2017 NORTHEASTERN NATURALIST 24(4):391–412

Assessment of Wildlife Habitat Attributes at Restoration Projects on Northern Wisconsin Lakeshores

Daniel E. Haskell[1,*], Christopher R. Webster[1], Alex L. Bales[1], Michael W. Meyer[2], and David J. Flaspholer[1]

Abstract - Housing development along lakeshores typically results in the loss of native shoreline vegetation, which can negatively impact habitat structure and associated wildlife populations. We evaluated vegetation restoration efforts on 2 lakeshores in Vilas County, WI, and contrasted them with undeveloped reference lakeshores. The primary goal of the restoration activities was to restore native understory vegetation and habitat structure. Initial measurements made at reference lakeshores showed greater visual obstruction density, greater sapling and shrub densities, greater abundance of downed woody material, and higher canopy coverage relative to initial measurements made at developed lakeshore sites. Three years post-restoration we observed significant increases in visual obstruction density and increased shrub and sapling density at restoration sites. While restoration of complex understory habitats is a slow and uncertain process, a non-metric multi-dimensional scaling ordination of wildlife habitat attributes suggested that restoration sites are on a developmental trajectory that should increase their similarity to reference sites with time. Further monitoring and adaptive management will likely be needed to ensure restoration goals are met.

Introduction

Freshwater ecosystems have attracted human development for centuries (Naiman 1996, Rierra et al. 2001). The Midwest region of the US experienced a 146% increase in housing development from 1940 to 2000 with one of the highest relative growth rates occurring in northern Wisconsin (Radeloff et al. 2005), which contains one the highest densities of freshwater glacial lakes in the world. Since 1965, the number of new houses built along Wisconsin lakeshores has increased by over 200% (Radeloff et al. 2001, WDNR 1996). Gonzalez-Abraham et al. (2007) suggest that lakes are the single most important factor determining both housing density and spatial patterns of housing development throughout this region.

Lakeshores provide critical habitat for a variety of wildlife (Engel and Pederson 1998). Increased light and water availability often results in vegetation communities that are more species-diverse and structurally complex along lakeshore forest edges relative to interior forests (Elias and Meyer 2003, Harper and MacDonald 2001, Kaufmann et al. 2014a, Whittier et al. 2002). Nevertheless, across North America high concentrations of housing development along

[1]Ecosystem Science Center, School of Forest Resources and Environmental Science, Michigan Technological University, 1400 Townsend Drive, Houghton, MI 49931. [2]Wisconsin Department of Natural Resources, 107 Sutliff Avenue, Rhinelander, WI 54501. [*]Corresponding author - dehaskel@mtu.edu.

Manuscript Editor: David Halliwell

lakeshores and associated removal of native vegetation (Christensen et al. 1996, Elias and Meyer 2003, Haskell 2009, Kaufmann et al. 2014a, Marburg et al. 2006, Whittier et al. 2002) has been shown to fragment wildlife habitat (Theobald et al. 1997), alter habitat use and movement patterns, and reduce local biodiversity (Czech et al. 2000, Wilcove et al. 1998).

Removal of native vegetation can alter the physical characteristics of lakes and the biological processes that occur near and within them. For instance, highly developed lakeshores have been shown to contain lesser amounts of coarse woody debris (Christensen et al. 1996, Whittier et al. 2002) and aquatic vegetation in the littoral zone (Kaufmann et al. 2014b, Radomski and Goeman 2001, Whittier et al. 2002), thereby reducing habitat for waterfowl and fish (Jennings et al. 1999, Moyle and Hotchkiss 1945) and decreasing fish growth rates and abundance (Sass et al. 2006, Schindler et al. 2000). Furthermore, Lindsay et al. (2002) reported altered foraging guilds of breeding birds along lakeshores with a high degree of housing development in the upper Midwest. Similarly, Kaufmann et al. (2014b) reported lower percentage of native neo-tropical bird on lakes in the Northeast corresponding with increases in road density and near-shore human disturbance. Housing density has also been negatively associated with *Lithobates clamitans melanota* (Rafinesque) (Northern Green Frog) abundance (Woodford and Meyer 2003) and carnivore species richness and diversity in northern Wisconsin (Haskell et al. 2013). In central Ontario, housing development on lakeshores has resulted in altered behavior and diet of *Neovison vison* (Schreber) (American Mink; Racey and Euler 1983a) and reduced diversity and abundance of small mammals (Racey and Euler 1982). Piscivorous birds such as *Gavia immer* (Brunnich) (Common Loon.) and *Pandion haliaetus* L. (Osprey) have been shown to avoid lakes with a high level of human disturbance (Newbrey et al. 2005).

Many studies have cited habitat structure as the most influential ecological factor determining patterns of habitat occupancy by wildlife (Anderson and Shugart 1974, Blanchette et al. 2007, Buskirk and Powell 1994, DeGraaf and Yamaski 2003, Mooty et al. 1987, Morrison et al. 1998). If vegetation is tall and layered (stratified), it can support a more diverse and rich suite of biota (Hunter and Schmiegelow 2011, MacArthur and MacArthur 1961). Saplings and shrubs are a critical component of the understory habitat in lake riparian areas (Clark et al. 1984, Elias and Meyer 2003, Kaufmann et al. 2014a, Racey and Euler 1983b, Robertson and Flood 1980) because they provide vertical structure and food sources for a variety of birds and mammals (Ehrlich et al. 1988, Goodrum et al. 1971, Martin et al. 1961). For example, non-game bird species use saplings and shrubs for nesting and foraging (DeGraaf and Yamaski 2003). This shrubby, sapling layer also provides habitat and food for *Bonasa umbellus* (L.) (Ruffed Grouse; Blanchette et al. 2007), *Meleagris gallopavo* L. (Wild Turkey; Dickson 1992), and *Odocoileus virginianus* (Zimmermann) (White-tailed Deer; Mooty et al. 1987). In addition, sapling and shrubs provide shoreline stability, with saplings eventually recruiting into the overstory. Standing dead trees and logs are additional habitat components relatively scarce along developed lakeshores (Christensen et al. 1996, Schindler et al. 2000). Standing dead and downed woody material are important to the function and structure of healthy terrestrial and aquatic ecosystems (Harmon et al. 1986, McComb 2016) and also provide habitat for a wide variety of wildlife species (Gilbert et al. 1997, Jaeger 1990, Maser et al. 1979, Rusch et al. 2000, Tallmon and Mills 1994).

Interest in lakeshore restoration has grown due to a greater awareness of the vulnerability and importance of lakeshore ecosystems. Lakeshores denuded of native vegetation are increasingly viewed as unnatural and aesthetically unappealing by lake residents and the public at large (Engel and Pederson 1998, Macbeth 1992). Restoration on human altered lakeshores can remedy habitat simplication of biotic habitat (Lorenz et al. 2017). In this paper, we present data on lakeshore habitat structure, vegetation density, and composition before and after understory restoration of shrubs and saplings intended to improve wildlife habitat. We compare these restored plots to unrestored control plots on developed lakeshores and undeveloped reference lakeshores over a 3-year period. We predicted that changes in habitat structure and vegetation composition would change at restored lakeshores more dramatically than control lakeshores. We also predicted that measurements made at restored lakeshores after restoration would trend towards those made at reference lakeshores.

