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Quantifying the ecological benefits of lakeshore restoration in northern Wisconsin

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QUANTIFYING THE ECOLOGICAL BENEFITS OF LAKESHORE RESTORATION
IN NORTHERN WISCONSIN

By

Daniel E. Haskell

A Thesis

Submitted in partial fulfillment of the requirements

For the degree of

MASTER OF SCIENCE IN APPLIED ECOLOGY

MICHIGAN TECHNOLOGICAL UNIVERSITY

2009

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This thesis, “Quantifying the ecological benefits of lakeshore restoration in northern Wisconsin,” is hereby approved in partial fulfillment of the requirements for the Degree of MASTER OF SCIENCE IN APPLIED ECOLOGY.

DEPARTMENT School of Forest Resources and Environmental Science

Signatures:

Thesis Advisor _____
David J. Flaspohler

Department Chair _____
Margaret R. Gale

Date _____

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ABSTRACT

Housing development has increased dramatically in the Midwest with a high concentration around lakes. This development plays an important role in the economy of Northwoods communities. However, poorly planned development has the potential to alter a lake's ecological processes and integrity. Studies have documented the impacts of housing developments and reported dramatic, negative changes to the flora and fauna in Vilas County, Wisconsin. One component of my research included examining the previously unstudied effects of residential development on the abundance and diversity of medium to large-bodied mammals using lakeshore ecosystems. The results suggest that a higher diversity of mammals were detected on low-development lakes. Coyotes were the most numerous species detected with the majority encountered on low-development lakes. White-tailed deer and red fox were more abundant on high-development lakes as compared to low-development lakes. I concluded that high-development lakes are having a negative affect on the mammal community in this area.

Recently, lakeshore restoration has occurred on privately owned property in Vilas County and elsewhere in the Northwoods, but little is known about the benefit, if any, from these restoration efforts. A partnership between government agencies and academia has launched a long-term research project investigating the ecological benefits of lakeshore restoration. I investigated the impacts of using down woody material (DWM) to increase the success of restoration projects. Specifically, I tested the hypothesis that down woody material would reduce the variation in soil temperature, retain soil moisture, and improve plant survival and growth rates. I randomly assigned three DWM coverage treatments (0%, 25%, and 50%) on 3 m \times 3 m experimental plots ($n = 10$ per treatment).

The mean maximum soil temperature, temperature variation, and change in soil moisture content were significantly lower in the 25% and 50% DWM plots. I found no difference in survival, but snowberry (*Symphoricarpos albus*) and Barren strawberry (*Waldstenia fragaroides*) growth was significant greater in the 25% and 50% DWM plots. DWM addition can be considered a useful technique to physically manipulate soil properties and improve plant growth.

Finally, I provided baseline data on vegetation structure, bird and small mammal community diversity and abundance for three lakes targeted for restoration efforts and their paired reference lakes. This study is one of the first of it kind in the area and continuing to document the degree of change in subsequent years will provide insight into the way the local ecosystem functions and how ecological communities are structured.

CHAPTER 1

VARIATION IN SOIL TEMPERATURE, MOISTURE AND PLANT GROWTH WITH THE ADDITION OF DOWN WOODY MATERIAL ON LAKESHORE RESTORATION SITES

ABSTRACT

Down woody material (DWM) is an important ecosystem component that performs many critical functions. Soil temperature and moisture can affect plant growth and survival. Residential development along lakeshores has increased dramatically in the past few decades in northern Wisconsin. Human development can have a dramatic effect on the presence of woody material in terrestrial and aquatic ecosystems. Shoreline restoration projects have occurred in the past few years in the region, but with little or no evaluation of success. In 2007 a collaborative lakeshore restoration research project was initiated on two lakes in Vilas County, Wisconsin. I investigated the benefits of the addition of DWM as part of these restoration projects. I randomly assigned three coverage treatments (0%, 25%, and 50%) of DWM on 3 m × 3 m experimental plots ($n = 10$ per treatment). I monitored soil temperature and volumetric soil water content at a depth of 10 cm. Three soil temperature variables daily mean, daily maximum, difference in daily high and low, and percent change in moisture content following a watering event were compared among treatments. All plots were planted with two native shrub species and five native understory herbaceous species; change in plant canopy volume was compared among treatments. The mean maximum soil temperature, mean difference in daily high and low soil temperature, and percent change in soil moisture content were significantly lower in the 25% and 50% DWM plots. Plant canopy volume growth for snowberry (*Symphoricarpos albus*) and Barren strawberry (*Waldstenia fragaroides*) was significant

greater in the 25% and 50% DWM plots. I conclude the addition of DWM had a significant positive effect on soil temperatures, soil moisture, and plant volume growth for two species of native plants used for restoration projects.

Introduction

Down woody material (DWM) is vital to the function and structure of healthy terrestrial and aquatic ecosystems. DWM can come in many forms including standing and fallen dead trees, large branches, and is often abundant in natural forests, streams (Harmon *et al.* 1986), and lake ecosystems (Christensen *et al.* 1996, Marburg *et al.* 2006). Input mechanisms of DWM into a system include wind throw, insects, diseases, and beaver (*Castor canadensis*) activity which can display an aggregated spatial pattern (Harmon *et al.* 1986) adding complexity to the forest floor and below ground heterogeneity (McComb 2008). Many people consider DWM to be a waste of wood fiber and a fire hazard which can lead to multiple and sometimes conflicting values. However, DWM performs many crucial ecological functions such as habitat, energy flow and nutrient cycling, influencing soil and sediment transport and storage (Harmon *et al.* 1986), and providing nursery sites for germination of plants (Gray and Spies 1997, Rasmussen and Whigham 1998). In addition, DWM provides organic matter to the soil, enhances infiltration capacity of water runoff, creates microclimates (Harmon *et al.* 1986, Reid *et al.* 1999), moderates flow of organic matter from terrestrial ecosystems into aquatic systems (Bormann and Likens 1979, France *et al.* 1998, Hagan and Grove 1999), and is a critical factor influencing interactions between terrestrial and aquatic ecosystems (Harmon *et al.* 1986).

DWM provides critical habitat for a variety of wildlife species. Small mammals and amphibians use DWM for cover, nesting, foraging, and connectivity across the forest floor (Jaeger 1990, Tallmon and Mills 1994, Stevens 1997, Ucitel *et al.* 2003, McComb 2008). Depending on the size and volume of DWM, it provides crucial habitat for small to mid-size carnivores (Gilbert *et al.* 1997), courtship sites for ruffed grouse (*Bonasa umbellus*), and perching, feeding, mating and nesting sites for a variety of bird species (Maser *et al.* 1979). Many invertebrates use and are dependent on DWM in one form or another as food, shelter, and as a site for breeding (Harmon *et al.* 1986). Furthermore, many decomposer bacteria and fungi utilize DWM as an energy and nutrient source as well as habitat (Harmon *et al.* 1986).

DWM also influences the abiotic environment such as acting as moisture reservoir and ground surface temperatures (Harmon *et al.* 1986, Gray and Spies 1997). Soil temperature and moisture can affect plant and root growth (Russell 1973), nutrient uptake (Dong *et al.* 2001), and plant survival and productivity which may contribute the success or failure of flora restoration projects (Castro *et al.* 2002). The effect of soil moisture content on soil temperature is complex. Moist soils conduct heat vertically more efficiently than dry soils. During a sunny day the surface of dry soils warm quicker and at night cool quicker (Russell 1973). Therefore, dryer soils should have greater daily differences in temperature. The amount of radiation received affects soil temperature (Russell 1973) and varies depending on the aspect, slope and percent canopy cover. Thus, a south facing slope would potentially have greater differences in daily soil temperatures than a north facing slope due to greater sun exposure. Dry sandy soils will

commonly heat up quicker in the spring and throughout the growing season than sandy loam or clay soils (Russell 1973).

In the last few decades humans have had a propensity for development in and around natural areas. Lakes, streams, and forested areas attract residential development because they provide a clean environment, opportunities for recreation, and scenery (Schnaiberg *et al* 2002). Northern Wisconsin contains the third largest density of freshwater glacial lakes in the world, with more than 12,400 lakes scattered across the northern third of the state (WDNR 1996). Vacationers have been attracted to this region for decades, and more recently, increasing numbers of people are replacing small seasonal cottages with large year-round houses along lakeshores in this region. In parts of the northern Great Lakes region, this growth has been concentrated around inland lakes (Radeloff *et al.* 2001, Gonzales-Abraham *et al.* 2007). Since 1965, two thirds of previously undeveloped inland lakes in northern Wisconsin (i.e. lakes with no residential housing) have since become developed with homes and cottages near the shoreline (WDNR 1996).

Many studies have reported a significant reduction of trees, shrub layer, and DWM on high-development compared to low-development lakes (Christensen *et al.* 1996, Elias and Meyer 2003, Marburg *et al.* 2006). Some residents equate lakeshore beauty with park like conditions of manicured lawns and scattered trees (Macbeth 1992). Human land-use practices have significantly altered DWM in ecosystems for decades which may alter productivity of several organisms, reduce biodiversity, and disrupt ecosystem function (Harmon *et al.* 1986). Removal of DWM and vegetation structure

along shorelines on high-development lakes is a common practice especially following storm events.

The Great Lakes region is one of the most active weather zones in the northern hemisphere (Frelich 2002). In 1999, the residents of Found Lake, Vilas County, Wisconsin experienced a thunderstorm with high winds. The storm's path followed the north shoreline toppling hundreds of trees in its wake, including trees estimated at 100 years old, thus opening the overstory canopy along the shoreline. A similar wind storm occurred in 2005 on Statehouse Lake in Vilas County, home to the North Lakeland Discovery Center (NLDC). The DWM was removed by residents leaving the understory vegetation exposed to environmental elements (sun, extreme temperatures, wind, and precipitation) and human activity. In the following years, a die off of understory vegetation occurred with little regeneration and soil erosion increased at and near the shoreline. However, where DWM was retained, some regeneration of vegetation had occurred (personal obs.).

In the summer (July-August) of 2007, Wisconsin Department of Natural Resources (WDNR), Michigan Technological University, Vilas County Land and Water Conservation Department (VCLWD), and Wisconsin Department of Agriculture, Trade and Consumer Protection (WDATCP) launched a long-term (≥ 10 years) research project investigating the potential positive impacts of shoreline restoration on riparian and littoral communities in Vilas County, Wisconsin. This restoration project requires property owners to plant native trees, shrubs and ground cover plants within a 35-foot buffer zone along the shoreline and to correct erosion problems. Several landowners on Found Lake and NLDC expressed interest in this project and enrolled in the VCLWD shoreline

restoration cost share program. This program is funded annually by the WDATCP. Lakeshore restoration projects in Vilas County have been ongoing since 2000 costing \$30,000 to \$60,000 annually, depending on the budget cycle (C. Scholl VCLWD conservationist, personal comm.). However, little or no evaluation of these past projects has occurred to identify the factors that affect the success of restoration. Furthermore, soils in Vilas County range from loam to sandy soils (NRCS 1986) and in the past few years the region has been in a historical drought with record breaking ambient temperatures (http://mrcc.sws.uiuc.edu/climate_midwest). The soil types and current weather regime could profoundly affect the success of these restoration projects.

Shoreline restoration is a relatively new practice in northern Wisconsin. Prior evaluation of lakeshore restoration has focused on vegetation planting techniques (Weiher *et al.* 2003) but not on restoration of other attributes including ecological function and long-term plant survival and growth. In order to better understand the dynamics and benefits of lakeshore restoration, I added DWM to seven restoration projects with three coverage treatments of DWM and monitored the soil temperature and moisture content over the course of the growing season. I also recorded the first year survival and plant canopy volume growth of several native plant species within these treatments.

The objectives of my research were to (1) determine if DWM addition will reduce the difference between low and high daily soil temperature and moisture on restoration sites, (2) provide first year data on plant survival and growth rates, (3) and provide a better understanding of how the presence of DWM may affect the success of lakeshore restoration. I hypothesized that the addition of DWM to restoration sites, soil

temperatures and moisture would vary less during the growing season. Furthermore, plant survival and growth will be greatest with the presence of DWM.

Methods

Study area and site selection. - This project was conducted on two lakes in a forested landscape on deep sands with pitted glacial outwash in Vilas County of northern Wisconsin (Stearns and Likens 2002). The first study site is located along 1500 m of the north-northeast shoreline of Found Lake (T40N, R8E, Section 14). Found Lake is a drainage lake with a surface area of 131 ha, a maximum depth of 7 m, and is accessible to the public (WDNR 2005). Found Lake was home to several fishing resorts in the past, but in recent decades, these resorts have been sold to developers and parceled for resale to individuals for seasonal or permanent homes. In addition, recent construction of larger dwellings has occurred on Found Lake with little or no regard for a vegetated buffer zone near the shoreline, though mature trees were often maintained or preserved. The second study site is located along 40 m of the northeast shoreline of Statehouse Lake (T42N, R5E, Section 5). Statehouse Lake is a seepage lake with a surface area of 9.3 ha, maximum depth of 6 m, and is surrounded by public lands (WDNR 2005). Statehouse Lake is home to NLDC, formerly a Youth Conservation Camp, which has a 26.7 ha campus community-based environmental learning center that promotes stewardship of the region's natural and cultural resources. The combination of human impact and the wind storms in the past have left these shorelines in a degraded state. Therefore, on both study sites regeneration of vegetation is low and soil erosion is occurring thus making both shorelines prime candidates for lakeshore restoration. Both lakes are within the Northern Highland Lake District. The mean daily ambient air temperature is 3.4° C,

ranging from -2° C in January to 10° C in July and the mean precipitation is 80.25 cm (http://mrcc.sws.uiuc.edu/climate_midwest).

Experimental Design - Restoration activities occurred on six privately owned properties on the north-northeast shore of Found Lake and State House Lake during the summer of 2007 (July-August). Thirty 3 m × 3 m experimental plots were placed within these restoration areas, 24 on Found Lake and six on the State House Lake site. Ten sets of three experimental plots (0%, 25%, and 50%) were established. Two properties on Found Lake and State House Lake site were large enough to place two sets of experimental plots. Each set of experimental plots were placed in line and parallel with the shoreline and 3 m inland from the original high water mark. This placed the experimental plots in the middle of the 35-foot state mandated buffer zone (see Wisconsin's Shoreland Management Program, chapter NR 115), a consistent distance from the shoreline, and far enough from the lakeshore edge to minimized the risk of high wave action. The three plots were place 0.5 to 1.0 m apart. A random number table was used to assign three coverage densities of DWM to each experimental plot (Figure 1.1).

- 1) 50 percent of area covered by DWM ($n = 10$).
- 2) 25 percent of area covered by DWM ($n = 10$).
- 3) 0 percent of area covered by DWM ($n = 10$), control treatment.

Woody material is defined as branches ≥ 2.5 cm and ≤ 15 cm in diameter and ≤ 3 m in length. All DWM was northern red oak (*Quercus rubra*) acquired from a recent (within one year) logging site nearby. All experimental plots were protected from herbivory with 2.4 m high nylon fences erected around the perimeter of each restoration area.

In each experimental plot I planted three shrubs and 25 forbs and grasses. One snowberry (*Symphoricarpos albus*) ($n = 30$) and two sweet fern (*Comptonia peregrine*) ($n = 60$) comprised the shrubs species for each experimental plot. For each shrub one liter of organic compost was incorporated into the soil before shrubs were planted. I planted five of each of the following forbs and grasses, little-blue stem (*Schizachyrium scoparium*) ($n = 150$), Barren strawberry (*Waldstenia fragaroides*) ($n = 150$), pearly everlasting (*Anaphalis margaritacea*) ($n = 150$), bergamot (*Monarda fistulosa*) ($n = 150$), and large-leaved aster (*Aster marcophyllus*) ($n = 150$). A total of 90 shrubs and 750 ground cover individuals were planted and uniquely identified with a numbered metal tag. The location of each individual plant within the plot was mapped for future relocation. Plant densities were based on recommendation from the Wisconsin Biology Technical Note 1: Shoreland Habitat (NRCS 2002). Snowberry shrubs were delivered in 3-gallon nursery containers, sweet fern in 1-gallon nursery containers, and all ground cover species were in 2 - inch nursery containers. A local nursery (Hanson's Garden Village, Rhinelander, Wisconsin) supplied all plant material.

Abiotic variables. – All abiotic data were collected prior to DWM installation. Soil samples were collected from each experimental plot ($n = 30$) and analyzed for organic matter and nutrients at the Soil & Plant analysis Lab, UW-Madison. Slope, aspect, and canopy gap fraction ($n = 29$; 1 plot missing in 50% DWM treatment) were measured on each plot. I determined the slope and aspect using a Silva Ranger compass with built-in clinometer. In order to quantify the gap fraction, I took a digital hemispherical photograph (Nikon Cool Pix 5000 and FC-E8 fisheye converter) at 50 cm above the ground and centered in each plot. Digital hemispherical photographs were analyzed with

the software WinSCANOPY (WinScanopy 2005). Gap fraction is defined as a fraction of pixels classified as open sky in a region in the image [*Gap fraction* = number of pixels classified as sky in a region/total number of pixels in a region (WinScanopy 2005)]. In each experimental plot two microenvironment characteristics (soil temperature and moisture) were measured.

Soil Temperature. – From each plot corner a temperature data logger (Standard Logger, KoolTrak, Inc) was placed systematically 1 m inward at a 45 degree angle and at a depth of 10 centimeters in each plot ($n = 120$). I deployed all loggers 4-6 weeks prior to restoration which provided data before the applied DWM. All loggers were programmed to record soil temperatures every hour during the growing season (May 6th to September 26th). I computed the means and standard errors for three soil temperature variables (daily maximum, daily mean, and difference between low and high daily temperature).

Soil Moisture.—Four soil moisture readings (volumetric soil water content) were measured on each plot within 5-10 cm of temperature sensor locations. Data was recorded manually using a hand held soil moisture sensor (HydroSense CS620, CD620, 12 cm probes, Campbell Scientific, Inc., Logan, Utah). All data was recorded 12 hours after a weekly watering event (irrigation or precipitation) and then again 24 hours after the first reading. I collected soil moisture data for two months during the 2008 growing season (July $n = 25$ /treatment, August $n = 34$ /treatment). The monthly (July-August) means of percent change between moisture readings was calculated. Rainfall and irrigated water quantities were measured with plastic rain gauges. If precipitation was not adequate, 10-30 mm within a week, each plot was irrigated using a gas or electric water pump with oscillating sprinkler system.

Plant survival and growth. –Plant measurements included height and canopy area. Height was measured from the soil surface to the highest point of the living tissue in its natural state. Plant canopy area was determined by measuring the width of the canopy at its widest point, then a second width perpendicular to the first. The mean of the two widths was used to calculate the canopy radius and circular canopy area. The height and canopy area were used to compute the cylindrical volume (m^3) for each plant (Bussler *et al.* 1995). The percent change in cylindrical volume (m^3) for each plant was calculated based on measurements at two time periods and indicates plant growth. Shrub species were measured at the time of planting in 2007 and again in mid-August 2008. Forbs and grass species were measured in late May and again in mid-August 2008. Forbs and grass species were propagated under artificial light at local nursery which affected their initial height at the time of planting.

