

Avian recolonization of eastern Canadian bogs after peat mining

André Desrochers, Line Rochefort, and Jean-Pierre L. Savard

Abstract: To evaluate the potential of bog ecosystems to recover following peat mining, we compared bird species richness, abundance, and assemblages and vegetation among naturally revegetated and undisturbed bog sites in southeastern Quebec. Based on mining history, we selected 28 sites (12 natural, 9 abandoned after blockcut extraction, and 7 abandoned after vacuum extraction) in 15 bogs. We estimated percent cover for six vegetation strata in 106 plots with 100 m radius, on which bird point counts were conducted in 1993 and 1996. Vegetation structure differed significantly between natural, post-blockcut and post-vacuum sites. While vegetation cover was almost complete in natural sites, abandoned sites, especially post vacuum, were less vegetated, even after 20 years. Bird species richness and abundance were similar in natural and post-blockcut sites and both were higher than in post-vacuum sites. Ten of the 28 species studied in detail responded to site perturbation. Among them, the Palm Warbler was most closely associated with natural sites. Bird communities were closely associated with vegetation structure. Communities of post-blockcut sites were more similar to those of natural bogs than were bird communities of post-vacuum sites. Since the blockcut method of peat mining is no longer economically feasible, we conclude that bog habitat restoration should be accompanied by a preservation "safety net" area to counteract the lasting effect of vacuum peat mining on bird species assemblages.

Résumé : Pour évaluer le potentiel de récupération des écosystèmes de tourbière après la récolte de la tourbe, nous avons comparé la richesse en espèces, l'abondance et les associations chez les oiseaux, de même que la nature de la végétation, à des sites non perturbés et des sites naturellement recolonisés du sud-est du Québec. Nous avons choisi 28 sites d'échantillonnage dans 15 tourbières, d'après l'historique de leur exploitation : 12 sites intacts, 9 sites abandonnés après extraction de blocs et 7 sites abandonnés après extraction par aspiration. Nous avons estimé le pourcentage de couverture de six strates végétales en 106 parcelles d'un rayon de 100 m dans lesquelles des inventaires de la faune aviaire avaient été faits en 1993 et 1996. La structure de la végétation différait significativement entre les sites naturels, les sites exploités par extraction de blocs et ceux exploités par aspiration de la tourbe. Alors que la couverture végétale s'est avérée presque complète dans les sites naturels, celle des sites abandonnés, surtout après aspiration de la tourbe, était beaucoup moins abondante, même après 20 ans. La richesse en espèces et l'abondance des oiseaux étaient semblables aux sites naturels et aux sites exploités par extraction de blocs et plus élevées qu'aux sites exploités par aspiration de la tourbe. Dix des 28 espèces étudiées en détail ont réagi aux perturbations du milieu. Parmi celles-ci, la Paruline à couronne rousse était plus particulièrement associée aux sites naturels. Les communautés d'oiseaux étaient associées de près à la structure de la végétation. Les communautés des sites exploités par extraction de blocs étaient plus semblables à celles des sites naturels que les communautés d'oiseaux des sites exploités par aspiration. Comme la méthode d'extraction de tourbe par découpage de blocs n'est plus rentable économiquement, il faut prévoir, dans les opérations de récupération des tourbières, l'aménagement d'un « filet protecteur » pour contrer les effets persistants de l'exploitation par aspiration de tourbe sur les associations d'espèces d'oiseaux.

Introduction

Peatlands in Canada cover 17% of the land and are mostly distributed in the boreal biome (Gorham 1990). In southern

landscapes of the country, their occurrence is more limited and is decreasing because of drainage for agriculture, urban sprawl, and mining for peat moss. Although the proportion of Canadian peatlands transformed by humans remains very small (<0.1%; Rubec 1996), untouched peatlands, especially large ones, have become rare in some regions, such as the lowlands of the St. Lawrence River estuary (Fig. 1).

In Canada, exploitation is currently aimed mostly at *Sphagnum*-dominated peatlands, or bogs (Zoltai and Vitt 1995). Putting bog to uses other than peat mining (e.g., cranberry crops, Christmas trees) does not allow the habitat to recover its former structure and function. According to some authors, bogs abandoned after peat mining may revert to functional peat-accumulating ecosystems by plant succession (Green 1983; Smart et al. 1989; Famous et al. 1995). To date, however, little is known about the propensity of bogs abandoned after mining to recover naturally. In

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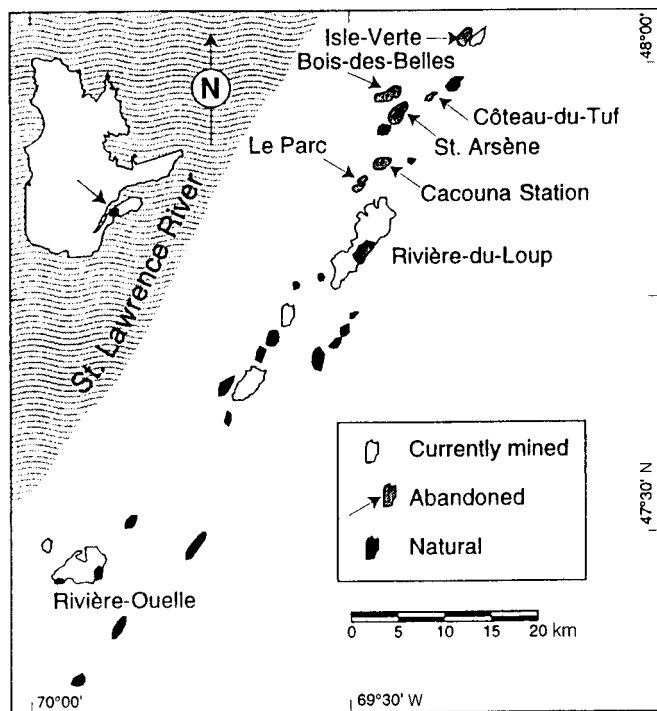
A. Desrochers.¹ Centre de recherche en biologie forestière, Faculté de foresterie et de géomatique, Université Laval, Sainte-Foy, PQ G1K 7P4, Canada.

