

Detrimental effects of peat mining on amphibian abundance and species richness in bogs

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Abstract

Peat bogs of eastern North America are increasingly being mined for peat, which results in the extensive draining of these systems. First, I quantified the effects of peat mining on amphibian species richness and abundance in bog remnants adjacent to mining activity and unmined bogs. I then investigated amphibian occurrence patterns in bog remnants relative to the distance to the mined edge, after accounting for microhabitat and distance to landscape elements. The response of amphibians to peat mining varied across taxa. For instance, amphibian species richness, total amphibian captures (all spp. combined), as well as those of green frogs (*Rana clamitans*) were greater in unmined bogs than in bog remnants. Wood frogs (*Rana sylvatica*) were most abundant in unmined bogs in areas far from bog ponds, as well as in unmined bogs in areas near shrub patches. After accounting for microhabitat and landscape variables, American toads (*Bufo americanus*) in bog remnants were most abundant close to mined edges, whereas the other species did not respond to the proximity of mined edges. Peat mining negatively impacts amphibians occurring in bog remnants. The response of amphibians to peat mining is similar to the one of birds and plants, but differs with small mammals. Maintaining a complex mosaic of bog ponds, shrub and forest patches might help mitigate peat mining effects on amphibian patterns of abundance.

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1. Introduction

Since the late 1970s, amphibian populations have been declining around the globe, both in pristine and disturbed regions (Barinaga, 1990; Vitt et al., 1990; Pounds, 1991; Wake, 1991). Many agents are considered responsible, but habitat destruction and fragmentation remain well-recognized threats to amphibians (Wyman, 1990; Blaustein et al., 1994; Beebee, 1996). Indeed, amphibians have low vagility compared to other vertebrates (Sinsch, 1990), which can make them more vulnerable to habitat perturbation. Most amphibians require wetlands, either as breeding or summering grounds, to complete their life cycles (Wilbur, 1980). Continuing wetland conversion through agriculture or urban expansion invariably results in habitat loss and

severe changes in water regimes (Rubec et al., 1988; Wilen and Frayer, 1990), and puts amphibian populations at risk (Gibbs, 1993).

Peatlands, which are acidic wetlands mostly occurring in northern countries (predominantly Canada and the Independent States of the former USSR), cover approximately 4 million km² worldwide (Maltby and Proctor, 1996), and like their less acidic counterparts, are drained for agriculture, forestry, and urbanisation. Few peatlands have remained unaltered in certain parts of Europe. For instance, less than 15% of the original area of peatlands have remained unscathed in Denmark, Germany, Poland, and the Netherlands (reviewed in Poulin and Pellerin, 2001). Furthermore, the deep volumes of peat in bogs of North America and Europe are coveted for extraction, as peat is extensively used in horticulture or as fuel (Wheeler and Shaw, 1995; Lavoie and Rochefort, 1996). Global peat mining production reached 194 million tonnes in 1989, 87% of it destined to supply the demand for peat in horticulture (Keys, 1992). Canada currently ranks third as a peat producer,

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behind the former USSR and Germany (Poulin and Pellerin, 2001). Although a greater proportion of Canadian peatlands occur in remote boreal regions, the less numerous and more accessible peatlands of south-eastern Canada have been disappearing as a result of the expansion of the peat mining industry.

Current peat mining methods consist in intensively draining bogs through networks of excavated ditches (Keys, 1992). Once the surface vegetation is removed to expose the bare peat on the drained portion of the sites, the peat is then extracted by sequentially harrowing and removing the surface layer with tractor-driven vacuums (Wheeler and Shaw, 1995; Robert et al., 1999). Peat mining severely disrupts peatlands and modifies the structure of plant, bird, and small-mammal assemblages in the remaining bog fragments (Poulin et al., 1999; Delage et al., 2000; Mazerolle et al., 2001). In addition to draining the wetland, peat mining forms abrupt edges and breaks up bogs into smaller fragments. With their moisture requirements and use of different elements of the landscape (Sinsch, 1990), pond-breeding amphibians occurring in bogs might be sensitive to peat mining activities. These effects could be particularly strong near the edges of bog remnants, where draining is most intense.

Against this background, I investigated the amphibian abundance and species composition in unmined bogs and bog remnants adjacent to mined peat surfaces. I hypothesized that the species richness and abundance of amphibians occurring in bogs is negatively influenced by the presence of adjacent peat mining. I also predicted that amphibians occurring in bog remnants are more dependent on the proximity of certain landscape elements, such as the distance of the capture site to the closest pond, than in unmined bogs. This was followed by a more detailed analysis within mined bogs, to assess amphibian occurrence patterns at each array relative to the proximity of the mined edge.

