



# Efficiency of buffer zones around ponds to conserve odonates and songbirds in mined peat bogs

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Patch isolation resulting from habitat loss and fragmentation generally has detrimental effects on associated species. Peatlands may be especially sensitive to such effects because peat mining results in drastic changes in the hydrology of natural remnants. This study aimed to assess the efficiency of conservation zones surrounding ponds in mined bogs for two taxa: songbirds and odonates. We compared songbird distribution and odonate assemblages between ponds isolated by peat mining ( $n = 6–12$ ) and control ponds ( $n = 11–13$ ) located in natural bogs. Birds did not show major responses to pond isolation, whether in terms of their relative abundance or reproductive activity. However, longer-term data would be required to confirm this trend. In contrast, odonate abundance, as estimated from exuviae, was higher in natural ponds than in isolated ones. Some taxa, especially bog specialists, were more sensitive than others. Hence, pond isolation by peat mining significantly altered the structure of odonate assemblages. Pond size also influenced odonate abundances and distribution. Effective conservation of bog ponds should account not only for variations in the response of different taxa, but also for pond structural diversity, which influence species response to isolation.

Human activities generally create increasingly isolated patches of natural habitat. Habitat fragmentation and its detrimental effects on wildlife have been studied in a variety of contexts (see reviews by Fahrig 2003, Ewers and Didham 2006, Watling and Donnelly 2006). Species may be negatively affected by habitat isolation through several processes that may act synergistically on populations of habitat fragments (Laurance and Cochrane 2001). Firstly, small, isolated patches may be more vulnerable to human disturbance and undergo habitat changes, for example through edge effects (Harper et al. 2005). Secondly, species with large area requirements may not be able to maintain viable populations in small, scattered fragments (Tilman et al. 1994, Fahrig 2003, Ewers and Didham 2006). Finally, isolation may decrease functional connectivity among populations, especially when habitat amount falls below a certain proportion in the landscape (Flather and Bevers 2002, Van Houtan et al. 2007). Subsequent losses in genetic diversity through reduced gene flow, inbreeding, or genetic drift may then increase the risk of local extinction in fragments (Britten and Baker 2002). Moreover, the probability of recolonisation declines with distance (Villard et al. 1995, Hanski 1999), whereas the nature of the matrix likely influences permeability to dispersal as well (Taylor et al. 1993, Tischendorf and Fahrig 2000, Gobeil and Villard 2002).

In spite of the well-developed theory on potential effects of habitat loss and fragmentation, relatively few empirical

studies allow determining whether isolated habitat patches maintain their biological integrity in some landscape types. This question is especially relevant when evaluating the efficiency of conservation strategies maintaining small fragments within managed landscapes. In southern Canada, bogs are harvested for peat moss production (Chapman et al. 2003, Poulin et al. 2004). Mined areas consist in extensive barren lands where few natural fragments are preserved. Those remnants mainly consist of peripheral areas where peat deposits were not deep enough to justify harvesting, and of conservation zones focused on one or a few ponds. In New Brunswick, Canada, conservation zones have buffer widths varying from 50 to 100 m from the pond edges and their purpose is to maintain important features of bog ecosystems. Indeed, bog ponds add significantly to biodiversity because they comprise several unique microhabitats (Poulin et al. 2002). The ponds protected thus represent natural bog patches isolated from other natural habitats.

In the present study, we used birds and odonates as indicators of biological integrity (Angermeier and Karr 1994) to assess the efficiency of buffer zones surrounding ponds in mined bogs. Odonates are frequently used as bioindicators because they respond not only to local abiotic variables and landscape structure and composition (Bulánková 1997, Chovanec and Raab 1997, Sahlén and Ekstubbbe 2001, D'Amico et al. 2004), but also to the composition of prey and predator assemblages. Because few

vertebrate predators (no fishes) occur in bog ponds, odonates are a major factor influencing the composition of other invertebrate taxa (Larson and House 1990). We also surveyed birds using bog ponds and buffer strips because they are relatively easy to detect and identify and respond to very different ecological characteristics than odonates. For odonates, we tested whether the structure of species assemblages differed between ponds isolated by peat mining and natural bog ponds (hereafter isolated ponds and natural ponds, respectively). In the case of birds, we compared the abundance and reproductive activity of focal species. To our knowledge, this is the first study explicitly testing the effects of pond isolation by peat mining, although peripheral remnants have been studied using a broadly similar approach (Poulin et al. 1999, Delage et al. 2000, Mazerolle et al. 2001, Mazerolle 2003).

