WISCONSIN DEPARTMENT OF NATURAL RESOURCES

Bureau of Science Services

Wildlife and Forestry Research Section

PERFORMANCE REPORT

PROJECT W-160-P

STATEWIDE WILDLIFE AND FORESTRY RESEARCH

# MEASURING THE VALUE OF WILDLIFE HABITAT RESTORATION ON NORTHERN WISCONSIN LAKES: THE WISCONSIN LAKESHORE RESTORATION PROJECT

Study SSFL

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Final Report

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**STUDY OBJECTIVES:**

There is a globally significant concentration of glacial lakes in the Northern Highland Ecological Landscape (NHEL) of Wisconsin (Figure 1) http://dnr.wi.gov/topic/landscapes/index.asp?mode=detail&Landscape=12: 4,291 lakes; 1,543 miles of streams, including the headwaters of the Wisconsin and Manitowish-Flambeau-Chippewa river systems. Many lakes are connected by small streams. Rare aquatic species and extensive wetlands occur here. The current land cover is 48% upland forest, 34% wetlands (both forested and non-forested), 13% open water, 5% grassland and open land, and 1% urban; 30% of the land area and 43% of the forestland is in public ownership. Population density is relatively low; 2010 census = 23 persons/square mile. Despite low settlement density, the land cover and hydrology of the region has been dramatically altered the past 140 years (see Background). A high level of demand, and exceptional water quality, has driven the current (2016) real estate value of vacant lakeshore properties of a minimum allowed size (100' x 300') to over $100K. Recent studies have shown that high levels of development can impact the ecological health of NHEL lakes.

In 2007, the first-ever Environmental Protection Agency's National Lakes Assessment (NLA, https://www.epa.gov/sites/production/files/2013-11/documents/nla_newlowres_fullrpt.pdf) confirmed the significance of lakeshore habitat to lake biological health. Nationally, the most widespread stressors measured as part of the NLA were those that affected the shoreline and shallow water areas, which in turn can affect biological condition. Results from the NLA showed that the most widespread of these is the alteration of lakeshore habitat (EPA 2007). That same year, the Wisconsin Department of Natural Resources (WDNR) Bureau of Science Services initiated a long-term study to quantify the ecological benefits of lakeshore restoration on NHEL lakes with shorelines significantly altered by development for housing and recreation in Vilas County, Wisconsin, USA. WDNR partnered with Michigan Technological University (MTU), local conservation departments, contractors and nurseries, landscapers and designers, and lake property owners to rehabilitate lakeshore habitat by planting native trees, shrubs, and groundcover, and installing shore and toe erosion management systems within a ten-meter buffer (35') of the ordinary high water mark (OHWM).

Known as the Wisconsin Lakeshore Restoration Project (WLRP), the project also investigates whether these endeavors led to enhanced wildlife habitat quality on 5 developed lakes (Crystal, Found, Lost, Little St. Germain, and Moon Lakes) within the NHEL (Figure 1). The goal of the project is to establish lakeshore restoration projects on private and public properties and assess whether wildlife habitat structure, wildlife populations, and native plant diversity increase on restored lakeshores and whether the restored habitat is becoming more like that found on paired, undeveloped (reference) lakes. Each paired "Reference Lake" (n=5) was chosen to have similar morphometry, water chemistry, and land cover to the "Developed Lake." Habitat and wildlife measures are made at "Control" (unrestored) and "Treated" (restored) lakeshores on the Developed Lakes and compared to those made at the Reference Lake.

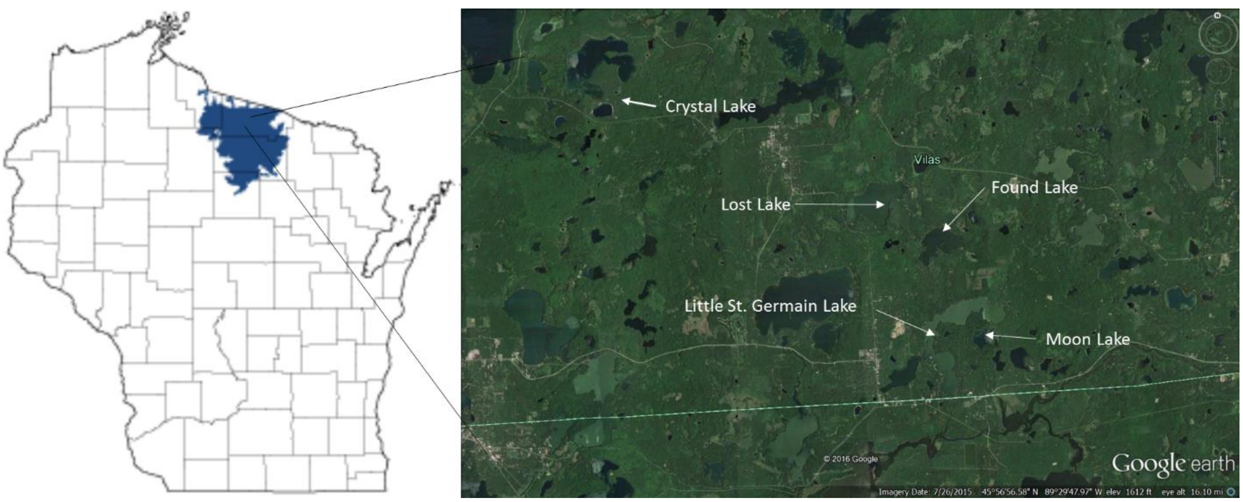


Figure 1. The Northern Highlands Ecological Landscape and 5 developed lakes with restoration projects (http://dnr.wi.gov/topic/landscapes/index.asp?mode=detail&Landscape=12). Restoration sites are within Vilas County, Wisconsin.

Specific objectives include: 1) evaluating lakeshore development impacts in the NHEL by comparing mammalian carnivore diversity and abundance at developed and undeveloped lakes, 2) comparing habitat structure before and after lakeshore restoration projects on developed lakeshores, and comparing results to undeveloped lakeshores, and 3) developing Best Management Practices for Lakeshore Restoration in the NHEL by investigating a) the benefits of Downed Woody Material on restoration projects, b) the cost-benefits of fencing, irrigation, and plant stock source for restorations, and c) the cost-benefits of bare-root vs. container vs. gravel culture trees and shrubs.

This research project was conducted by Michigan Technological University scientists Dan Haskell, Dr. David Flaspohler, and Dr. Chris Webster and staff under contract and in collaboration with Dr. Michael Meyer, WDNR Science Services. A decision was made early in the project to put an “non-government face" on the project as it was thought access to private lands would be better acquired. Mr. Haskell directed field activities and data collection, while the MTU team worked together on data analysis, report writing, and manuscript preparation. Results presented in this report are currently being readied for dissemination to private and government lake managers in the region, as well as to lake associations and private property owners.

**BACKGROUND:**

Rural landscapes in the Midwestern United States have experienced dramatic changes in recent decades due to residential development (Radeloff et al., 2005). Residential development in rural landscapes causes fragmentation and loss of wildlife habitat (Theobald et al., 1997) thus poses a serious threat to biodiversity (Wilcove et al., 1998; Czech et al., 2000). Humans are inclined to construct primary or secondary homes in and around natural areas because they provide amenity values such as 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 (Wisconsin Department of Natural Resources [WDNR], 1996; Radeloff et al., 2001; Gonzales-Abraham et al., 2007).

In 1968, the State of Wisconsin attempted to protect lakeshore habitat by implementing ordinances that mandated vegetation cutting standards in a buffer zone along lakeshores. The Wisconsin Shoreland Management Program (WDNR Chapter NR 115 https://docs.legis.wisconsin.gov/code/admin_code/nr/100/115/Title) states that vegetation within a buffer zone must be left intact for 10.8 m (35 feet) inland from the ordinary high water mark and no more than 9.1m (30 feet) for every 30.5 m (100 feet) of shoreline can be cleared of vegetation. This program recommended the remaining shoreline be left in a naturally vegetated state. However, many lakeshore owners routinely ignore or are unaware of these ordinances which often results in the removal of vegetation structure along shorelines (Christensen et al., 1996; Elias and Meyer, 2003). Wildlife can be affected directly or indirectly by these actions (Ford and Flaspohler, 2010).

Recent studies comparing low- and high-development lakes in Vilas County, Wisconsin, documented declines in the flora and fauna on the more developed lakeshores. 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. Vilas County, which is within the Northern Highland Ecological Landscape (NHEL), encompasses a 2,636-km2 area along Wisconsin's northern border with the Upper Peninsula of Michigan. This is an area of Wisconsin that is home to the third-largest concentration of freshwater glacial lakes on the planet. Approximately 53 percent of the county is privately owned; the remainder is in county, state, and federal forests, or in tribal jurisdiction. While archeological evidence shows Native American settlement of the NHEL lakes and rivers goes back several thousand years, only during the past 140 years have settlers of European origin been dominant. One of the largest timber operations in North America occurred in the NHEL 1880-1910, with over 3 billion board feet harvested and shipped to the growing Midwestern cities – primarily old-growth pine and hardwoods. Once clear cut of timber, much of the land was abandoned by the timber interests, bought up by speculators or homesteaded, with the intent of converting the land to agriculture. The short growing season and poor soils prevented a sustainable agricultural economy from developing, and the land reverted to early successional forestland, much of which today is cropped for lumber and paper products. The abundant lakes proved a recreational draw from 1900 - present, tourists from Midwest cities traveled first by train, then auto, to fishing resorts which grew in scale, comfort, and size through the 1960s. While many lake resorts remain, much of the lake shoreline has been divided into small parcels and developed for seasonal and year round housing. Thus the recent history of most lakeshores in the NHEL has been conversion from virgin pine forests to clear-cut and slash, then the lakeshore remaining in private ownership (much abandoned land in the NHEL became part of state, county, and federal forest lands – and Lac du Flambeau tribal lands encompass many acres in the west) transitioned from farming or secondary forest to recreational and housing development. The future NHEL land cover will likely reflect a patchwork of cropped forested lands and lakeshores that remain in public ownership along with dense settlement around lakeshores and river riparian zones (current zoning permits one residence per 100' of lakeshore), with less dense residential development away from water features.

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 lakeshore restoration on riparian and littoral communities in Vilas County, Wisconsin. This restoration project requires participating property owners to plant native trees, shrubs, and herbaceous plants within a 35-ft (10.7 m) buffer zone along the lakeshore and to correct erosion problems. VCLWCD has funded private property lakeshore restoration projects since 2000 with a cost of $30,000 to $60,000 annually (C. Scholl 2006, VCLWD Conservationist, personal communication). However, little or no evaluation of these past projects has occurred to identify the factors that affect the success of restoration. Lakeshore restoration is a relatively new practice in northern Wisconsin and throughout North America. 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. Quantifying these factors is the primary project goal of this project..

Literature Cited

Christensen, D.L., Herwig, B.R., Schindler, D.E, and Carpenter, S.R. 1996. Impacts of lakeshore residential development on coarse woody debris in north temperate lakes. *Ecol. Appl*., **6**:1143-1149.

Czech, B., Krausman, P.R., and Devers, P.K. 2000. Economic associations among causes of species endangerment in the United States. BioScience, **50**:593-601.

Elias, J.E., and Meyer, M.W. 2003.Comparisons of undeveloped and developed shorelands, northern Wisconsin, and recommendations for restoration. *Wetlands* **23**:800-816.

Ford, M. and D.J. Flaspohler**.** 2010. Scale-dependent response by breeding songbirds to residential development along Lake Superior. *Wilson J. Ornithol.,* **122:**296-306.

Gonzalez-Abraham, C.E., Radeloff, V.C., Hammer, R.B., Hawbaker, T.J., Stewart, S.I., and Clayton, M.K. 2007. Building patterns and landscape fragmentation in northern Wisconsin, USA. *Landscape Ecol*., **22**: 217-230.

Lindsay, A.R., Gillum, S.S., and Meyer, M.W. 2002. Influence of lakehore development on breeding bird communities in a mixed northern forest. *Biol. Conserv*., **107**:1-11.

Naiman, R.J. 1996. Water, society, and landscape ecology. *Landscape Ecol*., **11**:193-196.

Radeloff, V.C., Hammer, R.B., and Stewart, S.I. 2005. Rural and suburban sprawl in the U.S. Midwest from 1940 to 2000 and it relation to forest fragmentation. *Conserv. Biol*., **19**:793-805.

Riera, J., Voss, P.R., Carpenter, S.R., Kratz, T.K., Lillesand, T.M., Schnaiberg, J.A., Turner, M.G., and Wegener, M.W. 2001. Nature, society and history in two contrasting landscapes in Wisconsin, USA: Interactions between lakes and humans during the twentieth century. *Land Use Policy*, **18**:41-51.

Schnaiberg, J., Riera, J., Turner, M.G., and Voss, P.R. 2002. Explaining human settlement patterns in a recreational lake district: Vilas County, Wisconsin, USA. *Environ. Manage.*, **30**:24-34.

Theobald, D.M, Miller, J.R., and Hobbs, N.T. 1997. Estimating the cumulative effects of development on wildlife habitat. *Landscape Urban Plan.*, **39**:25-36.

Weiher, E., S.P. Poet, and K. Voss. 2003. Experimental Restoration of Lake Shoreland in Western Wisconsin. Ecological Restoration 21:186-190.

Wilcove, D.S., Rothstein, D., Bubow, J., Phillips, A., and Loso, E. 1998. Quantifying threats to imperiled species in the United States. *Bioscience,* **48**:607-615.

Woodford, J.E., and Meyer, M.W. 2003. Impact of lakeshore development on green frog abundance. *Biol. Conserv.*, **110**:277-284.

**PERFORMANCE:**

This study quantifies the ecological benefits of lakeshore habitat conservation and restoration by measuring riparian ecosystem health (via biotic surveys) before, during, and after conservation and restoration activities on 5 developed lakes in the Northern Highlands Ecological Landscape in northcentral Wisconsin. Projects restore and conserve native vegetation within the Lakeshore vegetation buffer zone of private and public properties participating in the project, and biologists quantify the benefits of restoration activities by conducting habitat and plant and animal species surveys at reference, control, and treatment lakes before restoration occurs and in subsequent years. Findings support WDNR NR115 Shoreland Management Program.

Shoreland restoration projects have been completed at 5 lakes (Found Lake, Moon Lake, Lost Lake, Little St. Germain, and Crystal Lake) in Vilas County. Work began on Found Lake 2007-2008 in partnership with WDNR, MTU, VCLWCD and WDATCP. A total of 13 landowners participated with the Found Lake project, and an additional 6 property owners participated on the Lost Lake projects 2010-11.

While PR dollars supported the field staff and vehicle costs, material and supplies were obtained by leveraging external funding - $30K/year 2007-2009 and $15K/year 2010-11 was provided by the WDATCP County Conservation Cost-share program. A 3rd large-scale restoration project was implemented on Moon Lake, Vilas County 2009-2010, with external funding for materials and supplies (plants, erosion control materials, rain garden construction, fencing, irrigation system) with grant support ($100K) from the WDNR Lake Protection Program to the Alma/Moon Lake Association. Restoration occurred at one property, the UCC Moon Beach Camp, which houses >2000 visitors annually in 21 lakeside cabins – the project was completed June 2010. A second grant from the WDNR Lake Protection Program ($110K) was received by the Little St. Germain Lake District in fall 2009 allowing for the initiation of a 4th restoration project on Little St. Germain Lake. Over 1000' of shoreline buffer was installed during the summer 2011 with the remaining 700' completed during summer/fall 2012. Finally, WDNR Forestry provided grant money ($60K) to fund the materials and supplies needed for the 5th large lakeshore restoration project, this project at the Northern Highland American Legion State Forest Crystal Lake Campground, in Vilas County. Work began in June 2010 and was completed in June 2011, establishing >1700 linear feet of lakeshore restoration (width 75-100'), as well as a public demonstration site where visitors can walk amongst the restoration and learn of management techniques.

**Table 1. Lakeshore restoration projects, years installed, number of participants, lakeshore restored, plantings, and external funding associated with the Wisconsin Lakeshore Restoration Project**

| Restoration Site | Year | Participants | Lakeshore Restored | Trees Planted | Shrubs Planted | Forbs, grasses/sedges, ferns | External (non-PR) Funding |
|---|---|---|---|---|---|---|---|
| Found Lake | 2007-2009 | 13 property owners | 1600 linear ft, 56,000 sq ft | 235 | 1907 | >7000 | $60,000 |
| Lost Lake | 2009-2011 | 7 property owners | 900 linear ft, 32,000 sq ft | 154 | 576 | 5600 | $30,000 |
| Little St. Germain Lake | 2010-2012 | 9 properties, 6 owners | 1800 linear ft, 138,000 sq ft | 729 | 2524 | >10000 | $125,000 |
| Moon Lake | 2008-2010 | UCC Moon Beach Camp | 1700 linear ft, 128,000 sq ft | 184 | 1558 | 9684 | $100,000 |
| Crystal Lake | 2010-2012 | NHAL Crystal Lake Campground | 1700 linear ft, 195,000 sq ft | 658 | 1460 | 4430 | $60,000 |
| | | TOTALS | 7700 linear ft, 549,000 sq ft | 1960 | 8025 | >27000 | $375,000 |

The research findings from this project are presented in the next 5 sections, each representing a peer-reviewed scientific manuscript. Two are published, one is in review, and two are being readied for submission. An overview precedes each section, describing the primary findings and management implications.

### Quantifying Lakeshore Development Impacts in the NHEL

<u>*Impacts of Lakeshore Development on Mammalian Carnivores*</u> (this section is a synopsis of published manuscript *Haskell, D, Flaspohler, D, Webster, C., Meyer, M.W. (2013). Relationship between carnivore distribution and landscape features in the Northern Highlands Ecological Landscape of Wisconsin. American Midland Naturalist 169(1):1-16.* The full manuscript with Tables and Figures is attached.)

SYNOPSIS

Relationship between Carnivore Distribution and Landscape Features in the Northern Highlands Ecological Landscape of Wisconsin

Daniel E. Haskell, Christopher R. Webster, David J. Flaspohler, and Michael W. Meyer

***Overview*** *– Previous studies in the NHEL have shown that lakeshore housing development has had negative impacts on fish and wildlife habitat, avian communities, and green frogs. In this study, furbearer populations are found to be less diverse and abundant on developed lakes, a pattern associated with landscape habitat fragmentation.*

**Abstract**

Residential development has been associated with habitat fragmentation and loss and declining diversity of indigenous species, especially when development occurs in ecologically sensitive environments such as wetlands and/or riparian zones. In recent decades, the upper mid-west region of the United States has experienced a dramatic increase in residential development along lakeshores. In northern Wisconsin, recent studies have documented negative effects of such development on local flora and certain fauna (avian and amphibian communities) but less is known about how mammal communities, especially carnivores, respond to housing development. To quantify the influence of lakeshore development on these taxa, we conducted snow track surveys on ten pairs of low-and high-development lakes and deployed remote cameras at four lakes in Vilas County, Wisconsin, in 2008. Our results suggest that a higher diversity of carnivores ($P = 0.006$) were present on low-development lakes. Coyotes (*Canis latrans*) were detected most frequently ($n = 34$) especially on low-development lakes. Fishers (*Martes pennanti*), wolves (*Canis lupus*), bobcats (*Lynx rufus*), and northern river otters (*Lontra canadensis*) were exclusively detected on low-development lakes by snow track surveys. Raccoon (*Procyon lotor*) and red fox (*Vulpus vulpus*) detection was greater on higher-development lakes than low-development lakes. These results also were supported by 12 remote cameras on a subset of four lakes. We also investigated the influence of housing and road density in the surrounding landscape (500 m buffer) on carnivore community composition by means of a non-metric multidimensional scaling ordination. Significant associations were observed between community composition and landscape attributes associated with development. Our results suggest that residential development along lakeshores is having a negative impact on carnivore diversity in this region.

**Introduction**

Recent studies comparing low- and high-development lakes in Vilas County, Wisconsin, documented declines in the flora and fauna on the more developed lakeshores. 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. Very little is known about the effect of residential development on the mammalian carnivore community in this region, especially along lake riparian areas. In this project we evaluated the relationship between human settlement density and carnivore diversity and abundance in lake riparian areas of Vilas County, WI, USA.

Human dominated areas can lead to the decline or extirpation of carnivores, either through competitions for resources, direct persecution, or habitat loss (Woodroffe, 2000; Cardillo *et al.*, 2004). The absence of carnivores in an ecosystem can have a significant impact on the relative abundance of herbivores and small carnivores. In some localities, the loss of larger carnivores has allowed one or two smaller mammalian predator species to dominate a community and further reduce biodiversity (Crooks and Soule, 1999; Berger *et al.*, 2001; Hebblewhite *et al.*, 2005, Prugh *et al.,* 2009). Thus, maintenance of carnivore species diversity is an important consideration in managing healthy ecosystems (Eisenberg, 1989); however, management of natural habitats for carnivores is becoming one of the greatest challenges for conservation biologists and policy makers in North America (Noss *et al.*, 1996).

The objectives of our research were to (1) determine if residential development on lakeshores is related to carnivore diversity and relative abundance and (2) establish baseline data for long-term monitoring of carnivores. Because residential development has been shown to have a negative impact on species richness and diversity for other taxa, we hypothesized that lakeshores with higher-development will have fewer carnivore species than lakeshore with lower-development.

## Methods

### Study area

We conducted our study in Vilas County, Wisconsin, which is within the Northern Highland Ecological Landscape (Puhlman *et al*., 2006). Vilas County encompasses a 2636 $km^2$ area along the Wisconsin'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 county 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 relatively high residential development with 61% occurring within 100 m of lakes in recent decades (Schnaiberg *et al.*, 2002). Study lakes were systematically chosen from the University of Wisconsin, Trout Lake Limnology, North Temperate Lakes BioComplexity project data base as a function of their development density and morphometric characteristics (http://lter.limnology.wisc.edu). We paired ten low-development lakes (< 10 houses/km, mean = 2.10 ± SE 0.64) with ten high-development lakes (≥ 10 houses/km, mean = 23.45 ± SE 2.69), controlling for surface area and lake type (*i.e.* drainage, seepage, spring fed; http://lter.limnology.wisc.edu Table 1).

### Snow track surveys

We conducted winter snow track surveys between January – February 2008 on all 20 lakes. Transect surveys were conducted 48 to 96 h following snowfalls of ≥ 2.5 cm, at temperatures above -17 C, and with winds less than 16 km/hour. Survey 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. We identified all carnivore species according to methods described by Halfpenny (1986). If tracks were not immediatley identified, we backtracked the trail to suitable topography to record measurements and determine the species. We recorded all carnivore tracks encountered 10 m on each side of the survey transect. In addition, we tallied encounters with domestic dogs (*Canis familiarus*) and non-carnivore species including: microtine rodents (*e.g*. *Peromyscus sp., Myodes sp.*), snowshoe hares (*Lepus americanus*), eastern cottontail rabbits (*Sylvilagus floridanus*), tree squirrels (*Sciuridae* s*p.*), and white-tailed deer (*Odocoileus virginianus*). We calculated Shannon's Index of species diversity and evenness (Magurran 2004) for each lake within a group of ten lakes categorized as low- or high-development. We used a paired t-test to test the null hypothesis that low- and high-development lakes have equal species diversity. The abundance indices for non-carnivore species were averaged by treatment and interpreted by relative abundance

Remote Cameras

To augment the winter track surveys we deployed remote cameras to detect carnivore species. Twelve motion sensor, digital cameras (Cuddeback™ Expert, Non Typical, Inc., Park Falls, Wisconsin) with a ¾ second trigger speed were placed on the subset of four paired lakes, two low- and two high-development (Table 1). Six cameras were deployed on low-development and six cameras deployed on high-development lakes from 12 June 2007 to 31 August 2008 for 5700 camera nights. 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 where some vegetation cover was present rather than in a resident's yard. 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 camera. Cameras were programmed to take photos 24 hr/day, pause for one minute intervals between events, and record date and time of event on each image. Batteries and compact flash cards were examined every 2 to 4 wks. Mean rate of occurrence (number of events/camera night) was calculated for each species, at each camera location, by development type (O'Connell et al., 2006).

Landscape Features

We used (GIS) software to assess landscape features that contributed to carnivore presence. We used ArcGis version10 (ESRI, 2010) and 2006 National Land Cover Dataset (NLCD) to analyze landscape-feature patterns and to generate landscape indices of housing density, percent landuse/landcover for all lakes listed. Principle methods for each included the creation of two concentric buffers of a pre-determined distance from the edge or center (NLCD 10 km Hydro) of each lake which were then used to conduct Intersect analysis on county-derived address points, NLCD landcover units, and Wisconsin roads for geospatial analyses. To evaluate the influence of measured landscape feature variables on carnivore community composition, we used non-metric multidimensional scaling conducted with PC-ORD.

RESULTS

Snow track survey

We recorded 83 encounters of tracks of nine carnivore species across all lakes sampled (n = 20). Coyotes were the most encountered species (n = 34) across all lakes. Red foxes (*Vulpes vulpes*) accounted for 14 encounters of which nine encounters were recorded on high-development lakes. Mink detections were four times higher on low-development than high-development lakes (Fig. 1). Shannon's index of species diversity was significantly higher ($t$ = 3.547, df = 9, P = 0.006) on low-development (mean = 1.974 ± 0.438 SE) than on high-development lakes (mean = 0.277 ± 0.113 SE). Evenness was also significantly higher ($t$ = 7.321, df = 9, P = <0.001) on low-development lakes (mean = 1.50 ± 0.282 SE) than on high-development lakes (mean = 0.40 ± 0.163 SE). Overall, there were twice as many carnivore species on low-development lakes (n = 8) than on high-development lakes (n = 4).

For non-carnivores species, white-tailed deer were abundant on all high-development lakes, but were detected on only 50% of low-development lakes. Snowshoe hare (P = 0.017) and eastern cottontail occurrence differed statistically (P = 0.003) between the types of development. Hares were detected on 70% of low-development lakes and 20% of high-development lakes, whereas cottontails were recorded on 80% of high-developments lakes and 10% of low-development lakes. Domestic dogs were common on high-development lake and rare on low-development lakes (P = <0.001).

Remote Cameras

Nine carnivore species were detected by cameras ($n$ = 12) across all lakes sampled (n = 4). Beavers (*Castor canadensis*), wolves, and fishers were photographed only on low-development lakes (Fig. 2). Rate of occurrence for raccoons was approximately 2.5 times higher on high-development (mean = 0.048 occurrence/camera night ± SE 0.036) than on low-development lakes (mean = 0.019 occurrence/camera night ± SE 0.012). Red fox rate of detection was nearly twice as high on high-development lakes (mean occurrence /camera night = 0.005 ± SE 0.003) than on low-development lakes (mean = 0.003 individual/camera night ± SE 0.002). Rate of detection for domestic dogs was over four times higher on high-development (mean = 0.037 occurrence /camera night ± SE 0.019) than low-development lakes (mean = 0.009 individual/camera night ± SE 0.004). For non-carnivore species, white-tailed deer were photographed ≥3 times more frequently on high-development (mean = 0.20 occurrence /camera night ± SE 0.09) than low-development lakes (mean = 0.06 occurrence /camera night ± SE 0.02).

Landscape Features

Landscapes surrounding high and low development lakes varied predictably at the 150 m buffer scale, with high-development lakes displaying housing densities an order of magnitude greater than those associated with low-development lakes. The percent of land classified as developed within the 150 m buffer averaged 18.7 ± 2.5 for high-development lakes versus 5.9 ± 1.1 for low- development lakes. At the 500 m buffer scale there was less difference in percent of land developed and road density, likely indicating the impacts to carnivores was related to changes to the riparian buffer or human impacts on the lakeshore, not some larger landscape scale effect. Raccoons and foxes were most strongly associated with landscape attributes indicative of development, such as housing density. The other carnivore species observed displayed repulsion in species space to environmental vectors associated with development.

**Discussion**

Our results suggest that carnivore diversity, evenness and species richness are higher on low-development than high-development lakes in our study region. Coyotes were by far the most frequently encountered carnivore species on low-development lakes in this study; bobcats were exclusively detected on low-development lakes during the snow tracking surveys. Red foxes and coyotes can be sympatric (McDonald *et al.*, 2008) but foxes usually avoid coyotes by locating territories on the periphery of coyote territories (Voigt and Earle, 1983; Sargeant *et al.*, 1987) or by avoiding habitats frequented by coyotes (Dekkar, 1989). Remote cameras did not detect mink (*Mustele vision*) on any lakes, but they were encountered on snow track surveys primarily on low-development lakes. A similar study in Ontario, Canada, reported that mink occurrence and activity decreased with increasing levels of residential development (Racey and Euler, 1983).

The higher rate of detections for white-tailed deer on high development lakes is likely due to supplemental feeding by humans living on the lake (pers. obs.). Supplemental feeding can affect deer movement patterns by concentrating them around rich food sources (Ozoga and Verme, 1982). Such aggregations of deer can negatively affect natural vegetation at and adjacent to feeding sites (Doenier *et al.*, 1997). Our snow tracking survey revealed an inverse relationship between snowshoe hare and cottontail detections with more snowshoe hares detected on low-development lakes compared to high-development lakes, and with cottontails showing the opposite pattern. As expected, raccoons were detected 2.5 times more often on high-development lakes compared to low-development lakes. Our results suggest the distribution of carnivores in our study area may be associated with the landscape scale matrix of development/fragmentation within which the high- and low-development lakes occur. Enforcement of current policies regarding habitat along lake riparian areas and carnivore conservation could provide sustainable populations or natural recolonization. In addition, efforts should be made to educate developers and property owners of the ecological importance of preserving a natural vegetation buffer zone adjacent to the lake shore. Furthermore, undeveloped lake shoreland should be protected via purchase, conservation easements, or other means of conservancy.

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**Literature Cited**

Alverson, W.S., and Waller, D.M. 1997. Deer populations and the widespread failure of hemlock regeneration in northern forests, p. 280-297. *In*: McShea, W.J, Underwood, H.B., and Rappole, J.H. (eds.), The Science of Overabundance: Deer Ecology and Population Management. Smithsonian Institution Press, Washington and London.

Beals, E.W., G. Gottam, and R.J. Vogl. 1960. Influence of deer on vegetation of the Apostle Islands, Wisconsin. *J. Wildl. Manag.*, **24**:68-80.

Berger, J., Stacey, P.B., Bellis, L., and Johnson, M.P. 2001. A mammalian predator-prey imbalance: grizzly bear and wolf extinction affect avian neotropical migrants. *Ecol. Appl*., **11**:947-960.

Buehler, D.A, and Keith, L.B. 1982. Snowshoe hare distribution and habitat use in Wisconsin. *Can. Field-Nat*., **96**:19-29.

Cardillo, M., Purvis, A., Sechrest, W., Gittleman, J.L., Bielby, J., and Mace, G.M. 2004. Human population density and extinction risk in the world's carnivores. *PLoS Bio.,* **2**:909-914.

Chapman, J.A., and Litvaitis, J.A. 2003. Eastern cottontail, p.101-125. *In*: Feldhamer, G.A., Thompson, B.C., and Chapman, J.A. (eds.), Wild Mammals of North America: Biology, Management, and Conservation. John Hopkins University Press, Baltimore, MY.

Christensen, D.L., Herwig, B.R., Schindler, D.E, and Carpenter, S.R. 1996. Impacts of lakeshore residential development on coarse woody debris in north temperate lakes. *Ecol. Appl*., **6**:1143-1149.

Crooks, K.R., and Soulé, M.E. 1999. Mesopredator release and avifaunal extinctions in a fragmented system. *Nature*, **400**:563-566.

Crooks, K.R. 2002. Relative sensitivities of mammalian carnivores to habitat fragmentation. *Conserv. Biol*., **16**:488-502.