2. Methods

2.1. Study area

I conducted this study in six disturbed and six unmined ombrotrophic bogs (914 ± 962 ha, mean ± 1 S.D.; pH 3.71 ± 0.14 , mean ± 1 S.D.) within the Greater Kouchibouguac Ecosystem, a 6400 km² area in eastern New Brunswick, Canada where 8.6% of the landscape consists of peatlands (Fig. 1). Ombrotrophic bogs are *Sphagnum*-dominated peatlands characterized by a pH oscillating around 4.0, and in which precipitations provide the only source of nutrients and water (Schwintzer, 1981; Gorham et al., 1984; Vitt, 1994). The study area encompasses both Kouchibouguac National Park (238 km²), under federal jurisdiction, and the surrounding

area which is under provincial jurisdiction and subjected to forestry and peat mining activities. I use the terms “mined” and “unmined” bogs to distinguish bogs undergoing mining from unmined peat bogs. Within mined bogs, the intact portion of the bog immediately adjacent to the mining operation was actually sampled (i.e., hereafter bog remnant), as the mined plots are barren and regularly subjected to major interference from heavy machinery.

The vegetation at the sites consisted of scattered shrubs (<3 m) of *Picea mariana* and *Larix laricina*, whereas *Kalmia angustifolia*, *Kalmia polifolia*, *Chamaedaphne calyculata*, *Ledum groenlandicum*, *Andromeda glaucophylla*, *Vaccinium* spp., *Gaylussacia baccata*, and *Gaylussacia dumosa* dominated the low shrub layer (10–30 cm). *Eriophorum* spp. were common in the herb layer. A mixture of *Sphagnum* mosses and lichens (mainly *Cladonia rangiferina*) covered the ground.

2.2. Amphibian capture

I used drift fences associated with pitfall traps to capture amphibians. Each 5-m drift fence was erected using 60-cm aluminum flashing placed in a trench 15–20 cm in depth. Fences were assembled in groups of three (referred to hereafter as an array), in a closed “Y” formation fastened together at their intersection with duct tape. The arms of the array radiated outward at angles of 120 degrees. Pitfall traps were fashioned from 11.4-l plastic buckets provided with lids. Traps were filled to the fourth with water and a floating mat of *Sphagnum* moss was added. I cut out the center part of each lid, leaving a rim which was placed on each trap to prevent trapped individuals from escaping (Mazerolle, 2003). Each drift-fence array was fitted with nine traps sunk flush with the bog surface: two traps at the end of each fence (one on each side), and a trap at each of the fence intersections at the array center.

I randomly deployed four drift-fence arrays with pitfall traps over each of six unmined bogs, in open bog habitat. Similarly, I installed four drift-fence arrays over each of six bogs undergoing mining. In the latter, however, the four arrays were placed on an intact bog remnant at 15, 50, 100, and 200 m from the edge of mined plots. The exact location of an array at a given distance was determined randomly.

Installation of the 48 arrays took place from May to July 1997. Trapping was conducted during 1997 and 1998: mid July 1997 to early September 1997 (20 592 trapnights, where 1 trapnight equals 1 pitfall trap open for 1 night), mid June 1998 to mid July 1998 (10 368 trapnights), and late July 1998 to mid October 1998 (32 832 trapnights). Traps were checked every 4 days. Captured individuals were identified, marked with a toe-clip (date-specific mark) and released on the other side of the fence. I anaesthetized salamanders by immersion in

