RELATIONSHIP BETWEEN LAKESHORE DEVELOPMENT AND ANURAN POPULATIONS IN PORTAGE COUNTY, WISCONSIN

By

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ABSTRACT

Lakeshore development is increasingly common on inland lakes and may significantly impact anuran populations dependent on shoreline habitat. The objective of this study was to evaluate the possible impacts of lakeshore development in Portage County, Wisconsin on local anuran populations. Breeding call surveys were conducted at 14 study lakes from April to July 2003 to examine species diversity in relation to 16 habitat, land use, and water quality variables. Additionally, visual encounter surveys were conducted at three of the study lakes to examine green frog (*Rana clamitans*) use in relation to 10 microhabitat variables. A significant positive relationship was found between anuran diversity and agricultural land use ($p=0.033$, $r^2=0.359$), possibly due to the increase in agriculture in less urban areas. *Rana clamitans* selected areas with emergent vegetation ($p<0.001$) and avoided open water ($p<0.001$). Lakeshore development appears to be affecting anuran populations through microhabitat and landscape-level alterations.

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PROLOGUE

This research was conducted in conjunction with an inter-disciplinary lake study at the University of Wisconsin-Stevens Point, supported by a grant from Portage County and the Wisconsin Department of Natural Resources. This Portage County Lakes Study examined the environmental impacts of lakeshore development on water quality, vegetation, and wildlife. Data were collected through fieldwork, historical records, and global information systems (GIS) analyses.

The first chapter of this thesis has been accepted for publication (Jung, R.E, and J.C. Mitchell (eds.). In press. Urban Herpetology. Herpetological Conservation Vol. 3, Society for the Study of Amphibians and Reptiles, Salt Lake City, UT) and is currently in final review. The version presented here includes comments from Joseph C. Mitchell, Robin E. Jung, and an anonymous reviewer.

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INTRODUCTION

Wisconsin has a diverse topography and contains one of the largest concentrations of glacially created freshwater lakes in the world (Curtis 1959, Baker 1998). These lakes provide vital habitat for many amphibians. However, an increasing number of lakeshore habitats are being converted into residential developments, which may threaten local amphibian populations.

Freshwater lakes are subject to numerous forms of degradation; two of the largest are habitat alteration and pollution (Noss and Cooperrider 1994). Commerce and urban centers are often concentrated around water because of historical importance to transportation and trade and opportunity for recreational activities and aesthetic living space. Because of this demand, at least thirty-two percent of freshwater lakes in the United States are now severely threatened by habitat modification (Noss and Cooperrider 1994).

In temperate regions, many anurans congregate along lake shorelines during breeding seasons in spring and early summer. Some species remain close to water throughout the year while others travel significant distances into the surrounding uplands. Many of the more terrestrial species overwinter in uplands adjacent to water bodies. Because of their dependence on water and vegetated or forested upland areas throughout their life cycle, anurans in this region can be affected in numerous ways by lakeshore development.

Habitat preferences may determine a species' ability to adapt to shoreline or urban development. Anuran species inhabiting forested areas may be especially susceptible to shoreline and urban development because of the associated high levels of forest loss, alteration or fragmentation (Moriarty 1998, Mossman et al. 1998). In Wisconsin for example, forest-dependent species such as the Wood Frog (*Rana sylvatica*), Spring Peeper (*Pseudacris crucifer*), and Gray Treefrog (*Hyla versicolor*) are often absent from highly urbanized areas (Vogt 1981, Mossman and Hine 1984, Oldfield and Moriarty 1994, Moriarty 1998, Mossman et al. 1998). On the other hand, species inhabiting open areas such as the Western Chorus Frog (*Pseudacris triseriata*), Northern Leopard Frog (*Rana pipiens*), and Cope's Gray Treefrog (*Hyla chrysoscelis*) may be able to withstand moderate levels of development (Vogt 1981, Mossman and Hine 1985, Oldfield and Moriarty 1994, Mossman et al. 1998). The Green Frog (*Rana clamitans*), a generalist species, may be able to adjust to some levels of urbanization (Vogt 1981, Moriarty 1998). The American Toad (*Bufo americanus*) is also able to withstand moderate levels of development but is known to be susceptible to fertilizers and pesticides in urban systems (Vogt 1981, Oldfield and Moriarty 1994, Moriarty 1998).

Despite the numerous developmental pressures on lakeshores, only a few studies have looked specifically at shoreline development and its possible effects on local amphibian populations (Engel and Pederson 1998). For example, Woodford and Meyer (2003) found that *Rana clamitans* abundance on developed lakes was significantly lower than abundances recorded on less urbanized lakes. The objective of this study was to evaluate the effects of urban development on breeding frog populations at fourteen lakes with varying degrees of shoreline development in Portage County, Wisconsin.

MATERIALS AND METHODS

Calling surveys were used to survey anuran populations at 14 study lakes in central Wisconsin (Portage County) from April to July 2003 (Figure 1). Portage County has 136 glacially created lakes, comprising 4,938 ha (2.4%) of the 208,857 ha of surface area in the county. The county has recently experienced modest growth, with a population increase of 9.4% between 1990 and 2000 (United States Census Bureau 2002). Fourteen public access lakes, varying in size from 6-32 ha and depth from 2-17 m were sampled in the spring and summer of 2003 (Wisconsin Department of Natural Resources 2001) (Table 1).

Calling surveys included a one-minute waiting period followed by a three-minute listening period at one sampling point per lake. A four value call index was used to document species calling: 1 = one individual calling, 2 = multiple individuals with space between calls, 3 = calls of individuals are still distinguishable but calls overlap, 4 = full chorus, calls of individuals are not distinguishable (Mossman et al. 1998). All surveys were conducted within the peak of daily breeding activity between sunset and 02:00 h (Mossman et al. 1998). Surveys were only conducted when beginning air temperatures were over 13°C and were not conducted in moderate or heavy precipitation. One calling survey per lake was conducted during each of three calling periods for Wisconsin anurans: early spring (8-30 April), late spring (20 May-5 June), and summer (1-15 July).

Anuran species richness was calculated from the calling survey data by summing the total number of species per lake: ΣS, where S = the number of species. The Shannon index (H') was used to calculate species diversity at each lake using calling indices:

