

**HABITAT RELATIONSHIPS OF AVIAN AND BAT SPECIES ASSEMBLAGES
WITHIN MANAGED PINE FORESTS OF THE GREAT LAKES**

By

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ABSTRACT

Intensive forest management, resulting in plantations, has been criticized for potential reductions in biological diversity when compared to natural forests. Commercial forestry is an important contributor to the economy of the Great Lakes states, resulting in increased management intensity and frequency within forest landscapes. Private landowners are experiencing increasing demands to manage for ecological objectives, placing more value on biological diversity. However, landowners currently have little information to aid development of practical management plans that integrate ecological and timber management objectives. In the Great Lakes Region, red pine (*Pinus resinosa*) is being restored to its pre-settlement range and jack pine (*Pinus banksiana*) is being replaced with more economically valuable species. As red pine increases in the great lakes, jack pine stands will become increasingly rare. Therefore, understanding the relative contributions of each forest type is critical for maintaining wildlife diversity in managed forests. I present results of a study evaluating habitat relationships of avian and bat communities within managed pine forests of Minnesota and Wisconsin, including the relative contributions of red pine and jack pine forest types. In 2008 and 2009, I conducted avian point count and acoustic bat detection surveys in 12 red pine and 12 jack pine stands. I measured stand- and macro-level habitat attributes, and present multiple stepwise logistic and linear regression modeling results that relate presence and abundance (birds) or activity (bats) with habitat attributes. Over the course of this study, 60 avian species were detected in jack pine, and 48 in red pine. In red pine and jack pine, 5 species of bats were detected. My results were as expected avian presence and abundance and bat presence and activity varied with forest structure.

Mann-Whitney U-tests identified significant differences in habitat structure, avian species abundance and bat activity between red and jack pine, with jack pine having greater below canopy structure and avian abundance and diversity and bat activity. The identification of habitat variables associated with greater avian and bat diversity within managed forests could provide needed information to land owners for enhancing the wildlife habitat potential of their lands. The importance of a commercial aged jack pine component in the landscape could also improve forest management and conserve wildlife diversity.

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INTRODUCTION

Forest managers increasingly are challenged to balance harvest of forest products with protecting environmental quality, including maintenance of wildlife habitats and conservation of biological diversity (Tuchman et al. 1996, Moore and Allen 1999, Loehle et al. 2002). Concerns about even-aged management, particularly clearcutting, have prompted considerable research on responses of wildlife to timber harvest. In particular, intensive forest practices associated with establishment and management of conifer plantations have been criticized for potential negative effects on biological diversity (Gysel 1966, Benzie 1977*a, b*; Bender et al. 1997, Moore and Allen 1999). Although previous research has demonstrated compatibility of intensive forest practices with some wildlife species (Moore and Allen 1999, Russell et al. 2002, 2004; NCASI 2008), the increasing intensity of forest management in many regions is expected to increase potential conflicts between timber production and protection of biological diversity.

Europeans settled northern portions of the Great Lakes states beginning in the late 1830s. European settlement resulted in extensive forest clearing followed by burning of residual slash that extended into the 1940s (Cole et al. 1998). Forested land in the region has declined by 40% in the last 150 years and only 1% of pre-settlement forest remains unmodified by human disturbance (Frelich 2002). Coniferous forests of white pine (*Pinus strobus*), red pine (*P. resinosa*), and jack pine (*P. banksiana*) have experienced the greatest declines. The area of these forest types has purportedly been reduced by 78% through timber harvest, wild fires, and land conversion (Cole et al. 1998). For example, prior to European settlement red pine comprised 2.8 million ha of pine forests in Minnesota, Wisconsin, and Michigan (Gilmore and Palik 2006), but has been reduced to

0.8 million ha from pre-settlement conditions. Additionally, only 3% of jack pine and 0.6% of mixed red pine-white pine forests remain unmodified by logging or other human disturbance. As a result, forest distribution and composition has shifted significantly in the Lakes States region (Frelich 2002). Early-succession stands of aspen (*Populus* spp.) and mixed aspen-conifer stands now occupy a much larger proportion of forested area in the region than in the pre-settlement period.

To reverse these trends, forest managers have increased the percentage of coniferous forest types in the Lake States, primarily by establishing intensively managed, short-rotation stands of red pine (Gilmore and Palik 2006). To meet projected softwood demands in the region, reestablishment of red pine has been recommended (Benzie 1977a, Gilmore and Palik 2006). However, an increasing number of red pine stands are being established by converting other coniferous and deciduous stands (Bender et al. 1997). Because forest managers consider jack pine less economically valuable and therefore less desirable than other northern tree species, existing stands of jack pine continue to be converted to red pine and other species (Benzie 1977a). For example, between 1968 and 1996, quantities of commercially forested jack pine in Wisconsin decreased by 47% (Spence and Thorne 1972, Schmidt 1997). In Minnesota, jack pine cover types decreased more than 30% during the last 32 years (Jakes 1980, Milles and Brand 2007).

Prior to European settlement of the Great Lakes region, cycles of natural disturbance followed by succession maintained dynamic forest landscapes (Stearns 1990, Frelich and Lorimer 1991, Mladenoff and Pastor 1993). Wildfires were the primary natural disturbance in pine forests of the area and facilitated a diverse array of stand

conditions, from multi-aged, structurally and compositionally complex pine forests to relatively homogenous even-aged stands (Heinselman 1973, Whitney 1986, Frelich and Reich 1995). Natural rotation ages of pine forests in the Lake States ranged 80-260 years, depending on species, site conditions, and disturbance regime (Frissell 1973, Heinselman 1973, Whitney 1986). For example, the historic age class structure of red pine stands ranged from largely even-aged stands, originating from stand-initiating fires, to stands comprised of multiple age classes (Frelich 2002, Gilmore and Palik 2006). Because red pine is a long-lived species (i.e., stand ages \leq 200 yrs old; individual trees \leq 400 yrs old), naturally-regenerated mature stands typically contained a combination of large live trees, snags, and downed woody debris in various stages of decay. Composition of natural red pine stands varied from nearly pure stands to mixtures with other conifer and deciduous species within the over-story, mid-story, and understory layers, depending on site conditions and disturbance regimes (Frelich 2002, Gilmore and Palik 2006). Therefore, naturally occurring red pine stands historically ranged from relatively homogeneous, even-aged stands to multi-aged, structurally complex mixed-species stands.

Unlike with red pine, jack pine is a relatively short-lived tree (80-100 years old), growing to 15-25 m in height and 20-30 cm in diameter on typical sites (Kenkel et al. 1997). The species is found on excessively drained, nutrient-poor, and somewhat acidic soils (e.g., coarse to fine sands and gravels). Jack pine stands historically regenerated following catastrophic crown fires, and the species is among the most shade-intolerant of northern trees, confirming its status as a pioneer, early-succession species (Kenkel et al. 1997). Natural stands often regenerate at high stem densities, and undergo substantial

self-thinning by ages 20 to 30. In jack pine stands with high stem densities, trees may develop weak, small-diameter stems that are highly susceptible to damage by wind, ice, or snow. In contrast, low initial stem densities often produce trees that are susceptible to tapered or crooked growth forms and larger branches (Benzie 1977*a*). Jack pine also is susceptible to diseases and pests that cause damage or mortality at various stages of stand development (Rudolph 1983). Accordingly, the mortality rate of jack pine is among the highest of all northern tree species, and most trees in a stand die before the next replacement crown fire (Kenkel et al. 1997). As a result, compositional and structural features of naturally-regenerated jack pine stands differ greatly from those of red pine, and forest managers typically consider jack pine to be less economically desirable than red pine or other forest cover types (Benzie 1977*a*).

Currently, most existing pine stands in the Great Lakes are intensively managed on short rotations. Intensive management has caused a dramatic shift in stand dynamics, with timber harvest replacing natural fires as the primary source of disturbance (Radeloff et al. 1999, Frelich 2002). In the Lakes States, rotation ages for managed pine stands range 40-70 years for jack pine (Benzie 1977*a*) and 60-120 years for red pine (Benzie 1977*b*). These stands typically are even-aged with closed canopies, and lack the horizontal or vertical structure of natural stands (Bender et al. 1997, Gilmore and Palik 2006). In particular, shortened rotation ages associated with intensive management effectively retards succession of understory and mid-story vegetation within stands because time is insufficient for shade-tolerant species to develop (Edgerton and Thomas 1978, Bunnell and Kemsater 1990, Moore and Allen 1999). Even-aged, pure stands of

red pine that regenerated after natural disturbances likely were more structurally complex than most current managed stands (Gilmore and Palik 2006).

In addition to truncated rotation ages, intensive site preparation, planting, and stand improvement treatments associated with plantation management may retard development of stand structure by eliminating competing vegetation, defective live trees and snags, coarse woody debris (CWD), and understory species (Hunter 1990, Duvall and Grigal 1999, Moore and Allen 1999). In the Lake States region, volumes of CWD are typically lower and snags are typically fewer in managed stands of red pine than in unmanaged stands, with effects of management most pronounced in younger stands (Duvall and Grigal 1999). At stand initiation, biomass of CWD was 80% lower and snags were 99% fewer in managed stands than on unmanaged stands (Duvall and Grigal 1999). Dense planting of seedlings (e.g., 990-2970 seedlings/ha) is the most common method for reestablishing managed stands of red pine (Benzie 1977*b*). Before or after planting, herbicides are typically applied to reduce or eliminate competing vegetation, thereby facilitating rapid growth and survival of seedlings and ultimately shorter rotation periods. Both natural seeding and planting are used to establish managed stands of jack pine. Natural seeding is used on sites where mineral soil has been exposed, competition from other vegetation is low, and sufficient soil moisture remains for adequate germination and early seedling survival (Benzie 1977*a*). Such stands are clearcut and cone-bearing slash is left on the ground, where radiant heat stimulates release of seeds from serotinous cones. When direct seeding is used, jack pine stands are usually stocked at a level of 49,000 viable seeds/ha (Benzie 1977*a*). Thinning and other intermediate treatments are periodically conducted in developing stands of both red pine and jack pine

to accelerate growth of remaining trees and to improve stand health. During thinning, diseased, dying, and dead trees are typically removed (Benzie 1977a, b).