Curtis, J.T. 1959. The vegetation of Wisconsin. University of Wisconsin Press, Madison, WI. 657 p.

Czech, B., Krausman, P.R., and Devers, P.K. 2000. Economic associations among causes of species endangerment in the United States. BioScience, **50**:593-601.

deCalesta, D.S. 1994. Impact of white-tailed deer on songbirds within managed forests in Pennsylvania. *J. Wildl. Manag*., **58**:711-718.

Dekkar, D. 1989. Population fluctuations and spatial relationships among wolves, *Canis lupus,* Coyotes, *Canis latrans,* and red foxesk, *Vulpus vulpus,* in Jasper National Park, Alberta. *Can. Field Nat*., **103**: 261-264.

Doenier, P.B., DelGiudice, G.D., and Riggs, M.R. 1997. Effects of winter supplemental feeding on browse consumption by white-tailed deer. *Wildlife Soc. B*., **25**:235-243.

Elias, J.E., and Meyer, M.W. 2003.Comparisons of undeveloped and developed shorelands, northern Wisconsin, and recommendations for restoration. *Wetlands* **23**:800-816.

Eisenberg, J. F. 1989. An introduction to the Carnivora, p.1-9. *I*n: J. L. Gittleman (eds.), Carnivore Behavior, Ecology, and Evolution. Cornell University Press. Ithaca, New York, USA.

ESRI. 2010. ArcGis version 10. Environmental Systems Research Institute. Redlands, California.

Ford, M. and D.J. Flaspohler**.** 2010. Scale-dependent response by breeding songbirds to residential development along Lake Superior. *Wilson J. Ornithol.,* **122:**296-306.

Fruth, K. 1986. The coyote (*Canis latrans*). Wisconsin Department of Natural Resources, Bureau of Wildlife Management. PUBL-WM-148.

Gehrt, S.D. 2004. Ecology and management of striped skunks, raccoons, and coyotes. In urban landscapes, p.81-104. *In*: Fascinone, N. Delach, A., and Smith, M.E. (eds.), People and Predators: from conflict to coexistence. Island Press, Washingtion, D.C.

Gehrt, S.D. 2007. Ecology of coyotes in urban landscapes. Wildlife Damage Management, Internet Center for Wildlife Damage Management Conferences –Proceedings, University of Nebraska – Lincoln.

Gompper, M.E. 2002. Top carnivores in the suburbs? Ecological and conservation issues raised by colonization of northeastern North American by coyotes. *BioScience*, **52**:185-190.

Gonzalez-Abraham, C.E., Radeloff, V.C., Hammer, R.B., Hawbaker, T.J., Stewart, S.I., and Clayton, M.K. 2007. Building patterns and landscape fragmentation in northern Wisconsin, USA. *Landscape Ecol*., **22**: 217-230.

Gosselink T.E., Van Deelen, T.R., Warner, R.E., and Joselyn, M.G. 2003. Temporal habitat partitioning and spatial use of coyotes and red foxes in east-central Illinois. *J. Wildl. Manag*.,**67**:90-103.

Halfpenny, J.C. 1986. A field guide to mammal tracking in North America. Johnson Printing Co. Boulder, Colorado, USA. 161 p.

Haskell, D.E. 2009. Quantifying the Ecological Benefits of Lakeshore Restoration in Northern Wisconsin. M.S. thesis. Michigan Technological University, Houghton, Michigan.

Hawbaker, T.D., Radeloff, V.C., Clayton, M.K., Hammer, R.B., and Gonzalez-Abraham, C.E. 2006. Road Development, housing growth, and landscape fragmentation in northern Wisconsin: 1937-1999. *Ecol. Appl*., **16**:1222-1237.

Hebblewhite, M., White, C.A., Nietvelt, C.G., McKenzie, J.A., Hurd, T.E., Fryxell, J.M., Bayley, S.E., and Paquet, P.C. 2005. Human activity mediates a trophic cascade caused by wolves. *Ecology*, **86**:2135-2144.

Hoffman, C.O., and Gottschang, J.L. 1977. Numbers, distribution, and movement of a raccoon population in a suburban residential community. *J. Mammal*., **58**:623-636.

Hoffman, R.S. 1996. Foreword. In: Wilson, D.E., Cole, F.R., Nichols, J.D., Rubran, R., and Foster, M.S., p. xxi-xxiii. (eds.), Measuring and Monitoring Biological Diversity: Standard Methods for Mammals. Smithsonian Institution, Washington, D.C., USA.

Holmes, S.A., Webster, C.R., Flaspolher, D.J., and Froese, R.E. 2009. Dealth and taxus: the high cost of palatability for a declining evergreen shrub, *Taxus canadensis. Can. J.Forest Res*., **39**:1366-1374.

Jackson, H.H.T. 1961. Mammals of Wisconsin. The University of Wisconsin Press. Madison, Wisconsin. 504 p.

Keith, L.B., and. Bloomer, S.E.M. 1993. Differential mortality of sympatric snowshoe hares and cottontail rabbits in central Wisconsin. *Can. J. Zool*., **71**:1694-1997.

Lindsay, A.R., Gillum, S.S., and Meyer, M.W. 2002. Influence of lakehore development on breeding bird communities in a mixed northern forest. *Biol. Conserv*., **107**:1-11.

Linnell, J.D.C., Swenson, J.E., and Andersen, R. 2001. Predators and people: conservation of large carnivores is possible at high human densities if management policy is favorable. *Anim. Conserv*, **4**:345-349.

Markovchick-Nicholls, L., Regan, H.M., Deautschman, D.H., Widyanata, A., Martin, B., Noreke, L. and Hunt, T.A. 2008. Relationship between human disturbance and wildlife land use in urban habitat fragments. *Conserv. Biol.* **22**: 99-109.

Magurran, A.E. 2004. Measuring Biological Diversity. Blackwell Publishing, Oxford, United Kingdom.

McCann, N., Haskell, D.E., and Meyer, M.W. 2005. Capturing common loon nest predators on 35mm film. *Passenger Pigeon,* **66**:351-361.

McDonald, P.T., Nielsen, C.K., Oyana, T.J., and Sun, W. 2008. Modelling habitat overlap amony sympatric mesocarnivores in southern Illinois, USA. *Ecol Model,* **215**:276-286.

Mladenoff, D.J., Sickley, T.A., Haight, R.G.., and Wydeven, A.P. 1995. A regional landscape analysis and prediction of favorable gray wolf habitat in the northern Great Lakes region. *Conserv. Biol* **9**:279-294.

Mladenoff, D.J., Haight, R.G.., Sickley, T.A. and Wydeven, A.P. 1997. Causes and implications of species restoration in altered ecosystems. *BioScience*, **47**:21-31.

Naiman, R.J. 1996. Water, society, and landscape ecology. *Landscape Ecol*., **11**:193-196.

Noss, R.F, Quigley, H.B., Hornocker, M.G., Merril, T., and Paquet, P.C. 1996. Conservation biology and carnivore conservation in the Rocky Mountains. *Conserv. Biol.*, **10**:949-963.

O'Connell, A.F. Jr., Talancy, N.W., Baikiley, L.L., Sauer, J.R., Cook, R., and Gilbert, A.T. 2006. Estimating site occupancy and detection probability parameters for meso- and large-mammals in a coastal ecosystem. *J. Wildl. Manag.,* **70**:1625-1633.

Oehler, J.D. and Litvaitis, J.A. 1996. The role of spatial scale in understanding responses of medium-sized carnivores to forest fragmentation. *Can. J. Zool.* **74**:2070-2079.

Opperman, J.J, and Merenlender, A.M. 2000. Deer herbivory as an ecological constraint to restoration of degraded riparian corridors. *Restoration Ecol*., **8**:41-47.

Ozoga, J.J., and Verme, L.J. 1982. Physical and reproductive characteristics of a supplemental-fed white-tailed deer herd. *J. Wildl. Manag*., **46**:281-301.

Peitz, P.J., and Tester, J.R. 1983. Habitat selection by snowshoe hares in north central Minnesota. *J.Wildl.Manag*., **47**:686-696.

Prange, S., Gehrt, S. D., and Wiggers, E.P. 2003. Demographics factors contributing to high raccoon densities in urban landscapes. *J. Wildl. Manag.*., **67**:324-333.

--------------. 2004. Influences of anthropogenic resources on raccoon (*Procyon lotor*) movements and spatial distribution. *J. Mammal*., **85**:483-490.

Prugh, L.R, Stoner, C.J., Epps, C.W., Bean, W.T., Ripple, W.J., Laliberte, A.S., and Brashares, J.S. 2009. The rise of the mesopredator. *BioScience*, **59**:779-790.

Puhlman, J.D., Bartelt, G.A., Hanson, A.C., Scott, P.H., and Thompson, C.D. (editors) 2006. The Wisconsin Land Legacy Report: An inventory of places to meet future conservation and recreation needs. Wisconsin Department of Natural Resources, Madison, WI. 250 p.

Racey, G.D., and Euler, D.L. 1982. Small mammal and habitat response to shoreline cottage development in central Ontario. *Can. J. Zool*.,**60**: 865-880.

Racey, G.D., and Euler, D.L. 1983. Changes in mink habitat and food selection as influenced by cottage development in central Ontario. *J. Appl. Ecol.,* **20**:387-402.

Radeloff, V.C., Hammer, R.B., Voss, P.R., Hagen, A.E., Field, D.R., and Mladdenoff, D.J. 2001. Human demographics trends and landscape level forest management in the northwest Wisconsin Pine Barrens. *Forest Sci.***, 47**:229-241.

Radeloff, V.C., Hammer, R.B., and Stewart, S.I. 2005. Rural and suburban sprawl in the U.S. Midwest from 1940 to 2000 and it relation to forest fragmentation. *Conserv. Biol*., **19**:793-805.

Randa, R.A., and Yunger, J.A. 2006. Carnivore occurrence along an urban-rural gradient: landscape-level analysis. *J. Mammal.,* **87**:1154–1164.

Riera, J., Voss, P.R., Carpenter, S.R., Kratz, T.K., Lillesand, T.M., Schnaiberg, J.A., Turner, M.G., and Wegener, M.W. 2001. Nature, society and history in two contrasting landscapes in Wisconsin, USA: Interactions between lakes and humans during the twentieth century. *Land Use Policy***, 18**:41-51.

Robertson, R.J., and Flood, N.J. 1980. Effects of recreational use of shorelines on breeding bird populations. *Can. Field-Nat.,* **94**:131-138.

Rogers, C.M., and Caro, M.J. 1998. Song sparrows, top carnivores and nest predation: a test of the mesopredator release hypothesis. *Oecelogia*, **116**:227-233.

Russell, F.L., Zippin, D.B., and Fowler, N.L. 2001. Effects of white-tailed deer (*Odocoileus virginianus*) on plants, plant populations and communities: a review. The *Am. Midl. Nat.,* **146**:1-26.

Sargeant, A.B., Allen, S.H., and Hastings, J.O. 1987. Spatial relations between sympatric coyotes and red foxes in North Dakota. *J. Wildl. Manag.,* **51**:283-293.

Schmitz, O.J., Hamback, P.A., and Beckerman, A.P. 2000. Trophic cascades in terrestrial systems: a review of the effects of carnivore removals on plants. *Am. Nat.*, **155**:141-153.

Schnaiberg, J., Riera, J., Turner, M.G., and Voss, P.R. 2002. Explaining human settlement patterns in a recreational lake district: Vilas County, Wisconsin, USA. *Environ. Manage.*, **30**:24-34.

Séquin, E.S., Brussard, P.F., Jaeger, M.M., and Barrett, R.H. 2007. Cameras, coyotes and the assumption of equal detectability. *J. Wildl. Manag.*, **71**:1682-1689.

Soulé, M.E., Bolger, D.T., Alberts, A.C., Wright, J., Sorice, M,.and Hill, S. 1988. Reconstructed dynamics of rapid extinctions of chaparral-requiring birds in urban habitat islands. *Conserv. Biol.*, **2**:75-90.

Systat. 2006. SigmaStat Version 3.5 Systat Software, Inc. Point Richmond, California.

Theobald, D.M, Miller, J.R., and Hobbs, N.T. 1997. Estimating the cumulative effects of development on wildlife habitat. *Landscape Urban Plan.*, **39**:25-36.

Voigt, D.R., and Earle, B.D. 1983. Avoidance of coyotes by red fox families. *J. Wildl. Manag*., **47**:852-857.

WDNR. 1996. Northern Wisconsin's Lakes and Shorelands: a report examining a resource under pressure. Wisconsin Department of Natural Resources. Madison, WI 53707.

WDNR. 2005. Wisconsin Lakes. Bureau of Fisheries and Habitat Management. PUB-FH-800. 180 p.

Wilcove, D.S., Rothstein, D., Bubow, J., Phillips, A., and Loso, E. 1998. Quantifying threats to imperiled species in the United States. *Bioscience,* **48**:607-615.

Wise, S. 1986. The snowshoe hare (*Lepus americanus*). Wisconsin Department of Natural Resources, Bureau of Wildlife Management. PUBL-WM-017.

Witt, J.C., and Webster, C.R. 2010. Regeneration dynamics in remnant *Tsuga canadensis* stands in the northern Lake States: potential direct and indirect effects of herbivory. Forest Ecol. Manag., **269**:519-525

Woodford, J.E., and Meyer, M.W. 2003. Impact of lakeshore development on green frog abundance. *Biol. Conserv.*, **110**:277-284.

Woodroffe, R. 2000. Predators and people: using human densities to interpret declines of large carnivores. *Anim. Conserv.*, **3**:165-173.

Wydeven, A.P., Mladenoff, D.J., Sickley, T.A., Kohn, B.E., Theil, R.P., Hansen, J.L. 2001. Road density as a factor in habitat selection of wolves and other carnivores in the Great Lakes Region. *Endangered Species Update*, **18**:110-114.

Wydeven, A.P., Schultz, R.N., and Boles, S.R. 2004. Lynx and other carnivore surveys in Wisconsin in winter 2003-2004. Section 6 Report to U.S. Fish and Wildlife Service. Wisconsin DNR, Park Falls, Wisconsin.

Wydeven, A.P., Wiedenhoeft, J.E., Schultz, R.N., Fromm, E.A., and Boles, S.R. 2007. Lynx and other carnivore surveys in Wisconsin in winter 2006-2007. Section 6 Report to U.S. Fish and Wildlife Service. Wisconsin DNR, Park Falls, Wisconsin.

**II. Baseline Habitat Measures Before and After Lakeshore Restoration in the NHEL**

*Assessing Wildlife Habitat Attributes Before and After Lakeshore Restoration Installation*

(The manuscript below is currently in preparation for submission to the American Midland Naturalist; thus the information below is Draft version)

## BASELINE ASSESSMENT OF WILDLIFE HABITAT ATTRIBUTES AT RESTORATION PROJECTS ON NORTHERN WISCONSIN LAKESHORES

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***Overview*** – *Previous studies in the NHEL demonstrated that lakeshore development has negative impacts on wildlife habitat by reducing understory shrubs and saplings, shoreline vegetation, down woody material, and native forbs and grasses. In this study we install 15 restoration projects, measure the habitat structure and vegetation before and after implementation, and compare findings to developed unrestored shorelines and undeveloped reference shorelines. We found that after 3*

*years, restored lakeshores had an increase in understory structure at 0 – 1m height, increased sapling and shrub density, increased downed wood – all measures becoming more like that measured at undeveloped lakeshores.*

**Abstract**

Housing development has increased dramatically in the Midwest over several decades with a high concentration around lakes. This development results in the loss of native plants and alters habitat structure on high-development lakes, negatively impacting wildlife populations. Lakeshore restoration efforts have been implemented in Vilas County, Wisconsin to curtail the negative consequences of housing development on lakeshores. In this study, we measure habitat attributes before and after restoration to evaluate the success in reversing the ecological effects of development. Restoration efforts were completed on 9 properties on Found Lake and 6 properties on Little St. Germain Lake 2007-2012. Initial measurements made at the reference lakes showed greater Visual Obstruction Density (VOD) at all heights, greater stem densities of saplings and shrubs, greater numbers of Downed Woody Material (DWM), and more canopy coverage as compared to initial measurements made at the developed lake plots, consistent with previous measures made at developed and undeveloped NHEL lakes. In this study, measurements made 3 years following installation of restoration projects on developed lakes showed significant increases in VOD at the 0.0-0.3 height and a marginally significant increase at the 0.3-1.0m height. Shrub and sapling density increased at the restoration projects as expected, however the increase was only significant for shrubs. The number of logs did increase at the treated sites following restoration however the change was not significant. Nonmetric Multi-Dimensional Scaling Ordination indicates that the restoration projects are creating wildlife habitat that will be conducive to an increase in abundance and diversity of understory dwelling wildlife species -– establishing early progress towards achieving the long-term habitat improvement goal. To fully document performance, long-term assessment of the restorations should be conducted by monitoring vegetation and habitat response 10 years post-restoration.

**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 housing 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 live close to one another when on lakes (Gonzalez-Abraham *et al.* 2007). In Vilas County alone, 61% of medium-sized (1000-3000 sq ft) 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 forests (Harper and MacDonald 2001, Elias and Meyer 2003). Such riparian zones provide critical habitat for a variety of wildlife (often aquatic dependent), protect water quality, and have aesthetic appeal when the shoreline is naturally vegetated (Engel and Pederson 1998). However, removal of vegetation, thus habitat 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 vision*) 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 a native vegetation buffer zone must be left intact 35 feet inland from the ordinary high water mark (OHWM). No more than 30 feet for every 100 feet of shoreline can be cleared of vegetation. 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, no studies have evaluated the potential ecological benefits of lakeshore restoration. 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. Four high-development lakes (≥ 10 houses/km) were targeted for lakeshore restoration efforts in Vilas County as well as one state-owned lakeshore property (Crystal Lake State Forest Campground). WDNR and MTU personnel solicited property owners to participate by offering restoration to their lakeshore free of charge.

In this paper we present data on lakeshore habitat structure and vegetation density and composition before and after implementation of the restoration projects, and compare these data to that measured on control plots on developed lakes without restoration efforts. Finally, measurements are compared to those made at undeveloped, reference lakes. We predict changes in habitat structure and vegetation composition will change at restored lakeshores differently than at control lakeshores. We also predict measurements made at restored lakeshores will trend towards those made at reference lakeshores.

**Methods**

Study Area

This project was conducted in a forested landscape on deep sands with pitted glacial outwash in Vilas County, Wisconsin (Stearns and Likens 2002), which is located in the Northern Highland Ecological Landscape (NHEL). 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 daily mean ambient temperature is 3.4 °C, ranging from -2 °C in January to 10 °C in July and the mean precipitation is 80.25 cm (WDNR 2014b).

We conducted habitat restoration on two high-development lakeshores: Found Lake (T40N, R8E, Section 14, housing density = 21 homes/mile lakeshore) and Little Saint Germain [LSG (T40N, R8E, Section 35, housing density = 25 homes/mile lakeshore)] both of which were home to fishing and vacation resorts in the past. Found Lake's northern shoreline experienced a wind storm in 1999, which toppled hundreds of mature trees. The combination of human impact and the wind storms in the past have left the lakeshore in a degraded state. LSG has several active vacation resort businesses that operate during the summer months. Therefore, on both lakes a negative impact on the riparian habitat has occurred thus making both lakes prime candidates for lakeshore restoration. We also established control sites (properties that did not receive restoration) on the same lake that restoration occurred. We made an effort to acquire a contiguous shoreline for restoration and control sites. We also established reference sites on two low developed lakes (<5 houses/mile lakeshore): Star and Escanaba both located in NHEL. These reference lakeshores were matched with Found and LSG to similar attributes (surface area, substrate, and lake type) and will be used to compare habitat attributes on lakeshore and before and after restoration efforts.

Installation of Restoration Projects

We recruited property owners interested in participating in the project by conducting educational workshops, mailing educational materials/flyers, and attending lake association meetings. Additionally, lake leaders and property owners on Found Lake worked neighbor to neighbor to recruit volunteers. Restoration installations were at no-cost to the property owners however access was required for survey measurements for 10 years following installation. Site-specific management recommendations were developed for each property taking into account recreational use and storage requirements. The goal was to install the projects from the Ordinary High Water Mark inland a minimum of 35', though providing an access and view corridor not to exceed 30'. Restoration projects were completed at 13 Found Lake properties 2008-20010 and nine LSG properties 2011-2012, including over 1700' of developed lakeshore on LSG and 1200' on Found Lake. Restoration activities included conservation and restoration of native trees, shrubs, and groundcover, placement of physical structure such as downed trees and down woody material for fish and wildlife habitat, bank and toe erosion control with biodegradable materials, and other management techniques designed to reduce overland erosion and nutrient runoff.

Native plant species chosen were selected via presence at undeveloped lakeshores in the NHEL, expert advice from VCLWCD and local botanists specializing in lakeshore restoration on NHEL lakes, as well as availability at private and public nurseries. Woody plant density was that used by VCLWCD (1 tree sapling and 3 shrubs/100 square feet) as prescribed by the Wisconsin Biology Technical Note 1 – Shoreland Restoration (NRCS 2002). Ground cover (grasses, sedges, forbs, ferns) were chosen on the basis of availability and suitability for each site - an effort was made to choose some species with aesthetic appeal (showy flowers, berries, colorful leaves). All plantings were installed by researcher D. Haskell and field staff from MTU and staff from VCLWCD. All plant material was purchased from a local business. Saplings were approximately 152-183 cm (5-6 ft) tall and shrubs were 30.5-61.0 cm (12-24 in) tall.

Manual or automatic irrigation systems consisting of sprinkler heads set up above ground were established on LSG and Found Lakes, providing approximately 2.5 cm (~1 in) of water per week for the first year after planting from late May to mid-September. Lake water was supplied to each sprinkler by an electrical pump. To promote downward root growth, irrigation was slowly reduced the following years after restoration activities. The automated irrigation system was installed and maintained by a local contractor.

Examination of previously installed lakeshore restorations in the NHEL showed moderate to severe browse damage. To deter herbivory for the first 3-5 years, we installed eight foot tall, nylon mesh, UV protected fence around the entire perimeter of reach restoration. To hold the fence upright, 5.5 foot steel T-post were pounded into the ground every 16 feet apart. A five foot long, ¾ inch diameter, steel electrical conduit was attached to T-post with six inch long, 16 gauge tie wire. A 1/8 inch diameter, 7x7 braided steel cable was attached to the top of post assemblies and strung the entire length of fence. The cable was attached to corner posts with a 5/16 inch diameter by six inch long turn-buckle which was attached to a ¼ inch diameter by two inch long eye bolt. The cable then was secured to the turn-buckle by two cable clamps. Wooden braces were installed at each 90 degree corner and at various places along fence and gate entrances which strengthen and provided rigidity.

These braces were secured to the post assemblies by ¼ inch diameter by 2 ½ inch long hex bolts, nuts and flat washers. After the post assembles, corner braces and cable were erected, then the nylon mesh fence was strung up to the post assembles and attached with six and eight inch long, UV protected zip-ties. The nylon mesh fence was also zip-tied to the cable securing the top of the fence and six and eight inch long sod pins secured the bottom of the fence to the ground. Entrance gates were placed in various places along fence.

Vegetation and Downed Wood 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, etc.). We established 10 m x 10 m plots on each site. Each plot was divided into four 5 m × 5 m subplots.

We used a density board or checker board (0.5m x 3m) with 10 cm × 10 cm grid squares to measure visual obstruction density (VOD) to estimate the percent cover at four different height categories (0.0-0.3 m, 0.3-1.0 m, 1.0-2.0 m, 2.0-3.0 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 VOD board was placed at 1 m, 5 m, and 9 m inland from the shoreline at the edge of each 10 m x 10 m plot. This would give 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.

Two subplots were randomly chosen and all live deciduous and coniferous saplings and shrubs that were ≥ 30 cm in height but having ≤ 5 cm DBH were identified to species and tallied. We calculated density to the hectare from the total number of saplings and shrubs in each plot.
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 2006)]. Digital hemispherical photographs were taken when the sun was low in the sky or when sky was overcast and then analyzed with the software WinSCANOPY (WinScanopy 2006).

We also recorded downed woody material (DWM) in the 10 m x 10 m plots. DWM was defined as a log that is ≥ 10 cm in diameter and ≥ 150 cm in length and touching the ground at 2 or more points. In addition, we recorded snags (standing dead trees) ≥ 10 cm at DBH and at a height of ≥ 1.37 m and stumps.

We collected the above data prior to restoration efforts on both lakes and then again three years later. The Found Lake data was collected in 2007 and 2010, LSG data was collected in 2011 and 2014.

Data Analysis

We used two-way ANOVA models to test whether changes in total sapling density, total shrub density, gap fraction at 0.5 and 1.5 m, visual obstruction at each of four height categories, and DWM measures (logs, snags, stumps, and total per plot) between pre-restoration surveys and surveys taken three years after restoration differed between control, treated, and/or reference plots. Model effects for all response variables include “Treatment” (Control, Restored, and Reference plots), “Survey

Number” (Survey 1 and Survey 2 refer to pre-restoration and three years post-restoration, respectively), and “Treatment × Survey Number” interaction. A significant interaction indicates that changes in the response variable between survey years differed between Control, Restored, and/or Reference plots. We also included “Lake” in the model as a fixed effect nested within “treatment” in order to control for variation between lakes. We nested the effect because some treatments only occur at some of the four lakes (e.g., the Reference treatments are only at Escanaba and Found lakes). We used Tukey’s Honest Significant Difference (HSD) tests to test for statistical differences between survey years for each treatment. Treatments having any letter in common (A, B, and/or C) are not statistically different from one another ($p > 0.05$). Treatments having no letters in common are statistically different from one another ($p < 0.05$). We conducted all above analyses in JMP version 11.2.0 (SAS Institute Inc. 2013).

To simultaneously examine the composition of habitat features through time across treatments, we used nonmetric multi-dimensional scaling ordination. Habitat features were relativized to a common scale for analysis. We chose this approach since wildlife often respond to a suite of habitat features rather than a single metric. This approach allows for the visualization of changes in the composition of these features among treatments. Site/treatment locations in the ordination space indicate dissimilarity, with points further apart being more compositionally dissimilar. Arrows show the movement of each site/treatment through time. The beginning and end of each arrow represents the average location in the ordination space of plots associated with each treatment.

## Results

### Landowner Participation

Interest in the project was low among the 425 LSG lake district property owners contacted, despite the no-cost/no-labor investment on their behalf. Four property owners enrolled a total of 6 lakeshore parcels in the project, allowing us to meet our restoration objectives (1700’ lakeshore for restoration). The low level of enrollment may have been a consequence of required temporary (3-year) 8’ deer-proof fencing around restoration projects, follow-up visits by researchers for maintenance and periodic wildlife and vegetation surveys, and a restrictive covenant on the property deed protecting the restoration going forward. Also, landowners may have been deterred from participation due to the involvement of WDNR in the project – that concern was expressed by some.

We found an effort initiated from the “grassroots” yielded greater participation than one initiated and sponsored by WDNR as on LSG. On Found Lake where 13 property owners volunteered to participate, local, trusted on-lake champions (lake association president and members) of lake management secured the volunteers. We recommend future large-scale lake rehabilitation projects be led by trusted property owners such as lake association officers, private sector business owners, or master gardeners who can make for effective peer-to-peer learning and project buy-in.

### Restoration Activities

During spring and summer months of 2007, 74 tree saplings and 525 shrubs were planted within the 35’ buffer zone along approximately 800’ linear lakeshore on 6 private properties on Found Lake. In the spring and summer of 2008 an additional 161 tree saplings and 1382 shrubs were planted within the

35’ buffer zone along approximately 1000’ linear lakeshore on 7 private properties on Found Lake. Over 7000 forbs, grasses, and sedges were planted. Geotextile bag walls, soil lifts, and erosion control blankets were installed to reduce bank erosion and coconut coir biologs were used to reduce toe erosion. Rain gardens were installed to reduce runoff from impervious surfaces.

During the spring and summer months of 2011, 187 trees, 1014 shrubs, two vines, 65 ferns, 4000 forbs and grasses and sedges were planted within the 35’ buffer zone along approximately 500’ of linear lakeshore on two privately owned LSG properties. In the spring and summer months of 2012, 542 trees, 1510 shrubs, eight vines, 93 ferns, 6000 forbs, grasses and sedges were planted within the 35’ buffer zone along approximately 1200’ of linear lakeshore on four privately owned properties. Geotextile bag walls and erosion control blankets were installed to reduce bank erosion and coconut coir biologs were used to reduce toe erosion. Rain gardens were installed to reduce runoff from impervious surfaces and tree drops were created to enhance fish habitat and reduce bank undercutting from wave action.

Visual Obstruction Data

2-way ANOVA results for VOD at all heights is presented in Table 1. At 0.0 – 0.3 m height, treated plots had a greater increase in visual obstruction between pre-restoration and year three surveys relative to control and reference plots (interaction effect; $F_{2, 79} = 3.24$, $P = 0443$). Tukey’s HSD tests indicate that only treated plots showed significant increases in visual obstruction between surveys (refer to Figure 1).

At 0.3 to 1.0 m height, the interaction of treatment × survey number is marginally significant ($F_{2, 79} = 2.53$, $P = 0.086$), with the treated plots having a greater increase in visual obstruction between pre-restoration and year 3 surveys relative to the control and reference plots (refer to Figure 2). Tukey’s HSD indicates that treated plots are the only ones to show significant increases in visual obstruction between surveys (refer to Figure 2).

At 1.0 to 2.0 m height, visual obstruction differed between treatment groups (Treatment main effect; $F_{2, 79} = 13.95$, $P < 0.0001$; refer to Figure 3). Tukey’s HSD indicates that reference plots had a greater percentage of visual obstruction than control plots ($P < 0.05$), and treated plots were not significantly different from either control or reference plots ($P > 0.05$). Visual obstruction increased for all plots between surveys (Survey Number effect; $F_{1, 79} = 24.84$, $P < 0.0001$; refer to Figure 3). Increases in visual obstruction were not dependent on plot treatment (i.e., interaction not significant).

At the 2.0 to 3.0 m height, visual obstruction differed between treatment groups (Treatment main effect; $F_{2, 79} = 7.91$, $P = 0.001$), and Tukey’s HSD shows that reference plots had greater percentage of visual obstruction than both control and treated plots ($P < 0.05$). Control and treated plots were nearly identical for both survey years (refer to Figure 4). Visual obstruction generally increased for all plots between surveys (Survey Number effect; $F_{1, 79} = 25.58$, $P < 0.0001$). Increases in visual obstruction were not dependent on plot treatment (i.e., interaction not significant).

Total Sapling Density

2-way ANOVA results for sapling stem density is presented in Table 2. Treated plots appeared to exhibit an increase in sapling density slightly more than control and reference plots between survey years, but the effects are not statistically significant ($F=2.08_{(2, 79),}$ $P=0.132$; refer to Figure 5).

### Total Shrub Density

2-way ANOVA results for shrub stem density is presented in Table 2. Treated plots showed increased shrub density between survey years, while reference and control plots showed little change and slightly decreased, respectively (interaction effect; $F_{2, 79} = 24.62$, $P < 0.0001$; refer to Figure 6). Shrub density also varied significantly between lakes ($F_{3, 79} = 3.16$, $P = 0.029$).

### Downed Woody Material

2-way ANOVA results for Downed Woody Material is presented in Table 3. The number of logs present in each plot differed significantly between plot treatments ($F_{2, 79} = 5.87$, $P = 0.004$). Tukey's HSD results indicate that treated and reference plots had significantly more logs per plot than control plots ($P < 0.05$; refer to Figure 7). It also appears that the treated plots had a greater increase in logs than other treatments following restoration, but the interaction effect was not significant ($F_{2, 79} = 2.01$, $P = 0.141$).