Plant survival (alive or dead) was recorded one year after planting. All shrub and ground cover individuals were included in the survival comparisons. All individual shrubs were used for growth volume analyses. Some ground cover individuals were missed during the initial measurements in May 2008 but were located in August; I excluded the missing individuals in May and all summer mortalities from ground cover volume growth analyses.

Data Analyses. – The means for soil temperature variables were calculated with the software KoolTrak. Monthly soil temperature and moisture data were subjected to analysis of variance (ANOVA) using a one-way procedure within SigmaStat 3.5 software (Systat Software Inc. 2006) to test for differences in soil temperature and moisture across DWM treatments. I also used ANOVA to compare the slope, aspect, soil organic matter,

and canopy gap fraction across treatments. The Holm-Sidak method was used for all pair-wise multiple comparison tests. For ANOVA tests, I determined if all test assumptions (normality and equal variance) were met. The Kolmogorov-Smirnov test was used to test for normally distributed samples. I used arcsine square roots and natural logarithms to transform independent variables to meet normality assumptions. When transformation of variables was unsuccessful in producing a normal distribution, I used the nonparametric Kruskal-Wallis test. The Tukey method was used for all pair-wise multiple comparison tests for nonparametric data. All statistical tests were set at $\alpha = 0.05$.

Results

Abiotic variables. – I found no significant differences in slope ($H = 0.0126$, $df = 2$, $P = 0.994$), aspect ($H = 0.000$, $df = 2$, $P = 1.000$), soil organic matter ($F_{2,27} = 0.790$, $P = 0.464$), and gap fraction ($H = 1.252$, $df = 2$, $P = 0.535$; Figure 1.2) between DWM coverage treatments (Table 1.1).

Soil Temperature. – The soil temperature data collected prior to DWM installation in 2007 revealed no significant differences between experimental plots for the three temperatures variables (Table 1.2). I collected daily soil temperature data during the 2008 growing season for 144 days resulting in 13,824 temperature samples (Figure 1.3). I discovered no significant differences in the average daily temperatures (June: $F_{2,27} = 1.780$, $P = 0.188$; July: $F_{2,27} = 2.285$, $P = 0.121$; August $F_{2,27} = 3.141$, $P = 0.059$) (Figure 1.4, Table 1.3). However, the average maximum daily temperature per month revealed a significant difference (June: $F_{2,27} = 3.700$, $P = 0.038$; July: $F_{2,27} = 6.050$, $P = 0.007$; August $F_{2,27} = 9.042$, $P = <0.001$). The 25% and 50% DWM coverage plots were 2-3° C

cooler than the 0% coverage plots from June through August (Figure 1.4). Furthermore, I unearthed a significant difference between low and high daily soil temperature per month (June: $F_{2,27} = 6.506$, $P = 0.005$; July: $F_{2,27} = 11.894$, $P = <0.001$; August $F_{2,27} = 14.658$, $P = <0.001$). The difference between low and high daily soil temperatures were reduced in the 25% and 50% DWM coverage plots by over 2° C in June and 3-4° C in July and August (Figure 1.4). Pair-wise multiple comparisons found no significant difference between 25% and 50% DWM coverage plots for both daily maximum and difference between low and high daily temperatures.

Soil Moisture. – In July, mean percent change in moisture content was 21.4% (± 0.0156) for 0% DWM coverage, 7.3% (± 0.00985) for 25% DWM coverage, 4% (± 0.00979) for 50% DWM coverage and was significantly different across treatments (July: $F_{2,27} = 58.964$, $P = <0.001$). Pair-wise multiple comparisons found no difference between 25% and 50% DWM coverage in July. For August moisture data was similar to July for each plot, 19% (± 0.0156) for 0% DWM coverage, 8.6% (± 0.008) for 25% DWM coverage, 5.2% (± 0.007) for 50% DWM coverage (August $F_{2,27} = 66.511$, $P = <0.001$); however, pair-wise multiple comparisons showed significant differences between all three coverage treatments (Figure 1.5).

Plant survival and Growth. – All 30 *S. albus* shrubs survived the first year after planting and 59 out of 60 *C. peregrine* (99.98%) survived the first year after planting. One *C. peregrine* died in a 50% DWM cover plot. However, I did find a significant loss in *S. albus* canopy volume growth over one year (*S. albus*: $F_{2,27} = 4.961$, $P = 0.015$). *S. albus* shrubs in 0% DWM treatment plots experienced a 14.3% (± 0.0849) decline in mean canopy volume (m^3) (Figure 1.6). Pair-wise multiple comparisons found no

significant difference between 25% and 50% DWM, and also between 0% and 25% DWM coverage for *S. albus* canopy volume data. There was no significant difference in *C. peregrine* canopy volume after one year ($F_{2,27} = 1.398$, $P = 0.264$). *C. peregrine* canopy volume data required a natural logarithm transformation to produce a normality distributed sample.

All ground cover species combined exhibited a 92.8% survival rate. The data may suggest that there is no significant difference of ground cover survival between treatments of DWM. *M. fistulosa* had the lowest survivor (85.3%) rate while *W. fragaroides* exhibited the highest survival rate (98%) (Table 1.2). The ground cover canopy volume data revealed no significant difference for four out of the five species (*A. margaritacea*: $H = 1.280$, $df = 2$, $P = 0.527$; *Aster marcophyllus*: $H = 2.191$, $df = 2$, $P = 0.334$; *M. fistulosa*: $H = 0.281$, $df = 2$, $P = 0.869$; *S. scoparium*: $H = 2.255$, $df = 2$, $P = 0.324$). The growth patterns for *A. margaritacea* and *A. marcophyllus* had a 2-4 times increase in mean volume in 50% DWM plots compared to the 0% and 25 % DWM plots, but variability was the highest in the 50% DWM plots. *W. fragaroides* canopy volume data revealed a significant difference ($H = 6.991$, $df = 2$ degrees, $P = 0.030$) with a mean of -10% (± 0.225) in 0% DWM coverage plot. Pair-wise multiple comparisons found a significant difference between 0% and 25% DWM plots but no significant difference between other pairs for *W. fragaroides* canopy volume data. The large standard errors for canopy volume for ground cover species suggest there is much variability (Table 1.4). Several individuals were overlooked in May for the initial measurements which may have an effect on the sample size and variability in the data.

Discussion

Restoration efforts on disturbed sites with native vegetation are dependent on successful establishment and survival of plant species. The effects of soil temperature and evaporation rates are important for both herbaceous and woody plants. The loss of moisture by soil evaporation reduces the amount of water available to plants, which can have negative effects on plant growth and survival and thus on the success of the restoration projects. Bhattacharjee *et al.* (2008) reported the rate of soil moisture decline was the single most important variable influencing cottonwood (*Populus deltoides*) seedling survival in sandy soils.

Addition of DWM lowered the difference between low and high daily soil temperature, the maximum daily temperatures, and the percent change in soil moisture content relative to plots without DWM. The percent change in soil moisture content was less on the 25% and 50% DWM coverage compared to 0% DWM coverage in July and August. The mean percent change in moisture content for 0% DWM coverage plots increased 3-5 fold compared to the 25% and 50% DWM coverage plots. There was a slight increase in moisture change for the 25% and 50% DWM coverage plots in August, which correlates with an increase of ambient temperatures and drought conditions during that time (http://mrcc.sws.uiuc.edu/climate_midwest). However, 0% DWM coverage experienced a slight decrease in percent change of moisture content between months.

Although DWM has been shown to play a number of important roles in terrestrial ecosystems, to my knowledge no studies have investigated soil temperature and moisture relative to DWM coverage and how these factors affect plant survival and growth. Gray and Spies (1997) compared surface temperatures and western hemlock (*Tsuga*

heterophylla) seedling survival on north and south sides of large logs (~ 50 cm in diameter). They found that surface temperatures were lower on the north side of logs, and western hemlock seedling survival was higher within 15 cm of the north side of logs than on the south side. They suggest that shade from large logs facilitated establishment of western hemlock seedlings in large gaps exposed to direct solar radiation in a mature to old growth conifer forest. Breshears *et al.* (1998) looked at the influence of forest canopy density on soil characteristics and found that soil temperatures and soil evaporation rates were lower under woody plant coverage compared to soils with no canopy coverage. Additionally, Callaway (1992) found that certain species of oak (*Quercus spp*) seedlings had higher survival and root elongation rates in a shaded canopy of shrubs in southern California. A number of restoration projects have used shrubs and grasses as nurse plants to facilitate early establishment of seedlings in restoration projects in the Mediterranean region (Maestre *et al.* 2001, Castro *et al.* 2002 & 2004), and in northern Africa (Aerts *et al.* 2007). These studies reported higher seedling survival under shrubs and grasses which reduced solar radiation and slow the soil-water evaporation and seedling transpiration. However, these studies were conducted in semiarid woodlands where ambient temperatures are twice as high and precipitation is half that in northern Wisconsin. It is well established that soil temperature and moisture influence plant survival.

My soil temperature and moisture data positively correlates with the increase in *S. albus* canopy volume data within the 25% and 50% DWM coverage plots. However, there was no significant difference for *C. peregrine* canopy volume among treatments. Because *C. peregrine* has adapted to open, sterile, sandy and gravelly soils with low to

neutral pH (Hightshoe 1988, Soper and Heimbürger 1994), it may be more tolerant of dry conditions than *S. albus*. Additionally, *C. peregrine* is a nitrogen-fixing plant which is used primarily for ground cover and erosion control on steep sandy soils (NRCS 2002). *C. peregrine* may tolerate transplant shock better than *S. albus* and may efficiently utilize the compost that was added to each shrub. *S. albus* is also considered a plant that will tolerate well drained sandy soils (Hightshoe 1988, Soper and Heimbürger 1994, and Smith 2008). However, the decrease in *S. albus* canopy volume in 0% DWM coverage plots may suggest that *S. albus* may have difficulty establishing in drier conditions without supplement of DWM or water. Yellowing of leaves of *S. albus* was prevalent among plants in all treatments which may suggest that it was lacking nutrients. There is some contradiction in the literature about the preferred soil and moisture regimes for *S. albus*. For example Henderson (1987) suggests that it grows best in moist and clay soils as compared to drier, sandier soils suggested by Hightshoe (1988), Soper and Heimbürger (1994), and Smith (2008). Nevertheless, both species are native to the area and are highly recommended by county conservationists and local nursery personnel for lakeshore restoration projects.

The ground cover species used in this study are adapted to moderate to dry soil conditions and are also highly recommended for use in lakeshore restoration projects. *W. fragaroides* may have lost canopy volume in the 0 % DWM coverage plots between treatments because it is a spring ephemeral and blooms early in the spring. Drier soil conditions later in the year may result in plant desiccation. The 25% and 50% DWM coverage plots may have retained enough soil moisture to slow plant desiccation of *W. fragaroides*. It is also a mat forming plant that spreads by runner-like rhizomes below the

ground surface. These growing characteristics may be beneficial in dry, sandy soils conditions which allow the plant to take advantage of early spring soil moisture and use less energy to spread on top of or near to the soil surface. It also exhibited the highest survival rate among all ground cover species. *M. fistulosa* experienced the lowest survival rate, which may reflect its preference for more moderately moist and loamy soils. *S. scoparium* showed the largest increase in canopy volume across all treatments. This is perhaps because it is a warm season grass that grows slowly until mid-summer. *S. scoparium* is one of the most widely distributed native grasses in North America. It will grow on a wide variety of soils but is well adapted to well-drained, medium to dry, infertile soils. The plant has excellent drought and partial shade tolerance (NRCS 2002). Because of its growth habit and adaptability to a wide range of soil conditions, *S. scoparium* may be useful as a component of lakeshore restoration projects. Nevertheless, it suffered the second highest mortality rate. The huge increase in the mean canopy growth and variability for *A. margaritacea* and *A. marcophyllus* in the 50% DWM plots may be due to the fact that *A. marcophyllus* prefers partial shade; the opposite may be true for *A. margaritacea* which prefers more open sites. However, I found no significant difference in the gap fraction across treatments these species may be more sensitive to the amount of openness hence the large variability in the canopy volume standard errors. Additional evaluation and measurements of abiotic factors may be necessary to fully understand species-specific mechanisms governing growth.

The southern aspect may have a greater influence on growing rates along lake shores with sandy soils as compared to northern, eastern and perhaps western aspects. In the absence of irrigation plant mortality may have been higher and plant canopy volumes

reduced especially, in drought conditions. DWM may also reduce the microclimate stress on plants during the night in early spring. Because nighttime temperatures are lowest at or near bare soil surfaces causing frost and adding stress to newly planted seedlings, DWM may reduce thermal imbalance at the soil surface by absorbing and storing infrared radiation during the day and protecting fragile plants at night (Ehleringer and Sandquist 2006). In this study, DWM did show that it can stabilize soil temperature and reduce soil moisture loss throughout the growing season which could have a positive effect on plant growth and survival in the following years.

Significantly degraded sites may require physical manipulation of soil properties (physical, chemical, or biological) to improve restoration success. Some restoration projects may be limited to focusing on one specific structure or process to improve plant success. Heneghan *et al.* (2008) reviewed many physical manipulations that have been successful in restoring soil characteristics with a positive effect on plant growth and community composition. Though these techniques are often effective, they can be time consuming and expensive, making them impractical for certain restoration projects. They argue that soil ecology should be considered in restoration projects.

DWM may also provide other positive functions in restoration projects such as reducing soil erosion on steep slopes (Hagan and Grove 1999). Sediment runoff from the lake shoreline can have negative effects on aquatic systems (Engel and Pederson 1998). I observed sediment accumulation on the upward side of DWM on steeper slopes indicating the DWM was reducing sediment runoff into the lake.

Conclusion

The upper Midwest has experienced moderate to severe drought conditions with abnormally high temperatures over the past several years. In Vilas County during 2007, record low precipitation and high ambient temperatures resulted in record low lake water levels. In 2008, temperatures were relatively normal but drought conditions continued and reached severe levels in late summer months (<http://mrcc.sws.uiuc.edu>). The aspect, slopes, and sandy soils at these restoration sites coupled with the weather conditions can put extreme stress on recent plantings. Previous restoration projects in the area have used cedar mulch on woody plant species to minimize soil-water evaporation. However, cedar mulch has a tendency to require continuous maintenance over the summer months due to high winds or being washed away during rain or irrigation events. This was especially problematic on steeper slopes (personal obs.), and if mulch is applied too heavy it may hinder recruitment of plants in the area. The amount of DWM available for lake riparian is related to the vegetation structure in the area (Christensen *et al.* 1996). While planting trees and shrubs into restoration sites will provide DWM through natural succession, trees grow slowly and it may take decades to centuries for DWM to be replenished naturally along high-development lakes (Christensen *et al.* 1996). Elias and Meyer (2003) advocate the active input of DWM.

DWM addition reduced the difference between low and high daily soil temperatures and the change in soil moisture and thus can be considered a useful technique to physically manipulate soil properties. However, longer term monitoring of plant survival and growth may be required to fully understand the effects of DWM (see Castro *et al.* 2004).

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Table 1.1. Abiotic data from three down woody material (DWM) coverage treatments. Data were collected during the summer of 2007 on Found and State House Lakes in Vilas County, Wisconsin prior to restoration efforts. No significant difference were found

	<i>N</i>	Max	Min	Mean	Std. Error
Gap Fraction:					
0 % DWM Coverage	10	65.8	30.0	42.1	4.3
25% DWM Coverage	10	63.0	21.6	37.4	4.6
50% DWM Coverage	9*	65.5	21.1	38.6	5.2
Slope:					
0 % DWM Coverage	10	30.0	8.0	16.5	2.8
25% DWM Coverage	10	30.0	5.0	17.2	3.1
50% DWM Coverage	10	30.0	8.0	16.7	2.8
Aspect:					
0 % DWM Coverage	10	248.0	154.0	210.0	31.5
25% DWM Coverage	10	248.0	154.0	210.0	31.5
50% DWM Coverage	10	248.0	154.0	210.0	31.5
% Organic Matter:					
0 % DWM Coverage	10	2.8	0.6	1.8	0.2
25% DWM Coverage	10	3.7	0.5	2.1	0.3
50% DWM Coverage	10	2.4	0.1	1.7	0.2

* Missing one digital hemispherical photograph.

Table 1.2. Pre-down woody material (DWM) addition soil temperature variables ($\alpha = 0.05$). Data were collected during the summer of 2007 on Found and State House Lakes in Vilas County, Wisconsin prior to restoration efforts.

Month	Variable	Treatment	N	Mean	Std. Err.	F	P
June	Ave. Temp.	0 % DWM	6	19.8	1.0	$F_{2,17} = 0.526$	0.600
		25% DWM	7	19.4	0.6		
		50% DWM	7	20.5	0.7		
	Max. Temp.	0 % DWM	6	24.6	1.8	$F_{2,17} = 0.460$	0.639
		25% DWM	7	23.2	0.9		
		50% DWM	7	24.7	1.2		
	Temp.Var.	0 % DWM	6	8.0	1.3	$F_{2,17} = 0.194$	0.825
		25% DWM	7	7.4	0.8		
		50% DWM	7	8.4	1.4		
July	Ave. Temp.	0 % DWM	8	19.8	0.9	$F_{2,20} = 0.252$	0.780
		25% DWM	7	19.3	0.6		
		50% DWM	8	19.9	0.6		
	Max. Temp.	0 % DWM	8	23.9	1.5	$F_{2,20} = 0.313$	0.735
		25% DWM	7	22.8	0.9		
		50% DWM	8	23.8	1.0		
	Temp.Var.	0 % DWM	8	6.8	0.9	$F_{2,20} = 0.152$	0.860
		25% DWM	7	6.3	0.6		
		50% DWM	8	6.9	1.1		
August	Ave. Temp.	0 % DWM	4	21.7	0.5	$F_{2,12} = 0.567$	0.582
		25% DWM	6	21.2	0.3		
		50% DWM	5	21.3	0.3		
	Max. Temp.	0 % DWM	4	26.2	0.4	$F_{2,12} = 1.230$	0.327
		25% DWM	6	24.9	0.7		
		50% DWM	5	25.7	0.6		
	Temp.Var.	0 % DWM	4	7.6	0.4	$F_{2,12} = 1.053$	0.379
		25% DWM	6	6.2	0.6		
		50% DWM	5	7.3	0.9		

Table 1.3. Post-down woody material (DWM) addition soil temperature variables ($\alpha = 0.05$). Data were collected during the summer of 2008 on Found and State House Lakes in Vilas County, Wisconsin after restoration efforts and the addition of DWM.