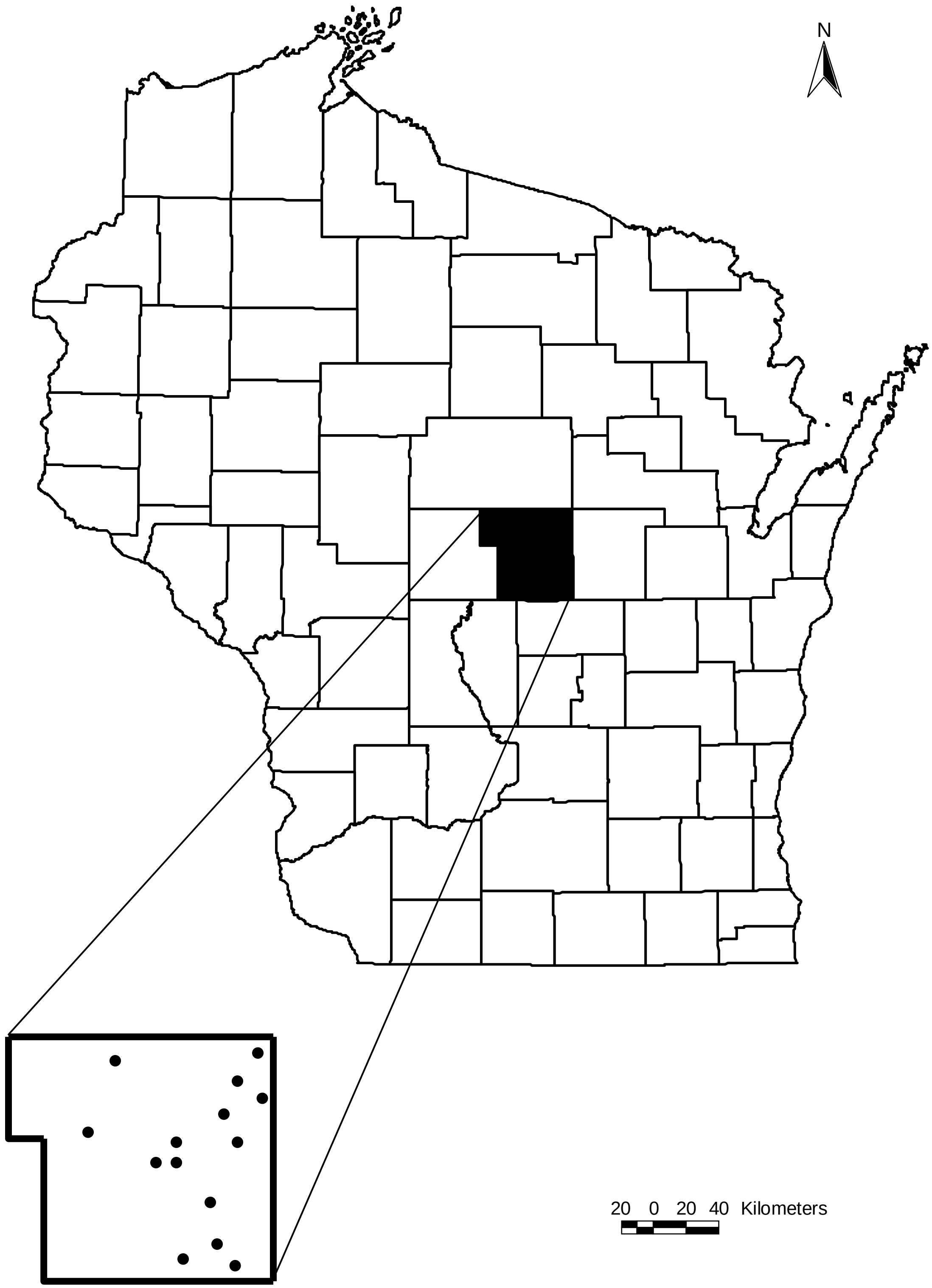

Figure 1. Location of study lakes in Portage County, Wisconsin.

Table 1. Description of 14 study lakes in Portage County, Wisconsin. [a]

Site	Type[b]	Area (ha)	Depth (m)
Adams Lake	SP	12	16
Bear Lake	SE	14	11
Fountain Lake	SP	6	7
Helen, Lake	DN	32	6
Jacqueline, Lake	SE	16	5
Lime Lake	SE	18	9
Lions Lake	DN	16	2
Pickerel Lake	SE	16	5
Rinehart Lake	DN	17	8
Springville Pond	DG	7	4
Sunset Lake	SE	25	17
Thomas Lake	SE	13	9
Tree Lake	DG	30	10
Wolf Lake	SE	9	5

[a] Wisconsin Department of Natural Resources (2001)

[b] DG=Drainage Lake (outlet and inlet, primary water source is stream drainage)

DN=Drained Lake (outlet but no inlet, primary water source is precipitation and runoff)

SE=Seepage Lake (no outlet and no inlet, primary water source is precipitation, runoff, and groundwater)

SP=Spring Lake (outlet but no inlet, primary water source is groundwater)

$H' = -\Sigma p_i \ln(p_i)$, where p_i = the proportion of the total sample belonging to the *i*th species (Krebs 1999). Evenness (J') was also calculated for each lake: $J' = H' / \ln(n)$, where n = total number of species present (Krebs 1999).

Shoreline habitat at each lake was classified into one of eight cover types (Table 2, see also Meyer et al. 1997). Shoreline habitat included a water zone from the shoreline to 5 m into the lake and a shore zone from the shoreline to 10 m inland. Total length of shoreline habitat classified into each cover type per lake was summed and a percentage of each type calculated.

ArcView 3.2 was used, with 2000 orthophotos (Wisconsin Department of Natural Resources 2000) to create a 250 m buffer around each study lake to categorize land use within the buffers into five types: agriculture, undeveloped, urban, road, and water (Table 2). Area within each category was summed per lake and a percentage of land use types within the buffers were calculated.

Nitrate (NO_3), total phosphorus (TP), and chloride (Cl^-) levels were analyzed at each of the study lakes to examine the possible correlation of water quality on anuran populations (Table 2). Integrated mid-lake samples from the upper 3 m of water were collected multiple times between April 23 and September 18, and average test results per lake were used in statistical analyses. Samples were transported on ice to the Water and Environmental Analysis Laboratory (WEAL) at the University of Wisconsin-Stevens Point for analysis.

Statistical analyses were conducted using SYSTAT 10.2. Univariate analyses were conducted to examine the relationship between habitat variables and species

Table 2. Description of variables measured at study lakes.[1]

Variable	Description	Method of Measurement
Wetland Shore 1	Wetland shore zone with a sweet gale or leather leaf shrub layer associated with tamarack or black spruce canopy	Field measurement
Wetland Shore 2	Wetland shore zone with an alder shrub layer	Field measurement
Wetland Shore 3	Narrow wetland shore zone (<5 m) with an adjacent upland component that is not developed	Field measurement
Undeveloped Shore 1	Upland shore zone with a densely vegetated shoreline component	Field measurement
Undeveloped Shore 2	Upland shore zone lacking dense shoreline grasses and shrubs, or a water zone with a rocky substrate	Field measurement
Low Shoreline Development	Low level of vegetation disturbance, unaltered shore zone except for pier access	Field measurement
Moderate Shoreline Development	Moderate level of vegetation disturbance, shore zone contains mowed lawn but has intact overstory	Field measurement
High Shoreline Development	High level of vegetation disturbance, highly disturbed cover including a shoreline that is mowed to the water or contains a beach, rip rap, or sea wall	Field measurement
% Agriculture	Agriculture within 250m buffer	GIS analysis
% Undeveloped	Undeveloped land within 250m buffer	GIS analysis
% Urban	Urban areas within 250m buffer	GIS analysis
% Road	Roads within 250m buffer	GIS analysis
% Water	Open water within 250m buffer	GIS analysis
TP	Average total phosphorus value	Water sample
NO_3	Average nitrate value	Water sample
Cl^-	Average chloride value	Water sample

[1]Shoreline habitat variables are based on cover types used by Meyer et al. (1997)

diversity. Mann-Whitney U-tests were conducted for each species to identify factors that may influence their presence or absence at a lake. Habitat variables were examined for intercorrelation using a correlation coefficient matrix. Variables were considered highly correlated when $r > 0.75$. Correlated variables were eliminated based on biological considerations. Forward stepwise multiple regression was then conducted to determine the influence of the remaining variables on anuran diversity. Variables not significant at $\alpha = 0.05$ were removed from the model.

RESULTS

Rana sylvatica, *Pseudacris crucifer*, *P. triseriata*, *R. pipiens*, *Bufo americanus*, *Hyla versicolor*, *H. chrysoscelis*, and *R. clamitans* were recorded during calling surveys. Only the Pickerel Frog (*R. palustris*), found in Portage County, was not heard. The American Bullfrog (*Rana catesbeiana*) has been found in adjacent counties but was also not recorded during surveys. Blanchard's Cricket Frog (*Acris crepitans blanchardi*) was historically found in Portage County but has dramatically declined over the past several decades throughout Wisconsin and much of the Midwest for unknown reasons. In Wisconsin, it only remains in the extreme southwestern portion of the state. *Pseudacris crucifer* was the most commonly recorded species, found at all 14 study lakes, followed by *R. clamitans* at 10 lakes. *Rana sylvatica* and *H. chrysoscelis* were the least common species, each found at only three study lakes. Species richness (ΣS) at the lakes ranged from 1 at Springville Pond to 7 at Adams Lake (Table 3). Diversity values (H') ranged from 0.00 at Springville Pond to from 1.82 at Adams Lake (Table 3). Evenness (J') was lowest at Springville Pond (0.00) and highest at Rinehart Lake (1.00) (Table 3).

Shoreline variables varied widely among lakes (Table 4). Wetland Shore 1 ranged from 0.0% at 12 of the 14 study lakes to 23.6% at Lake Jacqueline. Wetland Shore 2 ranged from 0.0% at nine of the study lakes to 28.5% at Rinehart Lake. Wetland Shore 3 ranged from 0.0% at six study lakes to 51.2% at Bear Lake. Undeveloped Shore 1 was lowest at Sunset Lake (0.0%) and was highest at Pickerel Lake (86.8%). Undeveloped Shore 2 was 0.0% at all study lakes except Bear Lake (8.7%). Low Shoreline Development ranged from 0.0% at five study lakes to 58.0% at Sunset Lake. Moderate

Table 3. Maximum calling indices recorded during field surveys.

