Impact of lakeshore development on green frog abundance

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Abstract

Many amphibian species exhibit metapopulation spatial dynamics and temporally are faced with local population extinction and re-colonization. These natural population fluctuations can exhibit stochastic effects when human-caused alteration and fragmentation of habitats occur during sensitive life-cycle events. In this study, we explored the effects of shoreline development on adult green frogs *Rana clamitans melanota* on lakes ($n = 24$) of northern Wisconsin. We estimated green frog abundance using both auditory and direct observation surveys. The immediate shoreline habitat was mapped and placed into a Geographical Information System (GIS) for analysis. Adult green frog populations were significantly lower on lakes with varying degrees of shoreline house and cottage development than lakes with little or no development. A negative linear relationship existed between shoreline development densities and the number of adult green frogs. However, house and cottage densities alone did not directly explain this reduction. Analysis of variance (ANOVA) identified that the amount of suitable habitat, not development density, significantly affected green frog abundance. Therefore, greater development densities significantly decrease breeding habitat quality, resulting in lower adult frog abundance. These and other findings suggest that lakeshore development regulations are not protecting sensitive amphibian species.
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1. Introduction

Reduction in the regional distribution of a species may render populations more susceptible to demographic and environmental events leading to overall population decline (With and King, 1999). Many amphibian species are suspected to have metapopulation spatial dynamics (Gill, 1978; Hecnar and M'Closkey, 1996). Populations that follow such regimes are likely to be affected negatively by habitat alteration and fragmentation (Beier, 1993; Gibbs, 1998). Gibbs (1998) contends that amphibians are especially prone to local extinction resulting from human-caused transformation and fragmentation of their habitats. In altered environments, habitat fragmentation is considered the most critical factor in determining amphibian abundance (Minton, 1968; Hecnar and M'Closkey, 1996; Lehtinen et al., 1999). It is also the most difficult to measure. Other suggested causes for population declines include

introduction of predators and competitors, poor water quality, mining and logging, increased levels of ultra-violet radiation, introduction of exotic species, climate change, vehicle traffic, and harvesting by humans (Fahrig et al., 1995). In addition to population declines, species richness can be reduced in human-altered habitats (Hecnar and M'Closkey, 1998; Lehtinen et al., 1999).

Our objective was to examine the effect of lakeshore development on a widely distributed amphibian *Rana clamitans melanota*, the green frog. A high rate of housing construction on shorelines of lakes in northern Wisconsin during the 1990s has raised significant concern about the impacts on water quality and lakeshore dependent wildlife species [Wisconsin Department of Natural Resources (WDNR, 1996)]. However, few studies exist on the direct effects of anthropogenic disturbance on lakeshore habitats (Radomski and Goeman, 2001). Several life-cycle characteristics make the green frog an ideal indicator species of lakeshore habitats in northern Wisconsin. First, green frogs are a shoreline-dependent species that inhabits nearly all

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types of permanent water in this region (Vogt, 1981). Adult males are easily surveyed by visual and auditory detection, they establish and defend distinct territories, and tend to remain along the periphery of lakes and ponds throughout the summer breeding season or in areas of shallow water with emergent vegetation (Minton, 1972; Vogt, 1981; Hecnar and M'Closkey, 1997). Finally, studies have purported that amphibians inhabiting pool and lake systems express high site fidelity and low interdemic migration (Gill, 1978; Berven and Grudzien, 1990; Hecnar and M'Closkey, 1997).

2. Study area

We carried out our study within a 2200 km^2 area of northern Wisconsin (Fig. 1). This area contains one of the highest concentrations of glacial lakes in the world and has been extremely altered by the construction of seasonal dwellings along lakeshores. In the past 35 years, approximately 66% of the lakes > 4 ha in size, that were unaltered, have been developed (WDNR, 1996). Furthermore, the average number of dwellings on shorelines in private ownership has more than doubled over the same time period. Curtis (1959) classified the habitat of the area as a mixture of bog and northern wet forest, boreal forest, and northern dry or northern dry mesic forest. Meyer et al. (1997) provides a more

Fig. 1. Study area in northern Wisconsin, USA.

detailed analysis of the vegetation structure found at lakes we studied.