Methods

Study area

This project was conducted in the Northern Highlands Ecological Landscape on 2 lakeshores in a forested landscape on deep sands with pitted glacial outwash in Vilas County, WI (Thwaites 1929; Fig. 1). Vilas County encompasses a 2636-km^2 area along the state's northern border with the Upper Peninsula of Michigan. Glacial lakes cover ~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,

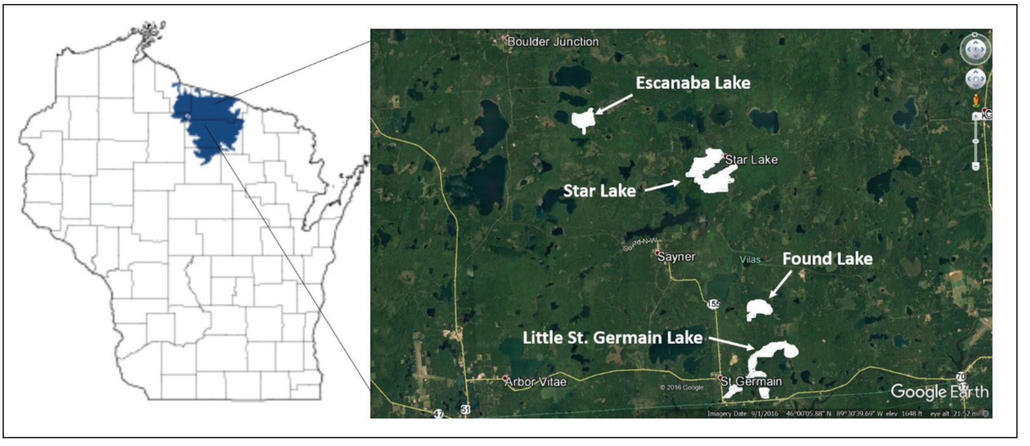

Figure 1. The Northern Highlands Ecological Landscape (http://dnr.wi.gov/topic/landscapes/index.asp?mode=detail&Landscape=12) showing the location of restoration sites (Found and Little St. Germain Lakes) and reference sites (Star and Escanaba Lakes) within Vilas County, WI.

northern wet forest, boreal forest, and northern dry to xeric forest (Curtis 1959). The daily mean ambient temperature is 3.4 °C annually, varying from -2º C in January to 10º C in July, and the mean annual precipitation is 80.25 cm (WDNR 2014a). The soils on these lakeshores are sandy with low nutrient values (see Table 1 for soil characteristics on each site; NRCS 1986, WDNR 2014a).

We conducted wildlife habitat restoration projects on 2 high-development lakeshores: Found Lake (45°57'20.71"N, 89°26'58.08"W; housing density = 21 homes per linear km of lakeshore) and Little Saint Germain Lake (45°55'15.49"N, 89°27'23.64"W; housing density = 25 homes per linear km of lakeshore). We established control sites (properties that did not receive restoration) on the same 2 lakes where habitat restoration occurred. Additionally, we established unrestored reference sites on 2 nearby lakeshores (Star and Escanaba Lakes; Fig. 1) that contain low levels of housing development (<10 houses per linear km of lakeshore; Marburg et al. 2006), which allowed us to gauge the success of our restoration efforts (Hobbs and Harris 2001, SER 2004). We selected reference lakeshore sites that were matched with Found and Little Saint Germain Lakes sites to have similar morphological characteristics, such as surface area, substrate, and lake type (Morrison 2002, SER 2004).

Installation of restoration projects

From 2007 to 2012, we planted a variety of tree saplings and shrubs within the state-mandated lakeshore vegetated buffer zone that is 10.8 m wide from the original high water mark (WDNR 2014b). A total of 334 tree saplings from 17 species and 1415 shrubs from 28 species were planted within the buffer zone along ~500 m of linear lakeshore on 13 private properties on Found Lake from 2007 to 2008 (Table 2). From 2011 to 2012, a total of 221 trees saplings from 18 species and 587 shrubs from 28 species were planted along ~300 m of linear lakeshore on 6 privately owned Little Saint Germain Lake properties (Table 2). Restoration plans were designed by Vilas County Land and Water Conservation Department personnel.

Table 1. Mean soil and site characteristics of 4 lakeshores in Vilas County, WI. Soil samples were collected at each site prior to restoration activities and analyzed for percent nitrogen (N), phosphorus (P), and potassium (K) at the Soil and Plant Analysis Lab at the University of Wisconsin-Madison. Aspect is direction of plot in degrees facing lake.

Lake	Surface area (ha)	Lake perimeter (m)	Houses per km of shoreline	Treatment	pH	% organic matter	% N	P (ppm)	K (ppm)	Soil texture	Aspect (°)	Slope (°)
Escanaba	132	8135	0.56	Reference	4.8	6.5	0.16	12	46	Sand	174	18
Found	119	6362	21.06	Control	5.0	4.6	0.18	11	58	Loamy sand	163	20
				Restored	5.3	3.0	0.08	10	45	Sand	196	14
Star	488	19,124	3.92	Reference	4.4	10.1	0.27	10	63	Sand	292	18
LSG	397	17,856	25.50	Control	4.9	4.0	0.15	23	106	Sand	249	16
				Restored	4.5	5.1	0.23	16	80	Sand	244	25

Table 2. Species of trees and shrubs restored on 2 lakeshores in Vilas County, WI.

			% of species planted per lake	
	Species	Common name	Found	Little St. Germain
Trees	*Abies balsamea* (L.) Mill.	Balsam Fir	0.036	0.113
	Acer rubrum L.	Red Maple	0.040	0.090
	Betula papyrifera Marshall	Paper Birch	0.114	0.140
	Ostrya virginiana (Mill.) K. Koch	Ironwood	0.009	0.023
	Picea glauca (Moench) Voss	White Spruce	0.087	0.113
	Picea mariana (Mill.) Britton, Sterns, & Poggenb.	Black Spruce	0.000	0.009
	Pinus resinosa Aiton	Red Pine	0.060	0.072
	Pinus strobus L.	E. White Pine	0.150	0.136
	Populus balsamifera L.	Balsam Poplar	0.012	0.000
	Populus tremuloides Michx.	Quaking Aspen	0.027	0.018
	Prunus Americana Marshall	American Plum	0.054	0.009
	Prunus pensylvanica L. f.	Pin Cherry	0.069	0.045
	Prunus serotine Ehrh.	Black Cherry	0.009	0.009
	Prunus virginiana L.	Chokecherry	0.060	0.023
	Quercus bicolor Willd.	Swamp White Oak	0.012	0.000
	Quercus macrocarpa Michx.	Bur Oak	0.012	0.000
	Quercus rubra L.	Northern Red Oak	0.108	0.090
	Sorbus Americana Marshall	American Mt. Ash	0.069	0.054
	Thuja occidentalis L.	Northern White Cedar	0.066	0.027
	Tsuga canadensis (L.) Carrière	Eastern Hemlock	0.003	0.027
Shrubs	*Amelanchier canadensis* (L.) Medik.	Canada Serviceberry	0.018	0.034
	Amelanchier laevis Wiegand	Allegheny Serviceberry	0.007	0.015
	Arctostaphylos uva-ursi (L.) Spreng.	Bearberry	0.083	0.077
	Aronia melanocarpa (Michx.) Elliott	Glossy Black Chokeberry	0.089	0.068
	Comptonia peregrine (L.) J.M. Coult.	Sweetfern	0.071	0.094
	Cornus alternifolia L.f.	Pagoda Dogwood	0.005	0.015
	Cornus racemosa Lam.	Grey Dogwood	0.034	0.000
	Cornus rugosa Lam.	Roundleaf Dogwood	0.000	0.034
	Cornus sericea L.	Redosier Dogwood	0.035	0.034
	Corylus americana Walter	American Hazelnut	0.033	0.068
	Corylus cornuta Marshall	Beaked Hazelnut	0.030	0.187
	Diervilla lonicera Mill.	Low-bush Honeysuckle	0.139	0.085
	Ilex verticillata (L.) A. Gray	Winterberry	0.002	0.012
	Myrica gale L.	Sweet Gale	0.029	0.000
	Physocarpus opulifolius (L.) Maxim.	Common Ninebark	0.044	0.043
	Rhus hirta L.	Staghorn Sumac	0.029	0.000
	Rosa blanda Aiton	Wild Rose	0.000	0.003
	Rosa carolina L.	Carolina Rose	0.011	0.000
	Rosa palustris Marshall	Swamp Rose	0.016	0.009
	Sambucus nigra L.	American Elder	0.027	0.000
	Spiraea alba Du Roi	Meadowsweet	0.067	0.017
	Symphoricarpos albus (L.) S.F. Blake	Common Snowberry	0.140	0.051
	Vaccinium angustifolium Aiton	Low-bush Blueberry	0.059	0.126
	Viburnum lentago L.	Nannyberry	0.022	0.003
	Viburnum opulus L. var. *americanum* Aiton	High-bush Cranberry	0.008	0.000
	Viburnum rafinesqueanum Schult.	Downy Arrowwood	0.001	0.024

Tree saplings and shrubs were delivered from a local private nursery and varied in height from 152.0 to 183.0 cm and 30.5 to 61.0 cm, respectively. Tree saplings and shrubs were planted at densities of 1 sapling and 3 shrubs per 9.29 m^2 (100 ft^2), as prescribed by the "Wisconsin Biology Technical Note 1: Shoreland Restoration" (NRCS 2002). We selected native tree and shrub species based on their presence at low-developed lakeshores (D.E. Haskell, unpubl. data) in the Northern Highlands Ecological Landscape and expert advice from local botanists and private nursery personnel that specialize in lakeshore restoration. All planting activities were performed by field staff from Michigan Technological University and the Vilas County Land and Water Conservation Department.