Month	Variable	Treatment	N	Mean	Std. Err.	$F_{2,27}$	P
June	Ave. Temp.	0 % DWM	10	17.0	0.4	1.780	0.188
		25% DWM	10	15.9	0.4		
		50% DWM	10	16.2	0.4		
	Max. Temp.	0 % DWM	10	21.4	0.8	3.700	0.038
		25% DWM	10	18.9	0.7		
		50% DWM	10	19.1	0.7		
	Temp.Var.	0 % DWM	10	7.2	0.6	6.506	0.005
		25% DWM	10	4.9	0.4		
		50% DWM	10	4.9	0.5		
July	Ave. Temp.	0 % DWM	10	20.1	0.5	2.285	0.121
		25% DWM	10	19.0	0.5		
		50% DWM	10	19.0	0.4		
	Max. Temp.	0 % DWM	10	25.1	0.8	6.050	0.007
		25% DWM	10	22.2	0.8		
		50% DWM	10	22.0	0.6		
	Temp.Var.	0 % DWM	10	8.2	0.6	11.894	<0.001
		25% DWM	10	5.4	0.5		
		50% DWM	10	5.0	0.4		
August	Ave. Temp.	0 % DWM	10	19.7	0.4	3.141	0.059
		25% DWM	10	18.5	0.5		
		50% DWM	10	18.3	0.3		
	Max. Temp.	0 % DWM	10	25.0	0.7	9.042	<0.001
		25% DWM	10	21.8	0.8		
		50% DWM	10	21.1	0.5		
	Temp.Var.	0 % DWM	10	9.0	0.6	14.658	<0.001
		25% DWM	10	5.8	0.6		
		50% DWM	10	5.1	0.3		

Table 1.4. Ground cover species survival rates for one year (2007-2008) after planting in three woody material (DWM) coverage treatments. Survival rates were recorded from Found and State House Lakes' restoration projects in Vilas County, Wisconsin.

Species	DWM Coverage (%)			Total
	0	25	50	
<i>Anaphalis margaritacea</i>	96%	98%	92%	95.3%
<i>Aster marcophyllus</i>	96%	96%	96%	96.0%
<i>Monarda fistulosa</i>	92%	82%	82%	85.3%
<i>Schizachyrium scoparium</i>	90%	80%	98%	89.3%
<i>Waldstenia fragaroides</i>	100%	96%	98%	98%
Total	94.8%	95.4%	93.2%	92.8%

Table 1.5. The percent change of canopy volume for five ground cover species relative to three treatments of down woody material (DWM) coverage. Data were recorded in 2008 from Found and State House Lakes in Vilas County, Wisconsin.

Species	N	Max	Min	Mean	Std. Error
<i>Anaphalis margaritacea</i> (n = 132)					
0% DWM Coverage	10	269.4	3.6	49.4	26.1
25% DWM Coverage	10	311.3	11.6	61.2	29.0
50% DWM Coverage	10	826.9	7.0	110.7	80.0
<i>Aster marcophyllus</i> (n = 135)					
0% DWM Coverage	10	66.3	4.9	26.1	6.1
25% DWM Coverage	10	78.1	8.4	30.7	6.6
50% DWM Coverage	10	528.2	9.8	106.9	50.6
<i>Monarda fistulosa</i> (n = 128)					
0% DWM Coverage	10	148.2	3.2	29.5	13.9
25% DWM Coverage	10	148.8	1.4	31.1	14.0
50% DWM Coverage	10	91.5	3.6	27.2	10.7
<i>Schizachyrium scoparium</i> (n = 102)					
0% DWM Coverage	10	5256.4	102.6	871.0	493.6
25% DWM Coverage	9*	8083.2	61.0	1458.6	858.0
50% DWM Coverage	9*	19051.6	59.8	3536.6	2007.3
<i>Waldstenia fragaroides</i> (n = 144)					
0% DWM Coverage	9*	1.8	-0.7	-0.1	0.2
25% DWM Coverage	10	2.8	-0.5	0.2	0.3
50% DWM Coverage	8*	10.7	-0.3	1.4	1.1

* Species were missing from the DWM plots do to mortality or missing plants during the initial measurements in May 2008.



(a)



(b)



(c)

Figure 1.1 Represents experimental plots with woody material in place: (a) 0 % woody material coverage, (b) 25 % woody material coverage, (c) 50 % woody material coverage.

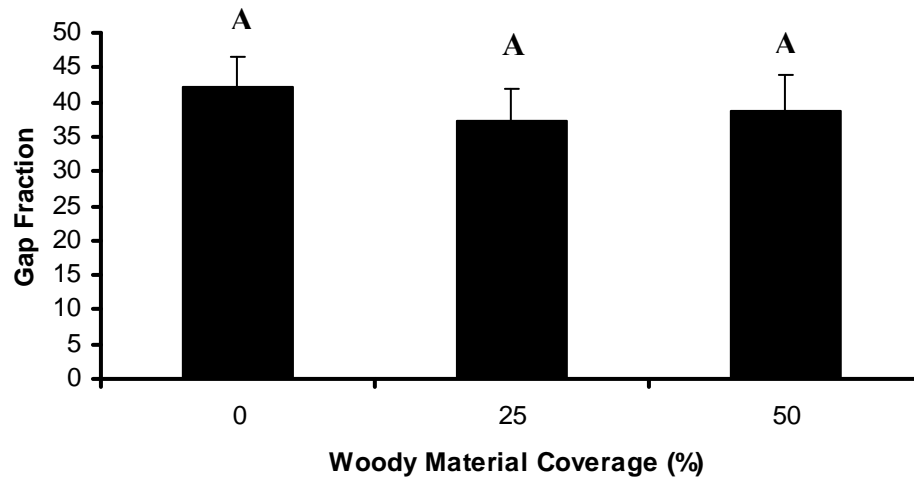


Figure 1.2 Mean gap fraction and standard error for each treatment of percent down woody material (DWM) coverage. Data was taken prior to restoration efforts and the addition of DWM on Found and State House Lakes, Vilas County, Wisconsin. There was no significant differences between treatments ($H = 1.252$, $df = 2$, $P = 0.535$). Bar columns with the same letter are not significantly different by Holm-Sidak Pairwise Multiple Comparison Procedures ($P = <0.001$)

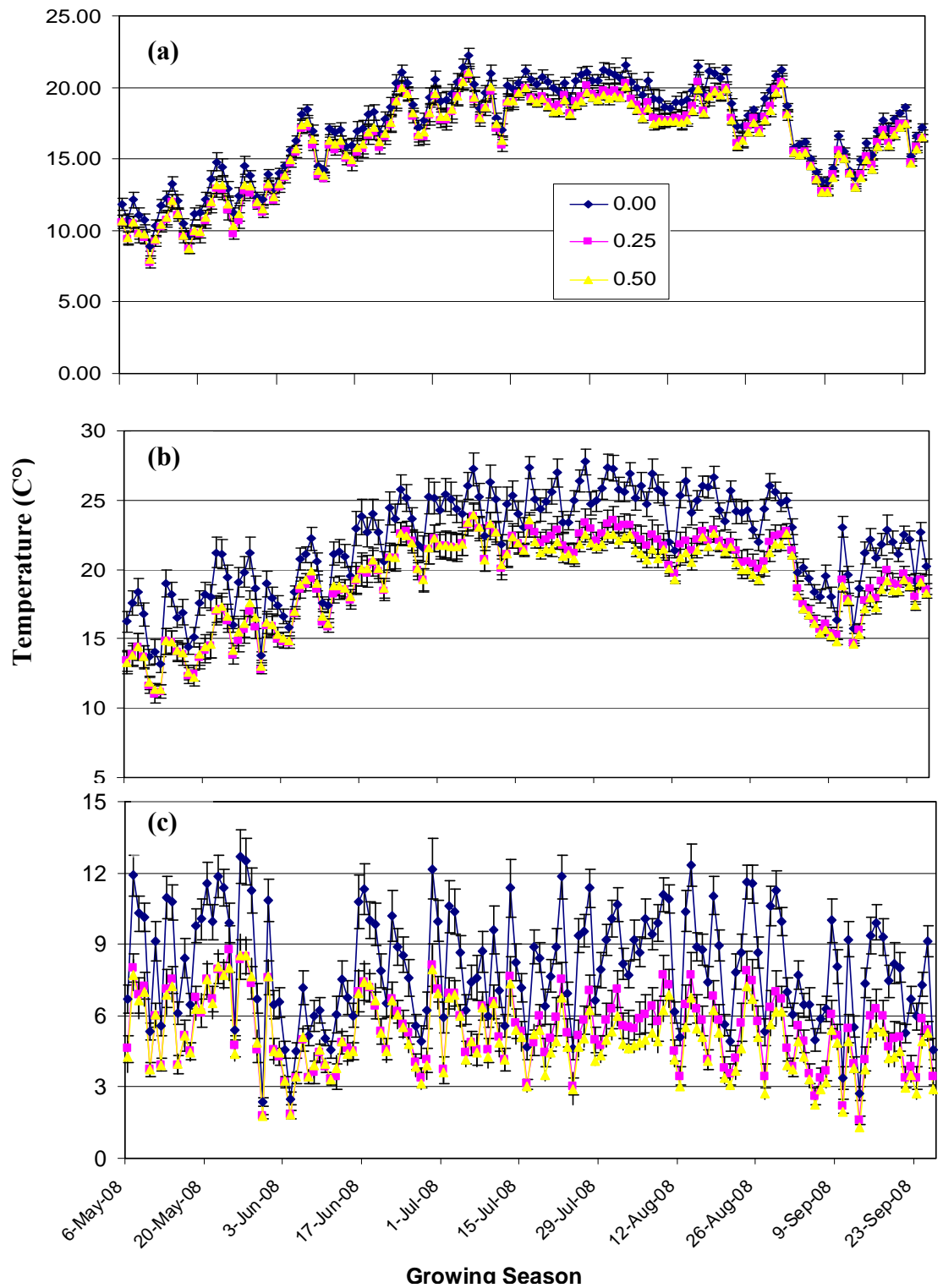


Figure 1.3. Three soil temperature variables (a) mean daily, (b) mean daily maximum, and (c) mean daily difference between high and low temperatures measured during the 2008 growing season with standard error bars. Temperatures were compared between three different percent coverage of down woody material on Found and State House Lakes, Vilas County, Wisconsin

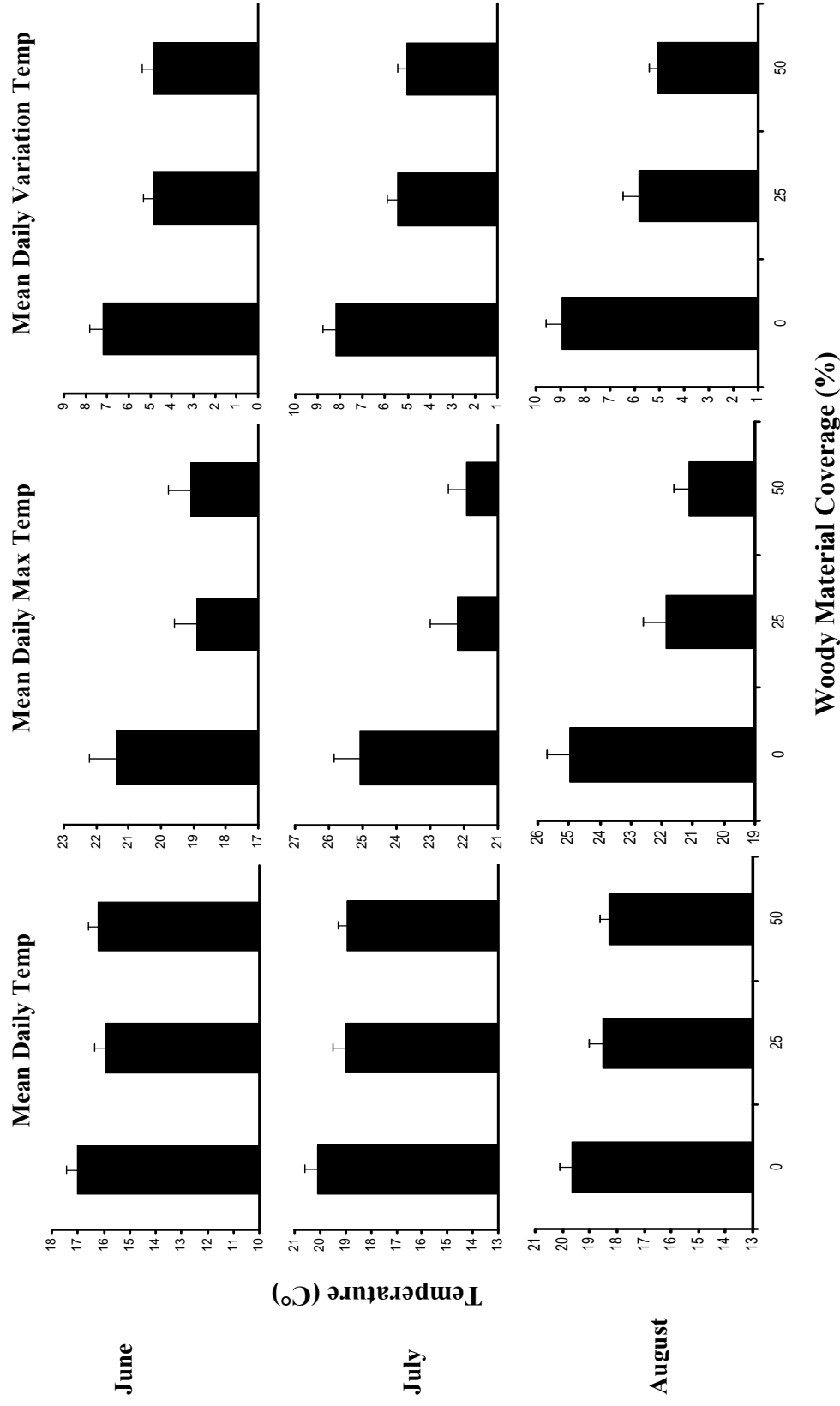


Figure 1.4. Mean daily, mean maximum soil temperatures and the mean daily soil temperature variation and standard errors for three months in 2008 on woody material coverage treatments. Data were collected during the summer of 2008 on Found and State House Lakes in Vilas County, Wisconsin.

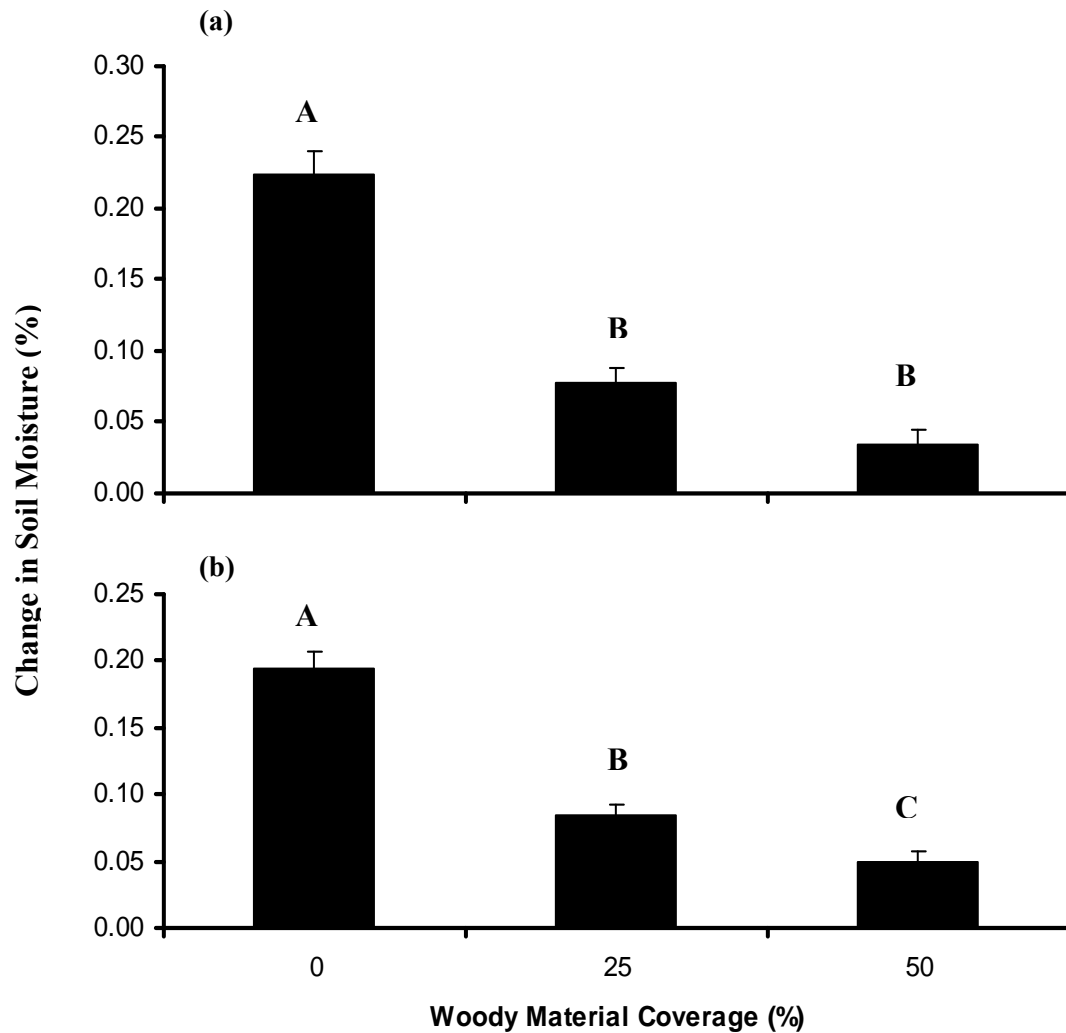


Figure 1.5. Mean percent change of soil moisture content from 12 hours to 36 hours after watering from July (a) and August (b) 2008 on three woody material coverage treatment. Data was collected from restoration projects on Found and State House Lakes, Vilas County, Wisconsin. Bar columns with the same letter are not significantly different by Holm-Sidak Pairwise Multiple Comparison Procedures ($P = <0.001$)

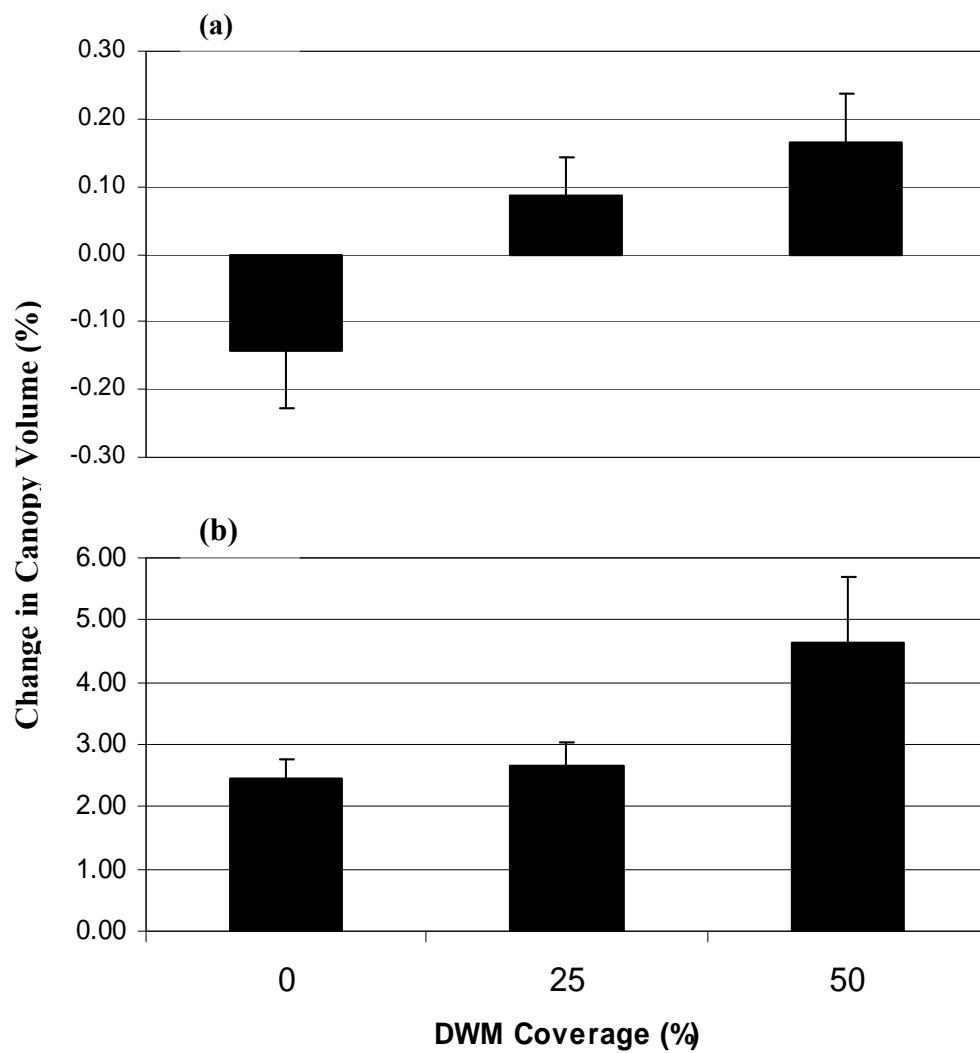


Figure 1.6. Percent change in canopy volume for snowberry (a) and sweet fern (b) over a one year period. Data collected on Found and State House Lakes Vilas County, Wisconsin from August 2007 to 2008.