Site	*Rana sylvatica*	*Pseudacris crucifer*	*Pseudacris triseriata*	*Rana pipiens*	*Bufo americanus*	*Hyla versicolor*	*Hyla chrysoscelis*	*Rana clamitans*	ΣS	H '	J '
Adams Lake	2	4	2	1	4	1		2	7	1.82	0.94
Bear Lake		2			2	2		3	4	1.37	0.99
Fountain Lake		3						2	2	0.67	0.97
Helen, Lake	2	3	2	1		2		2	6	1.75	0.98
Jacqueline, Lake		3	1	2				3	4	1.31	0.95
Lime Lake		2				4	2	3	4	1.34	0.97
Lions Lake		3	1						2	0.56	0.81
Pickerel Lake		3				2			2	0.67	0.97
Rinehart Lake		2						2	2	0.69	1.00
Springville Pond		2							1	0.00	0.00
Sunset Lake	2	3			2	2	2		5	1.59	0.99
Thomas Lake		2			2	2	1	2	5	1.58	0.98
Tree Lake		1			2			2	3	1.05	0.96
Wolf Lake		1						2	2	0.64	0.92

Table 4. Variables measured at 14 study lakes.

Site	Wetland Shore 1 (%)	Wetland Shore 2 (%)	Wetland Shore 3 (%)	Undev Shore 1 (%)	Undev Shore 2 (%)	Low Dev Shore (%)	Med Dev Shore (%)	High Dev Shore (%)	Ag (%)	Undev (%)	Urban (%)	Road (%)	Water (%)	TP (µg/L)	NO_3 (mg/L)	Cl^- (mg/L)
Adams Lake	0.0	3.3	1.6	61.1	0.0	8.3	1.3	24.4	6.0	73.5	10.4	8.4	1.7	11.9	0.210	4.67
Bear Lake	0.0	4.6	51.2	27.6	8.7	3.8	0.0	4.1	16.7	71.5	4.3	3.5	4.0	14.9	0.057	0.58
Fountain Lake	0.0	0.0	36.1	61.8	0.0	0.0	0.0	2.1	0.0	95.3	1.4	2.9	0.4	22.0	0.720	2.33
Helen, Lake	0.0	1.6	0.0	5.5	0.0	0.0	15.8	77.1	24.9	30.2	36.6	8.4	0.0	22.4	0.200	19.50
Jacqueline, Lake	23.6	0.0	0.0	11.3	0.0	9.8	21.3	34.0	8.7	54.1	29.8	7.3	0.1	27.1	0.073	5.48
Lime Lake	0.0	0.0	0.0	84.4	0.0	13.4	0.0	2.3	39.6	43.4	8.8	5.4	2.8	28.1	0.203	10.67
Lions Lake	0.0	0.0	0.0	62.3	0.0	20.5	0.0	17.2	3.1	85.5	7.6	2.4	1.4	17.3	0.053	1.00
Pickerel Lake	0.0	0.0	3.2	86.8	0.0	0.0	0.0	10.0	0.0	84.1	9.7	2.5	3.8	18.6	0.350	7.00
Rinehart Lake	0.0	28.5	4.8	21.4	0.0	6.1	23.5	15.6	6.0	74.3	9.6	10.1	0.0	14.7	0.145	6.50
Springville Pond	0.0	0.0	0.0	5.1	0.0	5.8	26.2	62.9	0.0	1.0	84.0	15.1	0.0	29.4	5.993	17.67
Sunset Lake	0.0	0.0	2.2	0.0	0.0	58.0	15.7	24.1	10.5	74.3	2.3	8.3	4.5	19.9	0.047	1.00
Thomas Lake	0.0	0.0	1.5	65.6	0.0	0.0	16.4	16.4	27.5	54.7	9.8	5.0	2.9	20.7	0.107	0.75
Tree Lake	15.1	1.2	0.0	6.1	0.0	3.2	11.0	63.5	8.1	58.8	20.0	6.9	6.2	25.3	0.640	11.83
Wolf Lake	0.0	0.0	14.9	60.0	0.0	0.0	0.0	25.1	0.1	87.4	0.5	0.9	11.1	19.7	0.027	0.42

Shoreline Development ranged from 0.0% at six lakes to 26.2% at Springville Pond. High Shoreline Development ranged from 2.1% at Fountain Lake to 77.1% at Lake Helen.

Land use within lake buffers also varied significantly from lake to lake (Table 4). Agricultural land use ranged from 0.0% at three study lakes to 39.6% at Lime Lake. Undeveloped land use ranged from 1.0% at Springville Pond to 95.3% at Fountain Lake with the majority of sites having greater than 50% undeveloped habitat. Urban land use ranged from 0.5% at Wolf Lake to 84.0% at Springville Pond. Roads made up only 0.9% of total land use surrounding Wolf Lake, but accounted for 15.1% of total land use surrounding Springville Pond. Open water surrounding each study lake ranged from 0.0% at three study lakes to 11.1% at Wolf Lake.

Average total phosphorus values at the study lakes ranged from 11.9 µg/L at Adams Lake to 29.4 µg/L at Springville Pond (Table 4). Average nitrate values ranged from 0.027 mg/L at Wolf Lake to 5.993 mg/L at Springville Pond, the only lake with nitrate levels over 1.000 mg/L. Average chloride values ranged from 0.42 mg/L at Wolf Lake to 19.50 mg/L at Lake Helen.

Univariate analyses showed a significant relationship between species diversity and percentage agricultural land use and NO^3 (Table 5). Mann-Whitney U-tests identified few factors that were influencing specific species presence or absence at study lakes (Tables 6-12). *Hyla versicolor* and *H. chrysoscelis* were positively correlated with percentage of agricultural land use within a 250 m buffer.

Similar shoreline habitats were found to be highly intercorrelated and combined into three general categories: wetland shoreline, undeveloped shoreline, and developed shoreline. A correlation coefficient matrix was then created with the resulting 11 habitat

Table 5. Relationship between independent variables and species diversity.

Independent Variable	r-value	p-value
Wetland Shore 1	0.215	0.459
Wetland Shore 2	-0.122	0.676
Wetland Shore 3	-0.084	0.776
Wetland Shoreline Combined	-0.040	0.893
Undeveloped Shore 1	-0.092	0.753
Undeveloped Shore 2	0.128	0.663
Undeveloped Shoreline Combined	-0.084	0.776
Low Shoreline Development	0.209	0.473
Moderate Shoreline Development	-0.023	0.938
High Shoreline Development	0.015	0.959
Developed Shoreline Combined	0.098	0.739
% Agriculture	0.572	0.033
% Undeveloped	<0.001	1.000
% Urban	-0.306	0.288
% Road	-0.012	0.968
% Water	-0.063	0.831
TP	-0.205	0.483
NO^3	-0.578	0.030
Cl^-	-0.104	0.723

Table 6. Lakeshore variables recorded at lakes with *Rana sylvatica* present and absent (mean ± SD).

Variable	*Rana sylvatica* present	*Rana sylvatica* absent	P-value[a]
Wetland Shoreline (%)	2.9 ± 1.7	16.8 ± 18.7	0.584
Undeveloped Shoreline (%)	22.2 ± 33.8	45.6 ± 30.7	0.139
Developed Shoreline (%)	74.9 ± 35.5	37.7 ± 30.4	0.102
% Agriculture (%)	13.8 ± 9.8	10.0 ± 13.0	0.348
% Undeveloped (%)	59.3 ± 25.3	64.5 ± 26.8	0.697
% Urban	16.4 ± 17.9	16.9 ± 23.8	0.586
% Road	8.4 ± 0.0	5.6 ± 4.1	0.102
% Water	2.1 ± 2.3	3.0 ± 3.4	0.815
TP (µg/L)	18.1 ± 5.5	21.6 ± 5.2	0.484
NO^3 (mg/L)	0.2 ± 0.1	0.8 ± 1.8	0.697
Cl^- (mg/L)	8.4 ± 9.8	5.8 ± 5.7	0.640

[a] Mann-Whitney U-test

Table 7. Lakeshore variables recorded at lakes with *Pseudacris triseriata* present and absent (mean ± SD).