Only Treatment had a significant effect on the number of snags per plot (Treatment effect; $F_{2, 79} = 9.92$, $P < 0.001$), and Tukey's HSD results indicate that reference plots had more snags than control plots, overall ($P < 0.05$; Figure 8). The number of snags did not appear to change significantly between surveys (Survey number; $F_{2, 79} = 0.02$, $P = 0.881$). The treatment × survey year interaction was not significant.

There was no significant influence of treatment ($F_{2, 79} = 0.10$, $P = 0.910$) or survey number ($F_{2, 79} = 0.01$, $P = 0.912$) on the number of stumps counted per plot (refer to Figure 9).

Taken together, only treatment had a significant effect on the total DWM per plot (Treatment effect; $F_{2, 79}=3.81$, $P=0.026$). Tukey's HSD results indicate that reference plots had more DWM than control plots ($P < 0.05$; Figure 10). The amount of DWM did not appear to change significantly between surveys (Survey number effect; $F_{2, 79} = 0.09$, $P = 0.912$). The interaction was not significant.

### Canopy Gap Fraction

Canopy gap fraction at 0.5M height differed significantly between treatments (Treatment effect; $F_{2, 79}=25.03$, $P<0.001$). Tukey's HSD shows that treated and control plots had a significantly higher fraction of sky in canopy photos relative to reference plots ($P < 0.05$; Figure 11). Gap fraction decreased slightly between surveys for treated and control plots, but this change was not statistically significant (Survey number; $F_{2, 79}=0.97$, $P=0.328$). Gap fraction varied significantly between lakes ($F_{2, 79}=2.96$, $P=0.037$).

At 1.5 M height, change in gap fraction between survey years was dependent on Treatment (i.e., significant interaction; $F_{2, 79}=3.42$, $P=0.038$). It appears that, for reference plots, gap fraction increased considerably, while for control and treated plots, gap fraction decreased slightly (refer to Figure 12). Results from Tukey's HSD tests indicate that pre-restoration reference plots had a significantly lower gap fraction than both pre-restoration control and treated plots (figure). Gap fraction also varied between lakes, but the effect is only marginally significant ($F_{2, 79}=2.56$, $P=0.061$).

### Nonmetric Multi-Dimensional Scaling Ordination

Reference lakes, as expected, showed little change in habitat feature composition between our sample periods. Treatment lakes on the other hand displayed longer vectors and movement towards reference conditions. This increase in similarity was associated with increasing similarity in visual obstruction and shrub and sapling density among treatments and reference lakes. The Found Lake control also displayed a large change in habitat feature composition associated with an increase in visual obstruction but did not tend as clearly towards the domain occupied by the reference lakes. Collectively, these results suggest that changes in understory habitat conditions associated with restoration treatments may increase the similarity of habitat features for understory dwelling wildlife. Large structural changes (tree density, size, and diversity) will require more time, but improving understory conditions and diversity are a requisite first step.

**Discussion**

Initial measurements made at the reference lakes showed greater VOD at all heights, greater stem densities of saplings and shrubs, greater numbers of Downed Woody Material, and more canopy coverage as compared to initial measurements made at the developed lake plots, consistent with previous measures made at developed and undeveloped NHEL lakes (Elias and Meyer 2003). In that study, quantitative comparisons of vegetation structural characteristics (percent cover of canopy, sub-canopy, and understory vegetation layers; percent of shoreline overhung by trees and shrubs; and amount of coarse woody debris) showed significantly greater complexity and cover at undeveloped versus developed sites.

Measurements made 3 years following installation of restoration projects on developed lakes on this study showed significant increases in VOD at the 0.0-0.3 height and a marginally significant increase at the 0.3-1.0m height. Changes in VOD measures over time at the greater heights were not related to treatment. This observation is consistent with the fact that plantings at the restoration sites were primarily < 1m in height, requiring several growing seasons to add structure at a greater height.

Shrub and sapling density also increased at the restoration projects as expected, however the increase was only significant for shrubs. This likely reflects the fact that >3x as many shrubs were planted as compared to saplings (Found Lake = 74 saplings, 525 shrubs; LSG = 525 trees, 1548 shrubs).

Reference plots had significantly more total Down Woody Material than did the Restored or the Control sites, again similar to results presented by Elias and Meyer (2003). The number of logs did increase at the Restored sites following restoration however the change was not significant. Because of the importance of DWM for retaining soil moisture and moderating soil temperature fluctuations at lakeshore restoration projects in the NHEL (Haskell et al. 2012) it is recommended that log augmentation occur at future projects – research found that soil moderating benefits were attained when augmented logs covered 25-50% of the ground within the plots.

Nonmetric Multi-Dimensional Scaling Ordination indicates that the restoration projects are creating wildlife habitat that will be conductive to an increase in abundance and diversity of understory dwelling wildlife species – characteristics similar to that of early successional forests. The ordination analysis also illustrates the trend for habitat attributes at the Restoration sites are to become more like that those at Reference sites over time – establishing the early success of the restoration projects in achieving the long-term habitat improvement goal.

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## Literature Cited

Christensen, D.L., B.R. Herwig, D.E Schindler, and S.R. Carpenter. 1996. Impacts of lakeshore residential development on coarse woody debris in north temperate lakes. Ecological Applications 6:1143-1149.

Clark, K.L., D.L. Euler, and E. Armstrong. 1984. Predicting avian community response to lakeshore cottage development. Journal of Wildlife Management 48:1239-1247.

Curtis, J.T. 1959. The vegetation of Wisconsin. University of Wisconsin Press, Madison, WI. 657 pp.

Czech, B., P.R. Krausman, and P.K. Devers. 2000. Economic associations among causes of species endangerment in the United States. BioScience 50:593-601.

Dobson, A.P., A.D. Bradshaw, and A.J.M. Baker. 1997. Hopes for the future: restoration ecology and conservation biology. Science 277:515-521.

Elias, J.E., and M.W. Meyer. 2003. Comparisons of undeveloped and developed shorelands, northern Wisconsin, and recommendations for restoration. Wetlands 23:800-816.

Engle, S. and J.L. Pederson, Jr. 1998. The construction, aesthetics, and effects of lakeshore development: a literature review. Wisconsin Department of Natural Resources PUBL-SS-577-99.

Fletcher, R.J. Jr., and R.R. Kofored. 2003. Changes in breeding bird populations with habitat restoration in northern Iowa. American Midland Naturalist 150: 83-94.

Gobster, P.H., and M.G. Rickenbach. 2004. Private forestland parcelization and development in Wisconsin's Northwoods: perceptions of resource-oriented stakeholders. Landscape and Urban Planning. 69:165-182.

Gonzelez-Abraham, C.E., V.C. Radeloff, R.B. Hammer, T.J Hawbaker, S.I. Stewart, and M.K. Clayton. 2006. Building patterns and landscape fragmentation in northern Wisconsin, USA. Landscape Ecology.

Green, R.H. 1979. Sampling design and statistical methods for environmental biologist. John Wiley and Sons, New York. 257 pp.

Harper, K.A., and S.E. MacDonald. 2001. Structure and composition of riparian boreal forest: new methods for analyzing edge influence. Ecology 82: 649-659.
Hulbert, S.A. 1984. Pseudoreplication and the design of ecological field experiments. Ecological Monographs 54:187-211.

Haskell, D.E., Flaspolher, D.J., Webster, C.R., M.W. Meyer. 2012. Variation in soil temperature, moisture, and plant growth with the addition of downed woody material on lakeshore restoration sites. Restoration Ecology 20:113-121.

Jackson, H.H.T. 1961. Mammals of Wisconsin. The University of Wisconsin Press. Madison, Wisconsin. 504 pp

Jennings, M.J., M.A. Bozek, G.R. Hatzenbeler, E.E. Emmons, and M.D. Staggs. 1999. Cumulative effects of incremental shoreline habitat modification on fish assemblages in north temperate lakes. North American Journal of Fisheries Management 19:18-27.

Johnson, P.S., S.L. Novinger, and W.G. Mares. 1984. Root, shoot, and leaf area growth potentials of northern red oak planting stock. Forest Science 30:1017-1026.

Lindsay, A.R., S.S. Gillum, and M.W. Meyer. 2002. Influence of lakeshore development on breeding bird communities in a mixed northern forest. Biological Conservation 107:1-11.

Macbeth, E.J. 1992. Protecting aesthetics and the visual resource of lakes. In Enhancing the states' lake management programs. North American Lake Management Society, Washington, D.C. 112 pp.

Magurran, A.E. 2004. Measuring Biological Diversity. Blackwell Publishing, Oxford, United Kingdom. 256 pp.

Marburg, A.E, M.G. Turner, and T.K Kratz. 2006. Natural and anthropogenic variation in coarse wood among and within lakes. Journal of Ecology 94:558-568.

Moyle, J.B. and N. Hotchkiss. 1945. The aquatic and marsh vegetation of Minnesota and its value to waterfowl. Minnesota Department of Conservation. Technical Bulletin 3. 122pp.

Murphy, R.E. 1931. The geography of the northwestern pine barrens of Wisconsin. Transaction of Wisconsin Academic Science, Arts, and Letters. 26:96-120.

Naiman, R.J., H. Décamps, and M. Pollock. 1993. The role of riparian corridors in maintaining regional biodiversity. Ecological Applications 3:209-212.

Naiman, R.J. 1996. Water, Society, and landscape ecology. Landscape Ecology. 11:193-196.

Newbrey. J.L., M.A Bozek, and N.D. Niemuth. 2005. Effects of lake characteristics and human disturbance on the presence and of piscivorous birds in northern Wisconsin, USA. Waterbirds 28:478-486.

NRCS (Natural Resource Conservation Service). 2002. Wisconsin Biology Technical Note 1: Shoreland Habitat. NRCS. ftp://ftp- fc.sc.egov.usda.gov/WI/technotes/biology-tn1.pdf

Oliver, C.D., and B.C. Larson. 1996. Forest Stand dynamics. John Wiley and Sons, Inc. 520 pp.

Opperman, J.J, and A.M. Merenlender. 2000. Deer herbivory as an ecological constraint to restoration of degraded riparian corridors. Restoration Ecology 8:41-47.

Patten, M.A. 1997. Reestablishment of a rodent community in restored desert scrub. Restoration Ecology 5:156-161.

Racey, G.D., and D.L. Euler. 1982. Small mammal and habitat response to shoreline cottage development in central Ontario. Canadian Journal of Zoology 60: 865-880.

Racey, G.D., and D.L. Euler. 1983. Changes in mink habitat and food selection as influenced by cottage development in central Ontario. Journal of Applied Ecology 20:387-402.

Radeloff, V.C., R.B. Hammer, P.R. Voss, A.E. Hagen, D.R. Field, and D.J. Mladdenoff. 2001. Human demographics trends and landscape level forest management in the northwest Wisconsin Pine Barrens. Forest Science 47:229-241.

Radeloff, V.C., R.B. Hammer, and S.I. Stewart. 2005. Rural and suburban sprawl in the U.S. Midwest from 1940 to 2000 and it relation to forest fragmentation. Conservation Biology 19:793-805.

Radomski, P., and T.J. Goeman. 2001. Consequences of human lakeshore development on emergent and floating-leaf vegetation abundance. North American Journal of Fishery Management 21:46-61.

Robertson, R.J., and N.J. Flood. 1980. Effects of recreational use of shorelines on breeding bird populations. Canadian Field Naturalist 94:131-138.

Sass, G.G., J.F. Kitchell, S.R. Carpenter, T.R. Hrabik, A.E. Marburg, M.G. Turner. 2006. Fish community and food web responses to a whole-lake removal of coarse woody habitat. Fisheries 31:321-330..

Schindler, D.E., S.I. Geib, and M.R. Williams. 2000. Patterns of Fish Growth along a residential development gradient in north temperate lakes. Ecosystems 3:229-237.

Schnaiberg, J., J. Riera, M.G. Turner, and P.R. Voss. 2002. Explaining human settlement patterns in a recreational lake district: Vilas County, Wisconsin, USA. Environmental Management 30:24-34.

Schmidt, K.A. and C.J. Whelan. 1998. Predator-mediated interactions between and with guilds of nesting songbirds: experimental and observational evidence. The American Naturalist. 152:393-402.

Soper, J.H., and M.L. Heimburger. 1994. Shrubs of Ontario. Royal Ontario Museum. Toronto, Canada. 495 pp.

Stearns, F., and G.E. Likens. 2002. One hundred years of recovery of a pine forest in Northern Wisconsin. American Midland Naturalist. 148:2-19.

Starbuck, C., D.K. Struve, and H. Mathers. 2005. Bare root and balled-and burlapped red oak and green ash can be summer transplanted using the Missouri gravel bed system. HortTechnology 15: 122-127.

Stewart-Oaten, A., W.W. Murdoch, and K.R. Parker. 1986. Environmental impact assessment: "pseudoreplication" in time? Ecology 67: 929-940.

Stewart-Oaten, A., J.R. Bence, and G.W. Osenberg. 1992. Assessing effects of unreplicated perturbations: no simple solutions. Ecology 73:1396-1404.

Theobald, D.M, and J.R. Miller, N.T. Hobbs. 1997. Estimating the cumulative effects of development on wildlife habitat. Landscape and Urban Planning 39: 25-36.

Underwood, A.J. 1991. Beyond BACI: experimental designs for detecting environmental impacts on temporal variations in natural populations. Australian Journal of Marine and Freshwater Research. 52: 569-587.

Underwood, A.J. 1994. On beyond BACI: sampling designs that might reliably detect environmental disturbances. Ecological Applications. 4: 3-15.

WDNR. 1996. Northern Wisconsin's Lakes and Shorelands: a report examining a resource under pressure. Wisconsin Department of Natural Resources. Madison, WI 53707.

WDNR. 2005. Wisconsin Lakes. Bureau of Fisheries and Habitat Management. PUB- FH-800. 180 pp.

Wilcove, D.S., D. Rothstein, J. Bubow, A. Phillips, ane E. Loso. 1998. Quantifying threats to imperiled species in the United States. Bioscience 48:607-615.

WinScanopy. 2005. WinSCANOPY 2005a for hemispherical image analysis. Regent Instruments Inc, Canada.

Woodford, J.E., and M.W. Meyer. 2003. Impact of lakeshore development on green frog abundance. Biological Conservation 110:277-284.

**Table 1. Results from two-way ANOVAs showing the effects of Treatment (control, treated, and reference plots), Survey Number (pre- and post-restoration), a Treatment × Survey Number interaction, and Lake (a fixed effect nested in Treatment) on visual obstruction at four height classes.**

| Visual Obstruction Height | Source | $F_{df}$ | *P* |
|---|---|---|---|
| 0.0 to 0.3 m | Treatment | $6.54_{(2, 79)}$ | 0.002 |
| | Survey Number | $15.02_{(1, 79)}$ | 0.002 |
| | Treat × Survey Number | $3.24_{(2, 79)}$ | 0.044 |
| | Lake | $0.37_{(3, 79)}$ | 0.773 |
| 0.3 to 1.0 m | Treatment | $5.95_{(2, 79)}$ | 0.004 |
| | Survey Number | $19.22_{(1, 79)}$ | < 0.0001 |
| | Treat × Survey Number | $2.53_{(2, 79)}$ | 0.086 |
| | Lake | $0.78_{(3, 79)}$ | 0.508 |
| 1.0 to 2.0 m | Treatment | $13.95_{(2, 79)}$ | < 0.0001 |
| | Survey Number | $24.84_{(1, 79)}$ | < 0.0001 |
| | Treat × Survey Number | $1.47_{(2, 79)}$ | 0.236 |
| | Lake | $5.04_{(3, 79)}$ | 0.003 |
| 2.0 to 3.0 m | Treatment | $7.91_{(2, 79)}$ | 0.001 |
| | Survey Number | $25.58_{(1, 79)}$ | < 0.0001 |
| | Treat × Survey Number | $1.81_{(2, 79)}$ | 0.171 |
| | Lake | $5.87_{(3, 79)}$ | 0.001 |

**Table 2. Results from two-way ANOVAs showing the effects of Treatment (control, treated, and reference plots), Survey Number (pre- and post-restoration), a Treatment × Survey Number interaction, and Lake (a fixed effect nested in Treatment) on sapling and shrub density**

| Plant Type | Source | $F_{df}$ | *P* |
|---|---|---|---|
| Sapling Density | Treatment | $2.08_{(2, 79)}$ | 0.132 |
| | Survey Number | $1.53_{(1, 79)}$ | 0.22 |
| | Treat × Survey Number | $0.62_{(2, 79)}$ | 0.542 |
| | Lake | $0.40_{(3, 79)}$ | 0.752 |
| Shrub Density | Treatment | $19.65_{(2, 79)}$ | < 0.0001 |
| | Survey Number | $16.88_{(1, 79)}$ | < 0.0001 |
| | Treat × Survey Number | $24.62_{(2, 79)}$ | < 0.0001 |
| | Lake | $3.16_{(3, 79)}$ | 0.029 |

**Table 3. Results from two-way ANOVAs showing the effects of Treatment (control, treated, and reference plots), Survey Number (pre- and post-restoration), a Treatment × Survey Number interaction, and Lake (a fixed effect nested in Treatment) on the amount of down woody material (DWM; logs, snags, and stumps) per plot. Total DWM is equal to the sum of logs, snags, and stumps.**

| DWM type | Source | $F_{df}$ | *P* |
|---|---|---|---|
| Number of logs | Treatment | $5.87_{(2, 79)}$ | 0.004 |
| | Survey Number | $0.32_{(1, 79)}$ | 0.575 |
| | Treat × Survey Number | $2.01_{(2, 79)}$ | 0.141 |
| | Lake | $2.09_{(3, 79)}$ | 0.108 |
| Number of snags | Treatment | $9.92_{(2, 79)}$ | 0.000 |
| | Survey Number | $0.02_{(1, 79)}$ | 0.881 |
| | Treat × Survey Number | $0.05_{(2, 79)}$ | 0.948 |
| | Lake | $0.28_{(3, 79)}$ | 0.839 |
| Number of stumps | Treatment | $0.10_{(2, 79)}$ | 0.910 |
| | Survey Number | $0.01_{(1, 79)}$ | 0.912 |
| | Treat × Survey Number | $0.63_{(2, 79)}$ | 0.537 |
| | Lake | $0.62_{(3, 79)}$ | 0.604 |
| Total DWM | Treatment | $3.81_{(2, 79)}$ | 0.026 |
| | Survey Number | $0.06_{(1, 79)}$ | 0.806 |
| | Treat × Survey Number | $0.09_{(2, 79)}$ | 0.912 |
| | Lake | $1.25_{(3, 79)}$ | 0.297 |

**Table 4. Results from two-way ANOVAs showing the effects of Treatment (control, treated, and reference plots), Survey Number (pre- and post-restoration), a Treatment × Survey Number interaction, and Lake (a fixed effect nested in Treatment) on gap fraction (the fraction of pixels classified as sky) estimated from canopy photos taken at two heights**

| Height | Source | $F_{df}$ | *P* |
|---|---|---|---|
| 0.5 m | Treatment | $25.03_{(2, 79)}$ | < 0.0001 |
| | Survey Number | $0.97_{(1, 79)}$ | 0.328 |
| | Treat × Survey Number | $0.56_{(2, 79)}$ | 0.571 |
| | Lake | $2.96_{(3, 79)}$ | 0.037 |
| 1.5 m | Treatment | $6.64_{(2, 79)}$ | 0.002 |
| | Survey Number | $1.16_{(1, 79)}$ | 0.285 |
| | Treat × Survey Number | $3.42_{(2, 79)}$ | 0.038 |
| | Lake | $2.56_{(3, 79)}$ | 0.061 |


Figure 1. The Northern Highlands Ecological Landscape (http://dnr.wi.gov/topic/landscapes/index.asp?mode=detail&Landscape=12) Location of restoration sites (Found and Little St. Germain Lakes) within Vilas County, Wisconsin. These lakes is where habitat restoration efforts were conducted on their riparian areas. These lakes were matched with low-development lakes which are referred to as reference.

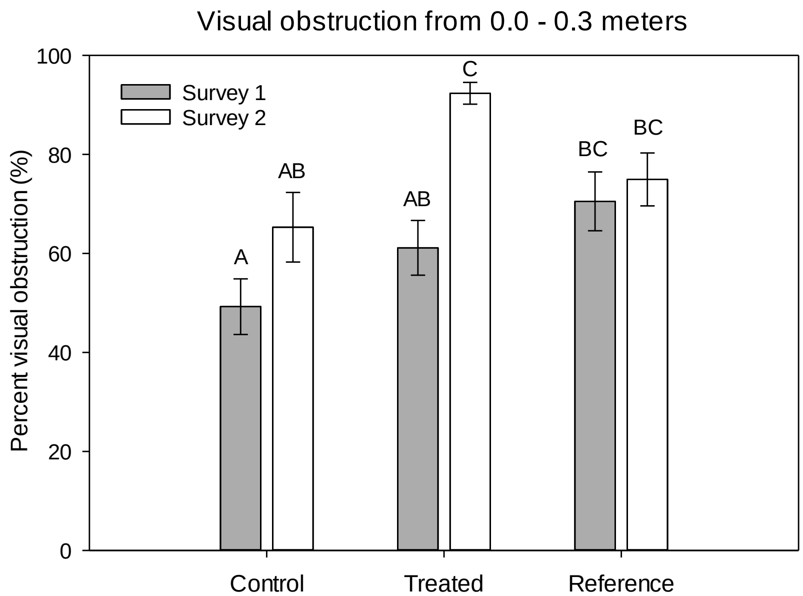



Figure 2. Percent VOD coverage, by Treatment, measured at the 0.0-0.3m height, before (Survey 1) and 3 years after (Survey 2) restorations occurred at the Treated sites. Tukey's Honest Significant Difference (HSD) tests to test for statistical differences between survey years for each treatment. Treatments having any letter in common (A, B, and/or C) are not statistically different from one another ($p > 0.05$). Treatments having no letters in common are statistically different from one another ($p < 0.05$).

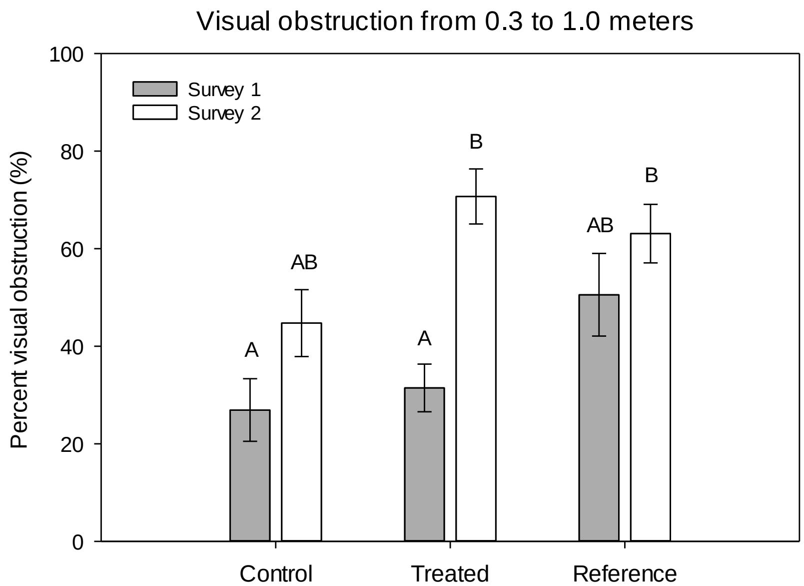



Figure 3. Percent VOD coverage, by Treatment, measured at the 0.3-1.0m height, before (Survey 1) and 3 years after (Survey 2) restorations occurred at the Treated sites. Tukey's Honest Significant Difference (HSD) tests to test for statistical differences between survey years for each treatment. Treatments having any letter in common (A, B, and/or C) are not statistically different from one another ($p > 0.05$). Treatments having no letters in common are statistically different from one another ($p < 0.05$). The Survey x Treatment Interaction was nearly significant for this height ($P = 0.08$). Results indicate that Reference plots had significantly higher percentage of visual obstruction than control plots overall.

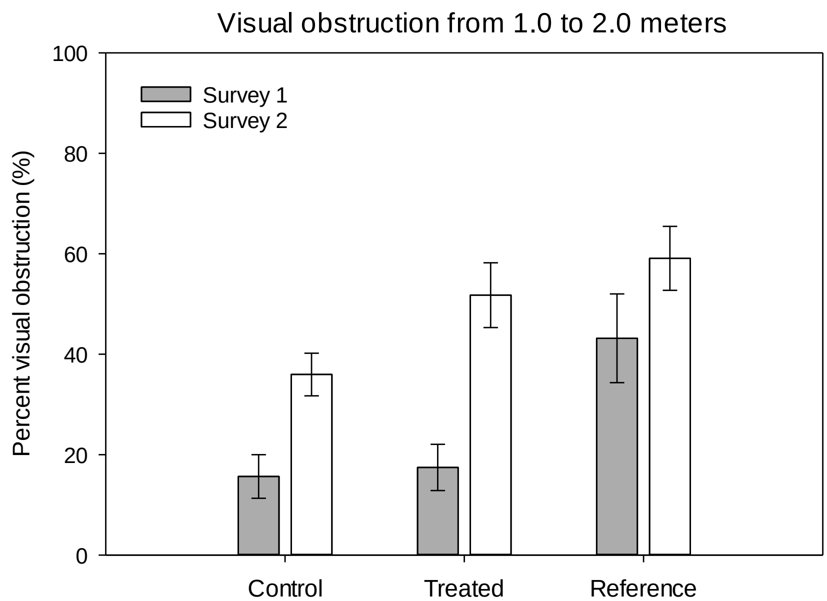



Figure 4. Percent VOD coverage, by Treatment, measured at the 1.0-2.0m height, before (Survey 1) and 3 years after (Survey 2) restorations occurred at the Treated sites.

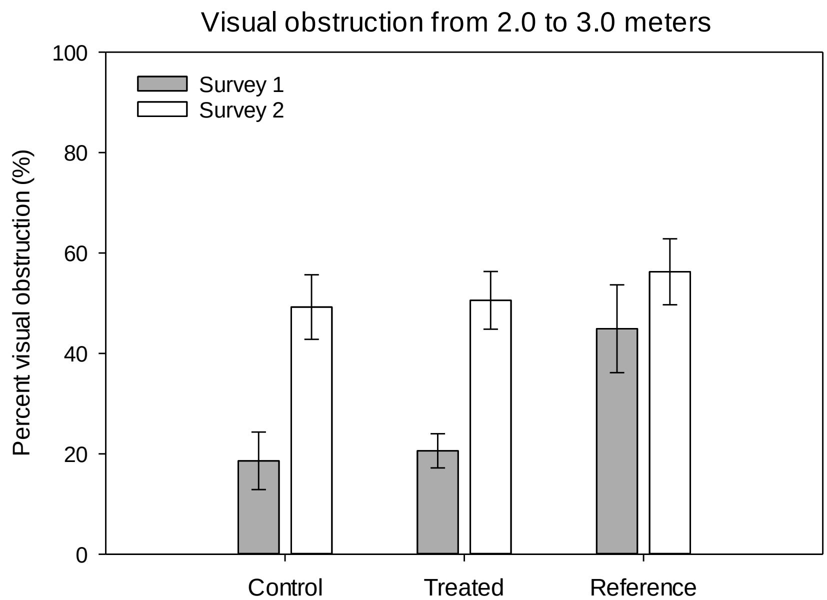



Figure 5. Percent VOD coverage, by Treatment, measured at the 2.0-3.0m height, before (Survey 1) and 3 years after (Survey 2) restorations occurred at the Treated sites.

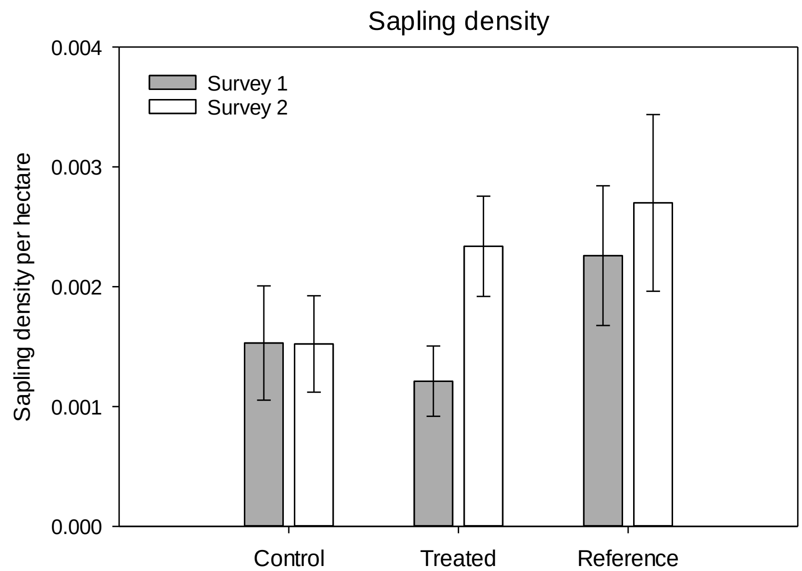



Figure 6. Sapling stems per hectare, by Treatment, before (Survey 1) and 3 years after (Survey 2) restorations occurred at the Treated sites.

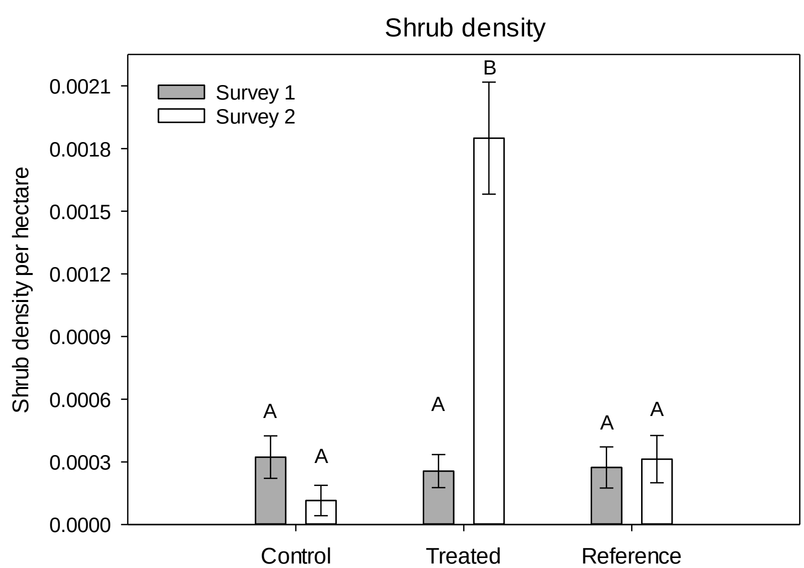



Figure 7. Shrub stems per hectare, by Treatment, before (Survey 1) and 3 years after (Survey 2) restorations occurred at the Treated sites. Tukey's Honest Significant Difference (HSD) tests to test for statistical differences between survey years for each treatment. Treatments having any letter in common (A, B, and/or C) are not statistically different from one another ($p > 0.05$). Treatments having no letters in common are statistically different from one another ($p < 0.05$).