CHAPTER 2

RESIDENTIAL DEVELOPMENT IMPACT ON MAMMALIAN DIVERSITY ALONG LAKESHORES IN NORTHERN WISCONSIN

Abstract

Residential development has expanded across North America at a dramatic rate which reduces biodiversity. The upper mid-west has experienced a high percentage of development around lake shores. Recent studies have documented negative effects on the local floral and fauna but little is known of the effect residential development has on the mammal community. I investigated the effect residential development is having on the local mammal community on lakeshores. I conducted snow track surveys on ten pairs of low-and high-development lakes in Vilas County, Wisconsin in 2008. Twelve remote cameras were deployed on four lakes in the area. The results suggest that a higher diversity of mammals, especially carnivores, were detected on low-development lakes. Coyotes were the most numerous species detected with the majority encountered on low-development lakes. White-tailed deer and red fox were detected more on higher-development than low-development lakes.

Introduction

Rural landscapes in the Midwest have experienced dramatic changes in recent decades due to residential development (Radeloff *et al.* 2005). Residential development in rural landscapes causes fragmentation and the loss of wildlife habitat (Theobald *et al.* 1997) and thus poses a serious threat to biodiversity (Wilcove *et al.* 1998, Czech *et al.*

2000). People are inclined to construct primary or secondary homes in and around natural areas because they provide a natural environment, opportunities for recreation, and scenery (Schnaiberg *et al.* 2002). Freshwater ecosystems have attracted people and development for centuries (Naiman 1996, Riera *et al.* 2001). In northern Wisconsin, residential development has increased over 200% along lakeshores in recent decades (WDNR 1996, Radeloff *et al.* 2001, Gonzales-Abraham *et al.* 2007).

Residential development often results in the removal of vegetation structure along shorelines (Elias and Meyer 2003). Wildlife can be affected directly or indirectly by removal of vegetation structure. Recent studies comparing low- and high-development lakes in Vilas County, Wisconsin documented declines in the floral and fauna on these lake shorelines. For example, species composition of breeding birds differed significantly (Lindsay *et al.* 2002), abundance of green frogs was substantially lower (Woodford and Meyer 2003), and vegetation structure and composition in riparian and littoral zones were dramatically different (Elias and Meyer 2003) along low- and high-residential development lakeshores. However, no known studies investigated the effect of housing development on the mammal community in this region, and in particular on medium and large mammals.

Crooks (2002) reported that certain carnivore species are sensitive to human habitat fragmentation and the presence and abundance of carnivores can reflect the health of an ecosystem. Carnivores play an important role in structuring communities (Eisenberg 1989, Oehler and Litvaitis 1996, Crooks and Soulé 1999, Schmitz *et al.* 2000). For example, in southern California the occurrence of bobcats (*Lynx rufus*) and coyotes

(*Canis lantrons*) were less common in landscapes with greater residential development (Crooks 2002). The absence of carnivores in an ecosystem can have a significant impact on the relative abundance of herbivores and small predators. In some cases, the loss of larger carnivores has allowed one or two species may dominate a community and further reduces biodiversity (Crooks and Soulé 1999, Berger *et al.* 2001, Hebblewhite *et al.* 2005). Thus, maintenance of carnivore species becomes an important consideration in managing healthy ecosystems (Eisenberg 1989). The management of natural habitats for carnivore is becoming one of the greatest challenges for conservation biologists and policy makers in North America (Noss *et al.* 1996).

Certain carnivore species are among the most elusive animals in the world, and many are nocturnal and secretive, live in low densities, and have large home ranges which make them difficult to detect and monitor (Hoffman 1996). I used two non-invasive techniques to determine the presence of mammalian species on lakeshores in northern Wisconsin. Winter snow track surveys were used on ten pairs of low- and high-developments lakes in Vilas County during the winter of 2008. In addition, I deployed and monitored 12 remote digital cameras on two pairs of low- and high-development lakes in Vilas County from June 2007 to August 2008. The latter are currently undergoing restoration of native vegetation along a 35 foot shoreline buffer. I chose these two techniques because certain species have different seasonal behavior patterns. For example, black bears (*Ursus americanus*), and raccoons (*Procyon lotor*) hibernate though the winter months and may not be detected by snow track surveys. Certain canid species that are wary of human scent may avoid cameras. In addition, vegetation and

seasonality can produce species-specific differences in detectability, and body size characteristics of species may influence detection (O'Connell *et al.* 2006).

The objectives of my research were to: (1) determine if residential development on lakeshores is related to mammalian diversity and relative abundance, (2) provide baseline data for long-term monitoring of medium and large mammals and, (3) provide baseline data for current lakeshore restoration projects. I hypothesized that lakeshores with higher-development will have fewer mammal species than lakeshore with lower-development.

Methods

Study area

This study was conducted in Vilas County, Wisconsin, which is within the Northern Highland Lake District. Vilas County encompasses a 2,636 km² area along the states northern border with the Upper Peninsula of Michigan. Vilas County contains 1320 pitted outwash glacial lakes ranging in size from 0.1 to > 1500 ha and covering 16% of the county's area (WDNR 2005), and 53% of the area is privately owned. (Schnaiberg *et al.* 2002). The land cover is a mixture of bogs, northern wet forest, boreal forest, and northern dry to northern xeric forest (Curtis 1959). Vilas County has undergone extreme residential development in recent decades with the majority of development occurring within 100 m of a lake (Schnaiberg *et al.* 2002).

Study lakes were systematically chosen from the University of Wisconsin, Trout Lake Limnology BioComplexity project data base (<http://biocomplexity.limnology.wisc.edu>). I matched ten pairs of lakes according to

similar surface area and lake type (i.e. drainage, seepage, spring fed) (see Woodford and Meyer 2003); one lake in each pair had a high density (≥ 10 houses/km, mean = 23.45 ± 2.69) of shoreline development and the other lake had a low density (< 10 houses/km, mean = 2.10 ± 0.64) of shoreline development (Table 2.1).

Snow track surveys

Observing tracks in the snow is a traditional and often a reliable technique for determining carnivore presence, abundance, distribution, behavior, and habitat use (Heinemeyer *et al.* 2008). Carnivore species can be identified by characteristics of tracks, gait patterns, stride and straddle (Halfpenny 1986), and snow reveals a continuous record of animal movement between successive snowfalls (Halfpenny *et al.* 1995). This snow tracking technique is used to survey and monitor carnivore populations throughout the region (Wydeven *et al.* 2004, 2007). Snow tracking is non-invasive and does not alter natural behavior of the target species. In addition, this technique seldom requires specialized equipment and is usually less costly relative to other more intensive techniques.

I conducted winter snow track surveys during January – February 2008 on all 20 lakes. Surveys were conducted 48 to 96 hours following snowfalls of ≥ 2.5 cm, at temperatures above -17° C, and with winds less than 10 mph. Transects started at a point of lake access (e.g. boat landing) and traveled (via snow-shoes or cross-country skis) 1500 linear meters on the frozen lake surface, along the shoreline. I identified all carnivore species according to methods described by Halfpenny (1986). If tracks were not immediately identified, I backtracked the trail to suitable topography to take

measurements and determine the species. I recorded all carnivore tracks encountered 10 m on each side of the transect. In addition, I tallied encounters with non-carnivore species: micro-tine rodents, Snowshoe Hare (*Lepus americanus*), Eastern Cottontail Rabbit (*Sylvilagus floridanus*), *Sciuridae* species, White-tailed deer (*Odocoileus virginianus*), and Domestic Dog (*Canis familiaris*). I developed the following index to categorize the abundance of these species: 0 If no tracks were detected, 1 = 1 to 5 tracks, 2 = 6 to 10 tracks, 3 = > 10 tracks for each transect (Table 2.2). Both lakes in a pair were surveyed sequentially the same day with no more than 30 min between surveys periods.

Remote Cameras

Remote cameras have been used in wildlife research to address a variety of questions. The data collected by cameras for this analysis are from two high-development lakes currently undergoing restoration of vegetation along the shoreline and their low-development pairs (Table 2.1). This information should be interpreted as baseline data for the long term research project.

Twelve motion sensor, digital cameras (Cuddeback™ Expert, Non Typical, Inc., Park Falls, Wisconsin) with a $\frac{3}{4}$ second trigger speed were placed on the subset of four paired lakes, two low- and two high-development with six cameras deployed on low-development and six cameras deployed on high-development lakes. Camera sites were determined by dividing the shoreline into 50 m segments using GIS (Geographic Information System) software and labeled by numbers (1, 2, 3,). Segments were randomly picked such that until cameras were placed at least ≥ 1 km apart to increase independence. The number of cameras per lake was determined by the length of the

shoreline such that 2 km of shoreline contained one camera for example, if the shoreline was 4 km in length, then two cameras were used on that lake. Cameras were moved if people disturbed them. There were 11 camera sites on the high development lakes and eight camera sites on low-development lakes.

Cameras were placed within 10 m of the shoreline, positioned toward a game trail when present, and attached to a tree 50 cm above the ground. On high-development lakes, cameras were placed in relatively unaltered area (i.e. intact natural vegetation). A cotton ball saturated with lure (shellfish oil) was placed inside an empty plastic, perforated film canister and hung in a tree within 5 m of a camera. Cameras were programmed to take photos 24 hr/day, pause for one minute intervals between events, and to record date and time of event on each image. I checked batteries and compact flash cards every 2 to 4 weeks.

Data analyses

Snow track survey

I calculated Shannon's Index of species diversity (H') (Magurran 2004) for each lake within a group of ten categorized as low- or high-development. I used a t -test to test the null hypothesis that low- and high-development lakes have equal H' indices of diversity. The abundance indices for non-carnivore species were averaged by treatment and interpreted by relative abundance (Table 2.2). I used a t -test to compare mean relative abundance of non-carnivore species between low- and high-development lakes. For t -tests, I determined if all test assumptions (normality and equal variance) were met. The Kolmogorov-Smirnov test was used to test for normal distribution of the samples. Data

that violated assumptions were transformed using natural logarithms. When transformation of variables was unsuccessful in producing a normal distribution, I used the nonparametric Mann-Whitney Rank Sum *U*-test. Analyses were conducted using SigmaStat 3.5 software (Systat Software Inc.2006) and significance levels were set at $\alpha = 0.05$.

Remote Cameras

I calculated rate of occurrence (number of events/camera nights) for each species and at each camera location and calculated the mean for each type of development (O'Connell *et al.* 2006). I defined an event as a single species detection within a 24 hour period. Twelve cameras were deployed from June 12, 2007 to August 31, 2008 for a total of 5,700 camera nights. I excluded the data collected in the months of January and February 2008 because extreme cold temperatures and blowing drifting snow rendered some cameras inoperable.

Results

Snow track survey

I recorded 83 encounters of nine furbearer species across all lakes sampled ($n = 20$). Five of the nine species were detected exclusively on low-development lakes (Table 2.3). Sixty-eight individual track detections accounted for 92% of all individuals recorded on low-development lakes, and 15 detections accounted for 8% of all individuals recorded on high-development lakes. Coyotes were the most encountered species ($n = 34$) across all lakes. Red fox (*Vulpes vulpes*) accounted for 14 encounters and nine individuals were recorded on high-development lakes. Mink encounters were four times higher on low-

development than high-development lakes (Table 2.3). Shannon's Index of diversity was significantly higher on low-development (mean = 1.974 ± 0.438) than on high-development lakes (mean = 0.277 ± 0.113) ($t = 3.497$, $df = 9$, $P = 0.007$).

For non-carnivores, white-tailed deer were abundant on high-development lakes with encounters on all of the high-development lakes, but were found to be uncommon being detected on only 50% of low development lakes. Snowshoe hare and eastern cottontail rabbits were significantly different to the type of development. Hares were detected on 70% of low-development lakes, while cottontails were recorded on 90% of high-developments lakes, both species were significantly different. Domestic dogs were considered common on high-development while rare on low-development lakes. There was no significant difference for *Sciuridae* spp. and micro-tine rodents (Table 2.4).

Remote Cameras

Nine carnivore species were detected by cameras ($n = 12$) across all lakes sampled ($n = 4$). Beaver (*Castor canadensis*), wolf, and fisher were exclusively photographed only on low-development lakes (Figure 2.2). Rate of occurrence for raccoon was approximately 2.5 times higher on high-development (mean = 0.048 individual/camera night ± 0.036) than on low-development lakes (mean = 0.019 individual/camera night ± 0.012). Red fox rate of occurrence was nearly twice as high on high-development lakes (mean individual/camera night = 0.005 ± 0.003) than on low-development lakes (mean = 0.003 individual/camera night ± 0.002). Rate of occurrence for domestic dog was over four times higher on high-development (mean = 0.037 individual/camera night ± 0.019) than

low-development lakes (mean = 0.009 individual/camera night \pm 0.004). Wolf and black bear occurrence was extremely low on all lakes sampled (Figure 2.2).

For non-carnivore species, white-tailed deer were detected more than 3 times more frequently on high-development (mean = 0.20 individual/camera night \pm 0.09) than low-development lakes (mean = 0.06 individual/camera night \pm 0.02) (Figure 2.3). Snowshoe hare, *Sciuridae* species, and eastern cottontail rabbit had low occurrence rates on all lakes. Eastern cottontail rabbits were not detected on low-development lakes. *Sciuridae* species had similar rates of occurrence on both types of lakes, and no micro-tine rodents were detected by remote cameras (Figure 2.4).

Discussion

These results suggest that mammal diversity and species richness were higher on low-development than high-development lakes. Many studies have investigated the effect of residential development on mammal presence and abundance relative to patch size and isolation (Crooks 2002), trophic cascades (Crooks and Soulé 1999, Hebblewhite *et al.* 2005), species interactions (Gosselink *et al.* 2003, McDonald *et al.* 2008) and wildlife habitat (Theobald *et al.* 1997). However, few studies have investigated the effect on mammal diversity on lake riparian areas relative to residential development. In one of the few studies, Racey and Euler (1982) found a decrease in small mammal diversity with increasing development on lakeshores in Ontario, Canada. However, their study was conducted on lakes with smaller seasonal cottages represented the type of development and where extreme habitat alternation was uncommon (Robertson and Flood 1980).

Coyotes were by far the most common detected species recorded on low-development lakes, and bobcats were exclusively detected on low-development lakes during the snow tracking surveys. This suggests that these species may be sensitive to residential development or the many landscape and stand level changes associated with residential development as reported by Crooks (2002). Winter track surveys conducted by WDNR throughout the northern third of Wisconsin also found that coyotes were the most frequently encountered carnivore species (Wydeven *et al.* 2004, 2007). In addition, Wydeven *et al.* (2007) reported a two-fold increase in coyote detections between 2004 and 2007 winter track survey. Historical records suggests that coyotes were common to abundant throughout Wisconsin in the late 1800s and early 1900s but they were considered vermin and thus were hunted vigorously resulting in declining populations through the mid-1900s (Jackson 1961). Currently, coyotes have become more common in the northern half of the Wisconsin (Fruth 1986) as a reflection of increasing populations throughout North America (Voight and Berg 1987, Gompper 2002).

Coyotes have adapted to suburban and urban landscapes across North American (Gompper 2002, Gerht 2004, Markovchick-Nicholis *et al.* 2008) and yet my data suggests that they avoid high-development lakes in northern Wisconsin even while they are ubiquitous across the region (Wydeven *et al.* 2007). Gehrt (2007) postulated that coyotes will avoid humans, both temporally and spatially, while still living in the immediate area. My low detection rate of coyotes on high-development lakes suggests that coyotes, like most secretive mammals, prefer brushy habitat with tall vegetation (Fruth 1986). The park-like structure near shorelines on high-development lakes (Elias

and Meyer 2003) may be the reason for lower coyote use and no detections of fisher and bobcat. Both fisher and bobcat prefer relatively large contiguous low conifer cover in the winter (Buskirk and Powell 1984, Lovallo and Anderson 1996) which is absent on the high-development lakes (Elias and Meyer 2003).

Coyote and red fox rate of occurrence at camera sites showed a similar pattern to that of snow track surveys for low- and high-development lakes. However, the number of total coyote camera detections was substantial lower than the total for snow track surveys. This may be due to the fact that alpha coyotes are able to avoid cameras (Séquin *et al.* 2003), the characteristics of camera location will influence the number of photo-captures (Séquin *et al.* 2007), and the small sample size of lakes.

