

Society for the Study of Amphibians and Reptiles

Amphibian Activity, Movement Patterns, and Body Size in Fragmented Peat Bogs

Author(s): Marc J. Mazerolle

Source: *Journal of Herpetology*, Vol. 35, No. 1 (Mar., 2001), pp. 13-20

Published by: Society for the Study of Amphibians and Reptiles

Stable URL: <http://www.jstor.org/stable/1566017>

Accessed: 18/11/2008 13:05

Your use of the JSTOR archive indicates your acceptance of JSTOR's Terms and Conditions of Use, available at <http://www.jstor.org/page/info/about/policies/terms.jsp>. JSTOR's Terms and Conditions of Use provides, in part, that unless you have obtained prior permission, you may not download an entire issue of a journal or multiple copies of articles, and you may use content in the JSTOR archive only for your personal, non-commercial use.

Please contact the publisher regarding any further use of this work. Publisher contact information may be obtained at <http://www.jstor.org/action/showPublisher?publisherCode=ssar>.

Each copy of any part of a JSTOR transmission must contain the same copyright notice that appears on the screen or printed page of such transmission.

JSTOR is a not-for-profit organization founded in 1995 to build trusted digital archives for scholarship. We work with the scholarly community to preserve their work and the materials they rely upon, and to build a common research platform that promotes the discovery and use of these resources. For more information about JSTOR, please contact support@jstor.org.



Society for the Study of Amphibians and Reptiles is collaborating with JSTOR to digitize, preserve and extend access to *Journal of Herpetology*.

Amphibian Activity, Movement Patterns, and Body Size in Fragmented Peat Bogs

MARC J. MAZEROLLE¹

Department of Biology, Dalhousie University, Halifax, Nova Scotia B3H 4J1, Canada

ABSTRACT.—I investigated the activity, direction of movement, and body size (snout-vent length) of amphibians in both pristine and fragmented bogs of southeastern New Brunswick. I used drift-fences with pitfall traps to capture amphibians in six pristine bogs and six bogs undergoing peat mining (i.e., bog fragments) in 1997 and 1998. Results indicate that seasonal activity patterns of amphibians in bogs peak during August and correspond to movements of adults (following breeding) and juveniles (after metamorphosis) from adjacent wetlands. A seasonal shift in species composition occurred, as most captures early in the season consisted almost exclusively of ranids, with an increase in salamander captures in late summer and fall. Climatic variables generally explained more of the variation in amphibian activity in fragments than in pristine bogs. Wood frog activity near fragment edges was more dependent on amount of precipitation than in pristine bogs. Wood frog and green frog movements were nonrandomly oriented relative to mined fragment edges. Orientation of leopard frog movements was strongly influenced by year. Wood frogs occurring in fragments were larger than those in pristine bogs. The size difference in green frogs was not significant but followed the same patterns as wood frogs. Leopard frogs within bog fragments were larger than those in pristine bogs but only in 1998. This study implies that peat mining influences amphibian activity and movement patterns in neighboring bog fragments. Larger individuals may be better suited for survival in disturbed environments, such as mined bogs, because they are less sensitive to desiccation than smaller ones.

Anthropogenic alteration of pristine environments can decimate amphibian populations. These alterations occur in various forms, ranging from complete habitat destruction to more subtle edge effects into adjacent habitat, leading to dryer conditions in neighboring habitat patches. For instance, clearcut forests yield lower amphibian abundance than continuous habitat (Blymyer and McGinnes, 1977; Bury, 1983; Petranksa et al., 1993; Dupuis et al., 1995; Ash, 1997), because the absence of canopy increases substrate temperatures and accelerates desiccation. From a hydrological perspective, peat mining and forest clearcutting are very similar. Indeed, the first step in peat mining consists of extensively draining the area through trench networks and harvesting the barren peat once it is dry. The absence of plants on exposed peat layers during bog mining can generate severe conditions, and this transition from wetland to a more arid habitat may have serious repercussions on amphibian populations.

Amphibian activity is sensitive to climatic variables such as precipitation or air temperature (e.g., Martof, 1953; Heatwole, 1961; Bellis, 1962; Dole, 1965; Bider, 1968; MacCulloch and Bider, 1975; Douglas and Monroe, 1981; Klee-

berger and Werner, 1983; Sinsch, 1988; Sexton et al., 1990; Palis, 1997). Because disturbed habitats are less buffered against climatic extremes than their pristine counterparts, amphibian activity may depend more strongly on climatic variables, particularly precipitation, in harsh environments such as clearcuts. Furthermore, amphibian movement patterns also may be influenced by anthropogenic disturbances (*sensu* Raymond and Hardy, 1991). That is, if certain elements of the landscape (e.g., roads, clearcuts, or peat mining fields) impede or prevent dispersal, movements will be modified accordingly (i.e., the direction component will be affected). Finally, individuals occurring in disturbed habitats should be larger than those in pristine habitats, because larger individuals are more resistant than smaller ones to desiccation (Thorson, 1955; Ray, 1958; Spight, 1968).

I tested these predictions by studying amphibians in pristine bogs and in bog fragments within peat mining fields. Specifically, I investigated (1) the relationship between amphibian activity and environmental variables in bog environments, (2) the change of amphibian species composition over seasons, (3) the movement patterns (directionality) in bogs with emphasis on bog fragments, and (4) the body size of individuals in pristine and fragmented bogs.