3. Methods

We surveyed 12 lakes with little or no shoreline development or alteration and 12 with > 50% of the shoreline developed. To reduce the inherent variability of lake parameters, each developed lake was paired with an undeveloped lake of similar surface area, lake type (i.e. drainage, seepage, spring fed), pH, and alkalinity.

All lakes were surveyed four times (three calling, one walking) during the field season (June 5–July 17), which spanned the peak breeding period for green frogs in our region. Calling surveys began approximately 30 min after sunset with each lake pair visited on the same night to reduce confounding effects (i.e. temperature, wind, and precipitation). We surveyed the entire shoreline of each lake from approximately 10–20 m offshore by canoe, stopping every 100 m to listen for calling males. Each male was recorded and its approximate location was marked onto a field map. If males were too numerous to be individually distinguished by call, an estimate of the total number for that portion of the shoreline was recorded and mapped. The calling intensity of all other amphibian species was recorded following WDNR frog and toad survey methods (Mossman and Hine, 1984). We also recorded one near-shore water and air temperature reading, approximate wind speed, and any precipitation events during the visit. Occurrence of moderate to heavy rain or wind velocity > 16 km/h greatly reduced our auditory detection abilities. If either condition occurred, we canceled surveys until the following evening. The first series of calling surveys were completed on all lakes before the second began, with each series requiring 14 days to finish. In addition to the calling surveys, one diurnal walking survey was conducted following a night survey on each lake. At least two researchers performed each walking survey, one walking the immediate terrestrial side of the shoreline, and one walking or canoeing the immediate aquatic side of the shoreline. Both adult male and female green frogs observed were recorded and marked onto field maps. Similar to Hecnar and M'Closkey (1997), we used the maximum number of adults recorded at a lake during a single visit to estimate relative population abundance for the breeding season. We defined species richness for each lake as the cumulative number of amphibian species detected during the field season.

3.1. Assessing green frog habitat

We assessed vegetation structure of the entire shoreline for the littoral (ca. 5 m into lake) and riparian (ca. 10 m inland) zones of each lake. The assessment began
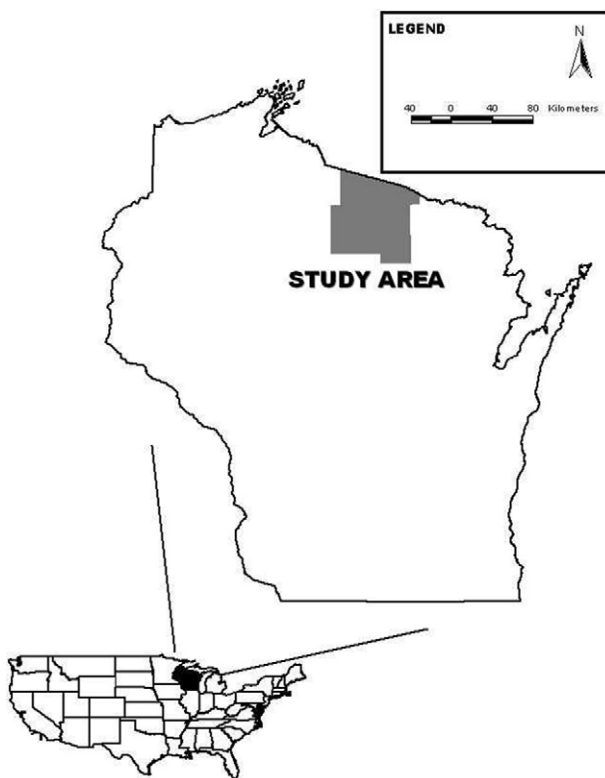
with a detailed description of the dominant and secondary species by abundance for the canopy and shrub level of the riparian zone, emergent and floating level of the littoral zone, and substrate type. Next, we paddled along the lakeshore until a change in vegetation structure, dominant species, or substrate occurred, at which point we created and mapped a new entry. Typically, we recorded 12–20 descriptions per lake. All lakes were surveyed by one individual to eliminate any bias caused by multiple observers. We measured house and cottage density using a Geographic Information Systems (GIS) database containing building locations mapped from aerial orthophotography.