L. Rochefort. Département de Phytologie et Centre d'études nordiques, Université Laval, Sainte-Foy, PQ G1K 7P4, Canada.

J.-P.L. Savard. Service canadien de la faune, Environnement Canada, 1141 Route de l'Église, C.P. 10100, Sainte-Foy, PQ G1V 4H5, Canada.

¹ Author to whom all correspondence should be addressed (e-mail: Andre.Desrochers@sbf.ulaval.ca).

Fig. 1. Currently mined, abandoned, and natural bogs in the lower St. Lawrence part of the study area. Rivière-du-Loup and Rivière-Ouelle bogs had abandoned sites besides the currently mined ones. See Table 1 for details.



eastern Canada, bogs can revegetate naturally after mining, but they rarely contain any significant amount of *Sphagnum* moss (Lavoie and Rochefort 1996; see below). Thus, the unaided reversion of post-mining bogs to peat-accumulating ecosystems cannot be taken for granted.

Post-mining sites may eventually form a considerable proportion of the area covered originally by peatlands in populated parts of eastern Canada. There are already about 30 abandoned sites in Quebec and New Brunswick, many of which are parts of bogs that are still being mined (L. Rochefort, unpublished data). It is unclear whether we can rely on abandoned, mined sites to serve as ecological substitutes for the bogs that existed before mining, because of the growing demand for peat (Bergeron 1993) and the fact that exploited bogs are clustered in the landscape for economical access and use of equipment. In response to this uncertainty, efforts are currently under way to restore mined peatland ecosystems (Wheeler and Shaw 1995; Wheeler et al. 1995; Quinty and Rochefort 1997; Rochefort and Campeau 1997; Rochefort et al. 1997).

If we have to rely on natural revegetation or habitat restoration to conserve southern bogs' contribution to biological diversity, we need to understand not only natural revegetation of abandoned bogs but also natural recolonization by other organisms. Renowned for their diversity of plants and insects (Damman and French 1987; Wright et al. 1992; Finnmore and Marshall 1994), eastern Canadian bogs also harbor a unique assemblage of boreal- and temperate-zone-nesting bird species (Stockwell 1994; Morneau 1995).

Peatland birds have been well studied in Europe (e.g., Sam-

malisto 1957; Hakala 1971; Kouki et al. 1992; Bölscher 1995), but much remains to be discovered about bird populations in North American peatlands, let alone about their response to anthropogenic habitat changes. In this paper we compare vegetation structure and bird species richness, abundance, and assemblages between naturally revegetated and undisturbed bog sites. We show that natural return of vegetation after several years of recovery following exploitation using current methods is incomplete and not sufficient to elicit the return of bird species assemblages typical of natural peatlands.

Study area and methods

We studied 15 bogs, most of which have been partly or entirely exploited, in three regions of southeastern Quebec: Saguenay/Lac-St-Jean, Bas St-Laurent, and Côte-du-Sud (Table 1). These regions encompass most of the peatlands currently mined or available for eventual mining in Quebec. We considered three types of sites in the bogs under study: (1) sites that have not been subject to mining (hereafter "natural"), (2) sites that have been abandoned after being mined with the blockcut method (hereafter "post-blockcut"), and (3) sites that have been abandoned after being mined with the vacuum method (hereafter "post-vacuum"). Post-blockcut sites had a characteristic microtopography consisting of alternating baulks (~2 m wide) and trenches ranging from 6 to 15 m wide. By contrast, post-vacuum sites were relatively flat surfaces split into 30 m wide fields separated by drainage ditches (Rochefort and Campeau 1997). Most abandoned sites had a 2–3 m deep layer of peat left unmined. Though most abandoned peat substrates would still be of good quality for mining, with the advent of mechanization in the late 1960s, the extensive surfaces being mined by the blockcut method were not necessary any more. A chemical study of the substrate of abandoned peatlands in eastern Canada (Wind-Mulder et al. 1996) showed that the water and peat chemistry of residual peat does not differ markedly from that of natural poor fens (*Sphagnum*-dominated peatlands). Thus, based only on exploitation history we identified 28 sites (12 natural, 9 post-blockcut, and 7 post-vacuum) in the study bogs. All sites were visited in 1993 and 1996, except for two post-vacuum sites that were not visited in 1996.