## Methods

### Study area

We surveyed 25 ponds in peat bogs of the Escuminac Peninsula, New Brunswick, Canada (Fig. 1; Supplementary material Table S1). In the region, peat mining constitutes the major factor altering bog integrity. We studied ponds isolated before systematic application of conservation measures. Therefore, there was a fair amount of variability among isolated ponds, particularly with respect to the distance to the nearest mined edge, some having narrower conservation buffers or being still connected to other bog or forest patches. Twelve ponds were partially or completely isolated by peat mining, i.e. they were surrounded by at least 50% mined bog within a 500 m radius, and by <30% natural bog habitat within a 1000 m radius (Fig. 1). The

closest natural bogs were several tens or hundred meters away. Thirteen ponds were entirely surrounded by natural bog habitat within a radius of at least 500 m. Candidate ponds were located on 1:12 500 aerial photographs (NB-DNR 2002) and selection was confirmed by ground truthing. To the extent possible, we matched natural and isolated ponds so that they had similar area, perimeter (Supplementary material Table S1), shape and ecological characteristics. However, the context varied to some extent, not only with respect to the degree of isolation by peat mining, but also in terms of presence and quantity of other ponds in the vicinity (Fig. 1). Indeed, in the study area, bog ponds tend to be found in clumps in the central portion of relatively large bogs. Because there were relatively few ponds isolated by peat mining in the study area, we sometimes had to choose ponds located within the same clump (ca 260 and 30 m apart, for birds and odonates, respectively).

We distinguished two pond sizes: small (160–730 m<sup>2</sup>) and medium-sized (1–3 ha). We surveyed eight small ponds in each context (natural vs isolated), as well as four isolated and five natural ponds in the medium size category. We surveyed each pond bimonthly from June to August 2006, alternating visits to isolated and natural ponds. The selected ponds were representative of most peat bog ponds of the Escuminac Peninsula, i.e. there were few or no trees on the generally firm-edged banks, although some marshy areas were occasionally present. There were some water fluxes (small streams or interstitial runoffs) in many ponds. Streams or runoffs seemed more conspicuous in natural ponds, possibly because isolation by peat mining impaired natural fluxes or because conservation of interconnected ponds was more difficult. The bank flora was dominated by *Sphagnum* mosses, shrubs (mainly *Ericaceae*) and herbaceous species (*Cyperaceae*). The importance of the last two

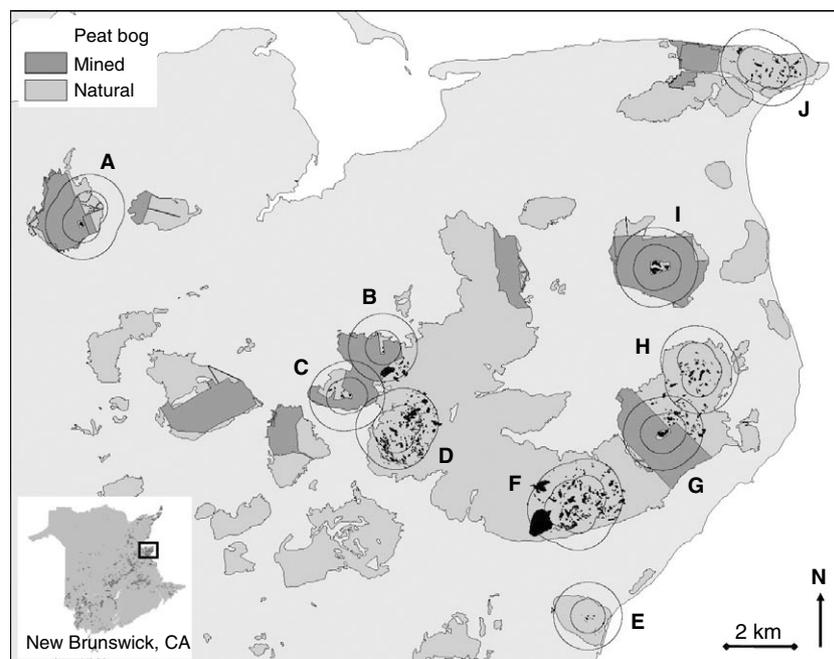


Figure 1. Study sites (ponds) isolated by peat mining (A, B, C, G, I) or located within natural peat bogs (D, E, F, H, J) in the Escuminac Peninsula, New Brunswick, Canada. Concentric circles show ponds (black dots) within 500 and 1000 m from the study ponds. See Supplementary material Table S1 for details.

