Small-mammal responses to peat mining of southeastern Canadian bogs

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Abstract: Bogs, or ombrotrophic peatlands, are well represented in parts of southeastern Canada but are subjected to increasing pressure from the peat industry. We assessed the impact of peat mining on small mammals inhabiting unexploited bog fragments on the periphery of mined bogs. We conducted two separate studies in bogs mined to different levels (0–83%) in southeastern Québec and New Brunswick. The first study used a low sampling effort over 1 month in 26 bogs, while the second used a high sampling effort of 6 months spread across 2 years in 12 bogs. Of the 15 small-mammal species encountered, only 2 were bog specialists. Abundance and species richness of small mammals in bog fragments increased significantly with percentage of area mined and, in some cases, increased with bog area. Both studies suggest that disturbances resulting from peat mining facilitate the invasion of more generalized small-mammal species. Furthermore, small mammals were more abundant near forest or mined edges than at bog centers, and some species responded strongly to vegetation cover. The response of small mammals to peat mining contrasts with the one documented for birds, amphibians, and plants.

Résumé : Les bogs, ou tourbières ombrotrophes, recouvrent une partie importante du sud-est canadien. Ils subissent toutefois des pressions croissantes de l'industrie de la tourbe. Nous avons évalué l'impact de l'exploitation de bogs sur les petits mammifères occupant des fragments naturels situés en périphérie de bogs exploités. Nous avons effectué deux études distinctes dans des bogs soumis à différents degrés d'exploitation (0–83 %) au Québec et au Nouveau-Brunswick. La première comportait un effort d'échantillonnage restreint à 1 mois dans 26 bogs, et la deuxième, plus intensive, portait sur 6 mois d'échantillonnage répartis sur 2 ans dans 12 bogs. Quinze espèces de petits mammifères ont été capturées, dont 2 spécialistes des tourbières. Dans les fragments naturels en périphérie de bogs exploités, la richesse en espèces et l'abondance de petits mammifères augmentaient en fonction de l'importance de la surface exploitée du bog, et dans certains cas, avec la superficie du bog. Les deux études indiquent que l'exploitation des bogs favorise l'invasion de petits mammifères d'espèces généralistes. De plus, les petits mammifères étaient plus abondants près des bordures exploitées et forestières. Certaines espèces étaient également influencées par la structure de la végétation. La réaction des petits mammifères à l'exploitation des bogs diffère de celle rapportée pour les oiseaux, les amphibiens et les plantes.

Introduction

Peatlands cover 17% of Canada (Gorham 1990), with the majority located in remote areas of the boreal zone. Peatlands in the southern part of the country are less numerous and more accessible than their northern counterparts. Consequently, increasing habitat degradation in southeastern Canada, resulting from industrial, agricultural, or urban development, raises concern about the conservation of peatlands and, especially, of ombrotrophic peatlands or bogs (Rubec 1996). The peat-mining industry is currently expanding and generates up to 90 million Canadian dollars annually (Keys 1992). Large bogs with deep deposits of organic matter are particularly valuable in southeastern Canada, as they offer a considerable volume of horticultural peat. These bogs are mined using the vacuum method, which creates flat surfaces of bare peat divided into 30 m wide fields separated by drainage ditches (Wheeler and Shaw 1995; Robert et al. 1999).

Bogs contribute significantly to regional diversity by harboring endemic and uncommon species of plants (Poulin et al. 1999), insects (Rosenberg and Danks 1987; Larson and House 1990), birds (Calmé and Desrochers 1999), and small mammals (Nordquist 1992). Indeed, three species of small mammals show a marked preference for peatlands in eastern North America: the northern bog lemming, *Synaptomys borealis*; the southern bog lemming, *Synaptomys cooperi*; and the Arctic shrew, *Sorex arcticus* (Banfield 1977; Nordquist 1992). Researchers have only recently begun studying the responses of vertebrates to bog habitat lost through peat mining, having observed adverse effects on amphibians (Mazerolle 1999) and birds (Calmé and Desrochers 1999; Delage et al. 2000). However, no study has yet investigated such effects on small mammals, despite the numerous studies of this group in the peatlands of North America and Europe (Manitoba: Buckner 1957*a*, 1957*b*, 1966; Maine:

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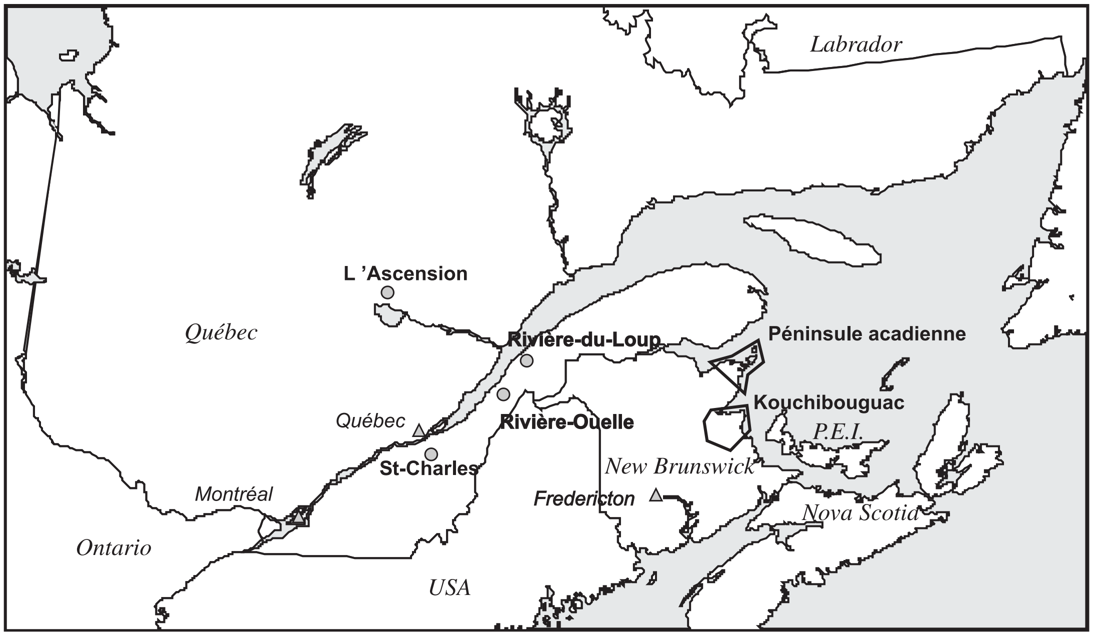
Fig. 1. Location of the small-mammal trapping sites in southeastern Canada. Sites for the large-scale study were St-Charles (*n* = 3), L'Ascension (*n* = 1), Rivière-Ouelle (*n* = 1), Rivière-du-Loup (*n* = 1), and Péninsule acadienne (*n* = 17). The intensive study sites were all in the Kouchibouguac area of southeastern New Brunswick (*n* = 12).



Stockwell 1985; Michigan: Getz 1961; Minnesota: Nordquist 1992; New Jersey: Connor 1953; Finland: Boström and Hansson 1981; Henttonen et al. 1977; Norway: Oksanen et al. 1999).

We present a 2-year census of small mammals in bogs of southeastern Canada and assess the effects of peat mining on their species richness and abundance. We compared small-mammal occurrence in residual fragments left within bogs mined for peat moss with their occurrence in nearby unexploited bogs.

Study area

Two censuses of small mammals were conducted in southeastern Canadian bogs. The first, a large-scale census, involved 26 bogs (372.3 ± 79.2 ha (mean ± 1 SE)) in southeastern Québec and northern New Brunswick (Fig. 1), each of which was subjected to a low trapping effort over a period of 1 month. The second, an intensive census using a high sampling effort spread across 2 years, focused on 12 bogs (914.0 ± 277.7 ha (mean ± 1 SE)) in southeastern New Brunswick (Fig. 1). Bogs undergoing peat mining and still having intact fragments, as well as unexploited bogs that are available for future mining, were included. The proportion of mined area varied greatly between bogs (0–83%). All sampled fragments were adjacent to an area currently being mined, and had been subjected to at least 5 years of prior mining activity.