MATERIALS AND METHODS

Study Area.—This study was conducted in southeastern New Brunswick in six fragmented

¹ Present Address: Centre de Recherche en Biologie Forestière, Pavillon Abitibi-Price, Université Laval, Sainte-Foy, Québec G1K 7P4, Canada; E-mail: acd611@agora.ulaval.ca.

and six pristine ombrotrophic bogs within the Greater Kouchibouguac Ecosystem, a 6400-km² area including Kouchibouguac National Park and the surrounding area. Ombrotrophic bogs are *Sphagnum*-dominated peatlands with a pH oscillating around 4.0 and in which the nutrient and water inputs are derived solely from precipitations (Schwintzer, 1981; Gorham et al., 1984; Vitt, 1994). Bogs undergoing peat mining are referred to herein as fragmented bogs, whereas pristine bogs are unaltered. In the fragmented bogs, I sampled the intact portion of the bog immediately adjacent to the mining operation, because mined plots are barren and subject to major interference from heavy machinery. The 12 bogs under study ranged in size between 26 and 2982 ha ($\bar{x} \pm SE$, 914 ± 277.7 ha), with 0–39% ($\bar{x} \pm SE$, $8.0 \pm 3.6\%$) of their area mined for horticultural peat.

Vegetation at the sites consisted of *Picea mariana* and *Larix laricina* scattered in shrub form (< 3 m), and a low shrub layer (10–30 cm) dominated by *Kalmia angustifolia*, *Kalmia polifolia*, *Chamaedaphne calyculata*, *Ledum groenlandicum*, *Andromeda glaucophylla*, *Vaccinium* spp., *Gaylussacia baccata*, and *Gaylussacia dumosa*. *Eriophorum* spp. were common in the herb layer. A continuous carpet of *Sphagnum* mosses covered the ground.

Amphibian Capture.—I randomly deployed four drift-fence arrays with pitfall traps in open bog habitat within the six pristine bogs. Each array was erected from three aluminum drift fences (5 m × 0.60 m) set at 120° angles in a closed Y-formation. Fences were placed in trenches 15–20 cm in depth. Pitfall traps were fashioned from 11.4-L plastic buckets provided with lids. I cut out the center of each lid, leaving a narrow rim that acted as a lip hindering escape of trapped individuals. Each trap was filled to the fourth with water, and a thick mat of floating *Sphagnum* moss was added as cover. I sunk two pitfall traps at fence extremities (i.e., one on each side) and one at fence intersections, yielding a total of nine traps in each array. I also installed four drift-fence arrays in open bog habitat within six bogs undergoing mining. The arrays were placed on intact bog fragments within fragmented bogs, at 15 m, 50 m, 100 m, and 200 m from mined edges. The exact location of arrays was determined randomly across the width of the mined sites. Arrays were oriented identically relative to mined edges.

Installation of the 48 drift-fence arrays was initiated during the spring thaw in May and continued in June and July 1997. I trapped from mid-July 1997 to early September 1997 (20,592 trap-nights, where 1 trap-night equals 1 trap open for 1 night), mid-June 1998 to mid-July 1998 (10,368 trap-nights), and late July 1998 to

mid-October 1998 (32,832 trap-nights). I checked traps every four days. Captured amphibians were measured for snout-vent length (SVL), marked with a toe-clip (date-specific mark) and released on the other side of the fence. Prior to marking, I anaesthetized salamanders by immersion in 30% ethanol dissolved in distilled water (Fellers et al., 1994). I captured 10 amphibian species (salamanders: *Ambystoma laterale*, *Ambystoma maculatum*, *Notophthalmus viridescens*, and *Plethodon cinereus*; anurans: *Rana clamitans*, *Rana pipiens*, *Rana septentrionalis*, *Rana sylvatica*, *Pseudacris crucifer*, and *Bufo americanus*) at the bogs under study (Mazerolle, 1999). In this report, I focus on green frogs (*Rana clamitans*), leopard frogs (*Rana pipiens*), and wood frogs (*Rana sylvatica*), the most abundant species encountered during the study.

Amphibian Activity.—Total amphibian captures in a given bog were pooled at each trap visit as a measure of amphibian activity. Similarly, I pooled captures in a given bog at each trap visit for each of the three *Rana* species to investigate their individual activity patterns. A thermometer 30 cm above the bog surface recorded maximum/minimum air temperatures in each bog under study between trap visits. A rain gauge similarly measured the amount of precipitation (mm) at each site.

Poisson regression models corrected for under- and overdispersion (McCullagh and Nelder, 1989; SAS Institute Inc., 1993) were used to describe amphibian activity patterns across Julian day (i.e., day of the year), as well as the influence of precipitation and maximum/minimum air temperatures. I built separate models for fragments and pristine bogs. To assess whether the activity of a given species was more strongly related to precipitation in bog fragments than in pristine bogs (i.e., comparison of two regression coefficients), I performed a one-tailed *t*-test at $\alpha = 0.05$ based on the difference of the precipitation coefficients. I used the sum of the residual degrees of freedom of the two models as the degrees of freedom for the *t*-test. In addition, I used a logistic regression to assess the change in capture composition (i.e., the proportion of amphibian captures consisting of salamanders) across seasons.