Because of their lack of compositional and structural diversity, intensively managed pine stands have been described as “biological deserts” (Castles 1974) and are widely considered to be poor wildlife habitats (Gysel 1966, Benzie 1977b, Bender et al. 1997, Tibbels and Kurta 2003). Despite this widespread assertion, relatively few studies have characterized wildlife use of managed pine stands in the Great Lakes region. Common species of birds and mammals in northern Michigan were rarely encountered in red pine plantations (Gysel 1966). Young, managed stands of red pine provide only low quality habitat for game birds and many species of mammals, whereas mature pine stands are used by some species, including red squirrels (*Tamiasciurus hudsonicus*), American marten (*Martes americana*), and some passerine birds (Benzie and McCumber 1983). Research in Michigan comparing bat communities within thinned and unthinned stands of red pine indicated that bats were rarely detected in red pine plantations and that thinning did not significantly increase either bat species richness or activity (Tibbels and Kurta 2003). In contrast, in a study of breeding bird communities in the Upper Peninsula of Michigan, 48 species occurred or bred within intensively managed, 6 to 50-year-old stands of red pine (NCASI 1996). Greater structural diversity of stands generally was associated with higher avian diversity and abundances, whereas lowest avian diversity and abundance were usually associated with recently established stands and older, closed-canopy stands (NCASI 1996).

Most research on wildlife associations with jack pine forests has focused on the endangered Kirtland’s warbler (*Dendroica kirtlandii*), a habitat specialist that requires

large blocks of early-succession jack pine (e.g., 5-25 years old) for breeding (Nelson and Buech 1996, Kirk and Hobson 2001, Donner et al. 2008). Associations with jack pine habitats also have been documented for snowshoe hares (*Lepus americanus*), ungulates including white-tailed deer (*Odocoileus virginianus*), and selected species of birds (Kohn and Mooty 1971, Benzie 1977a, Erskine 1977, James and Peck 1995, Kirk and Hobson 2001). However, contributions of jack pine cover types, and older (i.e., rotation age) stands in particular to wildlife diversity in the Lakes States region remain poorly understood. Given continued conversions of jack pine stands to red pine and other species, lack of information concerning the potential importance of this formerly abundant habitat should be of concern to both wildlife and forest managers.

The presence and abundance of many vertebrate taxa related to the vertical and horizontal structure of forests illustrate the potential value of these species as indicators of biological diversity within forest ecosystems (Ferris and Humphrey 1999). Among vertebrates, communities of birds and bats are among the most commonly recommended indicators of forest biodiversity (Pearson 1994, Canterbury et al. 2000, Ford et al. 2005). For example, associations between presence and abundance of these taxa and forest habitat characteristics have been used to better understand wildlife responses to forest management and to identify silviculture treatments that could be employed to improve quality of wildlife habitats in managed forests (Bender et al. 1997, Chambers et al. 1999, Tittler 2001, Mazurek and Zielinski 2004, Atwell et al. 2008). Birds are a diverse and well-studied group, with established monitoring methods, and their apparent relationships with forest composition and structure make them valuable as indicators of wider biodiversity in forests. In addition to the large species diversity within many avian

communities, several other attributes of birds contribute to their potential value as indicators of forest habitat conditions (Robbins 1979). Many species of birds require specific nesting and foraging habitats, thereby representing a variety of habitat associations (Robbins 1979). Birds also may require distinctive breeding and wintering habitats, and typically range across wider areas than other vertebrate taxa. Therefore, bird species may be sensitive indicators of changes in habitat features at multiple spatial scales ranging from individual sites (i.e., stands) to landscapes (Pithon et al. 2005).

Numerous studies have documented the importance of habitat composition and structure for birds (e.g., MacArthur and MacArthur 1961, James 1971, Willson 1974, Whitcomb et al. 1981, James and Wamer 1982, Erdelen 1984). In particular, diversity in the structure of live and dead forest vegetation (e.g., foliage height diversity; MacArthur and MacArthur 1961) is thought to exert a significant influence on avian community composition because different resources are used by birds for foraging, nesting, and protection from the elements and predators (Cody 1985). Avian habitat relationships, including the effects of forest management, have been investigated within several forest types in the Great Lakes region, including northern hardwoods (Steffen 1985, Probst et al. 1992, Bub et al. 2004, Brashear 2006), boreal forests (Helle and Nieme 1996, Kirk and Hobson 2001), and forested wetlands (Zolkowski 2008). However, the diversity and habitat relationships of avian communities within intensively managed pine stands of the Great Lakes, including effects of intensive forest management on these species, remain poorly understood (NCASI 1996).

Because of their small size, mobility, and longevity, bats have been suggested as appropriate indicators of environmental change, including quality of wildlife habitat

(Fenton 1997). Bat communities are taxonomically diverse and vary significantly in feeding and roosting behavior (Altringham 1996). Bats also represent diverse and unique habitat associations and have been increasingly recognized as important components of forest ecosystems (Miller et al. 2003). However, research on habitat relationships of bats has lagged behind that of other mammals and birds (Fenton 1997, Menzel et al. 1998). A review of habitat ecology of bats in western coniferous forests indicated that although recent studies have started to elucidate relationships between individual bat species and forest composition and structure, sizeable knowledge gaps remain (Hayes 2003).

Previous studies have shown that tree boles, branches, and foliage affect bat foraging behavior because these structural elements obstruct prey detection and pursuit (Findley 1976, Crome and Richards 1988, Findley 1993). Specific habitats used by bats are at least partially determined by wing morphology and the structure of each species' echolocation call (Sleep and Brigham 2003). Bat species with high frequency calls and lower wing-loading can maneuver better through more structurally complex ("cluttered") habitats, whereas bats with high-wing loading and low-frequency calls require more open habitats (Aldridge and Rautenbach 1987, Nowak 1994). As for avian communities, the diversity and habitat relationships of bats within intensively managed pine stands of the Great Lakes remains poorly understood.

Because of landscape-level changes in forest composition and structure that have resulted from decades of intensive forest management, the suitability of managed forests as wildlife habitat and for maintaining biological diversity in natural forests continues to be questioned (Ruggiero et al. 1991, Noss 1993, Hejl et al. 1995, Thompson et al. 1995, Drapeau et al. 2000). In the Great Lakes region, the percentage of intensively managed

pine forests is expected to increase significantly (Gilmore and Palik 2006). In addition, forest types such as jack pine that provide little economic value to landowners will continue to be converted to more economically valuable plantations of red pine. However, the implications of these changes in forest composition and structure for wildlife species and communities within the region remain poorly understood. In particular, research is needed that identifies wildlife responses to variation in key compositional and structural habitat attributes (e.g., overstory density, shrub species diversity, vertical layering) within plantation forests. Knowledge of how variation in composition and structure of intensively managed stands influence the presence and abundance of wildlife species should allow forest managers to identify practices that may enhance the structural complexity of natural stands while maintaining production of timber (Moore and Allen 1999, LeGrand et al. 2007, Atwell et al. 2008). Accordingly, the purpose of my study is to investigate the habitat relationships of avian and bat communities within intensively managed, rotation-age stands of red pine and jack pine in Wisconsin and Minnesota.

Objectives

My first objective was to determine if variation in the presence and abundance of avian species and communities within intensively managed stands of red pine and jack pine could be explained by compositional and structural habitat variables. My second objective was to determine if variation in the presence and activity of bat species and communities within intensively managed stands of red pine and jack pine also could be explained by compositional and structural habitat variables. In order to accomplish these objectives, I sampled breeding bird and bat communities and macro- and site-level

habitat characteristics from 24 rotation-age pine stands distributed in Wisconsin and Minnesota. I then modeled presence, bird relative abundance, and bat foraging activity as a function of these habitat variables using principal components analysis (PCA) and stepwise logistic and linear regression models. My third objective was to determine if Species and community presence, avian abundance, bat activity, and habitat characteristics differed between jack pine and red pine.

METHODS

Study Area

My study areas included industrial forest lands located near Brainerd, Minnesota in Cass, Morrison, and Wadena Counties (Potlatch Corporation) and near Tomahawk, Wisconsin in Oneida County (Plum Creek Timber Company). Both study areas occur within the Laurentian Mixed Forest (LMF) Province (Bailey and Cushwa 1981). The LMF Province spans northeastern Minnesota, northern Wisconsin, and the upper and northern lower peninsulas of Michigan. The climate in both areas is characterized by long winters and short, cool summers. Mean temperatures in Brainerd range from -20.4 °C in winter to 27.0 °C in summer. The mean annual precipitation is 69.4 cm and the mean annual snowfall is 115.8 cm (High Plains Regional Climate Center 2009). The mean temperatures in Tomahawk range from -17.9 °C in winter to 25.9 °C in summer. The mean annual precipitation is 81.0 cm and the mean annual snowfall is 103.9 cm (Wisconsin State Climatology Office 2007).

The Minnesota study area occurs within the Northern Minnesota Pine Moraines and Outwash Plains ecosystem (Albert 1995). Soils are sandy loams derived from sandy

loam to loam till or loamy sands derived from outwash sands and gravels classified primarily as Psamments and Hemists (Anderson and Grigal 1984). Prior to European settlement, these soils supported forests of mixed red pine-white pine and trembling aspen (*Populus tremuloides*)-paper birch (*Betula papyrifera*) on rolling to irregularly-sloped end moraines. These forests were most likely maintained by wildfires, recurring every 10-40 years (Frissell 1973) and originating on the outwash plain. In areas protected from fire by irregular topography, broad wetlands, and large lakes, a diverse mix of northern hardwood and northern pine cover types dominated. Windthrow was likely the predominant natural disturbance in hardwood-pine forests. Presently, these forests have a higher proportion of paper birch and trembling aspen than during the pre-settlement period (Albert 1995).

The Wisconsin study area occurs within the Northern Continental Wisconsin Lac Veaux Desert Outwash Plain ecosystem (Albert 1995). Soils are Orthods with Spodic Udipsamments loamy sands on upper slopes and Entic Haplorthod loamy sands in depressions (Hole and Germain 1994). Pre-settlement vegetation was dominated by white pine and red pine forests over pitted outwash plain. A broad area of barrens dominated by jack pine and northern pin oak (*Quercus ellipsoidalis*) lies between the Tomahawk and Wisconsin Rivers where the outwash plain is rolling and least dissected by kettle lakes. Hardwood-conifer swamps are common along the margin of the Lac Veaux Desert outwash Plain and extensive peatlands occur in kettle depressions and stream headwaters. Fire was the primary pre-settlement natural disturbance in this area with most fires occurring in jack pine barrens. Forests in northern Wisconsin contain a

greater proportion of paper birch and aspen than prior to European settlement (Albert 1995).

Site Selection

In spring 2008, I selected 24 study stands: 12 jack pine stands and 12 red pine stands. Jack pine stands were located in north-central Minnesota and red pine stands in northern Wisconsin as a result of the availability of stands that fit study criteria. To the degree possible, stands within each study area were chosen to minimize differences in size, vegetation composition and structure, and disturbance histories. All stands were at rotation age (i.e., ≥ 60 -years-old for red pine and ≥ 40 -years-old for jack pine) and at least 10 ha in size.