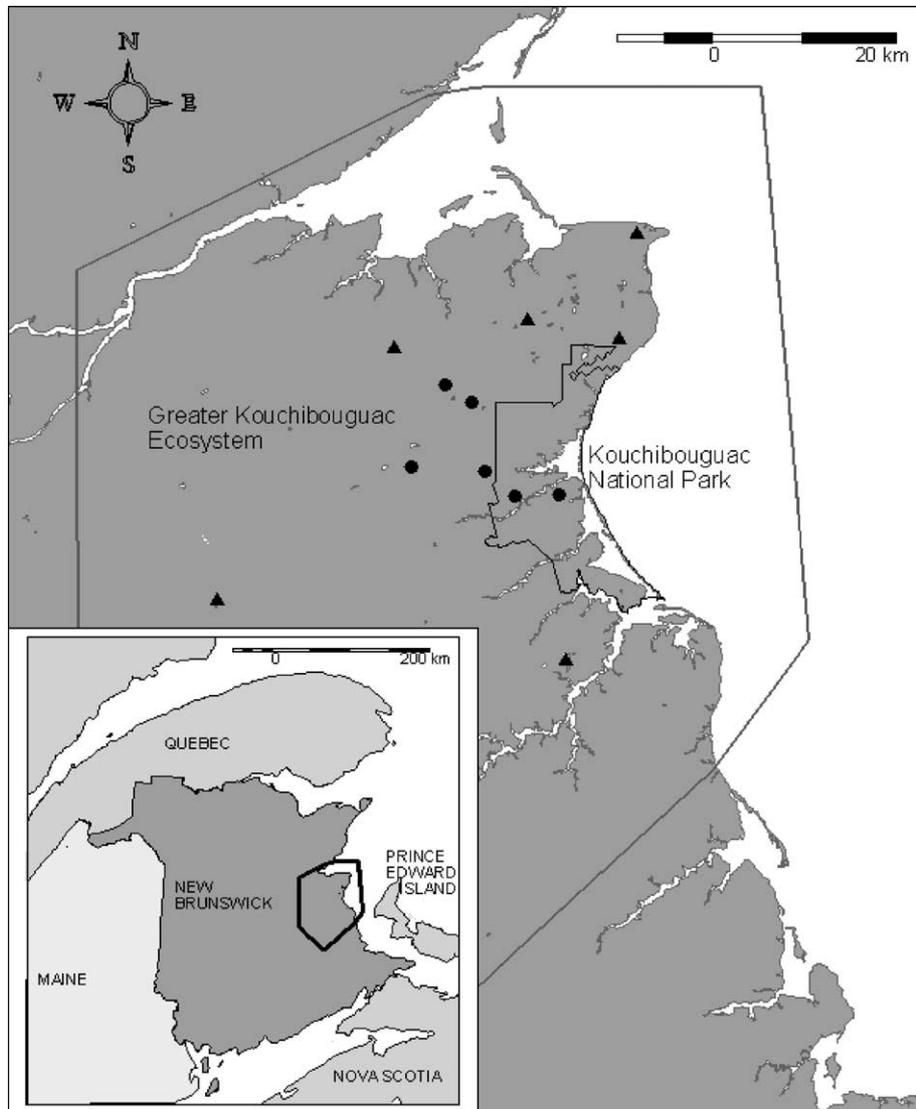


Fig. 1. Study area and location of unmined (●) and mined (▲) bogs where drift-fence arrays were deployed (four arrays/bog) in eastern New Brunswick, Canada.

15% ethanol prior to marking, as suggested by Fellers et al. (1994). Traps were closed between trapping periods.

2.3. Microhabitat

Vegetation structure was measured in circular plots (10-m radius) centered on each array. I employed the relevé technique (Mueller-Dombois and Ellenberg, 1974) to sample vegetation on two occasions during spring and summer 1998, each relevé taking between 45 and 60 min. I defined vegetation structure based on a combination of height and life form: tree layer (> 3 m), shrub layer 1 (0.5–3 m), shrub layer 2 (30–50 cm), shrub layer 3 (10–30 cm), shrub layer 4 (< 10 cm), herb layer (herbaceous vegetation), and moss layer (*Sphagnum* spp. and lichens). A semi-quantitative scale was used to quantify cover (<5% but rare, <5% but abundant, 5–25%, 25.1–50%, 50.1–75%, and > 75%). I measured

the bog water pH at each drift-fence array with an HI 9024 pH meter fitted with a temperature probe (Hanna Instruments Inc., Rhode Island, USA). Descriptive statistics for the microhabitat variables are given in Table 1.

I used principal components analysis (PCA) to summarize vegetation structure data at each array within unmined bogs and remnants. Factor loadings for arrays on PCA axes were used in subsequent analyses. The PCA produced three PCA axes with eigenvalues > 1. The first axis was strongly correlated with the cover of tall shrubs and herbs, the second was an index of tree and moss cover, whereas the third axis was related to low shrubs (Table 2).