Red foxes and coyotes can be sympatric (McDonald *et al.* 2008) but the smaller canid usually avoids coyotes by locating its territory on the periphery of coyote territories (Voigt and Earle 1983, Sargeant *et al.* 1987) or by avoiding habitats frequency by coyotes (Dekkar 1989). In east-central Illinois rural foxes selected human-associated habitats, which coyotes generally avoided (Gosselink *et al.* 2003). It is not uncommon for these two canids to have inverse population densities in an area (Dekkar 1989) which may explain the higher rate of fox detections on high-development lakes.

Remote cameras did not detect mink (*Mustela vison*) on any lakes, but was encountered on snow track surveys primarily on low-development lakes. A similar study in Ontario, Canada reported that mink occurrence and activity decreased with increase levels of residential development (Racey and Euler 1983). They revealed that mink feeding behavior and habitat use was affected by residential development.

The higher rate of detections for white-tailed deer is probably due to supplemental feeding by humans living on the lake (pers. obs.). The presence of supplemental feeding sites can affect deer movement patterns. White-tailed deer will show a preference for feeding sites and will congregate around the area (Ozoga and Verme 1982). And natural vegetation may be affected by this increased activity around feeding sites (Doenier *et al.* 1997).

My snow tracking survey revealed an inverse relationship between snowshoe hare and cottontail rabbit with higher abundance of snowshoe hare observed on low-development than high-development lakes and cottontails showing the inverse. Both species live sympatrically and utilize somewhat similar habitat types (Keith and Bloomer 1993). Snowshoe hares prefer conifer forest and areas of dense brushy understory and avoid open areas (Pietz and Tester 1983, Wise 1986). Cottontails prefer a wide variety of disturbed, early successional, or shrub dominated habitats that include dense understory cover (Chapman and Litvaitis 2003). Predation is an important factor affecting abundance of cottontails in northern Wisconsin and primarily the direct cause of regulating cottontail populations (Keith and Bloomer 1993, Chapman and Litvaitis 2003). In central Wisconsin, Keith and Bloomer (1993) speculated that where snow and low temperatures are persistent throughout the winter, the cottontails' larger foot loading, brown coloration, and escape behavior make them more vulnerable to predation. They postulate that these characteristics explain cottontail absence to low abundance in northern forests of Wisconsin. Furthermore, Bueller and Keith (1982) found that

cottontails were associated with human development and were absent in extensive forests in northern Wisconsin.

Unlike the snow tracking survey, remote cameras detected snow shoe hare and bobcats at a higher rate on high-development than low-development lakes, suggesting that like coyotes, characteristics of camera location will influence the number of photo-captures (O'Connell *et al.* 2006, Séquin *et al.* 2007). However, no cottontails were detected on low-development lakes with remote cameras, reinforcing our track survey finding that cottontails may be more abundant on high-development lakes.

Sciuridae species use a variety of habitats, adapt well to residential development (Wilson and Ruff 1999), and may benefit from supplemental feeding (i.e. bird feeders) on high-development lakes. These two survey techniques are not the best to infer on micro-tine rodents because of their life history characteristics. For example, their smaller size may not have triggered the cameras, some species go through torpor and can be subnivean during the winter months, and are relatively cyclic in their abundance. It is unclear how residential development has affected smaller mammals in this study area.

The 2.5 times higher occurrence rate of raccoon on high-development lakes is not surprising. Several studies from throughout North America have shown that raccoon populations increase with increasing housing development and habitat fragmentation (Oehler and Litvaitis 1996, Crooks and Soulé 1999, Crooks 2002). It is well documented that raccoon densities are higher in urban and suburban areas (Hoffman and Gottschang 1977, Prange *et al.* 2003). Historically, raccoons were not common in northern Wisconsin (Jackson 1961) and recently have increased in abundance with wide spread

human development. Furthermore, housing development displaces higher trophic level carnivores, such that coyotes may control raccoon populations or result in a “mesopredator release” (Soulé *et al.* 1988, Crooks and Soulé 1999, Schmidt 2003). A mesopredator release involves the increased density of a consumer species usually following a decline in predation by species at higher trophic levels. The increased abundance of raccoon results in higher predation rates, on lower species in the trophic level. This can cause prey populations to decline and can potentially alter community structure (Terborgh *et al.* 1999). Raccoons adapt well to human development (Hecht and Nickerson 1999, Prange *et al.* 2004) and prey heavily on bird eggs and young (Johnson *et al.* 1989, Sargent, *et al.* 1993, Schmidt 2003, McCann *et al.* 2005). Certain avian species that nest on or near lakeshores are currently in decline, which may be due to an increase in raccoon densities and distribution (Lindsey *et al.* 2002).

Raccoons have the most diverse diet of any carnivore in North America, which has been important in their success in human dominated landscapes (Gehrt 2004). The raccoon has probably benefited more than any other furbearer due to high human development on lakeshores. Raccoons readily exploit human garbage, pet food, and other food resources related to human activities (Gehrt 2004, Prange *et al.* 2004). The raccoon’s climbing ability allows it to access garbage cans, dumpsters, and bird feeders which are common in residential developments. This artificial food resource has positively affected raccoon demographics throughout its range (Hoffman and Gottschang 1977, Prange *et al.* 2003, 2004). Raccoons often lose 50% of their body mass over winter (Mech *et al.* 1968), but in suburban areas, raccoons may lose only 10% (Riley *et al.*

1998). Prange *et al.* (2004) reported that raccoons have relatively small home ranges in urban and suburban environments in contrast to rural areas, which was due to the abundance of artificial food resources. In addition, seasonal changes in home range size were least pronounced in suburban areas (Prange *et al.* 2004). Furthermore, Hoffman and Gottschang (1977) documented that raccoons used linear travel routes going to and from feeding areas and home range averaged 5.5 times as long as wide. They suggested that high population densities and abundant food resources are the cause of small linear home ranges. Little is known about raccoon movement patterns in my study landscape.

The higher rate of occurrence for white-tailed deer on high-development lakes was supported by both remote camera and snow tracking surveys. Numerous studies have investigated the effect of deer over abundance and the ecological impact on landscapes. Plant communities can be devastated by deer herbivory (Beals *et al.* 1960, Russell *et al.* 2001) and wreak havoc on restoration projects (Opperman and Merenlender 2000). Opperman and Merenlender (2000) found that sapling densities were approximately ten times higher in enclosures compared to control areas and 97% of saplings in control areas displayed leaf and stem damage characteristic of deer browse. Restoration projects where there is high deer abundance should install an abatement system which can reduce herbivory and increase the success of restoration efforts (Opperman and Merenlender 2000, Sweeney *et al.* 2002).

Research has documented the effects on community structure when large carnivorous furbearers are removed or missing (McLaren and Peterson 1994, Berger *et al.* 2001, Hebblewhite *et al.* 2005). For example McLaren and Peterson (1994) found

evidence supporting top-down control of a food chain by wolves on Isle Royale. Balsam fir (*Abies balsamea*) growth rates were regulated by moose (*Alces alces*) whose densities were controlled by wolf predation. When the wolf population declined moose densities expanded and suppressed fir growth (McLaren and Peterson 1994). However, presence of large carnivore (i.e. wolves and cougars) within or near residential development can be highly controversial. Unfortunately, no cougars were detected during this survey period.

Although many studies have looked at the relationships between coyotes, bobcats, and foxes in other regions of North American (Voigt and Earle 1983, Sargeant *et al.* 1987, Gosselink *et al.* 2003), there has been no research looking how these species partition their territories in this study area. In addition, it has been documented that coyotes prey on foxes (Harrison *et al.* 1989) supporting interspecific relationships among canid species. Few studies have investigated the relationship patterns of coyote and raccoons during major shifts in abundance (Gehrt and Clark 2003), which would support the “mesopredator release theory” caused by residential development (Soulé *et al.* 1988, Crooks and Soulé 1999).

Conclusion

The landscape of northern Wisconsin is unique with glacial lakes scattered in a mixed deciduous-coniferous forest. However, many lakes are ringed with residential housing developments creating a suburban setting in an undeveloped landscape. Residential development can have an effect on the spatial and movement patterns of mammal species and may differ on a larger spatiotemporal scale with specific species (Gehrt 2004).

Though based on a relatively small sample size, the results from this project do shed some light on the mammalian diversity and species interactions on paired lakes and offer important hypotheses for future research in this area. Further monitoring and larger sample sizes may be warranted to come to more definitive conclusions.

Aldo Leopold considered maintenance of carnivores a critical test to society's commitment to conservation (Meine 1988). Though current restoration projects will restore shoreline vegetation, time will tell if this will be adequate to increase mammalian diversity and abundance on high-development lakes.

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Table 2.1. 2008 snow tracking survey lake characteristics in Vilas County, Wisconsin (WDNR 2005,). Low-development lakes (<10 houses/km, mean = 2.10 ± 0.64) are matched with high-development lakes (≥ 10 houses/km, mean = 23.45 ± 2.69) by surface area, lake type (drainage, seepage, spring fed), and perimeter of shoreline. Paired lakes are sequenced top to bottom.

Development	Lake	Surface Area ha	Type	Perimeter m	House Density/km
Low	Escanaba*	119	DG	8135	0.37
	Jag*	158	SE	4935	1.4
	White Sand	220	DG	9881	5.8
	Lac Du Lune	172	SE	13724	2.0
	Erickson	106	DG	3570	0.5
	Nebish	40	SE	4295	0.2
	Palmer	257	DG	10617	3.1
	Round	47	DG	3586	0.3
	Little John	67	SP	5369	2.1
	Laura	242	SE	8239	5.2
High	Found*†	132	DG	6362	16.7
	Moon*†	124	SE	3190	14.7
	Lost	297	DG	7537	26.2
	Carpenter	135	SE	5492	18.0
	Brandy	110	DG	3470	29.8
	Vandercook	38	SE	3257	13.8
	Eagle	231	DG	7490	30.2
	Johnson	32	DG	3546	26.2
	Towanda	59	SE	6119	18.7
	Stormy	211	SE	7595	40.2

† = Lakes currently under shoreline restoration.

* = Lakes with digital remote camera deployed

Lake type: DG = drainage, SE = seepage, SP = spring fed (WDNR 2005)

Table 2.2. Abundance index categories for non-furbearer mammals detected on snow track surveys on ten pairs of low- and high-development lakes in Vilas County, Wisconsin.

Range of mean abundance index values	Abundance Interpretation
0	Absent
0.1-.0.4	Rare
0.5-1.4	Uncommon
1.5-2.4	Common
> 2.4	Abundant

Table 2.3. The total number of furbearer species encountered during snow track surveys on ten pairs of lakes in Vilas County, Wisconsin. Data was collected in January and February of 2008.

Species		Residential Development	
Common Name	Scientific Name	High	Low
Coyote	<i>Canis lantrans</i>	2	32
Wolf	<i>Canis lupus</i>	0	4
Porcupine	<i>Erethizon dorsatum</i>	1	0
Otter	<i>Lontra canadensis</i>	0	8
Bobcat	<i>Lynx rufus</i>	0	4
Fisher	<i>Martes pennanti</i>	0	8
Ermine	<i>Mustele erminea</i>	0	2
Mink	<i>Mustele vison</i>	1	5
Raccoon	<i>Procyon lotor</i>	2	0
Red fox	<i>Vulpes vulpes</i>	9	5

Table 2.4. Other mammals detected during snow track surveys on ten pairs of lakes in Vilas County, Wisconsin. Species were assigned categories based on the average frequency detected on low- and high-development lakes. Categories are (0) absent, (0.1-0.4) rare, (0.5-1.4) uncommon, (1.5-2.4) common, (>2.4) abundant (see Table 2.2). Data was collected during the winter of 2008.

Species		Development		Test Stat	P
Common Name	Scientific Name	High	Low		
Domestic Dog	<i>Canis familiaris</i>	1.5	0.1	3.500*	<0.001
White-tailed Deer	<i>Odocoileus virginianus</i>	2.5	0.6	4.000*	<0.001
Squirrels	<i>Sciuridae</i> spp.	2.2	1.4	1.697	0.107
Micro-tine rodents	NA	0.7	1.1	-1.434	0.169
Eastern Cottontail	<i>Sylvilagus floridanus</i>	1.1	0.1	14.000*	0.003
Snowshoe Hare	<i>Lepus americanus</i>	0.2	1.4	79.000*	0.017

*Nonparametric Mann-Whitney Rank Sum *U*-test.

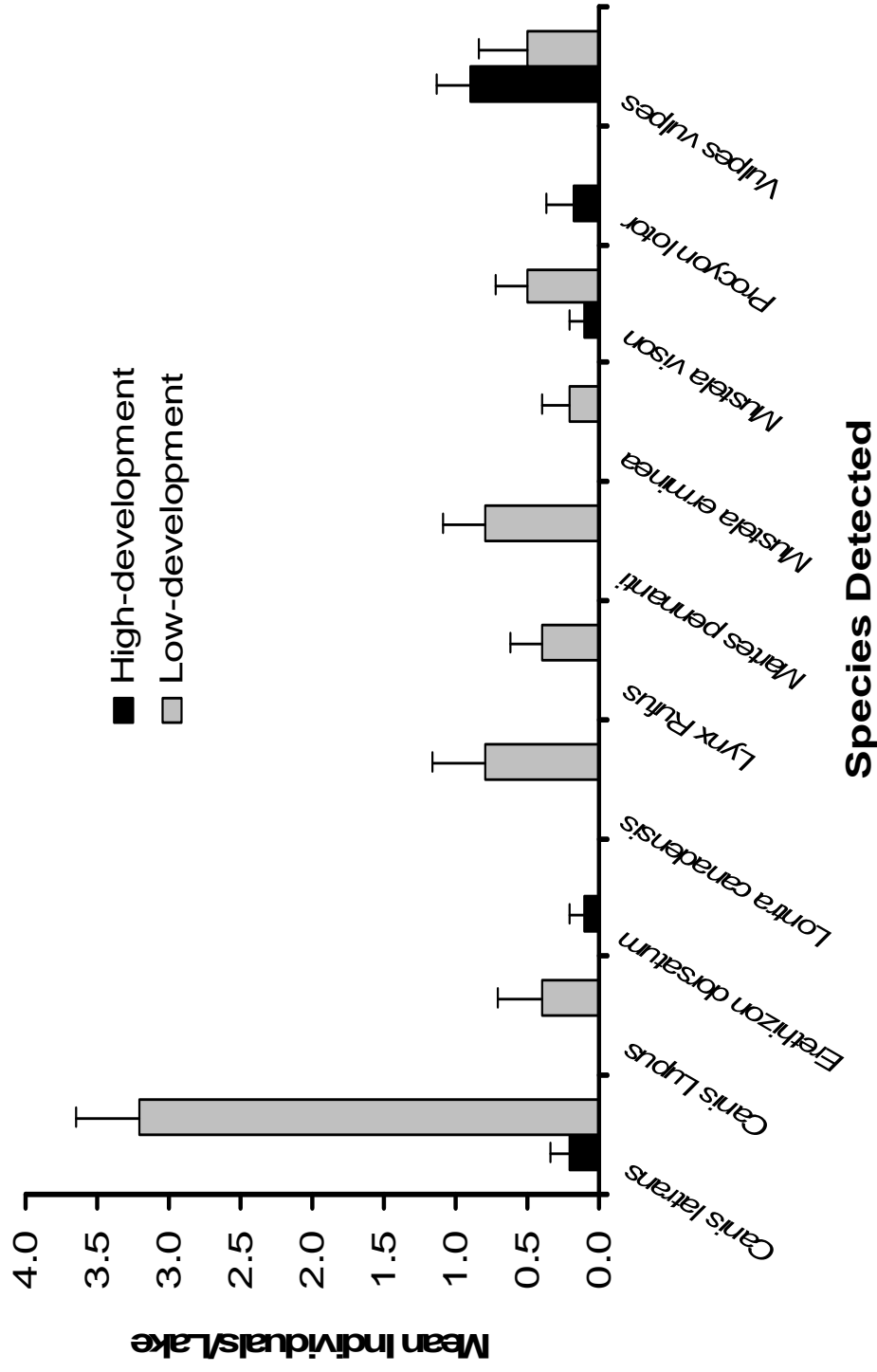


Figure 2.1. The mean and standard error of individual species detected by snow track surveys within pairs of ten lakes each pair containing a low- and high-development lake, in Vilas County, Wisconsin. Data was collected in January and February of 2008.

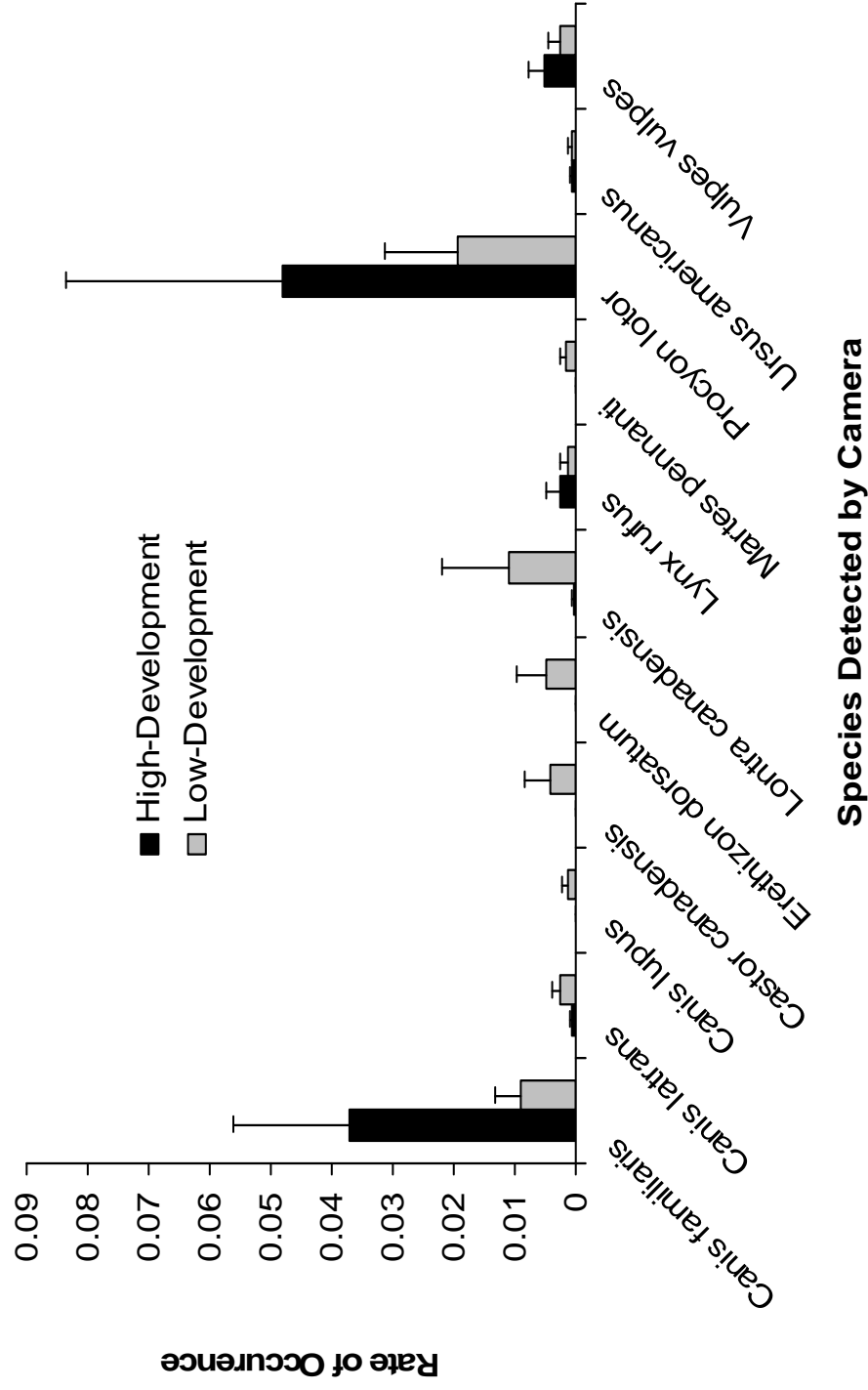


Figure 2.2. Mean rate of occurrence with standard error bars for furbearer species and domestic dog detected by remote camera on two pairs of low- and high-development shoreline lakes in Vilas County, Wisconsin. Data collected from June 2007 to August 2008 (excludes January and February 2008 due to technical problems with cameras).