Variable	*Pseudacris triseriata* present	*Pseudacris triseriata* absent	P-value[a]
Wetland Shoreline (%)	7.5 ± 10.9	16.3 ± 19.3	0.570
Undeveloped Shoreline (%)	35.1 ± 30.9	42.7 ± 33.2	0.777
Developed Shoreline (%)	57.4 ± 27.4	40.9 ± 36.5	0.322
% Agriculture	10.7 ± 9.7	10.8 ± 13.5	0.722
% Undeveloped	60.8 ± 24.2	64.5 ± 27.3	0.572
% Urban	21.1 ± 14.3	15.0 ± 24.9	0.157
% Road	6.6 ± 2.9	6.1 ± 4.2	0.572
% Water	0.8 ± 0.9	3.6 ± 3.4	0.118
TP (µg/L)	19.7 ± 6.6	21.3 ± 5.0	0.671
NO^3 (mg/L)	0.1 ± 0.1	0.8 ± 1.8	0.572
Cl^- (mg/L)	7.7 ± 8.1	5.9 ± 6.0	0.620

[a] Mann-Whitney U-test

Table 8. Lakeshore variables recorded at lakes with *Rana pipiens* present and absent (mean ± SD).

Variable	*Rana pipiens* present	*Rana pipiens* absent	P-value[a]
Wetland Shoreline (%)	10.0 ± 11.9	14.8 ± 19.0	0.815
Undeveloped Shoreline (%)	26.0 ± 30.6	44.5 ± 32.1	0.392
Developed Shoreline (%)	64.0 ± 29.5	40.6 ± 34.7	0.312
% Agriculture	13.2 ± 10.2	10.1 ± 13.0	0.434
% Undeveloped	52.6 ± 21.7	66.4 ± 26.7	0.186
% Urban	25.6 ± 13.6	14.4 ± 23.7	0.052
% Road	8.0 ± 0.6	5.7 ± 4.2	0.139
% Water	0.6 ± 1.0	3.4 ± 3.3	0.137
TP (µg/L)	20.5 ± 7.8	21.0 ± 4.9	0.938
NO^3 (mg/L)	0.2 ± 0.1	0.8 ± 1.8	0.938
Cl^- (mg/L)	9.9 ± 8.3	5.4 ± 5.8	0.311

[a] Mann-Whitney U-test

Table 9. Lakeshore variables recorded at lakes with *Bufo americanus* present and absent (mean ± SD).

Variable	*Bufo americanus* present	*Bufo americanus* absent	P-value[a]
Wetland Shoreline (%)	16.1 ± 22.9	12.5 ± 15.0	0.547
Undeveloped Shoreline (%)	33.8 ± 30.3	44.3 ± 33.4	0.549
Developed Shoreline (%)	50.0 ± 36.6	43.2 ± 34.5	0.739
% Agriculture	13.8 ± 8.7	9.1 ± 13.9	0.140
% Undeveloped	66.6 ± 9.1	61.7 ± 31.8	0.841
% Urban	9.4 ± 6.9	20.9 ± 26.6	0.947
% Road	6.5 ± 2.1	6.1 ± 4.6	0.641
% Water	3.9 ± 1.7	2.2 ± 3.6	0.052
TP (µg/L)	18.5 ± 15.2	22.2 ± 5.1	0.317
NO^3 (mg/L)	0.2 ± 0.2	0.9 ± 1.9	0.641
Cl^- (mg/L)	3.8 ± 4.8	7.8 ± 6.9	0.230

[a] Mann-Whitney U-test

Table 10. Lakeshore variables recorded at lakes with *Hyla versicolor* present and absent (mean ± SD).

Variable	*Hyla versicolor* present	*Hyla versicolor* absent	P-value[a]
Wetland Shoreline (%)	9.9 ± 20.3	17.7 ± 14.5	0.404
Undeveloped Shoreline (%)	48.5 ± 35.5	32.6 ± 27.5	0.406
Developed Shoreline (%)	41.6 ± 38.1	49.7 ± 31.9	0.565
% Agriculture	17.9 ± 13.7	3.7 ± 3.9	0.040
% Undeveloped	61.7 ± 19.5	65.2 ± 32.1	0.406
% Urban	11.7 ± 11.4	21.9 ± 29.3	0.949
% Road	5.9 ± 2.5	6.5 ± 5.0	0.848
% Water	2.8 ± 1.5	2.7 ± 4.3	0.404
TP (µg/L)	19.5 ± 5.2	22.2 ± 5.4	0.482
NO^3 (mg/L)	0.2 ± 0.1	1.1 ± 2.2	0.749
Cl^- (mg/L)	6.3 ± 6.9	6.5 ± 6.3	0.898

[a] Mann-Whitney U-test

Table 11. Lakeshore variables recorded at lakes with *Hyla chrysoscelis* present and absent (mean ± SD).

Variable	*Hyla chrysoscelis* present	*Hyla chrysoscelis* absent	P-value[a]
Wetland Shoreline (%)	1.3 ± 1.1	17.2 ± 18.3	0.101
Undeveloped Shoreline (%)	50.0 ± 44.3	38.0 ± 29.5	0.586
Developed Shoreline (%)	48.7 ± 43.3	44.8 ± 33.6	0.815
% Agriculture	25.9 ± 14.6	6.7 ± 7.9	0.023
% Undeveloped	57.5 ± 15.6	65.0 ± 28.1	0.484
% Urban	7.0 ± 4.1	19.4 ± 24.3	0.484
% Road	6.2 ± 1.8	6.2 ± 4.2	0.938
% Water	3.4 ± 0.9	2.6 ± 3.5	0.309
TP (µg/L)	22.9 ± 4.6	20.3 ± 5.5	0.392
NO^3 (mg/L)	0.1 ± 0.1	0.8 ± 1.7	0.392
Cl^- (mg/L)	4.1 ± 5.7	7.0 ± 6.7	0.535

[a] Mann-Whitney U-test

Table 12. Lakeshore variables recorded at lakes with *Rana clamitans* present and absent (mean ± SD).

Variable	*Rana clamitans* present	*Rana clamitans* absent	P-value[a]
Wetland Shoreline (%)	18.8 ± 18.5	1.4 ± 1.6	0.065
Undeveloped Shoreline (%)	41.4 ± 28.8	38.5 ± 42.8	0.777
Developed Shoreline (%)	39.8 ± 30.3	60.1 ± 43.4	0.258
% Agriculture	13.7 ± 13.1	3.4 ± 5.0	0.118
% Undeveloped	64.3 ± 19.9	61.2 ± 40.5	0.572
% Urban	13.1 ± 12.0	25.9 ± 38.8	1.000
% Road	5.9 ± 2.9	7.1 ± 6.0	0.888
% Water	2.9 ± 3.5	2.4 ± 2.1	1.000
TP (µg/L)	20.7 ± 5.5	21.3 ± 5.5	1.000
NO^3 (mg/L)	0.2 ± 0.2	1.6 ± 2.9	1.000
Cl^- (mg/L)	6.3 ± 6.2	6.7 ± 7.9	0.777

[a] Mann-Whitney U-test

variables (Table 13). Three variables were included in the multiple regression analysis: developed shoreline, percentage of agricultural land use within a 250 m buffer, and percentage of urban land use within a 250 m buffer. Developed shoreline was significantly negatively correlated with undeveloped shoreline. Because this study examines lakeshore development, developed shoreline was chosen to include in the analysis. Percent of agricultural land use appeared significant in univariate analyses and was not correlated with any other variables. Percentage of urban land use was highly correlated with percent undeveloped land use, percent road, average nitrate, and average chloride. Percent urban area was thus chosen to represent these variables. Diversity values were used as the dependent variable because they represented both anuran abundance and richness. The only variable remaining in the model was percent agricultural land use, which was positively correlated with species diversity ($F = 5.832$, $df = 1$, $p = 0.033$, $r^2=0.359$).

Table 13. Correlation matrix of variables.

	Wetland Shoreline	Undeveloped Shoreline	Developed Shoreline	% Agriculture	% Undeveloped	% Urban	% Road	% Water	TP (µg/L)	NO_3 (mg/L)	Cl^- (mg/L)
Wetland Shoreline	1.00										
Undeveloped Shoreline	-0.13	1.00									
Developed Shoreline	-0.39	-0.86	1.00								
% Agriculture	-0.18	0.12	-0.02	1.00							
% Undeveloped	0.36	0.46	-0.61	-0.38	1.00						
% Urban	-0.29	-0.51	0.62	-0.10	-0.88	1.00					
% Road	-0.21	-0.67	0.73	0.00	-0.75	0.77	1.00				
% Water	0.00	0.19	-0.18	-0.10	0.36	-0.42	-0.51	1.00			
TP (µg/L)	-0.29	-0.26	0.39	0.24	-0.65	0.59	0.30	-0.10	1.00		
NO_3 (mg/L)	-0.21	-0.31	0.40	-0.28	-0.68	0.87	0.66	-0.27	0.50	1.00	
Cl^- (mg/L)	-0.34	-0.41	0.55	0.20	-0.80	0.77	0.63	-0.37	0.56	0.54	1.00

DISCUSSION

Anuran species richness and diversity varied by study lake as did the habitat types surrounding the lakes. Most lakes were located in rural areas, some with high concentrations of residential lakeshore development. Springville Pond was the only study lake located entirely within an urban area. This lake had the lowest species diversity with only one species recorded, *Bufo americanus*. Interestingly, only one *B. americanus* was heard calling on one night. Springville Pond is an impoundment with a minimal amount of suitable anuran habitat. The majority of the shoreline (94.9%) is residentially developed with few areas of undeveloped shoreline. It is difficult to determine whether natural areas once existed along Springville Pond or were never present along the impoundment shorelines. It is also important to note that although a low species diversity was recorded at Springville Pond, this may not be the result of a cause and effect relationship between anuran abundance and land use (Crisafulli 1997). Due to the nature of impoundments and ease of development in certain areas, residential developments may have been created more often in areas with little shoreline and littoral vegetation; areas less favorable to anurans. However, identifying the lakeshore variables critical to local anuran populations still provides valuable information for future land use and management decisions.