2.4. Distance measures

Because pond-breeding amphibians use different habitats at different times of the year (Sinsch, 1990), I

Table 1
Descriptive statistics (mean \pm 1 S.D.) of microhabitat and distance measures (i.e., relative to landscape variables) at drift-fence arrays in unmined bogs and bog remnants of eastern New Brunswick, Canada

| Variable | Unit | Unmined bogs (n = 24) | Mined bogs (n = 24) |
|--|---------|--------------------------|------------------------|
| <i>Microhabitat</i> | | | |
| Bog water pH | pH | 3.71 \pm 0.16 | 3.70 \pm 0.2 |
| Tree layer (> 3 m) | % cover | 0.2 \pm 0.6 | 0.1 \pm 0.2 |
| Shrub layer 1 (0.5–3 m) | % cover | 17.2 \pm 16.3 | 14.1 \pm 15.6 |
| Shrub layer 2 (30–50 cm) | % cover | 28.0 \pm 23.6 | 22.0 \pm 21.9 |
| Shrub layer 3 (10–30 cm) | % cover | 68.8 \pm 19.8 | 83.3 \pm 12.0 |
| Shrub layer 4 (< 10 cm) | % cover | 15.7 \pm 9.7 | 18.0 \pm 12.5 |
| Herb layer | % cover | 49.5 \pm 24.3 | 35.8 \pm 25.9 |
| Moss layer | % cover | 87.5 \pm 0.0 | 82.4 \pm 16.0 |
| <i>Distance measures</i> | | | |
| Distance to closest woodland | m | 178.0 \pm 129.9 | 300.4 \pm 168.0 |
| Distance to closest bog pond | m | 23.2 \pm 28.6 | 160.3 \pm 129.6 |
| Distance to closest spruce/ larch shrub patch | m | 3.2 \pm 1.7 | 11.9 \pm 15.9 |

Table 2
Factor loadings of principal components analysis (PCA) used to summarize vegetation structure data of unmined bogs and bog remnants of eastern New Brunswick, Canada

| Variable | Factor loadings | | |
|--------------------------|-----------------|-------|-------|
| | PCA1 | PCA2 | PCA3 |
| Tree layer (> 3 m) | 0.48 | 0.62 | -0.04 |
| Shrub layer 1 (0.5–3 m) | 0.72 | 0.32 | 0.40 |
| Shrub layer 2 (30–50 cm) | 0.87 | 0.08 | -0.05 |
| Shrub layer 3 (10–30 cm) | 0.30 | -0.42 | 0.16 |
| Shrub layer 4 (< 10 cm) | -0.35 | -0.25 | 0.78 |
| Herbaceous layer | -0.62 | 0.54 | -0.28 |
| Moss layer | -0.35 | 0.63 | 0.50 |
| Eigenvalue | 2.23 | 1.42 | 1.13 |
| Variance explained (%) | 31.9 | 20.2 | 16.1 |

measured the distance from drift-fence arrays to three landscape features within and adjacent to bogs potentially used by amphibians. These consisted in two distance measures within bogs, the closest bog pond (water body > 1 m²), and the closest shrub patch > 1 m², whereas the third dealt with the nearest woodland habitat patch (> 0.6 ha with vegetation > 3 m in height) adjacent to the bogs.

3. Statistical analyses

3.1. Generalized estimating equations

To account for the repeated measures design of the study, I used regression models computed from Generalized Estimating Equations (GEE's) (Diggle et al., 1994; Stokes et al., 1995; Horton and Lipsitz, 1999) with

the GENMOD procedure in SAS 8.01 (SAS Institute Inc., 1993). GEE's are an extension of generalized linear models and are especially designed for longitudinal data (i.e., repeated measures), yielding robust estimates of parameters and their standard errors. Here, the repeated subject was the array, each with two observations (i.e., 2 sampling years). Similarly to generalized linear models, GEE's offer the possibility of modeling different types of responses, such as continuous, discrete, or binary. GEE's incorporate an additional term into the model which accounts for the correlation structure among a set of observations from the same subject (Diggle et al., 1994; Stokes et al., 1995). This correlation structure has to be specified by the investigator. As recommended by Horton and Lipsitz (1999) and Stokes et al. (1995), an unstructured correlation matrix was used in the analyses presented herein since the number of observations on a given subject was low.

Patterns of amphibian species richness, total number of individuals captured at least once (total amphibian abundance), as well as the abundance of the species most frequently encountered, were modeled with normal regressions computed from GEE's. All response variables were converted to trap rates (i.e., number of captured individuals trapnights⁻¹), including species richness, and then square-root transformed [$X' = \sqrt{X} + \sqrt{(X+1)}$] before analysis. Explanatory variables consisted of a mining categorical variable with 2 levels (i.e., unmined or mined bog), bog water pH, vegetation structure (i.e., first three PCA axes), distance to closest woodland, distance to closest bog pond, and distance to closest shrub patch. I also included a site effect nested within the bog type effect to account for replication within bogs.

