum russowii* | Sphagnaceae | m-o |
| *Sphagnum squarrosum* | Sphagnaceae | m |
| *Sphagnum wulfianum* | Sphagnaceae | m |
| *Warnstorfia exannulata* | Amblystegiaceae | m |
| *Warnstorfia fluitans* | Amblystegiaceae | m |
| LIVERWORTS | | |
| *Bazzania trilobata* | Lepidoziaceae | m-o |
| *Calypogeja sphagnicola* | Calypogejaceae | o |
| *Cephalozia bicuspidata* | Cephaloziaceae | unknown |
| *Cephalozia connivens* | Cephaloziaceae | o |
| *Cephalozia lunulifolia* | Cephaloziaceae | unknown |
| *Cephalozia pleniceps* | Cephaloziaceae | o |
| *Cladopodiella fluitans* | Cephaloziaceae | o |
| *Lophocolea heterophylla* | Geocalycaceae | m-o |
| *Lophozia ventricosa* | Jungermanniaceae | unknown |
| *Mylia anomala* | Jungermanniaceae | o |
| *Ptilidium ciliare* | Ptilidiaceae | o |
| *Ptilidium pulcherrimum* | Ptilidiaceae | m |
| LICHENS | | |
| *Cladina mitis* | Cladoniaceae | o |
| *Cladina rangiferina* | Cladoniaceae | o |
| *Cladina stellaris* | Cladoniaceae | o |
| *Cladonia bacilliformis* | Cladoniaceae | m |
| *Cladonia cenotea* | Cladoniaceae | m |
| *Cladonia chlorophaea* | Cladoniaceae | m |
| *Cladonia coniocraea* | Cladoniaceae | o |
| *Cladonia conista* | Cladoniaceae | m |
| *Cladonia crispata* | Cladoniaceae | o |
| *Cladonia cyanipes* | Cladoniaceae | m-o |
| *Cladonia deformis* | Cladoniaceae | m |
| *Cladonia fimbriata* | Cladoniaceae | m |
| *Cladonia gracilis* | Cladoniaceae | o |
| *Cladonia humilis* | Cladoniaceae | m |
| *Cladonia macilenta* | Cladoniaceae | m |
| *Cladonia peziziformis* | Cladoniaceae | m |
| *Cladonia phyllophora* | Cladoniaceae | m |
| *Cladonia rei* | Cladoniaceae | m-o |
| *Cladonia squamosa* | Cladoniaceae | o |
| HERBACEOUS PLANTS | | |
| *Aralia nudicaulis* | Araliaceae | m |
| *Aralia racemosa* | Araliaceae | m |
| *Aster acuminatus* | Compositae | m |
| *Aster radula* | Compositae | m |
| *Calamagrostis canadensis* | Poaceae | m |
| *Carex canescens* | Cyperaceae | m |
| *Carex disperma* | Cyperaceae | m |
| *Carex echinata* | Cyperaceae | m |
| *Carex hirtifolia* | Cyperaceae | m |
| *Carex oligosperma* | Cyperaceae | m |
| *Carex trisperma* | Cyperaceae | m |
| *Clintonia borealis* | Liliaceae | m |
| *Coptis trifolia* | Ranunculaceae | m |
| *Cornus canadensis* | Cornaceae | m |
| *Cypripedium acaule* | Orchidaceae | m-o |
| *Drosera rotundifolia* | Droseraceae | o |
| *Dryopteris campyloptera* | Dryopteridaceae | m |
| *Dryopteris carthusiana* | Dryopteridaceae | m |
| *Dryopteris intermedia* | Dryopteridaceae | m |
| *Elytrigia repens* | Poaceae | m |
| *Epilobium angustifolium* | Onagraceae | m |
| *Equisetum arvense* | Equisetaceae | m |
| *Equisetum sylvaticum* | Equisetaceae | m |
| *Eriophorum vaginatum* ssp. *spissum* | Cyperaceae | o |
| *Iris versicolor* | Iridaceae | m |
| *Lythrum salicaria* | Lythraceae | m |
| *Maianthemum canadense* | Liliaceae | m |
| *Maianthemum trifolium* | Liliaceae | o |
| *Melampyrum lineare* | Scrophulariaceae | m-o |
| *Monotropa uniflora* | Pyrolaceae | m |
| *Osmunda cinnamomea* | Osmundaceae | m-o |
| *Osmunda claytoniana* | Osmundaceae | m |
| *Pteridium aquilinum* | Dennstaedtiaceae | m-o |
| *Ribes glandulosum* | Saxifragaceae | m |
| *Rubus chamaemorus* | Rosaceae | o |
| *Rubus idaeus* | Rosaceae | m |
| *Rubus pubescens* | Rosaceae | m |
| *Sanguisorba canadensis* | Rosaceae | m |
| *Solidago rugosa* | Compositae | m |
| *Thalictrum pubescens* | Ranunculaceae | m |
| *Trientalis borealis* | Primulaceae | m |
| SHRUBS | | |
| *Alnus crispa* | Betulaceae | m |
| *Alnus incana* ssp. *rugosa* | Betulaceae | m |
| *Amelanchier bartramiana* | Rosaceae | m-o |
| *Aronia melanocarpa* | Rosaceae | m-o |
| *Chamaedaphne calyculata* | Ericaceae | o |
| *Cornus stolonifera* | Cornaceae | m |
| *Empetrum nigrum* | Empetraceae | o |
| *Gaultheria hispidula* | Ericaceae | m-o |
| *Kalmia angustifolia* | Ericaceae | o |
| *Kalmia polifolia* | Ericaceae | o |
| *Linnaea borealis* | Caprifoliaceae | m |
| *Myrica gale* | Myricaceae | m |
| *Nemopanthus mucronatus* | Aquifoliaceae | m-o |
| *Rhododendron canadense* | Ericaceae | o |
| *Rhododendron groenlandicum* | Ericaceae | o |
| *Salix discolor* | Salicaceae | m |

APPENDIX I. Continued.

| Species | Family | Trophic regime | Species | Family | Trophic regime |
|---|---|---|---|---|---|
| *Salix humilis* | Salicaceae | m | *Betula cordifolia* | Betulaceae | m-o |
| *Salix pyrifolia* | Salicaceae | m | *Betula papyrifera* | Betulaceae | m |
| *Spiraea latifolia* | Rosaceae | m | *Betula populifolia* | Betulaceae | m-o |
| *Vaccinium angustifolium* | Ericaceae | o | *Larix laricina* | Pinaceae | m-o |
| *Vaccinium myrtilloides* | Ericaceae | o | *Picea glauca* | Pinaceae | m |
| *Vaccinium oxycoccos* | Ericaceae | o | *Picea mariana* | Pinaceae | o |
| *Vaccinium vitis-idaea* | Ericaceae | o | *Picea rubens* | Pinaceae | m |
| *Viburnum nudum* var. *cassinoides* | Betulaceae | m | *Pinus banksiana* | Pinaceae | m |
| | | | *Populus tremuloides* | Salicaceae | m |
| | | | *Prunus pensylvanica* | Rosaceae | m |
| TREES | | | *Sorbus americana* | Rosaceae | m |
| *Abies balsamea* | Pinaceae | m | *Sorbus decora* | Rosaceae | m |
| *Acer rubrum* | Aceraceae | m | *Thuja occidentalis* | Cupressaceae | m-o |