Wildlife Community Sampling

Birds. I employed point count methodology (Ralph et al. 1995, Howe et al. 1997a) to assess presence and relative abundance of breeding passerine birds (Robbins 1991) within each of the 24 stands. Point count surveys were conducted three times from late May to mid-July in 2008 and 2009 to minimize detection of non-breeding birds and to account for seasonal variation in bird activity. Point-count stations were established within each stand with the number of stations being proportional to stand size (i.e., more points at larger sites). Each station was located ≥ 50 -m from stand edges (i.e., the mapped boundaries of each stand) to minimize detection of birds associated with adjacent stands and other habitat types (Howe et al. 1997a).

Point-count stations were located ≥ 100 -m apart to ensure independence of detections among points (Ralph et al. 1995, Howe et al. 1997a). Point count radii were 50-m with count duration of 10 min occurring between 04:00 to 09:30 Central Daylight

Time. Because multiple individuals surveyed point counts, observers were rotated among sites to minimize observer bias. Surveys were not conducted during periods of rain, heavy fog, or high winds (i.e., Beaufort >3) because these conditions are known to decrease detectability of birds (Ralph et al. 1995).

Species and sex (if known) of all birds heard or seen during counts were recorded. Counts were conducted within three intervals (0-3 min, 3-5 min, 5-10 min) and initial detections of all individuals were recorded within these intervals. Distance from the observer to each bird detected was measured using rangefinders. Birds that flew over the point during surveys (i.e., “flyovers”) or that were detected before and after the 10-min sampling period were recorded separately. Wind and sky conditions and temperature (°C) were recorded at each point-count station prior to initiating a survey.

Bats. I employed Anabat SD1 detectors (Anabat SD1, Titley Electronics) and passive monitoring techniques (O’Farrell 1998) to assess presence and foraging activity of bat species within jack pine and red pine stands. Bat community surveys were conducted three times from early June to August of 2008 and 2009 to account for seasonal increase in flying bats as young bats begin to forage (Kurta 1980). A survey station was established at the center of each stand ≥ 100 m from stand edges to avoid detections of bat activity in adjacent cover types. Anabat detectors were mounted on a pole 1.5 m above ground level. Only nights without significant precipitation were used in the analyses because rain could result in decreased bat activity (Ford et al. 2005). Each sampling occasion consisted of Anabat detectors continuously recording all bat activity in each study stand between 20:00 and 05:00 Central Daylight Time for two consecutive nights.

All echolocation data were interpreted with the use of Anabook 4.8i (Corben Scientific, Rohnert Park, CA). A single call sequence is defined by the 15-second recording saved and identified by the Anabat system as a unique file. Prior to analyses, all call sequences were filtered to eliminate files with <3 individual ultrasonic pulses (Johnson et al. 2002, Francl et al. 2004).

Quantitative interpretation of echolocation data included using frequency parameters for identifying individuals to species or frequency groups. I also qualitatively interpreted sonographs by comparison to reference species sonographs from known call libraries (Redell, unpublished data). Call sequences were identified to species or in most cases species groups (Myotis [*Myotis spp.*], LaboPisu [*Lasiurus borealis* and *Pipistrellus subflavus*], HFG > 35, LFG > 35, EpfuLano [*Eptesicus fuscus* and *Lasionycteris noctivagans*], and Hoary [*Lasiurus cinereus*]) that exhibit highly similar call structures. In some cases, poor quality calls (i.e., highly fragmented, high interference) prevented identification to a species group. Therefore, some calls were identified as 1 of 2 frequency groups (i.e., high frequency group (HFG) \geq 35kHz; low frequency group (LFG) < 35kHz). Anabat detectors were used to collect bat community data, therefore in place of abundance we used activity index (AI) (Miller, 2001) for analyses of habitat relationships. The AI is the sum of all 1-minute time blocks in which a species was detected (n) as being present (P). In order to standardize the AI, I divided by the unit effort or the number of hours (t) data was collected during each survey (i.e., 18 hrs)(Miller, 2001).

Activity Index formula:

$$AI = \frac{\sum_1^n P}{t}$$

Macro-habitat Data

Macro-level habitat was defined as a 300-ha circular area delineated around each stand for birds (McGarigal and McComb 1995, MacFaden and Capen 2002). For bats the macro-level habitat was defined as the area within a 25 km radius circular area centered at each stand. This macro-level habitat scale is consistent with the longest known average commuting distance from roost to foraging site of a bat species (*Lasiurus cinereus*) present in Minnesota and Wisconsin (Barclay 1989, Hickey and Fenton 1996). All metrics chosen for inclusion in analyses have been used in similar studies evaluating landscape effects on species presence and abundance or activity (MacFaden and Capen 2002, Ford et al. 2005, Loehle et al. 2005, Yates and Muzika 2006, St Laurent et al. 2008).

To evaluate macro-level habitat, I compiled several Geographic Information Systems (GIS), (ArcGIS 9.1) data sets. I used GIS data layers from the national landcover database (Homer et.al. 2004) for a variety of macro-habitat metrics calculated with the use of GIS and FRAGSTATS 3.3 (MacGarigal et al. 2000). I first used the landcover data layer to evaluate the number of adjacent patches as well the presence of each landcover class. Prior to metrics quantification with FRAGSTATS, I reclassified the landcover database into forested and non-forested areas, with each forest/ non-forest polygon considered a patch for macro-habitat metrics analysis (MacFaden and Capen 2002). Mitchell et al. 2006

Measurements obtained in these macro-habitat analyses included: core area, percent of landscape, number of patches, largest patch index, total edge and edge density. Core area (CA) is equal to the sum of the total amount of forest/ non-forest area within

each macro-habitat (landscape). Percent landscape (PLAND) for forest/non-forest is a function of core area values divided by total landscape area. The number of patches is the total number of forest/ non-forest polygons in the macro-habitat. Largest patch index is the proportional area of the largest forest/non-forest patch to the entire macro-habitat area. Total edge is a summation of all forest/ non-forest polygon edges within the macro-habitat area, with edge density representing the proportion of total forest/ non-forest edge to the total macro-habitat area. Measures evaluating patch shape complexity included: patch area distribution (AREA), shape index distribution (SHAPE) and fractal index distribution (FRAC). Patch area distribution were measures associated with mean and coefficient variation of all forest/ non-forest patch areas within the macro-habitat. Shape index distribution for all forest/ non-forest patches was a measure of patch perimeter proportion to a minimum possible perimeter given the total area corresponding to each patch. Shape index distribution values will increase with patch shape complexity. Fractal index distribution is twice the natural log of a patch perimeter divided by the natural log of that patch area. A fractal index distribution value approaching 2 represents a deviation from a simple geometric shaped patch to a highly convoluted shape with a plane filling perimeter. Other metrics produced include: Euclidean nearest neighbor, contagion, Simpson's Diversity Index, and Simpson's Evenness Index. Euclidean nearest neighbor was a measure of the shortest distance between like (i.e., forest, non-forest) patches. Contagion is an index of landcover interspersion. Contagion is equivalent to the sum of proportional abundances between all forest and non-forest patches divided by the proportional adjacencies between all forest and non-forest patches with this quantity then being divided by its logarithm and multiplied by 100 to produce a percent. Simpson's

Diversity index is equivalent to 1 minus the sum of all forest/ non-forest patch proportional abundance values, squared. Simpson's Evenness Index is a function of Simpson's Diversity Index divided by 0.5 to incorporate the number of patch types (i.e., 2- forest and non-forest) for a measure of overall patch diversity within the macro- level habitat (MacCarigal et al. 2000).

I used digital elevation models (DEMs), hydrology, and transportation GIS data layers produced by the Minnesota and Wisconsin Departments of Natural Resources to further quantify the macro-level habitat. The digital elevation models contained elevation and slope values used for the calculation of macro-level habitat curvature and exposure. Curvature was calculated as the second derivative of the slope and is a measure of the extent to which the land is concave or convex. Exposure is the sum of the mean elevation of the macro-level habitat plus the elevation at the center of each stand divided by the standard deviation of the sum mean elevation and elevation at sampling point (Mitchell et al. 2006). Hydrology layers were used to quantify the total length of all streams and total area of all lakes within the macro-level habitat. I also measured the shortest distance to each water feature type (i.e., stream and lake) from each stand. The transportation data layers were used to quantify the total length of all roads within the macro-habitat and also the distance from each stand to the closest paved road.

Stand-level habitat Data

Stand-level habitat variables were measured from four 0.04-ha vegetation plots within each 50-m point count survey radius. One vegetation plot was centered on the point count station and the other three plots were centered 30.6 m from the point count center at 0°, 120°, and 270° (Titler et al. 2001, Machtans and Latour 2003).

Measurements from the four vegetation plots were averaged for each point count station, and then averaged to index stand-level habitat characteristics. Stand-level habitat variables were measured during summer 2008 and 2009.

At each 0.04 ha vegetation plot, I measured percent canopy closure using a spherical densiometer (Lemmon 1956). Densiometer readings from each cardinal direction were averaged to yield a canopy measurement for each vegetation plot. I measured the diameter at breast height (dbh) of all trees (>8 cm dbh), poles (3-8 cm dbh), and saplings (<3 cm dbh, >2 m in height) in each plot. I recorded canopy stature of all trees as either dominant (≥ 5 m above canopy), suppressed (≤ 5 m below canopy), or subcanopy for individuals below canopy level. Overstory tree, pole, and sapling heights were estimated by measuring heights of the 5 tallest stems in each diameter class per plot (Heltzel and Leberg 2006). I measured dbh, height, number of cavities and assigned a decay class to all snags. Decay classes followed those described by Thomas et al. (1979). I identified all snags to species or as conifer or hardwood whenever possible. I measured diameter, length, and decay class of all downed woody debris (DWD) that intersected a north-south transect within each vegetation plot. Downed woody debris were defined as pieces >8 cm in diameter and >50 cm in length. Decay classes followed those described by Bartels et al. (1985). I measured visual obscurity using a 2.5×150 cm cover pole (Robel et al. 1970) marked in 10-cm increments. The pole was placed in the center of each plot and the total number of sections that were $\geq 75\%$ obscured was recorded at eye level, 4 m from plot center in each cardinal direction. The 4 readings were averaged to estimate % shrub obscurity for each plot. I randomly selected 2 quadrants in each vegetation plot and counted stems of all shrubs (≤ 2 m tall). Shrub height was measured

at 5 random locations within each quadrant. I measured percent ground cover at the center of each plot with a 1-m² Daubenmire frame (Daubenmire 1959, Hetzel and Leberg 2006). The % cover of herbaceous, woody debris, litter, and bare soil was estimated within each plot.

Data Analyses

Prior to data analysis, bird point-count and bat activity data were tested for significant year effects between 2008 and 2009 using non-parametric Mann-Whitney U-tests. No significant year effects were found in the avian community data however, bat data for 2008 and 2009 differed significantly ($p \leq 0.05$). I averaged 2008 and 2009 bird data for analysis. Bat data from 2008 and 2009 were analyzed separately.