3.2. Model building and model averaging

I considered a set of 19 plausible models describing amphibian abundance and species richness in mined and unmined bogs (Table 3). These models were analyzed with GEE's (see above) for each amphibian response variable. Model fit was assessed with the general model (i.e., most complex model) for each amphibian response variable. The strength of evidence for each model was based on the second-order Akaike Information Criterion (AIC_c) and the information-theoretic approach presented by Burnham and Anderson (1998) and Pan (2001). This framework is based on parsimony, a trade-off between model fit and the number of parameters in the model. It favors the least number of parameters required to adequately describe the data.

The models were ranked based on their AIC_c values, and I computed a measure of the weight of evidence, or Akaike weights, for each model. As recommended in the case of subset regression, where the objective is prediction, I calculated model-averaged parameters and

Table 3

Candidate models considered in the analyses of the effects of peat mining on amphibian abundance and species richness in peat bogs of eastern New Brunswick, Canada

| Model | DF |
|---|----|
| Basic model ^a | 84 |
| <i>General model^b</i> | |
| pH VEG1 VEG2 VEG3 Inwood Inpond shrub mined*Inwood mined*Inpond mined*shrub | 74 |
| <i>Local models</i> | |
| pH VEG1 VEG2 VEG3 | 80 |
| VEG1 VEG2 VEG3 | 81 |
| pH | 83 |
| <i>Landscape models</i> | |
| Lnwood Inpond shrub | 81 |
| Lnwood mined*Inwood | 82 |
| Inpond mined*Inpond | 82 |
| Shrub mined*shrub | 82 |
| Lnwood | 83 |
| Inpond | 83 |
| Shrub | 83 |
| <i>Local + landscape models</i> | |
| pH VEG1 VEG2 VEG3 Inwood Inpond shrub | 77 |
| pH VEG1 VEG2 VEG3 Inwood | 79 |
| pH VEG1 VEG2 VEG3 Inpond | 79 |
| pH VEG1 VEG2 VEG3 shrub | 79 |
| pH VEG1 VEG2 VEG3 Inwood mined*Inwood | 78 |
| pH VEG1 VEG2 VEG3 Inpond mined*Inpond | 78 |
| pH VEG1 VEG2 VEG3 shrub mined*shrub | 78 |

*Indicates interaction between two variables.

^a The basic model consists in the variables mined and site nested within mined. These variables were included in all the models.

^b The general model includes the full set of parameters considered for the analyses (i.e., basic model + local model + landscape model). VEG1, VEG2, and VEG3 correspond to the scores on the first, second, and third axes of the PCA on the vegetation structure variables, respectively. The natural log of the distance to closest bog pond (Inpond) and closest woodland (Inwood) was used in the analyses.

unconditional standard errors based on the Akaike weights (Burnham and Anderson, 1998, p. 202) for each of the variables of interest. Estimates obtained in this fashion typically have better precision and less bias (Anderson et al., 2000) than when based on a single model.

The effect of the distance to the mined edge was assessed after accounting for the other variables. To do so, I calculated predicted values and residuals for each of the models (i.e., observed value–predicted value). I then calculated model-averaged residuals based on the Akaike weights. The weighted residuals were then regressed on the distance to mined edge using a lowess regression with tension set to 0.1 to increase the sensitivity of this exploratory analysis (Cleveland, 1979; Trexler and Travis, 1993).

Table 4

Amphibian trap rates (mean captures/100 trapnights \pm 1 S.D.) in unmined bogs and bog remnants of southeastern New Brunswick, Canada^a

| Response | Unmined bogs | Mined bogs |
|---|-------------------|-------------------|
| Anura | | |
| American toad (<i>Bufo americanus</i>) | 0.157 \pm 0.165 | 0.226 \pm 0.356 |
| Green frog (<i>Rana clamitans</i>) | 1.386 \pm 0.966 | 0.315 \pm 0.471 |
| Leopard frog (<i>Rana pipiens</i>) | 1.122 \pm 2.385 | 0.482 \pm 0.722 |
| Mink frog (<i>Rana septentrionalis</i>) | 0.081 \pm 0.109 | 0.007 \pm 0.018 |
| Wood frog (<i>Rana sylvatica</i>) | 1.772 \pm 1.971 | 0.468 \pm 0.389 |
| Caudata | | |
| Mole salamanders (<i>Ambystoma</i> spp.) | 0.176 \pm 0.363 | 0.111 \pm 0.174 |
| Species richness | 0.232 \pm 0.087 | 0.168 \pm 0.066 |
| Total amphibian captures | 4.767 \pm 3.512 | 1.623 \pm 1.045 |

^a Total effort consisted of 63 792 trapnights.