Because maximum air temperature and Julian day were strongly correlated (partial correlations given bog and year class variables: $r = -0.703$, $P < 0.001$, $df = 175$, for pristine bogs; and $r = -0.656$, $P < 0.001$, $df = 193$ for fragments), I deleted maximum air temperature from the models. I included a year class variable with two levels and a bog class variable with six levels (to account for replication within bogs) in all Poisson and logistic regression models.

These models were computed with the GENMOD procedure (SAS Institute Inc., 1993).

Movement Orientation in Bogs.—To compare directionality of captures between bog fragments and pristine bogs, I standardized the data, since array orientation was specific in bog fragments (i.e., identical orientation relative to mined edge) while random in pristine bogs. Thus, I computed an index of variability of the captures across three directions (i.e., three sides of array), based on the difference between the maximum and minimum captures across the three sides of a given array relative to total captures at that array:

$$I = (\text{Max}_i - \text{Min}_i) / (C_i + 10^{-6}),$$

where Max_i and Min_i are respectively maximum and minimum captures at array i , and C_i represents total captures at array i , to which a small constant was added to account for array sides without captures. The index varied between 1, indicating that captures at an array were all on one side (i.e., difference in orientation), and 0 indicating that captures across array sides were identical (i.e., no difference in orientation). I used this measure of orientation for overall amphibian captures, as well as for each of the three frog species.

I arcsine-transformed each proportion (i.e., index of orientation variability) obtained before entering it as a response variable in two-factor ANOVA models with year and bog type (i.e., fragment or pristine bog) as fixed effects (Zar, 1984). I weighted the analysis by adjusting degrees of freedom, so each observation (i.e., index at each array) only made a contribution of 0.25 (4 arrays/bog) to the model giving each bog a total of 1 degree of freedom (Desrochers, 1992; Legendre, 1993). This method of scaling degrees of freedom allowed me to use all the information while maintaining statistical independence since each group of four arrays totaled one degree of freedom. However, this scaling of degrees of freedom modifies the error degrees of freedom, which makes all F -tests more conservative (Desrochers, 1992).

Movement Orientation Relative to Mining.—As arrays within bog fragments had an identical orientation relative to the mined edge, I analyzed movement patterns at each of these arrays across three directions. I used Poisson regressions corrected for overdispersion (McCullagh and Nelder, 1989) with captures (i.e., total amphibian captures and captures of each of the three ranids) as the response variable against class variables year (two levels), bog (six levels, one for each bog), mining proximity (four levels, one for each distance) and direction (three levels, one for each side of the arrays). To account for variation in sampling intensity across years,

an offset variable was included in the models (McCullagh and Nelder, 1989; Agresti, 1996; Lindsey, 1997). Offset variables help deal with Poisson (discrete) data occurring as rates, such as events over time (here captures over trap-nights; Agresti, 1996). I used the GENMOD procedure to compute these models (SAS Institute Inc., 1993).

Snout-Vent Length.—Snout-vent length of *R. clamitans*, *R. pipiens*, and *R. sylvatica* was compared between pristine bogs and fragments, with means computed for each bog. Snout-vent lengths were then log-transformed [i.e., $\log(\text{SVL}+1)$] to homogenize variances and entered in two-factor ANOVA models with year and bog type as fixed effects (Zar, 1984). Because there were differences in precision of estimates across sites (i.e., captures varied among bogs), I weighted each mean with the number of individuals used to compute it.

RESULTS

Activity.—Amphibian activity (total captures, and captures for each of the three ranids) across the summer somewhat followed a monotonic curve, peaking in late August (Table 1, Fig. 1). Julian day and Julian day-squared were generally efficient predictors of activity in multivariate Poisson regressions (Table 1). Climatic variables generally explained more of the variation in activity in fragments than in pristine bogs (Table 1). Wood frog activity was significantly more dependent on precipitation in fragments than in pristine bogs ($t = 3.58$, $df = 376$, $P < 0.001$). However, the same trend did not occur for green frogs ($t = -0.210$, $df = 376$, $P = 0.417$) and leopard frogs ($t = 0.522$, $df = 344$, $P = 0.301$). Although close to significance, the dependence of amphibian activity (total amphibian captures) on precipitation was not greater in fragments than in pristine bogs ($t = 1.404$, $df = 376$, $P = 0.08$).

Amphibian captures consisted almost exclusively of ranids in the late spring and early summer and shifted to salamanders in September and October in both pristine bogs and fragments (Table 2, Fig. 2). Precipitation was not a good predictor of the change in amphibian captures (proportion of amphibian captures consisting of salamanders) in either bog type, whereas minimum air temperature was positively related to the ranid-salamander shift in fragments (Table 2). Julian day was by far the best predictor of the change in amphibian captures (Table 2).

I checked autocorrelations of the residuals in each model (lag of 1 to 100). No high autocorrelations ($r > 0.5$) were detected, which indicates that the assumption of independent errors was not violated. Examination of deviance re-

TABLE 1. Activity patterns of amphibians in pristine bogs and bog fragments of southeastern New Brunswick across 1997 and 1998 with bog and year variables held fixed. Parameter estimates \pm SE are shown. Significance of parameters was assessed with an F-test based on deviance difference analogous to type III sums of squares. Year and site covariables were added in all models. * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$.