Vegetation composition

In a parallel study to the present one, we characterized the vegetational composition of natural and abandoned bogs in the summers of 1994 and 1995. We surveyed 30 natural bogs in various biogeographical regions of southern Quebec defined by Couillard and Grondin (1986). For each natural bog, 10 equidistant quadrats (~1 m²) were sampled along a transect. Distances between quadrats were one-tenth of the length of the bog axis sampled (varying from 800 m to 5 km). We also sampled all abandoned mined sites used for bird surveys by randomly selecting at least one abandoned peat field per homogeneous sector of bog. We sampled vegetation structures occurring in >10% of all peat fields in each bog. Each sampling unit (peat field) contained 10 equidistant transects along which plant species were recorded at 10 equidistant points along the whole length of each transect. In all, we recorded species occurrences in 190 vegetation-sampling units in post-blockcut sites and 11 sampling units in post-vacuum sites. For the purposes of this paper, we included only species with frequencies >20% in natural bogs and >5% in mined bogs, as mined bogs contained much ground covered with bare peat, as opposed to the species-rich *Sphagnum* moss layer of natural bogs.

Vegetation structure

To measure bird-vegetation associations, we estimated percent vegetation cover in circular plots of 100 m radius, separated by >50 m and delimited with surveying flags. We placed 59, 32, and 15 plots in nat-

Table 1. Characteristics of bogs studied in 1993 and 1996.

Bog	Location	Year abandoned	Area (ha)				No. of point-count stations			
			Natural	Currently mined	Post-blockcut	Post-vacuum	Total	Natural	Post-blockcut	Post-vacuum
Bagotville	48°21'N, 70°58'W	1972	282	0	26	0	308	3	4	0
L'Ascension	48°45'N, 71°43'W	1989	1487	186	0	28	1701	6	0	2
Sainte-Marguerite	48°49'N, 72°09'W	1990	4356	212	0	29	4597	10	0	5
Isle Verte	48°02'N, 69°18'W	1980	13	0	92	0	105	1	5	0
Bois-des-Belles	47°57'N, 69°27'W	1980	72	0	0	9	81	1	0	1
Côteau-du-Tuf	47°57'N, 69°22'W	1975	0	0	0	27	27	0	2	0
St-Arsène	47°57'N, 69°25'W	1965	31	116	34	0	181	1	1	0
Cacouna Station	47°52'N, 69°27'W	1970	0	0	70	12	82	0	4	2
		(post-blockcut) 1989								
		(post-vacuum) ca. 1967	4	0	26	6	36	1	3	0
Le Parc	47°53'N, 69°29'W	1962	368	1042	203	151	1764	6	9	3
		(post-blockcut) 1988								
		(post-vacuum) 1930	569	332	3	5	909	8	2	1
Rivière-Ouelle	47°28'N, 69°56'W	(post-blockcut) 1986								
		(post-vacuum)								
Saint-Charles	46°47'N, 70°57'W	Natural	724	124	0	36	884	7	0	0
Grande Plée Bleue	46°47'N, 71°03'W	Natural	471	0	0	0	471	10	0	0
Saint-Henri	46°42'N, 71°04'W	1982	32	94	0	10	136	0	0	1
Isle-aux-Coudres	47°23'N, 70°22'W	1973–1977	46	75	21	0	142	5	2	0
Total			8455	2181	475	313	11424	59	30	17

Note: Area estimates do not include sites with >50% tree cover. Saint-Charles and Grande Plée Bleue bogs were combined in matched-pairs analyses.

ural, post-blockcut, and post-vacuum sites, respectively. In each plot we recorded four estimates for each vegetation stratum by dividing plots into four quadrants. We considered six vegetation strata: bare soil (no mosses or lichens), *Sphagnum* moss, herbaceous plants, ericaceous plants, trees <5 m high, and trees ≥5 m high. Strata, particularly ericaceous plants and *Sphagnum* moss, often overlapped horizontally, allowing for cover totals >100% within point-count stations. We made three independent “blind” sets of measurements on each plot in 1993 and one set of measurements in 1996, the latter to assess short-term changes in vegetation. Measurements were repeated in 1993 to assess precision; mean standard deviations among estimates for all stratum cover measurements were <14%, despite the fact that estimates were generally made by different observers. Thus, we consider that percent cover estimates were accurate enough for the purpose of studying bird–vegetation associations. To further describe the recovery of vegetation structure after abandonment by the peat industry, we made additional vegetation cover estimates in the summers of 1994 and 1995 in sites not sampled for birds.

Birds

We conducted limited-radius point counts (Ralph et al. 1993) on each of the 106 circular plots with 100 m radius used for vegetation analysis (see above). Six observers conducted all point counts between 24 May and 13 July 1993 and between 1 June and 5 July 1996. We assume that there was no significant observer bias, since all observers had >5 years of birding experience and the plots were allocated randomly among them. Furthermore, each year we proceeded from south to north to account for differences in spring arrival dates among

regions. This approach should not introduce bias, because the three site types that we wished to compare were present in all regions.

Surveys were not conducted in strong wind or rain, to minimize sampling error due to detectability (Robbins 1981). All areas surveyed were open and we therefore assumed no bias due to visibility or sound propagation. Each point-count station was visited on three mornings (before 10:00) and one evening in 1993 and on one morning only in 1996. Successive visits to the same sites in 1993 were separated by at least 7 days. We accounted for the multiple visits to point-count stations in 1993 by computing means per point count for each species before conducting statistical tests. Point-count duration was 10 min in the mornings and 5 min in the evenings. Only three species were encountered exclusively in the evening: Ruffed Grouse, Sharp-shinned Hawk, and Whip-poor-will (see the Appendix for scientific names). Because the Whip-poor-will was the only species easier to detect in the evening, and since it was recorded only once, we did not include evening counts in the analyses. All nonflying birds and swallows recorded within morning point count limits were included in the species abundance and richness analyses. Only two species known not to be nesting in southern peatlands (Common Loon and Semipalmated Sandpiper) were excluded from analyses. Of all bird records, 81% involved singing males, which were considered evidence of nesting pairs. Females and birds of undetermined sex were counted as evidence of additional pairs only when no con-specific males were singing.