We established aboveground sprinkler irrigation systems on the restoration sites, providing ~2.5 cm of water per week for the first year from late May to mid-September. Lake water was supplied to each sprinkler by electric pumps. To promote downward root growth, irrigation was slowly reduced in the years following restoration activities. To deter herbivory by White-tailed Deer, we installed a 2.4-m–tall fencing around the entire perimeter of each restoration site.

Habitat sampling

We divided each shoreline reach designated for restoration (developed with restoration), control (developed without restoration), and reference (undeveloped) into 50-m segments, respectively, using GIS software. These segments were then subdivided into five 10 m x 10 m plots. We randomly selected 1 plot from each segment for monitoring (restoration n = 16, control n = 12, reference n = 15). We divided each plot into four 5 m × 5 m subplots and randomly chose 2 subplots within each 10 m × 10 m plot in which to tally by species all live saplings and shrubs ≥30 cm in height but ≤5 cm diameter breast height (dbh).

Because the vertical distribution of vegetation density plays a central role in habitat selection and how habitat is used by a wide range of avian and mammalian species (Morrison 2002), we measured the vertical distribution of vegetation using a 0.5 m × 3.0 m density board (checkerboard) with 10 cm × 10 cm grid squares to measure percent visual obstruction density at 4 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). We place the visual obstruction density board 1.0 m, 5.0 m, and 9.0 m inland from the shoreline at the edge of each 10 m × 10 m plot. Each measurement was taken from 10 m away with the observer and density board positioned perpendicular to the shoreline. In order to evaluate canopy cover, we used a digital hemispherical photograph taken at 0.5 and 1.5 m above the ground and centered in each plot. We used image analysis software (WinScanopy 2005) to estimate the fraction of total pixels in each photo classified as open sky (gap fraction = number of pixels classified as sky ÷ total number of pixels). We tallied coarse woody debris within each 10 m × 10 m plot, grouped into 3 classes: logs, snags (standing dead trees), and stumps. We defined logs as downed woody segments ≥10 cm in diameter and ≥150 cm in length, snags as standing dead trees ≥10 cm at dbh and ≥1.37 m tall, and stumps as standing dead trees ≥10 cm diameter but <1.37 m tall (Marburg et al.

2006). We collected the above data (sapling and shrub density, visual obstruction density, gap fraction, and course woody debris) at all sites prior to the initiation of restoration efforts at Found and Little Saint Germain Lakes, and then remeasured all sites 3 years post treatment. Found and Escanaba Lakes were sampled in 2007 and 2010. Little Saint Germain and Star Lakes were sampled in 2011 and 2014.

Data analysis

We used 2-way ANOVA models to test whether changes in total sapling density (saplings per ha), total shrub density (shrubs per ha), gap fraction at 0.5 and 1.5 m height, visual obstruction density at each of 4 height categories, and coarse woody debris between pre-restoration surveys and surveys taken 3 years after restoration varied between control, treated, and/or reference plots. Model effects for all response variables included "Treatment" (control, restored, and reference plots), "Survey Number" (survey 1 and survey 2 refer to pre-restoration and 3 years post-restoration, respectively), and "Treatment × Survey Number" interaction. A significant interaction indicates that changes in the response variable between survey years varied among control, restored, and/or reference plots. We also included "Lake" in the model as a fixed-effect nested within "Treatment" in order to account for variation between lakes. We nested the effect because some treatments only occur at some of the 4 lakes (e.g., the reference plots are only at Escanaba and Star Lakes). When an interaction was significant, we used Tukey's honest significant difference (HSD) to test for statistical differences between survey years for each treatment. We conducted analyses with 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 as implemented in PC ORD auto-pilot mode using the "slow and thorough" setting (McCune and Grace 2002), which employs Sorenson's distance and a random starting configuration. Habitat features were relativized by column maximum to a common scale for analysis. We chose this approach because wildlife often respond to a suite of habitat features rather than a single metric (Morrison et al. 1998) and it 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

Visual obstruction data

Restoration plots (treated) had a significantly greater increase in visual obstruction density at 0.0 m to 0.3 m height between pre- and post-restoration surveys relative to control and reference plots (interaction effect: $F_{2,79} = 3.24$, $P = 0.044$; Fig. 2A). Tukey's HSD tests indicate that only treated plots showed significant increases in visual obstruction between surveys (Fig. 2A). Similarly, 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 experiencing a greater increase in visual obstruction between pre- and post-restoration surveys relative to control and reference plots (Fig. 2B). At >1.0 to 2.0 m height, visual obstruction varied between treatment groups on the first survey with the reference sites having more visual obstruction (Treatment main effect: $F_{2, 79} = 13.95$, $P < 0.001$; Fig. 2C), and visual obstruction increased for all plots between surveys (Survey Number effect: $F_{1, 79} = 24.84$, $P < 0.001$; Fig. 2C). Similarly, at >2.0 to 3.0 m height, visual obstruction varied between treatment groups on the first survey with the reference sites having more visual obstruction (Treatment main effect: $F_{2, 79} = 7.91$, $P = 0.001$; Fig. 2D), and visual obstruction generally increased for all plots between surveys (Survey Number effect: $F_{1, 79} = 25.58$, $P < 0.001$; Fig. 2D).

Total sapling and shrub density

Treated plots experienced increased shrub density between survey years, while reference and control plots showed little change and slightly decreased, respectively (interaction effect: $F_{2, 79} = 24.62$, $P < 0.001$; Fig. 3A). Treated plots also appeared to