groups varied according to the bank type, herbaceous species dominating in the low, wet and marshy parts, whereas shrubs were common in higher, drier banks, and occasionally grew in the water at the front of banks, as in floating carpets for example. Water depth varied but the ponds selected remained wet all year round, although some parts might have temporarily dried up. Aquatic vascular vegetation was composed of yellow pond lily *Nuphar variegatum* and/or water bulrush *Schoenoplectus subterminalis*.

### Bird surveys

Birds were surveyed at the beginning of each visit, between sunrise and 10:00, by walking within 50 m of the pond edge and recording all species detected on the pond and up to 50 m from the shore. We stopped counting when we failed to add new species within 5 min of survey time. We used a roughly area-dependent count duration rather than a standardized length in order to lessen differences in the time/area ratio between small and larger sites. In sites comprising several ponds, the two observers surveyed adjacent ponds simultaneously and noted both the time of observation and the position of each individual encountered in order to reduce the risk of double counting. We only counted birds using ponds for breeding, feeding or resting to eliminate individuals in transit (e.g. fly overs). For each species, we estimated its abundance, and reproductive status using an index of reproductive activity (IRA; Bonifait et al. 2006). Reproductive activity was ranked as follows: 1) species present but showing no indication of territorial activity; 2) singing male; 3) pair (simultaneous observation of two nearby birds showing no agonistic interactions); 4) female carrying nest material, or a nest present with or without eggs; 5) bird carrying food, or nest containing nestlings; and 6) presence of fledglings (incapable of sustained flight). In this study, we analysed data for the most frequent songbirds (detected at least in 25% of the ponds): palm warbler *Dendroica palmarum*, common yellowthroat *Geothlypis trichas*, savannah sparrow *Passerculus sandwichensis*, song sparrow *Melospiza melodia* and Lincoln sparrow *Melospiza lincolni*. To determine whether adjacent ponds could be considered as independent, we examined field maps of bird detections, traced 50-m buffers around each pond, and pooled data from adjacent ponds when territories likely overlapped two buffer strips according to our field maps and published average territory sizes (Wheelwright and Rising 1993, Ammon 1995, Wilson 1996, Arcese et al. 2002). After this correction, 6 isolated sites (1–3 ponds each) and 11 natural sites (1–2 ponds) were considered independent. For each species in each site, we used the maximum abundance estimate recorded in the first three visits (breeding period – Bonifait and Barguil unpubl.) in order to limit contamination by birds undertaking postbreeding dispersal. We also used the maximum IRA rank recorded. We calculated relative densities (individuals  $\text{ha}^{-1}$ ) by measuring the area of natural terrestrial bog habitat sampled in each site using Caris GIS 4.4 (CARIS Universal System 2004).

### Odonate sampling

We collected odonate exuviae in 8 (small ponds) and 12 (medium-sized ponds) quadrats located systematically around the perimeter of each pond in order to minimize differences in sampling effort among ponds. In spite of this, sampling effort was still higher for small ponds. The  $3 \times 1$  m quadrats were centered on the shoreline so that half of their area ( $1.5 \times 1$  m) was above the water and the other half on the bank. When there were many exuviae, we restricted sampling time to 10 min per quadrat. For this reason, and because access was difficult in some cases (emerging or floating vegetation, etc.), we were not always able to completely sample each quadrat. In those cases, we estimated the proportion of each quadrat that had been sampled to assess species abundances. Exuviae were identified to the genus level for damselflies and to the species level for dragonflies (Walker 1958, Walker and Corbet 1975, Needham et al. 2000). Five of the seven dragonfly genera we recorded were monospecific in our samples (Supplementary material Table S2). The others (*Aeshna* and *Sympetrum*) included several rare species and many individuals could not be identified. Thus, we analysed exuviae abundance at the genus level. We found only one exuviae of *Celithemis elisa*. Hence, this species was excluded from the analyses of odonate assemblages.