Response	Poisson regression models (predictors with $P < 0.05$ were kept in the model)					Deviance	df
	Julian day	Julian day squared	Precipitation	Min. air temp.			
Pristine bogs							
Amphibians (taxa)	0.192 \pm 0.036***	-0.0004 \pm 0.0001***	0.133 \pm 0.076	0.013 \pm 0.013		936.643	174
<i>Rana clamitans</i>	0.564 \pm 0.0860***	-0.001 \pm 0.0002***	0.220 \pm 0.084*	0.004 \pm 0.015		382.930	174
<i>Rana pipiens</i>	0.288 \pm 0.048***	-0.0006 \pm 0.0001***	0.227 \pm 0.090*	-0.027 \pm 0.020		321.200	142
<i>Rana sylvatica</i>	0.258 \pm 0.060***	-0.0006 \pm 0.0001***	-0.138 \pm 0.124	0.050 \pm 0.017**		540.358	174
Bog fragments							
Amphibians (taxa)	0.076 \pm 0.035*	-0.0001 \pm 0.0001	0.291 \pm 0.083***	0.038 \pm 0.013**		438.579	202
<i>Rana clamitans</i>	0.498 \pm 0.111***	-0.001 \pm 0.0002***	0.185 \pm 0.144	0.006 \pm 0.021		171.270	202
<i>Rana pipiens</i>	0.333 \pm 0.070***	-0.0007 \pm 0.0001***	0.302 \pm 0.112**	0.026 \pm 0.025		252.913	202
<i>Rana sylvatica</i>	0.159 \pm 0.048***	-0.0003 \pm 0.0001***	0.465 \pm 0.114***	0.038 \pm 0.017*		252.416	202

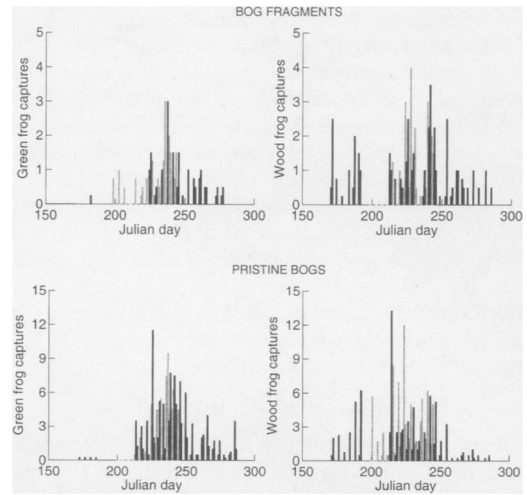


FIG. 1. Green frog and wood frog activity patterns across the season in 1997 (grey bars) and 1998 (black bars) in pristine bogs and fragments of southeastern New Brunswick. Mean captures per day across sites are shown. Note that days 150 and 300 correspond to 30 June and 27 October, respectively.

siduals plotted against predicted values did not reveal any systematic departures and suggested good model fit for each of the activity models.

Movement Orientation.—There were no statistically significant differences in the variability indices of directionality between pristine bogs and fragments nor a year effect, either for overall amphibian captures (Bog type: $F_{1,20} = 0.086$, $P = 0.772$; Year: $F_{1,20} = 0.168$, $P = 0.687$), green frog (Bog type: $F_{1,20} = 0.190$, $P = 0.667$; Year: $F_{1,20} = 0.093$, $P = 0.763$), leopard frog (Bog type: $F_{1,20} = 0.010$, $P = 0.922$; Year: $F_{1,20} = 0.506$, $P = 0.485$), or wood frog captures (Bog type: $F_{1,20} = 0.001$, $P = 0.972$; Year: $F_{1,20} = 0.028$, $P = 0.869$).

Within bog fragments, total amphibian captures at the sides of each drift-fence array were lower at 50 m (parameter estimate: -0.577 , Wald $\chi^2 = 8.646$, $df = 1$, $P = 0.003$) and at 100 m (parameter estimate: -0.434 , Wald $\chi^2 = 5.344$, $df = 1$, $P = 0.021$) than 200 m from mined edges (Table 3). However, the orientation of total amphibian captures differed between years (interaction between year and orientation, Table 3). In terms of individual taxa, both *R. clamitans* and *R. sylvatica* captured at arrays responded to orientation and proximity to mined edges (Table 3). Green frog captures were greatest at the sides of arrays facing away from mined edges than sides facing mined edges (parameter estimate: 0.747 , Wald $\chi^2 = 6.276$, $df = 1$, $P = 0.012$), and lower at 100 m than 200 m from mined edges (parameter estimate: -1.030 , Wald $\chi^2 = 7.188$, $df = 1$, $P = 0.007$). Wood frogs, however, were mostly captured at the sides of arrays facing

TABLE 2. Change in amphibian species composition (proportion of captures that were salamanders, i.e., salamanders/total captures) in bogs across 1997 and 1998. Parameter estimates \pm SE are shown. Significance of parameters was assessed with an F-test based on deviance difference analogous to type III sums of squares. Year and site covariables were added in all models. * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$.