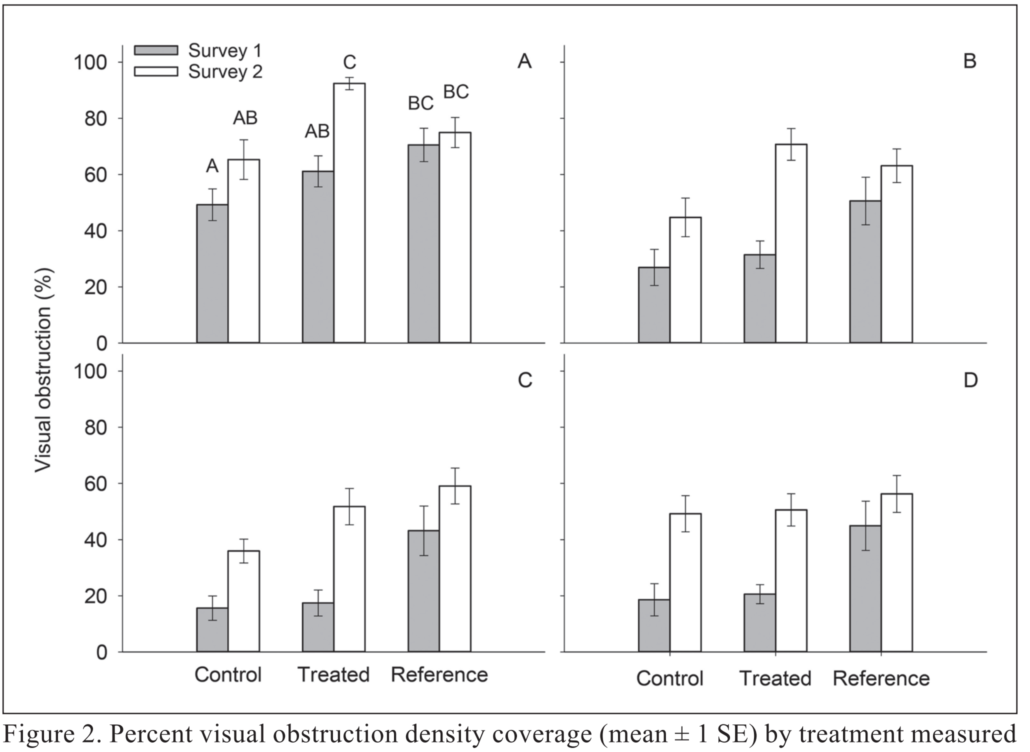

Figure 2. Percent visual obstruction density coverage (mean ± 1 SE) by treatment measured within the (A) 0.0–0.3 m, (B) 0.3–1.0 m, (C) 1.0–2.0 m, and (D) 2.0-3.0 m height classes before (Survey 1) and 3 years after (Survey 2) restoration occurred at the treated sites. Treatments having any letter in common (A, B, and/or C) are not statistically different from one another ($P > 0.05$) based on Tukey's honest significant difference (HSD) tests (Tukey's test used only when interaction effect was significant).

experience a greater increase in sapling density relative to control and reference plots between survey years, but the effects were not statistically significant (interaction effect: $F_{2,\ 79} = 0.17$, $P = 0.843$; Fig. 3B). However, shrub density varied significantly

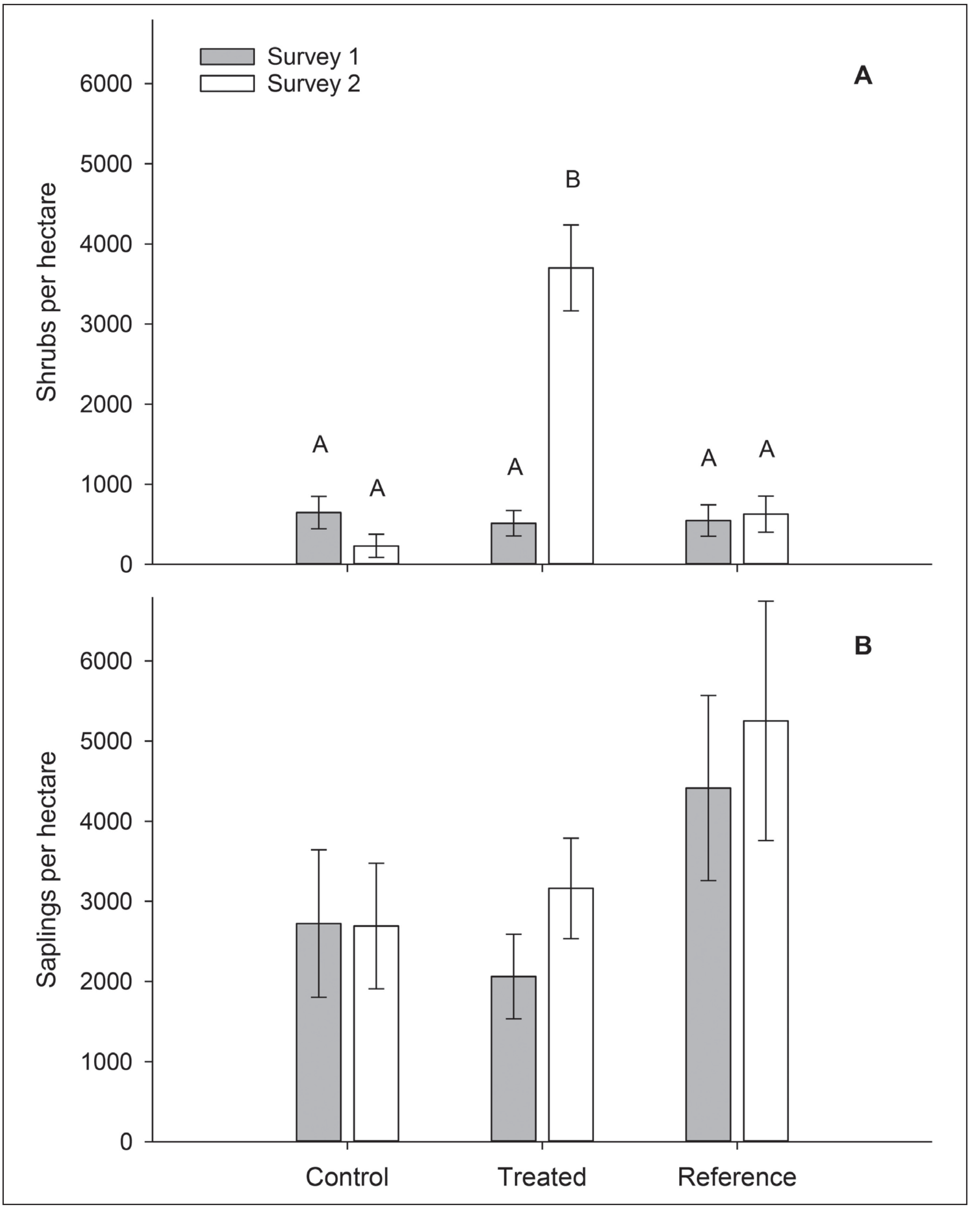

Figure 3. Density (mean ± 1 SE) per ha of (A) shrubs and (B) saplings by treatment type before (Survey 1) and 3 years after (Survey 2) restoration occurred at the treated sites. Treatments having any letter in common (A, B, and/or C) are not statistically different from one another ($P > 0.05$) based on Tukey's honest significant difference (HSD) tests (Tukey's test used only when interaction effect was significant).

between lakes ($F_{3, 79} = 3.16$, $P = 0.029$). Shrub density at our restored sites following restoration was far greater than that of reference sites (Fig. 3A).

Coarse woody debris

The number of logs (Treatment effect: $F_{2, 79} = 5.87$, $P = 0.004$) and snags (Treatment effect: $F_{2, 79} = 9.92$, $P < 0.001$) present in each plot differed significantly between plot treatments, with reference plots generally having more logs and snags than control and treated plots on average (Fig. 4A, B). There was no significant influence of Treatment or Survey Number on the number of stumps counted per plot (Fig. 4C). When all 3 coarse woody debris classes were taken as a whole, only Treatment had a significant influence (Treatment effect: $F_{2, 79} = 3.81$, $P = 0.026$), with reference plots having more total coarse woody debris than control and treated plots overall. Changes in coarse woody debris between surveys did not vary among treatment types for any of the 3 coarse woody debris classes (interaction effects not significant).

Canopy gap fraction

Canopy gap fraction at 0.5 m height varied significantly among treatment types (Treatment effect: $F_{2, 79} = 25.03$, $P < 0.001$), with the reference plots having considerably lower gap fraction (higher canopy coverage; Fig. 5A). 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 type