Because we consider exuviae to reflect larval assemblages, we used the abundance of exuviae collected per pond (i.e. along 8–12 m of pond edge) to estimate the relative density of larvae (individuals  $\text{m}^{-2}$  of pond), which in turn allowed us to compare small and medium-sized ponds while accounting for differences in sampling intensity as well as pond perimeter and area. We used these relative densities to compare odonate assemblages in the four pond types (2 pond sizes  $\times$  2 pond contexts). Those values, however, do not represent absolute larval densities, because the probability of detection undoubtedly varies among species and because in partivoltine species, exuviae represent only a fraction (final instars) of larval populations.

### Statistical analyses

#### Birds

Birds were surveyed in relatively open habitats, up to 50 m from the water's edge, so the probability of sighting was high. As habitats and sampling conditions were similar between sites, we considered the detectability to be constant. Relative densities tended to be negatively related to the area sampled. However, because the trends observed were not significant and the area sampled per site did not differ between isolated and natural sites, we did not account for this fact. Fine-scale ( $\sim 300$ – $500$ -m) spatial autocorrelation in density of each bird species was not significant. Hence, we considered our sampling sites to be statistically independent. The geographical distribution of isolated and natural sites was non-random, however: isolated sites were mainly located in the western portion of the study area whereas natural ones were concentrated in the eastern portion ( $t = -2.482$ ;  $p = 0.025$ ; Fig. 1). Bird response to this longitudinal gradient could have biased the detection of effects of pond isolation. We investigated this response using a data set collected in 2005 and including 130 point

count stations in the same study area. Abundance indices of common yellowthroat ( $r_s = 0.275$ ;  $p = 0.002$ ), song sparrow ( $r_s = 0.264$ ;  $p = 0.002$ ) and Lincoln sparrow ( $r_s = -0.333$ ;  $p = 0.001$ ) were correlated with longitude. For these three species, we compared isolated and natural sites, accounting for longitude through analyses of covariance (ANCOVAs). For palm warbler and savannah sparrow, we used Student and Mann-Whitney tests.

### Odonates

Detectability was not an issue as sampling small quadrats allowed us to search them thoroughly. Consequently, we had a detection probability approaching 100%. As sampling conditions were similar for all sites, we considered the detectability to be constant between and within sites. Mantel correlograms on matrices of geographical distance and Hellinger distance among odonate assemblages (Legendre and Legendre 1998, Goslee and Urban 2007) showed weak evidence of spatial autocorrelation at small (lag = 1150 m;  $r = 0.107$ ;  $p = 0.049$ ) and large (lag = 19620 m;  $r = -0.165$ ;  $p = 0.041$ ) distances. We elected to consider the study ponds to be independent owing to the weakness of the spatial autocorrelation observed. Although isolated and natural ponds were not distributed randomly along the longitudinal gradient ( $t = -2.515$ ;  $p = 0.019$ ), we tested for effects of pond size and context on pooled genera relative density using a standard ANOVA because longitude was found to have a low influence, both on assemblages and pooled genera relative density. We then tested the effects of pond size and context on odonate assemblages (with arcsine-transformed densities) using a MANOVA. Finally, we explored the influence of the two pond size categories and the two types of pond contexts using canonical discriminant function analysis.

## Results

### Birds

Although relative densities and IRA ranks tended to differ between isolated and natural sites (Table 1), none of the differences were statistically significant. For example, common yellowthroat's relative density differed significantly

between isolated and natural ponds ( $t = -2.227$ ;  $p = 0.042$ ) but this difference disappeared when accounting for longitude ( $F = 3.673$ ;  $p = 0.076$ ) even though longitude only had a small effect on this species. On the other hand, the difference in relative density for the song sparrow appeared to be almost exclusively associated with the longitudinal gradient.