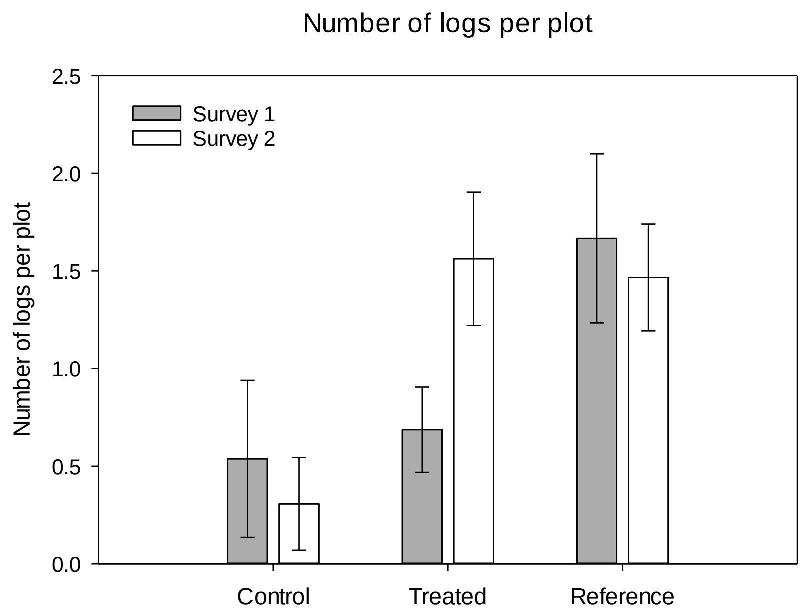



Figure 8.  Number of logs per 10m x 10m plot, before (Survey 1) and 3 years after (Survey 2) restorations occurred at the Treated sites.

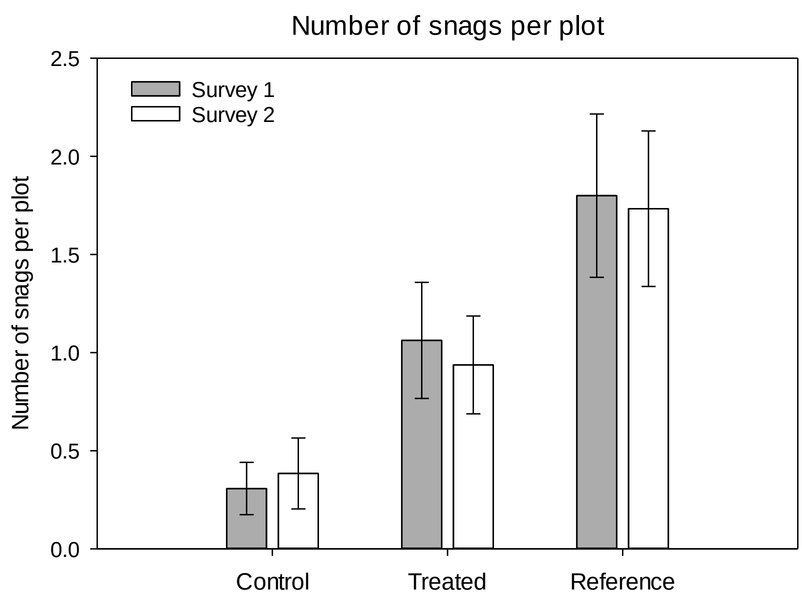



Figure 9.  Number of snags per 10m x 10m plot, before (Survey 1) and 3 years after (Survey 2) restorations occurred at the Treated sites.

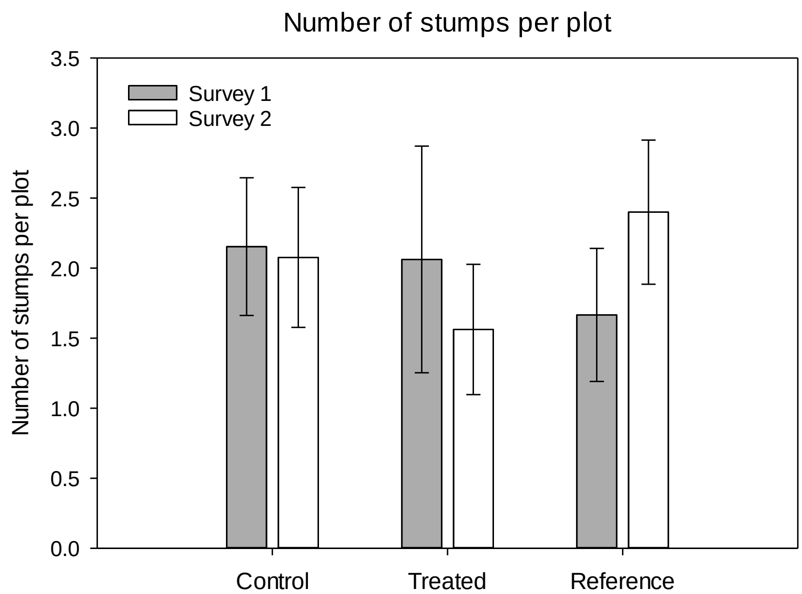



Figure 10. Number of stumps per 10m x 10m plot, before (Survey 1) and 3 years after (Survey 2) restorations occurred at the Treated sites.

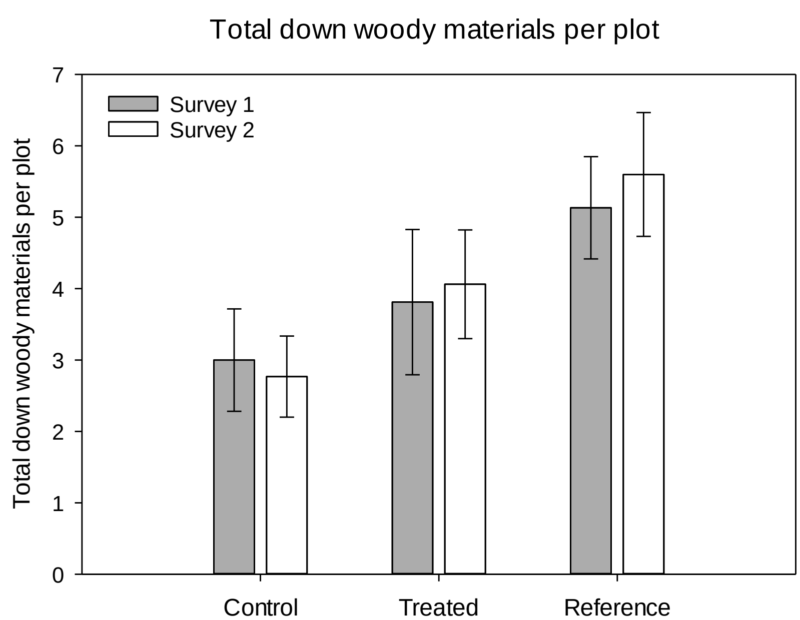



Figure 11. Total down woody material per 10m x 10m plot, before (Survey 1) and 3 years after (Survey 2) restorations occurred at the Treated sites.

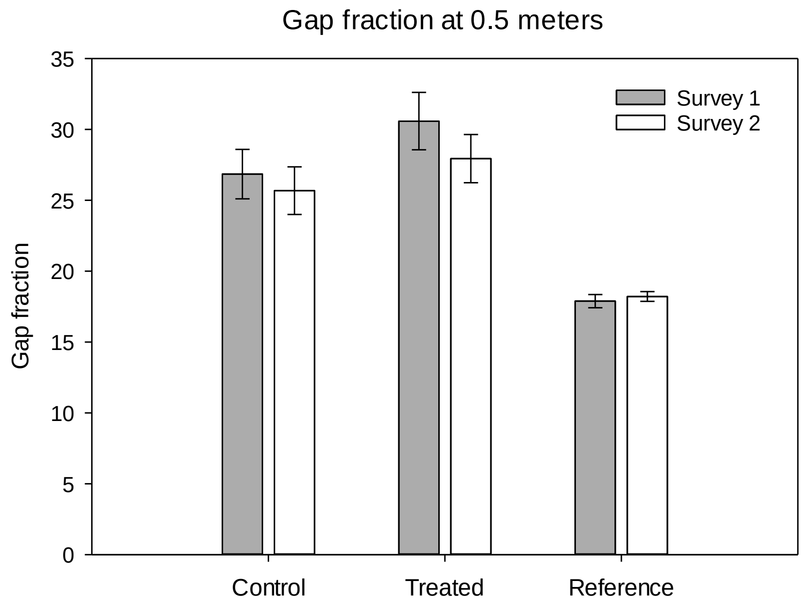



Figure 12. Total gap fraction as measured at 0.5m before (Survey 1) and 3 years after (Survey 2) restorations occurred at the Treated sites.

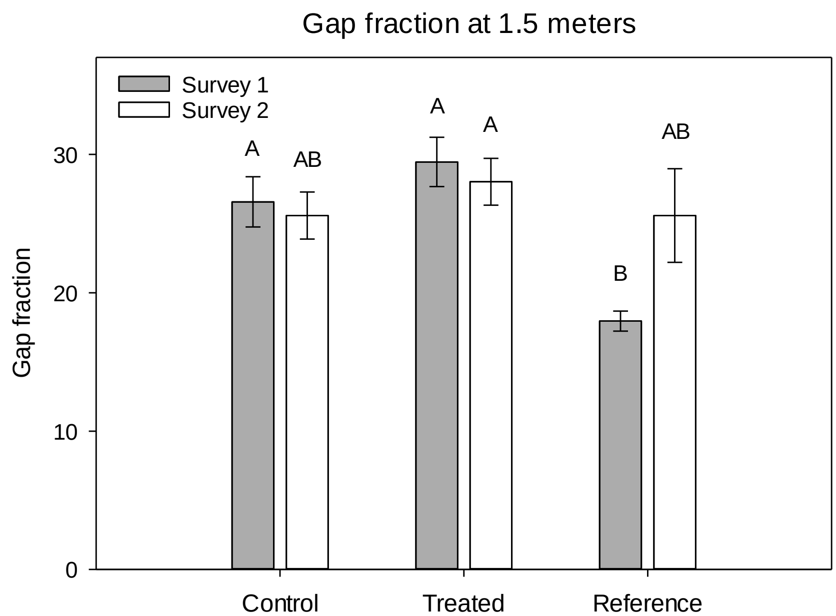
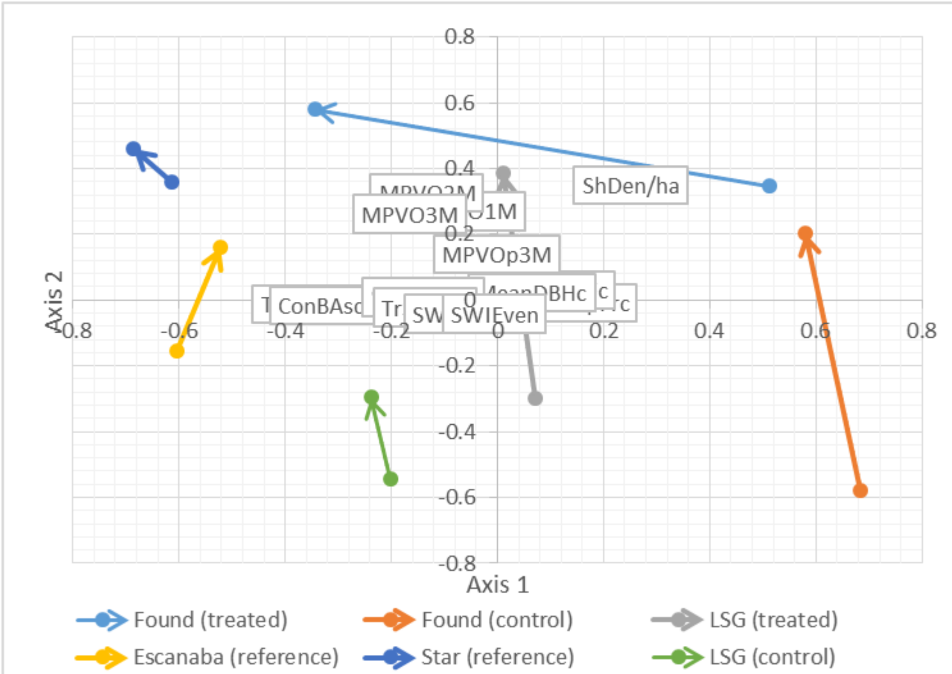



Figure 13. Total gap fraction as measured at 1.5m before (Survey 1) and 3 years after (Survey 2) restorations occurred at the Treated sites. Tukey's Honest Significant Difference (HSD) tests for statistical differences between survey years for each treatment. Treatments having any letter in common (A, B, and/or C) are not statistically different from one another ($p > 0.05$). Treatments having no letters in common are statistically different from one another ($p < 0.05$).



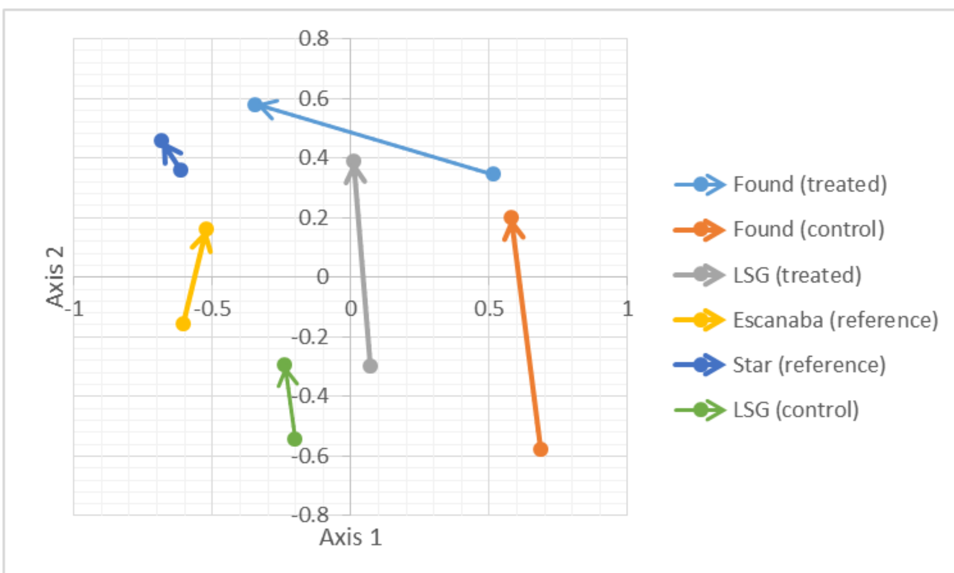




Figure 14. Nonmetric ordination of wildlife habitat attributes, with vectors illustrating average movement of treatments through time at each site. Points that are closer together in the ordination space are more similar in terms of the composition of habitat attributes. Movement towards each other or in the same direction indicate increasing similarity along habitat gradients. The upper left quadrant in the ordination space was associated with greater visual obstruction.

**III. Developing Best Management Practices**

*Evaluating the Efficacy of Downed Woody Material on Lakeshore Restoration Projects* (this section is a synopsis of published manuscript *Haskell, D, Flaspohler, D, Webster, C., Meyer, M.W. (2012). Variation in soil temperature, moisture, and plant growth with the addition of downed woody material on lakeshore restoration sites. Restoration Ecology 20: 113-121.* The full manuscript with Tables and Figures is attached.

**SYNOPSIS**

Variation in soil temperature, moisture, and plant growth with the addition of downed woody material on lakeshore restoration sites

Daniel E. Haskell, David J. Flaspohler, Christopher R. Webster, Michael W. Meyer

***Overview:*** *Previous studies in the NHEL found lakeshore housing development is associated with a reduction of downed woody material in the lakeshore riparian area. We found that addition of downed wood (small logs) to lakeshore restoration projects was associated with increased soil moisture and a decrease in soil temperature fluctuations. The performance of some plant species tested improved with augmented downed wood thus the use of downed wood on restoration projects is indicated.*


**Abstract**

Downed woody material (DWM) is an important ecosystem component that performs many critical functions including influencing soil temperature and moisture which affects plant growth and survival. Residential development along lakeshores has increased dramatically in recent decades in the northern Great Lakes region. Such development often leads to reductions in terrestrial and aquatic woody material. Although lakeshore restoration projects have occurred in the past few years in the region, there has been little effort to evaluate success. In 2007, a collaborative lakeshore restoration research project began on two lakes in Vilas County, Wisconsin. We investigated the benefits of the addition of DWM as part of these restoration projects. We randomly assigned three coverage treatments (0%, 25%, and 50%) of DWM on 3 m × 3 m experimental plots ($n$ = 10 per treatment), and monitored soil temperature and volumetric soil water content at a depth of 10 cm. All plots were planted with two native shrub species and five native understory herbaceous species. 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 significantly greater in the 25% and 50% DWM plots. We conclude that the addition of DWM had a significant positive effect on regulating soil temperature extremes, soil moisture, and plant volume growth for two species of native plants used for restoration projects.


**Introduction**

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. Much of 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 & Meyer 2003; Marburg et al. 2006). In fact, some residents equate lakeshore beauty with park like conditions of manicured lawns and scattered trees (Macbeth 1992). Removal of DWM and vegetation structure along shorelines on high-development lakes is a common practice.

Down woody material (DWM) is vital to the function and structure of healthy terrestrial and aquatic ecosystems. DWM includes fallen dead trees and large branches, and is often abundant in natural forest, stream (Harmon et al. 1986), and lake ecosystems (Christensen et al. 1996; Marburg et al. 2006). Additionally, DWM provides critical habitat for small mammals (Tallmon & Mills 1994; Ucitel et al. 2003), amphibians (Jaeger 1990), small to mid-size carnivores (Gilbert et al. 1997), a variety of bird species (Maser et al. 1979), and many invertebrates, 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 as a moisture reservoir and by buffering fluctuations in ground surface temperatures (Harmon et al. 1986; Gray& Spies 1997).

Lakeshore restoration is a relatively new practice in northern Wisconsin and throughout North America. 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. To better understand the dynamics and benefits of lakeshore restoration, we added DWM to seven restoration projects with three coverage treatments and monitored the soil temperature and moisture content over the course of the growing season. We also recorded the first year survival and plant canopy volume growth of several native plant species within these treatments.

Our objectives were to: 1) determine if DWM addition reduces 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. Because DWM will provide shade and retain soil moisture on disturbed, sandy soils, we hypothesized that sites with the DWM additions would show less temperature and moisture variation during the growing season. We also predicted that plant survival and growth will be greatest with the presence of DWM.

**Methods**

Study Area

This project was conducted on two lakes in a forested landscape on deep sands in a pitted glacial outwash landscape in Vilas County of northern Wisconsin (Stearns & 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 (WDNR 2005). Found Lake was home to several fishing resorts in the past, but in recent decades, many of these resorts have been sold to developers and parceled for resale to individuals for seasonal or permanent homes. 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. The combination of human impact and the wind storms in the past have degraded both lakeshores. Therefore, on both study sites regeneration of vegetation is low and much soil erosion is occurring, making both lakeshores prime candidates for restoration. The mean daily ambient air temperature is 3.4° C, ranging from -2° C in January to 10° C in July and the mean annual 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 shoreline 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 the shore of Found Lake and six on the shore of State House Lake. Ten sets of three experimental plots (0%, 25%, and 50% cover of DWM) were established. Each set of experimental plots was placed in line and parallel with the shoreline and 3 m inland from the ordinary high water mark. This placed the experimental plots in the middle of the 35-ft state mandated buffer zone (Wisconsin's Shoreland Management Program, chapter NR 115), a consistent distance from the shoreline, and far enough from the shoreline 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 one of three coverage densities of DWM to each experimental plot (Figure 1): 50 % of area covered by DWM ($n$ = 10), 25 % of area covered by DWM ($n$ = 10), and 3) 0 % of area covered by DWM ($n$ = 10).

We defined DWM 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 (Haskell 2009).

In each experimental plot we planted three shrubs and 25 forbs and grasses. A total of 90 shrubs and 750 ground cover individuals were planted and uniquely identified with a numbered metal tag. One snowberry (*Symphoricarpos albus)* ($n$ = 30) and two Sweet fern (*Comptonia peregrine*) ($n$ = 60) comprised the shrub species for each experimental plot. For each shrub, one liter of organic compost was incorporated into the soil before shrubs were planted. We 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). Plant densities were based on recommendation from the Wisconsin Biology Technical Note 1: Shoreland Habitat (NRCS 2002). *Symphoricarpos albus* were delivered in three-gallon nursery containers, *C. peregrine* in one-gallon nursery containers and all ground cover species were in 2.5 inch nursery containers. A local nursery (Hanson's Garden Village, Rhinelander, Wisconsin) supplied all plant material.

## Abiotic variables

The following 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 were measured on each plot. To quantify the gap fraction, we 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 (WinScanopy 2005).

## Soil Temperature

From each plot corner a temperature data logger (Standard Logger, KoolTrak, Inc) was placed systematically 1 m inward at a 45º angle and at a depth of 10 cm in each plot (*n* = 120). We deployed all loggers 4-6 weeks prior to restoration which provided data before DWM was applied. All loggers were programmed to record soil temperatures every hour during the 2008 growing season (May 6$^{th}$ to September 26$^{th}$). We 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 were recorded 12 hr after a weekly watering event (irrigation or precipitation) and then again 24 hr after the first reading. We 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 rainfall 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 was used to estimate 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.

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; we excluded from ground cover volume growth analyses the missing individuals in May and all summer mortalities.

## Data Analyses

The means for soil temperature variables were calculated with the software KoolTrak (KoolTrak, Inc 2004). 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. We 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, we determined if all test assumptions (normality and equal variance) were met. The Kolmogorov-Smirnov test was used to evaluate the assumption of normality. We 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, we used the nonparametric Kruskall-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

We 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) between treatments.

### 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. We collected daily soil temperature data during the 2008 growing season for 144 days resulting in 13,824 temperature samples (Figure 2). We found 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 3). However, the average maximum daily temperature per month was significantly different (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 3). Daily soil temperature ranges for each month were also significantly different between DWM treatments (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 3). Pair-wise multiple comparisons yielded no significant difference between 25% and 50% DWM coverage plots for both daily maximum and difference between low and high daily temperatures.

### Soil Moisture

Moisture content, after a watering event, was significantly different across plots in July and August (July: $F_{2, 27}$ = 58.964, $P$ = <0.001; August $F_{2, 27}$ = 66.511, $P$ = <0.001). However, pair-wise multiple comparisons found no difference between plots with DWM coverage in July, but showed significant differences between all treatments in August (Figure 4).

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, we did find a significant loss in *S. albus* shrub canopy volume (*S. albus* shrubs: $F_{2, 27}$ = 4.961, $P$ = 0.015). *Symphoricarpos albus* shrubs in 0% DWM treatment plots experienced a 14.3% (± 0.0849 SE) decline in mean canopy volume ($m^3$) (Figure 5). Pair-wise multiple comparisons yielded no significant difference between 25% and 50% DWM, or between 0% and 25% DWM coverage for *S. albus* shrub canopy volume. There was no significant difference in *C. peregrine* canopy volume after one year ($F_{2, 27}$ = 1.398, $P$ = 0.264).

Ground cover species combined had a 92.8% survival rate. *Monarda fistulosa* had the lowest survival (85.3%) rate while *W. fragaroides* had the highest survival rate (98%) (Table 1). The ground cover canopy volume data revealed no significant difference for four of the five species (*A. margaritacea*: H = 1.280, df = 2, $P$ = 0.527; *A. 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). *Anaphalis margaritacea* and *A. marcophyllus* had a 2-4 fold 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 (Table 2). *Waldstenia fragaroides* canopy volume was significantly different (H = 6.991, df = 2, $P$ = 0.030) between plots with and without DWM (Table 2). The large standard errors for canopy volume for ground cover species reveal generally high variability for this group of plants (Table 2).

**Discussion**

Ecological restoration efforts on disturbed sites depend on successful establishment and survival of native plant species. The effects of soil temperature and moisture are important for both herbaceous and woody plants. 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.

The addition of DWM lowered the difference between low and high daily soil temperature, maximum daily temperature, and 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 period (http://mrcc.sws.uiuc.edu/climate_midwest).

Several studies have investigated the ecological benefits of restoring DWM to streams and rivers (Hilderbrand et al 1997; Larson et al. 2001; Brooks et al. 2004). No studies to our knowledge have looked at restoring DWM to lake riparian areas. Our soil temperature and moisture results are consistent with the increase in *S. albus* canopy volume in the 25% and 50% DWM coverage plots. However, there was no significant difference for *C. peregrine* canopy volume among treatments

The ground cover species used in this study are adapted to moderate to dry soil conditions and are recommended for use in lakeshore restoration projects. *Waldstenia fragaroides* may have lost canopy volume in the 0 % DWM coverage plots between measures because this summer green herb completes most of its life-cycle (growth, flowering, and fruiting) in the early 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 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.

Restorations of lakeshores with sandy soil and a southern aspect may particularly benefit from addition of DWM. 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 & 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.

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

**Implication for Practice**

- The addition of DWM to restoration sites can reduce soil temperature and moisture extremes on degraded sites. Therefore, reducing stress on new plant stock.
- Because DWM positively influenced growth rates of plants used in shoreline restoration projects and it may take decades for DWM to occur naturally on human altered sites. The addition of DWM to restoration sites should be considered when planning restoration of riparian and other restoration projects.
- Because survival and growth rates of plants are crucial to the success of restoration, DWM can accelerate the success of restoration projects.
- Restoration projects with highly degraded, sandy soils and a southern aspect will benefit from the addition of DWM to sites.

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**Literature Cited**

Aerts, R., A. Negussie, W. Maes, E. November, M. Hermy, and B. Muys. 2007. Restoraion of dry afromontane forest using pioneer shrubs as nurse-plants of *Olea europaea* spp. *Cuspidate.* Restoration Ecology 15:129-138.

Bhattacharjee, J., J.P. Taylor, JR., L.M. Smith, and L.E. Spence. 2008. The importance of soil characteristics in determining survival of first-year cottonwood seedlings in altered riparian habitats. Restoration Ecology 16:563-571.

Bormann, F.H., and G.E. Likens. 1979. Pattern and process in a forested ecosystem. Springer-Verlag, New York, NY. 262 pp.

Brooks, A.P., P.C. Gehrke, J.D. Jansen, and T.B. Abbe. 2004. Experimental reintroduction of woody debris on the Williams River: Geomorphic and ecological responses. River Research and Applications 20:513-536.

Breshears, D.D., J.W.Nyhan, C.E. Heil, and B.P. Wilcox. 1998. Effects of woody plants on microclimate in a semiarid woodland: soil temperature and evaporation in canopy and intercanopy patches. International Journal of Plant Science 159:1010-1017.

Bussler, B.H., B.D. Maxwell, and K.J. Puettmann. 1995. Using plant volume to quantify interference in corn (*Zea mays*) neighborhoods. Weed Science 43:421-428.

Callaway, R.M. 1992. Effect of shrubs on recruitment of *Quercus douglasii* and *Quercus lobata* in California. Ecology 73:2118-2128.

Castro, J., R. Zamora, J.A. Hódar, and J.M. Gómez. 2002. Use of shrubs as nurse plants: A new technique for reforestation in Mediterranean Mountains. Restoration Ecology 10:297-305.

Castro, J., R. Zamora, J.A. Hódar, and J.M. Gómez, and L.Gómez-Aparicio. 2004. Benefits of using shrubs as nurse plants for reforestation in Mediterranean mountains: a 4-year study. Restoration Ecology 12:352-358.

Christensen, D.L., B.R. Herwig, D.E Schindler, and S.R. Carpenter. 1996. Impacts of lakeshore residential development on coarse woody debris in north temperate lakes. Ecological Applications 6:1143-1149.

Dong, S., C.F. Scagel, L. Cheng, L.H. Fuchigami, and P. Rygiewizc. 2001. Soil temperature and plant growth stage influences nitrogen uptake and amino acid concentration of apple during early spring growth. Tree Physiology 21:541-547.

Ehleringer, J.R., and D.R. Sandquist. 2006. Ecophysiological constraints on plant responses in a restoration setting. In Foundations of Restoration Ecology*,* pages 42-58. D.A. Falk, M.A. Palmer, and J.B. Zedler, editors. Washington D.C. Island Press. 364 pp.

Elias, J.E., and M.W. Meyer. 2003. Comparisons of undeveloped and developed shorelands, northern Wisconsin, and recommendations for restoration. Wetlands 23:800-816.

Engle, S. and J.L. Pederson, Jr. 1998. The construction, aesthetics, and effects of lakeshore development: a literature review. Wisconsin Department of Natural Resources PUBL-SS-577-99.

France, R., R.Peters, and L. McCabe. 1998. Spatial relationships among boreal riparian trees, litterfall and soil erosion potential with reference to buffer strip management and coldwater fisheries. Annual Botanica Fennici 35:1-9.

Frelich, L.E. 2002. Forest Dynamics and Disturbances Regimes. Cambridge University Press. 266 pp.

Gilbert, J.H., J.L. Wright, D.J. Lauten, and J.R. Probst. 1997. Den and rest-site characteristics of American Marten and Fisher in northern Wisconsin. In *Martes:* taxonomy, ecology, techniques, and management, pages 135-145. G. Proulx, H.N. Bryant, and P.M. Woodard, editors. Provincial Museum of Alberta, Edmonton, Alberta, Canada. 484 pp.

Gonzelez-Abraham, C.E., V.C. Radeloff, R.B. Hammer, T.J Hawbaker, S.I. Stewart, and M.K. Clayton. 2007. Building patterns and landscape fragmentation in northern Wisconsin, USA. Landscape Ecology 22: 217-230.

Gray, A.H., and T.A. Spies. 1997. Microsite controls on tree seedling establishment in conifer forest canopy gaps. Ecology 78:2458-2473.

Hagan, J.M., and S.L. Grove. 1999. Course woody debris. Journal of Forestry 97:6-11.

Harmon, M.E., J.F. Franklin, and F.J. Swanson. 1986. Ecology of course woody debris in temperate ecosystems. Advanced Ecological Research 15:133-302.

Haskell, D.E. 2009. Quantifying the ecological benefits of lakeshore restoration in northern Wisconsin. M.S.Thesis. Michigan Technological University, Houghton.

Henderson, C.L. 1987. Landscaping for wildlife. Minnesota Department of Natural Resources. Minnesota Bookstore. St. Paul, MN. 144 pp.

Hightshoe, G.L. 1988. Native trees, shrubs, and vines of urban and rural America. Van Nostrand Reinhold, New York. 819 pp.

Hilderbrand, R.H., A.D. Lemly, C.A. Dollofft, and K.L Harpster. 1997. Effects of large woody debris placement on stream channel and benthic macroinvertebrates. Canadian Journal of Fisheries and Aquatic Science 54:931-939.

Jaeger, R.G. 1980. Microhabitats of a terrestrial forest salamander. Copeia 1980:265-268.

Larson, M.G, D.B. Booth, and S.A. Morley. 2001. Effectiveness of large woody debris in stream rehabilitation projects in urban basins. Ecological Engineering 18: 211-226.

Macbeth, E.J. 1992. Protecting aesthetics and the visual resource of lakes. In Enhancing the states' lake management programs. North American Lake Management Society, Washington, D.C. 112 pp.

Maestre, F., S.Bautista, J. Cortina, and J. Bellot. 2001. Potential for using facilitation by grasses to establish shrubs on a semiarid degraded steppe. Ecological Applications 11:1641-1655.

Maser, C., R.G. Anderson, K. Cromack, Jr., J.T. Williams, and R.E. Martin. 1979. Dead and down woody material. In Wildlife habitats in managed forest: the Blue mountains of Oregon and Washington, pages 78-95. J.W. Thomas, editor. Agricultural Handbook No. 553. USDA Forest Service.

Marburg, A.E, M.G. Turner, and T.K Kratz. 2006. Natural and anthropogenic variation in coarse wood among and within lakes. Journal of Ecology 94:558-568.

McComb, B.C. 2008. Wildlife habitat management: concepts and applications in forestry. CRC Press. 319 pp.

NRCS (Natural Resource Conservation Service). 1986. Soil survey of Vilas County. Unites States Department of Agriculture.