Based on the littoral and riparian zones description data, we produced a map for each study lake with the entire shoreline classified to one of eight cover types (Table 1) using the following criteria. First, the riparian zone of each lake was placed into an undeveloped upland, developed upland, or wetland land-use type. Next, each land-use type was divided into specific cover types based on the composition of dominant and secondary species of the riparian zone and density of emergent and floating vegetation in the littoral zone. Wetland cover types included all riparian zones exhibiting a dominant sweet gale *Myrica gale* or leatherleaf *Chamaedaphne calyculata* shrub layer associated with a tamarack *Larix laricina* or black spruce *Picea mariana* canopy (cover 1), a dominant alder *Alnus* sp. shrub layer (cover 2), > 50% wetland indicator species (cover 3). Shoreline areas in the undeveloped upland were split into two cover types. The first (cover 4) included densely vegetated riparian zones (i.e. tall grasses or dense shrub component adjacent to the water) associated with a non-rocky littoral substrate. The second upland type (cover 5) was similar to cover 4, but lacked dense shoreline grasses or shrubs in the riparian area, or had a rocky substrate in the littoral area. Lakes with disturbed riparian areas were separated into cover types based on the degree of disturbance to the vegetation. Developed areas with low impact disturbance (cover 6) had unaltered riparian and littoral zones except for the immediate pier access. In several locations this cover type had a wetland component within the riparian zone. The second altered cover type (cover 7) had moderately developed riparian areas (e.g. mowed lawn), but retained an intact shrub or tree canopy. Our last cover type (cover 8) included all beach, rock stabilization, or sea wall areas where the riparian habitat was dominated by monotypic grasses mowed to the shoreline without a shrub or canopy layer. We transcribed locations of each cover type from field maps into a GIS database containing the riparian and littoral areas.

3.2. Analysis

SYSTAT version 5.0 (Wilkinson, 1991) was used for all statistical analyses. We transformed data where required to meet the assumptions of parametric tests (e.g. % of suitable habitat). Paired *t*-tests were used to test for a difference in lake area, pH, alkalinity, green frog abundance, suitable habitat, species richness, and fragmentation between developed and undeveloped lakes (Table 2). In addition, we analyzed adult abundance with a two-factor ANOVA (factors were shoreline house density and suitable habitat, plus interaction) to explore the relationship of green frog abundance to lakeshore metrics. We used linear regression to explore the relationship between house and cottage density and habitat suitability. However, the intent of this analysis was to identify a density threshold, that when surpassed, would cause green frog extinction.

We evaluated the quality of lakeshore habitat by calculating an index of selection (*S*) as the % total frogs/% total perimeter of each cover type. This index provides a measure of positive or negative preference for a cover type by green frogs. A value of 1.0 indicates neither a selection preference for or against a given cover type.

Because green frogs appear to be generalists relative to habitat utilization, we selected patch isolation (Forman and Godron, 1986) as an index of habitat fragmentation. Isolation of suitable habitats is calculated by:

$$D = \Sigma\left(\upsilon_x^2 + \upsilon_y^2\right),$$

where the geometric mean location and variance for all suitable habitats are calculated for each lake, and υ_x and υ_y are the variances on the *x* and *y* coordinates. With this measure, the value of *D* increases as habitats become more fragmented. We used the natural log (ln) of *D* for analysis because the data lacked a normal distribution.