Adams Lake supported the highest species diversity (H’=1.99) and richness (ΣS=7). Adams Lake contains a moderate amount of residential development, but the areas of development are concentrated in shorter continuous stretches of shoreline, leaving many large continuous stretches of undeveloped shoreline and thus less fragmented habitat. Many of the houses present on Adams Lake are set back from the lake, creating a natural buffer between the lake and developed areas. Most of the frogs calling at Adams Lake were concentrated in the large continuous stretches of undeveloped shoreline or within the shoreline buffer areas. The degree of habitat fragmentation may be more important than simply the amount of developed shoreline because of the possible cumulative effect that lakeshore development may have on anuran populations (Woodford and Meyer 2003).

I would have expected that less developed lakes would be more favorable to anurans, however several of the most undeveloped lakes, such as Fountain, Pickerel, and Wolf Lakes, had surprisingly low species diversity. A homogeneous forest habitat surrounded these lakes and may not have provided suitable for a wide variety of species as several of the Portage County anurans prefer open canopy habitats. Water levels at these three lakes had also declined significantly in the past several years for unknown reasons, likely resulting in less emergent and shoreline vegetation. Aquatic and shoreline vegetation provide habitat for many anuran species during critical life-cycle stages. Vegetation is used for attachment of eggs, forage material for larvae, shelter for adults throughout the spring and summer, and habitat for prey (Vogt 1981, Crisafulli 1997). Large amounts of littoral vegetation may also benefit anurans by slowing evaporation and moderating temperature fluctuations (Crisafulli 1997).

An unexpected relationship was found between anuran species diversity and agricultural land use. High anuran diversity was correlated with a high percentage of agricultural land use within a 250 m buffer of the study lakes. The presence of *Hyla versicolor* and *H. chrysoscelis* were also influenced by agricultural land use. A similar positive relationship between agriculture and species diversity was found by Knutson et al. (1999) when looking at the impacts of urbanization on frogs in Wisconsin. They suggested that the positive relationship between anuran abundance and agricultural land use may have been due to forest fragments remaining within the agricultural landscape that provided pockets of anuran habitat. In my study, this relationship may also reflect the greater percentage of agricultural lands that are often found away from developed areas. Water quality and shoreline habitat types showed little relationship with anuran diversity at the study lakes.

Future Directions

Land use surrounding lakes is a good measure of development and is a valuable approach to quantifying lakeshore development. These data could be especially useful in tracking lakeshore development changes over time. A variety of standard buffers, i.e., 100 m, 250 m should be used to look at various scales, as well as biologically significant buffers that incorporate the home ranges and dispersal abilities of specific anuran species (e.g., 1 km used by Knutson et al. 2000, Weir et al. 2005).

Frogs in this study were observed using larger continuous sections of shoreline more often than smaller fragmented sections, indicating fragmentation could be affecting populations and their distribution Shoreline development can severely fragment lake shorelines and limit or restrict amphibian movements (Engel and Pederson 1998). Fragmentation also prevents many species from migrating to more hospitable areas (Vos and Chardon 1998, Lehtinen et al. 1999). Amphibians are especially susceptible to habitat fragmentation because of their limited dispersal abilities; even small modifications may adversely affect populations (Murphy 1986, Blaustein and Wake 1995). Many amphibians remain in relatively small areas their entire lives and often have difficulty relocating or moving around barriers to find new suitable habitat. Relating habitat fragmentation to species diversity or population data can be difficult to quantify but could have important implications for future shoreline zoning, conservation, and management. Other habitat work could examine the importance of undisturbed uplands adjacent to shorelines used by frogs. Many anuran species require uplands for foraging and overwintering and may be severely impacted when shorelines are isolated from uplands. Long-term studies, particularly before and after studies of shoreline development, would help to assess specific trends in frog populations along lakeshores.

Anurans are impacted by landscape-level alterations in addition to shoreline alterations associated with lakeshore development. This study suggests that anuran populations can be affected by habitat variables that are more complex than simple levels of development. The impact of lakeshore development on anurans also appears to be species specific, varying according to the life history requirements of the individual species.

CHAPTER 2:

RANA CLAMITANS MICROHABITAT USE

INTRODUCTION

Amphibian Decline

Amphibian populations throughout the world have been declining since at least the 1970's (Wake 1991, Blaustein and Wake 1995, Houlahan et al. 2000). Habitat alteration (Vos and Chardon 1998, Knutson et al. 1999, Lehtinen et al. 1999), chemical contamination (Hecnar 1995, Davidson et al. 2001), UV-B radiation (Blaustein et al. 1994, Blaustein et al. 1998), disease (Laurance et al. 1996, Berger et al. 1998, Daszak et al. 1999), climate change (Pounds and Crump 1994, Stewart 1995), and exotic species introduction (Adams 1999, Knapp and Matthews 2000) have been associated with specific amphibian population declines but no single cause has been found to explain all instances of decline. Combinations of, or synergistic interactions among, these factors may also explain some declines (Long et al. 1995, Adams 1999, Relyea and Mills 2001).

There is still debate as to whether all declines are the direct result of anthropogenic activities or are simply natural fluctuations, however amphibians do respond negatively to habitat alterations and at least a portion of their population declines can be directly attributed to anthropogenic alterations of the environment (Pechmann et al. 1991, Wake 1991, Pechmann and Wilbur 1994). Habitat destruction and alteration is considered the most serious threat facing amphibian populations today, although the cause of declines have not yet been identified in approximately 48% of declining amphibian species (Blaustein et al. 1994, Blaustein and Wake 1995, Stuart et al. 2004). Additionally, natural fluctuations and anthropogenic activities can have negative synergistic effects on populations and recovery ability (Pechmann et al. 1991).

Population declines are particularly alarming because amphibians are integral members of many ecological communities (Blaustein et al. 1994, Blaustein and Wake 1995). The majority of adults are carnivores that are major consumers of invertebrates (Oldfield and Moriarty 1994). Amphibians are also often the most abundant vertebrates in some ecosystems, and their disappearance would have profound effects on the remaining species and the health of the ecosystems (Blaustein et al. 1994, Blaustein and Wake 1995).

Among amphibians, anurans are of particular concern because of their possible role as indicator species of environmental health (Phillips 1990, Wake 1991, Blaustein and Wake 1995). Anurans are thought to be particularly sensitive to environmental conditions for several reasons. Larvae are primarily herbivores, while adults are primarily carnivores, exposing anurans to multiple aspects of the environment throughout their life cycle. Their permeable skin and dependence on both aquatic and terrestrial habitats places them in constant contact with both environments. Anuran eggs lack protective coverings such as shells, allowing direct exposure to the environment during development (Blaustein and Wake 1995). The relative lack of mobility of anurans may also limit their ability to respond to environmental alterations.