### Odonates

We collected 10125 exuviae corresponding to ten genera (Supplementary material Table S2). Isolated ponds showed lower relative densities than natural ponds ( $F = 10.642$ ;  $p = 0.004$ ) whereas small ponds had higher relative densities than medium-sized ones ( $F = 11.698$ ;  $p = 0.003$ ) (Fig. 2). A MANOVA on data at the genus level showed that pond context (isolated vs natural) had a significant influence on odonate assemblages ( $F_{9, 13} = 5.740$ ;  $p = 0.003$ ). The effect of pond size on odonate densities was weaker ( $F_{9, 13} = 2.337$ ;  $p = 0.080$ ). The first discriminant function separated isolated and natural ponds, and the second contrasted small and medium-sized ponds (Table 2, Fig. 3). Among the nine genera considered in the analyses, *Lestes*, *Leucorrhinia*, *Enallagma* and *Aeshna* explained most of the differences associated with pond context, exhibiting relative densities higher in natural than in isolated ponds. The first two genera also explained differences associated with pond size, showing higher densities in small than in medium-sized ponds (Fig. 4, Supplementary material Table S2). Although some rare species were present in only one or two particular ponds, most species were present in several pond types but their relative density varied as a function of pond context. Only *Somatochlora cingulata* and *Aeshna subarctica* were restricted to medium-sized and small ponds, respectively (Supplementary material Table S2).

## Discussion

### Bird response to pond isolation

Breeding songbirds did not seem to respond to pond context, but this may hold only over the short-term. This may also

Table 1. Relative density (individuals  $ha^{-1}$ ; mean  $\pm$  SD) and index of reproductive activity (median rank, interquartile range) of songbirds around bog ponds isolated or not by peat mining. Arrows indicate significant trends in bird abundance from west to east of the study area based on an independent survey. Isolated ponds were mainly located in the west and natural ones in the east ( $t = -2.482$ ;  $p = 0.025$ ).

Species	Ponds	Isolated ponds (n = 6)	Geographical gradient	Natural ponds (n = 11)
Palm warbler	Density index	0.19 $\pm$ 0.19		0.60 $\pm$ 0.22
	IRA rank	0 (0–0.75)		2 (0–2)
Common yellowthroat	Density index	0.23 $\pm$ 0.10	→	0.74 $\pm$ 0.16
	IRA rank	2 (0–2.5)		3 (2–5)
Savannah sparrow	Density index	1.52 $\pm$ 0.21		1.03 $\pm$ 0.17
	IRA rank	3 (1.75–4.25)		2 (2–5)
Song sparrow	Density index	0.21 $\pm$ 0.10	→	0.56 $\pm$ 0.15
	IRA rank	0.5 (0–1.5)		2 (0–2)
Lincoln sparrow	Density index	0.69 $\pm$ 0.31	→	0.26 $\pm$ 0.14
	IRA rank	1.5 (0.75–5.25)		0 (0–2)

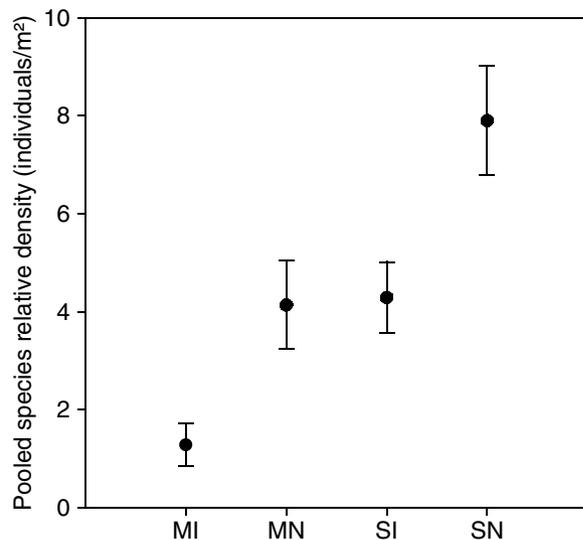


Figure 2. Pooled species relative density (mean  $\pm$  SE) of odonates is higher in small than in medium-sized bog ponds ( $F = 11.698$ ;  $p = 0.003$ ) and in natural than in isolated ponds ( $F = 10.642$ ;  $p = 0.004$ ). MI: medium-sized isolated pond ( $n = 4$ ); MN: medium-sized natural pond ( $n = 5$ ); SI: small isolated pond ( $n = 8$ ); SN: small natural pond ( $n = 8$ ).

reflect, in part, the relatively small sample size. However, the trends observed for the three species responding to the longitudinal gradient were largely responsible for this pattern, possibly reflecting confounding factors that could not be accounted for in this study. Of the five species considered, only palm warbler is a true bog specialist in the study region. Lincoln sparrow is also strongly associated with bogs, whereas savannah sparrow shows a looser connection to bog habitats. Finally, common yellowthroat and song sparrow are generalists of semi-open habitat types (Delage et al. 2000, Carignan 2001, Desrochers 2001). Palm warbler has been shown to be sensitive to bog isolation and area (Calmé and Desrochers 2000). Although there were no significant effects of isolation on our index of reproductive activity or relative density, we recorded palm warbler in only 1/6 isolated sites compared to 6/11 natural sites, a trend

Table 2. Discriminant function analysis of relative densities of odonates in bog ponds.