Statistical methods

Only two study bogs had no natural sites left, and the two types of postmining sites were present in only 2 of the 15 study bogs. In

Table 2. Plant species occurring in natural and post-mining sites.

	Site perturbation		
	Natural site (<i>N</i> = 300)	Post-blockcut site (<i>N</i> = 190)	Post-vacuum site (<i>N</i> = 11)
Bryophytes			
<i>Sphagnum capillifolium</i> (Ehrh.) Hedw.	52	5	—
<i>S. fuscum</i> (Schimp.) Klinggr.	47	—	—
<i>S. magellanicum</i> Brid.	47	—	—
<i>S. angustifolium</i> (C. Jens. ex Russ.) C. Jens.	32	—	—
<i>S. fallax</i> (Klinggr.) Klinggr.	23	—	—
<i>Polytrichum strictum</i> Brid.	—	7	—
<i>Pohlia nutans</i> (Hedw.) Lindb.	—	—	5
Ericaceous plants			
<i>Vaccinium oxycoccus</i>	75	—	—
<i>Chamaedaphne calyculata</i>	71	24	9
<i>Kalmia polifolia</i>	48	—	—
<i>K. angustifolia</i>	40	46	17
<i>Ledum groenlandicum</i>	36	41	14
<i>Andromeda glaucophylla</i>	32	—	—
<i>V. angustifolium</i>	—	36	14
<i>Rhododendron canadense</i>	—	12	—
Herbaceous plants			
<i>Drosera rotundifolia</i>	37	—	—
<i>Carex oligosperma</i>	33	—	—
<i>Rubus chamaemorus</i>	20	—	—
<i>Scirpus cespitosus</i>	20	—	—
<i>Eriophorum vaginatum</i>	—	—	13
Trees			
<i>Picea mariana</i>	20	7	—
<i>Larix laricina</i>	—	8	—
<i>Betula populifolia</i>	—	5	—

Note: Species are listed according to decreasing order of frequency in natural bogs. A dash indicates a species with frequency <5% (mined) or <20% (natural). The authority for vascular species names is Marie-Victorin (1964). Sample sizes represent numbers of quadrats (natural sites) or series of 10 transects (mined sites).

comparisons between the three site categories we therefore regarded bogs with either post-blockcut or post-vacuum sites as random samples of all the study bogs, and for comparing site types we chose statistical designs based on independent samples. To avoid pseudo-replication, the cover mean from all vegetation plots or the pair density from point counts was computed for each bog/treatment combination before all comparisons were conducted between natural, post-blockcut, and post-vacuum sites.

We compared species assemblages between pairs of sites by means of the Steinhaus index of similarity (Legendre and Legendre 1984), which uses quantitative data and does not include species absent from both sites. The Steinhaus index of similarity (here between site A and site B) is calculated as follows:

$$[1] \quad 2W/(A + B)$$

where *W* is the sum of the minimum abundances of all species (the minimum being the value for the site where the species was the least abundant) and *A* and *B* are the sums of abundance of all species for sites A and B, respectively. We used the Mantel equivalent of single-classification ANOVA (Sokal and Rohlf 1995) with 5000 permutations to compare similarity indices among site types. Finally, relationships between vegetation structure, site type, and species abundances were analyzed with canonical correspondence analysis (CANOCO; Ter Braak 1988).

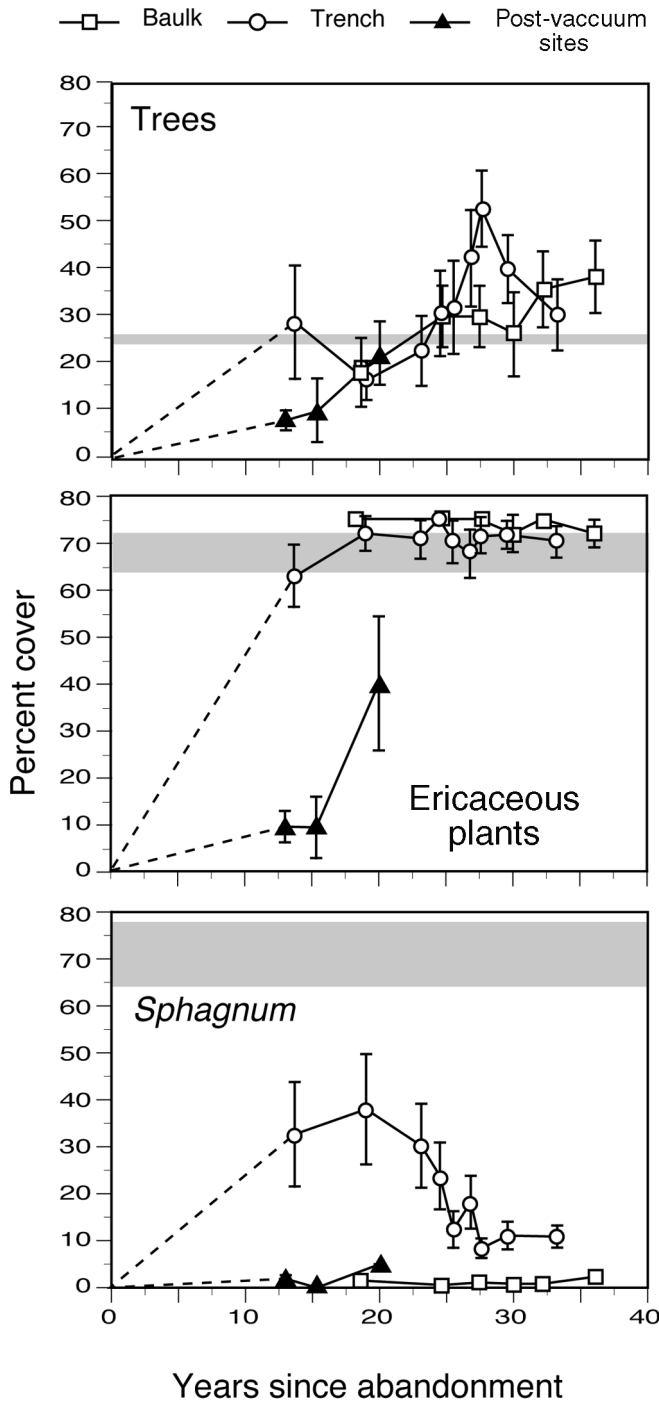
Proportion data were arcsine-transformed prior to analyses requiring the assumption of normality and homogeneity of variances. Statistical analyses were made with SPSS 6.0 (SPSS Inc. 1994) for standard designs, R 3.0 for Mantel tests (Legendre and Vaudor 1991), and Resampling Stats 4.0 for bootstrap power analyses (Resampling Stats Inc. 1995).