NRCS (Natural Resource Conservation Service). 2002. Wisconsin Biology Technical Note 1: Shoreland Habitat. NRCS. ftp://ftp-fc.sc.egov.usda.gov/WI/technotes/biology-tn1.pdf

Radeloff, V.C., R.B. Hammer, P.R. Voss, A.E. Hagen, D.R. Field, and D.J. Mladdenoff. 2001. Human demographics trends and landscape level forest management in the northwest Wisconsin pine barrens. Forest Science 47:229-241.

Rasmussen, H.N., and D.F. Whigman. 1998. Importance of woody debris in seed germination of *Tipularia discolor* (Orchidaceae). American Journal of Botany 85:829-834.

Reid, K.D., B.P. Wilcox, D.D. Breshears, and L. MacDonald. 1999. Runoff and erosion in a Pinon-Juniper woodland: influence of vegetation patches. Soil Science Society of America Journal 63:1869-1879.

Russell, E.W. 1973. Soil conditions and plant growth. Longman Group Limited, London, Great Britian. 849 pp.

Schnaiberg, J., J. Riera, M.G. Turner, and P.R. Voss. 2002. Explaining human settlement patterns in a recreational lake district: Vilas County, Wisconsin, USA. Environmental Management 30:24-34.

Smith, W.R. 2008. Trees and shrubs of Minnesota: complete guide to species identification. The University of Minnesota Press, Minneapolis, MN. 703 pp.

Soper, J.H., and M.L. Heimburger. 1994. Shrubs of Ontario. Royal Ontario Museum. Toronto, Canada. 495 pp.

Stearns, F., and G.E. Likens. 2002. One hundred years of recovery of a pine forest in Northern Wisconsin. American Midland Naturalist 148:2-19.

Tallmon, D.A., and L.S. Mills. 1994. Use of logs within home ranges of California Red-backed voles on a remnant forest. Journal of Mammalogy 74:97-101.

Ucitel, D., D.P Christian, and J.M. Graham. 2003. Vole use of course woody debris and implications for habitat and fuel management. Journal of Wildlife Management 67:65-72.

WDNR. 1996. Northern Wisconsin's Lakes and Shorelands: a report examining a resource under pressure. Wisconsin Department of Natural Resources. Madison, WI 53707.

WDNR. 2005. Wisconsin Lakes. Bureau of Fisheries and Habitat Management. PUB-FH-800

Weiher, E., S.P. Poet, and K. Voss. 2003. Experimental Restoration of Lake Shoreland in Western Wisconsin. Ecological Restoration 21:186-190.

WinScanopy. 2005. WinSCANOPY 2005a for hemispherical image analysis. Regent Instruments Inc, Canada.

Woodford, J.E., and M.W. Meyer. 2003. Impact of lakeshore development on green frog abundance. Biological Conservation 110:277-28.

*The Cost-Benefits of Fencing, Irrigation, and Plant Stock Source for Lakeshore Restorations*

(The manuscript below is currently in review at Native Plants Journal; thus the information below is Draft version)

**Assessing the Importance of Fencing, Irrigation, and Native Plant Source when Restoring Northern Wisconsin Lakeshore Wildlife Habitat**

Daniel E. Haskell*, Christopher R. Webster, Michael W. Meyer, David J. Flaspohler

***Overview:*** *We tested the cost/benefits of 3 lakeshore restoration approaches as well as the use of deer fencing and irrigation when conducting lakeshore restoration in the NHEL. We found that actively planting container plants from private nurseries and bare root stock from state nurseries both result in increased habitat structure and similar rates of growth and survival of trees and shrubs, however bare root stock was less costly. We also found that passive restoration when a seed bank is present will restore habitat quality but at a slower rate. Fencing and irrigation enhanced growth and survival in all restoration approaches, and the benefits are greater than the cost.*

***Abstract:*** Lake riparian areas perform many functions within lake ecosystems including providing critical habitat for wildlife species. However this habitat can be altered or entirely removed by residential development, affecting wildlife composition, abundance, and distribution. Restoration projects have recently been initiated on private lakeshore properties where residential development has occurred in Vilas County, Wisconsin. Vilas County Conservation Department offers a cost-share program to support restoration projects. A requirement for participation is installation of herbivory abatement and irrigation. In this experiment we tested the effectiveness of fencing and irrigation to increase the abundance and survival of plantings. Dormant bare root trees and shrubs can cost approximately half of a containerized trees and shrubs but their effectiveness to improve habitat has not been measured. In this study we compared how dormant bare root trees and shrubs from private and Wisconsin state nurseries improved habitat, and then compared the improvement to a natural recovery (control). We also tested the difference among these treatments with and without fencing and irrigation. With fencing and irrigation present, both nursery sources were equally effective in restoring sapling and shrub abundance five years post restoration. There was very little difference between all three treatments without fencing and irrigation. In addition, overall sapling and shrub survival was higher in fenced and irrigated areas. We conclude that fencing and irrigation accelerates lakeshore wildlife habitat restoration (planting of native trees, shrubs, and groundcover) and improves native plant survival. However natural recovery (reliance on the in-place seed bed) at this site promises a similar recovery over the long-term.

**Key words**: habitat restoration, lakeshore, bare root, fence and irrigation, private nursery, public nursery, natural recovery.

**Introduction**

Lakeshore riparian areas 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, residential development is often associated with the removal of vegetation structure along lakeshores (Christensen and others 1996; Elias and Meyer 2003; Marburg and others 2006), because some lakeshore residents prefer manicured lawns and scattered trees over natural riparian vegetation (Macbeth 1992). Recent studies in northern Wisconsin revealed that a high density of housing on lakeshores had a negative impact on wildlife communities and their habitats including altered bird community structure (Lindsey and others 2002; Ford and Flaspohler 2010), amphibian declines (Woodford and Meyer 2003), reduced carnivore richness and diversity (Haskell and others 2013), and reductions in understory vegetation and downed woody material (Christensen and others 1996; Elias and Meyer 2003; Marburg and others 2006).

The State of Wisconsin has attempted to protect shoreline habitat by implementing ordinances that mandate standards for vegetation conservation in a 10.8 m (35 ft) buffer zone along lakeshores that extends inland from the ordinary high water mark (WDNR Chapter NR 115 2014(a) https://docs.legis.wisconsin.gov/code/admin_code/nr/100/115.pdf). However, many lakeshore owners are unaware of or ignore these ordinances, and cutting and removal of vegetation from the buffer zone remains common.

In recent decades, interest in lakeshore restoration has increased among private property owners in Wisconsin. In 2007, a collaboration of staff from Vilas County Land Water Conservation Department (VCLWCD), Wisconsin Department of Natural Resources (WDNR), Michigan Technological University (MTU), and Wisconsin Department of Agriculture, Trade and Consumer Protection initiated a long-term (≥ 10 years) research project [Wisconsin Lakeshore Restoration Project (WLRP)] to investigate the feasibility and ecological value of lakeshore restoration on riparian and littoral communities in Vilas County, Wisconsin (Haskell 2009). One of the objectives of the WLRP is to restore understory wildlife habitat on lakes with a high density of housing development. The WLRP asks participating private property owners to plant native trees, shrubs and ground cover plants within the buffer zone along the lakeshore. The plant density is based on recommendations from the Wisconsin Biology Technical Note (WBTN) 1: Shoreland Habitat (NRCS 2002). WBTN also describes the benefits of promoting a "natural recovery" where feasible. For example, where adequate seed and/or root sources are present, and conditions are favorable, the site is protected from disturbance, and native vegetation is allowed to recover naturally (NRCS 2002). Additionally, "Accelerated recovery" techniques (e.g. site preparation and planting) are required where insufficient native vegetation is present for natural recovery techniques, or where quick results are desired (NRCS 2002).

One of the largest costs for accelerated lakeshore restoration projects is containerized trees and shrubs, currently a common practice. Dormant bare root trees and shrubs on the other hand can cost up to half as much as container trees and shrubs. Nevertheless, little is known about how bare root plant material survival and growth compare to containerized planting stock.

Lakeshore restoration is an uncertain practice and failures are common (Vanderbosch and Galatowitsch 2010). Reasons for failure can include little or no irrigation after planting (Friedman and Lewis 1995; Haskell 2009) and browsing by herbivores (Opperman and Merenlender 2000; Sweeney and others 2002; Haskell 2009). White-tailed deer (*Odocoileus virginianus* Zimmermann [Cervidae]) herbivory can have strong negative effects on plant communities (Beals and others 1960; Russell and others 2001), lowering recruitment of palatable species (Alverson and Waller 1997; Holmes and others 2009; Witt and Webster 2010), and can have a negative impact on restoration projects (Case and Kaufman 1997; Opperman and Merenlender 2000; Haskell 2009; Holmes and others 2009). Haskell and others (2013) observed that white-tailed deer abundance was significantly higher on high-development lakes (≥10 houses per km) in northern Wisconsin, which may be due to supplemental feeding by property owners. This feeding can aggregate white-tailed deer and negatively affect natural vegetation near feeding sites (Doenier and others 1997).

Maintaining proper soil moisture is also critical for plant establishment and growth (Haskell and others 2012). Vilas County soils are predominantly sandy to sandy loam (WDNR 2014b), necessitating regular irrigation on restoration projects during the establishment phase. Currently, the VCLWCD requires landowners who participate in their shoreland habitat restoration cost-share program (http://co.vilas.wi.us/index.php?page=lwcd-cost-share-program) to install herbivory abatement and irrigation system as terms to their contract. In this project, we test whether that additional requirement, thus cost, is justified.

To better understand the potential utility of dormant bare root trees, shrubs and herbivory abatement and irrigation for lake shore restoration, we launched a research project in 2010 to evaluate wildlife habitat development among restoration plantings. The objectives of our research were to: (1) determine if planting dormant bare root trees and shrubs from private and public nurseries as well as a natural recovery, are effective methods to restore understory wildlife habitat over a five year period and (2) determine whether the addition of herbivory abatement and irrigation provide measureable benefits.

## Materials and Methods

### Study Site

This project is located at Crystal Lake Campground in the Northern Highland-American Legion State Forest (NH-AL), which is within the Northern Highland Ecological Landscape (NHEL) (WDNR 2014b) (Figure 1). Crystal Lake is a seepage lake with a surface area of 35.6 ha, a maximum depth of 20 m, and is surrounded by public lands (WDNR 2005). Crystal Lake is part of a recreational area that is comprised of modern campgrounds with a nature center, paved bike paths, two public swimming beaches, and a day use area that has been maintained as lawn for decades. The area in which we conducted our experiment is on the northwest shore and lies between two swimming beaches and was used primarily as a day-use and picnic area. This area has been used for recreational purposes and managed as a public park since World War II (S. Peterson, superintendent NH-AL, personal comm.). The site lacks understory habitat (shrub layer) but has scattered mature red pine (*Pinus resinosa* Aiton [Pinaceae]) trees (Figure 2). The soil around Crystal Lake is acidic and sandy and derived from glacial outwash (WDNR 2014b).

### Experimental Design

We established 42-10 m x 10 m experimental test plots along 320 m of the northwest lakeshore of Crystal Lake, plots extended back 68 m from the shoreline (Figure 3). We randomly assigned one of three treatments to each plot: 1) natural recovery (control), 2) dormant bare root trees and shrubs from

WDNR nurseries (public nursery), and 3) dormant bare root trees and shrubs from privately owned nurseries (private nursery). We collected habitat data within all plots prior to restoration actions as well as abiotic variables such as soil nutrients and canopy closure. Each 10 m x 10 m plot was divided into four 5 m × 5 m subplots of which two were randomly chosen for sampling. On these plots, all live deciduous and coniferous saplings and shrubs that were ≥ 30 cm in height but having < 5 cm diameter breast height (dbh; 1.37 m) were identified to species and tallied. Saplings were categorized in two heights by determining if saplings were short (< 1.37 m) or tall (≥ 1.37 m). Sapling and shrub numbers were recorded for each subplot and the means computed for each treatment prior to restoration in 2010 and then again in 2011and 2015. 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 the image [*Gap fraction* = number of pixels classified as sky in a region/total number of pixels in a region (WinScanopy 2006)]. Digital hemispherical photographs were analyzed with the software WinSCANOPY (WinScanopy 2006). Soil samples were collected from each plot ($n$ = 42) and analyzed for organic matter and nutrients (N, P, and K) at the Soil & Plant analysis Lab, University of Wisconsin-Madison.

To better understand the benefits of herbivore abatement (fencing) and irrigation, we enclosed 30 plots, 10 plots per treatment (control, public nursery, private nursery), within a 2.4 m (8 ft) high meshed, nylon fence within which an automatic irrigation system (FI) was installed. Twelve plots (four plots per treatment) did not receive fencing and irrigation (NFI) (Figure 3). Because limited resources precluded a full factorial experiment, we grouped all irrigated plots together within the fence to prevent inadvertent irrigation on untargeted treatments and to simplify the irrigation system and fencing.

Plant Material

We used two planting densities from WBTN for the experiment. The first was recommended by personnel from VCLWCD for the private nursery plant stock [one tree and three shrubs/$9.3^2$ m ($100^2$ ft)]. Personnel from Natural Resource Conservation Service (NRCS) of Wisconsin recommended three trees and two shrubs/$9.3^2$ m ($100^2$ ft) for the public nursery stock (NRCS 2002). These densities are recommended to the property owners by the above agencies. We determined which species of trees and shrubs to plant from wildlife habitat surveys that were conducted on seven low-development lakes (< 10 houses/km of shoreline), located in the NH-AL state forest (Haskell 2009) (Table 1). All individual saplings and shrubs were mapped to allow us to calculate survival. All bare root saplings and shrubs were stored in a walk-in cooler with roots kept damp with wet oat straw until planted. In the spring of 2011, all bare root trees and shrubs, from both private and public nurseries, were planted after frost left the ground and prior to bud break (NRCS 2002).

Plant material for private nursery treatments were purchased from a local business. Saplings were approximately 152-183 cm (5-6 ft) tall and shrubs were 30.5-61.0 cm (12-24 in) tall for a total cost of $457.54 (US dollars) per plot. Public nursery stock was purchased from two state nurseries. Saplings were three year transplants, approximately 61.0-122 cm (2-4 ft) tall, from the Wilson State nursey and shrubs were approximately 30.5-45.7 cm (12-18 in) tall from Griffith State nursery for a total cost of $60.00 per plot.

Statistical Analysis

Mean canopy cover and soil nutrient variables were compared among treatments with one-way analysis of variance (ANOVA) using SigmaStat 3.5 software (Systat Software Inc. 2006). Additionally, we compared the change in total saplings in both height categories, and total shrubs within each treatment in 2011 and in 2015. We conducted one way ANOVAs on plots with fence and irrigation (FI) versus plots with no fence and irrigation (NFI). To compare the means among treatments the Holm-Sidak method was used for all pair-wise multiple comparisons using SigmaStat 3.5 software (Systat Software Inc.2006). For ANOVA tests, we determined if all test assumptions (normality and equal variance) were met. Kolmogorov-Smirnov was used to test for normally distributed samples. When necessary, we used arcsine square roots and natural logarithms to transform independent variables to meet normality assumptions. When transformation of variables failed to produce a normal distribution, we used the nonparametric Kruskall-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

We found no significant differences in the initial (2010) data of canopy cover [gap fraction ($F_{2, 39} = 0.384$, $P = 0.684$)], soil organic matter (H = 3.003, df = 2, $P = 0.223$), nitrogen (N) ($F_{2, 39} = 1.318$, $P = 0.279$), phosphorus (P) (H = 3.484 df = 2, $P = 0.175$), and potassium (K) ($F_{2, 39} = 2.317$, $P = 0.112$) between the three treatments. Because changes in the above variables were unlikely in the timeframe of this study, we did not resample the above variables in following years.

Sapling and Shrubs with Fence and Irrigation (FI)

We found no significant change of total abundance between 2011 and 2015 of short saplings (< 1.37 m height) ($F_{2, 27} = 1.902$, $P = 0.169$), and no significant difference in the change of abundance of tall saplings (≥ 1.37 m height) (H = 5.882, df = 2, $P = 0.053$), additionally there was no significant difference in the change of total shrubs (H = 5.7, df = 2, $P = 0.058$)(Table 2, Figure 4 and 5).

Paper birch (*Betula papyrifera* Marshall [Betulaceae]) was the most common sapling species in both height categories in 2015 on all treatments (Figure 6). Allegheny blackberry (*Rubus allegheniensis* Porter [Rosaceae]) was the most common shrub species on the control plots and American hazel (*Corylus americana* Walter [Betulaceae]) was the most common shrub on both the private and public treatments in 2015 (Figure 6).

Between the years 2011 and 2015, the public nursery treatments had the greatest change of abundance (n = 143) of tall saplings, but the control had the greatest change of abundance of short saplings (n = 1618). However, the private nursery treatments had the greatest change of abundance of shrubs (n = 219; Figure 7).

Sapling and shrub survival (2011-2015) on private nursery treatments was 96% compared to survival of plants from the public nursery at 90%. White pine (*Pinus strobus* L. [Pinaceae]) had the highest survival rate (93%) on the private nursery plots and the American plum (*Prunus americana* Marshall [Rosaceae]) experienced the highest survival rate (83%) on the public nursery treatments (Figure 8).

Sapling and shrubs with No Fence and Irrigation (NFI)

We observed no significant change in the total number of short saplings between treatments in 2011 and 2015 (< 1.37 m) $F_{2,9} = 1.47$, $P = 0.198$, but there was a significant differences with the change in the number of tall saplings (≥ 1.37m) H = 6.381, df = 2, $P = 0.033$. Pair-wise multiple comparisons showed significant differences between the private and public treatments. The number of tall saplings on private nursery plots showed a decline since restoration activities occurred in 2011 (Table 2, Figure 7). Other than this difference, there was little change among these treatments at both height categories (Figure 4). Additionally, the change in total number of shrubs did not change across treatments between 2011 and 2015 ($P = 0.923$) (Table 2, Figure 5).

Scots pine (*Pinus sylvertris* L. [Pinaceae]) was the most observed sapling species in the controls of FI and NFI at both height categories; scots pine was the only tall sapling detected in the NFI control plots (Figure 6). American hazelnut was the most common shrub species on the private and public treatments and northern blueberry (*Vaccinium angustifolium* Aiton [Ericaceae]) was the most shrub observed on the control treatments (Figure 6).

Between the years 2011 and 2015, the public nursery treatments had the biggest difference in total abundance (n = 18) of tall saplings, and again the control had the biggest difference in short saplings (n = 123). The public nursery treatments had the biggest difference in shrubs (n = 24) respectively (Figure 7).

The overall survival of saplings and shrubs on private nursery treatments (NFI) was 75% compared to the public nursery at 90%. Northern red oak and paper birch had the lowest survival at 50% survival on the private nursery treatments. American plum and paper birch both experienced the lowest survival (75%) on the public nursery treatments (Figure 8).

**Discussion**

The primary goal of most lakeshore restoration efforts is to establish riparian wildlife habitat along lakeshore as quickly, efficiently, and economically as possible. Accelerated restoration, which includes site assessment, preparation, and tree/shrub planting, as opposed to natural recovery is necessary at many sites because of excessive erosion, invasive competitors, high local herbivore populations, and a lack of natural seed source. Thus, there is a need to test additional techniques to improve the rate of wildlife habitat regeneration.

The increase in paper birch saplings, on the treatments with FI, is not surprising, since it is a pioneer species and is one of the first tree species to occur after a disturbance (Frelich 2002). Paper birch is adapted to well drained, acidic, sandy soils, and cold temperatures. It requires ample moisture, but is intolerant of shady conditions. Paper birch can provide habitat for a variety of wildlife that prefer early successional forests types. For example, ground and shrub nesting birds use such young forests (DeGraaf and Yamaski 2003), habitat use for ruffed grouse (*Bonasa umbellus* L. [Phasianidae]) (Blanchette and others 2007) and white-tailed deer (Mooty and others 1987). Our results reveal that treatments with FI may follow a more natural distribution of early successional sapling tree species following disturbance (Figure 6) (Frelich 2002).

We observed very little change in the shrub component on the treatments with FI and NFI. Recruited shrubs (those derived from the seed bank) that increased most were northern blueberry and blackberry on FI and NFI control treatments. Both of these species are common after a disturbance especially on well drained and low pH soils and provide habitat and a food source for variety of birds and mammals (Martin and others 1961).

Scots pine (a non-native pine species introduced to the region in the 1930s) increased in both the FI and NFI control treatments compared to treatments that were planted with native saplings and shrubs, suggesting that restoring areas with native plants may inhibit some invasive species (Shea and Chesson 2002). Scots pine is considered an early successional species (Richardson 1998) and is low in preference for white-tailed deer (Conover and Kania 1988), which may explain why it is doing well in NFI control treatments.

Several riparian restoration studies have focused on the effects of livestock exclosures on streams (Briggs and others 1994, Green and Kauffman 1995, Kaufman and others 1995), yet very few have investigated native herbivore exclosures on lake riparian areas (Haskell 2009). Fencing has been used as an herbivore abatement in other habitat restoration projects (Case and Kaufman 1997; Opperman and Merenlender 2000; Haskell 2009; Holmes and others 2009). Here, treatments with NFI suffered from white-tailed deer browse, and growth was retarded. Similar findings were reported by Opperman and Merenlender (2000) where restoration of saplings in stream riparian zones had a higher rate of survival in exclosures compared to control areas, and 97% of saplings in control areas displayed leaf and stem damage characteristics of deer browse. In addition, Case and Kaufman (1997) compared woody species growth in and outside of exclosures. They observed crown volume increased 550% for willow species (*Salix spp*. L [Salicaceae]) within exclosures compared to an increase of 195% outside. Additionally, Sweeny and others (2002) reported that overall survival and growth of five species of tree seedlings was significantly higher when tree shelters were applied to individuals compared to unsheltered seedlings (49% and 77.6 cm vs. 12.1% and 26 cm). Furthermore, Holmes and others (2009) investigated the survival of Canada yew (*Taxus canadensis* Marshal [Taxaceae]) for four growing seasons and reported that white-tailed deer exclusion had a 91.9% survival compared to 75% survival without exclosures.

Also, proper soil moisture regime is critical for establishing woody and herbaceous plants. Regular irrigation in the first few years of the restoration is one of the most important predictors of lakeshore restoration success. Regular irrigation allows vigorous root growth and allows roots to reach the depths where there is ample soil moisture. In this study, understory vegetation abundance in irrigated plots increased far more compared to plots without irrigation. Friedman and others (1995) observed significant increase of establishment of plains cottonwood (Populus deltoids W. Bartram ex Marshall subsp. Monilifera (Aiton) Eckenwalder [Salicaceae]) on plots that were irrigated in Colorado. In addition, Bhattachargee and others (2008) found that the rate of soil moisture decline was the best predictor of cottonwood seedling survival in sandy soils in southwestern United States. Furthermore, Haskell and others. (2012) showed that the addition of downed woody material on restoration sites had a significant positive effect on retaining soil moisture, which improved plant growth and survival. Our study also showed higher survival rates of trees and shrubs with the FI treatment – confirming the benefits (Figure 10). Thus, where herbivores are plentiful and soils are sandy, herbivory abatement and irrigation are required for successful restoration of wildlife habitat on high-development lake shores.

**Conclusions**

In conclusion, bare root plant stock from both private and public nurseries, can improve wildlife habitat structure on high-development lake shores. Natural recovery may be very cost-effective when combined with irrigation and herbivore fencing and immediate results are not required. However, where invasive species are a threat or where a reliable seed source is lacking, an accelerated recovery should be considered. Restoration projects where deer abundance is high require an abatement system to reduce herbivory and increase growth and survival of plantings. Property owners (and adjacent property owners) wishing to restore habitat should terminate supplemental feeding of white-tailed deer. Since the soils are coarse and sandy on most lakeshores in the NH-EL (WDNR 2014b) irrigation should be applied. Furthermore, since the shrub component of this restoration project had a low rate of change, restoring the shrub layer should be a priority.

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**Literature Cited**

Alverson, W.S., and Waller, D.M. 1997. Deer populations and the widespread failure of hemlock regeneration in northern forests, p. 280-297. *In*: McShea, W.J, Underwood, H.B., and Rappole, J.H. (eds.), The Science of Overabundance: Deer Ecology and Population Management. Smithsonian Institution Press, Washington and London.

Beals, E.W., G Gottam, and R.J. Vogl. 1960. Influence of deer on vegetation of the Apostle Islands, Wisconsin. Journal of Wildlife Management 24:68-80.

Bhattacharjee, J., J.P. Taylor, Jr., L.M. Smith, and L.E. Spence. 2008. The importance of soil characteristics in determining survival of first-year cottonwood seedlings in altered riparian habitats. Restoration Ecology 16:563-571.

Blanchette, P., J.C. Bourgeois, and S. St-onge. 2007. Ruffed grouse winter habitat use in mixed softwood-hardwood forests, Québec, Canada. Journal of Wildlife Management 71:1758-1764.

Briggs, M.K., B.A. Roundy, and W.W. Shaw. 1994. Trial and error: accessing the effectiveness of riparian revegetation in Arizona. Restoration and Management Notes 12:160-167.

Case, R.L., and J.B. Kaufman. 1997. Wild ungulate influences on the recovery of willows, black cottonwood, and thin-leaf alder following cessation of cattle grazing in northwest Oregon. Northwest Science 71:115-126.

Christensen, D.L., B.R. Herwig, D.E Schindler, and S.R. Carpenter. 1996. Impacts of lakeshore residential development on coarse woody debris in north temperate lakes. Ecological Applications 6:1143-1149.

Conover, M. R., and G.S. Kania, 1988. Browsing preference of white-tailed deer for different ornamental species. Wildlife Society Bulletin 16:175-179.

DeGraaf, R.M. and M. Yamasaki. 2003. Options for managing early-successional forest and shrubland bird habitats in northeastern United States. Forest Ecology and Management 185:179-191.

Doenier, P.B., G.D. Del Giudice, and M.R. Riggs. 1997. Effects of winter supplemental feeding on browse consumption by white-tailed deer. Wildlife Society Bulletin 25:235-243.

Elias, J.E., and M.W. Meyer. 2003. Comparisons of undeveloped and developed shorelands, northern Wisconsin, and recommendations for restoration. Wetlands 23:800-816.

Engle, S. and J.L. Pederson, Jr. 1998. The construction, aesthetics, and effects of lakeshore development: a literature review. Wisconsin Department of Natural Resources PUBL-SS-577-99.

Ford, M. and D.J. Flaspohler. 2010. Scale-dependent response by breeding songbirds to residential development along Lake Superior. Wilson Bulletin of Ornithology 122:296-306.

Frelich, L.E. 2002. Forest Dynamics and Disturbances Regimes. Cambridge University Press. 266 pp.

Friedman, J.M., M.L. Scott, and W.M. Lewis Jr. 1995. Restoration of riparian forest using irrigation, artificial disturbance, and natural seed fall. Environmental Management 19:547-557.

Green, D.M., and J.B. Kaufman. 1995. Succession and livestock grazing in a northwest Oregon riparian ecosystem. Journal of Range Management 48:307-313.

Haskell, D.E. 2009. Quantifying the Ecological Benefits of Lakeshore Restoration in Northern Wisconsin. M.S. thesis. Michigan Technological University, Houghton, Michigan.

Haskell, D.E., Flaspolher, D.J., Webster, C.R., M.W. Meyer. 2012. Variation in soil temperature, moisture, and plant growth with the addition of downed woody material on lakeshore restoration sites. Restoration Ecology 20:113-121.

Haskell, D.E., M.W. Meyer Webster, C.R., Flaspolher, D.J. 2013. The Relationship between Carnivore Distribution and Landscape Features in the Northern Highlands Ecological Landscape of Wisconsin. The American Midland Naturalist, 169:1-16.

Holmes, S.A., Webster, C.R., Flaspolher, D.J., and Froese, R.E. 2009. Dealth and taxus: the high cost of palatability for a declining evergreen shrub, *Taxus canadensis.* Canadian Journal of Forest Research, 39:1366-1374.

[ITIS] Integrated Taxonomic Information System. 2016. URL: http://itis. gov (accessed 12 May 2016). Washington (DC): National Museum of Natural History.

Kaufman, J.B., R.L. Case, D. Lytjen, N. Otting, and D.L. Cummings. 1995. Ecological approaches to riparian restoration in northwest Oregon. Restoration and Management Notes 13:12-15.

Lindsay, A.R., S.S. Gillum, and M.W. Meyer. 2002. Influence of lakeshore development on breeding bird communities in a mixed northern forest. Biological Conservation 107:1-11.

Macbeth, E.J. 1992. Protecting aesthetics and the visual resource of lakes. In enhancing the states' lake management programs. North American Lake Management Society, Washington, D.C. 112 pp

Marburg, A.E, M.G. Turner, and T.K Kratz. 2006. Natural and anthropogenic variation in coarse wood among and within lakes. Journal of Ecology 94:558-568.

Martin, A.C., H.S Zim, and A.L. Nelson. 1961. American wildlife & plants a guide to wildlife food habits: the use of trees, shrubs, weeds and herbs by birds and mammals of the United States. Dover Publications New York, NY. 500pp.

Mooty, J.J., P.D. Karns, and T.K. Fuller. 1987. Habitat use and seasonal range size of white-tailed deer in northcentral Minnesota. Journal of Wildlife Management 51:644-648.

NRCS (Natural Resource Conservation Service) 2002. Wisconsin Biology Technical Note 1: Shoreland Habitat. NRCS. ftp://ftp-fc.sc.egov.usda.gov/WI/technotes/biology-tn1.pdf

Opperman, J.J., and A.M. Merenlender. 2000. Deer herbivory as an ecological constraint to restoration of degraded riparian corridors. Restoration Ecology 8:41-47.

Richardson, D.M. 1998. Ecology and biogeography of Pinus. Cambridge University Press, Cambridge, 546 pp.

Richardson, D.M., P. Pysek, M. Rejmánek, M.G. Barbour, F.D. Panetta, and C.J. West. 2000. Naturalization and invasion of alien plants — concepts and definitions. Diversity and Distributions, 6: 93–107.

Russell, F.L., Zippin, D.B., and Fowler, N.L. 2001. Effects of white-tailed deer (*Odocoileus virginianus*) on plants, plant populations and communities: a review. The American Midland Naturalist 146:1-26.

Shea, K., and P. Chesson. 2002. Community ecology theory as a framework for biological invasions. Trends in Ecology and Evolution 17:170-176.

Sweeney, B.W., S.J. Czapka, T. Yerkes. 2002. Riparian forest restoration: Increasing success by reducing plant competition and herbivory. Restoration Ecology 10:392-400.

[USDA NRCS] USDA Natural Resources Conservation Service. 2016. The PLANTS database. URL: http://plants.usda.gov (accessed 12 May 2016). Greensboro (NC): National Plant Data Team.

Vanderbosch DA, Galatowitsch SM. 2010. An assessment of urban lakeshore restorations in Minnesota. Ecological Restoration 28: 71-80.

WinScanopy. 2006. WinSCANOPY 2006 for hemispherical image analysis. Regent Instruments Inc, Canada.

Wisconsin Department of Natural Resources (WDNR). 2005.  Wisconsin Lakes.  Bureau of Fisheries and Habitat Management.  PUB-FH-800

Wisconsin Department of Natural Resources (WDNR) 2014a. http://docs.legis.wisconsin.gov/code/admin_code/nr/100/115.pdf

Wisconsin Department of Natural Resources (DNR). 2014b. The ecological landscapes of Wisconsin: an assessment of ecological resources and a guide to planning sustainable management. Wisconsin Department of Natural Resources, PUB-SS-1131 2014, Madison.