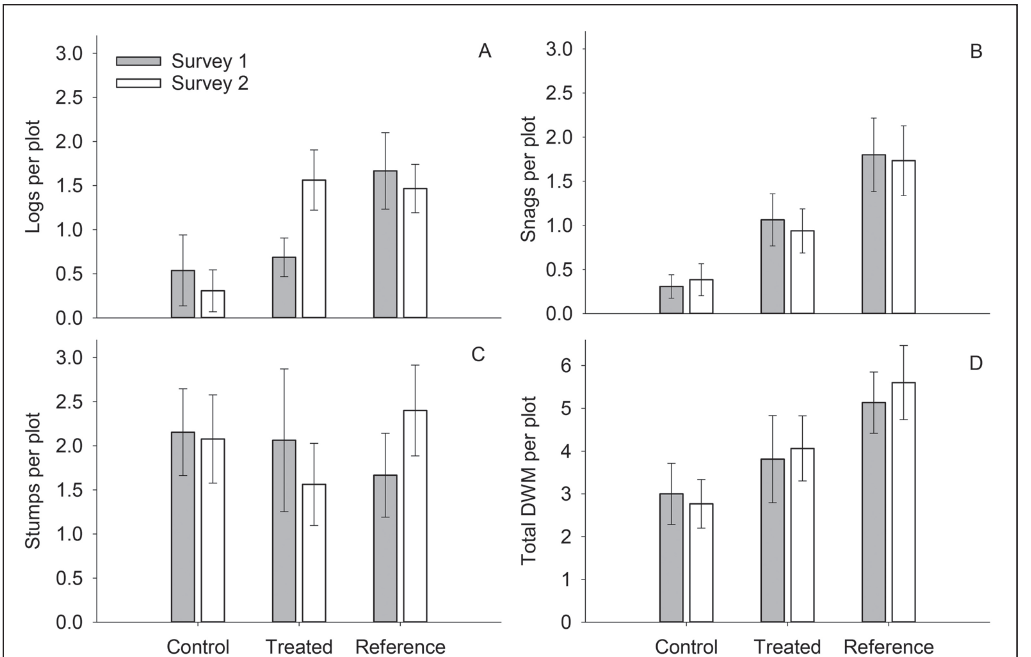

Figure 4. Abundance (mean ± 1 SE) of (A) logs, (B) snags, and (C) stumps per 10 m × 10 m plot before (Survey 1) and 3 years after (Survey 2) restorations occurred at the treated sites. (D) The mean total abundance of logs, snags, and stumps per 10 m × 10 m plot.

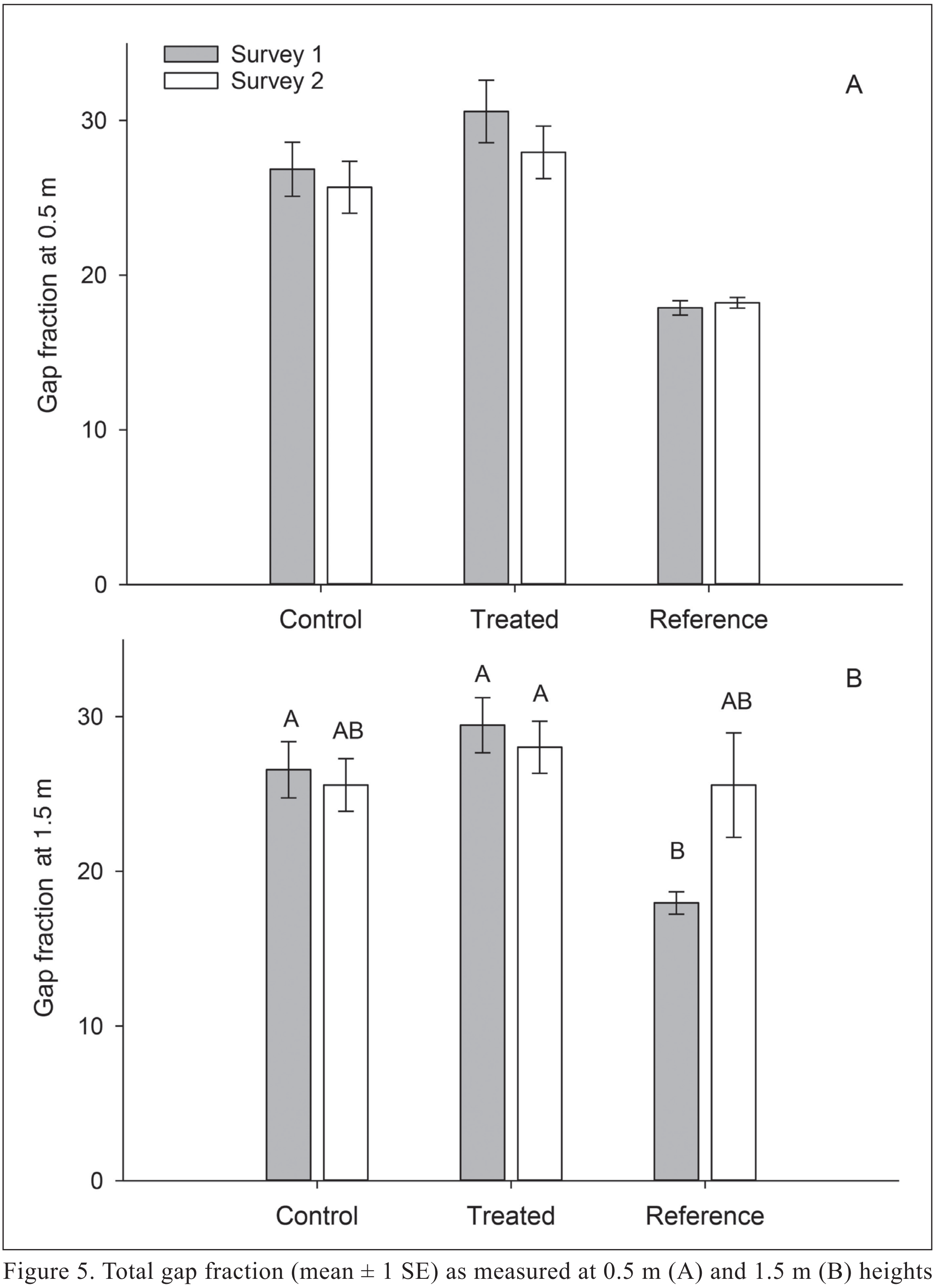

Figure 5. Total gap fraction (mean ± 1 SE) as measured at 0.5 m (A) and 1.5 m (B) heights before (Survey 1) and 3 years after (Survey 2) restoration occurred at the treated sites. Treatments having any letter in common (A, B, and/or C) are not statistically different from one another ($P > 0.05$) based on Tukey's honest significant difference (HSD) tests (Tukey's test used only when interaction effect was significant).

(i.e., significant interaction; $F_{2, 79} = 3.42$, $P = 0.038$). Here, reference plots experienced an increase in gap fraction between survey years, while control and treated plots experienced a slight decrease in gap fraction (Fig. 5B). Results from Tukey's HSD tests indicated that for the first survey the reference plots had a significantly lower gap fraction than both pre-restoration control and treated plots (Fig. 5B). Gap fraction also varied between lakes, but the effect was only marginally significant ($F_{2, 79}$=2.56, $P = 0.061$).

Nonmetric multi-dimensional scaling ordination

Habitat attribute data were best described by a 3-dimensional ordination solution. The solution has a final stress of 10.97 and instability of <0.00001 after 94 iterations. The ordination explained 93.1% of the variation in habitat attribute composition, with axis 1 explaining the most variation (54.2%) followed by axis 2 (22.6%) and axis 3 (16.2%), respectively. Visual inspection of the ordination plots suggested that reference lakes exhibited little change in habitat feature composition between our sample periods (Figs. 6, 7C). Restored lakeshores on the other hand, displayed longer vectors and movement towards reference conditions (Figs. 6, 7A–B). This increase in similarity was associated with increasing similarity in visual obstruction density (MPVOpM, MPVO1M, MPVO2M, MPVO3M) and shrub (ShDen/ha) and sapling (SaDen/ha) density among treatments and reference lakes (Table 3). The Found Lake control plots 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 (Fig. 6).

Table 3. Correlations between nonmetric multi-dimensional scaling ordination axes and wildlife habitat attributes at reference and lakeshore restoration sites. See Figure 6 for variable definitions.