Bog type	Logistic regression model of salamanders/total captures				
	Julian day	Precipitation	Minimum air temperature	Deviance	df
Pristine bogs	0.067 \pm 0.009***	0.292 \pm 0.166	-0.067 \pm 0.038	133.476	141
Bog fragments	0.147 \pm 0.014***	0.032 \pm 0.240	0.081 \pm 0.027**	42.606	116

mined edges (parameter estimate: 0.617, Wald $\chi^2 = 6.113$, $df = 1$, $P = 0.013$), with lower captures at 50 m than 200 m from mined edges (parameter estimate: -0.652, Wald $\chi^2 = 5.091$, $df = 1$, $P = 0.024$). *Rana pipiens* captures did not differ with the distance to mined edges, but orientation of captures differed across years (ori-

entation \times year interaction, Table 3). Examination of deviance residuals plotted against predicted values did not reveal any systematic departures and suggested good model fit for each of the direction models.

Snout-Vent Length.—Green frog snout-vent length did not differ between fragments and pristine bogs ($F_{1,19} = 1.291$, $P = 0.270$), but individuals captured in 1998 were slightly larger than during 1997 ($F_{1,19} = 6.112$, $P = 0.023$, Fig. 3). Wood frogs from fragments were larger than those from pristine bogs ($F_{1,19} = 10.793$, $P = 0.004$), and wood frogs captured in 1998 were larger than those caught in 1997 ($F_{1,19} = 41.645$, $P < 0.001$, Fig. 3). There were no interactive effects of year and bog type on SVL in either wood frogs ($F_{1,19} = 3.161$, $P = 0.091$) or green frogs ($F_{1,19} = 3.514$, $P = 0.076$). However, leopard frogs were larger in fragments than in pristine bogs during 1998 (year \times bog type interaction, $F_{1,15} = 18.771$, $P = 0.001$).

DISCUSSION

Activity.—The seasonal increase of amphibian captures in bogs, peaking in August, strongly suggests amphibian movements to bogs from other wetlands (i.e., breeding sites) following adult spring breeding migrations and juvenile dispersal after metamorphosis. This trend is consistent with other reports of amphibians migrating to bogs during the summer months (Bellis, 1959, 1962; Schroeder, 1976). Total amphibian captures within pristine bogs increased with forest proximity, further suggesting dispersal from other habitats during dryer periods (Mazerolle, 1999). These results support the hypothesis that bog habitats, despite their acidity, can serve as summering areas for amphibians (Mazerolle, 1999).

Climatic variables, either precipitation or minimum air temperature, were generally good predictors of amphibian (total amphibian captures), leopard frog, wood frog, and green frog activity. This is consistent with results from previous studies of amphibian activity at breeding sites and upland habitats (e.g., Martof, 1953; Heatwole, 1961; Bellis, 1962; Dole, 1965; Bider, 1968; Gibbons and Bennett, 1974; Palis, 1997).

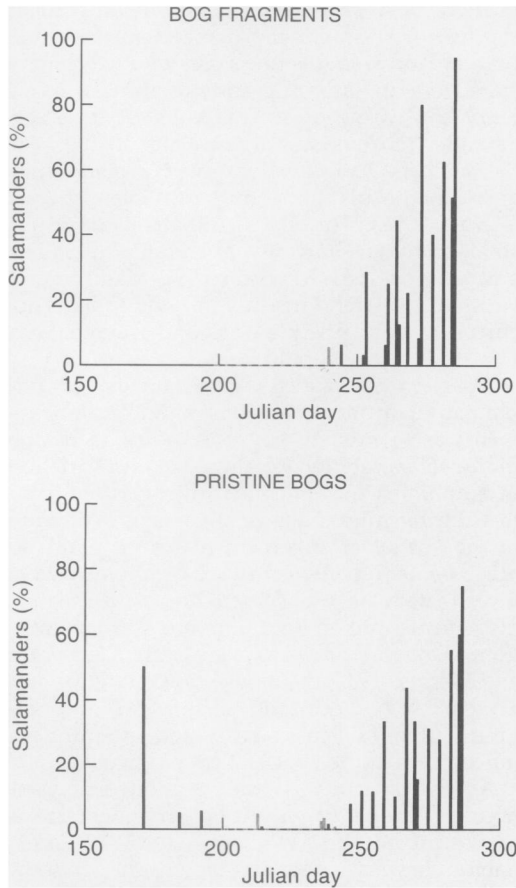


FIG. 2. Shift of amphibian captures from ranids to salamanders in pristine bogs and fragments of south-eastern New Brunswick in 1997 (grey bars) and 1998 (black bars). Mean proportions per day are shown. Note that days 150 and 300 correspond to 30 June and 27 October, respectively.

TABLE 3. Distribution of amphibian captures at sides of arrays within bog fragments during 1997 and 1998. Table summarizes the effects of the class variables mined edge proximity (four levels) and capture orientation (three levels) on amphibian captures. *F*-test statistics based on deviance difference analogous to type III sums of squares are given. Year and site covariables were added in all models. * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$.

Poisson regression model					
Response	Mined edge proximity	Capture orientation	Orientation × Year interaction	Deviance	df
Amphibians (taxa)	4.571**	3.233*	3.687*	291.419	130
<i>Rana clamitans</i>	3.629*	3.360*	—	143.446	132
<i>Rana pipiens</i>	1.652	2.665	4.347*	169.445	130
<i>Rana sylvatica</i>	3.221*	3.301*	—	181.382	132

Precipitation usually explained more of the variation in amphibian activity in fragments than in pristine bogs, presumably because amphibians require rainfall to move and forage across disturbed environments with low humidity, such as mined plots. The activity of wood frogs was particularly affected in fragments, with a stronger dependence on precipitation than in pristine bogs. Similarly, deMaynadier and Hunter (1998) found that rainfall explained salamander activity in clearcuts and plantations slightly better than in control stands.