Witt, J.C., and Webster, C.R. 2010. Regeneration dynamics in remnant *Tsuga canadensis* stands in the northern Lake States: potential direct and indirect effects of herbivory. Forest Ecology and Management 269:519-525

Woodford, J.E., and M.W. Meyer.  2003.  Impact of lakeshore development on green frog abundance. Biological Conservation 110:277-284.

**Table 1.** Total bare root saplings and shrubs species planted per public and private nursery treatment on each 10 m x 10 m plot at Crystal Lake, Wisconsin. Tree and shrub densities were recommended by personnel from Vilas County Land and Water Conservation Department for the private nursery treatments and personnel from Natural Resource Conservation Service for the public nursery treatments. The number of tree and shrub species planted on each plot was determined by the rate of occurrence on seven low-development lakes in Northern Highland – American Legion State forest of northern Wisconsin.

| Treatment | Plant Type | Species | Total/Plot |
|---|---|---|---|
| Private Nursery | Sapling | White Pine (*Pinus strobus* L. [Pinaceae]) | 3 |
| | | White Spruce (*Picea glauca (*Moench) Voss [Pinaceae]) | 2 |
| | | Red Maple (*Acer rubra* L. [Aceraceae]) | 2 |
| | | Northern Red Oak (*Quercus rubra* L. [Fagaceae]) | 2 |
| | | Paper Birch (*Betula papyrifera* Marshall [Betulaceae]) | 1 |
| | | American Plum (*Prunus americana* Marshall [Rosaceae]) | 1 |
| | Shrub | American Hazelnut (*Corylus Americana* Walter [Betulaceae]) | 11 |
| | | Common Ninebark (*Physocarpus opulifolius* L. [Rosaceae] ) | 11 |
| | | Serviceberry (*Amelanchier Canadensis* (L.) Medik. [Rosaceae] ) | 11 |
| Public Nursery | Sapling | White Pine (*Pinus strobus*) | 10 |
| | | White Spruce (*Picea glauca*) | 5 |
| | | Red Maple *(Acer rubra)* | 7 |
| | | Northern Red Oak (*Quercus rubra*) | 5 |
| | | White Birch (*Betula papyrifera*) | 3 |
| | | American Plum (*Prunus americana*) | 2 |
| | Shrub | American Hazelnut (*Corylus Americana*) | 11 |
| | | Common Ninebark (*Physocarpus opulifolius*) | 11 |

**Table 2.** Mean change of abundance of bare root saplings at two different height categories, short saplings (< 1.37 m height), tall saplings (≥ 1.37 m height) and total shrubs on two subplot (5 m x 5 m) per treatment (Private, Public nursery stock and control) with fence and irrigation (FI) and no fence and irrigation (NFI) on Crystal Lake, Wisconsin. Data was collected in the summer of 2011 after restoration efforts and compared to measurements in the summer of 2015.

| **Treatment** | **Fence/Irrigation** | **Plant Height** | ***N*** | **Mean** | **Std. Error** |
|---|---|---|---|---|---|
| Public Nursery | NFI | Tall Saplings | 4 | 4.500 | 1.190 |
| | FI | Tall Saplings | 10 | 14.400 | 3.250 |
| | NFI | Short Saplings | 4 | 20.250 | 5.893 |
| | FI | Short Saplings | 10 | 94.000 | 19.523 |
| | NFI | Shrubs | 4 | 6.000 | 2.041 |
| | FI | Shrubs | 10 | 9.900 | 2.814 |
| Private Nursery | NFI | Tall Saplings | 4 | -1.000 | 1.080 |
| | FI | Tall Saplings | 10 | 7.00 | 3.496 |
| | NFI | Short Saplings | 4 | 11.000 | 3.536 |
| | FI | Short Saplings | 10 | 102.000 | 22.228 |
| | NFI | Shrubs | 4 | 4.250 | 4.661 |
| | FI | Shrubs | 10 | 21.900 | 5.417 |
| Control | NFI | Tall Saplings | 4 | 3.250 | 2.358 |
| | FI | Tall Saplings | 10 | 11.300 | 5.914 |
| | NFI | Short Saplings | 4 | 30.750 | 10.160 |
| | FI | Short Saplings | 10 | 161.800 | 35.921 |
| | NFI | Shrubs | 4 | 5.000 | 1.683 |
| | FI | Shrubs | 10 | 11.900 | 5.564 |

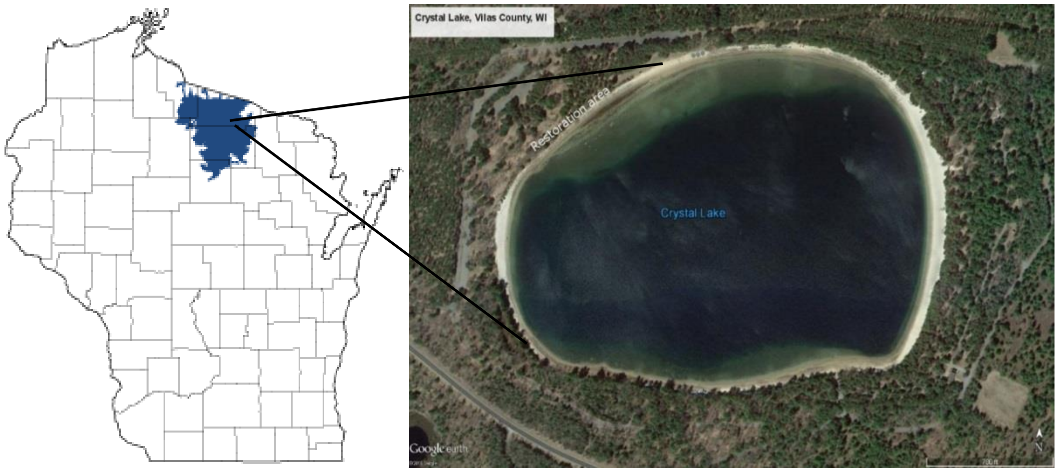


*Figure 1*. The Northern Highlands Ecological Landscape (http://dnr.wi.gov/topic/landscapes/index.asp?mode=detail&Landscape=12). Crystal Lake restoration project is located within the landscape.

*Figure 2*. Photo of study area prior to restoration in 2010 Crystal Lake, Wisconsin. Area was used for human recreation and mowed at a regular basis since the mid-1940 (Photo credit (D. Haskell).


*Figure 3*. Restoration area on Crystal Lake, Wisconsin. Restoration activities occurred in 2011 with two types of bare-root nursery plants (private and public) and control treatments. Treatments were within a fence and irrigation area (FI) and no fence and irrigation (NFI).

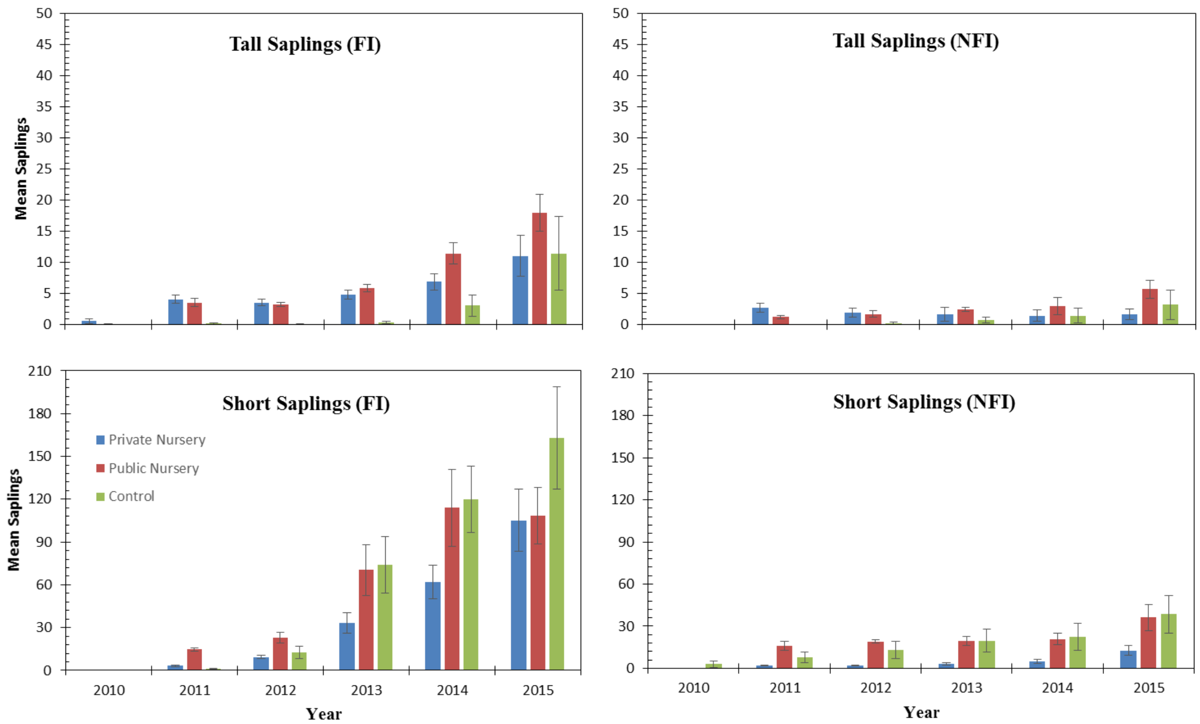


*Figure 4*. Mean change of two sapling heights, tall saplings (≥ 1.37 m) and short saplings (< 1.37 m). Data recorded from three restoration treatments from private nursery stock, public nursery stock and control (natural recovery) on Crystal Lake Wisconsin from 2010-2015. Data collected on 10 m x 10 m test plots. Measurement were collected on plots with Fence and Irrigation (FI) and plots no Fence and Irrigation (NFI).

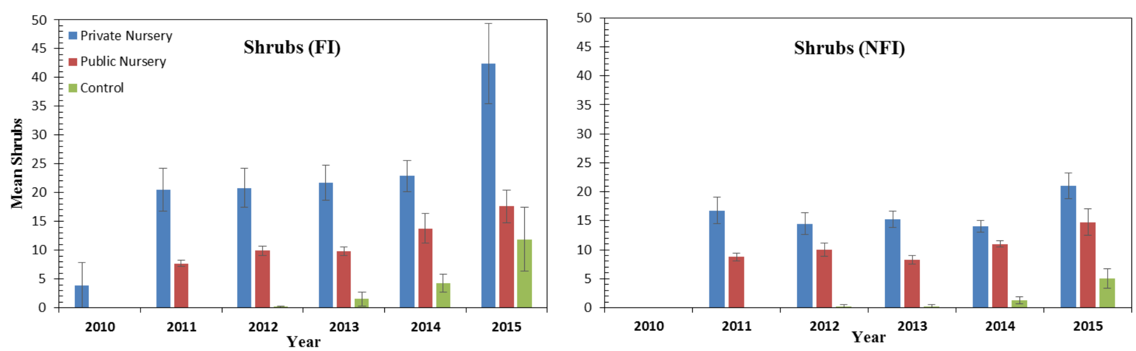


*Figure 5.* Mean change of shrub abundance from three restoration treatments from private nursery stock, public nursery stock and control (natural recovery) on Crystal Lake Wisconsin from 2010-2015. Data collected on 10 m x 10 m test plots. Measurements were collected on plots with Fence and Irrigation (FI) and plots no Fence and Irrigation (NFI).

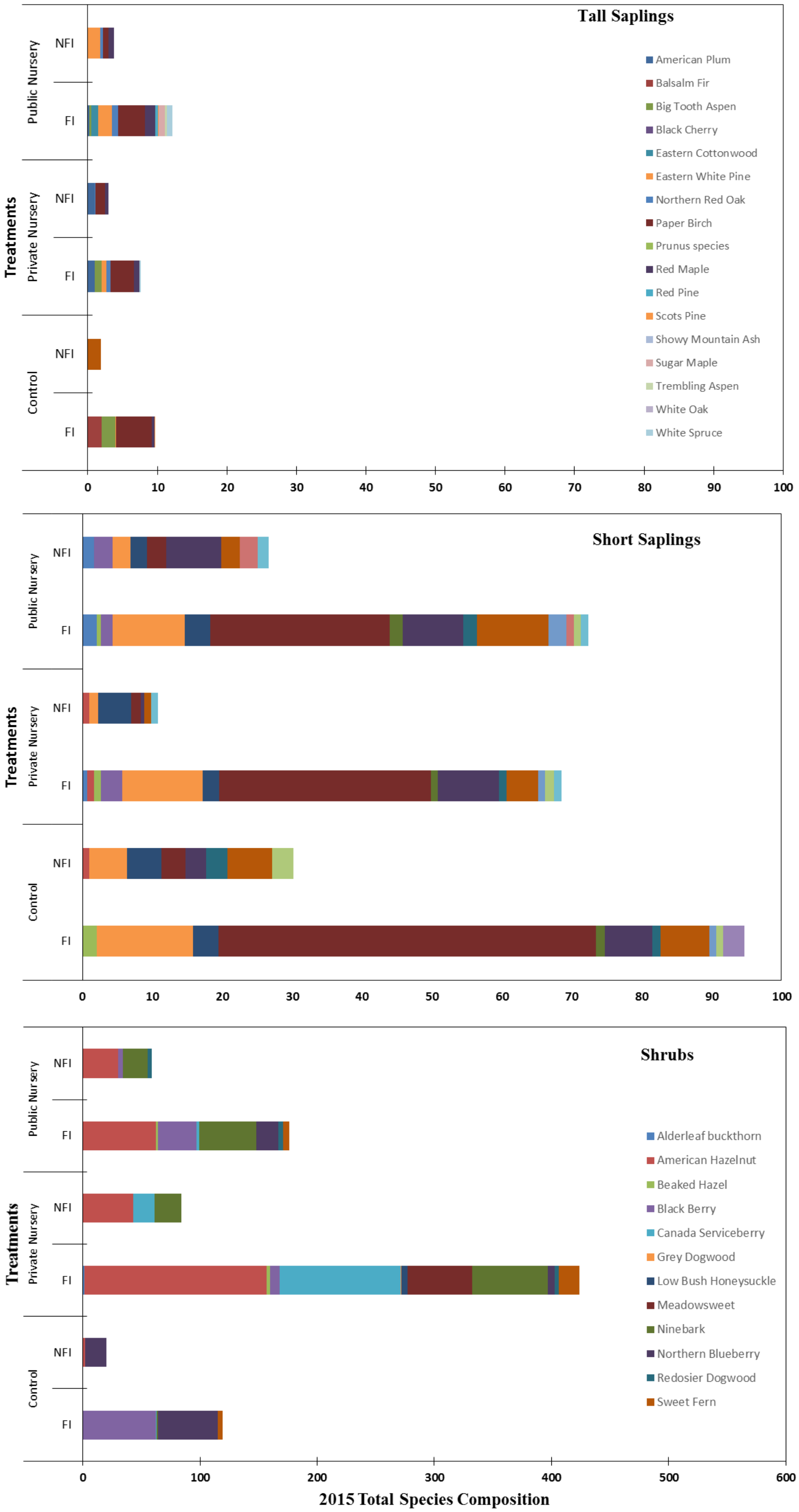
Tall Saplings
Treatments
Public Nursery
Private Nursery
Control
NFI
FI
American Plum
Balsalm Fir
Big Tooth Aspen
Black Cherry
Eastern Cottonwood
Eastern White Pine
Northern Red Oak
Paper Birch
Prunus species
Red Maple
Red Pine
Scots Pine
Showy Mountain Ash
Sugar Maple
Trembling Aspen
White Oak
White Spruce
0
10
20
30
40
50
60
70
80
90
100
Short Saplings
0
10
20
30
40
50
60
70
80
90
100
Shrubs
Alderleaf buckthorn
American Hazelnut
Beaked Hazel
Black Berry
Canada Serviceberry
Grey Dogwood
Low Bush Honeysuckle
Meadowsweet
Ninebark
Northern Blueberry
Redosier Dogwood
Sweet Fern
0
100
200
300
400
500
600
2015 Total Species Composition

*Figure 6*. Total species composition of tall (≥ 1.37 m) and short saplings (< 1.37 m) and shrubs tallied in summer of 2015 at Crystal Lake, Wisconsin, five years after restoration. The data was collected on two 5 m x 5 m subplots within 10 m x10 m plots with three treatments [bare root stock from private and public nurseries and a control (natural recovery)] with Fence and Irrigation (FI) and with no Fence and Irrigation (NFI).

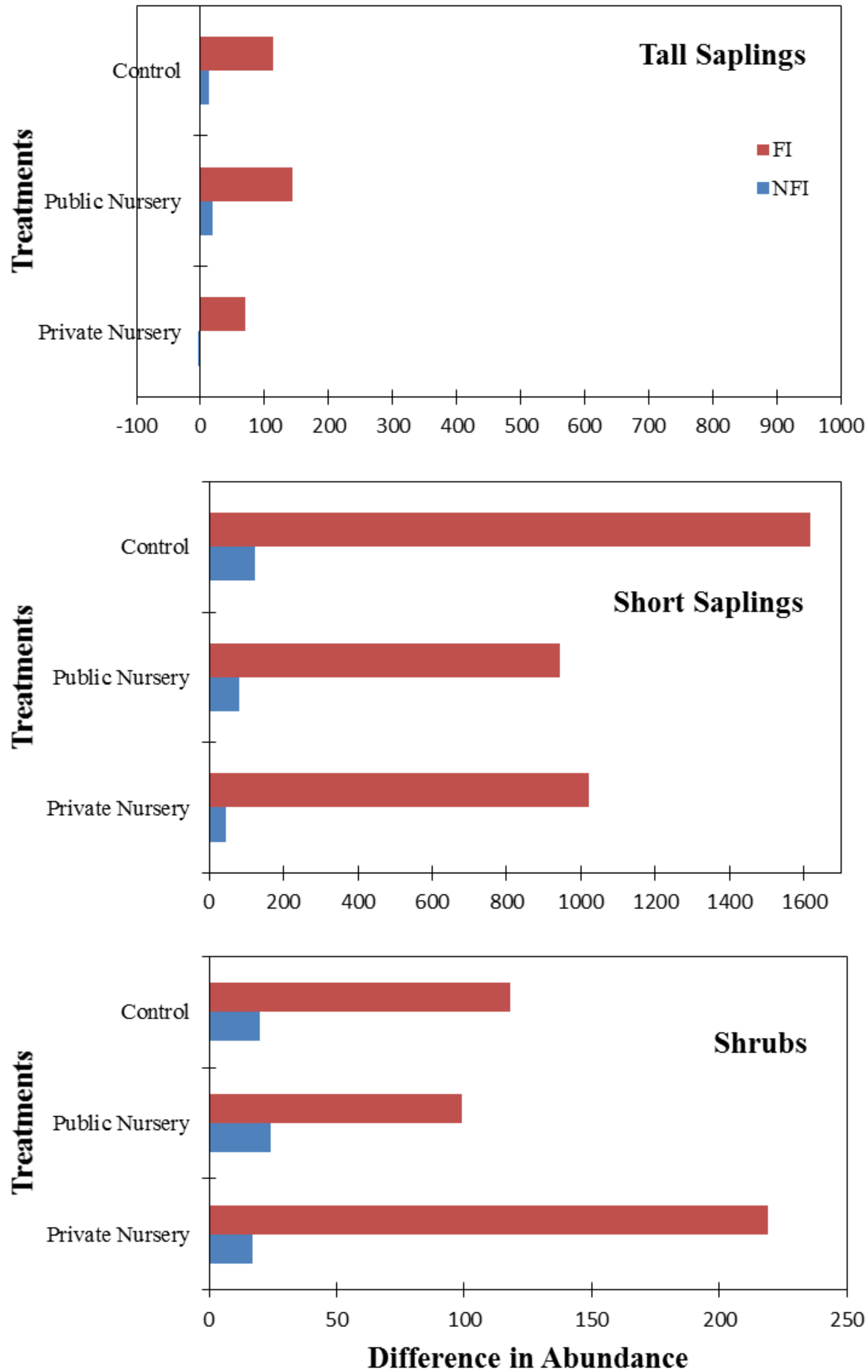


*Figure 7.* The difference in abundance of tall (≥ 1.37 m) and short saplings (< 1.37 m) and shrubs tallied from the summer 2011 and again in 2015 at Crystal Lake, Wisconsin. The data was collected on two 5 m x 5 m subplots within 10 m x10 m plots with three treatments [bare root stock from private and public nurseries and a control (natural recovery)] with Fence and Irrigation (FI) and with no Fence and Irrigation (NFI).

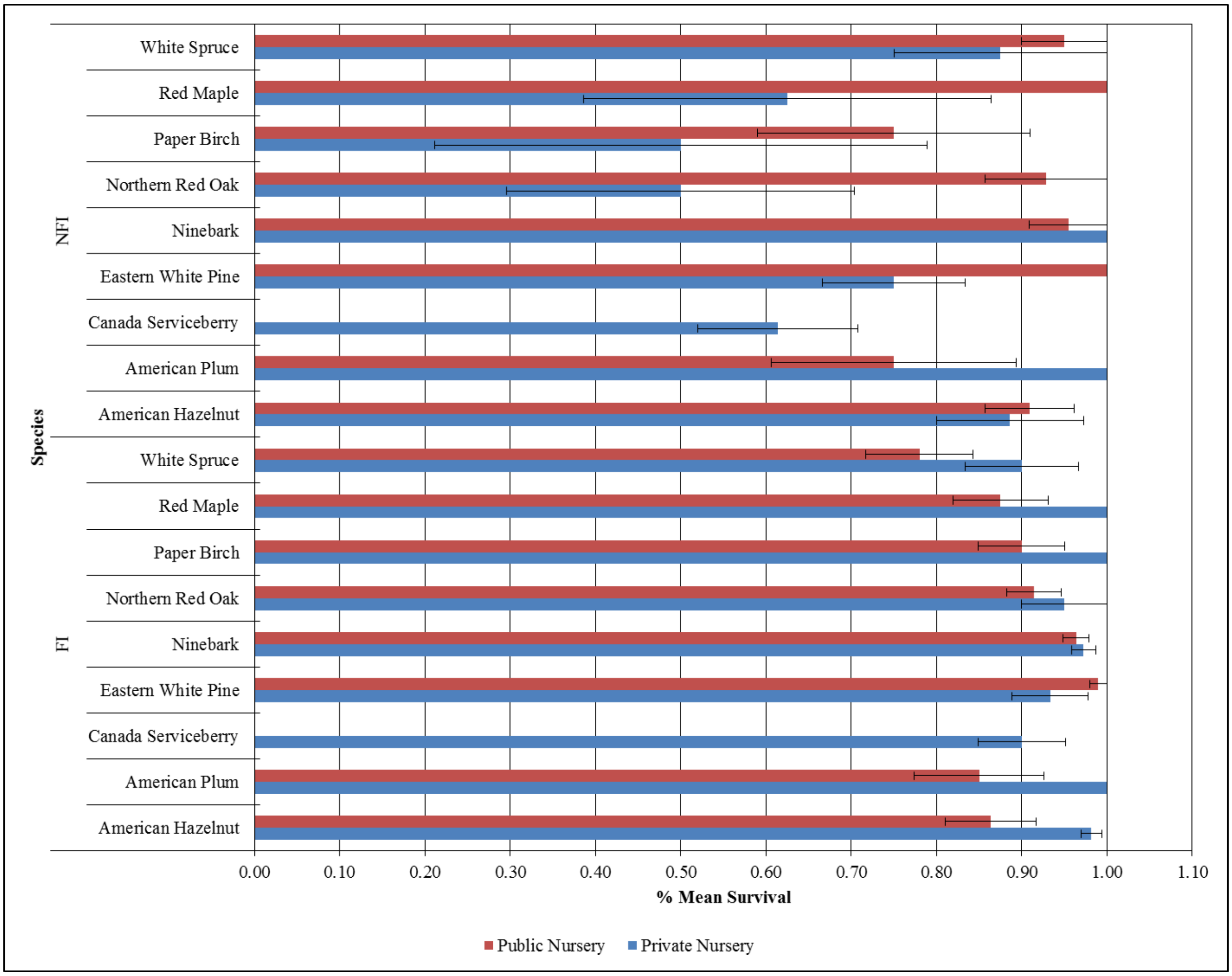


*Figure 8.* Mean survival of species of bare root trees and shrubs from two different nurseries (private and public) and with fence and irrigation (FI) and no fence and irrigation (NFI) planted in 2011 on Crystal Lake, Wisconsin. Survival data was collected from 10 m x 10 m plots in 2015 and compared to data collected in 2011.

*The Cost-Benefits of Bare-root vs. Container vs. Gravel Culture Trees and Shrubs for Lakeshore Restoration*

(The manuscript below is currently in preparation for submission to the Ecological Restoration Journal; thus the information below is Draft version)

**Bare-root and Gravel Culture shrubs used in wildlife habitat restoration on lake riparian areas in Northern Wisconsin**

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***Overview -*** *The use of potted (container) trees and shrubs is one of the largest costs in lakeshore restoration. We found less costly bare root and "gravel culture" (bare root grown in gravel medium and planted after leaf-out) shrubs had similar growth and survival as compared to paired container plants, however the results did vary by species. Long-term growth and survival measures will best define which source is most cost effective.*

**Abstract**

Human development on lake riparian habitat has greatly reduced shrub layer coverage throughout many North American lakeshores, negatively impacting associated floral and faunal communities. Several restoration projects have been implemented in recent decades to reverse the impacts of development on such lakeshore communities in northern Wisconsin. However, restoration practitioners are frequently limited to using containerized plant stock purchased at local nurseries, which can be cost prohibitive. As an alternative, we tested the effectiveness of using dormant bare-root shrubs in restoration projects along five lakeshores in northern Wisconsin. Because bare-root plant stock has a short time-frame for planting, we also experimented using bare-root stock that was incorporated into gravel medium at a local nursery and then planted later in the summer months. We term this new bare-root plant stock as “gravel culture.” We monitored plants from five species of native shrubs in each of three planting treatments over a five year period and used a repeated measures mixed-model approach to compare plant growth (volume) of both bare-root and gravel culture stock to growth of containerized plants. We used logistic regression models to compare the survival of plants from containers to those from bare-root and gravel culture stock. All five species experienced significant changes in growth during the years reported, and for some species, these changes were dependent on the planting treatment. We observed declines of growth and survival in the fifth year of monitoring.

Key words: lake riparian, shrubs, bare-root, wildlife habitat, restoration,

**Introduction**

A fundamental problem facing lake riparian areas in North America is the loss of understory wildlife habitat (Racey and Euler 1983, Elias and Meyer 2003). This habitat loss is often due to vegetation removal for housing construction and recreation, which can impact the associated floral and faunal communities (Robertson and Flood 1980, Racey and Euler 1982, Lindsey et al. 2002, Woodford and Meyer 2003, Ford and Flaspohler 2010, Haskell et al. 2013). Lake riparian areas are subjected to both terrestrial (e.g., point-source contaminant loadings; sedimentation associated with construction activities) and lake-wide (e.g., water level changes; water chemistry; introduction of exotic species) changes, typically making these systems more vulnerable than terrestrial and aquatic ecosystems. Thus, minor disturbances in lake riparian areas can have cascading effects if the threshold tolerance of an ecosystem is exceeded (Crowder et al. 1996). For example, Elias and Meyer (2003) and Haskell (2009) reported that the shrub layer coverage and density on developed lakes in northern Wisconsin was significantly lower than that of undeveloped lakes, and this reduction was shown to negatively affect ground and shrub nesting birds (Lindsey et al. 2002) and forest carnivores (Haskell et al. 2013) in these areas. Similar findings were reported in central Ontario, Canada, where shrub cover decreased with the increase of development (Racey and Euler 1983a), which also negatively impacted avian communities (Robertson and Flood 1980), small mammal community structure (Racey and Euler 1982), mink (*Mustela vision*) densities (Racey and Euler 1983b), and habitat structure (Clark et al. 1984).

An awareness of the ecological importance of riparian areas has increased simultaneously with the increase of human development. County government zoning offices may now require mitigation or restoration of lake riparian areas when approving building or remodeling permits on existing human dwellings, and interest in lake riparian habitat restoration has increased among property owners. Specifically, lakeshore property owners and restoration practitioners are in need of restoration guidelines and techniques which establish cost-effective practices. The “Wisconsin Biology Technical Note 1” (NRCS2002) on shoreland habitat describes two restoration recovery techniques: (1) “natural recovery” where feasible (i.e., where adequate seed and/or root sources are present) and (2) “accelerated recovery” (e.g. site preparation and planting). The latter would be required where insufficient native vegetation is present or where quick results are desired (NRCS 2002). Containerized trees and shrubs purchased at local nurseries are used when an accelerated recovery is implemented.

The use of containerized trees and shrubs by landowners, restoration practitioners, and landscape businesses for restoration projects is a common practice. However, containerized trees and shrubs are frequently one of the largest costs for lakeshore restoration projects. Alternatively, dormant bare-root trees and shrubs can be purchased for half the cost of containerized trees and shrubs, making bare-root plant stock an attractive option for habitat restoration projects. Traditionally, bare-root plant stock is planted between the periods of frost-free soil to bud break in the spring and leaf-fall to frozen soil in the fall (NRCS 2002). Thus, this method has a restrictive time-frame for use. Plants can also be slower to establish relative to container plants (Johnson et al. 1984) and can have a greater susceptibility to desiccation during transporting and planting if not properly handled. Starbuck et al. (2005) looked at using 6.4 mm-diameter (0.25 in) pea 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 pennsylanica*) and reported no mortality. This technique could provide a cost effective source of bare-root plant stock, which would extend the planting season into the summer. However, quantitative studies regarding the effectiveness of this technique for wildlife habitat restoration are lacking.

Our study investigated this technique (gravel culture nursery stock) for five native shrub species (Figure 1) commonly used in lakeshore restoration. Our objective was to compare the relative success of dormant bare-root (BR) and containerized (CT) planting treatments and the relative success of gravel culture (GC) and CT planting treatments in restoration projects. To do this, we used five native shrub species and compared the relative growth and survival of plants from BR and CT planting treatments and from GC and CT planting treatments.

**Methods**

Study Area

This project was conducted from 2007- 2015 on the shores of five lakes in in Vilas County, Wisconsin, USA, Vilas County encompasses a 2,636 km2 area along the state's northern border with the Upper Peninsula of Michigan and is in the Northern Highland Ecological Landscape (NHEL) (Figure 2). The landscape is primarily forested and soil is typified by deep sands with pitted glacial outwash (Stearns and Likens 2002). . Vilas County contains 1,320 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 daily mean ambient temperature is 3.4 °C, ranging from -2 °C in January to 10 °C in July and the mean precipitation is 80.25 cm (WDNR 2014b).

Four of the five lakeshores targeted for restoration are primarily in private ownership (Table 1). These lakeshores were home to several fishing and vacation resorts in the early 20$^{th}$ century with seasonal, modest size dwellings. In the recent decades, however, they have often been sold to developers and parceled for resale to individuals who often establish larger seasonal or permanent homes (Schnaiberg et al. 2002). Crystal Lake is in public ownership, and is part of a State of Wisconsin recreational area in the Northern Highland-American Legion State Forest (NH-AL) that is comprised of modern campgrounds, picnic areas, and swimming beaches. Crystal Lake lakeshores have been managed as a public park since the mid-1940s (*Personal communications* S. Peterson, superintendent NH-AL). All sites have been subjected to human development or high recreational use, therefore, making them candidates for lakeshore riparian zone restoration.