Results

Vegetation

Plant species composition and relative frequency contrasted between natural and post-exploitation sites (Table 2). A comparison of different-aged sites suggests that vegetation structure within sites occasionally changed greatly over long periods, but differences in ericaceous plants and *Sphagnum* moss between post-blockcut and post-vacuum sites persisted for at least 20 years (Fig. 2). Since several sites were abandoned in recent years (Table 1), we assessed changes in vegetation structure from 1993 to 1996. Vegetation did not change appreciably during the course of the study. We found no major differences in any of the cover measures between years for given sites (Wilcoxon's test, all *P* > 0.05 after Bonferroni

Fig. 2. Recovery of three vegetation strata with time elapsed since abandonment, based on a cross-sectional comparison of sites. Post-blockcut sites were separated into baulks and trenches because of the effects of drainage on vegetation recovery. Trees <5 m and trees ≥5 m are grouped as “trees.” Data are grouped in time categories representing ca. 10 samples each. Shaded areas represent mean values for natural sites and vertical bars denote ±1 standard error.



correction; Day and Quinn 1989). At $\alpha = 0.05$ and $N = 7$, we estimated statistical power ($1 - \beta$) at 95% for a mean difference of >15% in cover for all vegetation except *Sphagnum* moss (>30% difference required), according to bootstrap sim-

Table 3. Vegetation structure in natural, post-blockcut, and post-vacuum sites in southern Quebec bogs.

Stratum	Site perturbation		
	Natural sites (N = 12)	Post-blockcut sites (N = 9)	Post-vacuum sites (N = 7)
Bare ground	12.1±3.2	66.7±8.0**	72.5±13.1**
<i>Sphagnum</i> moss	71.4±6.9	27.7±8.0**	0.8±0.6**
Herbaceous plants	6.1±2.7	2.5±0.9	6.2±3.0
Ericaceous plants	68.7±4.2	80.0±4.4	13.9±9.9**
Trees <5 m high	20.5±2.9	16.3±2.0	6.4±3.1**
Trees ≥5 m high	3.7±0.7	3.8±1.4	1.2±1.1*

Note: Values are given as the mean ± SE of percent stratum cover. Sample sizes represent numbers of bogs.
 *Significantly different from natural sites, $P < 0.05$, two-tailed Mann-Whitney U test.
 **Significantly different from natural sites, $P < 0.005$, two-tailed Mann-Whitney U test.

ulations with the observed variance in differences between years.

After pooling years, we found marked differences in vegetation structure (all strata) between natural, post-blockcut, and post-vacuum sites (discriminant analysis, F approximation of Wilk's $\lambda = 11.9$, $P < 0.001$, $df = 12,40$), the first function accounting for 81% of the variation in vegetation cover. Post-blockcut sites had very little *Sphagnum* moss and much bare ground compared with natural sites, but were otherwise similar. Post-vacuum sites had significantly less cover than all vegetation strata except herbs (Table 3).

Bird abundance and species richness

Eighty species of birds were recorded within point counts. Five species accounted for 71% of the 3692 pairs recorded: Common Yellowthroat, White-throated Sparrow, Lincoln's Sparrow, Savannah Sparrow, Nashville Warbler, and Palm Warbler (in decreasing order of abundance).

The bird fauna was more abundant in 1996 than 1993 in 9 of the 12 natural peatland sites (Wilcoxon's matched-pairs signed-ranks test, $z = 2.4$, $P < 0.02$). Although our samples were small, we found no major changes in bird abundance between 1993 and 1996 at mined sites (Wilcoxon's test, post-blockcut sites: $z = 0.7$, $P = 0.5$, $N = 9$; post-vacuum sites: $z = 0.1$, $P = 0.9$, $N = 5$). At $\alpha = 0.05$, statistical power for a mean difference of fewer than three bird pairs was >95% according to bootstrap simulations of six pairs of observations with the observed variance. Site rankings according to bird abundance were similar between 1993 and 1996 ($r_s = 0.7$, $P < 0.001$, $df = 25$), which suggests that differences among sites remained consistent between years.