Birds. Bird species were grouped into species assemblages relative to 3 migratory strategies (residents, short-distance migrants, neotropical migrants), 4 habitat-use strategies (early-successional forest, open-shrub, late-successional forest, general), and 4 nesting habitat types (below canopy, canopy, cavity, general) for analyses (Robbins 1991, Calmé et al. 2002, Cutright et al. 2006, Mitchell et al. 2006)(Table 1). Flyovers and birds detected before and after the 10-min sampling period at each point were excluded from analyses to avoid double-counting individuals.

Bats. Because echolocation calls were often identified to species groups that included 2 species with different roosting and foraging behaviors, species assemblage analyses, according to migratory strategy, habitat preference, and roost habitat could not be conducted. Instead, I used species groups and frequency assemblages (i.e., HFG and LFG) as a substitute for species assemblages for all analyses (Table 2). I grouped all data

into HFG and LFG because of the call frequencies relationship to bat morphology and clutter tolerance and, therefore, habitat associations (Sleep and Brigham 2003).

Habitat Relationships

Birds. I used multiple stepwise logistic and linear regressions to examine stand- and macro-level habitat associations. I created models for 70 avian species and 11 species assemblages. Dependent variables for forward stepwise logistic regression included avian species presence and species assemblage presence. Dependent variables for stepwise multiple linear regression analyses included transformed avian species relative abundance and species assemblage relative abundance (i.e., migratory strategy, habitat-use, nesting habitat). All relative abundance data were log transformed to approximate normality. Models were created separately for each bird species and species group occurring in jack pine and red pine stands.

Bats. I used multiple stepwise linear and forward logistic regressions to examine site- and macro-level habitat relationships. I created stand- and macro-level models for 6 bat species groups and 2 species assemblages in jack pine and red pine forests. Dependent variables used in forward stepwise logistic regressions included species group and species assemblage presence. Dependent variables for stepwise multiple linear regression analyses included transformed bat species group activity index. All activity data were log transformed to approximate normality. Models were created separately for each bat species group and frequency assemblage occurring in jack pine and red pine stands.

Prior to model specification, I eliminated redundant habitat variables using Spearman's rho ($r^2 \geq 0.70$, $p \leq 0.05$). I developed 4 models: red pine stand-level, red pine

macro-level, jack pine stand-level, jack pine macro-level. After eliminating redundant variables I retained 13 habitat variables for the red pine stand-level model, 11- red pine macro-level model, 10- jack pine stand-level model, 7- jack pine macro-level model. Significance qualifications were used for habitat variable entry (0.05) and for removal (0.10) from model.

I used principle components analysis (PCA) to further examine overall variation in stand- and macro-habitat structure. Prior to analysis, I eliminated all variables that had no correlations (Spearman's $r^2 = 0.00$, $p \leq 0.05$) and highly correlated variables (Spearman's $r^2 > 0.90$, $p \leq 0.05$) to prevent singularity and extreme multicollinearity problems (Field 2005). I ran PCAs with jack pine and red pine combined habitat data, at the stand-level, avian macro-level and bat macro-level habitat to reduce habitat variables to a smaller set of orthogonal components while accounting for a large portion of variation within the original data. The stand-level PCA produced 7 principle components (PCs), as did the PCAs of avian macro-level habitat and bat macro-level habitat. Habitat variables with component scores that are greater than 0.63 are considered very good, and scores greater than 0.71 are considered excellent relative to their influence on a given principle component (Tabachnik and Fidell 1989). I then ran multiple stepwise linear regressions with principle components as independent variables to further elucidate species assemblage habitat relationships.

Comparison of Red Pine and Jack Pine Stands

I used Mann-Whitney U-tests (Quinn and Keough 2002) to compare avian abundance, bat activity, and stand- and macro-level avian and bat habitat variables between red pine and jack pine stands. I attempted to approximate normality in all data

sets through a square root transformation. When transformations failed, I resorted to the Mann-Whitney U-test. The Mann-Whitney U-tests, a non-parametric version of the Student's t-test.

RESULTS

Birds. I detected 3,340 birds of 70 species from point count surveys conducted in the 24 study stands during 2008 and 2009. One thousand seven hundred and three detections were recorded in the jack pine study stands and 1,637 detections occurred in the red pine stands. Of the 70 species detected overall, 60 were present in jack pine stands and 48 in red pine stands (Table 1). Species richness ranged 22-42 in jack pine stands and 16-38 in red pine stands. The most common species in jack pine stands were ovenbird (*Seiurus aurocapilla*), American redstart (*Setophaga ruticilla*), eastern wood pewee (*Contopus virens*), and red-eyed vireo (*Vireo olivaceus*). The most common bird species in red pine stands were ovenbird, pine warbler (*Dendroica pinus*), eastern wood-pewee and chipping sparrow (*Spizella passerina*).

Bats. Anabat detectors recorded 8,690 bat passes of 6 species groups in the 24 study stands during the summers of 2008 and 2009. All species groups were present in jack pine and red pine stands in 2008 and 2009 (Table 2). Species group richness ranged 3-6 in jack pine stands and 4-6 in red pine. The big brown (*Eptesicus fuscus*) and silver-haired bat (*Lasionycteris noctivigans*) group was most active in jack pine and *Myotis* were most active in red pine.

Habitat Relationships

Bird Communities. Logistic regression models of avian abundance in jack pine stand-level habitat produced significant models that most frequently included below canopy structural variables (Table 3). The open-shrub habitat use assemblage was positively associated with visual obscurity, as was yellow-throated vireo (*Vireo flavifrons*), a late succession specialist. While no significant models were produced for early and late succession specialist assemblages, individual species belonging to these habitat use assemblages did exhibit significant associations with the basal area of saplings and poles.

Significant logistic regression models at the jack pine macro-habitat level most frequently included water features (Table 4). No significant models were produced for species assemblages, only individual species. Individual species with significant logistic models were members of the early and late succession habitat assemblage and the habitat generalist assemblage. Total area of lakes was the most common positive macro-level habitat association for species in jack pine. Distance to nearest stream was positively associated with house wren (*Troglodytes aedon*).

Logistic regression models for red pine stand-level associations identified significant relationships most commonly with stand area and basal area of saplings (Table 4). Presence of individual avian species of the early and late succession specialist assemblage as well as habitat generalists exhibited positive associations with stand area. Other members of the early and late succession species assemblages exhibited positive associations with sapling basal area. Indigo bunting (*Passerina cyanea*), an open shrub

specialist, exhibited a negative association with pole height. Golden-crowned kinglet (*Regule satrapa*) had a significant negative association with canopy closure.

Macro-level associations for red pine bird communities were similar to jack pine communities in that water features (i.e., near stream distance, near lake distance and lake area) increased the probability of occurrence for many species. Open-shrub habitat specialists exhibited a negative association with distance to nearest stream. Nesting habitat generalists were positively associated with lake area. Core area of forested land and mean distance to nearest forest patch were also important metrics relative to increasing probability of avian species presence.

Stepwise linear regression models of bird species and species assemblage relative abundance produced significant models ($p \leq 0.05$) for 25 species and 7 species assemblages occurring in jack pine stands (Table 7). Pole basal area was positively associated with Neotropical migrants (e.g., black-throated green warbler [*Dendroica virens*]) and late succession habitat specialists (e.g., red-eyed vireo [*Vireo olivaceus*]). Conversely, pole basal area was negatively associated with migrants (e.g., house wren) and habitat generalists (e.g., brown-headed cowbirds [*Molothrus ater*]) and nesting habitat generalists. Resident species abundance was positively associated with sapling basal area. Canopy nesters exhibited positive associations with pole height and a negative association with basal area of trees.

Macro-level habitat linear regression analyses for jack pine stands produced significant models for 25 species and 6 species assemblages (Table 8). The resident species assemblage was positively associated with lake area and negatively related to distance to nearest stream. The late succession assemblage was positively associated

with core forest area; conversely, habitat generalists and canopy nesters exhibited a negative association with core forest area. The below canopy nest assemblage was positively correlated with distance to nearest stream. Nesting habitat generalists were positively associated with the number of adjacent landcover classes

Stand-level linear regression models of avian abundance and red pine habitat resulted in significant models for 27 species and 4 species assemblages (Table 9). Early succession forest specialists (e.g., blue-headed vireo [*Vireo solitaries*]) were negatively associated with snag decay. Open-shrub specialists were negatively associated with tree and pole basal area. Below canopy nest habitat specialists were positively associated with stand perimeter to area ratio. Canopy nesting specialists were positively associated with tree basal area.

Red pine macro-level habitat models were significant for 28 species and 8 species assemblages (Table 10). The resident species assemblage exhibited a positive association with the number of adjacent landcover classes. The early succession assemblage exhibited a positive association with terrain curvature and the number of adjacent landcover classes. Open-shrub habitat specialists were associated with forest patch shape complexity and negatively related to distance to nearest stream and number of adjacent landcover classes. Habitat generalists and canopy nesting species were negatively associated with increasing forest patch shape complexity. Below canopy nest habitat specialists were positively associated with forest patch shape complexity. Cavity nesting specialists exhibited a positive association with lake area and negative association with distance to nearest lake. Nesting habitat generalists were positively associated with core forested area and distance to nearest lake.

Bat Communities. Stepwise forward logistic regression analyses produced limited significant models relating bat presence to jack pine stand and macro-level habitat (Table 11). At the stand habitat level, the probability of *Myotis* presence was negatively associated with visual obscurity in 2008. However, in 2009 *Myotis* exhibited a significant negative relationship to canopy closure. The probability of hoary bat presence was negatively related to sapling basal area. Macro-level habitat associations with bat presence were not significant.

Logistic regression models relating stand- and macro-level red pine habitat to probability of bat presence also produced limited significant results (Table 12). The probability of the red bat and eastern pipistrelle species group being present was positively associated with pole basal area. Hoary bat presence was positively associated with volume of downed woody debris. At the macro-habitat level, the red bat and eastern pipistrelle species group exhibited positive associations with distance to nearest lake and distance to nearest road in 2008 and 2009, respectively. The presence of hoary bats was significantly related to distance to nearest neighbor in 2008 and negatively related to adjacent emergent herbaceous wetland in 2009.