Discriminant function	1	2	3
Eigenvalue	3.981	1.616	1.190
% of variance	58.6	23.8	17.5
Canonical correlation	0.894	0.786	0.737
Wilks' Lambda	0.035	0.174	0.457
$\chi^2$	58.652	30.554	13.722
Degrees of freedom	27	16	7
$p$	<0.000	0.015	0.056
Genus-discriminant function correlations			
<i>Lestes</i>	0.179	-0.610	-0.134
<i>Enallagma</i>	0.378	0.066	-0.115
<i>Nehalennia</i>	0.105	-0.154	-0.227
<i>Aeshna</i>	0.221	-0.106	-0.437
<i>Cordulia</i>	0.146	0.239	0.017
<i>Somatochlora</i>	0.291	0.566	0.506
<i>Ladona</i>	-0.050	-0.021	0.155
<i>Leucorrhinia</i>	0.262	-0.790	-0.163
<i>Sympetrum</i>	0.066	0.197	0.114

consistent with that observed in palm warbler frequency of occurrence in 130 stations surveyed in 2005.

Palm warbler and other species may respond to habitat structure or more subtle changes in pond environment rather than to larger-scale alteration. Indeed, peatland birds' distribution patterns have been shown to largely reflect the distribution of their microhabitats (Calmé and Desrochers 1999, Delage et al. 2000). Peat mining is a relatively recent phenomenon in the Escuminac Peninsula and isolation of study sites has been progressive, beginning in 1985 for the older mined sites, whereas some of them were still connected with peatland patches or surrounding forest at the time of this study. Therefore, habitat changes associated with isolation and proximity to mined areas may not be significant at the present time, but may increase gradually as the cumulative exploited area increases. Isolated fragments are vulnerable to disturbance, particularly to afforestation, which in turn can affect the bog flora and fauna (Pellerin and Lavoie 2000, Lachance et al. 2005).

### Odonate response to pond isolation

In contrast with birds, odonates responded quite strongly to pond isolation. Indeed, the effect of isolation on breeding odonates prevailed over that of pond size. Isolated ponds generally hosted the same genera as natural ponds. Differences in relative densities, however, were conspicuous: the relative density of some genera was more than twice as high in natural ponds as in isolated ones.

Pond isolation by peat mining may influence odonate responses through several processes. Peat mining may alter odonate larval habitat characteristics such as structure, composition, abiotic features and/or trophic webs. Owing to the importance of larval instars in the life cycle of odonates, such changes in aquatic habitat would probably affect population levels (Larson and House 1990, Chovanec and Raab 1997, D'Amico et al. 2004). Hydrological disturbance (and subsequent habitat changes) due to drainage of adjacent mined areas or peat dust released by mining activities are other potential causes for changes in aquatic habitats. Indeed, Mazerolle et al. (2006) have found differences in the abundance of some insects, including damselflies, in relation to the distance to mined edges.

Odonate requirements are not strictly restricted to aquatic habitats per se, but also encompass the surrounding landscape. Landscape structure may affect dispersal, maturation, foraging, and nocturnal roosting (Taylor and Merriam 1995, Bried and Ervin 2006). Peat mining around ponds results in habitat loss for adults and may affect populations in spite of the conservation of good larval habitats. In natural bogs, inter-pond distances range from a few to tens or even a few hundred meters. When isolated, inter-pond distances or distances to other terrestrial habitats used by adults increase rapidly and may reach hundreds or thousands of meters. Many odonate species have relatively poor dispersal ability, especially damselflies, and generally move within a few hundred meters at most, with rare long-distance dispersal events (Conrad et al. 1999, Angelibert and Gianni 2003). Increased distance to the nearest source habitat and reduced connectivity negatively affect species richness of odonates, both at the adult and larval stages, suggesting that isolation plays an