	Axis 1 ($R^2 = 0.542$)		Axis 2 ($R^2 = 0.226$)		Axis 3 ($R^2 = 0.162$)	
Habitat attribute	r	tau	r	tau	r	tau
%ConBA/ha	-0.585	-0.235	0.047	0.082	0.417	0.364
1p5mGpFc	0.479	0.478	0.164	0.020	0.232	0.160
BAsqM/ha	-0.765	-0.552	-0.06	-0.051	0.326	0.257
ConBAsqM	-0.787	-0.554	-0.051	-0.038	0.426	0.350
MeanDBHc	0.384	0.222	0.154	0.019	0.565	0.357
MPVO1M	-0.139	-0.079	0.825	0.657	-0.235	-0.161
MPVO2M	-0.267	-0.207	0.784	0.617	-0.225	-0.126
MPVO3M	-0.361	-0.249	0.687	0.534	-0.194	-0.091
MPVOp3M	-0.007	-0.001	0.726	0.539	-0.290	-0.224
p5mGpFrc	0.750	0.565	-0.046	-0.063	0.181	0.129
ShDen/ha	0.250	0.163	0.419	0.271	0.083	-0.075
SpDen/ha	-0.174	-0.112	0.483	0.365	-0.376	-0.266
SWIEven	-0.027	0.210	-0.226	-0.093	-0.744	-0.470
SWIndex	-0.268	-0.100	-0.177	-0.066	-0.769	-0.573
TrDen/ha	-0.872	-0.806	-0.034	-0.009	-0.033	-0.002
TrSpRich	-0.549	-0.414	-0.109	-0.090	-0.534	-0.385

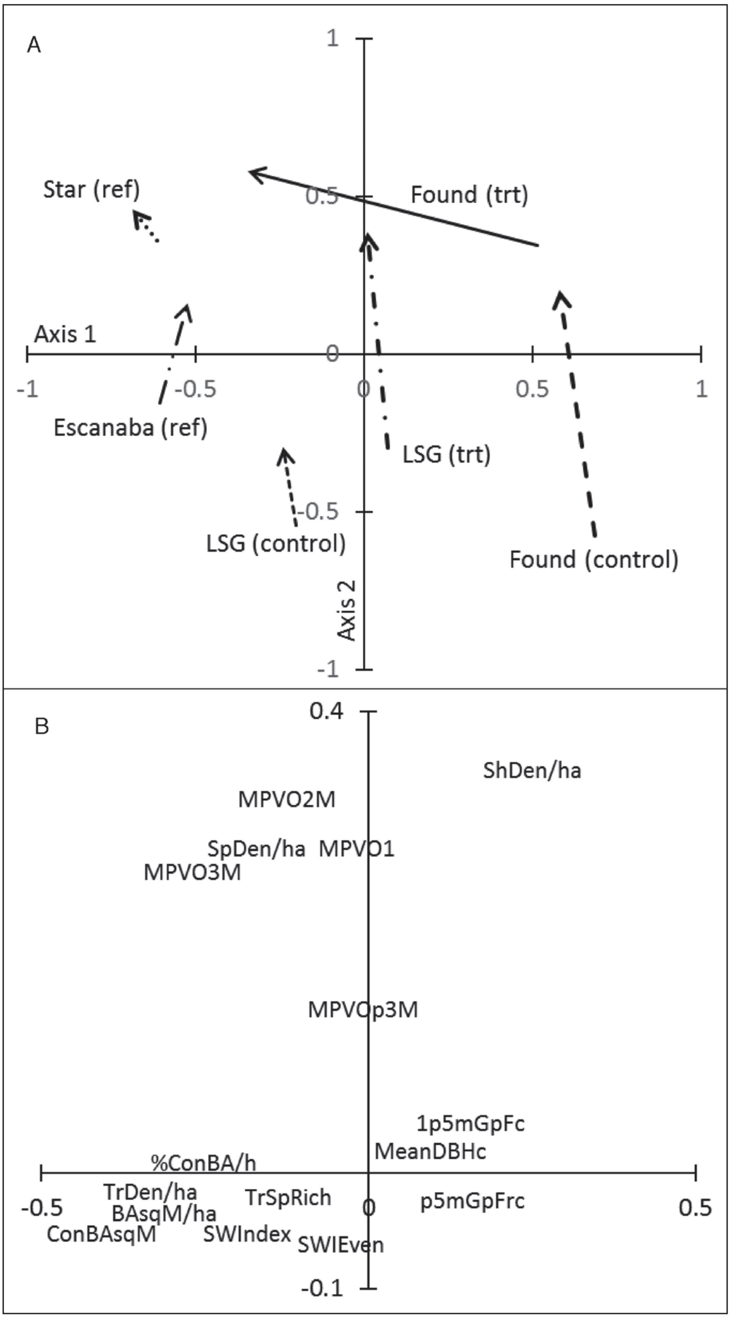

Figure 6. Nonmetric multi-dimensional scaling ordination of wildlife habitat attributes on reference and restored lakeshores. Data was collected prior to restoration and 3 years post restoration. (A) Mean location of sample plots through time are indicated by vectors (LSG = Little St. Germain). (B) Location of habitat attributes in the ordination space. Minor adjustments to locations were made to improve readability of abbreviated attribute titles. Correlations with ordination axes are provided in Table 3. Attributes are as follows: %ConBA/ha = percent conifer basal area per hectare; p5mGpFrc = canopy gap fraction at 0.5 m height; 1p5GpFrc = canopy gap fraction at 1.5 m height; BAsqM/ha = basal area square meter per hectare; ConBAsqM = conifer basal area in square meter per hectare; MeanDBHc = average diameter at breast height in centimeters for all tree species; MPVOpM = mean percent visual obstruction density at 0–0.3 m height; MPVO1M = mean percent visual obstruction density at >0.3–1 m height; MPVO2M = mean percent visual obstruction density at >1–2 m height; MPVO3M = mean percent visual obstruction density at >2–3 m height; SaDen/ha = sapling density per hectare; ShDen/ha = shrub density per hectare; SWIndex = Shannon–Weiner diversity (H') index of tree species; SWIEven = Shannon–Weiner evenness; TrDenHa = Tree density per hectare; TrSpRich = total number of tree species richness.

Figure 7. Photographs showing conditions (A) pre-restoration and (B) post-restoration on Found Lake, WI, and at (C) a reference site on Escanaba Lake, WI. (Photographs © D.E. Haskell).

Discussion

Our initial measurements made at reference lakes revealed greater visual obstruction density at all height classes, greater densities of saplings and shrubs, greater amounts of downed woody material and more canopy coverage (lower gap fraction) relative to initial measurements made at restoration sites. These findings are consistent with previous measurements made at developed and undeveloped lakes within the Northern Highlands Ecological Landscape (Elias and Meyer 2003), where quantitative comparisons of vegetative structural characteristics (e.g., canopy cover, sub-canopy and understory vegetation layers, and amount of coarse woody debris) showed significantly greater complexity and cover at undeveloped versus developed lakeshores. Our finding was also similar to northeastern US lakes reported by Whittier et al. (2002) and for lakes in all regions of the contiguous US by Kaufmann et al. (2014a). Whittier et al. (2002) showed that Northeastern lakes with no housing development had median canopy cover of 67% and median cover of combined canopy, mid-layer, and ground cover of 170%, contrasted with 35% canopy cover and 82% combined for the 3 vegetation layers for all developed shoreline stations.

Our visual obstruction density measurements conducted 3 years following implementation of restoration projects on developed lakes showed significant increases in visual obstruction density at the 0.0–0.3 m height class and a marginally significant increase at the >0.3–1.0 m height class. Visual obstruction density increased significantly between surveys overall at height classes above 1.0 m, but this did not vary significantly among treatments. Because vegetation planted at restored sites was generally <1.0 m in height, it seems likely that several more growing seasons are required to detect a strong effect from our restoration efforts at these height classes. A separate restoration project on a degraded lakeshore within the Northern Highlands Ecological Landscape, which implemented the same planting density, showed 2–3 times move coverage of vegetation at heights above 1.0 m for restored sites relative to control sites 5 years post-restoration (D.E. Haskell, unpubl. data), which together with our findings suggest it might generally take longer than 3 years for restored sites to diverge from unrestored control sites at these taller height classes.

Shrub and sapling density also increased at restoration sites as expected, but the increase was only statistically significant for shrubs. This result was likely influenced by the planting density prescribed in the "Wisconsin Biology Technical Note 1: Shoreland Restoration" (NRCS 2002), where shrub-planting densities are thrice those of saplings. In addition, the low shrub density at reference sites could be the result of shading of the lower layers by the increased canopy cover. A companion lakeshore restoration project located within the area, compared sapling and shrub densities on active and natural recovery plots with fence and irrigation over a 5-year period (D.E. Haskell, unpubl. data). The results showed no significant difference of sapling densities; however, there was significant differences in shrub densities between treatments with natural recovery having little change in densities. The results suggest that regeneration of saplings can occur over time if there is a seed source and that a shrub component should be restored. For this study, we did not monitor the sites for regeneration during the project time period. Practitioners may wish to adjust planting densities to better reflect those found on reference sites or to hasten development of the sapling layer.