The sampled unexploited bogs and fragments were in open habitat with <50% tree cover higher than 1.5 m. The ground-layer vegetation was a mixture of species, consisting of *Sphagnum* moss (mostly *Sphagnum capilifolium* and *Sphagnum fuscum*) and lichens (mostly *Cladonia rangiferina*). The upper layer was composed of herbaceous (mostly *Rubus chamaemorus*, *Eriophorum spissum*, and *Smilacina trifolia*) and ericaceous (mostly *Kalmia angustifolia*, *Chamaedaphne calyculata*, *Ledum groenlandicum*, and *Vaccinium* spp.) shrubs and conifer trees or other shrubs (mostly *Picea mariana* and *Larix laricina*).

Materials and methods

Small-mammal sampling

Large-scale study

Trapping of small mammals was carried out from 28 July to 30 August 1997 in 26 bogs: 16 mined bogs and 10 unexploited bogs. Intact bog fragments in 10 of the 16 mined bogs were paired with 10 nearby (<23 km) unexploited bogs that had similar habitat characteristics. Each of the remaining six mined bogs had large intact portions of unexploited fragments (>half total area) to which we paired peripheral unexploited fragments within the same bog. In these large fragments, which were considered to be controls, traps were located >500 m from peat-mining activities.

Within a given pair of bogs, a single trapping transect was laid out in the unexploited fragment located in the periphery of the mined bog. This transect was located in the middle of the fragment, equidistant from both the forest edge and the mined edge. Two transects were set in the unexploited-bog counterpart: the first was located in the bog periphery and was placed at a similar distance from the forest edge as the transect in the bog fragment of the same pair; the second was laid out in a straight line in the center of the bog to allow an assessment of the effect of distance from the forest edge. The length of each transect (282 ± 26.5 m (mean ± 1 SE), *n* = 16) and, hence, the number of traps used, was determined by the length of the bog fragment. While the number of traps set was constant for a given pair of bogs, it varied among pairs.

Small mammals were trapped along the transects using three types of trap, as different trap types target different groups (i.e., pitfalls for shrews (Williams and Braun 1983; Bury and Corn 1987; Mitchell et al. 1993) and live and snap traps for rodents (Boonstra and Rodd 1984; Mitchell et al. 1993)). Sherman live traps (8 × 9 × 23 cm) were set at 10-m intervals, while Victor No. 0 snap traps and pitfall traps (20-cm diameter × 25-cm height) were laid concurrently every 60 m. Traps were set for 3 consecutive days, baited with apple cubes, peanut butter, and cotton flannel, and checked every 12 h. Small mammals were marked by making 3-mm incisions in one ear. Recaptured individuals were excluded from the statistical analyses. Trapping effort was calculated as the number of trapping days divided by the number of functional traps. The correction recommended by Nelson and Clark (1973) for sprung snap traps and Sherman live traps (i.e., number of traps set minus half the number of traps triggered) was applied.

Intensive study

This study primarily targeted amphibians (Mazerolle 1999) but also proved to be efficient in capturing small mammals. Trapping was conducted in unexploited areas of six mined and six unexploited bogs from mid-July to early September 1997 (20 592 trap-days) and from mid-June to mid-October 1998 (43 200 trap-days). We installed four drift-fence arrays associated with pitfall traps in each bog. Each array consisted of three aluminum-flashing drift fences (5 × 0.60 m) at 120° angles disposed in a closed "Y" formation buried to a depth of 15–20 cm. Nine pitfall traps were set per array: two located at the end of each fence (one on each side) and a single trap located at each intersection of two fences at the center of the array. Pitfall traps were made from 11.4-L plastic buckets (24-cm diameter × 30-cm height), one-quarter filled with water, and provided with a floating mat of *Sphagnum* moss. Four drift-fence arrays were placed in the unexploited part of each bog currently being mined at 15, 50, 100, and 200 m from mined edges, while in unexploited bogs, the four arrays were deployed randomly. In addition, the distance of each array to the closest forest habitat was measured. Traps were checked every 4 days.