Amphibian decline is a global phenomenon, but often with local causes. Thirteen anuran species have been documented in Wisconsin: Northern Cricket Frog (*Acris crepitans*, American Toad (*Bufo americanus*), Western Chorus Frog (*Pseudacris triseriata*), Boreal Chorus Frog (*P. maculata*), Spring Peeper (*P. crucifer*), Gray Treefrog (*Hyla versicolor*), Cope’s Gray Treefrog (*H. chrysoscelis*), American Bullfrog (*Rana catesbeiana*), Green Frog (*R. clamitans*), Pickerel Frog (*R. palustris*), Northern Leopard

Frog (*R. pipiens*), Mink Frog (*R. septentrionalis*), and Wood Frog (*R. sylvatica*) (Vogt 1981, Casper 1996). Several Wisconsin anurans are believed to be in a general decline due to urbanization and habitat destruction (Casper 1998). Of the species inhabiting Wisconsin, four are declining (*A. crepitans*, *P. crucifer*, *H. chrysoscelis*, *R. pipiens*), seven are stable (*B. americanus*, *P. triseriata, P. maculata*, *R. catesbeiana, R. clamitans*, *R. palustris, R. septentrionalis*), and two are increasing (*H. versicolor*, R. *sylvatica*) (Christoffel et al. 2001).

Since anurans not only play an important role in their ecosystems, but may also be early indicators of environmental degradation, their decline is of serious concern. The recent worldwide increase in amphibian declines stresses the importance of habitat-based amphibian studies both at a global and local scale.

Lakeshore Development

Wisconsin has a diverse topography and contains one of the largest concentrations of glacially created freshwater lakes in the world (Curtis 1959, Baker 1998). These lakes provide vital habitat for many amphibians. Unfortunately, an increasing number of lakeshore habitats are being converted into residential developments which may threaten local amphibian populations.

Freshwater lakes are subject to numerous forms of degradation; two of the largest are habitat alteration and pollution (Noss and Cooperrider 1994). Commerce and urban centers are often concentrated around water because of their historical importance to transportation and trade and opportunity for recreational activities and aesthetic living space. Because of this demand, at least thirty-two percent of freshwater lakes in the

United States are now severely threatened by habitat modification (Noss and Cooperrider 1994).

Lakeshore development causes habitat fragmentation, reduces natural vegetation, and decreases water quality. Anurans are especially susceptible to changes in their environment and may be impacted by lakeshore development in a number of ways. Shoreline development can severely fragment lake shorelines and limit or restrict amphibian movements (Engel and Pederson 1998). Fragmentation also prevents many species from migrating to more hospitable areas (Vos and Chardon 1998, Lehtinen et al. 1999). Amphibians are especially susceptible to habitat fragmentation because of their limited dispersal abilities; even small modifications may adversely affect populations (Murphy 1986, Blaustein and Wake 1995). Many amphibians remain in relatively small areas their entire lives and often have difficulty relocating or moving around barriers to find new suitable habitat.

Shoreline structures may also inhibit amphibian movement. The Wisconsin Department of Natural Resources (WDNR 1996) found that wildlife, including amphibians and reptiles, more often used natural shorelines than shorelines with rip-rap or seawalls, most likely due to the greater abundance and diversity of aquatic vegetation and woody habitat along natural shorelines.

A decrease in canopy cover is often correlated with an increase in habitat fragmentation and lakeshore development, which could directly and indirectly affect amphibians (Meyer et al. 1997). Changes in canopy cover may alter water chemistry and temperature, as well as understory composition along shorelines (Crisafulli 1997).

Reductions in canopy cover negatively affect anuran populations (Findlay and Houlahan 1997, Gibbs 1998).

Shoreline, littoral, and riparian vegetation are often altered when lake shorelines are developed. Unfortunately, these habitats are used by many anurans during critical life-cycle stages such as the breeding season. Vegetation is used for attachment of eggs, forage material for larvae, shelter for adults throughout the spring and summer, and habitat for prey (Vogt 1981, Crisafulli 1997). Large amounts of littoral vegetation may benefit anurans by slowing evaporation and moderating temperature fluctuations (Crisafulli 1997). Significant reductions in emergent, floating-leaf, and submergent vegetation have been found at developed lakes in Minnesota and northern Wisconsin (Meyer et al. 1997, Radomski and Goeman 2001).

Water quality is often impacted by lakeshore development. Anurans are directly exposed to water throughout their lives and may be significantly affected by contaminants in the water. Elevated levels of nitrate, chloride, phosphorus, and triazine, among others, are commonly associated with urbanization and may impact frog populations at lakes. Nitrate, one of the most common contaminants in groundwater supplies in Wisconsin (Water and Environmental Analysis Laboratory 2002), indicates contamination from fertilizers and septic systems. Elevated nitrate levels have been correlated with low anuran diversity and decreased reproductive success of *Bufo americanus* and *Rana clamitans* in Ontario (Bishop et al. 1999). High levels of chloride in lake water may indicate contamination from septic systems, fertilizers, and landfills (Water and Environmental Analysis Laboratory 2002). Although little research has been published on anurans' responses to elevated levels of chloride, this contaminant is one of the major indicators of urbanization surrounding water bodies. Elevated phosphorus levels have been reported at highly developed lakes (Wisconsin Department of Natural Resources 2002) due to contamination from fertilizers, animal waste, and sewage treatment plants. High phosphorus levels have been correlated with low anuran diversity and decreased reproductive success of *B. americanus*, *R. clamitans*, and *R. aurora* (Bishop et al. 1999, de Solla et al. 2002). Atrazine, used in agriculture for control of broad-leaf and grassy weeds (Water and Environmental Analysis Laboratory 2002, United States Environmental Protection Agency 2002), is the most commonly found herbicide in groundwater supplies in Wisconsin. Frogs have developed gonadal abnormalities when exposed to atrazine at very low doses (Hayes et al. 2002).

Despite the numerous developmental pressures on lakeshores, only a small number of studies have looked specifically at shoreline development and its possible effects on local amphibian populations (Engel and Pederson 1998). *Desmognathus fuscus fuscus* (dusky salamander) populations near Atlanta, Georgia were negatively affected by urban development on streams (Orser and Shure 1972). Salamander population densities decreased as the density of urban areas increased. Salamander densities were negatively correlated with runoff and positively correlated with intact ground cover. Similarly, *Rana clamitans* populations in northern Wisconsin were negatively affected by lakeshore development (Woodford and Meyer 2003). *Rana clamitans* abundance on developed lakes was significantly lower than abundances recorded on less urbanized lakes.

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STUDY OBJECTIVES

Many studies have investigated anuran population declines, but few studies have examined the effects of urbanization and lakeshore development on anurans (Meyer 1997, Engel and Pederson 1998). The general objective of this study was to examine the impacts of shoreline development and associated anthropogenic disturbance on anuran populations of freshwater lakes in Portage County, Wisconsin. Specific objectives of the research included:

1) *Determination of* Rana clamitans *abundance across three lakeshore habitat types. Rana clamitans* abundance data were collected through field surveys.

2) *Measurement of microhabitat variables at* Rana clamitans *occurrences and random locations.* Microhabitat measurements at *Rana clamitans* and random locations were collected through field surveys.

3) *Analysis of* Rana clamitans *selection of habitat based on microhabitat variables. Rana clamitans* habitat use was analyzed relative to several microhabitat variables through statistical analyses.

MATERIALS AND METHODS

Study Area

Research was conducted at three primary study lakes from April – July 2003 in Portage County, Wisconsin (Figure 2). Portage County, located in central Wisconsin, has 136 glacially created lakes, comprising 4,938 ha (2.4%) of the 208,857 ha of surface area in the county. The county has recently experienced modest growth, with a population increase of 9.4% between 1990 and 2000 (United States Census Bureau 2002). Visual encounter surveys focused on Adams Lake, Lake Jacqueline, and Rinehart Lake (Table 14). These lakes contained substantial, discrete sections of both developed and natural shorelines.

Anuran Surveys

Visual encounter surveys along transects were used to inventory anuran populations along the shorelines of the three study lakes. Visual encounter surveys were conducted once per week from April 28, 2003 to July 12, 2003, with the exception of the week of May 5-11 due to extreme weather conditions. All surveys were conducted within the peak of daily breeding activity between sunset and 02:00 h (Mossman et al. 1998). Surveys were conducted only when beginning air temperatures were over 13°C and were not conducted in moderate or heavy precipitation.