In an urban lakeshore restoration study, Galbraith-Kent and Handel (2007) reported a 48% decrease of woody stem density over a 3-year period in Flushing Meadows Corona Park, NY. Their site was not fenced, and the reasons for the decline were herbivory and human vandalism (plants illegally removed and arson). Vanderbosch and Galatowitch (2010) surveyed 22 lakeshore restoration projects in Minnesota and reported that restoration sites with fencing had a higher species richness than sites without fencing. In northern Wisconsin, Haskell et al. (2013) reported the relative abundance of White-tailed Deer was 3 times higher on lakeshores where human development was present, supporting the need for herbivory abatement on restoration sites. Fencing is a common abatement technique in habitat restoration projects to protect young plants from herbivory (Case and Kaufman 1997, Opperman and Merenlender 2000). For example, Case and Kaufman (1997) reported crown volume increase of 550% for *Salix* spp. (willows) within exclosures compared to an increase of 195% outside of exclosures. Similarly, Opperman and Merenlender (2000) observed saplings had a higher rate of survival in exclosures compared to saplings with no protection from browse, and 97% of saplings outside exclosures suffered from stem and leaf damage characteristic of White-tailed Deer browse. Thus, the importance of protecting the restoration sites with a fence or other abatements systems is critical in early establishment of plants. Further monitoring on our restoration sites following fence removal is warranted and may provide practitioners useful insight into the resilience of plants to herbivory.

Our reference sites had significantly more coarse woody debris than restored and control sites overall, which is consistent with results presented by Elias and Meyer (2003), Christensen et al. (1996), and Whittier et al. (2002). Kaufmann et al. (2014b) reported a positive association of native fish and bird species richness along lakeshores with the presence of course woody material in the near shore littoral zone of northeastern lakes. While there was a modest non-significant increase in dead wood at restoration sites, augmentation in excess of in situ mortality and breakage of scattered residual canopy trees may be highly desirable in shoreline restoration settings. For example, Haskell et al. (2012) found that adding as little as 25% coverage of woody material, in the form of logs up to 15 cm in diameter and 3 m in length, in 3 m x 3 m plots on lakeshores improved plant growth and can moderate soil moisture and temperatures on degraded lakeshores. Adding course woody debris to restoration sites could have a positive impact on wildlife species abundance and distribution across landscapes (Maser et al. 1979, McComb 2016). For example, Mac Nally and Horrocks (2002) reported an increase in forest-floor mammal densities after 1 year when the quantity of new fallen timber was increased and re-distributed in floodplain forests of Australia. Furthermore, it is well documented that dead wood provides habitat for a wide variety of wildlife species, especially invertebrates, and provides nursery sites for plants (Harmon et al. 1986, Maser et al. 1979, McComb 2016, McMinn and Crossley 1996). Variability in the amount, size, and distribution of course woody debris is considerable across regions, landscapes, and forest types (McComb 2016). The amount of course woody debris available to lakeshores is related to the vegetation structure in the area (Christensen et al. 1996). While restoring trees and shrubs on human-developed lakeshores will provide woody material through natural succession, trees grow slowly and it may take decades to centuries for course woody debris to be replenished naturally along human-developed lakeshores (Christensen et al. 1996). Thus, augmentation of course woody debris should be considered on severely denuded lakeshores. However, we advise consulting with local zoning ordinances before restoring course woody debris to riparian-littoral areas, as it may be necessary to acquire a permit.

Nonmetric multi-dimensional scaling ordination of habitat attributes suggests that over time restoration sites are becoming more similar to reference sites based on the composition of their habitat attributes. Reference lakes, as expected, showed relatively little change in habitat attribute composition between our sample periods. Treatment lakes, on the other hand, displayed longer vectors and movement towards reference conditions. This trend 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 trend 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.

Habitat is not static, but continually changes because of natural and/or anthropogenic disturbances that operate at many scales (Engstrom et al. 1999). Thus, restoring wildlife habitat requires not only an understanding of the requirements of species but also the processes that maintain the habitat over time (George and Zack 2001). Therefore, we stress that a long-term monitoring of lakeshore restoration sites should be part of the restoration plan and that strategies to further this goal should be tested. We recommend future large-scale lakeshore rehabilitation projects be led by trusted property owners such as lake-association officers, private-sector business owners, or private-consultant firms who can facilitate effective peer-to-peer learning and project buy-in. Landowners should be involved at all stages of planning and be encouraged to participate during the restoration activities and monitoring. Naturally vegetated lakeshores have a strong aesthetic appeal (Korth 1994) and protect water quality (Engel and Pederson 1998), which can lead to increased property values (Michael et al. 1996). Restoring sections of lakeshores that are severely altered by a human activity can improve whole-lake ecological integrity (Lorenz et al. 2017). These considerations should motivate policy makers to establish programs that will encourage lakeshore owners to participate in restoring wildlife habitat and educate property owners of the ecological importance of preserving a natural vegetated buffer zone adjacent to lakeshores.

Acknowledgments

This project could not have been possible without the participatory collaboration of numerous private landowners on Found and Little St. Germain Lakes. Private landowners' included in this research project showed a strong desire to preserve the integrity of the local lake ecosystems. Funding for this project was supported by the Wisconsin DNR with Federal Aid in Wildlife Restoration Project W-160-P funds, county cost-share dollars administered by the Vilas County Land and Water Conservation Department, Wisconsin Department of Agriculture and Consumer Protection, Moon Beach, United Church Camps, Inc., USDA McIntire-Stennis Program, and Michigan Technological University Ecosystem Science Center. A special thanks to M. Woodford for providing GIS skills to this project. M. Marquita, P. Goggin, and B. Hanson provided advice on plant species and restoration plans. We offer huge thanks for all the field technicians over the years: D. Drekich, C. Mehls, D. McGary, T. Armstrong, M. Pytleski, M. Jarvi, A. Komar, J. Links, E. Delcamp, M. Boehmeer, E. Bowen, Quita, K. Merical, S. Simestad, A. Nachel, A. Bowen, C. Waas, K. Genther N. Comar, K. Kelly, C. Delzer, E. Collins, J. Wheeler, A. Sharp, A. Van Wagner, G. Brammer. We are grateful to B. Fevold, who provided QA/QC and database management services.

Literature Cited

Anderson, S.H., and H.H. Shugart Jr. 1974. Habitat selection of breeding birds in and east Tennessee deciduous forest. Ecology 77:215–227.

Bibby, C.J., N.D. Burgess, and D.A. Hill. 1992. Bird Census Techniques. Academic Press, London, UK 302 pp.

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.

Buskirk, S.W., and R.A. Powell. 1994. Habitat ecology of Fishers and American Martens. Pp. 283–296, *In* S.W. Buskirk, A.S Harestad, M.G. Raphael, and R.A. Powel (Eds). Martens, Sables, and Fishers: Biology and Conservation. Cornell University Press, Ithaca, NY. 484 pp

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.

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.

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.

Dickson, J.G. 1992. The Wild Turkey: Biology and Management. Stackpole Books, Mechanicsburg, PA. 463 pp.

Ehrlich P., D.S. Dobkin, and D. Wheye. 1998. The Birder's Handbook: A Field Guide to the Natural History of North American Birds. Simon and Schuster, Fireside, New York, NY. 783 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.

Engel, 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. 45 pp. Madison, WI.

Engstrom, R.T., S. Gilbert, M.L. Hunter, Jr., D. Merriwether, G. J. Nowacki, and P. Spencer. 1999. Practical applications of disturbance ecology to natural resources management. Pp. 313–330, *In* N.C. Johnson, A.J. Malk, W.T. Sexton, and R. Szaro (Eds.). Ecological Stewardship: A Common Reference for Ecosystem Management. Volume 2. Elsevier Science Ltd., Oxford, UK. 1500 pp.