The identification of all small mammals collected in both studies was confirmed using dental structure, based on van Zyll de Jong (1983) for shrews and Banfield (1977) for rodents. Most specimens trapped were deposited as vouchers at the New Brunswick Museum (Saint John, N.B.), Université de Moncton (Moncton, N.B.), Faune et Parcs Québec (Québec, Que.), and Collège de Ste-Anne-de-La-Pocatière (La Pocatière, Que.).

Vegetation structure

The percentage of vegetation cover was estimated with circular plots in two different settings, according to the study. In the large-scale study, vegetation cover was estimated using circular plots of 1 m^2. These plots were deployed in pairs: one pair on the trapping transect and two pairs on transects running parallel to and on each side of the first one (Poulin et al. 1999). In the intensive study, vegetation cover was estimated using circular plots with a 10-m radius. These were centered on each drift-fence array and used 15% interval classes. Four vegetation strata were considered in each study: the *Sphagnum* moss layer, the herbaceous layer, the ericaceous layer, and the tree layer.

Statistical analyses

The data from the two studies were analyzed separately, owing to the disparity between methods and sampling effort. Spatial correlation analysis was used to determine the relationship between bog proximity and species diversity (species richness and composition) by comparing the similarity of species assemblages (Jaccard index) with distances between bogs using Mantel tests (Legendre and Fortin 1989).

Abundance and species richness of small mammals in mined and unexploited bogs were analyzed using Poisson regression models (McCullagh and Nelder 1989) fitted using the GENMOD procedure (SAS Institute Inc. 1993). Data were corrected for overdispersion, and variation in sampling intensity was factored in with the number of trap-days as an offset variable (McCullagh and Nelder 1989; SAS Institute Inc. 1993). When analyzing abundances, all species found in fewer than 50% of the transects were excluded, to prevent spurious effects caused by low population density (Table 1). Only one species remained in the analysis in the large-scale study, while seven species remained in the intensive study.

The effects of habitat loss on small mammals were first investigated using models that included total area of bog (mined and intact) and percentage of area mined for both the large-scale (model 1) and intensive (model 2) studies. In the model for the latter study, a year covariable was added; total bog area and percentage of area mined were considered as categorical variables, owing to nonlinear responses of small mammals to these variables. Thus, model 2 included the variables: (*i*) year (two levels: 1997 and 1998), (*ii*) total bog area (two levels: ≤500 or >500 ha), and (*iii*) percentage of area mined (three levels: 0, 0–10, and >10%).

To assess the effects of forest proximity and mining proximity on small-mammal assemblages in the large-scale study, the model built included a trap-location class variable (three levels: unexploited bog center, mined bog periphery, and unexploited bog periphery, with the last-mentioned as the reference level) and a vegetation-structure variable (model 3). To reduce collinearity between variables, the vegetation-cover variable accounting for the highest explanatory power was included in the large scale study model.

In the intensive study, separate models were built for unexploited and mined bogs. The model for unexploited bogs included distance to forest habitat and the vegetation-structure variable with the greatest explanatory power (model 4). In cases where a vegetation variable was correlated with the distance to forest habitat, the variable accounting for the highest explanatory power was incorporated into the model (model selection based on the Akaike information criterion sensu Lindsey 1997). The models for mined bogs comprised the same variables entered in the unexploited-bog models, but the categorical variable of distance to mined edge (four levels: 15, 50, 100, and 200 m; model 5) was added. Two covariables were added to models of both bog types to account for plots nested within bogs and years: a year-class variable and a bog-class variable (six levels: one level for each bog). Unless otherwise specified, the significance of all relationships reported was evaluated with the Wald χ^2 statistic.

Results

Small-mammal diversity

A total of 4031 individuals from 15 species of small mammals were captured in the two studies. The total trapping effort was 68 914 trap-days (i.e., 5 122 trap-days for the large-scale study and 63 792 trap-days for the intensive study). Five species accounted for 91% of all captures from both studies: the masked shrew, *Sorex cinereus* (55%); the meadow jumping mouse, *Zapus hudsonius* (13%); the meadow vole, *Microtus pennsylvanicus* (11%); the pygmy shrew, *Sorex hoyi* (7%); and the Arctic shrew (5%) (Table 1). Captures of the ermine *Mustela erminea* (n = 1) and the long-tailed weasel *Mustela frenata* (n = 2) were not considered in any of the analyses. Twice as many species were recorded in the intensive study (14) as in the large-scale study (7). There was no significant geographic variation in the richness and the composition of the species assemblages between bogs for either study (Mantel test, P > 0.05). However, the Arctic shrew, the southern bog lemming, and the American water shrew (*Sorex palustris*) were only captured in the southeastern part of New Brunswick during the intensive study. Among the species expected to occur in the bogs of the study area, the northern bog lemming was the only species not captured.