Stepwise linear regression models of stand-level habitat associations in jack pine produced significant models for activity index of most bat species groups (Table 13). Decay of downed woody debris represented the most frequent habitat variable among significant models. *Myotis* activity was associated with downed woody debris decay in 2008; however, in 2009 activity was negatively related to sapling basal area. The HFG \geq 35 species group exhibited similar associations in 2008 and 2009 but was also positively correlated with pole height in 2008. The eastern pipistrelle and red bat grouping was

positively associated with downed woody debris decay in both 2008 and 2009. The big brown and silver-haired bat species group exhibited a positive association with stand area and negative associations with visual obscurity and canopy closure in 2008 but in 2009 was negatively associated with tree basal area. Hoary bats were positively associated with visual obscurity in 2009. The HFG frequency assemblage exhibited positive associations to downed woody debris decay and pole height in 2008, but a negative association to sapling basal area in 2009. The LFG frequency assemblage exhibited a positive association to stand area in 2008 and a negative relationship to tree basal area in 2009.

Macro-level habitat models of bat activity in jack pine stands produced few significant relationships (Table 14). *Myotis* activity in 2009 was positively associated with forest patch shape complexity. The big brown and silver-haired bat species grouping exhibited a negative association with core forest area in 2009. Hoary bat activity in 2009 related positively to lake area. The LFG frequency assemblage also related positively to lake area and exhibited a positive association with forest patch shape complexity.

Stepwise linear regression models of bat activity in red pine at the stand-level produced significant models for all species groups and frequency assemblages (Table 15). In 2009, *Myotis*, HFG>35, and the HFG frequency assemblage were positively associated with downed woody debris volume. In 2008, the HFG>35, LFG<35, and HFG assemblage were positively related to hardwood basal area. The eastern pipistrelle and red bat grouping related negatively to snag decay but positively to pole basal area in 2009. The big brown and silver-haired bat grouping related positively to snag decay in

2008. The LFG frequency assemblage exhibited a negative association with canopy closure.

Linear regression models relating bat activity to red pine macro-habitat produced significant models with water feature metrics representing the most common variables (Table 16). Distance to nearest lake was positively associated with the eastern pipistrelle and red bat grouping in 2008 and 2009. However, distance to nearest lake was negatively associated with the HFG>35 and the HFG frequency assemblage. The LFG<35 species group, hoary bats, and the LFG frequency assemblage exhibited a positive association with distance to nearest road in 2009. Hoary bats were associated with distance to nearest road in 2008 as well.

Principle components analysis of stand-level habitat variables produced 7 principle components (PCs) which collectively explained 83% of the variation in the original data set (Table 17). The first PC accounted for 27% of the total variance and included habitat variables that contribute to mid-story structure with excellent loadings on basal area of hardwood, poles, saplings, and shrubs as well as downed woody debris volume and visual obscurity. The second PC accounted for 19% of variation with excellent loadings on stand perimeter to area ratio and snag decay. Tree height stand perimeter, and stand age had very good loadings for the second PC. The third PC accounted for 10% of the total variance. Loading for bare soil ground cover on the third PC qualified as very good. The fourth PC accounted for 9% of the variance and had excellent loadings relative to downed woody debris decay and litter ground cover. Herbaceous ground cover had excellent loading on the fifth PC which accounted for 7% f

the variation within the original data set. The sixth and seventh principle components had no variables with excellent or very good loadings.

Bird Communities. Principle components analysis of macro-level avian habitat produced 7 PCs which collectively explained 89% of the variation in the original data set (Table 18). The first PC accounted for 29% of the total variance. Total edge, contagion, patch area, core area, Simpson's Diversity Index, Euclidean nearest neighbor, and fractal distribution of forest patches had excellent loadings on the first principle component. Presence of adjacent emergent herbaceous wetland had a very good loading on the first PC. The second PC accounted for 19% of the total variance. Presence of adjacent developed open space, the number of adjacent landcover classes, and forest patch shape had excellent loadings on the second PC and total length of roads had a very good loading. The third PC accounted for 14% of the total variance with excellent loadings relative to distance to nearest road and curvature with very good loading from presence of adjacent mixed forest. Total length of streams and distance to nearest stream had excellent loadings on the fourth PC which accounted for 11% of the total variance. Presence of adjacent woody wetland had a very good loading on the fifth PC, accounting for 6% of the total variance occurring within the original data set. The sixth and seventh PCs did not have factor loadings that qualified as excellent or very good.

Stepwise linear regressions of bird species assemblage relative abundance in jack pine and red pine on stand-level PCs produced significant models for all assemblages but residents, habitat generalists, nesting habitat generalist and cavity nesters (Table 19). Neotropical migrants and late succession specialists exhibited positive associations with the first stand-level PC. The migrant, early succession and open shrub

habitat assemblages were negatively associated with the first PC. Migrants exhibited a positive association with the sixth PC conversely the late succession assemblage had a negative association with the sixth PC. The below canopy nest assemblage was positively associated with the seventh PC, however canopy nesters exhibited a negative association.

Macro-level avian habitat principle component regressions did not produce significant models for Neotropical migrants, residents, or cavity nesters (Table 20). Migrants, early succession specialists and the canopy nest assemblage were negatively associated with the fourth avian macro-level PC. Conversely, open-shrub and generalist nesters exhibited positive associations with the fourth macro-level PC. Late succession specialists and below canopy nesters were positively associated with the second avian macro-level PC, however, habitat generalists, canopy nesters, and generalist nesters exhibited a negative association.

Bat Communities. Principle component analysis of macro-level bat habitat produced 7 PCs which collectively explained 87% of the variation in the original dataset (Table 21). The first PC accounted for 31% of the total variance with excellent component loadings relative to total stream length, Euclidean nearest neighbor, fractal patch distribution of non-forest patches, non-forest patch shape complexity, distance to nearest stream and adjacent mixed forest. Total edge had very good loading on the first PC. The number of adjacent landcover classes had excellent loading on the second PC, which accounted for 20% of the total variance. Presence of woody wetland as an adjacent landcover class had very good loadings on the second PC. The third PC accounted for 9% of the variation with very good loadings relative to curvature. The

fourth PC accounted for 8% of the variation of the original dataset with excellent loading relative to presence of adjacent open wetland. The fifth PC accounted for 7% of the total variation and had very good loading relative to exposure.

Stepwise linear regressions of bat species group activity in jack pine and red pine on stand-level PCs produced significant models for most species groups in at least one year, with the exception of the *Myotis* and red bat and eastern pipistrelle species groups (Table 22). The third stand-level PC was negatively associated with activity for most species groups; $HFG \geq 35$, $LFG < 35$, big brown and silver-haired bat species group, hoary, HFG and LFG frequency assemblages in 2009 and in 2008 for $LFG < 35$ and. $LFG < 35$, big brown and silver-haired species assemblage, hoary, LFG and HFG frequency assemblages were also all positively associated with the first principle component. $LFG < 35$, Efulano, Hoary, and the LFG frequency assemblage were positively associated with the second PC.

Stepwise linear regressions of bat activity and macro-level habitat PCs identified bat activity relationships highly related to the first, fourth and sixth PCs (Table 23). *Myotis* were positively associated with the first PC while $LFG > 35$, the big brown and silver-haired species group, hoary, and LFG frequency assemblage activity exhibited negative associations. The $LFG < 35$, big brown and silver-haired species group, and LFG frequency assemblage were positively associated with the fourth PC. The $HFG \geq 35$, $LFG < 35$, and LFG frequency assemblage were positively associated with the sixth principle component.

Comparison of Red Pine and Jack Pine Stands

Mann-Whitney U-test comparisons of stand level habitat metrics revealed several significant differences between jack pine and red pine stands (Table 24). Stand perimeter-to-area ratio was significantly different between cover types with a higher median ratio in jack pine stands. Jack pine stands also had significantly higher herbaceous and other (i.e., primarily moss and tree stump) ground cover. Red pine stands had greater percentages of litter as ground cover. Red pine stands had high basal area of trees while jack pine stands had significantly greater pole, sapling, shrub, and hardwood basal area. Jack pine stands had significantly higher stem counts and, therefore, higher visual obscurity. Jack pine and red pine stands also exhibited significant difference in canopy closure with jack pine having more closed canopies. Jack pine stands had significantly greater volumes of downed woody debris and basal area of snags. Tree height to canopy was greatest in red pine stands.

Birds. Mann-Whitney U-tests for differences among median avian species abundance produced significant results for several individual species and species assemblages (Table 25). Individual species with significantly different abundance in jack pine relative to red pine included species belonging to the Neotropical migrant assemblage, habitat generalists, and early succession forest specialists. Neotropical migrants were significantly more abundant in jack pine versus red pine whereas resident species were more prevalent in red pine. Species specializing in late succession forest habitat were more abundant in jack pine and early succession species were more abundant in red pine. The below canopy nest habitat assemblage was significantly more abundant in jack pine; canopy nesters were more abundant in red pine. I also conducted

Mann-Whitney U-tests to compare macro-level avian habitat between jack pine and red pine stands. Only distance to nearest road was significantly different between jack pine and red pine stands with greater distance to nearest road occurring in the jack pine. Core area forest and non-forest, distance to nearest stream and exposure failed to reject the null hypothesis of the independent samples median tests.

Bats. Mann-Whitney U-test comparisons of bat species group activity were significant for the LFG>35, big brown and silver-haired species groups, hoary bats, and the LFG frequency assemblage with greater median activity of these species occurring in jack pine (Table 26). *Myotis* and the HFG assemblage were significantly different between jack pine and red pine, with higher median activity occurring in red pine. Macro-level bat habitat Mann Whitney comparisons produced no significant differences. All tests were significant for the independent samples test.

DISCUSSION

Avian Habitat Relationships

Stand-level habitat. My research has identified habitat relationships of avian species and species assemblages in red pine and jack pine that are consistent with what is known about the general associations in the region (Robbins 1979, Howe et al. 1997, Cutright et al. 2006, MOU 2008). Also, the variation in habitat associations among migratory and habitat species assemblages supports previous groupings of these species (Robbins et al. 1991, Cutright et al. 2006). Habitat associations across jack pine and red pine stands were generally similar for species assemblages or individual species at the stand-level habitat.

Neotropical migrants are generally known to be associated with presence or volume of vegetative strata, plant or tree species compositions, and snags (Thompson et al. 1993). Species in this assemblage include American redstart (*Setophaga ruticilla*), black and white warbler (*Minotilla varia*), least flycatcher (*Empidonax minimus*) and red-eyed vireo. My logistic and linear modeling results for these species were similar and consistent with findings of previous research. In jack pine, at the stand-level the Neotropical species assemblage was associated with pole basal area. Red-eyed vireos, for example, were also associated with pole basal area. Other variables included in habitat association models for Neotropical migrants in both jack pine and red pine stands included visual obscurity, sapling basal area, pole height, and stand area.