4. Results

Adult green frogs occurred on all study lakes (range: 0.1 to 6.6 per 100m of lake perimeter), with the greatest count recorded during the second or third calling survey. Paired *t*-test analysis (Table 2) showed that adult abundance was significantly greater on undeveloped lakes. Green frog densities were greatest within cover type one at developed lakes and cover type two at undeveloped lakes (Fig. 2). Densities were higher at developed lakes within cover types two, seven, and eight than those measured at undeveloped lakes. We assumed that shoreline cover types with a selection value (*S*) > 0.5 was suitable habitat for adult green frogs (Table 1). This definition identifies cover types one, two, three, four, and six as suitable habitat. The amount of shoreline classified as suitable green frog habitat for undeveloped lakes was significantly greater than amounts for developed lakes

Table 1
Selection index (S) and qualitative descriptions of each cover type found along lakeshores of 24 study lakes in northern Wisconsin, USA. Habitat classification was based on adult frog preference for or slightly against ($S > 0.5$) available cover types

Cover type	Characteristics					
	Riparian zone	Littoral zone	Littoral zone Substrate	Frogs observed (%)	Total shoreline distance (%)	Selection index (S)
1	Wetlands throughout; shrub layer comprised of sweet gale or leatherleaf; forest layer comprised of tamarack and black spruce	Variable emergent and floating vegetation	Muck, detritus, sand, gravel, and stone	0.46	0.20	2.30
2	Wetlands throughout; shrub layer comprised of alder species	Variable emergent and floating vegetation	Muck, detritus, sand, gravel, and stone	0.11	0.07	1.57
3	Narrow Wetland belt at shore line; adjacent upland component not developed	Variable emergent and floating vegetation	Muck, detritus, sand, and gravel	0.08	0.10	0.80
4	Undeveloped upland with dense grass shrub layer adjacent to shore	Variable emergent and floating vegetation	Muck, detritus, sand, and Gravel	0.14	0.12	1.17
5	Undeveloped upland with dense grass shrub layer adjacent to shore	Little emergent or floating vegetation	Gravel and stone	0.10	0.21	0.48
6	Uplands with low house density; vegetation structure unaltered except for pier access; narrow wetland belt possible near shoreline	Variable emergent and floating vegetation	Muck, detritus, sand, and gravel	0.06	0.10	0.60
7	Uplands with moderate house density; vegetation structure altered significantly; overstory remaining intact	Little emergent or floating vegetation	Muck, detritus, sand, gravel, and stone	0.03	0.11	0.27
8	Uplands with high house density; vegetation structure removed (i.e. beach rip rap, sea wall, and lawn) to water edge	Very little emergent or floating vegetation remains	Muck, detritus, sand, gravel, and stone	0.02	0.09	0.22

Table 2
A comparison of lake attributes (physical characteristics), house and cottage density, green frog abundance, habitat fragmentation, and amphibian species richness among 12 developed and 12 undeveloped lakes in northern Wisconsin

|	Developed lakes ($n=12$)	Undeveloped lakes ($n=12$)	Paired t-test ($t=$)	P-value
Lake area (ha)	46.7 (range = 11.2–160.0)	46.5 (range = 6.4–144.8)	0.09	NS
PH	6.8 (range = 5.3–7.8)	6.8 (range = 5.7–7.5)	0.21	NS
Alkalinity (ppm)	11.5 (range = 1.0–48.0)	13.1 (range = 1.0–57.0)	0.08	NS
Total shoreline perimeter sampled (km)	43.3	44.9	0.51	NS
House or cottage density (per 100 m of shoreline)	1.3 (0.48)	0.179(0.24)	8.56	<0.001
Green frog population (per 100 m of shoreline)	1.02 (1.66)	2.3 (2.06)	2.77	0.02
Suitable habitat (%)	0.66 (0.23)	0.82 (0.20)	2.83	<0.02
Green frog population (per 100 m of habitat)	1.49 (1.03)	2.60 (1.92)	2.24	<0.05
Habitat fragmentation D (lnD)	23.42 (1.77)	22.24 (2.66)	2.47	<0.05
Amphibian species richness	5.08 (1.44)	5.08 (1.16)	0.01	NS