4. Results

I captured a total of 711 (1997) and 1264 (1998) amphibians from 10 species (four salamanders and six anurans) in the 12 peat bogs under study (Table 4). Amphibian species composition in these habitats consisted (in decreasing order of abundance) of wood frogs (*Rana sylvatica*), leopard frogs (*Rana pipiens*), green frogs (*Rana clamitans melanota*), American toads (*Bufo americanus*), blue-spotted salamanders (*Ambystoma laterale*), spotted salamanders (*Ambystoma maculatum*), mink frogs (*Rana septentrionalis*), red-spotted newts (*Notophthalmus viridescens viridescens*), red-backed salamanders (*Plethodon cinereus*), and spring peepers (*Pseudacris crucifer*). Captures consisted mainly of ranid juveniles. Trap mortality for the 2 years was 5.6%, consisting mostly of recently metamorphosed wood frogs.

4.1. Effects of peat mining assessed by model averaging

Only green frogs, wood frogs, leopard frogs, and American toads occurred on all bogs in sufficient numbers to allow species-level investigations of the effects of microhabitat and distance relative to landscape elements. Amphibian species richness, total amphibian abundance (all spp. combined), and green frog abundance were higher in unmined bogs than in bog remnants adjacent to peat mining (Table 5). Wood frogs however, were most abundant in unmined bogs far from ponds (interaction: mined \times distance to closest pond), and close to shrubs (interaction: mined \times distance to closest shrub patch). Bog water pH also had a strong positive effect on the abundance of total amphibians, green frogs, and wood frogs, whereas American toads and leopard frogs responded to vegetation structure variables (Table 5).

Table 5
Model-averaged parameter estimates (\pm unconditional standard error) computed from the full set of candidate models of the effects of peat mining on amphibians in bogs of eastern New Brunswick, Canada^a

| Response | Mined ^b | | | Local variables | | | | Landscape variables | | | | Interactions | | |
|-----------------|------------------------------------|------------------------------------|---------------------|------------------------------------|-------------------------------------|---------------------|---------------------|---------------------|---------------------|------------------------------------|------------------------------------|---------------|--|--|
| | | pH | | VEG1 | VEG2 | VEG3 | Lnwood | Lnpond | Shrub | Lnwood × mined | Lnpond × mined | Shrub × mined | | |
| Total abundance | 0.2079 (0.0281) | 0.1416 (0.0471) | 0.0030 (0.0037) | 0.0008 (0.0042) | -0.0053 (0.0053) | -0.0135 (0.0133) | -0.0161 (0.0095) | 0.0012 (0.0006) | -0.0082 (0.0242) | 0.0142 (0.0136) | 0.0028 (0.0060) | | | |
| Species | 0.0384 (0.0133) | 0.0067 (0.0078) | -0.0012 (0.0007) | 0.0017 (0.0012) | -0.0020 (0.0009) | -0.0021 (0.0035) | -0.0039 (0.0021) | 0 (0.0001) | 0.0018 (0.0077) | 0.0034 (0.0037) | 0.0017 (0.0001) | | | |
| American toad | 0.0362 (0.0390) | 0.0087 (0.0115) | 0.0011 (0.0016) | -0.0028 (0.0018) | -0.0055 (0.0022) | 0.0140 (0.0094) | -0.0012 (0.0035) | 0.0002 (0.0002) | -0.0162 (0.0114) | -0.0040 (0.0055) | -0.0009 (0.0028) | | | |
| Green frog | 0.0939 (0.0171) | 0.0955 (0.0432) | 0.0007 (0.0029) | -0.0014 (0.0039) | -0.0062 (0.0042) | -0.0161 (0.0084) | -0.0035 (0.0070) | 0 (0.0005) | 0.0085 (0.0127) | -0.0077 (0.0112) | -0.0002 (0.0031) | | | |
| Leopard frog | 0.0119 (0.0124) | -0.0073 (0.0272) | -0.0014 (0.002) | 0.0052 (0.0024) | -0.0013 (0.0026) | 0.0023 (0.0079) | -0.0048 (0.0037) | 0.0003 (0.0002) | -0.0003 (0.0131) | 0.0038 (0.0069) | -0.0037 (0.0028) | | | |
| Wood frog | 0.1690 (0.0198) | 0.0979 (0.0163) | 0.0008 (0.0026) | 0.0044 (0.0032) | 0.0053 (0.0031) | -0.0119 (0.0077) | -0.0150 (0.0091) | 0.0007 (0.0004) | 0.0003 (0.0143) | 0.0185 (0.0080) | 0.0068 (0.0031) | | | |