Migrants (i.e., short-distance migrants) are generally associated with diverse vegetation structure and conifer forests with a hardwood component (Adams and Morrison 1993). This assemblage is known to be more associated with early succession habitats and young forests than Neotropical migrants or residents (Kirk et al. 1996, Hagan et al. 1997). Species in this migratory assemblage include American robin (*Turdus migratorius*), brown-headed cowbirds, house wren, and white-throated sparrow (*Zonotrichia leucophrys*). My modeling results for migrants were similar to previous research. Migrants as an assemblage were associated with pole basal area but expressed variation in the type of relation (i.e. negative, positive). Brown-headed cowbirds and house wrens exhibited a negative association; however, white throated sparrow and house wren were positively associated with pole basal area. This is likely an indication of the variation that occurs between species within the migrant assemblage relative to preference thresholds of vertical strata height.

Resident species of Wisconsin and Minnesota vary in their habitat associations. Species of this assemblage include black-capped chickadees (*Poecile atricapillus*), golden-crowned kinglet, pileated woodpecker (*Dryocopus pileatus*), and white-breasted nuthatch (*Sitta carolinensis*). My logistic and linear regression modeling results were generally related to below canopy structure, basal area of trees, and stand area. For, example pileated woodpeckers were associated with tree and sapling basal area. This is consistent with pileated woodpeckers known preference for large diameter trees for cavity nests (Cutright et al. 2006). White-breasted nuthatches were associated with sapling basal area which is consistent with previous findings (James 1971).

As expected, models for the early succession species assemblage included measures of below canopy structure, thus findings were consistent with known preferences of this assemblage. Species of this assemblage include chestnut-sided warbler (*Dendroica pensylvanica*), black-backed woodpecker (*Picoides arcticus*), and gray catbird (*Dumetella carolinensis*). Logistic and linear regression models included sapling, pole, and tree basal area, as well as basal area of snags, pole height, and canopy closure. These associations are also consistent with research identifying shrubs, tree canopy, and tree basal area as important habitat features relative to bird abundance in early succession forest (Probst et al. 1992).

Habitat associations of the late succession species assemblage also were as expected and consistent with known associations that define this assemblage. Species of the late succession assemblage include black and white warbler, brown creeper (*Certhia Americana*), least flycatcher, and ovenbird (*Seiurus aurocapilla*). Regression models for this assemblage included associations with basal area of trees, pole, saplings, and

hardwoods, visual obscurity, pole height and canopy closure. These are measures of forest age effects (Thompson et al. 1993) that are known to effect late succession forest specialist bird abundance.

Logistic and linear and regression models for the open-shrub habitat assemblage were also consistent with what was expected based on the habitat preferences known to define this assemblage. Species of the open-shrub assemblage included American goldfinch (*Carduelis tristis*) and indigo bunting. My habitat models identified a positive association with visual obscurity for this assemblage. Relatively few individual species of this assemblage with few detections occurred in these pine stands compared to other assemblages with significant findings.

The below canopy nest assemblage was largely composed of Neotropical migrants and early and late succession specialists. Species of the below canopy nest assemblage include black and white warbler, dark-eyed junco (*Junco hyemalis*), ovenbird, and veery (*Catharus fuscescens*). My logistic and linear regression model resulted in similar associations as previous research (Beals 1960, Temple et al. 1978, Thompson et al. 1993). These models showed significant associations with sapling, pole, tree, and hardwood snag basal area, and pole height. Another common association in these models was with visual obscurity which has also previously been found to be associated with increasing abundance of ground nesting songbirds (Zovnic 1995).

The canopy nest assemblage habitat associations varied somewhat relative to individual species which corresponded to their habitat use associations. Species of this assemblage included American robin, blue jays (*Cyanocitta cristata*), eastern wood-pewee (*Contopus virens*), and least flycatcher. My logistic and linear regression models

produced positive associations most often with basal area of trees. Other significant associations included stand area and below canopy structural measurements that may be used by this assemblage for forage habitat. These findings are consistent with known associations of members of this guild relative to their nest habitat requirements (Cutright et al. 2006).

The general habitat use and nest habitat assemblages consisted of a variety of bird species with a variety of habitat associations within these assemblages. The generalist nature of these assemblages resulted in linear and logistic regression results that were highly varied with no common associations. Models of these species contained associations with a variety of habitat metrics including negative and positive associations to pole height as well as pole basal area, and basal area of trees and saplings. Habitat associations for cavity nesters similarly lacked any clear biological significance due the variety of habitat metrics included in the models.

Macro-level habitat. My logistic and linear regression models of avian assemblages and macro-level habitat variables resulted in associations consistent with previous findings (Thompson et al. 1993, Howe et al. 1997, Golet et al. 2001, Mitchell et al. 2006). Habitat models at the macro- habitat exhibited less consistency among species assemblages occurring in both jack pine and red pine, but each pine type had a suite of macro-level variables that were included in all species and species assemblage models. Jack pine macro-level models primarily included metrics associated with water features, number of adjacent landcover classes, core forest area, and area of forest patches. Mitchell et al. (2006) also found avian associations with water features; more specifically, they found stream length to be associated with Neotropical migrants, below

canopy nesters, and canopy nesters. Associations with core forest area are also consistent with previous research establishing the importance of these metrics to Neotropical migrants in particular (Thompson et al. 1993, Golet et al. 2001, Mitchell et al. 2006).

Macro-level logistic and linear regression models in red pine also included water feature metrics and core forest area though to a lesser extent than in jack pine. Red pine models primarily included curvature, exposure, and distance to nearest like patch and patch richness diversity. These results are also consistent with Mitchell et al. (2006) findings relative to the importance of curvature and exposure (i.e., measures of topography) to Neotropical migrants, below canopy nest specialists, and canopy nesters. Distance to nearest like patch and patch richness diversity are metrics of landscape configuration. These metrics have been shown to effect avian communities, particularly Neotropical migrants, short-distance migrants, and open-shrub habitat specialists (Mitchell et al. 2006).

Linear regressions of principle components and bird abundance generally supported the results of my logistic and linear regression analyses on the original habitat variables as well as known associations of the species assemblages (Cutright et al. 2006). Neotropical migrants and late succession specialists were positively associated with the first stand-level PC which consisted primarily of below canopy structure metrics. Conversely, open shrub and early succession species were negatively associated with the first principle component. This is likely a result of below canopy structural measures, with excellent loading on the first PC, representing densities beyond the thresholds preferred. Neotropical migrants were also positively associated with the fourth principle component with excellent loading relative to downed woody debris.

The second and fourth macro-level PCs were included in the majority of linear regression models. Several variables had excellent or very good loadings on the second PC, exposure only had good loading on this component but was a significant variable in logistic and linear regression models on the original data. The late succession and below canopy nest assemblages were positively associated with this PC. These results are consistent with models of original habitat data and previous studies (Mitchell et al. 2006). Conversely, canopy nesters associated negatively to the second PC. Total stream length and near stream distance had excellent loadings on the fourth PC. The migrant, early succession, open shrub, and canopy nest assemblages were all associated with the fourth PC, this association with water is again consistent with results of logistic and linear regressions on the original data. However, only open-shrub specialists related positively to this PC. This may be due to the negative loading of stream length on this PC.

Overall, this research investigating avian habitat associations in managed jack pine and red pine has concluded that both stands support significant avian species richness and a diversity of assemblages. Tree basal area, below canopy structure, vegetation density, snags and downed woody debris, components known to be associated with high bird diversity in other forest types, were also associated with bird communities in these managed pine stands. While the degree to which these elements were provided by jack pine and red pine varied between cover types the elements are potentially present in all stands. These bird abundances, species richness, and habitat associations were largely unexpected given the common conception that red pine stands, in particular, do not provide adequate habitat to support diversity. These findings also indicate the habitat provided by commercially mature jack pine is sufficient to support high levels of

diversity, especially to late succession specialists and Neotropical migrants who are experiencing drastic population decline.

Bat Habitat Relationships

Stand-level habitat. My logistic and linear regression model results for bat species, frequency group and frequency assemblage activity varied in consistency with expected results based on previous studies (Ford et al. 2005, Yates and Muzika 2006, Duchamp and Swihart 2008, Brooks 2009). More specifically my models of *Myotis* and the HFG ≥ 35 species groups and the HFG frequency assemblage habitat associations were consistent with findings of previous studies however, associations of big brown and silver-haired bat, hoary, LFG < 35 , and the LFG frequency assemblage exhibited associations that were somewhat contradictory to previous findings and known habitat use by these species. Also, models differed between jack pine and red pine significantly according to habitat variables included in logistic and linear regression models.

In jack pine, logistic and linear regression models included downed woody debris decay, sapling basal area and stand area. *Myotis*, eastern pipistrelle and red bat, and HFG > 35 species groups, as well as the HFG frequency assemblage were significantly and positively associated with decay of downed woody debris. Because bats are aerial insectivores, this may be a response to conditions associated with more mature forest, in which downed woody debris would be likely to occur and at greater stages of decay, rather than a direct association with downed woody debris. The *Myotis* and HFG > 35 species assemblages, and the HFG frequency assemblage exhibited negative correlations with sapling basal area. Sapling basal area was positively associated with tree height and tree height to canopy. This finding is contradictory to known habitat use by these

groupings of bat species. For example, northern long-eared bats (i.e., *Myotis*) are known to use the areas under high canopy with clear flyways for forage habitat (Ford et al. 2005). The LFG < 35, big brown and silver-haired species groups, and LFG frequency assemblage were negatively associated with tree basal area. This is consistent with the known low clutter tolerance of this group of bats. Low basal area may be related to wider flyways between trees used for foraging (Sleep and Brigham 2003). The big brown and silver-haired and LFG frequency assemblage were also positively associated with stand area, which may be indicative of the association of silver-haired bats on forest for forage but also roosting habitat (Kurta 1995).

Relationships of bat species frequency assemblages in red pine stands, similar to jack pine stands, exhibited a relationship to downed woody debris; however, in this case it is downed woody debris volume rather than degree of decay that is significant. It again is the *Myotis* and HFG > 35 species group and the HFG frequency assemblage that are associated with the downed woody debris. In this case, volume of downed woody debris was positively and highly correlated with snag basal area which would be more consistent with known species habitat requirements (Kurta 1995). Northern long-eared bats (i.e., *Myotis*) are known to roost in snags (Sasse and Pekins 1996, Waldien et al. 2000, Menzel et al. 2002). Both the LFG and HFG frequency assemblages were positively correlated with hardwood basal area. These two groups often exhibit very different associations because of their general difference in size and therefore clutter tolerance and habitat use (Brigham et al. 1997). This could also have resulted from the tree roosting species (e.g., silver-haired bat [LFG], eastern red bat [HFG]) within each

group influencing these models because of their preference for roosting among clumps of leaves (Shump and Shump 1982, Hutchison and Lacki 2000).