Table 1. Small-mammal trap rates (mean captures/100 trap-days ± SD) in unexploited and mined bogs of southeastern Canada.

		Large-scale study		Intensive study	
Common name	Scientific name	Unexploited (n = 10)	Mined (n = 16)	Unexploited (n = 6)	Mined (n = 6)
Rodents					
Meadow vole	*Microtus pennsylvanicus*	0.1±0.3	0.7±1.2	0.3±0.2	0.8±0.9
Red-backed vole	*Clethrionomys gapperi*	0.3±1.1	0.1±0.4	0.1±0.1	0.2±0.2
Meadow jumping mouse	*Zapus hudsonius*	0	0.1±0.3	0.6±0.3	1.1±0.9
Deer mouse	*Peromyscus maniculatus*	0	0.5±2.4	0	<0.01±<0.01
Southern bog lemming	*Synaptomys cooperi*	0	0	0.1±0.1	0.05±0.1
Woodland jumping mouse	*Napaeozapus insignis*	0	0	<0.01±<0.01	<0.01±<0.01
Red squirrel	*Tamiasciurus hudsonicus*	0	0.1±0.4	<0.01±<0.01	0
Eastern chipmunk	*Tamias striatus*	0	<0.1±0.2	0	0
Insectivores					
Masked shrew	*Sorex cinereus*	0.7±1.1	1.9±2.7	3.5±1.2	3.6±1.6
Pygmy shrew	*Sorex hoyi*	<0.1±0.2	0.1±0.2	0.3±0.2	0.6±0.3
Short-tailed shrew	*Blarina brevicauda*	<0.1±0.2	0.2±0.6	0.2±0.1	0.2±0.1
Arctic shrew	*Sorex arcticus*	0	0	0.2±0.2	0.5±0.4
American water shrew	*Sorex palustris*	0	0	0.1±0.1	0.1±0.1
Star-nosed mole	*Condylura cristata*	0	0	<0.01±<0.01	<0.01±<0.01
Smoky shrew	*Sorex fumeus*	0	0	<0.01±<0.01	0

Table 2. Small-mammal response to habitat loss in the large-scale (model 1) and intensive (model 2) studies.

	Model 1		Model 2			
				% bog area mined[b]		
	Total bog area	% bog area mined	Total bog area[a]	0	0–10	Interaction
Species richness		* (+)				—
Total abundance		** (+)	* (–)	* (–)	* (–)	—
Masked shrew			** (–)			—
Arctic shrew	—	—	* (+)	*** (–)	* (–)	—
Red-backed vole	—	—	** (–)	*** (–)	*** (–)	—
Pygmy shrew	—	—		* (–)		—
Meadow vole	—	—		* (–)		—
Short-tailed shrew	—	—		** (–)		** (+)
Meadow jumping mouse	—	—				—

Note: The significance of parameter estimates of Poisson regressions was assessed with the Wald χ^2 statistic. Significance is indicated as follows: *, P < 0.05; **, P < 0.01; and ***, P < 0.001; "—," not included in final model (see text). Signs in parentheses denote whether significant effects are positive or negative. See text for all variables included in the models. Both explanatory variables were treated as continuous variables in model 1 but as categorical variables in model 2.

[a]Bog-area variable with the highest value (>500 ha) as reference class.

[b]Percentage of mined area with the highest value (>10%) as reference class.

Bog-habitat loss

In the large-scale study, both the species richness and the total abundance of small mammals (all species combined) increased significantly with percentage of area mined. This was independent of total bog area (model 1, Table 2). The abundance of masked shrews did not vary with either of the two variables and there were no significant statistical interactions.