NS = not significant.
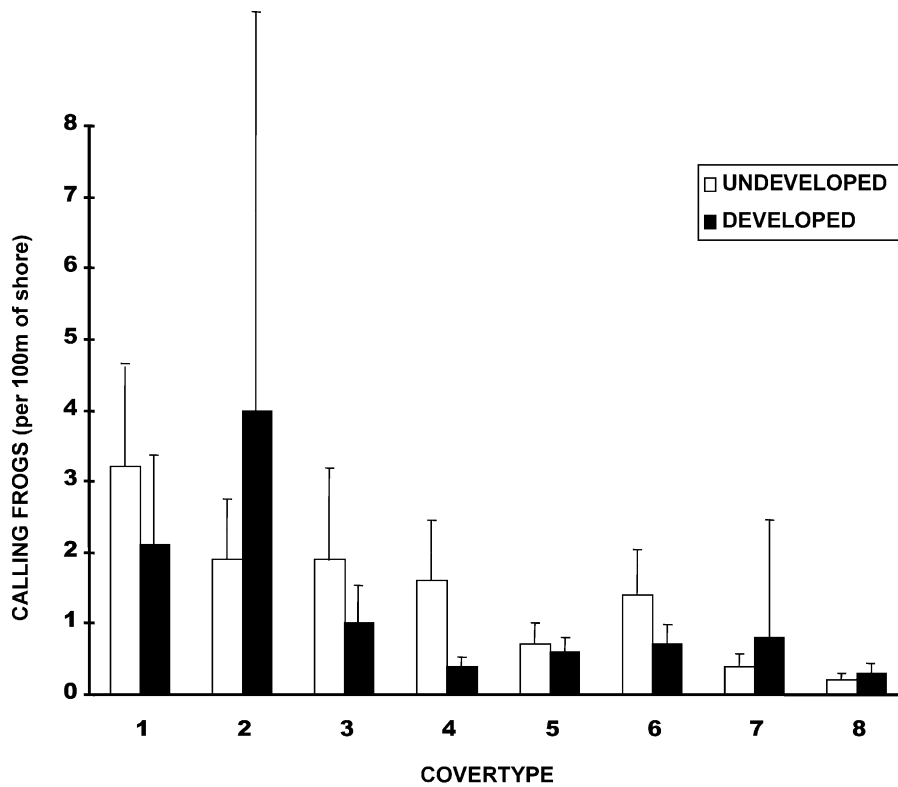
Fig. 2. Mean green frog density for each shoreline cover type found at lakes surveyed in northern Wisconsin, USA. Capped vertical lines represent standard errors of the mean.

(Table 2). Next, we controlled for the difference in available habitat between lake pairs by determining the number of adult green frogs per 100 m of shoreline classified as suitable habitat. Again, the number of adult green frogs per 100 m of habitat on undeveloped lakes was significantly greater than observed on developed lakes.

Habitat fragmentation calculated for all lakes ranged from $lnD = 18.1$ to 26.3. Shorelines of developed lakes had significantly greater fragmentation than those of the undeveloped lakes (Table 2).

We examined the data from each lake to identify if any shoreline metric was associated with green frog abundance. The two-factor ANOVA showed that green frog abundance was significantly affected by the amount of suitable habitat, but not development density or their interaction. Since the interaction was not significant, it was removed and the analysis was repeated. This ANOVA identified that green frog abundance was significantly ($F_{2,21} = 6.677$, $P < 0.05$) affected by the amount of suitable habitat available, but not develop-

ment density ($P=0.129$). However, house density along the lakeshore did significantly reduce the amount of suitable habitat ($F_{1,22}=4.91$, $P<0.05$). To justify our definition of suitable habitat [i.e. cover type selection value (S) >0.5], we repeated the original ANOVA using both a more and less restrictive definition, $S>0.75$ and $S>0.25$ respectively. The results of the more restrictive definition were similar to the original ANOVA. However, green frog abundance was not significantly affected by available habitat or development density when we used the less restrictive definition.