The shorelines of the study lakes were subdivided into three general habitat types: marsh, forest, and developed (residential development). Developed shorelines were further subdivided into moderate and high development to examine the varying degrees of residential development. Developed shorelines were considered only moderately developed if they had routinely mowed lawns to the shoreline, but retained aquatic

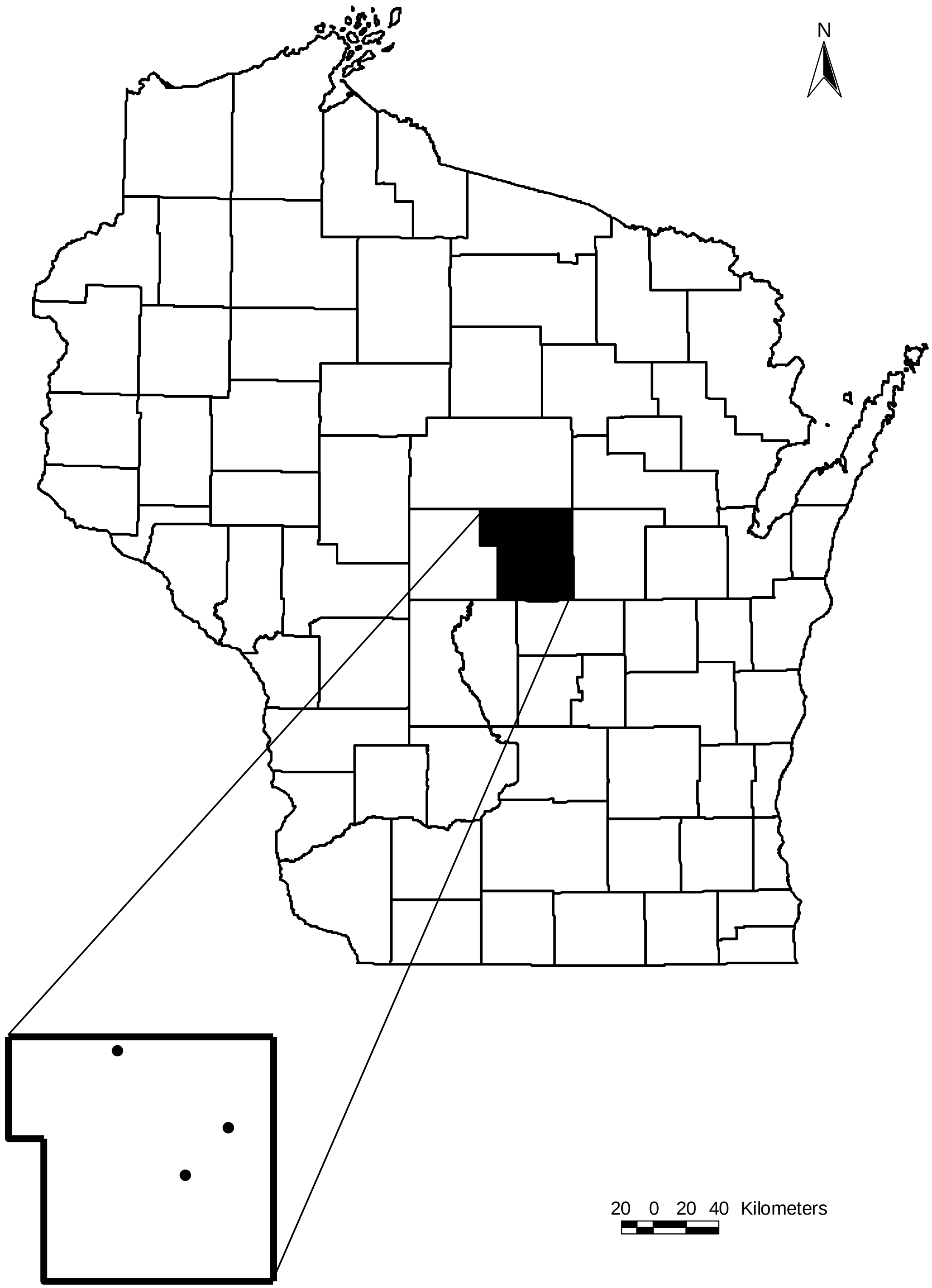

Figure 2. Location of three primary study lakes in Portage County, Wisconsin.

Table 14. Description of three primary study lakes in Portage County, Wisconsin. [a]

Site	Type[b]	Area (ha)	Depth (m)
Adams Lake	SP	12	16
Jacqueline, Lake	SE	16	5
Rinehart Lake	DN	17	8

[a] Wisconsin Department of Natural Resources 2001

[b] DN=Drained Lake (outlet but no inlet, primary water source is precipitation and runoff)

SE=Seepage Lake (no outlet and no inlet, primary water source is precipitation, runoff, and groundwater)

SP=Spring Lake (outlet but no inlet, primary water source is groundwater) vegetation. Developed shorelines were considered highly developed if they had routinely mowed lawns to the shoreline and removed aquatic vegetation.

Shoreline transects were randomly placed within the three habitat types using a random point generating program in ArcView 3.2. Because of the relatively short shoreline length of several habitat types on the lakes, 15 m transects were used to ensure placement of four transects per habitat type per lake. Thirty-six transects were placed on the three study lakes, 12 transects per lake as well as 12 transects per habitat type. The twelve developed transects consisted of six highly developed transects and six moderately developed transects.

Each transect was surveyed by two researchers. One researcher walked the lake shoreline, the shoreline defined as the edge of standing water. The second researcher walked or canoed parallel to the first observer, 2 m offshore. Parallel transects were used to more efficiently sample the littoral zone. All transects were actively searched, and any frogs visually observed regardless of location relative to the transect were recorded. All transects on a lake were surveyed on the same evening.

Habitat Inventory

Habitat inventories were conducted at all anuran locations during visual encounter surveys, as well as random locations at the study lakes to quantify the available shoreline and littoral microhabitat. A random point generating program in ArcView 3.2 was used to place 450 random shoreline points at the study lakes. Of the 150 random points per lake, 75 points were located 2 m offshore and 75 points were located at the shoreline.

Habitat measurements were calculated by placing a one-meter diameter hoop at each location. Variables were measured to the nearest 5% of occupied area within the hoop. Ten microhabitat variables, representing all major microhabitats encountered along lake shorelines, were measured (Table 15).

Data Analysis

Statistical analyses were conducted using Excel XP and SYSTAT 10.2. *Rana clamitans* abundance was calculated by transect type. Abundance values are presented, however because detectability of anurans was not equal between the three habitat types it is not meaningful to statistically compare relative abundance values.

Mann Whitney U-tests were used to determine if there was a significant difference in the median values of all ten microhabitat variables between *Rana clamitans* locations and random locations. This non-parametric test was used because the data were not normally distributed.

Habitat variables were examined for intercorrelation using a correlation coefficient matrix. Variables were considered highly correlated when $r > 0.75$. Multiple logistic regression was then used to determine which habitat variables were most important in predicting *Rana clamitans* occurrence at a given location at the study lakes. Forward stepwise regression was conducted with *Rana clamitans* presence or absence as the dependent variable and microhabitat variables included as independent variables. Variables that were not significant at $\alpha = 0.05$ at each step were removed from the model.

Ten models were then developed using combinations of microhabitat variables. Akaike's Information Criteria (AIC) was used to select the model that best represented the data. AIC considers both model fit and the number of variables in model ranking. Models with more variables are penalized because of the larger chance of error associated with an increasing number of variables. The model with the best fit has the smallest AIC

Table 15. Microhabitat variables used in shoreline habitat inventory at *Rana clamitans* and random locations.

Variable	Abbreviation	Description
Emergent vegetation	EMER	Vegetation breaking the water's surface
Submergent vegetation	SUBM	Fully submerged vegetation
Floating vegetation	FLOA	Floating-leaf and free-floating vegetation
Mowed lawn	LAWN	Routinely mowed residential areas
Debris	DEBR	Submersed organic matter and leaf litter
Open water	OPEN	Areas > 0.5 m deep
Sand	SAND	Particles ≤ 3 mm in diameter
Rock	ROCK	Particles > 3 mm in diameter
Woody debris	WOOD	Downed woody material > 1 cm in diameter
Bare soil	SOIL	Exposed top soil

value. AIC weights (w_i) *were* also calculated to show strength of evidence for each model. A w_i value > 0.9 indicates a single superior model (Burnham and Anderson 1998).

RESULTS

Six hundred eighty-three frogs were observed during visual encounter surveys on the transects. *Rana clamitans*, a species commonly associated with lakes in Wisconsin, was by far the most abundant species observed on the transects, accounting for 91.8% (n=627) of all frogs encountered, followed by *Bufo americanus* at 7.9% (n=54), *Hyla versicolor* at 0.2% (n=1), and *Pseudacris crucifer* also at 0.2% (n=1) (Vogt 1981). Because the observations of the latter three species were very low in relation to *R. clamitans* observations, the remaining analyses focus on *R. clamitans*.