Barren peat surfaces are saturated with water following early spring or late fall precipitation (pers. obs.) and cannot be mined under these conditions. However, the peak in amphibian activity in both pristine and fragmented bogs coincides with the peak of the peat mining season (July–August). At this period, the continuous mechanical activity on mined plots paired with

dry conditions may reduce the chance of survival of individuals venturing onto mined surfaces. In support of this hypothesis, I observed lower overall amphibian captures, as well as green frog and wood frog captures, within fragments than in pristine bogs (Mazerolle, 1999).

There is a proportional shift in amphibian captures from ranids to salamanders across the season. However, it is uncertain whether this results from an early migration of anurans to hibernacula within or outside bogs, or from salamander movements to bogs later in the year (September–October). Bogs may provide suitable hibernacula for some amphibian species (Karns, 1992). For instance, salamanders use small-mammal burrows as refugia (Douglas and Monroe, 1981; Madison, 1997; Madison and Farrand, 1998), and insectivores and rodents occurred in both pristine bogs and fragments in this study area (unpubl. data).

Movement Orientation.—Directionality of amphibian movements was as variable in fragments as in pristine bogs, as indicated by the indices of variability. We should expect variation in amphibian movements within pristine habitats during migrations or dispersals according to the spatial arrangement of forest, pond, or other landscape elements. For example, several investigators have observed that *A. maculatum* movements into and out of ponds were nonrandom (Douglas and Monroe, 1981; Kleeberger and Werner, 1983; Stenhouse, 1985; Phillips and Sexton, 1989). Dodd and Cade (1998) and Sjögren-Gulve (1998a) also noted nonrandom movements in the species they studied.

Amphibians in this study exhibited nonrandom directionality within bog fragments relative to mined edges. Previous studies in forest habitat have yielded similar results. Indeed, Raymond and Hardy (1991) found fewer salamanders coming from the clearcut side of their study pond. Similarly, Gibbs (1998) observed that forest-road edges were less permeable to amphibian movement than either forest interior or the forest-open land interface. Orientation of

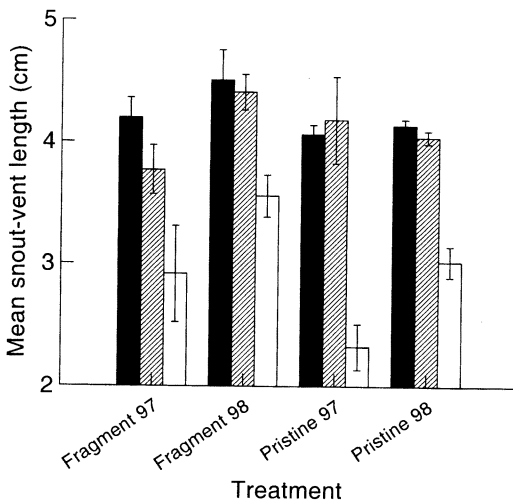


FIG. 3. Mean snout-vent length of green frogs (solid black bars), leopard frogs (hatched bars), and wood frogs (white bars) captured in pristine bogs and fragments of southeastern New Brunswick during 1997 and 1998. Error bars represent 1 SE around the mean.

amphibian movement patterns in relation to various components of the landscape can vary between species (Sjögren-Gulve, 1998a, b). This was also the case for the three ranid species of my study, as indicated by their differential sensitivity to array orientation. Directionality of amphibian movements on bog fragment edges suggests that artificial structures such as trenches and barren habitat influence amphibian movement in mined bogs. These structures may reduce connectivity among fragments, and between fragments and nonbog habitat.

Snout-Vent Length.—Thorson (1955), Ray (1958), and Spight (1968) observed that small amphibians lose water faster than larger individuals of the same species, because of their large surface to volume ratio. Therefore, larger individuals should be better equipped to forage and move across dryer habitats, such as mined bogs. This size difference occurred consistently only for wood frogs in my study area. Leopard frogs captured in fragments were larger than in pristine bogs during 1998, but not during 1997. Bellis (1962) observed larger wood frogs moving across dry habitats, whereas smaller individuals were limited to more humid habitats. Similarly, Ash (1997) also noted that most salamanders colonizing clearcut stands are adults, able to withstand dryer conditions in the sparse litter cover of regenerating stands. Sattler and Reichenbach (1998) also found more adult salamanders in clearcut and shelterwood than their control during certain years.

Wood frogs, the only species to respond to bog type effects, are smaller at metamorphosis than green frogs and leopard frogs (Wright and Wright, 1949; Pough and Kamel, 1984; Berven, 1990). One possible explanation for the lack of a consistent size effect for green frogs and leopard frogs is the presence of a threshold effect. Most individuals of these two species may exceed the minimum size necessary to survive at the edges of bog fragments and in the actual mining field.