To predict habitat loss and local green frog extinction due to increasing house and cottage densities, we used the least squares method of regression analysis to find the "best fit" models for the data. A significant negative relationship existed between the number of houses per 100 m of shoreline and the % of shoreline classified as suitable green frog habitat ($F=4.92$, $r^2=0.18$, $P<0.05$). This comparison resulted in a "best fit" model of $Y=-0.14X+0.845$ and an estimated X intercept (no remaining suitable habitat) at 6.0 house or cottages per 100m of perimeter (model a; Fig. 3). Again, after controlling for available habitat, the number of green frogs per 100 m of habitat was significantly affected by shoreline house density ($F=5.85$, $r^2=0.22$, $P<0.05$). For this comparison, the "best fit" model of

$Y=-1.08X+2.838$ estimates a X intercept (green frog extinction) at 2.6 house or cottages per 100 m of perimeter (model b; Fig. 3).

We found no difference in amphibian species richness (range: 3 to 7) between developed and undeveloped lakes. The list of amphibians detected (Table 3) is for the entire field season, additional species may have been present at other times of the year.

5. Discussion

Few studies have compared amphibian populations by examining the subtle differences in habitat availability and connectivity. Our results suggest that human-caused riparian and littoral zone alterations on lakes in northern Wisconsin are negatively affecting green frog populations. Other studies in this same region have reported reductions in fish production capacity in lakes altered by development (Jennings et al., 1999; Schindler et al., 2000). In these studies, causation appears to be the direct alteration of riparian and littoral areas associated with shoreline development, not house and cottage densities. This same relationship was responsible for reduced green frog abundance on our study lakes. One negative effect of shoreline development to a lacustrine ecosystem is the removal of coarse woody debris (CWD). Meyer et al. (1997) and others within the region (Christensen et al., 1996; Radomski and Goeman, 2001) have reported significant reductions in CWD and vegetative cover in the littoral areas adjacent to development. Most of the reduction is attributable to common landscaping practices used on the lakeshores. These practices include retaining wall construction, clearing of CWD, replacement of native grasses and shrubs with exotic species, and removal of emergent and floating vegetation. The highest densities of adult green frogs were associated with riparian habi-
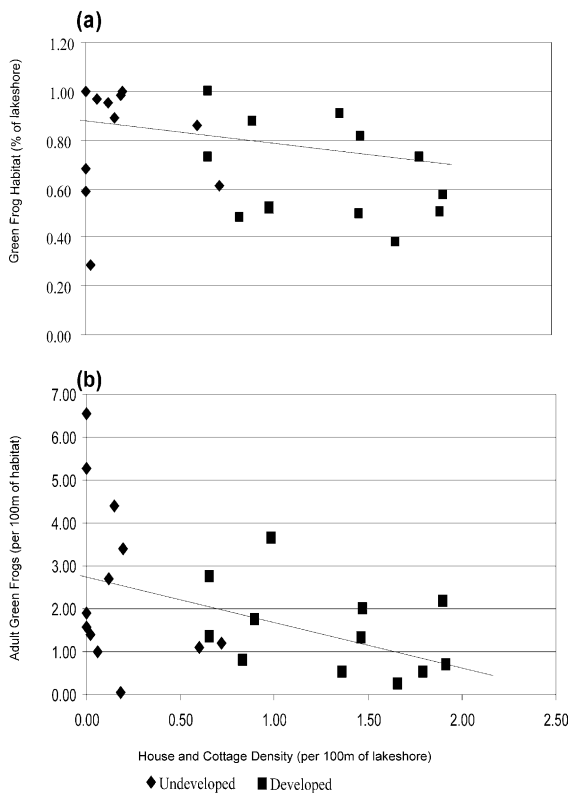

Fig. 3. "Best fit" models from linear regression for decreasing (a) green frog habitat ($y=-0.14x+0.845$; $P<0.05$) and (b) adult abundance ($y=-1.08x+2.838$; $P<0.05$) at developed and undeveloped lakes as shoreline house and cottage density increased.