We found no overall change in species richness within sites from 1993 to 1996 (Wilcoxon's test, $z = 1.9$, $P = 0.05$, $df = 25$), while site rankings according to species richness were similar between 1993 and 1996 ($r_s = 0.8$, $P < 0.001$, $df = 25$). Thus, as with abundance, site differences in bird richness remained consistent between years.

After pooling years for each site, we found 10.0 ± 0.8 (SE) pairs of birds per point count in natural sites ($N = 12$), 9.5 ± 0.4 pairs in post-blockcut sites ($N = 9$), and 5.0 ± 2.4

pairs in post-vacuum sites ($N = 7$). We conducted a repeated-measures ANOVA with year as a within-subject factor and site perturbation as a between-subject factor on the 26 sites that were visited in both years. Mean bird abundance per point count varied significantly among site types ($F_{[2,23]} = 22.8, P < 0.001$) when all three site types were included, but not when post-vacuum sites were excluded ($F_{[1,19]} = 0.26, P = 0.6$). Mean bird species richness for natural, post-blockcut, and post-vacuum sites (years pooled) were $6.1 \pm 0.5, 5.4 \pm 0.4,$ and $2.8 \pm 1.1,$ respectively. A repeated-measures ANOVA similar to that used for bird abundance data showed strong differences among all three site types ($F_{[2,23]} = 16.8, P < 0.001$) but no significant difference between natural and post-blockcut sites ($F_{[1,19]} = 1.2, P = 0.3$). No significant year \times perturbation interactions were found in repeated-measures analyses of bird abundance and species richness.

Based on the eigenvalue ratio, the first two axes of a canonical correspondence analysis including vegetation structure and bird species density explained 29.9% of the variation in songbird species assemblages. Based on these axes, natural and post-blockcut sites were mostly clustered together, but there was much variation among post-vacuum sites, with respect to vegetation parameters (Fig. 3a). The bird-vegetation ordination (Fig. 3b) revealed two main species assemblages: species associated with tall trees (especially prominent in two post-vacuum sites; Fig. 3a) in the upper right quadrant and species loosely associated with vegetation features more typical of natural bogs, particularly ericaceous plants and *Sphagnum* moss (left side of the diagram).

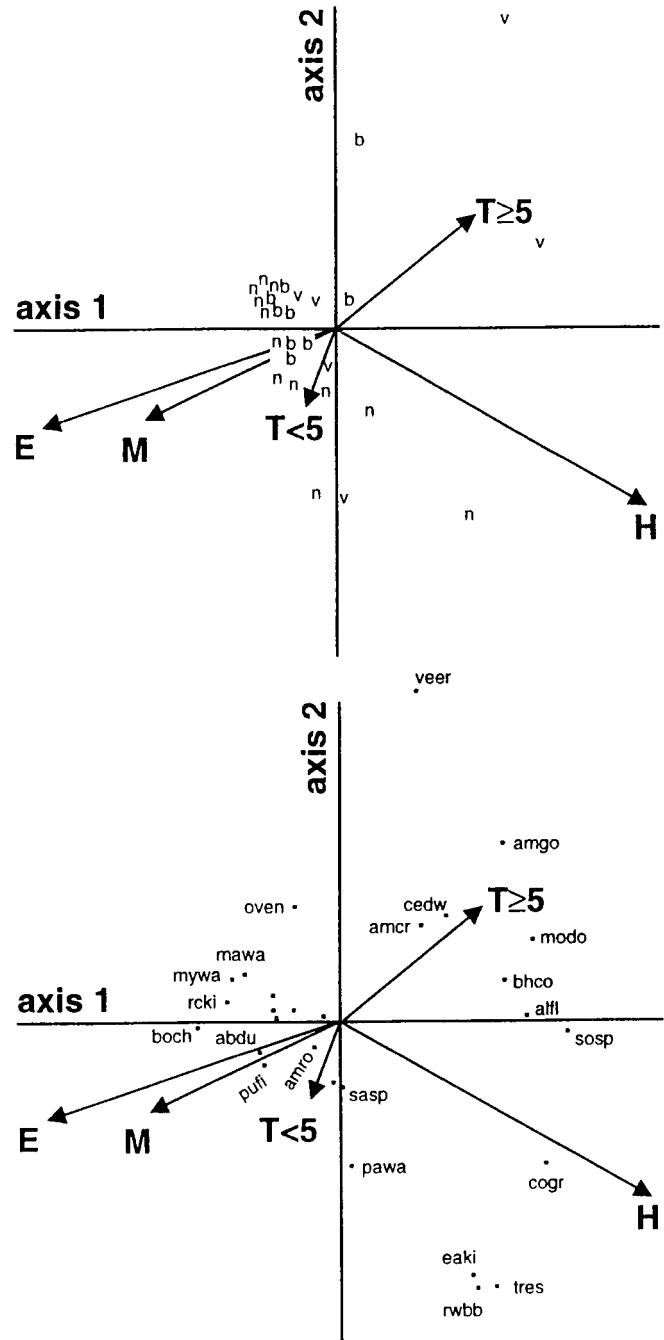
Bird species assemblages

To reduce the effect of sampling error, we removed from the analyses of species assemblages all species found on fewer than 10 occasions. Similarity matrices were calculated from bird species densities and vegetation structure. Bird species and vegetation structure similarities were strongly correlated, with or without post-vacuum sites (Mantel test, $r = 0.79$ and $r = 0.36,$ respectively, $P < 0.007$ in both cases).