Plant Material

We planted 2,430 deciduous shrubs of 24 species from 2007 through 2012 on the above lakeshores (Appendix 1). For this article, we report on five species of shrubs that were tracked over the course of the project: Glossy Black Chokeberry [(*Aronia melanocarpa*) USDA plant code ARME6], Red-osier Dogwood, [(*Cornus stolonifera*) USDA plant code COSES], Northern Bush Honeysuckle [*(Diervilla lonicera)* USDA plant code DILO], Ninebark [(*Physocarpus opulifolius*) USDA plant code PHOP], and Snowberry [(*Symphoricarpos Albus*) USDA plant code SYAL]. These five species are known to provide quality habitat and food sources for a variety of birds and mammals in Northern Wisconsin (Martin et al. 1961). All species will hereafter be referred to by their USDA plant code (USDA NRCS 2016).

Each GC and BR shrub was planted with a CT shrub of the same species within two meters, and shrubs were marked and identified with a unique numbered metal tag. All pairs of BR and CT shrubs were planted after the ground was frost free and prior to bud break (NRCS 2002). All pairs of GC and CT shrubs were planted after full leaf development (between July and September). CT shrubs were delivered in three-gallon nursery containers from local nurseries. All BR and GC shrubs were also delivered from local nurseries' and roots were kept damp with wet oat straw when transported from the nursery, and if GC shrubs were not planted within the day of delivery, roots were submerged in water for not more than 12 hours. For each shrub, approximately one liter of compost was incorporated into the soil before shrubs were planted. For all planting treatments, the soil was thoroughly irrigated until saturated and watered again after planting. Cedar mulch was placed around the basal area extending out 30 cm (~1ft) from base of shrubs, at approximately a depth of five centimeters. All shrubs were protected from herbivory by constructing 2.4 m high nylon fences around restoration areas. Metal T-posts and a 3.175 mm (1/8 inch ) steel cable was used to support fence (Haskell 2009). Plants were irrigated as needed throughout the growing season during the first three years post planting. All shrubs were planted within the state prescribed vegetation buffer 10.8 m inward from the ordinary high water mark (WDNR Chapter NR 115 2014(a) https://docs.legis.wisconsin.gov/code/admin_code/nr/100/115.pdf).

Plant Growth and Survival

In order to compare the relative success of both BR and GC plants to CT plants, we measured plant growth and survival for up to five years following planting. To measure plant growth, we used a composite metric to estimate the cylindrical volume ($m^3$) of each plant and compare changes in volume over the five-year span between planting treatments. To estimate volume, we first measured the shrub canopy area ($A$) using the following formula:

$$A = \pi \left( \frac{w_1 + w_2}{4} \right)^2$$

where $w_1$ is the canopy diameter at its widest point and $w_2$ is the canopy diameter perpendicular to $w_1$. We then measured plant height from the soil surface to the highest point of the living tissue in its natural state and multiplied plant height by shrub canopy area ($A$) to compute the cylindrical volume ($m^3$) for each shrub (Haskell et al. 2012). To measure survival, we recorded whether each plant was alive or dead at the time of volume measurements. Volume was not measured on dead plants. All measurements were performed between late July and August for five years after planting.

Because deer-proof fences were removed during the fourth year of growth, we recorded whether shrubs were browsed during their fourth and fifth years of growth (presence/absence of herbivory). If shrubs were browsed so heavily that a lack of foliage made it difficult to obtain accurate volume measurements, volume was not measured. However if any live (green) plant material was still present the plant was recorded as "alive" and used in survival analyses. Because of smaller samples sizes resulting from both reduced sampling efforts and increased mortality during the fifth year of growth, some species' volume measurements are only reported up to the fourth growth year. This includes ARME6, COSES, and PHOP from the BR/CT pairs, which were exclusively sampled at Lost Lake during the fifth year, and DILO from the GC/CT pairs, which were exclusively sampled at Found Lake during the fifth year.

Statistical Analysis

In order to determine whether changes in plant volume over time were dependent on planting treatment (BR vs. CT and/or GC vs. CT), we used a repeated measures mixed-model approach with plant volume as the response variable. Model effects included planting treatment (a between-subject effect), growth year (a within-subject repeated effect), planting treatment × growth year interaction, and lake as fixed effects, and plant ID as a random effect (a subject variable). Separate mixed-effect models were run for each of the five species and for each planting treatment pair (i.e., BR vs. CT and GC vs. CT) for a total of ten models. The repeated measures mixed-model approach allowed us to account for correlations between repeated observations made on the same plant while also retaining individual plants in the model when one or more year's volume measurements were missing from the dataset as a result of sampling error or mortality (Wang and Goonewardene 2004). A significant planting treatment × growth year interaction ($P < 0.05$) indicates that changes in volume over time were significantly different for CT plants compared to either BR or GC plants. To determine whether planting treatment influenced the odds of plants surviving to the fourth and/or fifth year, we used logistic regression models to calculate odds ratios for each of the five species in both planting treatment pairs (BR vs. CT and GC vs. CT). All analyses were conducted in JMP version 12.1.0 (SAS Institute Inc. 2015).

**Results**

Overall, plants from all five species experienced significant changes in volume during the 4-5 years reported (Table 2, Figure 3). Changes in volume over time, for some species, were dependent on the planting treatment (i.e., a significant planting treatment × growth year interaction effect). For instance, containerized COSES plants appeared to increase in volume more rapidly than those in the BR treatment (Figure 3B, Table 2). Similarly, containerized DILO plants appeared to increase in volume more rapidly than those in the GC treatment (Figure 3H). For some species, containerized plants had larger initial volumes than plants from the same species, and these larger sizes were maintained throughout the four or five years of growth (i.e., a significant planting treatment effect with no interaction). This was seen for ARME6 plants in the BR vs. CT treatments and the ARME6, COSES, and PHOP plants in the GC vs. CT treatments (Table 2, Figure 1A, F, G, I). SYAL plants grown in containers appeared to grow larger than both GC and BR plants during the first three years, but these differences became less pronounced during years four and five (Figure 3E, J). For SYAL plants, containerized plants initially began growing more rapidly than BR and GC, but by year four and five, they were fairly equivalent in size to BR and GC planting treatments.

Relative to containerized plants, survival to the fourth year was only significantly different for DILO plants in the GC planting treatment. Here, GC plants were nearly four times more likely to die than containerized DILO plants (Table 3, Fig. 4A). This difference in survival between planting types did not appear to be influenced by mammal browse, which did not differ significantly between GC and CT DILO plants during the fourth growth year (Table 4, Figure 5). During the fifth year of growth, many plants from all five species experienced a decrease in survivorship, and this was, in some cases, dependent on the planting treatment. For instance, in the fifth year of growth, ARME6 and DILO plants planted as GC were 4.35 and 4.20 times more likely to die, respectively, than containerized ARME6 and DILO plants (Figure 4, Table 3 – Odds ratios). For ARME6 plants, higher mortality in the GC treatment could be at least partially explained by a significantly higher frequency of deer browse found on GC plants relative to CT plants (Table 4, Figure 5). No other significant difference was found in survivorship between planting treatments (Table 4).

Most species experienced browse at year four and five, except for containerized DILO plants matched with BR in year four and COSES BR in year five. ARME6 CT, matched with BR, experienced 100% browse and DILO GC suffered 79% browse in year five. There was an overall average increase of browse from year four to year five on BR-CT match of 25% on BR and 38% on CT. PHOP in year four had the highest percentage of browse for both planting treatments, GC 75% and CT 92%, however, PHOP had the biggest decrease in browse in year five. DILO had the highest percent browse in year five on both planting types GC 79% and CT 56%. There was overall average decrease of browse from year four to year five on GC-CT match of -09% CT and -18% GC (Figure 5).

**Discussion**

Wildlife habitat restoration efforts on degraded sites depend on successful establishment and survival of native plants. Several studies have researched plant growth and survival on bare-root and containerized trees (Johnson et al 1981, Allen 1997, Castro et al 2002, Sweeney et al 2002), but very few have researched BR and GC shrubs in restoration projects. This project is one of the first restoration projects to use gravel as medium to extend the use of BR plant stock on restoration sites throughout the growing season. We evaluated whether the planting treatments of BR and GC are comparable with containerized plants when used in habitat restoration on lake riparian areas.

Our results show that BR and GC stock perform either equally well or more poorly relative to containerized plants, and that these differences are dependent on species and planting treatment (i.e., BR vs. GC), and they may be influenced by environmental effects such as herbivory, drought conditions, and low soil nutrients.

Containerized plants often had larger initial volumes at the time of planting relative to BR and GC stock. This larger initial volume was typically maintained during the four to five year period of growth and could be beneficial for the long-term survival of plants. This pattern was observed in ARME6 plants (both BR and GC pairs), COSES and PHOP (both in the GC/CT pairs). Additionally, for ARME6 plants in the GC pairs, mortality was significantly higher relative to containerized plants, which suggests that GC may not be a worthwhile alternative to containerized plants for this species.

In some instances, containerized plants grew more rapidly than those in the BR/GC planting treatments. Examples of this can be seen in COSES (BR/CT pairs) and DILO (GC/CT pairs). For DILO plants planted as GC stock, survival was also significantly reduced relative to paired containers. This further indicates that, for this species, the reduced cost of GC stock may not make up for high mortality and low growth rate relative to containers.

SYAL plants from the BR and CT treatments showed an overall reduction in volume over the five year period, and those from the GC/CT pairs did not experience very significant increases in growth. We also noticed a yellowing of leaves on SYAL plants from all planting treatments, suggesting that it was lacking proper nutrients. SYAL has been recommended in the past by local restoration practitioners and local nursery personnel in lakeshore restoration projects because it is considered a plant that will tolerate well-drained sandy soils (Hightshoe 1988, Soper and Heimburger 1994, Smith 2008) and is unpalatable to white-tailed deer (*Odocoileus virginianus*). Haskell et al. (2012) also noticed that containerized SYAL plants had reduced plant volume where there was no supplement of downed woody material (DWM) added to restoration sites. The DWM on restoration sites enhanced soil moisture retention and reduced soil temperature fluctuations (Haskell et al. 2012). Our results suggest that SYAL had difficulty getting established in the sandy soils with low nutrients found at these restoration sites. Furthermore, Henderson (1987) suggested that SYAL prefers moist and loamy soils as compared to Hightshoe (1988), Soper and Heimburger (1994), and Smith (2008).

Starbuck et al. (2005) reported no mortality for green ash and red oaks that were transplanted from pea gravel during the summer months over a three year study. Their project was conducted on Missouri Turgrass Research Center and they compared bare-root and balled & burlapped trees that were healed into the pea gravel during the early spring months and then transplanted in July. The trees were monitored for transplant shock and leaf-wilt shortly after transplanting. They reported no significant difference in central leader and root elongation between trees and treatment after three years. However, they did report that both tree species within each treatment experienced transplant shock shortly after moving into the research area.

The decrease in survival during year five of this study may be due to the herbivores having access to plants after fencing was removed following the third year of data collection. For example, there was a significant difference in survival of GC plant treatment for ARME6, DILO, and PHOP compared to CT of the same species in year five. These three species experienced heavy browsing after the fencing was removed, with the GC plantings most affected. Fencing is a common technique used as a herbivore abatement in habitat restoration (Case and Kaufman 1997; Opperman and Merenlender 2000; Haskell 2009; Holmes et al. 2009). These studies reported an increased in tree growth and survival with a herbivore abatement system Haskell et al. (2013) observed that white-tailed deer abundance was significantly higher on lakeshores where housing density was ≥10 houses per km at our restoration sites, supporting the need for herbivore abatement on habitat restoration projects.

Presence and abundance of many wildlife populations are correlated with quality habitat structure (Morrison et al. 1998). For many species, a shrub layer is an important component of habitat structure (Racey and Euler 1983b, Lindsey et al. 2002, Woodford and Meyer 2003,). Haskell et al. (In review) found few shrubs established at restoration sites where passive "natural recovery" (fencing and irrigation present, no plantings) was allowed to proceed. Thus a priority for lakeshore habitat restoration projects should include restoring a shrub component..

**Conclusions**

In conclusion, our results show that specific species of dormant bare root plant stock can be extended throughout the growing season by using gravel as a medium. And both BR and GC shrub species that were tested on the project showed increase in growth rates over five years. SYAL was the only shrub species that had declines in growth rate and this may be due to poor soil characteristics. Therefore, if SYAL is to be used on restoration sites it should be planted where soil moisture and nutrients are adequate. However, survival of all shrubs declined once the fence was removed and herbivores were able to access shrubs. We recommend that all restoration projects on developed lakeshores implement long-term herbivory abatement efforts and further research be conducted to identify shrub species resistant to herbivory. In addition, more research on other species of shrub should be considered in future restoration projects.

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**References**

Allen, J.A. 1997. Reforestation of Bottomland Hardwoods and the Issue of Woody Species Diversity. Restoration Ecology 5:125-134.

Case, R.L., and J.B. Kaufman. 1997. Wild ungulate influences on the recovery of willows, black cottonwood, and thin-leaf alder following cessation of cattle grazing in northwest Oregon. Northwest Science 71:115-126.

Castro, J., R. Zamora, J.A. Hódar, and J.M. Gómez. 2002. Use of shrubs as nurse plants: A new technique for reforestation in Mediterranean Mountains. Restoration Ecology **10:**297-305.

Clark, K.L, D.L. Euler, D.L., and E. Armstrong. 1984. Predicting avian community response to lakeshore cottage development. Journal of Wildlife Management 48:1239-1247.

Crowder, A.A., J.P. Smol, R. Dairymple, R. Gilbert, A. Mathers, and J. Price. 1996. Rates of natural and anthropogenic change in shoreline habitat in the Kingston Basin, Lake Ontario. Canadian Journal of Fisheries and Aquatic Science 53: 121-135.

Curtis, J.T. 1959. The vegetation of Wisconsin. University of Wisconsin Press, Madison, WI. 657 pp.

Haskell, D.E. 2009. Quantifying the Ecological Benefits of Lakeshore Restoration in Northern Wisconsin. M.S. thesis. Michigan Technological University, Houghton, Michigan.

Haskell, D.E.**,** D. J. Flaspohler, C. Webster, and M.W. Meyer. 2012. Variation in soil temperature, moisture and plant growth with the addition of down woody material on lakeshore restoration sites. Restoration Ecology 20: 113-121.

Haskell, D.E., M.W. Meyer Webster, C.R., Flaspolher, D.J. 2013. The Relationship between Carnivore Distribution and Landscape Features in the Northern Highlands Ecological Landscape of Wisconsin. The American Midland Naturalist, 169:1-16.

Henderson, C.L. 1987. Landscaping for wildlife. Minnesota Department of Natural Resources. Minnesota Bookstore. St. Paul, MN. 144 pp.

Highshoe, G.L. 1988. Native trees, shrubs, and vines of urban and rural America. Van Nostrand Reinhold, New York.

Holmes, S.A., Webster, C.R., Flaspolher, D.J., and Froese, R.E. 2009. Dealth and taxus: the high cost of palatability for a declining evergreen shrub, *Taxus canadensis.* Canadian Journal of Forest Research, 39:1366-1374.

Johnson, P.S., S. L. Novinger, and W.G. Mares. 1984. Root, shoot, and leaf area growth potentials of Northern Red Oak planting stock. Forest Science 30:1017-1026

Martin, A.C., H.S Zim, and A.L. Nelson. 1961. American wildlife & plants a guide to wildlife food habits: the use of trees, shrubs, weeds and herbs by birds and mammals of the United States. Dover Publications New York, NY. 500 pp.

Morrison, M.L., B.G. Marcot, and R.W. Mannan. 1998. Wildlife-habitat relationships: concepts and applications. University of Wisconsin Press, Madison WI. 435pp

NRCS (Natural Resource Conservation Service). 2002. Wisconsin Biology Technical Note 1: Shoreland Habitat. NRCS. ftp://ftp-fc.sc.egov.usda.gov/WI/technotes/biology-tn1.pdf

Opperman, J.J., and A.M. Merenlender. 2000. Deer herbivory as an ecological constraint to restoration of degraded riparian corridors. Restoration Ecology 8:41-47.

Racey, G. D. and D. L. Euler. 1982. Small mammal and habitat response to shoreline cottage development in central Ontario. Canadian Journal of Zoology 60:865–880.

Racey, G. D. and D. L. Euler. 1983a. An index of habitat disturbance for lakeshore cottage development. Journal of Environmental Management 16:173–179.

Racey, G. D. and D. L. Euler. 1983b. Changes in mink habitat and food selection as influenced by cottage development in central Ontario. Journal of Applied Ecology 20:387-402.

Robertson, R. J. and N. J. Flood. 1980. Effects of recreational use of shorelines on breeding bird populations. Canadian Field-Naturalist 94:131–138.

Schnaiberg, J., J. Riera, M.G. Turner, and P.R. Voss. 2002. Explaining human settlement patterns in a recreational lake district: Vilas County, Wisconsin, USA. Environmental Management 30:24-34.

Smith, W.R. 2008. Trees and shrubs of Minnesota. University of Minnesota Press, Minneapolis, MN. 703 pp.

Soper, J.H., and M.L. Heimburger. 1994. Shrubs of Ontario. Royal Ontario Museum. Toronto, Canada.

Starbuck, C., D.K. Struve, and H. Mathers. 2005. Bare root and balled-and burlapped red oak and green ash can be summer transplanted using the Missouri gravel bed system. HortTechnology 15: 122-127.

Sweeney, B.W., S.J. Czapka, T. Yerkes. 2002. Riparian forest restoration: Increasing success by reducing plant competition and herbivory. Restoration Ecology 10:392-400.

[USDA NRCS] USDA Natural Resources Conservation Service. 2016. The PLANTS database. URL: http://plants.usda.gov (accessed 12 May 2016). Greensboro (NC): National Plant Data Team.

Wang, Z., L.A. Goonewardene. 2004. The use of MIXED models in the analysis of animal experiments with repeated measures data. Canadian Journal of Animal Science 84(1): 1-11.

Wisconsin Department of Natural Resources (WDNR). 2005. Wisconsin Lakes. Bureau of Fisheries and Habitat Management. PUB-FH-800

Wisconsin Department of Natural Resources (WDNR) 2014a. http://docs.legis.wisconsin.gov/code/admin_code/nr/100/115.pdf

Wisconsin Department of Natural Resources (DNR). 2014b. The ecological landscapes of Wisconsin: an assessment of ecological resources and a guide to planning sustainable management. Wisconsin Department of Natural Resources, PUB-SS-1131 2014, Madison.

Woodford, J.E., and M.W. Meyer. 2003. Impact of lakeshore development on green frog abundance. Biological Conservation 110:277-284.

**Table 1. Characteristics of restoration lakes in Vilas County, Wisconsin (WDNR 2005).**

| Lake | Ownership Type | Surface Area ha | Type | Perimeter m | House Density/km | Legal Description |
|---|---|---|---|---|---|---|
| Found | Private | 132 | DG | 6362 | 21.0 | T40N, R8E, Sect 14 |
| Moon | Private | 50 | SE | 3190 | 21.3 | T40N, R8E, Sect 25 |
| Lost | Private | 297 | DG | 7537 | 33.8 | T40N, R8E, Sect 10 |
| Little St. Germain | Private | 397 | DG | 23330 | 25.2 | T40N R8E Sect 35 |
| Crystal | Public | 36 | SE | 2188 | 1.8 | T41N, R7E, Sect 27 |

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

**Table 2. Repeated measures results for effects of planting treatment (BR vs. CT and GC vs. CT), growth year, and lake on the volume of five shrub species. PT × GY is a planting treatment × growth year interaction.**

| | | **BR vs. CT** | | **GC vs. CT** | |
|---|---|---|---|---|---|
| **Species** | **Source** | $F_{df}$ | ***P*** | $F_{df}$ | ***P*** |
| ARME6 | Planting treatment | $8.66_{(1, 78.5)}$ | 0.0043 | $28.21_{(1, 242.3)}$ | < 0.0001 |
| | Growth year | $14.16_{(4, 244.2)}$ | < 0.0001 | $3.00_{(5, 565.7)}$ | 0.011 |
| | PT × GY | $0.37_{(4, 247.6)}$ | 0.827 | $1.12_{(5, 571.7)}$ | 0.349 |
| | Lake | $10.14_{(4, 76.8)}$ | < 0.0001 | $9.62_{(4, 184.5)}$ | < 0.0001 |
| COSES | Planting treatment | $17.59_{(1, 117.9)}$ | < 0.0001 | $11.54_{(1, 139.4)}$ | 0.0009 |
| | Growth year | $22.38_{(4, 291.3)}$ | < 0.0001 | $29.54_{(5, 320.6)}$ | < 0.0001 |
| | PT × GY | $2.79_{(4, 299.2)}$ | 0.027 | $0.53_{(5, 325.9)}$ | 0.7528 |
| | Lake | $21.49_{(3, 105.1)}$ | < 0.0001 | $10.08_{(4, 102.9)}$ | < 0.0001 |
| DILO | Planting treatment | $1.98_{(1, 404.1)}$ | 0.160 | $68.87_{(1, 224.7)}$ | < 0.0001 |
| | Growth year | $14.13_{(5, 680.5)}$ | < 0.0001 | $23.80_{(4, 731.2)}$ | < 0.0001 |
| | PT × GY | $0.65_{(5, 710.4)}$ | 0.663 | $4.91_{(4, 735.8)}$ | 0.0007 |
| | Lake | $97.08_{(4, 240.0)}$ | < 0.0001 | $41.20_{(4, 225.9)}$ | < 0.0001 |
| PHOP | Planting treatment | $0.71_{(1, 123.7)}$ | 0.401 | $9.81_{(1, 117.0)}$ | 0.002 |
| | Growth year | $5.96_{(4, 250.7)}$ | 0.0001 | $5.41_{(5, 239.8)}$ | < 0.0001 |
| | PT × GY | $1.79_{(4, 259.5)}$ | 0.131 | $1.43_{(5, 243.5)}$ | 0.214 |
| | Lake | $47.26_{(4, 91.4)}$ | < 0.0001 | $7.27_{(3, 69.0)}$ | 0.0003 |
| SYAL | Planting treatment | $0.002_{(1, 111.9)}$ | 0.997 | $11.39_{(1, 226.6)}$ | 0.001 |
| | Growth year | $27.45_{(5, 291.5)}$ | < 0.0001 | $3.56_{(5, 675.6)}$ | 0.004 |
| | PT × GY | $5.80_{(5, 294.1)}$ | < 0.0001 | $3.98_{(5, 683.4)}$ | 0.002 |
| | Lake | $9.63_{(3, 91.6)}$ | < 0.0001 | $3.30_{(4, 198.5)}$ | 0.012 |

**Table 3. Odds ratio results calculated using the ratio of both bare root (BR) and gravel culture (GC) survival odds (No/Yes) to container (CT) survival odds (No/Yes). Odds ratios significantly greater than 1 for BR/CT or GC/CT ratios ($p < 0.05$) indicate a greater likelihood of mortality for GC or BR plants, respectively, relative to CT plants.**

| | | Fourth Growth Year | | | Fifth Growth Year | | |
|---|---|---|---|---|---|---|---|
| **Species** | **Source** | **Odds Ratio** | **95% C.I.** | ***P*** | **Odds Ratio** | **95% C.I.** | ***P*** |
| ARME6 | BR/CT | 0.975 | (0.307, 3.518) | 0.968 | 0.462 | (0.106, 1.903) | 0.285 |
| | GC/CT | 2.563 | (0.684, 12.242) | 0.166 | 4.346 | (1.211, 20.687) | 0.023 |
| COSES | BR/CT | 1.043 | (0.325, 3.288) | 0.942 | 1.138 | (0.303, 4.255) | 0.847 |
| | GC/CT | 3.333 | (0.406, 69.038) | 0.406 | 2.667 | (0.275, 60.133) | 0.411 |
| DILO | BR/CT | 1.526 | (0.620, 3.907 ) | 0.359 | 1.444 | (0.460, 4.638) | 0.528 |
| | GC/CT | 3.994 | (1.367, 14.542) | 0.010 | 4.200 | (1.201, 16.592) | 0.024 |
| PHOP | BR/CT | 2.731 | (0.897, 9.441) | 0.078 | 2.057 | (0.458, 9.774) | 0.346 |
| | GC/CT | 1.063 | (0.041, 27.606) | 0.966 | 3.429 | (0.404, 72.235) | 0.268 |
| SYAL | BR/CT | 1.024 | (0.038, 25.218) | 0.987 | 3.231 | (0.361, 69.972) | 0.305 |
| | GC/CT | 4.395 | (0.634, 86.872) | 0.142 | 5.300 | (0.818, 103.364) | 0.084 |

**Table S1. Results of nominal logistic regression examining whether the percentage of plants browsed differed significantly by planting treatment (BR vs. CT and GC verses CT) for five shrub species in their fourth and fifth years of growth.**

| | | **Year Four** | | **Year Five** | |
|---|---|---|---|---|---|
| **Species** | **Source** | **Chi-Square*** | ***P*** | **Chi-Square*** | ***P*** |
| ARME6 | BR vs. CT | 0.53 | 0.468 | – | – |
| | GC vs. CT | 0.29 | 0.593 | 4.35 | 0.023 |
| COSES | BR vs. CT | 0.03 | 0.871 | – | – |
| | GC vs. CT | 0.24 | 0.624 | 0.02 | 0.890 |
| DILO | BR vs. CT | – | – | 1.12 | 0.290 |
| | GC vs. CT | 0.69 | 0.405 | 1.62 | 0.203 |
| PHOP | BR vs. CT | 2.60 | 0.107 | 1.13 | 0.287 |
| | GC vs. CT | 1.10 | 0.294 | 0.37 | 0.544 |
| SYAL | BR vs. CT | 0.13 | 0.721 | 0.00 | 1.000 |
| | GC vs. CT | 1.84 | 0.175 | 0.83 | 0.363 |

*DF = 1 for all models

Dashes represent values that were incalculable due to a lack of browse variation (Yes/No) within planting treatments


Figure 1. A) Bare root shrubs planted in gravel medium for use in restoration activities during the summer months. Shrubs will pulled out of gravel once full leaf out and transported to restoration sites. B) Gravel culture shrubs on site with full leaf out and root development.

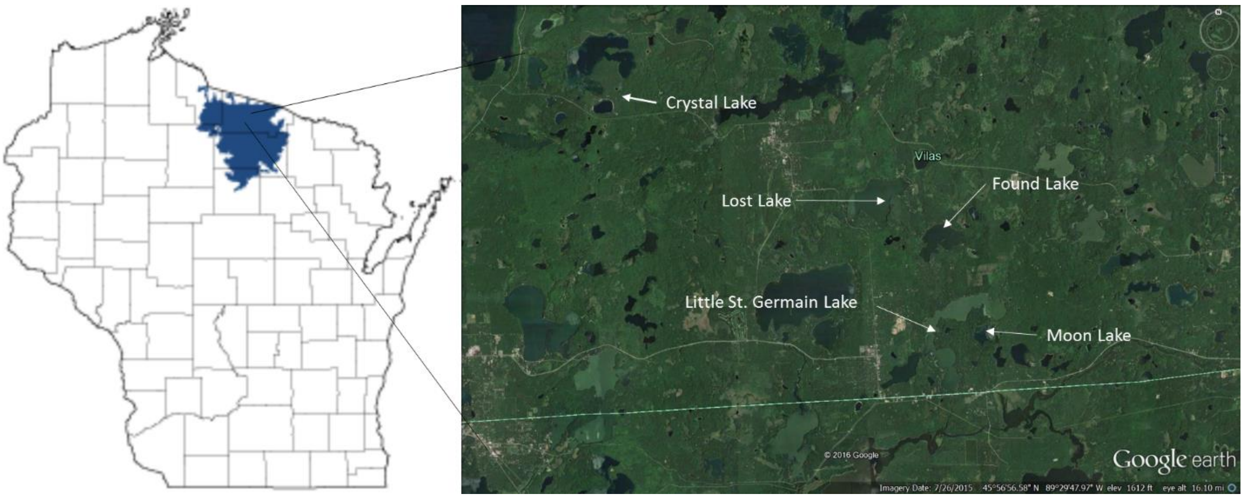


Figure 2. The Northern Highlands Ecological Landscape ( http://dnr.wi.gov/topic/landscapes/index.asp?mode=detail&Landscape=12). Restoration sites within Vilas County, Wisconsin. These sites were planted with gravel culture, bare root and container deciduous shrubs and monitored up to five years post planting.

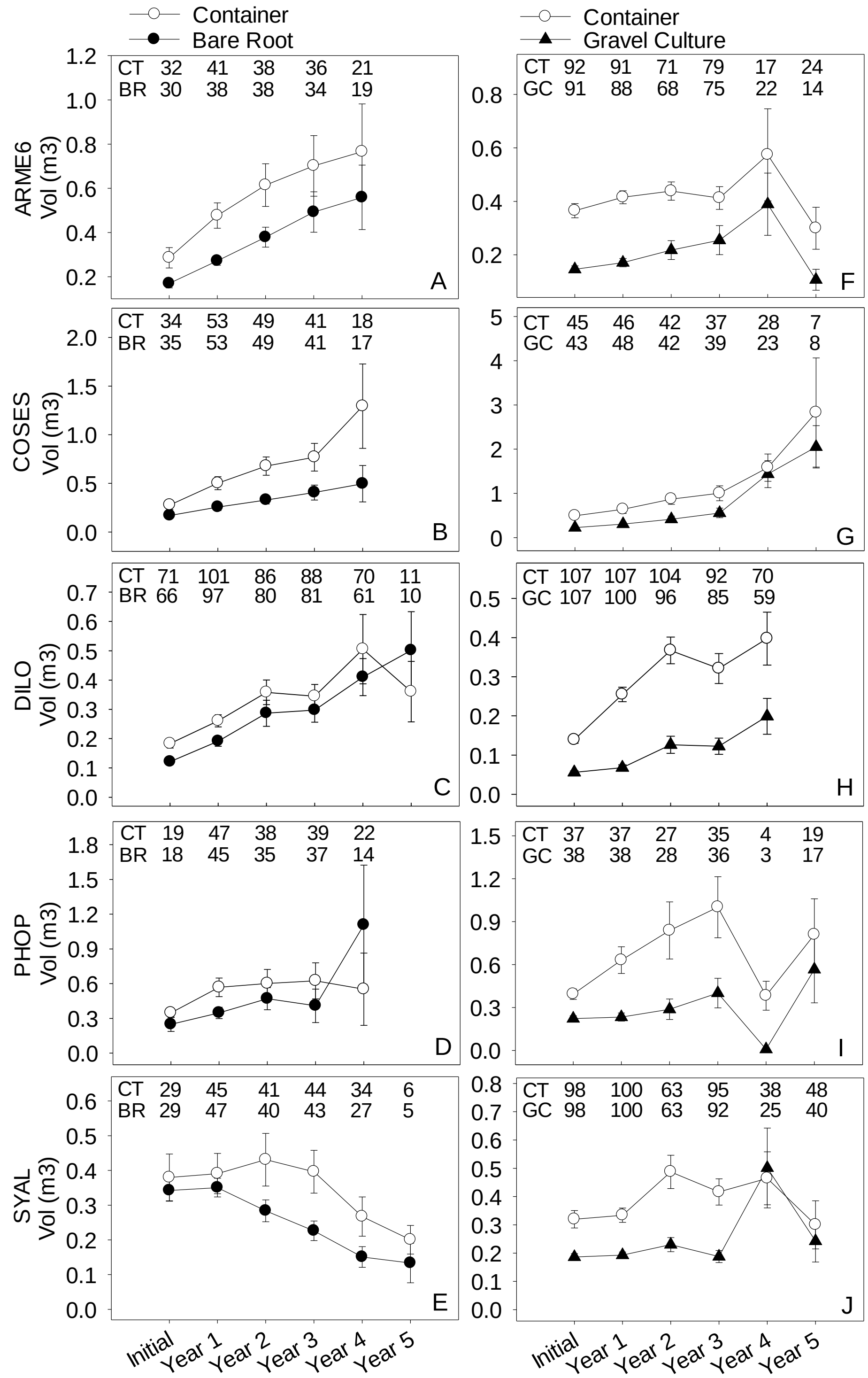


Figure 3. Results from repeated measures analyses showing the relative change in plant volume ($m^3 \pm 1$ SE) over four or five years by planting treatment for five shrub species. Figures in the left (A-E) and right (F-J) columns show the relative growth of BR/CT and GC/CT shrubs, respectively. Numbers above lines represent the number of individual shrubs sampled by planting treatment for each corresponding growth year below.