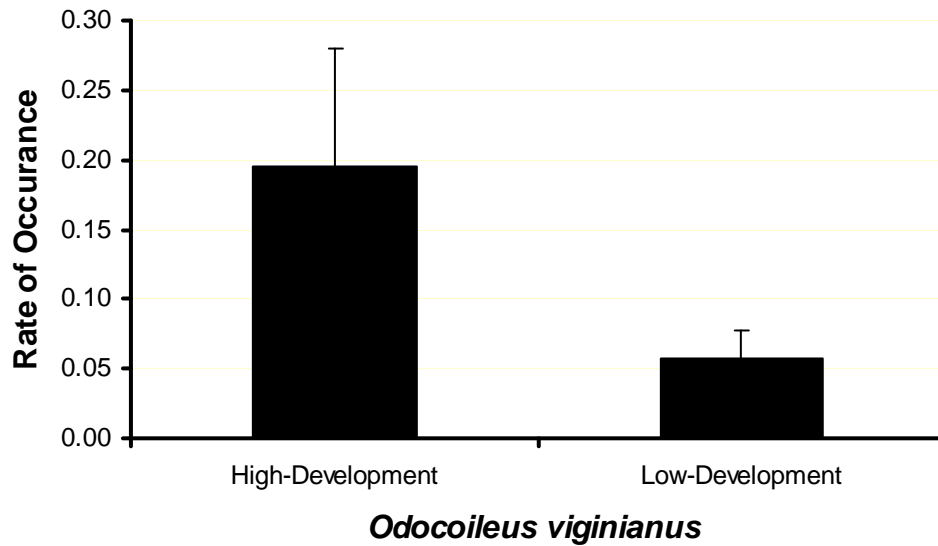


Figure 2.3. Mean rate of occurrence with standard error bars for white-tailed deer (*Odocoileus virginianus*) detected by remote camera on two pairs of matched low- and high-development shoreline lakes in Vilas County, Wisconsin. Data collected from June 2007 to August 2008, excluding January and February 2008.

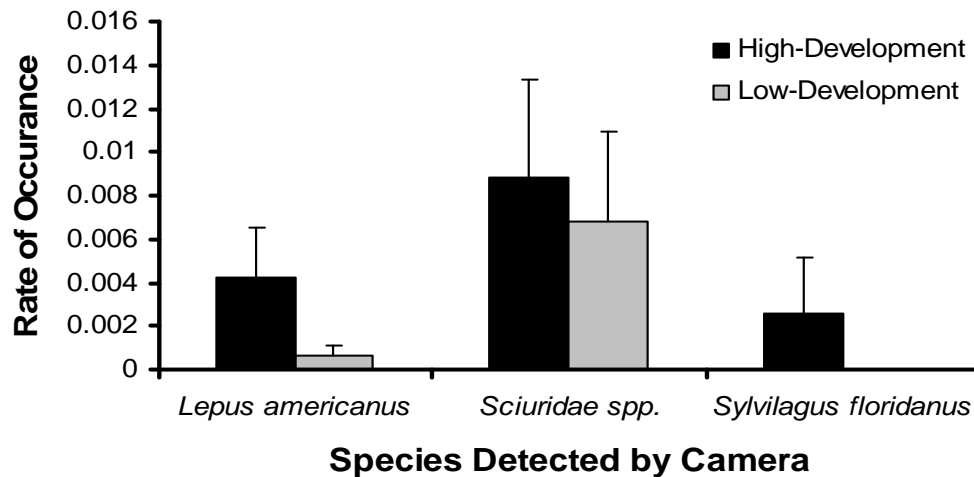


Figure 2.4. Mean rate of occurrence with standard error bars of non-furbearer mammals detected by remote camera on two pairs of matched low- and high-development shoreline lakes in Vilas County, Wisconsin. Data collected from June 2007 to August 2008, excluding January and February 2008.

CHAPTER 3

BASELINE ASSESSMENT OF WILDLIFE HABITAT RESTORATION IN NORTHERN WISCONSIN: THE WISCONSIN LAKESHORE RESTORATION PROJECT

ABSTRACT

Housing development has increased dramatically in the Midwest over several decades with a high concentration around lakes. Humans remove native plants and alter vegetation structure on high-development lakes. Previous research has revealed negative effects to the local fauna and flora species on high-development lakes. Recent lakeshore restoration efforts in Vilas County, Wisconsin were implemented to curtail the negative consequences of housing development on lakeshores. However, little or nothing is known about the success of restoration in reversing the ecological effects of development. A partnership between agencies and academia has launched a long-term research project investigating the ecological benefits of lakeshore restoration. I recruited private landowners on three high-development lakes in Vilas County to participate in restoring shoreline habitat. Landowners allowed me to access their properties to gather data on wildlife species and vegetation structure characteristics in return for free lakeshore restoration services. Restoration efforts were completed on 12 properties on Found Lake from 2007-2008. Assessment of the restoration will be conducted in subsequent years by monitoring wildlife response. In addition, I tested six native shrub species for survival and canopy volume growth rates that were transplanted in the summer from bare root stock and compared them to shrubs planted from nursery containers.

INTRODUCTION

The Midwest region of the U.S. experienced a 146% increase in housing development from 1940 to 2000 with the highest growth rate (596%) occurring in northern Wisconsin (Radeloff *et al.* 2005). Northern Wisconsin contains one the highest density of freshwater glacial lakes in the world, and since 1965 the number of new houses built has increased over 200 % along lakeshores (WDNR 1996, Radeloff *et al.* 2001). Gonzalez-Abraham *et al.* (2007) suggest that lakes are the single most important factor determining both housing density and spatial pattern of housing development in this region. Their results revealed that 41% of human development occurred within 100 m of lakeshores in northern Wisconsin since the 1930s, and most of these buildings were within 50 m of each other, suggesting that even in rural areas, people will tolerate living close to one another on lakes (Gonzalez-Abraham *et al.* 2007). In Vilas County alone, 61% of medium-sized (1000-3000 ft²) houses were within the 100 m of the lakeshores (Schnaiberg *et al.* 2002). This concentration of housing development along lakeshores can fragment wildlife habitat (Theobald *et al.* 1997), alter habitat use and movement patterns, and reduce local biodiversity (Wilcove *et al.* 1998, Czech *et al.* 2000).

Because of increased light and water availability, vegetation along lakeshore forest edges is often more diverse and structurally complex than in closed canopy forest (Harper and MacDonald 2001, Elias and Meyer 2003). Such riparian zones provide critical habitat for a variety of wildlife, protect water quality, and have aesthetic appeal when the shoreline is naturally vegetated (Engel and Pederson 1998). However, removal of vegetation structure along shorelines is often associated with residential development (Christensen *et al.* 1996, Elias and Meyer 2003, Marburg *et al.* 2006).

Some lakeshore residents prefer manicured lawns and scattered trees over a natural riparian vegetation (Macbeth 1992). Such changes to vegetation can change the physical characteristics of lakes and the biological processes that occur near and within them. Several studies in the Great Lakes region have examined the influence of habitat changes associated with residential development on native plants and animals. Lindsay *et al.* (2002) reported foraging guilds of breeding birds differed significantly along inland lakeshore stretches with vs. without housing development; granivorous and omnivorous species were associated with high-development and insectivorous species were associated with low-development lakes. Green frog (*Rana clamitans*) abundance decreased with an increase in shoreline housing density (Woodford and Meyer 2003). In central Ontario, housing development on lakeshores resulted in a decline of small mammal diversity and abundance (Racey and Euler 1982) and mink (*Mustela vison*) behavior and diet was negatively affected (Racey and Euler 1983). In addition, certain piscivorous birds such as the Common Loon (*Gavia immer*), and Osprey (*Pandion haliaetus*) avoid lakes with a high level of human disturbance (Newbrey *et al.* 2005). Lakeshores with more shoreline development have less down woody material (Christensen *et al.* 1996) and aquatic vegetation in the littoral zone (Radomski and Goeman 2001) reducing habitat for waterfowl and fish (Moyle and Hotchkiss 1945, Jennings *et al.* 1999) and decreases fish growth rate and population size (Schindler *et al.* 2000, Sass *et al.* 2006).

The State of Wisconsin has attempted to protect shoreline habitat by implementing ordinances that mandate vegetation cutting standards in a buffer zone along lakeshores. The Wisconsin Shoreland Management Program (WDNR Chapter NR 115) states that vegetation within a buffer zone must be left intact for 35 feet inland from the ordinary

high water mark and no more than 30 feet for every 100 feet of shoreline can be cleared of vegetation. The program recommends that the remaining shoreline be left in a naturally vegetated state. However, many shoreline owners routinely ignore or are unaware of these ordinances and cutting and removal of vegetation from the buffer zone is common.

Some lakeshore owners and local government agencies are interested in restoring high-development lakeshores to a more natural state. Recently, restoration efforts have been conducted on lakeshores within the 35 ft buffer zone on high-development lakes in Vilas County, Wisconsin. However, almost nothing is known about the ecological benefits of lakeshore restoration within the 35 ft buffer zone. Restoration efforts have been shown to improve habitat for breeding birds (Fletcher and Koford 2003) and small mammals (Patten 1997). Moreover, little is known regarding the survival and growth rates of native plant species used in such lakeshore restorations.

A collaboration of Vilas County Land and Water Conservation Department (VCLWCD), Wisconsin Department of Natural Resources (WDNR), Michigan Technological University (MTU), and Wisconsin Department of Agriculture, Trade and Consumer Protection (WDATCP) initiated a long-term (≥ 10 years) research project in 2007 investigating the ecological value of shoreline restoration on riparian and littoral communities in Vilas County, Wisconsin. This restoration project requires participating private property owners to plant native trees, shrubs and ground cover plants within a 35-foot buffer zone along the shoreline. Three high-development lakes (≥ 10 houses/km) were targeted for lakeshore restoration efforts in Vilas County. WDNR and MTU

personnel solicited property owners to participate by offering restoration to their lakeshore free of charge.

To better understand the dynamics and benefits of lakeshore restoration, this project is an ongoing effort to compare wildlife and vegetation communities between restored and reference lakeshores, and to monitor specific bare root shrubs species for survival and growth rates in restored areas.

The objectives of this research are to: 1) gather data on vegetation structure, density and composition, breeding bird and small mammal diversity, species richness and abundance before and after restoration efforts, and monitor the response of wildlife in subsequent years (≥ 10 years), 2) compare and contrast bare root plant survival and canopy volume growth rates used on restoration projects, 3) and provide best management restoration practices for lakeshore landowners and agencies.

This project is ongoing and the data presented in this chapter represent the results from the first year's restoration projects.

METHODS

Experimental Design

The Before-After-Control-Impact-Paired (BACIP) design was implemented to contrast 500 m of an impact (restoration lakeshore) with 500 m of a control (control lakeshore) on high-development lakes and, additionally, a paired low-development lake (reference lakeshore). The reference lakeshore are paired with restoration lakeshore with similar attributes (surface area, substrate, and lake type) as the restored shoreline and used as a reference. This design is commonly used for impact assessment with subsamples taken at

all sites before and after treatment (Green 1979, Stewart-Oaten *et al.* 1992) and sites are sampled simultaneously over time (Stewart-Oaten *et al.* 1986).

MTU, VCLWCD, and WDNR staff developed site specific restoration plans for each participating property owner on the restoration lakeshores. Each plan was designed to provide the maximum ecological value while still integrating property owners' land-use preferences. Native plant species were used in restoration plans and soil erosion issues were addressed with various bioengineering techniques. All bioengineering techniques were approved by WDATCP engineers. Once all parties agreed on plans, property owners signed a ten-year contract with VCLWCD which states that the restoration area will not be manipulated by landowners for a ten-year period. Planting densities were based on recommendation from the Wisconsin Biology Technical Note 1: Shoreland note (NRCS 2002). A local nursery (Hanson's Garden Village, Rhinelander, Wisconsin) supplied all plant material. A 2.4 m high nylon fence was erected around all restoration sites to protect plants from herbivory (Opperman and Merenlender 2000, Holmes *et al.* In Press).

Study Area

This project was conducted on three matched pairs of lakes (Table 3.1) in a forested landscape on deep sands with pitted glacial outwash in Vilas County, Wisconsin (Stearns and Likens 2002). Vilas County encompasses a 2636 km² area along the state's northern border with the Upper Peninsula of Michigan. Vilas County contains 1320 pitted outwash glacial lakes ranging in size from 0.1 to > 1500 ha and covering 16% of the county's area (WDNR 2005), and 53% of the area is in private ownership (Schnaiberg *et*

al. 2002). The land cover is a mixture of bogs, northern wet forest, boreal forest, and northern dry to northern xeric forest (Curtis 1959).

The three high-development lakes targeted for restoration are located within the Northern Highland Lake District. All three lakes were home to several fishing resorts in the past. On Found Lake (T40N, R8E, Section 14) and Lost Lake (T40N, R8E, Section 10) these resorts have been sold to developers and parceled for resale to individuals for seasonal or permanent homes. In addition, recent construction of larger dwellings has occurred with little or no regard for a vegetated buffer zone near the shoreline, though mature trees are often maintained or preserved. Found Lake's north shoreline suffered a disturbance from a wind storm in 1999 which toppled hundreds of mature trees (see Chapter One). The third lake, Moon Lake (T40N, R8E, Section 25) is currently home to Moon Beach Camp, which is affiliated with the United Church of Christ. The restoration and control sites on Found Lake are located along 1500 m of the north-northeast shoreline, Lost Lake 1500 m along the south-southwest shoreline, and Moon Lake 1200 m along the north and east shorelines, property of Moon Beach Camp. Reference lakes were paired with high-development lakes according to similar aspect and substrate of restoration lakeshores.

Restoration efforts were initiated on Found Lake in the summers of 2007 and 2008 with 12 individual property owners. Moon Lake restoration was started in the fall of 2008 and is currently ongoing. Lost Lake restoration is pending and restoration should occur in 2009 and 2010.

Vegetation Sampling

Each shoreline targeted for restoration, control, and reference was divided into 50 m segments using GIS (Geographic Information System) software and was labeled with numbers (1, 2, 3,). Each 50 m segment was divided into 10 m sub-segments and coded as follows 1a, 1b, 1c, 1d, 1e, 2a, 2b, 2c, 2d, 2e, etc (1a through 1e represents the first 50 m segment and 2a through 2e the second segment). The intention was to survey a $10\text{ m} \times 10\text{ m}$ (1 are = 100 m^2) vegetation plot every 50 m. An attempt was made to survey every point that fell on the letter “a” (i.e. 1a, 2a, 3a). Each survey plot always began to the right of the point (start of $10\text{ m} \times 10\text{ m}$ plot at point, end of plot to the right when facing shore from the lake). However, if a point fell on a resident’s usage area or access area to the lake ($30' \times 35'$) then a sub-segment was randomly picked, using a random number table, until the vegetation plot did not fall on usage or access area. For example, if plot 3a fell on a usage area then another point was randomly picked such as 3b, 3c, 3d or 3e. A metal rebar ($1.25\text{ cm} \times 15\text{ cm}$) with a 1.25 cm flat washer welded to one end was used for a permanent survey stake and driven flush with the ground at an inland corner of the vegetation plot. The metal stakes can be relocated in subsequent years with a metal detector to resample the plots. Each plot was divided into four $5\text{ m} \times 5\text{ m}$ subplots (Figure 3.1).

All living trees and woody plants in the plots that were $\geq 5\text{ cm}$ diameter breast height (dbh; 1.37 m) within restored, control and reference lakeshores were identified to species and their dbh recorded. Trees that fell on plot lines were measured if 50% of the tree at dbh was within the plot. Two subplots were randomly chosen and all live deciduous and coniferous saplings and shrubs that were $\geq 30\text{ cm}$ in height but having ≤ 5

cm dbh were identified to species and tallied. Tree, sapling, and shrub density were calculated for each plot and the means computed for each treatment. In order to measure canopy cover, gap fraction was calculated using a digital hemispherical photograph (Nikon Cool Pix 5000 and FC-E8 fisheye converter) at 50 cm above the ground and centered in each plot. Gap fraction is defined as a fraction of pixels classified as open sky in a region in the image [*Gap fraction* = number of pixels classified as sky in a region/total number of pixels in a region (WinScanopy 2005)]. Digital hemispherical photographs were analyzed with the software WinSCANOPY (WinScanopy 2005).

I used a density board or checker board (0.5m x 3m) with 10 cm × 10 cm grid squares to measure understory foliage density and to estimate the percent cover at four different height categories (0-0.3 m, 0.3-1 m, 1-2 m, 2-3 m). Squares at least 50% obstructed by green vegetation were counted and converted to a relative index of percent cover (Bibby *et al.* 1992). The density board was placed at 1 m, 5 m, and 9 m inland from the shoreline at the edge of each plot. This gave a height and density profile within each plot at three different distances from the shoreline. Each measurement was taken 10 m away while observer and density board moved perpendicular away from the shoreline. Vegetation sampling was conducted on Found, Escanaba, Jag and Moon Lakes in 2007, while Lost and White Sand Lakes were sampled in 2008.

Avian Surveys

A dependent, double-observer 250 m line transect (LT) method was used to characterize breeding bird communities along targeted lakeshores. Transects were placed in three lakeshore treatments: 1) high-development lake, control, 2) high-development lake, impact (restored), and 3) low-development lake, paired (reference). Volunteers from the

North Lakeland Discovery Center Bird Club conducted the bird surveys concurrently on each pair of lakes in two separate visits in June. Transects followed the shoreline, and all birds seen and heard on the terrestrial side of the transect were recorded and tallied. Bird surveys were conducted between 0600 and 1000 hrs. Surveys were not conducted during rain or high winds (>20 km/hr), or when wave noise influenced bird song rates and/or detectability. Bird species diversity, richness and abundance were calculated for each treatment. Bird surveys were conducted on Found, Escanaba, Jag and Moon Lakes in 2007 and 2008, while Lost and White Sand Lakes were surveyed only in 2008.