Sixteen species were found in all three site types and only the Eastern Kingbird was found in only one site type (Table 4). Ten of the 28 bird species studied responded strongly to site type (Table 4). The most notable species-site associations were the Palm Warbler with natural sites, the White-throated Sparrow with post-blockcut sites, and the American Goldfinch with post-vacuum sites. While White-winged Crossbills were more abundant in post-blockcut sites, their breeding status could not be confirmed because of their complex nesting chronology (Gauthier and Aubry 1995). We found no relationship between observed preference for natural sites and whether species usually nest on the ground (Mann-Whitney U test, $N = 28, z = 0.17$ (corrected for ties), $P = 0.9$).

Based on the mean number of pairs per point count per site, assemblages from the 28 species studied tended to be more similar among sites of the same type than among sites with different mining histories (Mantel single-classification ANOVA (Sokal and Rohlf 1995), $r = 0.11, P < 0.03$). This tendency did not remain when post-vacuum sites were eliminated from the similarity matrices ($r = 0.01, P = 0.3$), which

Fig. 3. Ordination diagram based on the first two axes of a canonical correspondence analysis of peatland sites derived from songbirds' scores (n is natural sites, b is post-blockcut sites, and v is post-vacuum sites) (top) and songbird species abundance (see the Appendix for species code legends) (bottom). Vegetation structure data are indicated by arrows (M, *Sphagnum* mosses; H, herbaceous plants; E, ericaceous plants; L5, trees < 5 m; GE5, trees ≥ 5 m). Eigenvalues for the first two axes are 0.315 and 0.194; the sum of all canonical eigenvalues is 0.812.



suggests that most of the differences in similarity stemmed from the contrasting species assemblages in post-vacuum sites.

Table 4. Numbers of pairs detected per 100-m point count within natural and abandoned bog sites in southern Quebec.

	Site perturbation		
	Natural sites (<i>N</i> = 12)	Post-blockcut sites (<i>N</i> = 9)	Post-vacuum sites (<i>N</i> = 7)
Significant response			
Palm Warbler	0.61±0.19 _a	0.11±0.07 _b	— _b
Ruby-crowned Kinglet	0.24±0.07 _a	0.16±0.06 _a	— _b
Purple Finch	0.1±0.04 _a	0.12±0.06 _a	— _b
White-winged Crossbill	0.03±0.03 _a	0.52±0.24 _b	— _a
Yellow-rumped Warbler	0.2±0.07 _a	0.06±0.02 _a	— _b
Hermit Thrush	0.55±0.09 _a	0.45±0.09 _a	0.11±0.09 _b
Nashville Warbler	0.69±0.17 _a	0.83±0.09 _a	0.16±0.14 _b
White-throated Sparrow	1.57±0.16 _a	2.57±0.28 _b	0.56±0.32 _c
Common Yellowthroat	1.86±0.26 _a	2.12±0.14 _a	0.92±0.39 _b
American Goldfinch	0.02±0.01 _a	0.17±0.05 _b	1.01±0.58 _b
No significant response			
Eastern Kingbird	0.07±0.05	—	—
Boreal Chickadee	0.14±0.10	0.03±0.02	—
Red-winged Blackbird	0.09±0.07	0.02±0.01	—
Black Duck	0.06±0.03	0.03±0.01	—
Ovenbird	0.02±0.02	0.05±0.03	—
Veery	0.01±0.01	0.14±0.12	—
Tree Swallow	0.07±0.07	0.02±0.01	—
Magnolia Warbler	0.25±0.11	0.09±0.04	0.05±0.05
Savannah Sparrow	0.61±0.18	0.07±0.04	0.25±0.17
American Robin	0.17±0.06	0.18±0.05	0.04±0.03
Lincoln's Sparrow	1.00±0.16	1.15±0.27	0.42±0.19
Common Grackle	0.29±0.23	0.03±0.02	0.21±0.21
Cedar Waxwing	0.12±0.04	0.11±0.08	0.14±0.14
Brown-headed Cowbird	0.10±0.05	0.03±0.03	0.23±0.21
Alder Flycatcher	0.13±0.09	0.16±0.06	0.31±0.28
Song Sparrow	0.25±0.18	0.13±0.08	0.64±0.64
American Crow	0.03±0.02	0.05±0.03	0.07±0.07
Mourning Dove	0.03±0.02	0.02±0.02	0.14±0.14

Note: Species are grouped according to whether their densities varied significantly among site perturbation groups ($P < 0.05$), as determined by Kruskal–Wallis tests. Within groups, species are ranked by decreasing order of preference for natural sites (as calculated by Schieck et al. 1995). Values followed by a different letter are significantly different, based on pairwise two-tailed Mann–Whitney U tests.

Discussion

Even though vacuum peat mining removes all live bog vegetation, certain plants and associated birds recolonized even post-vacuum sites within a few years. However, bird numbers and species composition differed from those in natural sites. Most of the differences in vegetation and bird occupancy were caused by the contrast between post-vacuum and other sites. We infer that these differences stem mainly from the fact that post-vacuum sites were sparsely vegetated but were colonized by different sets of plant species.