^a Typescript in bold indicates that 95% confidence interval for a given parameter excludes 0. VEG1, VEG2, and VEG3 correspond to the scores on the first, second, and third axes of the PCA on the vegetation structure variables, respectively.

^b Categorical variable with mined bog as reference level.

4.2. Distance to mined edge

Within bog remnants, the abundance of most amphibians changed little across the distance to mined edges, after accounting for microhabitat and landscape variables. Indeed, lowess regressions on amphibian species richness, as well as the abundance of total amphibians (all spp. combined), green frogs, leopard frogs, and wood frogs, yielded plots without much variation (Fig. 2A). American toads, however, behaved differently with a slightly greater number of individuals close to mined edges (Fig. 2B).

5. Discussion

5.1. Mined vs unmined bogs

Peat mining adjacent to bog remnants, and in some cases, combined with the proximity of the pitfall arrays to bog ponds or shrub patches exerted a negative influence on the abundance of all amphibian species, with the exception of American toads and leopard frogs. Investigators have observed similar negative responses of birds (Delage et al., 2000) and plants (Poulin et al., 1999) to peat mining, whereas small-mammals were generally more abundant in bog remnants than unmined bogs (Mazerolle et al., 2001). Here, however, amphibian captures were generally least frequent in bog remnants.

The ability of an organism to reach a patch depends on the distance between patches, the nature of the route used, as well as the physiology and behavior of the organism (Henein and Merriam, 1990). Peat mining radically modifies bog habitat complexity, not only through habitat loss per se, but by the addition of new structures, namely networks of drainage ditches. Pond-breeding amphibians undertake migrations between hibernacula, breeding, and summering sites across the landscape (Sinsch, 1990). Thus, differences in amphibian abundance between unmined bogs and remnants are likely the result of reduced connectivity (sensu Taylor et al., 1993) between remnants, or remnants and adjacent upland habitat. Amphibians are relatively less mobile than other vertebrates (Sinsch, 1990), with movements (i.e., dispersal or migration) of up to a few kilometers for anurans (Dole, 1971; Schroeder, 1976; Berven and Grudzien, 1990), and less than 250 m for most salamanders (Douglas and Monroe, 1981; Semlitsch, 1981; Kleeberger and Werner, 1983; Madison and Farrand, 1998). Indeed, physiological constraints (water balance and temperature regulation) prevent them from venturing far from moist habitats (Sinsch, 1990). The activity of amphibians in bog remnants depends strongly on climatic variables (i.e., amount of precipitation, minimum air temperature), whereas the relationship is

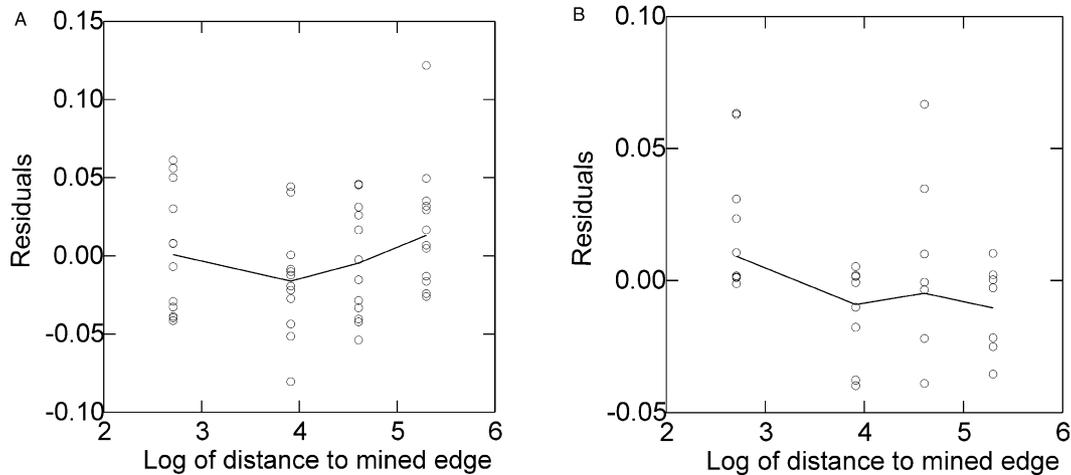


Fig. 2. Lowess regressions (tension=0.1) of amphibian abundance in bog remnants corrected for the other explanatory variables (i.e., model-averaged residuals obtained from full set of candidate models) across the proximity of mined edges. (A) Total amphibian abundance. Note that the lowest regressions for green frogs, leopard frogs, wood frogs and species richness yielded the same trends and are not shown. (B) American toads.