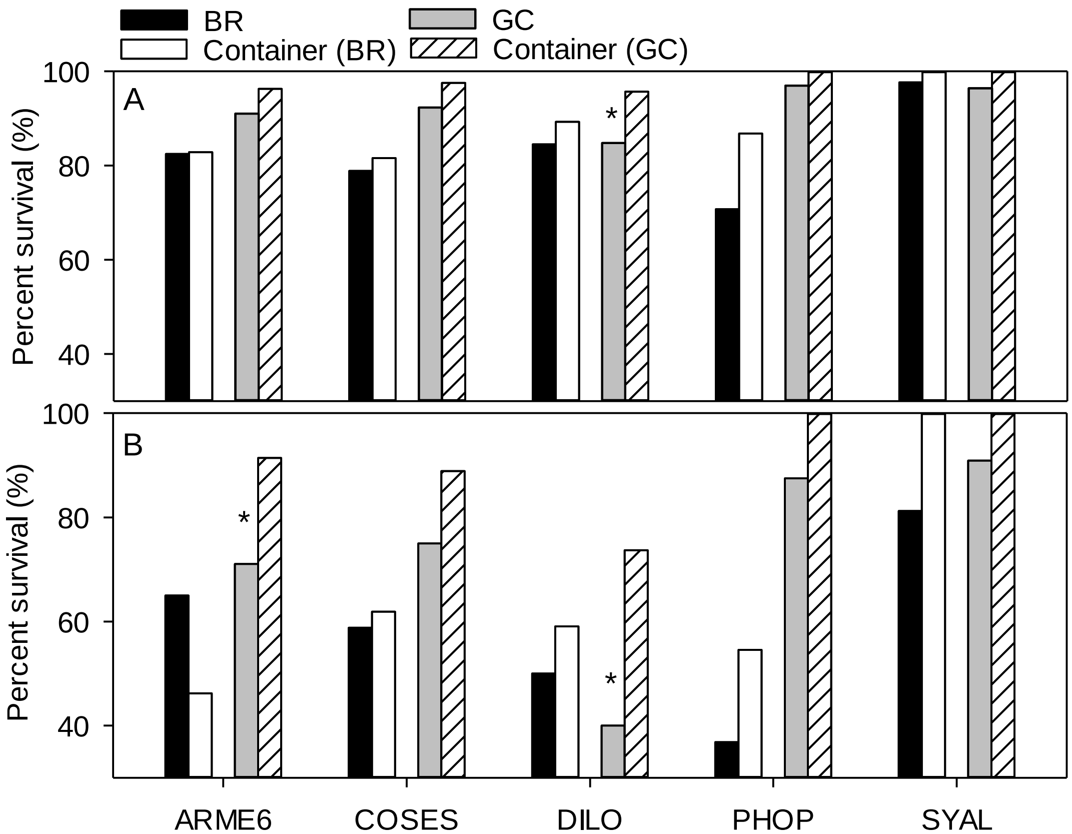


Figure 4. Percentage of shrubs from each planting treatment surviving to their fourth A) and fifth B) year of growth by species. Asterisks above bare root (BR) and gravel culture (GC) treatment bars represent significant differences in survival between their paired containers (“Container (BR)” and “Container (GC),” respectively) determined from odds ratio tests.

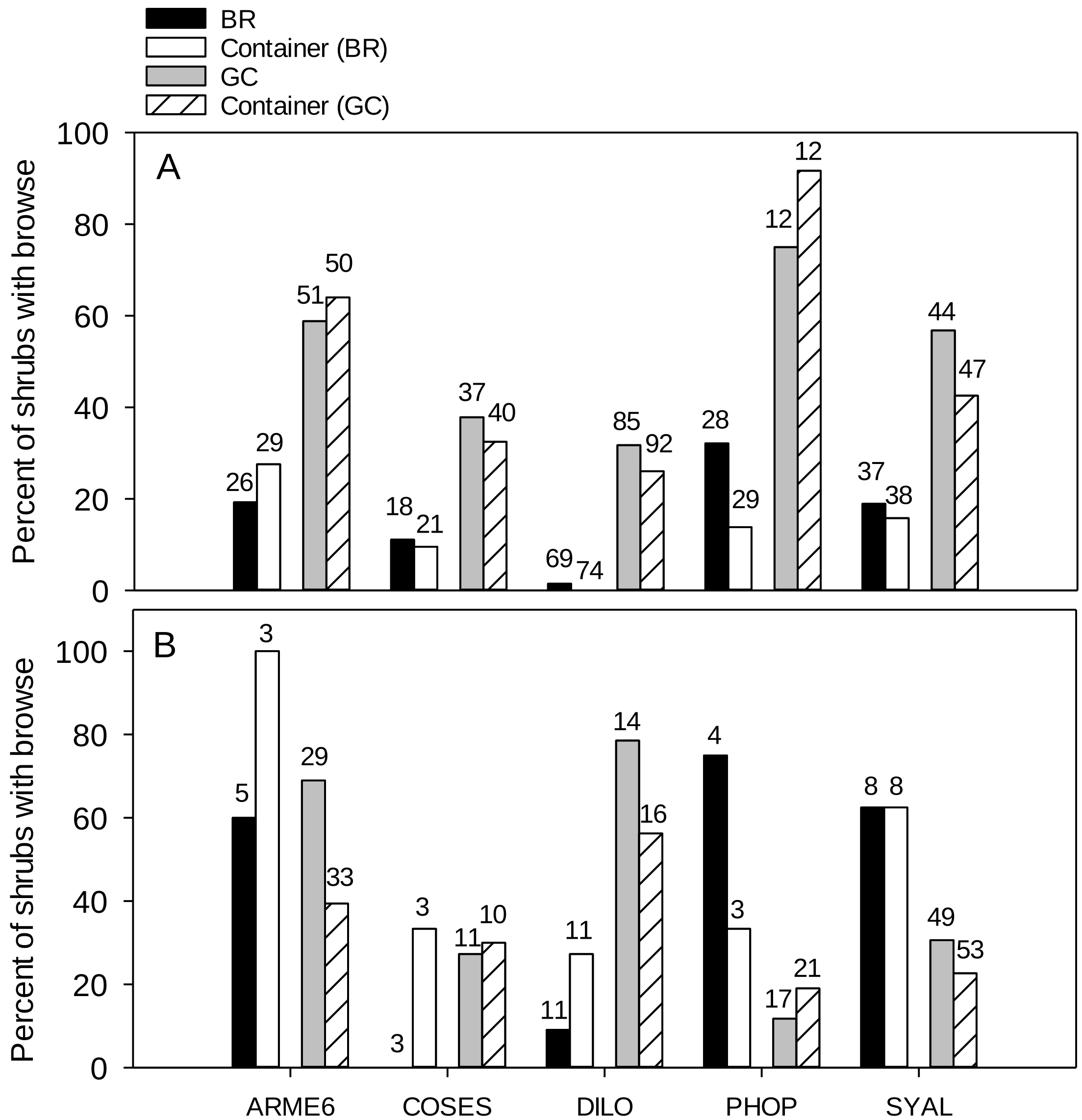


Fig. 5: The percentage of plants from each of five species and three planting treatments that were browsed by deer during their fourth A) and fifth B) years of growth. Numbers above each bar represent the total number of plants sampled from each species and planting treatment.

*Lakeshore Restoration in the Northern Highlands Ecological Landscape - Lessons Learned*

- Landowners are essential to any restoration strategy; without willing lakeshore property owners, opportunities for rehabilitating private lakeshore habitat are minimal. Finding local, on-lake champions of lakeshore restoration work like lake association officers or master gardeners can make for effective peer-to-peer learning and project buy-in. Two lakes involved with this project had less success with securing landowners because no effective local lake champion could be found to make the case for recruiting suitable lakeshore property owners. Lakeshore rehabilitation efforts are best led by lake property owners themselves or a partnership with private business (i.e. landscape and nursery companies).

- Natural resource educators, contractors, planners, and other consultants to these landowners need to be hands-on with their assistance. Landowners do not typically have the knowledge and tool box necessary to successfully implement lakeshore rehabilitation. However, private sector lake specialists must openly communicate with each landowner to understand their vision for their lakeshore properties on access points, view corridors, plant selection, storage needs, landscaping preferences, and other facets of the project. For example, we need to meet landowners where their landscape values are, whether they champion a more natural lakeshore that resembles a wild, pristine, rustic lakeshore or a 'tidy', suburban aesthetic that might accentuate drifts of plants, delineated edgings, and lower growing native vegetation, but still be ample to provide adequate habitat for wildlife.

- Approaching lakeshore management at the 'whole-lake" level is the most efficient approach – lake leaders can access WDNR Lake Protection grants (http://dnr.wi.gov/lakes/grants/) to implement small and large-scale lake planning activities and to obtain funds to contract private sector lake specialists to map lakeshore areas of critical need (allowing for rehabilitation prioritization) and to help secure grants to implement individual lakeshore projects via the WDNR Healthy Lakes program (http://healthylakeswi.com/,http://dnr.wi.gov/wnrmag/2016/06/Lakes.PDF) and WDNR Lake Protection Grants for larger scale efforts. UW Extension lakeshore management expertise can also be found at http://www.uwsp.edu/cnr-ap/UWEXLAKES/Pages/default.aspx. In the NHEL, the WDNR Lake Specialist and Grants Coordinator in Woodruff, WI can provide assistance and guidance to interested parties (Kevin Gauthier, 715-356-5211 ext. 214).

- Incorporating ecological design principles of water infiltration, retention, reuse and flow control into our strategies with landowners pays dividends. This includes low impact development (LID) approaches and practices that are targeted to reduce runoff of water and pollutants like rain gardens and barrels, permeable pavements, green roofs, living walls, infiltration planters, drain systems, water bars, brush bundles, gutters, and cisterns. Again, lake management specialists can assist private landowners develop these solutions. These approaches are an alternative to the more conventional "hard-scaping" practices.

- Finding erosion control solutions for landowners to challenges from ice heave and wave action are critical to success. Bank and toe erosion problems often bring willing landowners to the table for doing lakeshore restoration so we need to make sure we address these concerns effectively. Often these problems have developed because landowners remove shore-protecting shrubs such as tag alder, sweet gale, leather-leaf, *Spirea* spp. to increase viewing and access. Best practice would use fiber coir logs and planted shrubs that hold the bank but tolerate deer browsing to stabilize and rehabilitate the bank. We have found red-osier dogwood to work very well in the NHEL. It is probable some native willow species may also work well – however reintroduction of tag alder and Spirea spp. may be the most efficient – they are adapted to the near shore zone and contain high levels of chemicals which deter herbivory. Innovative advances in erosion control materials that meet state standards and codes can be found by partnering with land and water conservation departments, consultants, and others.

- Shoreland zoning and other regulatory instruments alone are not enough to protect lakeshore habitat. Lakes with minimum frontage lake lots at 200 feet versus 100 feet (or less) withstand the stressors of human disturbance more positively. The state of Wisconsin has now prohibited counties from increasing shoreland zoning standards beyond the statewide minimums (e.g. 100' lakeshore lots are now permitted statewide). Therefore protection of the ecological integrity of lakeshores via conservation easements or restoration/conservation practices is now the responsibility of property owners and private citizens.

- Holistic and inclusive lake community partnerships can support lakeshore restoration work of all kinds. Be open to possible project helpers like lake organizations, scouting groups, master gardeners, churches and other community organizations.

- Lakeshore rehabilitation projects are good for local economies and small business owners. Expenditures from these lake projects provide income to area contractors, nurseries, landscapers, erosion control specialists, and others employed in facets of the work.

- Select native ground cover plant species that are proven work horses, namely sedges, grasses, and rushes. These soil-holding plants are important to the goal of restoring ecological functions to lakeshore areas and they can persist throughout the transition zone from upland areas to near-shore locations with wet feet. In the NHEL, select tree saplings and shrubs that are tolerant of deer and hare browsing as well as those adapted to the local soils (often sandy with low nutrient content) and short growing season. An inventory of plants present on undeveloped lakeshore can provide a good starting point for selection.

- Upland plant species can be a challenge to get established without proper maintenance. The soil condition, aspect, and slopes should be considered when generating a plant list. It is critical to provide irrigation the first 3 years, and to apply a minimum of 1" rainfall equivalent per week the first year and then slowly reduce irrigation to harden new plants.

- Maintenance is a vital part of the process [i.e., monitoring for ample watering regimes; invasive species control needs; browse protection systems like spray deterrents (not always effective, and require constant reapplication), temporary fencing, or motion-sensory sprinkler plans; proper dock storage; etc].

- Degradation of lakeshore habitat cover is the most important stressor of lakes – it has negatively impacted fish and wildlife populations in the NHEL.

- At present, voluntary restoration of lakeshore habitat will likely have only a modest influence on watershed health. Even mandatory mitigation requirements wrapped up in local shoreland rules may only marginally increase participation. But when politically possible, shoreland rules or zoning that require lakeshore habitat conservation and restoration can provide the greatest benefit in the long term. Understanding more deeply and clearly the barriers landowners confront in ultimately accepting the practice of lakeshore habitat restoration and devising marketing strategies that utilize this information may also pay dividends in the future.

- This lakeshore restoration research project restored native vegetation to over 500,000 square feet of lakeshore and repaired erosion issues on 7000 linear feet of shoreline. In the process, over $350,000 was transferred to local business for goods and services. It is obvious that there is a great need for this lake management practice, and in the process, local businesses stand to make a sizable income.

- Additional biotic and abiotic surveys need to be implemented to measure change that more likely occurs at the scale of our lakeshore restorations (e.g. pollinators; soil microbes/arthropods; soil chemistry; fine woody material; root growth and depth; etc.).

- Fish and wildlife habitat is degraded, bird communities are altered, amphibian populations are negatively affected, and furbearer abundance and diversity declines when NHEL lakeshores are developed to the density currently permitted by the Wisconsin Shoreland Management Program (NR 115 https://docs.legis.wisconsin.gov/code/admin_code/nr/100/115/Title) minimum standards (100' lot width per property) studies have shown. Until 2015, Vilas and Oneida County Zoning required additional lot width on lakes considered at risk to development impacts. The Wisconsin legislature passed Act 55 in 2015 removing that ability from the counties http://dnr.wi.gov/topic/ShorelandZoning/documents/Act55-2015-10-01.pdf and now permits lakeshore development to the density prescribed by the minimum standards throughout the NHEL.

- Lake management approaches in Wisconsin should not be implemented at the state-wide level (e.g. one size fits all). The Headwater Lakes of northern Wisconsin retain the best water quality in the state, and are an economic engine for the local economies, thus increased protection should be legislated for these waterbodies by amending NR 115 to provide increased protection for northern headwater lakes. The loss of county authority to enhance statewide shoreland zoning in the headwaters under Act 55 will ultimately lead to ecological damage to this vital economic resource.

- Even with active planting, irrigation, and fencing, growth and maturation of restoration projects is slow in the NHEL (likely due to low soil fertility and short growing season). We recommend the long-term (10 year) measures initially planned for this research experiment be implemented 2017-2022 to fully evaluate the success of these restoration projects and methods.

*Lakeshore Restoration in the Northern Highlands Ecological Landscape – Recommendations for Best Management Practice*

1. When possible, establish lakeshore restoration projects at the "whole lake" level by securing a WDNR small-scale lake planning grant (http://dnr.wi.gov/lakes/grants/). This grant can be used to formulate a plan for lakeshore management around the entire lake. A protocol being developed by WDNR Waters program should be used to map lakeshore properties into categories of ecological status, identifying properties with degraded lakeshores most in need of rehabilitation. This categorization can be used to prioritize properties in need of rehabilitation. In the NHEL, grant guidance can be obtained from WDNR Lake Specialist and Grants Coordinator Kevin Gauthier, 715-356-5211 ext. 214.

2. Individual property owners should apply for WDNR Healthy Lakes (http://healthylakeswi.com/, http://dnr.wi.gov/wnrmag/2016/06/Lakes.PDF) or Lake Protection grants (http://dnr.wi.gov/lakes/grants/) can be sought by lake associations, conservation NGOs, local municipalities to secure funding to develop and implement lake-wide restoration plans for each priority property owner willing to participate. These grants pay up to $3K for individual projects, $100K for large-scale lake projects.

3. It is important to develop individual lakeshore restoration plans for each property owner willing to participate. Property owners can contract private lake specialists to meet with them at their properties to design individual plans which suit their needs. WDNR Lake Specialists can direct property owners to qualified private sector lake management specialists (i.e. landscape companies that qualified and local nurseries personnel) with this expertise. Property owners can also use on-line resources to develop plans of their own (http://healthylakeswi.com/best-practices/ http://www.uwsp.edu/cnr-ap/UWEXLakes/Pages/ecology/shoreland/default.aspx http://co.vilas.wi.us/index.php?page=lwcd-shoreland-management though best success will be through contracting experienced lakeshore management specialists.

4. Individual lakeshore restoration plans should focus on rehabilitating lakeshore fish and wildlife habitat, reducing run-off from impervious surfaces, strengthening the land/lake interface to withstand wave action and ice-heave, and to take into account property owner objectives such as view, access, and storage of recreational gear. Restoration of the vegetative buffer (from the ordinary high water mark inland 35') should be considered the minimum standard for rehabilitating native vegetation and wildlife habitat. Current WDNR Shoreland Management rules (NR 115, https://docs.legis.wisconsin.gov/code/admin_code/nr/100/115/Title) allows the buffer to be cleared of vegetation 30' for every 100' of property lakeshore – the amount cleared should be reduced below this benchmark and the 35' vegetation buffer should be broadened when practical.

5. Research has shown that passive recovery of the lakeshore buffers will occur when 1) a seed bank of native plants is present (e.g. lawn sod, heavy foot traffic thus compaction, or grading has not occurred), 2) the buffer is protected from cutting and herbivory (fencing is the most cost-effective method), and 3) it is amply watered for a 3 years during the growing season. This approach will be the least expensive, but can take >10 years to attain sufficient structure to provide a canopy with an understory of wildlife habitat.

6. Research has shown that when a canopy cover is absent, lakeshore restorations benefit from the addition of downed woody material such as small logs. The placement of logs moderates soil conditions (temperature and moisture) and increases plant growth and survival. Ground coverage of 25-50% small logs was associated with these benefits. This material can be acquired from local logging operations but permission and permits must be obtained. Landowners should refrain from removing DWM wind fall within the restoration projects.

7. When a more rapid recovery of the lakeshore buffer is desired, active planting of native tree saplings and shrubs is indicated. Landowners should consult with local experts to determine the native plant species most suited to their individual property, and local nurseries should be consulted to learn of the native plant availability. Nursery owners can also provide good advice as to planting methods, timing, and site suitability. White tailed deer browsing severely damages restoration projects on private lands in the NHEL, thus native plant species that are unpalatable to deer, but provide habitat structure and mast should be chosen. UW Extension, Vilas County Land and Water Conservation Department, and WDNR Lakes program all provide guidance when choosing plants for restorations (http://healthylakeswi.com/best-practices/ http://www.uwsp.edu/cnr-ap/UWEXLakes/Pages/ecology/shoreland/default.aspx http://co.vilas.wi.us/index.php?page=lwcd-shoreland-management though best success will be through contracting experienced lakeshore management specialists. Additional guidance, including recommendations for planning and planting density can be found in NRCS (Natural Resource Conservation Services) publication "Wisconsin Biology Technical Note 1: Shoreland Habitat".

8. Deer-proof fencing and irrigation accelerates lakeshore wildlife habitat restoration (planting of native trees, shrubs, and groundcover) and improves native plant survival in the NHEL. Including plans for these practices is essential for the success of lakeshore restoration on private lands in the NHEL. Research has shown that a durable, effective fencing system includes eight foot tall, nylon mesh, UV protected fence around the entire perimeter of reach restoration. Plans for effective fencing can be obtained from local landscapers. Chicken wire or hardware cloth (4' width due to winter snow) should be placed at the base of the fence to prevent rabbit/hare damage, which gnaw through the nylon and can cause considerable damage to plantings, particularly in winter. Depending on the size of the restoration, gas or electric water pumps or commercial automatic irrigation systems can be purchased to provide a minimum equivalent of 1" rainfall weekly during the first growing season, drawing from the lake. Landscapers or irrigation specialists can recommend best practices for individual properties. Fencing should be

maintained and irrigation should continue when needed the first 3-5 years following planting. This time period will be determined by the soil types and severe drought conditions.

9. Native trees and shrubs can be purchased in containers (e.g. in potting soil) for planting in spring, summer, and fall, or as bare root stock for planting during dormancy. Container plants are more expensive, larger, and for some species grow more rapidly than do bare-root stock, however are over 4x the cost. Research on the NHEL shows that bare root stock does increase in volume and has high survival the first 5 years of measurement, thus may be a cost-effective alternative. Growing bare-root trees and shrubs in a gravel medium (gravel culture) can extend the planting period beyond leaf-out, which is a constraint of using bare-root. However not all gravel culture trees and shrubs performed as well as the bare-root or container forms. Native trees and shrubs can be obtained from many local nurseries in the NHEL, while bare root native tree and shrubs can be obtained from both private and Wisconsin DNR nurseries. Hanson's Garden Village, Rhinelander, WI, has carried some gravel culture native tree and shrub stock in the past. Nursery owners can provide advice on species to choose as well as planting techniques.

10. Lakeshore restoration projects need to be tended year round. In addition to irrigation during the growing season and deterring herbivores year round, the sites should also be watched for planting mortality and occurrence of invasive plant species. Dead plant material should be replaced, and invasive species should be removed.

11. Supplemental white-tailed deer feeding should be eliminated where restoration activities are occurring. Even after deer fencing had been in place for over 3 years, some shrubs and saplings were severely browsed once the fencing was removed. Due to concerns over Chronic Wasting Disease, supplemental deer feeding is now prohibited in the Northern Highlands Ecological Landscape. Participating property owners should ensure that all adjacent property owners adhere to this rule as unusually high densities of deer (thus plant damage) occur near feeding sites, particularly in the winter.

12. Over the 9 years of this project, certain plant species performed better than others, much of which was due to site conditions and herbivory. Within the NHEL conifer tree species performed best and if sandy steep slopes are present red and jack pine are best, with sweet fern and bear berry shrubs underneath. Other trees that grew and survived well include red and pin oaks, red maple, and if soil and moisture conditions are adequate, paper birch can be considered. Best performing shrubs include hazels, ninebark, native *Prunus* species (cherries) and honeysuckles, sweet fern and bear berry in the upland with *Spirea*, dogwoods, leather-leaf and tag alder at the shoreline. Best ground cover species would be native sedges in the upland and near shore, several mint species (which can be deer resistant), large leaf aster, barren strawberry, wild sarsaparilla, sky-blue aster, frost aster, pearly everlasting; best grasses include little blue stem, blue joint grass, poverty oats grass, rough leaf rice grass, and manna grass.

13. Climate change has increased average temperature and the frost-free period in the NHEL, and will continue to increase into the future. Consult with nursery owners to insure that the plant species you select will survive in the projected new environment. For instance, many of the conifers and some cold adapted deciduous trees currently found in the NHEL may not remain after 2100.

**TECHNOLOGY TRANSFER**

PUBLICATIONS

Haskell, D, Flaspohler, D, Webster, C., Meyer, M.W. (2013). Relationship between carnivore distribution and landscape features in the Northern Highlands Ecological Landscape of Wisconsin. American Midland Naturalist 169(1):1-16.

Haskell, D, Flaspohler, D, Webster, C., Meyer, M.W. (2012). Variation in soil temperature, moisture, and plant growth with the addition of downed woody material on lakeshore restoration sites. Restoration Ecology 20: 113-121.

Goggin, P, Haskell, D., Meyer, MW. 2009. Wisconsin Lakeshore Restoration. LakeLine, Spring 2009, pp. 23-27.

Haskell, D. Meyer, M, Schotthoefer, A, Goggin, P. 2013. Wisconsin Lakeshore Restoration Project, Lakeline, Spring 2013. pp. 10-16.

Haskell, D.E. 2009. Quantifying the Ecological Benefits of Lakeshore Restoration in Northern Wisconsin. M.S. thesis. Michigan Technological University, Houghton, Michigan.

In prep/review

Haskell, D, Flaspohler, D, Webster, C., Meyer, M.W. Assessing the Importance of Fencing, Irrigation, and Native Plant Source when restoring wildlife habitat along northern Wisconsin lakeshores. Submitted to Native Plants Journal.

Haskell, D, Flaspohler, D, Webster, C., Meyer, M.W. Bare-root and Gravel Culture shrubs used in wildlife habitat restoration on lake riparian areas in Northern Wisconsin. To be submitted to Ecological Restoration.

Haskell, D, Flaspohler, D, Webster, C., Meyer, M.W. Baseline Assessment of Wildlife Habitat Restoration Projects on Northern Wisconsin Lakeshores. To be submitted to American Midland Naturalist.

PRESENTATIONS

D. E. Haskell, M.W. Meyer, C.R. Webster, and D. J. Flaspohler. *Testing Multiple Methods for Wildlife Habitat Restoration on Lakeshores: Crystal Lakeshore Restoration Project.* Oral Presentation. February 17-19, 2015. Joint Meeting Wisconsin & Minnesota Chapters of The Wildlife Society Conference, Duluth, MN.

D. E. Haskell, D. J. Flaspolher, C.R. Webster, and M.W. Meyer. *Comparison of Multiple Methods for Wildlife Habitat Restoration on Lakeshores: Crystal Lakeshore Restoration Project.* Oral Presentation. October 15-17, 2014 Science in the Northwoods Conference. Boulder Junction, WI.

D. E. Haskell, M.W. Meyer, C.R. Webster, and D. J. Flaspolher. *Benefits of adding downed woody material to lakeshore restorations.* Oral presentation, Symposium-Evaluating the success of restoration on human altered lakeshores in the upper Midwest of USA. Fifth World Conference on Ecological Restoration. October 6-11, 2013 Madison, WI.

D. E. Haskell, M.W. Meyer, and B. Fevold. 2013. *Measurements of Lakeshore Habitat Restoration: Preliminary Findings 2007-2012.* Oral Presentation. April 9-11, 2013 Wisconsin Lakes Convention. Green Bay, WI.

D. E. Haskell, M.W. Meyer, C.R. Webster, and D. J. Flaspolher. *The Relationship between Carnivore Distribution and Landscape Features in the Northern Highlands Ecological Landscape of Wisconsin*. Poster Presentation. 18th Annual Conference of The Wildlife Society. November 6-10, 2011, Waikoloa, HI.

D. E. Haskell, D. J. Flaspolher, C.R. Webster, and M.W. Meyer. *Residential Development Impact on Mammalian Diversity along Lakeshores in Northern Wisconsin.* March 3, 2011 Joint Meeting Wisconsin Chapter of The Wildlife Society and Society of American Foresters. Wisconsin Dells, WI.

D. E. Haskell, D. J. Flaspolher, C.R. Webster, and M.W. Meyer. *Quantifying the Ecological Benefits of Lakeshore Restoration in Wisconsin.* Oral Presentation. September 30, 2010 Science in the Northwoods Conference. Boulder Junction, WI.

D. E. Haskell, D. J. Flaspolher, C.R. Webster, and M.W. Meyer. *The Wisconsin Lakeshore Restoration Project.* Poster Presentation. April 12, 2010 Wisconsin Lakes Convention. Green Bay, WI.

D. E. Haskell, D. J. Flaspolher, C.R. Webster, and M.W. Meyer. *Quantifying the Ecological Benefits of Lakeshore Restoration in Northern Wisconsin.* Oral Presentation. April 12, 2010 Wisconsin Lakes Convention. Green Bay, WI.

D. E. Haskell, D. J. Flaspolher, C. Webster, and M.W. Meyer. *Measuring the Value of Wildlife Habitat Restoration on Northern Wisconsin Lakes - The Wisconsin Lakeshore Restoration Project.* Poster Presentation. December 3, 2007 68th Midwest Fish and Wildlife Conference. Madison, WI.

Meyer, M.W. *Lakeshore Habitat Restoration in the Northern Highlands.* WDNR Wildlife Management Statewide Meeting, 16 January 2014, Oshkosh, WI.

Meyer, M.W., and D. Haskell. *Evaluating the Success of Restoration on Human-altered Lakeshores in the Upper Midwest*, USA. 5th World Conference on Ecological Restoration Symposium, 9 October 2013, Madison, WI.

Meyer, M.W. *Evaluating the Ecological Benefits of Lakeshore Habitat Restoration in the Northern Highlands.* Vilas County Lakes and Rivers Association (VCLRA), 8 October 2013, St. Germain, WI.

Meyer, M. *Wisconsin lakeshore restoration project.* Wildlife and Forestry Research Section Meeting, 29 August 2013, Kemp Research Station, Minocqua, WI.

OUTREACH PROGRAMS

*Lake Shore Restoration: Why is it important?* Kemp Natural Resources Station, summer outreach program. Oral presentation. August 21, 2006. Woodruff, WI.

*Lake Shore Restoration.* North Lakeland Discovery Center, bird club meeting. Oral presentation. August 6, 2007. Manitowish Waters, WI.

*Quantifying the Ecological Benefits of Shoreland Restoration in Wisconsin: The Beginning (2007-2017).* North Lakeland Discovery Center, bird club meeting. Oral presentation. August 4, 2008. Manotowish Waters, WI.

*Effects of Shoreline Development on Birds and Other Wildlife in Northern Wisconsin.* Copper Country Audubon Society. Oral presentation. October 27, 2009. Houghton, MI.
*Influence of Residential Development on Mammalian Carnivore Diversity along Lakeshores in Northern Wisconsin.* Oral presentation. Kemp Natural Resources Station, summer outreach program. July 31, 2013.

*Bird Response to Lakeshore Restoration in Vilas County.* North Lakeland Discovery Center, 10th annual Northwood's Birding Festival. Oral presentation. May 9-10, 2014. Manitowish Waters, WI.

Local Media Contacts:

*Found Lake Restoration. Living on the Lake: Wisconsin's Northwoods Lifestyle Magazine. June/July 2008 Pp 20-22.*

*Ten-year study will assess impact of development on wildlife, vegetation. The Lakeland Times: Outdoors. July 25, 2008. Pp 7-8.*

*State officials' tour shore habitat sites. Vilas County News-Review. August 20, 2008. Pp 1 & 7.*

*Kemp Profile: Dan Haskell. Kemp's Point, News from the University of Wisconsin-Madison's Kemp Natural Resources Station. Vol 10 (2). October 2009. Pp 6-7.*

*Research to restore lakeshores underway at NHAL Crystal Lake campground. Northern Highland-American Legion State Forest Visitor's Guide 2011. Pp 14.*

*Take a walk through the Crystal Lake shoreland restoration project. Northern Highland-American Legion State Forest Visitor's Guide 2012. Pp 13.*

*Site Tour at Crystal Lake Restoration Project. Explore the Forests of Wisconsin's Northwoods Field Tour. Science on Tap Minocqua, WI. June 11, 2015.*

*Vilas County research spotlights healthy, natural shorelands. Interview with TV reporter from WJFW, NBC Channel 12 Rhinelander WI. Submitted: 06/24/2015. http://wjfw.com/stories.html?sku=20150624181018*