Other factors such as habitat patch size (Robbins et al. 1989; Calmé and Haddad 1996) and differing ages of post-blockcut and post-vacuum sites may have influenced occupancy by birds. However, we argue that the latter effect was negligible, based on our observation of persistent differences in ericaceous and *Sphagnum* moss cover among post-vacuum

and post-blockcut sites. Furthermore, Lavoie and Rochefort (1996) noted that under good conditions (especially post-blockcut), bog vegetation, particularly the ericaceous stratum, recovered within less than 5 years, which was approximately the minimum time elapsed in our most recently abandoned sites. With the exception of trees like *Betula* spp., post-vacuum sites may simply not be able to revegetate fully, let alone accumulate peat, without restoration.

Bird species assemblages and vegetation structure in post-blockcut sites were remarkably similar to those of natural sites. The only difference in vegetation structure between post-blockcut and natural sites was the lack of *Sphagnum* moss cover on baulks in post-blockcut sites. Even then, the lack of *Sphagnum* moss on the ground did not seem to affect ground-nesting species, which were represented in post-blockcut sites as much as in natural sites. Apart from the Palm Warbler, few bird species stood out as being signifi-

cantly associated with natural sites, and they were mostly species of forested habitats. We cannot conclude that other bird species were not influenced by whether sites had been mined or not, because their numbers may have been too small for differences to be detected. Of species associated with natural sites, the Palm Warbler deserves special attention, because it was not only rarely found in post-mining sites (regardless of the mining method), but is also known to depend primarily on peatlands in most regions (Wilson 1996), especially the south. Given the current pressure on peatlands by agriculture, urban development, and peat mining, the status of the Palm Warbler points to the necessity of conserving large expanses of natural bog near mined sites. Furthermore, even if the rate of natural recovery of post-blockcut sites and their associated bog bird species is encouraging, the block-cut mining method is no longer used, since the peat industry has turned to vacuum mining (Canadian Sphagnum Peat Moss Association 1997). Because of the lasting effect that vacuum mining of peat has on birds, it would be prudent to ensure that sufficient natural bog habitat is maintained to allow the species to persist in southeastern Canada.

The potential of bog restoration for birds

One way to conserve avian peatland specialists is to restore post-mining sites. Habitat restoration is increasingly regarded as a potential solution to wildlife conservation problems like peatland loss (Wheeler et al. 1995; Rochefort and Campeau 1997). In some cases avian species have returned rapidly to restored wetland habitats (Sewell and Higgins 1991; VanRees-Siewert and Dinsmore 1996). Thus, restoring bogs after mining may eventually provide significant additional support for bog specialists. The goal of bog restoration in ornithological terms has been defined as a "re-establishment of a bird assemblage as similar as possible to that of a natural raised bog" (Bölscher 1995). A first step towards bog restoration is the rewetting of post-mining sites, which we have been doing in some of the bogs under study (Price 1996). However, although rewetting may, in principle, facilitate the reversion of a mined site to a peat-accumulating ecosystem, Bölscher (1995) concluded that rewetting was insufficient to restore bird habitat in formerly exploited bogs of northern Europe. In light of the apparent inability of mined bogs to revert naturally to the original bird habitats, we conclude that bog habitat restoration should be accompanied by a preservation "safety net" area to counteract the lasting effect of mining on bird species assemblages.

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Appendix

Table A1. Scientific bird names and codes.

Common name	Scientific name	Code
Alder Flycatcher	<i>Empidonax alnorum</i>	alfl
American Crow	<i>Corvus brachyrhynchos</i>	amcr
American Goldfinch	<i>Carduelis tristis</i>	amgo
American Robin	<i>Turdus migratorius</i>	amro
American Black Duck	<i>Anas rubripes</i>	abdu
Boreal Chickadee	<i>Parus hudsonicus</i>	boch
Brown-headed Cowbird	<i>Molothrus ater</i>	bhco
Cedar Waxwing	<i>Bombusilla cedrorum</i>	cedw
Common Grackle	<i>Quiscalus quiscula</i>	cogr
Common Loon	<i>Gavia immer</i>	colo
Common Yellowthroat	<i>Geothlypis trichas</i>	coye
Eastern Kingbird	<i>Tyrannus tyrannus</i>	eaki
Hermit Thrush	<i>Catharus guttatus</i>	heth
Lincoln's Sparrow	<i>Melospiza lincolnii</i>	lisp
Magnolia Warbler	<i>Dendroica magnolia</i>	mawa
Mourning Dove	<i>Zenaida macroura</i>	modo
Nashville Warbler	<i>Vermivora ruficapilla</i>	nawa
Ovenbird	<i>Seiurus aurocapillus</i>	oven
Palm Warbler	<i>Dendroica palmarum</i>	pawa
Purple Finch	<i>Carpodacus purpureus</i>	pufi
Red-winged Blackbird	<i>Agelaius phoeniceus</i>	rwbl
Ruby-crowned Kinglet	<i>Regulus calendula</i>	rcki
Ruffed Grouse	<i>Bonasa umbellus</i>	rugr
Savannah Sparrow	<i>Passerculus sandwichensis</i>	sasp
Semipalmated Sandpiper	<i>Calidris pusilla</i>	sesa
Sharp-shinned Hawk	<i>Accipiter striatus</i>	ssha
Song Sparrow	<i>Melospiza melodia</i>	sosp
Tree Swallow	<i>Tachycineta bicolor</i>	tres
Veery	<i>Catharus fuscescens</i>	veer
Whip-poor-will	<i>Caprimulgus vociferus</i>	wpwi
White-throated Sparrow	<i>Zonotrichia albicollis</i>	wtsp
White-winged Crossbill	<i>Loxia leucoptera</i>	wwcr
Yellow-rumped Warbler	<i>Dendroica coronata</i>	mywa