weaker in unmined bogs (Mazerolle, 2001). Barren peat surfaces, such as those left by mining operations, combined with the presence of networks of trenches may reduce amphibian movements during dry periods, as optimal conditions are required to venture across these environments.

5.2. Microhabitat vs landscape variables

Once the effect of peat mining was accounted for, few variables influenced amphibian abundance and species richness. Most of these were microhabitat variables, either bog water pH or vegetation structure. Both pH and vegetation structure modify the distribution of metamorphosed individuals of several amphibian species in forested habitats (Szaro et al., 1988; deMaynadier and Hunter, 1995; Wyman, 1988; Wyman and Jancola, 1992). On the other hand, landscape variables (i.e., proximity of the closest pond, woodland, and shrub patch) were generally not important after accounting for the peat mining effect, except for wood frogs.

Only recently have investigators started to integrate landscape components, such as the proximity to the nearest breeding sites or amount and type of habitat within a given radius, into models of amphibian occurrence. When incorporated into such models, these variables often have significant effects (see references in Mazerolle and Villard, 1999; Bearegard and Leclair, 1988; Loman, 1988; Sjögren Gulve, 1994; Lehtinen et al., 1999). This is not surprising given the complex life cycles of these organisms (Wilbur, 1980) and their movements between different landscape components throughout the year (Sinsch, 1990). As a result, we should expect amphibians, when engaging in movements across disturbed habitats, to depend more strongly on landscape variables than in pristine environments. In this study of bog habitats, most amphibians

were captured in late summer (Mazerolle, 2001) and recaptures were typically low. Therefore, individuals were seemingly in a movement phase during part of the capture period. Here, however, the effect of peat mining generally overwhelmed the effects of the landscape-level variables under study, and the latter explained very little of the variation in amphibian species richness and abundance. Further investigations on amphibian path selection and physiological costs related to movements over hostile habitat such as peat fields are currently under study.

5.3. Distance to mined edge

American toads were more abundant near mined edges, whereas the other species did not respond to the variable. The different response of American toads may stem from a tolerance to relatively drier habitats or even a preference for drained bogs, as opposed to the other more aquatic species encountered in this study (see Thorson and Svihla, 1943; Schmid, 1965). This was somewhat unexpected, as negative edge effects of roads and silvicultural practices on pond-breeding amphibians have previously been reported in New England forests (Gibbs, 1998; deMaynadier and Hunter, 1998). Because amphibians were more abundant in unmined bogs than in bog remnants, the lack of response to the distance to mined edges may indicate that edge effects extend beyond 200 m. Alternately, the distance increments (15, 50, 100, and 200 m) from mined edges might have been too large to detect a gradient for the amphibians under study, except for American toads.

5.4. Implications for conservation

The regulation of mining and the management of Canadian peatlands is of provincial jurisdiction, and

certain provinces have adopted policies to preserve wetlands (Poulin and Pellerin, 2001). However, policies and conservation strategies targeting peatlands have yet to be created and implemented in Quebec and New Brunswick, where peat mining operations are most intense (Poulin and Pellerin, 2001). Preserving intact portions of bogs which consist of a complex mosaic of ponds, woodland, and shrub patches on natural portions of bogs adjacent to currently mined sites may mitigate peat mining impacts on amphibians by enhancing the movement of individuals from adjacent habitats. Such measures will help maintain amphibian populations in peatlands.

Results show that peat mining activities alone or in combination with the proximity of certain landscape elements definitely exert a negative impact on amphibian species richness, as well as the abundance of total amphibians (all spp. combined), green frogs, and wood frogs. American toads, however, were more abundant near mined edges, potentially due to their relatively greater tolerance to dehydration than the other anurans studied herein. In order to minimize the impacts of peat mining on amphibians, management initiatives could strive to maintain a mosaic of different elements such as bog ponds, shrub patches, and woodlands.

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