Galbraith-Kent, S.L., and S.N. Handel. 2007. Lessons from an urban lakeshore restoration project in New York City. Ecological Restoration 25:123–128.

George, T.L., and S. Zack. 2001. Spatial and temporal considerations in restoring habitat for wildlife. Restoration Ecology 9:272–279.

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. Pp. 135–145 *In* G. Proulx, H.N. Bryant, and P.M. Woodard (Eds). Martes: Taxonomy, Ecology, Techniques, and Management. Provincial Museum of Alberta, Edmonton, AB, Canada. 474 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.

Goodrum, P.D., V.H. Reid, and C.E. Boyd. 1971. Acorn yields, characteristics, and management criteria of oaks for wildlife. Journal of Wildlife Management 35:520–532.

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.

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.

Haskell, D.E. 2009. Quantifying the ecological benefits of lakeshore restoration in northern Wisconsin. M.Sc. Thesis. Michigan Technological University, Houghton, MI. 101 pp.

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, C.R. Webster, and D.J. Flaspolher. 2013. The relationship between carnivore distribution and landscape features in the Northern Highlands ecological landscape of Wisconsin. American Midland Naturalist 169:1–16.

Hobbs, R.J., and J.A. Harris. 2001. Restoration ecology: Repairing the earth's ecosystem in the new millennium. Restoration Ecology 4:93–110.

Hunter, M.L. and F.K.A. Schmiegelow. 2011. Wildlife, Forests, and Forestry: Principles of Managing Forests for Biological Diversity. Prentice Hall, Upper Saddle River, NJ. 259 pp.

Jaeger, R.G. 1980. Microhabitats of a terrestrial forest salamander. Copeia 1980(2):265–268.

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.

Kaufmann, P.R., D.V. Peck, S.G. Paulsen, C.W. Seeliger, R.M. Hughes, T.R. Whittier, and N.C. Kamman. 2014a. Lakeshore and littoral physical habitat structure in a national lakes assessment. Lake and Reservoir Management 30:192–215.

Kaufmann, P.R., R.M. Hughes, T.R. Whittier, S.A. Bryce, and S.G. Paulsen. 2014b. Relevance of lake physical habitat assessment indices to fish and riparian birds. Lake and Reservoir Management 30:177–191.

Korth, R.M. 1994. Why do we enjoy Wisconsin's Lakes?: Survey results. Lake Tides 19:3.

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.

Lorenz, S., M.T. Pusch, O. Miler, and U. Blaschke. 2017. How much ecological integrity does a lake need: Managing the shores of a peri-urban lake. Landscape and Urban Planning 164:91–98.

MacArthur, R.H., and J.W. MacArthur. 1961. On bird species diversity. Ecology 42:594-598.

Macbeth, E.J. 1992. Protecting aesthetics and the visual resource of lakes. Pp. 17–23, *In* Enhancing the States' Lake Management Programs. North American Lake Management Society, Washington, DC. 112 pp.

Mac Nally, R., and G. Horrocks. 2002. Habitat change and restoration: Responses of a forest-floor mammal species to manipulations of fallen timber in floodplain forests. Animal Biodiversity and Conservation 25:41–52.

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 and 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. 499 pp.

Maser, C., R.G. Anderson, K. Cromack Jr., J.T. Williams, and R.E. Martin. 1979. Dead and down woody material. Pp.78–95. *In* J.W. Thomas (Ed). Wildlife Habitats in Managed Forest: The Blue Mountains of Oregon and Washington, Agricultural Handbook No. 553. USDA Forest Service, Washington, DC. 512 pp.

McComb, B.C. 2016. Wildlife Habitat Management: Concepts and Applications in Forestry. CRC Press, Boca Raton, FL. 385 pp.

McCune, B., and J.B. Grace. 2002. Analysis of Ecological Communities. MjM Software Design, Gleneden Beach, OR. 300 pp.

McMinn, J.W., and D.A. Crossley (Eds.). 1996. Biodiversity and coarse woody debris in southern forests. USDA Forest Service General Technical Report SE-94. Southern Research Station, Asheville, NC. 156 pp.

Michael, H.J., K.J.Boyle, and R. Bouchard. 1996. Water quality affects property prices: A case study of selected Maine lakes. Maine Agricultural and Forest Experimental Station Miscellaneous Report 398. University of Maine, Orono, ME. 15 pp.

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

Morrison, M.L. 2002. Wildlife Restoration: Techniques for Habitat Analysis and Animal Monitoring. Island Press, Washington, DC. 209 pp.

Morrison, M.L., B.G. Marcot, and R.W. Mannan. 1998. Wildlife–Habitat Relationships: Concepts and Applications. University of Wisconsin Press, Madison, WI. 435 pp.

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

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.

Natural Resource Conservation Service (NRCS). 1986. Soil survey of Vilas County. United States Department of Agriculture, Washington, DC. 157 pp.

NRCS (Natural Resource Conservation Service). 2002. Wisconsin biology technical note 1: Shoreland habitat. NRCS. Available online at http://dnr.wi.gov/topic/shorelandzoning/documents/nrcsbiotechnote.pdf. Accessed 26 March 2007.

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. Changes in mink habitat and food selection as influenced by cottage development in central Ontario. Journal of Applied Ecology 20:387-402.

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

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 US 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.

Riera, J., P.R. Voss, S.R. Carpenter, T.K. Kratz, T.M. Lillesand, J.A. Schnaiberg, M.G. Turner, and M.W. Wegener. 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 N.J. Flood. 1980. Effects of recreational use of shorelines on breeding bird populations. Canadian Field Naturalist 94:131–138.

Rusch D.H., S. DeStefano, M.C. Reynolds, and D. Lauten. 2000. Ruffed Grouse (*Bonasa umbellus*). No. 515, *In* A. Poole and F. Gills (Eds). The Birds of North American. The Birds of North America, Inc., Philadelphia, PA.

SAS Institute Inc. 2015. JMP verison Pro 12.1.0, 100 SAS Campus Drive, Gary, NC 27513.

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.

Society for Ecological Restoration International Science and Policy Working Group (SER). 2004. The SER International Primer on Ecological Restoration. Tucson, AZ. Available online at http://c.ymcdn.com/sites/www.ser.org/resource/resmgr/custompages/publications/ser_publications/ser_primer.pdf. Accessed 1 April 2007.

Tallmon, D.A., and L.S. Mills. 1994. Use of logs within home ranges of California red-backed voles on remnant forest. Journal of Mammalogy 74:91–101.

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.

Thwaites, F.T., 1929. Glacial geology of part of Vilas County, Wisconsin. Transactions of the Wisconsin Academy of Sciences, Arts, and Letters 24:109–125.

Vanderbosch, D.A., and S.M. Galatowitsch. 2010. An assessment of urban lakeshore restorations in Minnesota. Ecological Restoration 28:71–80.

Whittier, T.R., S.G. Paulsen, D.P. Larsen, S.A. Peterson, A.T. Herlihy, and P.R. Kaufman. 2002. Indicators of ecological stress and their extent in the population of northeastern lakes: Regional-scale assessment. Bioscience 52:235–247.

Wilcove, D.S., D. Rothstein, J. Bubow, A. Phillips, and 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., Québec City, QC, Canada.

Wisconsin Department of Natural Resources (WDNR). 1996. Northern Wisconsin's Lakes and Shorelands: A report examining a resource under pressure. Madison, WI. 18 pp.

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

WDNR. 2014a. The ecological landscapes of Wisconsin: an assessment of ecological resources and a guide to planning sustainable management. Chapter 14, Northern Highland Ecological Landscape. PUB-SS-1131. Madison, WI. 84 pp

WDNR. 2014b. Wisconsin's shoreland protection program. Available online at http://docs.legis.wisconsin.gov/code/admin_code/nr/100/115.pdf. Accessed 11 July 2014.

Woodford, J.E., and M.W. Meyer. 2003. Impact of lakeshore development on Green Frog abundance. Biological Conservation 110:277–284.