Table 3
Amphibian species detected during field season at lakes in northern Wisconsin, USA

Species	Common name	Developed lakes (n)	Undeveloped lakes (n)
Rana clamitans	Green frog	12	12
Rana catesbeiana	Bullfrog	4	3
Bufo americanus	Eastern american toad	9	8
Rana pipiens	Northern leopard frog	1	3
Hyla crucifer	Northern spring peeper	12	12
Rana sylvatica	Wood frog	6	3
Rana septentrionalis	Mink frog	2	5
Hyla versicolor	Eastern gray tree frog	11	11

tats dominated by the wetland plant species sweet gale and leatherleaf. Although these woody shrubs are normally found in wetland complexes, some shorelines have a narrow zone (only 1–2 m wide) adjacent to the lake. It is these critical areas that are often altered or destroyed when waterfront property is developed.

Findings from our study and others suggest that current regulations and enforcement are not protecting the shoreline habitat that is crucial to sensitive amphibian species. Regulations in Wisconsin limit the maximum development density surrounding lakes to 3.3 homes or cottages per 100 m of shoreline. Using the "best fitting" models from our regression analysis (Fig. 3), we predict that if a lake was developed to its regulatory potential, less than 50% of suitable shoreline habitat would remain and the local green frog population would disappear. Thus, the risk of extinction for green frog populations inhabiting lakes with house and cottage densities approaching the regulatory limit is great. Evidence supporting this prediction was observed at Big Saint Germain Lake, Vilas County, Wisconsin, which had 2.3 homes or cottages per 100 m of perimeter, and no green frogs recorded during calling surveys (Woodford, unpublished data). We omitted this data from our analysis because it failed to meet the criteria of the experimental design. Regardless, the probability that breeding green frogs will return to this lake appears extremely low.

Relatively new advances in GIS have aided researchers in assessing populations from a regional extent. Although few investigations using a geographical perspective to determine the abundance of amphibians exist, they are of extreme importance as global populations continue to decline (Hecnar and M'Closkey, 1996). The use of population density alone to distinguish between favorable and unfavorable habitat has seen significant debate. Van Horne (1982) reported that this type of inference was not appropriate for some species, contrary to findings reported by Dettmers and Bart (1999). We feel that the use of empirical data to identify suitable habitat was appropriate for this study.

Widespread degradation of both riparian and littoral areas of lakes in the Great Lakes region is a significant problem. In Wisconsin, regulations set maximum shoreline building densities, minimum setback distances and lot widths, and limit the amount of lakeshore vegetation that can be removed or altered. Recent efforts in local areas have succeeded in reducing the maximum house and cottage density allowable on lakes with sensitive habitats.

Unfortunately, when viewed from a regional perspective, this patchwork coverage of regulations needs significant time and effort to fully understand. Required inspections and enforcement of these regulations take place when a house or cottage is constructed. However, very little monitoring of additional shoreline vegetation removal or alteration in subsequent years occurs. In most cases, it was this cumulative removal or alteration overtime that is responsible for the significant habitat fragmentation and degradation observed at lakes we studied. There are at least two methods to overcome these limitations. First, increase the efficiency of shoreline monitoring programs through the application of GIS and remotely sensed data. This approach could provide immediate benefits. A second method would be to conduct workshops for shoreline residents that illustrate the negative impact littoral and riparian habitat alterations have on the local fish and wildlife species. These are not novel ideas. Many examples of lakeshore education and automated monitoring programs exist. Still, rather than incorporating these approaches regionally, much greater effort and support is afforded the process of creating new or updating existing regulations.

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