Macro-level Habitat. My logistic and linear regression models of macro-level associations in jack pine stands were consistent with previous studies (Ford et al. 2005, Yates and Muzika 2006). *Myotis* and the LFG frequency assemblage were positively associated with patch shape complexity which is proportionate to the amount of edge in the landscape. Edge habitats or open areas between forest patches and non-forest patches likely provide additional foraging opportunities (Ford et al. 2005). The LFG frequency assemblage and hoary bats were associated with lake area in the landscape. This is consistent with findings establishing the importance of water features as foraging habitat for many bat species (Krusic et al. 1996, Menzel et al. 2001, 2003, 2005, Johnson 2002).

My logistic and linear regression models of red pine macro-level habitat included metrics associated with water features and roads. Distance to nearest lake was positively associated with eastern pipistrelle and red bat but negatively associated with HFG>35 and the HFG frequency assemblage. Bat species are generally associated with water features because of their use as foraging habitat. The positive relationship with distance to nearest lake is inconsistent with current knowledge of bat habitat use (Krusic et al. 1996, Menzel et al. 2001, 2003, 2005, Johnson 2002). Hoary, LFG<35, and the LFG frequency assemblage were positively correlated to distance to nearest road. Although bats do use landscape edges for foraging opportunities, they may avoid developed edges such as roads because of a lack of prey as a result of little to no herbaceous cover.

Linear regressions of stand-level principle components and bat activity generally were consistent with the results of my logistic and linear regression analyses on the original habitat variables as well as known associations of the species groups and frequency assemblages. Hardwood basal area, downed woody debris volume, sapling and pole basal area had excellent loadings on the first PC. My linear regression model for the HFG assemblage was associated with the first PC which was consistent with regression results relative to the original habitat variables. Snag decay had an excellent loading on the second PC, while snag height loading qualified as very good. The LFG < 35 and big brown and silver-haired species assemblages, hoary bats, and the LFG frequency assemblage were positively associated with the second PC. These findings, again, are consistent with the associations found in my original regression models.

Linear regressions of macro-level principle components and bat activity were generally consistent but some discrepancies did occur relative to the original regression models. Average mean shape of non-forest patches had excellent loading on the first macro-level principle component. Myotis were positively associated with this PC which is consistent with their association with non-forest patch shape in my original regressions. The LFG < 35 and big brown and silver-haired species groups and the LFG frequency assemblage had negative associations with the first PC. This may be related to the distance to nearest like patch decreasing which had excellent loadings on the first PC. In original regression models LFG < 35 was positively associated with increasing distances between like patches. The highly prevalent associations with water features in the original regressions were not clear in regressions of the PCs. Distance to nearest lake only had a moderate loading on the third PC.

Overall bat presence and activity suggest that both managed pine types provide habitat for all bat species occurring in the region. Though there is variation in activity level among species groups and assemblages occurring in jack pine and red pine stands, variation did not occur as expected. All LFG species, species groups and frequency assemblages are heavy wing loaded bats with poor maneuverability and therefore known to be clutter intolerant. Thus, their positive association with various measures of vertical strata in jack pine was not expected. This, however, may indicate insect prevalence and abundance, particularly flies, moths, and caddisflies (Tibbels and Kurta 2003), may be a more important factor than habitat structure. Additionally, this may indicate the lack of lower herbaceous cover prevalent in red pine does not support sufficient invertebrate communities for bat forage. Bat macro-level associations confirm the importance of water features, forest edges and open areas between patches as potential foraging habitat.

Jack Pine Red Pine Comparison

Managed red pine forests have been criticized for the minimal amount of habitat they provide wildlife, and the contribution of jack pine in providing wildlife habitat is poorly understood. As rotation age jack pine is largely being converted to red pine in the landscape, its potential to provide habitat to more diverse wildlife communities is becoming increasingly important. My findings revealed significant differences in stand-level-habitat variables relative to below canopy structure, vegetation density, snags and downed woody debris. These habitat features are known to be associated with bird diversity (Robbins 1979, Thompson et al. 1993, Howe 1997, Loehl et al. 2005) Jack pine stands had significantly more below canopy vegetation structure (i.e., pole, sapling, shrub

basal area) and significantly higher density of these components in the vertical plane (i.e., visual obscurity) than did the red pine stands.

Birds. The variation in structural components present in jack pine stands and red pine stands influenced the avian communities occurring in each pine type. Neotropical migrants, late succession specialists and below canopy nesters were more prevalent in jack pine. Given that the jack pine stands had greater below canopy structure and vegetation density these results are consistent with previous studies (MacArthur and macArthur 1971, Thompson et al. 1983, Howe et al. 1997, Loehl et al. 2005). Residents, early succession specialists, and canopy nesters were more prevalent in red pine stands which were characterized by greater basal area of trees and below canopy structure that was sparser or not present. These findings are consistent with known associations of these assemblages (Cutright et al. 2006).

Bats. Results from the Mann-Whitney U-tests were not consistent with expected results or known habitat associations. *Myotis* and the HFG frequency assemblage were significantly more abundant in red pine stands than in jack pine. These species are lighter wing-loaded than the LFG species and therefore better able to maneuver through cluttered environments (Brigham et al. 1997). Red pine stands represented a significantly less cluttered habitat relative to jack pine; therefore, greater maneuverability would not be necessary. Conversely, the LFG < 35 and big brown and silver-haired species group, hoary, and the LFG frequency assemblage were more active in jack pine than in red. This pattern was evident in regression models for each stand type and is contrary to known habitat use of these species. However, Ford et al. (2005) observed a similar discrepancy

and suggested that overall prey abundance may be a more important factor than habitat structure in associations with bat activity.

Overall, jack pine stands and red pine stands differ greatly in the amount of structural diversity, vegetation density, composition and legacy structures (i.e., snags and downed woody debris). These elements are directly related to the level of avian diversity occurring within a stand. These elements also, though not ideal were associated with bat diversity though, indirectly because of the relationship between vegetation cover and insect community abundance. These findings suggest that the value of commercially mature jack pine, though largely overlooked, is significant and its presence in the landscape is highly important to the conservation of wildlife diversity.

Management Implications

Managers of private industrial pine forests in the Great Lakes lack information relative to; wildlife present in these stands, the diversity currently supported, and the habitat features that could improve these stands as wildlife habitat. This study further elucidates the importance of below canopy structure in supporting higher levels of diversity. This structure is lacking in red pine stands and is the reason for criticisms directed at red pine managers for the lack of habitat they provide. Implications of this research have been the identification of key structural features associated with greater avian abundance and bat activity within managed jack pine and red pine stands. Those elements include a pole and sapling component with some degree of density (i.e., not sparse). Stand legacies (i.e., snags and downed woody debris) are also important in providing habitat to support greater diversities of wildlife.

Commercial age jack pine represents forest habitat that though managed for timber or paper production can support high levels of wildlife diversity. Jack pine silviculture uses natural stand establishment methods and operates on a commercial rotation age approaching natural maturity. This facilitates the development of late succession forest traits such as below canopy structure, hardwood components, downed woody debris, and snags. This pine type is largely being replaced in favor of red pine because of its greater economic value. The implications of the replacement of jack pine with red pine will be a further decrease in habitat that can support higher diversities of wildlife.

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Table 1. Common names of all bird species included in analyses with 4-letter code, scientific names and species assemblage designations for migratory strategy, habitat use, and nesting habitat.

Code	Common Name	Scientific Name	Migratory strategy (MS) ^a	Habitat-use (HU) ^b	Nesting habitat (NH) ^c
AMCR	American Crow	<i>Corvus brachyrhynchos</i>	R	Gen	Cnpy
AMGO	American Goldfinch	<i>Carduelis tristis</i>	M	OS	BC
AMRE	American Redstart	<i>Setophaga ruticilla</i>	NTM	ES	BC
AMRO	American Robin	<i>Turdus migratorius</i>	M	Gen	Cnpy
BAOR	Baltimore Oriole	<i>Icterus galbula</i>	NTM	Gen	Cnpy
BAWW	Black and White warbler	<i>Mniotilta varia</i>	NTM	LS	BC
BBWO	Black-backed Woodpecker	<i>Picoides arcticus</i>	R	ES	Cvty
BCCH	Black-capped Chickadee	<i>Poecile atricapillus</i>	R	Gen	Cvty
BHCO	Brown-headed Cowbird	<i>Molothrus ater</i>	M	Gen	Gen
BHVI	Blue-headed Vireo	<i>Vireo solitarius</i>	M	ES	BC
BLJA	Blue Jay	<i>Cyanocitta cristata</i>	R	Gen	Cnpy
BRCR	Brown Creeper	<i>Certhia americana</i>	R	LS	Cvty
BTNW	Black-throated Green Warbler	<i>Dendroica virens</i>	NTM	ES	BC
BWHA	Broad-winged Hawk	<i>Buteo platypterus</i>	NTM	LS	Cnpy
CAWA	Canada Warbler	<i>Wilsonia canadensis</i>	NTM	LS	BC
CEDW	Cedar Waxwing	<i>Bombycilla cedrorum</i>	M	Gen	BC
CHSP	Chipping Sparrow	<i>Spizella passerina</i>	M	ES	BC
CORA	Common Raven	<i>Corvus corax</i>	R	Gen	Gen
COYE	Common Yellowthroat	<i>Geothlypis trichas</i>	NTM	ES	BC
CSWA	Chestnut-sided Warbler	<i>Dendroica pensylvanica</i>	NTM	ES	BC
DEJU	Dark-eyed Junco	<i>Junco hyemalis</i>	M	Gen	BC
DOWO	Downy Woodpecker	<i>Picoides pubescens</i>	R	LS	Cvty
EABL	Eastern Bluebird	<i>Sialia sialis</i>	M	ES	Cvty
EAPH	Eastern Phoebe	<i>Sayornis phoebe</i>	NTM	Gen	Gen
EASO	Eastern Screech Owl	<i>Megascops asio</i>	R	Gen	Cvty
EATO	Eastern Towhee	<i>Pipilo erythrophthalmus</i>	M	Gen	BC
EAWP	Eastern Wood-Pewee	<i>Contopus virens</i>	NTM	Gen	Cnpy
GCFL	Great-crested Flycatcher	<i>Myiarchus crinitus</i>	NTM	LS	Cvty
GCKI	Golden-crowned Kinglet	<i>Regula satrapa</i>	M	ES	Cnpy
GRCA	Gray Catbird	<i>Dumetella carolinensis</i>	NTM	ES	BC
GWWA	Golden-winged warbler	<i>Vermivora chrysoptera</i>	NTM	OS	BC
HAWO	Hairy Woodpecker	<i>Picoides villosus</i>	R	LS	Cvty
HETH	Hermit Thrush	<i>Catharus guttatus</i>	NTM	ES	BC
HOWR	House Wren	<i>Troglodytes aedon</i>	M	Gen	Cvty
INBU	Indigo Bunting	<i>Passerina cyanea</i>	NTM	OS	BC
LEFL	Least Flycatcher	<i>Empidonax minimus</i>	NTM	LS	Cnpy
MODO	Mourning Dove	<i>Zenaida macroura</i>	M	Gen	Gen
MOWA	Mourning Warbler	<i>Oporornis philadelphia</i>	NTM	ES	BC
NAWA	Nashville Warbler	<i>Vermivora ruficapilla</i>	NTM	ES	BC

^aNeotropical migrants (NTM), Migrants (M), Residents (R)

^bEarly succession (ES), Late succession (LS), Open-shrub (OS), Generalist (Gen)

^cBelow canopy (BC), Canopy (Cnpy), Cavity (Cvty), Generalist (Gen)

Table 1 (cont'd). Common names of all bird species included in analyses with 4-letter code, scientific names and species assemblage designations for migratory strategy, habitat use, and nesting habitat.