Small Mammal Surveys

Small mammal surveys were conducted in late June to late July of 2007 and 2008.

Sherman traps were placed parallel with each other and with the shoreline and within 10 m of the shoreline along a 250 m long transect. One line of traps was placed within 1 m of the shoreline and the second line was approximately 10 m from the shoreline. Traps were placed at 10 m intervals along both trap lines for a total of 52 traps per transect. Each trap was baited with a mixture of rolled oats and peanut butter, and a handful of polyethylene fiber was added for bedding. Traps were covered with a ½-gallon cardboard milk container that provided captured animals with additional protection from inclement weather.

Traps were opened for 3 nights at each shoreline, checked every morning and closed, and reopened in the late evening hours. I alternated traps every other week between pairs of lakes, which resulted in two trapping sessions per treatment (lakeshore). All small mammals were identified to genus and species when possible. Data on sex, reproductive condition, overall condition, and weight were recorded for each captured

animal; all animals were released at point of capture. Small mammal trapping was conducted on Found, Escanaba, Jag and Moon Lakes in 2007, while Lost and White Sand lakes were sampled in 2008. Each pair of lakes was trapped concurrently. If a trap door was closed and no animal captured, it was not tallied as a trap night. Small mammal diversity, richness, and abundance were calculated for each treatment.

The Deer Mouse (*Peromyscus maniculatus*) and the White-footed Mouse (*Peromyscus leucopus*) were likely to be captured on the study area; because morphological characteristics were similar, field identification was difficult and unreliable; all *Peromyscus* species captured in 2007 were recorded to genus only. In 2008, buccal swab samples were taken from all captured *Peromyscus* individuals. All buccal swap samples ($n = 86$) were genetically analyzed and identified to species at Marshfield Clinic, Marshfield, Wisconsin.

Shrub survival and growth: Gravel Culture vs. Container

I compared the survival and plant growth for several bare root native shrub species (Table 3.2) that were established in a culture of 2.5 cm diameter gravel at a local nursery (Hanson's Garden Village, Rhinelander, Wisconsin). This technique was relatively new and provided bare root plant stock to restoration projects throughout the planting season (Starbuck *et al.* 2005). Bare root shrubs, defined as gravel culture (GC), can be cost efficient, for restoration projects, costing approximately half to $\frac{3}{4}$ of the price of traditional container plants (CT) (pers. comm. Brent Hanson). A comparison of CT vs. GC for six species of shrubs planted on Found Lake in 2007 ($n = 120$) and was increased to 17 species in 2008 (Table 3.2). Each GC shrub was matched with a CT shrub of the same species. The pair was planted within ≤ 2 m of each other, and each shrub was

identified with a unique numbered metal tag. All CT shrubs were delivered in 3-gallon nursery containers. For each shrub, one liter of organic compost was incorporated into the soil before shrubs were planted. Cedar mulch was placed around the basal area extending out 15 cm from base of shrubs, at approximately a depth of five cm, and shrubs were irrigated as needed throughout the growing season. Height and canopy area of each shrub were measured at the time of planting and one year later (see Chapter One). Plant survival (alive or dead) was recorded one year after planting. A subset of matched shrubs ($n = 22$) was planted outside of the fenced restoration areas to measure the impact by local herbivores.

Data analyses

Avian and small mammal.—Shannon's Index of species diversity (H') (Magurran 2004) was calculated for each lakeshore (restoration [Impact], control, and reference [Paired]). I used one-way ANOVA to compare the H' means between targeted lakeshores for avian, small mammal, and vegetation density data. The Kolmogorov-Smirnov test was used to test for normally distributed samples. Arcsine and natural logarithms were used to transform independent variables to meet normality assumptions. When the transformation of variables was unsuccessful in producing a normal distribution, the nonparametric Kruskal-Wallis test was substituted.

Shrubs.—A two way ANOVA test was used to compare the mean growth rates for paired shrubs in fenced and unfenced areas. The Tukey method was used for all pairwise multiple comparison tests for nonparametric data. A paired t -test was conducted on each species of paired shrubs within the fenced area to determine the difference in growth rate over one year. If test assumptions were not met for shrub data, then a Wilcoxon

Signed Rank Test was used. All analyses were conducted using SigmaStat 3.5 software (Systat Software Inc.2006) and significance levels were set at $\alpha = 0.05$.

RESULTS

Restoration efforts

Restoration activities occurred on 12 private properties on Found Lake in 2007 and 2008 which approximated a 6,720 m² restored area within the lakeshore buffer area.

Approximately 12,324 ground cover plants (grasses, sedges and wildflowers) 1,941 shrubs and 220 trees were planted within this lakeshore buffer area. Approximately 1,371 m of 2.4 m high nylon fence was erected around the restoration area.

Vegetation Sampling

Though tree, sapling, and shrub densities were consistently higher on reference lakeshores relative to control and restoration lakeshores, there was no significant difference between them ($P = 0.872 - 3.992$; Table 3.3). In addition, there was no significant difference in gap fraction among shorelines ($P = 0.191$; Table 3.3).

Understory foliage density tended to be higher on reference lakeshores at all height categories but no significant differences were found among lakeshores ($P = 0.665-2.715$; Table 3.3).

Avian Surveys

In 2007, 184 individual birds were recorded representing 46 species across treatments on Found, Escanaba, Jag and Moon Lakes. Twenty-seven species along the control lakeshores accounted for 25% of all individuals recorded, 40 species along the impact lakeshores accounted for 45% of all individuals, and 37 species along the reference shorelines accounted for 35% of all individuals. In 2008, 435 individuals were detected

representing 50 species on the above lakes plus the addition of Lost and White Sand Lakes. Thirty-seven species in the control lakeshores accounted for 37% of all individuals recorded, 37 species in the restoration shorelines accounted for 31% of all individuals, and 46 species in the reference shorelines accounted for 32% of all individuals. A summary of total bird abundance, species richness, Shannon's Index of Diversity (H'), and evenness is presented by lake, treatment, and year in Table 3.4.

There was no significant difference in bird species diversity among treatments for both. Grouping birds by foraging, diet, and nesting guilds found no significant differences among treatments for both years. However, power to detect differences was low due to small sample sizes. A summary of bird guilds is presented by lake, shoreline and year in Tables 3.5-3.7.

Small Mammals

In 2007, 186 total captures of seven species were recorded from 1719 trap nights on all lakeshores transects on Found, Escanaba, Jag and Moon Lakes. Five species in the control lakeshores accounted for 17% of all individuals captured, 5 species in the restoration lakeshores accounted for 36% of all individuals captured, and 7 species in the reference lakeshores accounted for 47% of all individuals captured. In 2008, 408 total captures of 11 species were recorded from 2832 trap nights on the above lakes plus Lost and White Sand Lakes. Ten species in the control lakeshores accounted for 30% of all individuals recorded, 8 species in the restoration lakeshores accounted for 28% of all individuals, and 9 species in the reference lakeshores accounted for 42% of all individuals. A summary of small mammal captures, species richness, H' , and evenness is presented by lake, lakeshores, and year in Table 3.8. There was no significant difference

in species diversity among lakeshores for both years for small mammal surveys (2007 $P = 0.933$; 2008 $P = 0.536$). However, power to detect differences (0.050) was low due to small sample sizes.

Of the 86 genetic samples collected, 66 yielded positive identification of deer mice (*Peromyscus maniculatus*) ($n = 52$) and white-footed mice (*Peromyscus leucopus*) ($n = 14$). Eighty-three percent of deer mice were captured on reference lakeshores, 15% were captured on control lakeshores, and 2% captured on restoration lakeshores. Twenty-eight percent of white-footed mice were captured on reference lakeshores, 36% were captured on control lakeshores, and 36% captured on restoration lakeshores. Abundances of deer ($P = 0.062$) and white-footed mice ($P = 0.967$) were not significantly different between lakeshores. The power of the performed test (0.437-0.050) is below the desired power of 0.800. However, there is evidence suggesting that deer mice may be associated with reference lakeshores (Figure 3.2). In addition, evidence suggests that eastern chipmunks (*Tamias striatus*) are more abundant control and restoration lakeshores (Figure 3.3) however there were no significant differences among lakeshores for both years (2007 $P = 0.533$; 2008 $P = 0.113$). The Least Chipmunk (*Tamias minimus*) was captured 27 times in 2007, all on restoration lakeshores which occurred only on Found Lake. In 2008, the Least Chipmunk was captured 82% of 38 captures on the restoration lakeshores and 8% captures occurred on control lakeshores of Found Lake. A summary of small mammal captures for both years is presented in Table 3.9.

Shrub survival and growth

There was no significant difference in the change of percent canopy volume between GC and CT shrubs ($P = 0.682$) however, there was a significant difference in percent canopy

volume ($F_{3, 236} = 11.867$, $P = <0.001$) between fenced (mean = 0.729 ± 0.104) and unfenced shrubs which experienced a negative growth rate (mean -0.111 ± 0.220). A paired t – test between GC and CT revealed a significant difference for two shrub species, common ninebark (*Physocarpus opulifolius*) ($n = 16$, $W = 78.000$, $P = 0.044$) and snowberry (*Symphoricarpos Albus*) ($n = 40$, $W = -308.000$, $P = 0.039$) in mean growth over one year. Common ninebark CT had a four times higher percent change in canopy volume (Mean = 2.457 ± 0.678) compared to GC shrubs (mean = 0.604 ± 0.345), suggesting that the CT out performed the GC. On the other hand, snowberry GC grew three times more (mean = 0.278 ± 0.0953) more than the CT shrubs (mean = 0.097 ± 0.084).

DISCUSSION

When large scale systems are studied, it can be impractical and sometimes impossible (i.e. cost) to include the ideal number of replicates (Green 1979, Hulbert 1984). Most restoration projects are conducted on a site-specific basis with no replication; the effect of the restoration is indicated by the difference on site before and after treatment (Green 1979, Underwood 1994). However, the problem that arises from this design is that observed changes may be the result of natural variation over time and not from the restoration efforts (Hulbert 1984). One of the common shortcomings of the BACIP design is the lack of replications which limits the inference drawn from the results (Hulbert 1984). To counter this problem, Underwood (1991) suggested taking measurements at multiple times before and after the restoration. With this in mind, the results of the vegetation sampling, avian and small mammal surveys from this project

should be interpreted as before-restoration data because restoration on Found Lake was initiated in 2007 and continued in 2008, providing two years of data prior to restoration.

Recent investigations of residential shoreline development on terrestrial and aquatic communities (e.g., Elias and Meyer 2003, Lindsey *et al.* 2002, Woodford and Meyer 2003) found that substantial physical and biological differences between developed and undeveloped shorelines. For example, Elias and Meyer (2003) reported a reduction of sub-canopy and shrub layer coverage on high-development lakes compared to low-development lakes. They found a two-fold increase in shrub coverage and half as much tree coverage on low-development lakes compared to high-development lakes (Elias and Meyer 2003). Here, we found approximately three times the density on undeveloped reference lakeshores compared to control and restoration lakeshores. Tree and sapling densities were also higher on reference lakeshores. Undeveloped referenced lakeshores also had higher foliage density at all height categories, a result similar to that found by Robertson and Flood (1980). Robertson and Flood (1980) found lower vertical structural diversity of foliage on high-development lakes in southern Ontario, Canada. However, it is important to note that in our study, Found Lake experienced a natural wind disturbance event in 1999 (see Chapter 1). It is well known that understory vegetation densities and structure increases after canopy disturbance (Oliver and Larson 1996). Thus, Found Lake may be going through an early successional period relative to the high-development along the lakeshores. Furthermore, several property owners on Found Lake own over 100 ft of shoreline (the minimum length stated in WDNR Chapter NR 115). Such properties have less human disturbance compared to properties with the minimum

requirement of 100 ft (pers. obs.). Further investigation at the micro-site level may reveal more robust results.

It is well known that riparian areas offer diverse habitat features and niches for many bird species (Naiman *et al.* 1993), and development along riparian areas can have a detrimental effect to bird communities. Lindsey *et al.* (2002) paired high-development lakes with low-development lakes of similar physical characteristics and performed point-counts around the perimeter of each lake to assess bird community structure. Their results revealed that several species and certain resource–selection guilds responded either negatively or positively to lake development. Ground nesting and insectivorous birds were more common on low-development lakes. Granivorous birds had approximately twice the abundance on control and restoration lakeshores as they did on reference lakeshores. As with the Lindsey *et al.* (2002) study, we found no significant difference in species diversity between lakeshores. However, unlike Lindsey *et al.* (2002), we found no differences in nesting, foraging and diet guilds among lakeshores. There is evidence suggesting that certain ground nesting birds are more abundant on reference lakes. For example, Black-and-White Warbler (*Mniotilta varia*) and Ovenbirds (*Seiurus aurocapillus*) occurred twice as often on reference lakes as on control and impact shorelines. Lindsey *et al.* (2002) reports the Black-and-White Warbler was associated with low-development lakes. The presence of species diversity around development raises some important questions about habitat-specific reproductive success and productivity along developed vs. undeveloped shoreline. Little is known about the correlation of nest predation rates with low-and high-development lakes. Previous

studies suggest that an increase of raccoon (*Procyon lotor*) and feral cats (*Felis catus*) predation rates are associated with human development (Schmidt and Whelan 1998).

Regarding small mammals, our findings are similar to those of Racey and Euler (1982) in central Ontario. In their study, eastern chipmunks were associated with higher residential density along inland lakeshores. In our study, the high numbers of eastern chipmunks on control and restoration lakeshores compared to the reference lakeshores suggest eastern chipmunks are also associated with high-development lakeshores.

Secondary products of residential development such as bird feeders and human garbage may be important to eastern chipmunks as a source for supplemental food. The deer mouse was the most frequently captured species on reference lakeshores. Racey and Euler (1982) reported that deer mice abundance was negatively correlated with human development in central Ontario, Canada. The inverse relationship between deer mouse abundance and lake development suggests the same maybe true in northern Wisconsin. The presence of white-footed mice also raises additional questions. Historically, white-footed mice were found in the southern three quarters of the state with a preference for deciduous forests (Jackson 1961). Currently, it may be moving slowly northward with the habitat alterations, climate change, and/or forest management practices.

Using bare root shrubs is not a new practice in restoration projects. Traditionally, bare root shrubs were used during the period from frost-free soil to bud break in the spring and defoliation to frozen soil in the fall (Starbuck *et al.* 2005). Bare root nursery stock can be cost efficient and provide handling ease and soil conservation as compared to container nursery stock (Starbuck *et al.* 2005). However, it has a restrictive time frame for use, a slower establishment time (Johnson *et al.* 1984), and greater susceptibility to

desiccation during transporting and planting (Starbuck *et al.* 2005). Starbuck *et al.* (2005) looked at using gravel as a medium to extend the use of bare roots throughout the summer months. They investigated this technique for red oak (*Quercus rubra*) and green ash (*Fraxinus pennsylvanica*) and reported no mortality. Our study investigated this technique on six native shrubs at a local nursery (Hanson's Garden Village, Rhinelander, Wisconsin) and integrated them into restoration projects as gravel culture nursery stock. The results overall revealed no significant difference in GC and CT across species. Ninebark was the only shrub that did not fair as well as other species used for GC. Ninebark can grow on sandy, gravelly, rocky soils, can be found along banks and lakeshores (Soper and Heimburger 1994), and is highly recommended by county conservationist and local nursery personnel. Additional investigation of this shrub is warranted. The shrubs in the unfenced area suffered from white-tailed deer (*Odocoileus virginianus*) herbivory, and shrub growth was drastically reduced. Similar findings were reported by Opperman and Merenlender (2000) where restoration of saplings in riparian zone had a higher rate of survival in enclosures compared to control areas, and 97% of saplings in control areas displayed leaf and stem damage characteristics of deer browse. Furthermore, Holmes *et al.* (In Press) investigated the survival of Canada yew (*Taxus canadensis*) for four growing seasons and reported that deer exclusion had the most influence on survival. Restoration projects where there is high deer abundance should install an abatement system to reduce herbivory and increase growth and survival of plantings (Opperman and Merenlender 2000, Holmes *et al.* In Press). Recent research in the area revealed high abundance of white-tailed deer on high-development lakes (see Chapter Two).

A human affinity for settlement near water appears widespread and in northern Wisconsin, this pattern of residential development has a long tradition. By 1931, summer homes were already present on most of the accessible lakes in the region (Murphy 1931). Humans like to live in open and natural-looking areas (Gobster and Rickenbach 2004) and open water acts as a center of organization within the landscape (Naiman 1996). However, this clustering of development causes habitat fragmentation and displaces wildlife. In many ecosystems, riparian areas play a disproportionate role in maintaining biodiversity and ecosystem functions (Naiman *et al.* 1993).

With the current interest in lakeshore restoration this study provides valuable ecological information to agency personnel and practical restoration techniques to landowners and restoration practitioners, and should enlighten policy makers. This study is one of the first of its kind in the area. Future research should be designed to provide insight into how specific land use patterns associated with lakeshore development and specific human activities influence ecological communities.

The challenges of conserving and restoring the intricate web of life was the subject of a quote from Dobson *et al* (1997, p 521): “There is a direct analogy with engineering: It is a relatively straightforward exercise to take apart an ecosystem or an automobile engine, yet quantifying the relative number of parts in an automobile engine (or an ecosystem) tells us little about how it functions. In contrast, reassembling the engine (or the ecosystem) will reveal a deeper level of understanding of how each of its components functions.”

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Table 3.1. Characteristics of restoration and reference lakes in Vilas County, Wisconsin (WDNR 2005,). Low-development lakes (<10 houses/km) are paired with high-development lakes (≥ 10 houses/km) by surface area, lake type (drainage, seepage, spring fed), and perimeter of shoreline. Paired lakes are in order as seen below.

Development	Lake	Surface Area ha	Type ^a	Perimeter m	House Density/km
Low	Escanaba	119	DG	8135	0.37
	Jag	64	SE	4935	1.4
	White Sand	220	DG	9881	5.8
High	Found	132	DG	6362	16.7
	Moon	50	SE	3190	14.7
	Lost	297	DG	7537	26.2

^aLake type: DG = drainage, SE = seepage, SP = spring fed (WDNR 2005)

Table 3.2. Shrubs species used to compare difference of survival and plant growth between gravel culture and container nursery stock. Shrubs were planted on restoration projects in Vilas County, Wisconsin.