The results of the present study indicate that peat mining influences amphibian activity, movement patterns and size in bog fragments. Amphibian activity patterns across the season in pristine bogs were similar to those in bog fragments, but climatic variables became apparently more important in the latter. Wood frogs were particularly affected, as their activity was more dependent on precipitation in bog fragments than in pristine bogs. Furthermore, wood frogs in pristine bogs were smaller than those in bog fragments. The orientation of their movements was also altered near edges, with non-random orientation relative to mined edges. It is unlikely that peat mining impacts on amphibians are restricted to edge effects per se, but it

is presently unknown whether amphibians actually venture onto barren peat within mined peat fields or avoid them altogether. The effects of trenches are also of concern in mined peat bogs, which efficiently lower the water table of peatlands within 15 m (Hillman, 1992; Prévost et al., 1997; Poulin et al., 1999). Further work is needed to assess whether these artificial structures (often reaching 1 km in length) promote amphibian dispersal or impede it (i.e., corridors vs. ecological trap) across peat landscapes.

Acknowledgments.—I thank É. Tremblay for his interest in this project and trust in granting me access to Kouchibouguac National Park resources. G. Vautour, W. Madil, D. Sock, J.-M. Mazerolle, and D. Mazerolle assisted in the drift-fence array installation. J. Thibault facilitated interactions with mining companies. R. Wassersug, K. Oseen, H. Whitehead, D. McAlpine, P. Taylor, A. Pinder, and A. Mathis reviewed the manuscript and earlier versions. This work was mainly supported by the Ecosystem Science Fund of Parks Canada, Atlantic Region. Additional funding was provided by the Wildlife Trust Fund of New Brunswick, the Grants-in-Herpetology in Conservation from the Society for the Study of Amphibians and Reptiles, and an NSERC operating grant to R. Wassersug.

LITERATURE CITED

- AGRESTI, A. 1996. An Introduction to Categorical Data Analysis. John Wiley and Sons, New York.
- ASH, A. N. 1997. Disappearance and return of plethodontid salamanders to clearcut plots in the southern Blue Ridge Mountains. *Conserv. Biol.* 11:983–989.
- BELLIS, E. D. 1959. A study of movement of American toads in a Minnesota bog. *Copeia* 1959:173–174.
- . 1962. The influence of humidity on wood frog activity. *Am. Midl. Nat.* 68:139–148.
- BERVEN, K. A. 1990. Factors affecting population fluctuations in larval and adult stages of the wood frog (*Rana sylvatica*). *Ecology* 71:1599–1608.
- BIDER, J. R. 1968. Animal activity in uncontrolled terrestrial communities as determined by a sand transect technique. *Ecol. Monogr.* 38:269–308.
- BLYMYER, M. J., AND B. S. MCGINNES. 1977. Observations on possible detrimental effects of clearcutting on terrestrial amphibians. *Bull. Md. Herpetol. Soc.* 13:79–83.
- BURY, R. B. 1983. Differences in amphibian populations in logged and old growth redwood forest. *Northwest Sci.* 57:167–178.
- DEMAYNADIER, P. G., AND M. L. HUNTER JR. 1998. Effects of silvicultural edges on the distribution and abundance of amphibians in Maine. *Conserv. Biol.* 12:340–352.
- DESROCHERS, A. 1992. Age and foraging success in European blackbirds: variation between and within individuals. *Anim. Behav.* 43:885–894.
- DODD JR., C. K., AND B. S. CADE. 1998. Movement patterns and the conservation of amphibians breeding in small, temporary wetlands. *Conserv. Biol.* 12:331–339.