Similarly, in the intensive study, the total abundance of small mammals varied both with total bog area and the percentage of area mined, with more captures in large bogs (>500 ha) and bogs with more than 10% of their surface mined (Table 2). Masked shrews were also more abundant in large bogs but were not influenced by percentage of area mined (Table 2). Although the abundance of Arctic shrews was higher in small bogs, it was positively associated with percentage of area mined. Red-backed voles (*Clethrionomys gapperi*) were more abundant in large bogs, and captures increased with the percentage of area mined (Table 2). The abundance of both pygmy shrews and meadow voles was independent of area, but was lower in unexploited bogs than in bogs with more than 10% of their area mined. Short-tailed shrew (*Blarina brevicauda*) captures were more frequent in the large bogs with more than 10% of their area mined (area × percentage of bog area mined interaction; Table 2). Neither species richness of small mammals nor abundance

Table 3. Small-mammal responses to forest proximity, vegetation structure, and peat-mining proximity in unexploited bogs and fragments in the intensive study (models 4 and 5).

	Model 4: unexploited bogs		Model 5: mined bogs					
				Distance to edge of mined area[a] (m)				
	Distance to forest	Vegetation layer variable	Distance to forest	15	50	100	Vegetation layer variable	Interaction[b]
Species richness	** (–)	Conifer					Ericacea	—
Total abundance	* (–)	Conifer*** (+)					Moss	***
Meadow jumping mouse	* (–)	Conifer** (+)		*** (–)	* (–)	*** (–)	Conifer* (+)	***
Red-backed vole		Herbs** (–)		* (–)	** (–)		Moss	**
Masked shrew		Conifer*** (+)			*** (–)		Moss	**
Pygmy shrew		Herbs** (–)	* (–)	** (+)			Conifer	—
Short-tailed shrew		Moss					Ericacea	—
Meadow vole	** (–)	Ericacea	—	** (+)			Herbs* (+)	—
Arctic shrew		Ericacea					Ericacea	—

Note: The significance of the parameter estimates of Poisson regressions was assessed with the Wald χ^2 statistic. The overall significance of interaction terms was assessed with a *F* test based on deviance difference analogous to Type III sums of squares. Significance is indicated as: *, $P < 0.05$; **, $P < 0.01$; and ***, $P < 0.001$; "—," not included in final model. Signs in parentheses denote whether significant effects are positive or negative.
[a]Distance to mined edge with the highest value (200 m) as reference.
[b]Distance to mined edge × distance to forest interaction.

of meadow jumping mice were sensitive to bog-habitat loss or total bog area.

Vegetation structure and trap location

In the large-scale study, species richness of small mammals, total capture rates of small mammals, and masked shrew capture rates did not vary with trap location (i.e., unexploited bog center, mined bog periphery, and unexploited bog periphery). The total abundance of small mammals and the abundance of masked shrews were positively influenced by the amount of ericaceous cover ($P < 0.001$ and $P < 0.01$, respectively), whereas species richness of small mammals was negatively related to herbaceous cover ($P < 0.01$).

In unexploited bogs in the intensive study, species richness and total abundance of small mammals, as well as the abundance of meadow jumping mice and meadow voles, were greater in proximity to forest habitat (Table 3). The total abundance of small mammals, as well as the abundance of meadow jumping mice and masked shrews, were positively associated with conifer cover (Table 3). Red-backed voles and pygmy shrews were more abundant in bog areas with low herbaceous cover (Table 3).

Within mined bogs in the intensive study, pygmy shrews and meadow voles were captured most frequently 15 m from mined edges, whereas red-backed voles were most abundant 50 m from mined edges (Table 3). Pygmy shrews were more abundant near forest habitat than far from it (Table 3). Captures of meadow jumping mice increased with the amount of conifer cover, while meadow voles were captured more frequently in areas of high herb cover (Table 3). Within mined bogs, the effect of forest proximity on small mammals depended on mining proximity. Indeed, the total abundance of small mammals, as well as the abundance of meadow jumping mice, red-backed voles, and masked shrews, were greater close to mined edges but far from forest habitat (distance to forest × distance to mined edge interaction, Table 3).