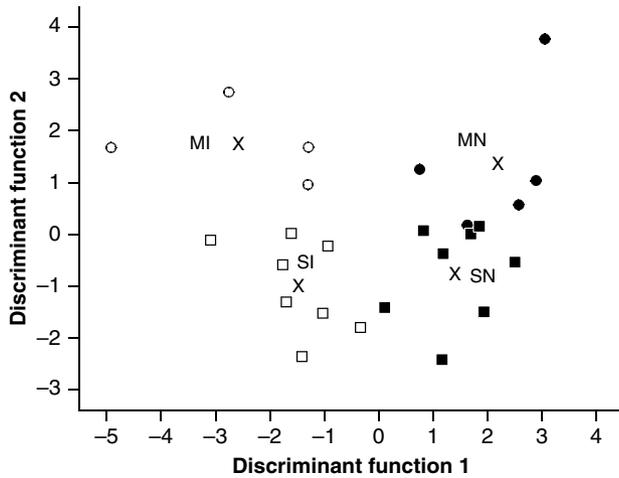


Figure 3. Projection of bog ponds classified by discriminant function analysis of odonate assemblages. The first function separates pond types (isolated vs natural) whereas the second one separates pond sizes. MI: medium-sized isolated ponds (open circles;  $n=4$ ); MN: medium-sized natural ponds (solid circles;  $n=5$ ); SI: small isolated ponds (open squares;  $n=8$ ); SN: small natural ponds (solid squares;  $n=8$ ); crosses represent each group's centroid.

important role in determining the structure of odonate assemblages (McCauley 2006).

As a result of peat mining, not only do distances among ponds increase, but the matrix changes as well. Landscape

structure is known to influence odonate movements (Pither and Taylor 1998, Jonsen and Taylor 2000a, b). We do not know whether mined areas actually represent barriers, but it is plausible that they impede movements, especially since mined areas are inhospitable. As a consequence of pond isolation, we would expect the number of immigrants to drop, which could reduce gene flow to isolated populations and increase the likelihood of local extinctions (Ewers and Didham 2006). The probability of recolonisation would decrease with isolation as well (McCauley 2006). There was no direct evidence of local extinctions in our study ponds, at least among common species. Some species, however, were present at very low densities in isolated ponds, with sometimes only a few exuviae collected (Supplementary material Table S2). Those results suggest that odonate assemblages are still responding to pond isolation i.e. that relaxation has not yet occurred. Korkeamäki and Suhonen (2002) found that specialized species associated with peatlands have a high probability of extinction, most likely associated with peatland disappearance. It is interesting to note that in our study, several sensitive species (e.g. *Lestes eurinus*, *L. disjunctus*, *Leucorrhinia glacialis*) are strongly associated with bog ponds.

### Odonate response to pond size

Odonate densities were higher in small than in medium-sized ponds and several taxa accounted for these differences (e.g. *Lestes*, *Leucorrhinia glacialis*). Some genera did not respond to pond size (e.g. *Enallagma*) or seemed to respond