Shrubs		Year and Total Planted	
Common Name	Scientific name	2007	2008
American Elder	<i>Sambucus Canadensis</i>	12	14
American Hazelnut	<i>Corylus Americana</i>	0	2
Beaked Hazelnut	<i>Corylus cornuta</i>	0	26
Black Chokeberry	<i>Aronia melanocarpa</i>	52	46
Bush Honeysuckle	<i>Diervilla lonicera</i>	0	30
Canada Serviceberry	<i>Amelanchier Canadensis</i>	0	24
Choke Cherry	<i>Prunus virginiana</i>	0	5
Grey Dogwood	<i>Cornus racmosa</i>	30	6
High Bush Cranberry	<i>Viburnum opulus</i>	0	4
Ninebark	<i>Physocarpus opulifolius</i>	42	2
Pin Cherry	<i>Prunus pensylvanica</i>	0	2
Red-osier Dogwood	<i>Cornus Stonelifera</i>	14	24
Nannyberry	<i>Viburnum lentago</i>	0	8
Snow berry	<i>Symphoricarpos Albus</i>	90	38
Staghorn Sumac	<i>Rhus typhina</i>	0	30
Winterberry	<i>Ilex verticillata</i>	0	8

Table 3.3. Vegetation data collected on riparian lakeshore of three paired lakes in Vilas County, Wisconsin. Density was calculated for m² for each shoreline. Gap fraction was determined by digital hemispherical photograph.

Variable	Shoreline (Treatment)	N	Mean	Std. Error	$F_{1,2}$	P
Tree Density	Reference	3	0.151	0.029	3.992	0.111
	Control	3	0.098	0.005		
	Restoration	3	0.081	0.005		
Sapling Density	Reference	3	0.040	0.006	0.872	0.485
	Control	3	0.030	0.007		
	Restoration	3	0.032	0.002		
Shrub Density	Reference	3	0.074	0.050	0.928	0.485
	Control	3	0.026	0.009		
	Restoration	3	0.027	0.011		
Gap Fraction	Reference	3	19.227	4.881	0.191	0.831
	Control	3	21.598	0.530		
	Restoration	3	18.838	3.315		
Understory Foliage Density (%)						
0-0.3 m	Reference	3	66.4	10.2	2.672	0.148
	Control	3	36.9	07.8		
	Restoration	3	44.1	10.1		
0.3-1 m	Reference	3	49.7	13.7	2.715	0.145
	Control	3	23.8	01.4		
	Restoration	3	30.4	03.1		
1-2 m	Reference	3	43.0	17.0	0.714	0.527
	Control	3	25.3	06.1		
	Restoration	3	30.6	04.5		
2-3 m	Reference	3	46.2	16.2	0.665	0.548
	Control	3	29.1	08.1		
	Restoration	3	33.8	05.0		

Table 3.4. Summary of bird species richness (S), total bird abundance (N), Shannon's index of diversity (H'), and evenness (E) separated by lake, treatment and year for three paired lakes in Vilas County, Wisconsin. Lost and White Sand Lakes were not surveyed in 2007.

Lake	Treatment	2007				2008			
		S	N	H'	E	S	N	H'	E
Found ^a	Control	21	36	2.88	0.94	27	53	3.16	0.96
	Restoration	18	31	2.70	0.93	32	55	3.30	0.95
Escanaba ^b	Reference	27	34	3.24	0.98	28	55	3.18	0.96
Moon ^a	Control	14	20	2.56	0.97	18	36	2.71	0.94
	Restoration	18	34	2.79	0.96	15	23	2.61	0.96
Jag ^b	Reference	17	28	2.68	0.95	16	35	2.64	0.95
Lost ^a	Control	NA	NA	NA	NA	22	74	2.80	0.91
	Restoration	NA	NA	NA	NA	22	43	2.97	0.96
White Sand ^b	Reference	NA	NA	NA	NA	27	51	3.11	0.94

^a = High development lake

^b = Low development lake

Table 3.5. Summary of bird foraging guild richness (G), total bird abundance within guilds (N), Shannon's index of diversity (H'), and evenness (E) separated by lake, treatment and year for three paired lakes in Vilas County, Wisconsin. Calculations based on Magurran (2004).

Lake	Treatment	2007				2008			
		G	N	H'	E	G	N	H'	E
Found ^a	Control	7	25	1.67	0.86	7	36	1.67	0.83
	Restoration	6	20	1.52	0.91	9	49	1.49	0.68
Escanaba ^b	Reference	7	32	1.68	0.86	7	43	1.59	0.89
Moon ^a	Control	6	19	1.24	0.69	6	26	1.80	1.00
	Restoration	8	25	1.75	0.84	6	31	1.36	0.76
Jag ^b	Reference	7	23	1.68	0.86	7	20	1.33	0.68
Lost ^a	Control	NA	NA	NA	NA	8	66	1.53	0.74
	Restoration	NA	NA	NA	NA	9	47	1.71	0.78
White Sand ^b	Reference	NA	NA	NA	NA	4	34	1.48	1.07

^a = High development lake

^b = Low development lake

Table 3.6. Summary of bird diet guild richness (G), total bird abundance within guild (N), Shannon's index of diversity (H'), and evenness (E) separated by lake, treatment and year for three paired lakes in Vilas County, Wisconsin. Calculations based on Magurran (2004).

Lake	Treatment	2007				2008			
		G	N	H'	E	G	N	H'	E
Found ^a	Control	5	30	1.23	0.77	5	41	1.21	0.75
	Restoration	4	24	0.94	0.68	6	55	0.95	0.53
Escanaba ^b	Reference	4	32	0.58	0.42	4	41	0.81	0.58
Moon ^a	Control	4	19	1.12	0.81	4	30	0.25	0.18
	Restoration	4	23	1.01	0.73	4	22	0.23	0.17
Jag ^b	Reference	4	20	0.59	0.73	4	29	0.26	0.19
Lost ^a	Control	NA	NA	NA	NA	4	64	1.11	0.80
	Restoration	NA	NA	NA	NA	3	30	0.47	0.47
White Sand ^b	Reference	NA	NA	NA	NA	4	47	0.93	0.67

^a = High development lake

^b = Low development lake

Table 3.7. Summary of bird nesting guild richness (G), total bird abundance within guild (N), Shannon's index of diversity (H'), and evenness (E) separated by lake, treatment and year for three paired lakes in Vilas County, Wisconsin. Calculations based on Magurran (2004).

Lake	Treatment	2007				2008			
		G	N	H'	E	G	N	H'	E
Found ^a	Control	6	25	1.51	0.84	5	38	1.50	0.93
	Restoration	5	23	1.58	0.98	6	55	1.43	0.80
Escanaba ^b	Reference	5	32	1.46	0.90	5	40	1.50	0.92
Moon ^a	Control	6	17	1.53	0.86	5	27	1.28	0.80
	Restoration	6	24	1.62	0.90	7	21	1.73	0.89
Jag ^b	Reference	6	22	1.65	0.92	6	28	1.65	0.92
Lost ^a	Control	NA	NA	NA	NA	5	61	1.36	0.85
	Restoration	NA	NA	NA	NA	5	33	1.50	0.92
White Sand ^b	Reference	NA	NA	NA	NA	6	47	1.62	0.90

^a = High development lake

^b = Low development lake

Table 3.8. Summary of small mammal species richness (S), total small mammal abundance (N), Shannon's index of diversity (H'), and evenness (E) separated by lake, treatment and year for three paired lakes in Vilas County, Wisconsin. Lost and White Sand Lakes were not surveyed in 2007. Calculations based on Magurran (2006).

Lake	Treatment	2007				2008			
		S	N	H'	E	S	N	H'	E
Found ^a	Control	5	27	1.17	0.72	5	32	1.42	0.88
	Restoration	7	56	1.22	0.63	6	79	1.41	0.79
Escanaba ^b	Reference	2	39	0.38	0.55	4	37	0.91	0.79
Moon ^a	Control	3	5	0.34	0.53	5	48	0.89	0.55
	Restoration	3	31	0.34	0.31	4	40	0.73	0.53
Jag ^b	Reference	5	28	1.28	0.79	5	27	0.83	0.60
Lost ^a	Control	NA	NA	NA	NA	5	41	1.05	0.65
	Restoration	NA	NA	NA	NA	5	50	0.42	0.48
White Sand ^b	Reference	NA	NA	NA	NA	4	51	0.75	0.55

^a = High development lake

^b = Low development lake

Table 3.9. Summary of small mammal captures on three paired lakes in Vilas, County Wisconsin.

Species		Lakeshore			
Common Name	Scientific Name	Year	Reference	Control	Restoration
Unk. Mouse	<i>Peromyscus sp.</i>	2007	49	3	1
		2008	63	13	9
Unk. Shrew	<i>Sorex sp</i>	2007	5	2	1
		2008	0	1	0
13-lined Gr.- squirrel	<i>Spermophilus tridecemlineatus</i>	2007	0	0	1
Red Squirrel	<i>Tamiasciurus hudsonicus</i>	2007	1	3	2
		2008	0	5	7
Least Chipmunk	<i>Tamias minimus</i>	2007	0	0	27
		2008	0	7	31
Eastern Chipmunk	<i>Tamias striatus</i>	2007	9	20	45
		2008	21	75	85
Meadow Jumping Mouse	<i>Zapus hudsonius</i>	2007	2	4	10
		2008	15	12	24
Short-tailed Shrew	<i>Blarina brevicauda</i>	2008	1	5	3
S. Red-backed Vole	<i>Clethrionomys gapperi</i>	2008	11	3	0
S. Flying Squirrel	<i>Glauckmys volans</i>	2008	2	1	0
Meadow Vole	<i>Microtus pensylvanicus</i>	2008	1	2	7

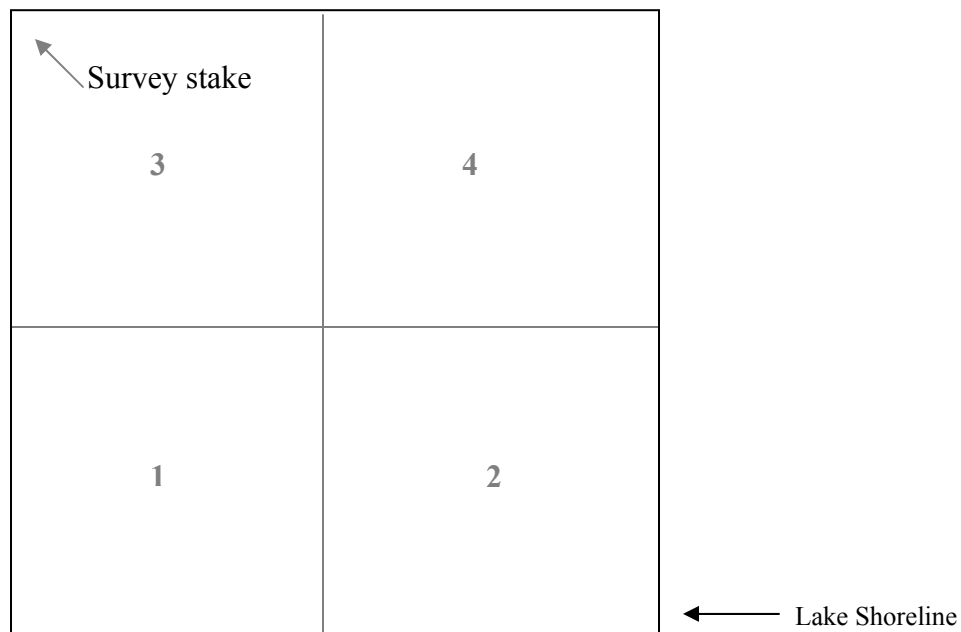


Figure 3.1. Example of 10 m × 10 m vegetation sampling plot with four 5 m × 5 m subplots on research shorelines in northern Wisconsin. All live trees ≥ 5 cm DBH were recorded in plot and live saplings and shrubs were recorded in two subplots. Figure 3.1 shows location of survey stake.

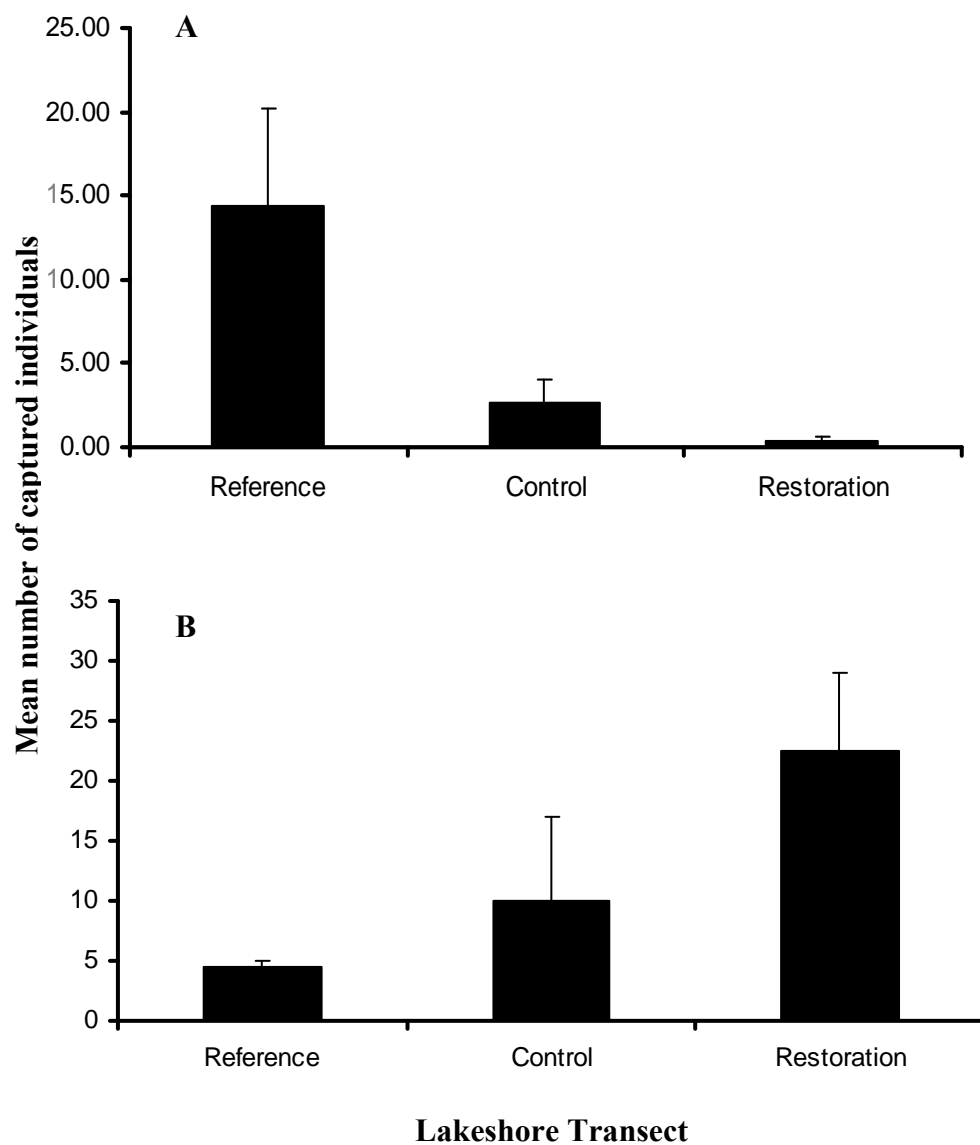


Figure 3.2. Means and standard errors of Deer Mouse (*Peromyscus maniculatus*) (A) and White-footed Mouse (*Peromyscus leucopus*) (B) captured on three paired lakes in Vilas County, Wisconsin in 2008.

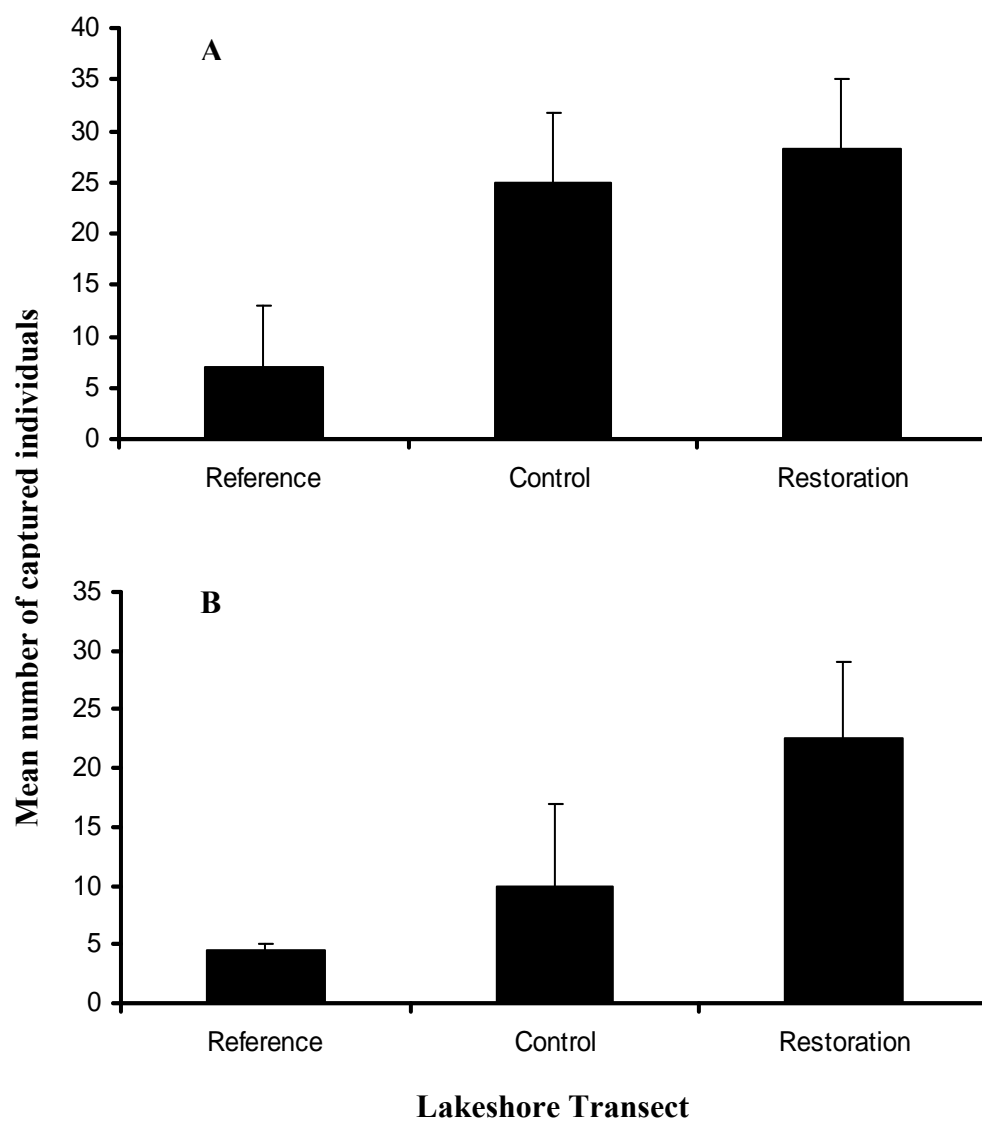


Figure 3.3. Means and standard errors of Eastern Chipmunk (*Tamias striatus*) in 2008 (A) and 2007 (B) captured on three paired lakes in Vilas County, Wisconsin.