Discussion

Bogs in the study area showed a rich assemblage of small-mammal species. At least five species of small mammals were likely to be encountered in the bogs of the study area, but only three species are known to prefer peatlands over other habitats: the northern bog lemming, the southern bog lemming, and the Arctic shrew (Banfield 1977; Nordquist 1992). Despite the large sampling effort in our study, only 6% of the individuals captured were southern bog lemmings and Arctic shrews and none were northern bog lemmings. The most abundant species captured (masked shrew, meadow vole, and meadow jumping mouse) are habitat generalists that use adjoining forest habitats in the same geographic region (Kirkland and Schmidt 1982; Swan et al. 1984; Monthey and Soutiere 1985; Parker 1989; Potvin et al. 1999; Bowman et al. 2000; Darveau et al. 2001). Small-mammal assemblages similar to those in this study have been reported in bogs in Manitoba (Buckner 1957*a*, 1957*b*), Maine (Stockwell 1985), and Minnesota (Nordquist 1992). This suggests that most small mammals captured in this study, although usually associated with forests, also extensively use bogs.

Small-mammal species in this study were not exclusively associated with either unexploited bogs or bog fragments. However, the results suggest that peat mining attracted small mammals, thus increasing their diversity in bog fragments relative to similar parts of unexploited bogs. This contrasts with similar studies for plants (Poulin et al. 1999), birds (Delage et al. 2000), and amphibians (Mazerolle 1999). Indeed, certain species of these groups (mainly bog specialists), either do not occur in bog fragments or have reduced abundances in these disturbed habitats. The scarcity of small mammals associated specifically with bogs relative to other small mammals may explain the contradictory patterns between small mammals and other groups. Furthermore, bog fragments may attract small mammals as a result of drainage ditches that lower the water table in peripheral bog fragments, especially near edges (Poulin et al. 1999). Indeed, dryer substrates in these areas, as opposed to unexploited bogs, could explain not only the high abundance of small mammals in fragments but also their tendency to concentrate near the edge of mined areas. This explanation is consistent with Buckner (1966), who observed higher densities of Arctic shrews in the dryer portions of a bog. An alternative explanation for the concentration of small mammals near mined edges is the documented tendency of mammals to follow obstacles in their movements (e.g., Bider 1968), but this cannot be substantiated without detailed data on movements. Although Mauritzen et al. (1999) observed that root voles, *Microtus oeconomus*, preferred ditch habitat in agricultural fields, the nature of the ditches in mined bogs (i.e., steep 90° slopes and the presence of water) renders the use of these improbable. We also argue against the possibility of a crowding effect in bog fragments sensu Hagan et al. (1996), because mined edges were well defined and had been established for a long time relative to the life span of the small mammals studied. Although we used different sampling techniques in different areas, the results of the two studies are consistent, showing that the response of small mammals to peat mining is similar over a large part of southeastern Canada.

The preference of small mammals for bog habitat near mined edges and the relative abundance of small mammals in these areas suggest that preservation of unexploited portions could provide refuges for small mammals during exploitation. Undisturbed fragments in a variety of habitats can serve as refuges for small mammals (Fitzgibbon 1997; Lindenmayer et al. 1999; Darveau et al. 2001). However, the general scarcity of the three species that prefer bogs suggests that the usefulness of such refuges could be limited to the Arctic shrew, the only species more abundant in bog fragments than in natural bogs. Further work is required to assess the habitat requirements of the two species of lemmings, *S. borealis* and *S. cooperi*. Particularly dry conditions in bogs due to climatic variation or drainage within bogs or in their vicinity may extend the range of certain species not typically associated with peatlands (Nordquist 1992). These disturbances may threaten *Synaptomys* spp. via competitive exclusion from invading species such as the meadow vole (Linzey 1984). To demonstrate whether scarcity of *Synaptomys* spp. in our study area is the result of competitive exclusion, a long-term experiment involving the removal of generalist species would be required. However, if bog specialists have already been extirpated regionally, even a removal experiment might yield inconclusive results. Further work will be necessary to assess the conservation status of mammalian bog specialists, especially in regions where bogs and the surrounding habitat are under intense management.

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