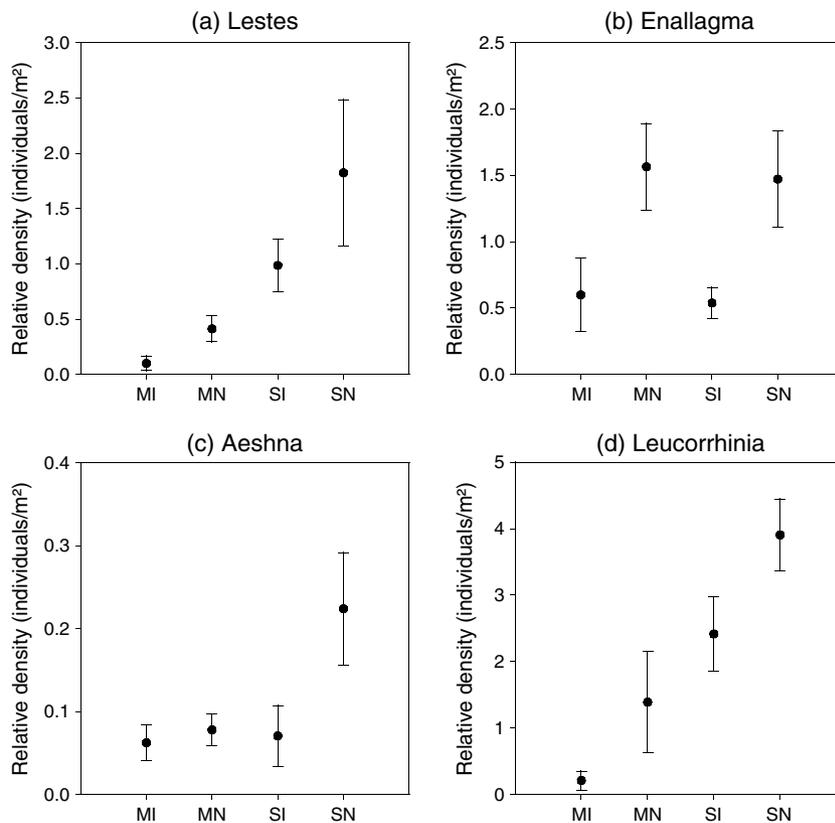


Figure 4. Relative densities (mean  $\pm$  SE) of four odonate genera among the most strongly influenced by pond context (a, b, c, d) and size (a, d). MI: medium-sized isolated ponds ( $n=4$ ); MN: medium-sized natural ponds ( $n=5$ ); SI: small isolated ponds ( $n=8$ ); SN: small natural ponds ( $n=8$ ).

to a combination of isolation and size factors. Explanation for these patterns would require further investigation but we hypothesize that those differences could be, at least in part, due to microhabitat differences. Medium-sized ponds may include microhabitats, like deep areas or steep shrubby banks, unfavourable to some odonate species. Likewise, a few microhabitats required by some species may be more frequent in small than in larger ponds. Lastly, small ponds generally have a proportionally longer perimeter than medium-sized ponds; consequently, species restricted to the vicinity of the bank would reach higher densities in smaller ponds.

### Conservation implications

Ponds are important features of bog ecosystems and add appreciably to local diversity. They host numerous invertebrates such as odonates, which may in turn benefit terrestrial species such as songbirds preying on them. Common yellowthroat and song sparrow were noticeably more frequent around ponds than in bog ecosystems as a whole, whereas savannah sparrow was slightly more frequent and Lincoln sparrow was slightly less (Bonifait and Paulin unpubl.). However, the value of pond conservation zones to songbirds could be limited because they are generally small. With 50 to 100 m wide buffer strips, the total terrestrial area of conservation sites would amount to a few hectares at most. In turn, this habitat would host only one or a few bird territories. The bog specialist palm warbler has the largest territories (1–4 ha) and would occur only in the largest suitable sites (Welsh 1971, Wilson 1996). This fact may explain why we detected this species in only one isolated site. Designing conservation sites favourable to most of the focal songbird species would thus require relatively large areas. Furthermore, larger conservation areas would probably reduce the influence of various effects of peat mining (drainage, peat dust) on ponds and further favour the maintenance of ecological integrity.

Odonate responses suggest that isolation has detrimental effects on other taxa as well. Indeed, they are undoubtedly more sensitive indicators of pond biological integrity than songbirds because they are more specifically associated with ponds and therefore, must be more sensitive to pond isolation as well. Many specialized invertebrates such as bog species may have relatively poor dispersal ability (Spitzer and Danks 2006) and bog invertebrate richness and abundance decrease with distance from undisturbed habitat (Watts and Didham 2006). In a peat-mining context, matrix permeability, the amount of similar habitat in the landscape, and distance to other bog ponds will affect connectivity (Taylor et al. 1993, Tischendorf and Fahrig 2000). Improving our understanding of these processes will require further investigation, but may help to plan future conservation areas so that populations are connected with natural ones.

Finally, pond size influenced odonate assemblages to a lesser degree than isolation. Some species, such as *Aeshna subarctica* or *Nehalennia* spp. were exclusively or more frequently found in small ponds, whereas others (*Somatochlora cingulata*) preferred bigger ponds. Here, we studied only two pond size categories, but other studies indicate that differences occur for other size categories as well

(Larson and House 1990). Current conservation zones designed around bog ponds in New Brunswick generally focus on medium-sized to large ponds and, therefore, do not account for the whole diversity of bog ponds. The occasional presence of streams further increases the complexity of bog pond ecosystems. Besides, the different types of ponds may have variable responses to isolation. At first sight, small ponds would probably appear to be the most vulnerable and sensitive but, surprisingly, medium-sized isolated ponds were more dissimilar to natural ponds than small ones. Effective conservation planning should thus consider the biotic differences among ponds when planning future conservation areas.

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