- DOLE, J. W. 1965. Summer movements of adult leopard frogs, *Rana pipiens* Schreber, in northern Michigan. *Ecology* 46:236-255.
- DOUGLAS, M. E., AND B. L. MONROE JR. 1981. A comparative study of topographical orientation in *Ambystoma* (Amphibia: Caudata). *Copeia* 1981:460-463.
- DUPUIS, L. A., J. N. M. SMITH, AND F. BUNNELL. 1995. Relation of terrestrial-breeding amphibian abundance to tree-stand age. *Conserv. Biol.* 9:645-653.
- FELLERS, G. M., C. A. DROST, AND W. R. HEYER. 1994. Handling live amphibians. In W. R. Heyer, M. A. Donnelly, R. W. McDiarmid, L.-A. Hayek, and M. S. Foster (eds.), *Measuring and Monitoring Biological Diversity: Standard Methods for Amphibians*, pp. 275-276. Smithsonian Inst. Press, Washington, DC.
- GIBBONS, J. W., AND D. H. BENNETT. 1974. Determination of anuran terrestrial activity patterns by a drift fence method. *Copeia* 1974:236-243.
- GIBBS, J. P. 1998. Amphibian movements in response to forest edges, roads, and streambeds in southern New England. *J. Wildl. Manage.* 62:584-589.
- GORHAM, E., S. E. BAYLEY, AND D. W. SCHINDLER. 1984. Ecological effects of acid deposition upon peatlands: a neglected field in "acid-rain" research. *Can. J. Fish. Aquat. Sci.* 41:1256-1268.
- HEATWOLE, H. 1961. Habitat selection and activity of the wood frog, *Rana sylvatica* Le Conte. *Am. Midl. Nat.* 66:301-313.
- HILLMAN, G. R. 1992. Some hydrological effects of peatland drainage in Alberta's boreal forest. *Can. J. For. Res.* 22:1588-1596.
- KARNS, D. R. 1992. Amphibians and reptiles. In H. E. Wright Jr., B. Coffin, and N. Aaseng (eds.), *The Patterned Peatlands of Minnesota*, pp. 131-150. Univ. of Minnesota Press, Minneapolis.
- KLEEBERGER, S. R., AND J. K. WERNER. 1983. Post-breeding migration and summer movement of *Ambystoma maculatum*. *J. Herpetol.* 17:176-177.
- LEGENBRE, P. 1993. Spatial autocorrelation: trouble or new paradigm? *Ecology* 74:1659-1673.
- LINDSEY, J. K. 1997. *Applying Generalized Linear Models*. Springer-Verlag, New York.
- MACCULLOCH, R. D., AND J. R. BIDER. 1975. Phenology, migrations, circadian rhythm and the effect of precipitation of [sic] the activity of *Eurycea b. bislineata*, in Québec. *Herpetologica* 31:433-439.
- MADISON, D. M. 1997. The emigration of radio-implanted spotted salamanders, *Ambystoma maculatum*. *J. Herpetol.* 31:542-552.
- MADISON, D. M., AND L. FARRAND III. 1998. Habitat use during breeding and emigration in radio-implanted tiger salamanders, *Ambystoma tigrinum*. *Copeia* 1998:402-410.
- MARTOF, B. 1953. Home range and movements of the green frog, *Rana clamitans*. *Ecology* 34:529-543.
- MAZEROLLE, M. J. 1999. Amphibians in fragmented peat bogs: abundance, activity, movements and size. Unpubl. M.Sc. thesis, Dalhousie Univ., Halifax, NS, Canada.
- MCCULLAGH, P., AND J. A. NELDER. 1989. *Generalized Linear Models*. 2nd ed. Chapman and Hall, New York.
- PALIS, J. G. 1997. Breeding migration of *Ambystoma cingulatum* in Florida. *J. Herpetol.* 31:71-78.
- PETRANKA, J. W., M. E. ELDRIDGE, AND K. E. HALEY. 1993. Effects of timber harvesting on southern Appalachian salamanders. *Conserv. Biol.* 7:363-370.
- PHILLIPS, C. A., AND O. J. SEXTON. 1989. Orientation and sexual differences during breeding migrations of the spotted salamander, *Ambystoma maculatum*. *Copeia* 1989:17-22.
- POUGH, F. H., AND S. KAMEL. 1984. Post-metamorphic change in activity metabolism of anurans in relation to life history. *Oecologia* 65:138-144.
- POULIN, M., L. ROCHEFORT, AND A. P. DESROCHERS. 1999. Conservation of bog plant species assemblages: assessing the role of natural remnants in mined sites. *Appl. Veg. Sci.* 2:169-180.
- PRÉVOST, M., P. BELLEAU, AND A. P. PLAMONDON. 1997. Substrate conditions in a treed peatland: responses to drainage. *Écoscience* 4:543-554.
- RAY, C. 1958. Vital limits and rates of desiccation in salamanders. *Ecology* 39:75-83.
- RAYMOND, L. R., AND L. M. HARDY. 1991. Effects of a clearcut on a population of the mole salamander, *Ambystoma talpoideum*, in an adjacent unaltered forest. *J. Herpetol.* 25:509-512.
- SAS INSTITUTE, INC. 1993. *SAS/STAT Software: The Genmod Procedure*. SAS Technical Report P-243, Cary, NC.
- SATTLER, P., AND N. REICHENBACH. 1998. The effects of timbering on *Plethodon hubrichti*: short-term effects. *J. Herpetol.* 32:399-404.
- SCHROEDER, E. E. 1976. Dispersal and movement of newly transformed green frogs, *Rana clamitans*. *Am. Midl. Nat.* 95:471-474.
- SCHWINTZER, C. R. 1981. Vegetation and nutrient status of northern Michigan bogs and conifer swamps with a comparison to fens. *Can. J. Bot.* 59:842-853.
- SEXTON, O. J., C. PHILLIPS, AND J. E. BRAMBLE. 1990. The effects of temperature and precipitation on the breeding migration of the spotted salamander (*Ambystoma maculatum*). *Copeia* 1990:781-787.
- SINSCH, Ü. 1988. Seasonal changes in the migratory behaviour of the toad *Bufo bufo*: direction and magnitude of movements. *Oecologia* 76:390-398.
- SJÖGREN-GULVE, P. 1998a. Spatial movement patterns in frogs: target-oriented dispersal in the pool frog, *Rana lessonae*. *Écoscience* 5:31-38.
- . 1998b. Spatial movement patterns in frogs: differences between three *Rana* species. *Écoscience* 5:148-155.
- SPIGHT, T. M. 1968. The water economy of salamanders: evaporative water loss. *Physiol. Zool.* 41:195-203.
- STENHOUSE, S. L. 1985. Migratory orientation and homing in *Ambystoma maculatum* and *Ambystoma opacum*. *Copeia* 1985:631-637.
- THORSON, T. B. 1955. The relationship of water economy to terrestrialism in amphibians. *Ecology* 36:100-116.
- VITT, D. H. 1994. An overview of factors that influence the development of Canadian peatlands. *Mem. Entomol. Soc. Can.* 169:7-20.
- WRIGHT, A. H., AND A. A. WRIGHT. 1949. *Handbook of Frogs and Toads of the United States and Canada*. 3rd ed. Comstock Publishing Company, Inc., Ithaca, NY.
- ZAR, J. H. 1984. *Biostatistical Analysis*. 2nd ed. Prentice Hall, Englewood Cliffs, NJ.