Two hundred twenty-one *Rana clamitans* (35.3%) were observed on marsh transects, 264 (42.1%) on forested transects, and 142 (22.7%) on developed transects (Figure 3). Within the developed transects, 120 of the 142 *R. clamitans* (84.5%) were observed on moderately developed transects, while only 22 (15.5%) were observed on highly developed transects.

Emergent vegetation was the most commonly recorded microhabitat variable at *Rana clamitans* locations, followed by submergent vegetation, and debris (Table 16). *Rana clamitans* was not often found in bare soil, woody debris, or sand. Emergent vegetation was also the most frequently encountered microhabitat variable at random sites, followed by debris, and open water (Table 16). Random locations contained small amounts of woody debris and bare soil. The Mann-Whitney U-test suggests that *Rana clamitans* selected for areas with emergent and submergent vegetation, debris, and woody debris, and avoided areas with open water and sand (Table 16). A correlation matrix was created all microhabitat variables but none were closely related. The stepwise multiple logistic regression model associated *Rana clamitans* occurrence with five microhabitat

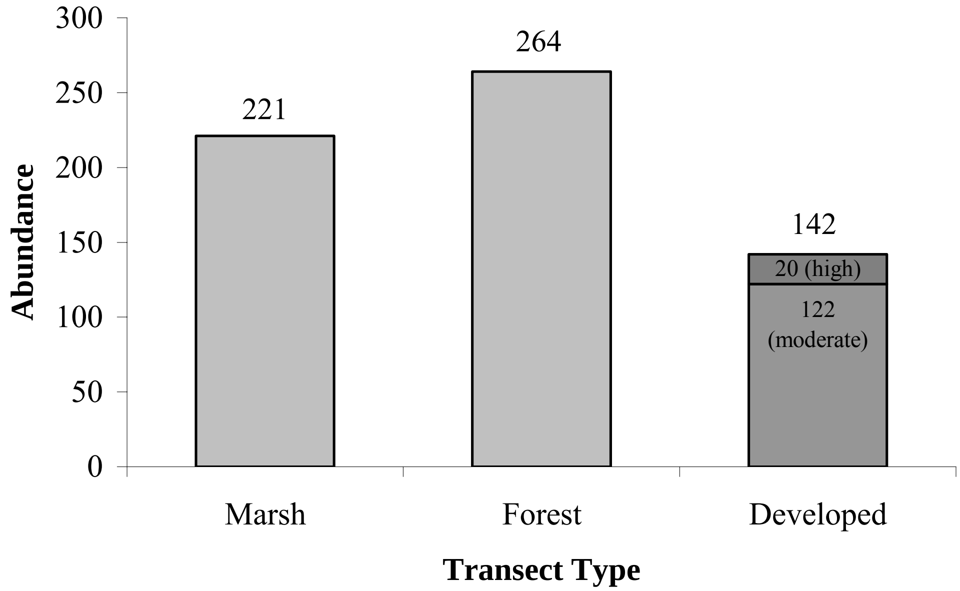

Figure 3. *Rana clamitans* distribution across three habitat types.

Table 16. Microhabitat variables at *Rana clamitans* and random locations (mean ± SD).

Variable	*Rana clamitans* Locations	Random Locations	P-value[a]
Emergent Vegetation	40.9 ± 25.6	30.7 ± 35.0	<0.001
Submergent Vegetation	23.8 ± 23.1	10.8 ± 20.5	<0.001
Floating Vegetation	6.6 ± 13.3	8.0 ± 19.2	0.170
Mowed Lawn	2.8 ± 11.5	5.1 ± 15.2	0.101
Debris	17.6 ± 23.1	16.6 ± 28.1	<0.001
Open Water	2.7 ± 8.4	14.0 ± 30.3	<0.001
Sand	0.8 ± 7.3	12.3 ± 29.6	<0.001
Rock	3.4 ± 12.8	1.5 ± 8.3	0.112
Woody Debris	0.8 ± 3.5	0.2 ± 1.1	0.002
Soil	0.6 ± 4.4	0.6 ± 4.7	0.403

[a] Mann-Whitney U-test

variables (Table 17). Emergent vegetation, submergent vegetation, and rock were positively correlated with *Rana clamitans* occurrences while open water and sand were negatively correlated with *Rana clamitans* occurrences. This model correctly predicted *Rana clamitans* occurrence 85.3% of the time, however only correctly classified random sites 49.3% of the time, with the overall model correctly predicting 70.3% of all cases.

Akaike's information criterion was lowest for the microhabitat model EMER/OPEN, representing areas with large amounts of emergent vegetation and small amounts of open water (Table 18). Microhabitat models with fewer variables generally had lower AIC scores than those with more variables.

Table 17. Results of logistic regresssion for microhabitat variables in relation to *Rana clamitans* occurence.

Variable	Parameter Estimate	S.E.	P-value
Emergent Vegetation	0.007	0.003	0.005
Submergent Vegetation	0.023	0.004	<0.001
Open Water	-0.023	0.005	<0.001
Sand	-0.053	0.011	<0.001
Rock	0.021	0.007	0.005
Constant	-0.269	0.167	0.108

Table 18. Comparison of microhabitat models as predictors of *Rana clamitans* occurence.

Model	AIC	ΔAIC	w_i
EMER/OPEN	95.816	0.000	0.999
EMER/SAND	109.152	13.336	0.001
SAND/LAWN/ROCK	113.905	18.089	0.000
EMER/SUBM	132.392	36.576	0.000
EMER/SUBM/LAWN	134.801	38.985	0.000
EMER/SUBM/FLOA	136.612	40.796	0.000
EMER/SUBM/OPEN	166.738	70.922	0.000
EMER/SUBM/LAWN/SAND	182.307	86.491	0.000
EMER/LAWN/OPEN/SAND	210.048	114.232	0.000
EMER/SUBM/LAWN/OPEN/SAND	242.188	146.372	0.000

DISCUSSION

Rana clamitans was found most often on forested transects. Forested shorelines did not typically contain large quantities of aquatic vegetation, but were undeveloped and offered access to unaltered adjacent uplands. Contiguous habitat such as this is necessary for juvenile *R. clamitans* that often forage significant distances from water during the summer (Vogt 1981). This connection to undeveloped uplands most likely benefits other anuran species as well. Many anurans congregate along shorelines during their breeding season but travel significant distances into the surrounding uplands throughout the remainder of the year to migrate to other sites, forage, or overwinter.

Marsh transects typically contained large amounts of aquatic vegetation, necessary microhabitat for *Rana clamitans* breeding and as a source of cover (Vogt 1981). The probability of detecting frogs in areas with large amounts of aquatic vegetation was lower than that of open areas, most likely resulting in a conservative estimate of *Rana clamitans* abundance on marsh transects. However, despite this difference in detectability, more anurans were found throughout the study on marsh transects than on developed transects. Even though statistical analyses of relative abundances between transect types was not possible, the data suggest the frogs may be utilizing undeveloped areas more than developed areas.

Rana clamitans was found least often on developed transects, however it is interesting to note the difference in abundances recorded on moderately and highly developed transects. A larger number of frogs were found on the moderately developed transects than on the highly developed transects, suggesting that some levels of development may be less detrimental to *R. clamitans*. The intact aquatic vegetation present on the moderately developed transects may provide the necessary microhabitat to *R. clamitans* during the breeding season.

It is also important to note that although *Rana clamitans* was not often found on developed transects, this may not be the result of a cause and effect relationship between anuran abundance and land use (Crisafulli 1997). Due to ease of development, residential developments may have been created more often in areas with little shoreline and littoral vegetation; areas less favorable to anurans. However, identifying the lakeshore microhabitats critical to local anuran populations still provides valuable information for future land use and management decisions.

Rana clamitans presence was positively associated with emergent vegetation, a critical component of their habitat. It is used for attachment of eggs and shelter for adults and provides habitat for prey (Vogt 1981, Crisafulli 1997). Large amounts of aquatic vegetation are also thought to benefit anuran species by slowing evaporation and moderating temperature fluctuations (Crisafulli 1997). *Rana clamitans* was negatively correlated with open water. Areas of open water, common along many developed lake shorelines, leave frogs vulnerable to predation, particularly from birds and fish (Vogt 1981).

Anurans may be impacted by lakeshore development at the macro-level as well as at the micro-level. This study suggests that lakeshore development may significantly impact local *Rana clamitans* populations by altering suitable lakeshore microhabitat. However, it also appears that some levels of lakeshore development may be less detrimental than others to *R. clamitans* populations, suggesting that it may be possible to protect local *R. clamitans* populations through proper management, while also allowing for some amount of lakeshore development.

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