Code	Common Name	<i>Scientific Name</i>	Migratory strategy (MS) ^a	Habitat-use (HU) ^b	Nesting habitat (NH) ^c
OVEN	Ovenbird	<i>Seiurus aurocapilla</i>	NTM	LS	BC
PIWA	Pine Warbler	<i>Dendroica pinus</i>	M	ES	Cnpy
PIWO	Pileated Woodpecker	<i>Dryocopus pileatus</i>	R	LS	Cvty
PUFI	Purple Finch	<i>Carpodacus purpureus</i>	M	ES	Cnpy
RBGR	Rose-breasted Grosbeak	<i>Pheucticus ludovicianus</i>	NTM	Gen	BC
RBNU	Red-breasted Nuthatch	<i>Sitta canadensis</i>	R	ES	Cvty
RBWO	Red-bellied Woodpecker	<i>Melanerpes carolinus</i>	R	LS	Cvty
RECR	Red Crossbill	<i>Loxia curvirostra</i>	R	ES	Cnpy
REVI	Red-eyed Vireo	<i>Vireo olivaceus</i>	NTM	LS	BC
RTHU	Ruby-throated Hummingbird	<i>Archilochus colubris</i>	NTM	Gen	BC
RUGR	Ruffed Grouse	<i>Bonasa umbellus</i>	R	LS	BC
RWBL	Red-winged Blackbird	<i>Agelaius phoeniceus</i>	M	OS	BC
SCTA	Scarlet tanager	<i>Piranga olivacea</i>	NTM	LS	Cnpy
SOSP	Song Sparrow	<i>Melospiza melodia</i>	M	Gen	Gen
TRES	Tree Swallow	<i>Tachycineta bicolor</i>	M	OS	Cvty
VEER	Veery	<i>Catharus fuscescens</i>	NTM	LS	BC
WAVI	Warbling Vireo	<i>Vireo gilvus</i>	NTM	LS	Cnpy
WBNU	White-breasted Nuthatch	<i>Sitta carolinensis</i>	R	LS	Cvty
WITU	Wild Turkey	<i>Meleagris gallopavo</i>	R	LS	BC
WTSP	White-throated Sparrow	<i>Zonotrichia leucophrys</i>	M	Gen	BC
YBSA	Yellow-bellied Sapsucker	<i>Sphyrapicus varius</i>	M	ES	Cvty
YRWA	Yellow-rumped Warbler	<i>Dendroica coronata</i>	NTM	LS	BC
YSFL	Northern Flicker	<i>Colaptes auratus</i>	M	ES	Cvty
YTVI	Yellow-throated Vireo	<i>Vireo flavifrons</i>	NTM	LS	Cnpy
YWAR	Yellow Warbler	<i>Dendroica petechia</i>	NTM	ES	BC

^aNeotropical migrants (NTM), Migrants (M), Residents (R)

^bEarly succession (ES), Late succession (LS), Open-shrub (OS), Generalist (Gen)

^cBelow canopy (BC), Canopy (Cnpy), Cavity (Cvty), Generalist (Gen)

Table 2. Common names of all bat species used in analyses with scientific name, and species and frequency group designations.

Common Name	<i>Scientific Name</i>	Species/Frequency Group membership ^a
Eastern Pipistrelle	<i>Pipistrellus subflavus</i>	LaboPisu; HFG
Eastern Red Bat	<i>Lasiurus borealis</i>	LaboPisu; HFG
Big Brown Bat	<i>Eptesicus fuscus</i>	EpfuLano; LFG
Hoary Bat	<i>Lasiurus cinereus</i>	Hoary; LFG
Silver-haired Bat	<i>Lasionycteris noctivigans</i>	EpfuLano; LFG
Little Brown Bat	<i>Myotis lucifugus</i>	Myotis; HFG
Northern Myotis	<i>Myotis septentrionalis</i>	Myotis; HFG

^aHFG= High Frequency Group (≥ 35 kHz); LFG= Low Frequency Group (< 35 kHz)

Table 3. Forward stepwise logistic regression results for bird species and species assemblages and stand-level habitat variables for jack pine stands in Cass, Morrison, and Wadena Counties, Minnesota, USA.

Bird Species	Habitat variables ^a	R^2
BAWW	+BA_Tree	0.603
BBWO	+Pole_Ht	1.000*
BCCH	+CC	1.000*
BLJA	+GC_S_arcsin	0.557
BRCR	+DWD_Decay	0.447
BTNW	+BA_Pole	1.000*
BWHA	+BA_Sapp	1.000*
CAWA	+BA_Tree	1.000*
CEDW	+GC_H_arcsin	0.781
CHSP	+BA_Tree	1.000*
EAPH	+BA_Pole	1.000*
EATO	+BA_Pole	0.595
EASO	+BA_pole	1.000*
GRCA	+BA_Sapp	1.000*
HOWR	+BA_Pole	0.657
LEFL	+BA_Tree	1.000*
YSFL	+BA_Sapp	1.000*
PIWO	+BA_Sapp	1.000*
PUFI	+StdArea	1.000*
RBGR	+StdArea	1.000*
RBWO	+BA_Sapp	1.000*
REVI	+StdArea	1.000*
RUGR	+BA_Sapp	0.469
SCTA	+GC_S_arcsin	1.000*
WITU	+BA_Sapp	0.508
YTVI	+VO	0.571
HU_OP	+VO	0.609

* Perfect fit is detected. This solution is not unique

^a Refer to Table 29 for full variable name and description

Table 4. Forward stepwise multiple logistic regression results for bird species and species assemblages and macro-level habitat variables for jack pine stands in Cass, Morrison and Wadena Counties, Minnesota, USA.

Bird Species	Habitat variables ^a	R^2
AMCR	- Near_lk_dist	1.000*
BAWW	- CA_for + - ACT#	0.822
BTNW	+Near_st_dist	1.000*
CAWA	+CA_for	1.000*
CHSP	+CA_for	1.000*
DEJU	+Lake_area	0.614
EAPH	+Near_st_dist	1.000*
EASO	+Near_st_dist	1.000*
GRCA	+Lake_area	0.441
GWWA	+Near_st_dist	1.000*
HOWR	+Near_st_dist	0.680
PIWO	+Lake_area	0.441
PUFI	+ACT#	1.000*
RBGR	+ACT#	1.000*
RBWO	+Lake_area	0.441
REVI	+ACT#	1.000*
RUGR	+CA_for + Lake_area	0.783
WAVI	+Near_lk_dist	1.000*
WITU	+Lake_area	0.826

* Perfect fit is detected. This solution is not unique

^a Refer to Table 30 for full variable name and description

Table 5. Forward stepwise multiple logistic regression results for bird species and species assemblages and stand-level habitat variables for red pine stands in Oneida County, Wisconsin, USA.

Bird Species	Habitat variables	R^2
BAWW	+Tree_Ht	1.000*
BHVI	+SnagHeight	0.486
BRCR	+StndArea	0.519
CEDW	+BA_Pole	1.000*
CORA	+StndArea	0.631
COYE	+SnagHW_BA	1.000*
CSWA	+Tree_Ht	1.000*
DOWO	- BA_Tree	0.582
EABL	+Pole_Ht	1.000*
GCFL	- BA_Pole	0.546
GCKI	- CC	0.496
GRCA	+SnagHW_BA	1.000*
INBU	-Pole_Ht	0.627
MOWA	+Stnd_PerimArea	0.717
YSFL	+StndArea	0.494
PIWO	+BA_Tree	0.579
RBGR	+StndArea	0.565
RECR	+StndArea	0.631
REVI	+Tree_Ht	0.625
SCTA	+Pole_Ht	1.000*
SOSP	+BA_Sapp	0.605
UNKN	+SnagDecay	1.000*
VEER	+BA_Sapp	1.000*
WAVI	+SnagHW_BA	1.000*
WITU	+BA_HW	0.538
WTSP	+BA_Sapp	0.500
YRWA	+BA_Sapp	0.482
NH_Gen	+Vcm3	1.000*

* Perfect fit is detected. This solution is not unique

Table 6. Forward stepwise multiple logistic regression results for bird species and species assemblages and macro-level habitat variables for red pine stands in Oneida County, Wisconsin, USA.

Bird Species	Habitat variables	R^2
AMGO	- Near_st_dist	0.558
BHCO	+CA_for	0.647
BHVI	+CA_for	1.000*
COYE	+Exposure	1.000*
DOWO	+Exposure	0.513
EABL	+FRAC_SD_nf	1.000*
EATO	+CA_for	0.538
EAWP	+Curvature	1.000*
GCFL	+ENN_MN	0.696
GRCA	+Exposure	1.000*
YSFL	+ENN_MN	0.398
PIWO	+Lake_area	1.000*
PUFI	+Curvature	1.000*
SCTA	+FRAC_SD_nf	1.000*
VEER	+ACT#	1.000*
WAVI	+Exposure	1.000*
WITU	+Lake_area	0.547
WTSP	+Near_lk_dist	0.505
HU_OP	-Near_st_dist	0.617
NH_Gen	+Lake_area	0.470

* Perfect fit is detected. This solution is not unique

Table 7. Multiple stepwise linear regression results for bird species and site-level habitat variables for jack pine stands in Cass, Morrison and Wadena Counties, Minnesota, USA.

Bird Species	Stand-level habitat model variables with standardized beta values	<i>F</i>	<i>P</i>	<i>R</i> ²
BAWW	0.671 VO + -0.466 BA_Tree	13.645	0.002	0.752
BBWO	-0.637 Pole_Ht	6.812	0.026	0.405
BHCO	-0.707 BA_Pole + -0.392 VO	12.834	0.002	0.740
BLJA	0.765 VO + 0.525 BA_Tree	13.700	0.002	0.753
BTNW	0.583 BA_Pole	5.142	0.047	0.340
BWHA	0.803 BA_Sapp + 0.305 GC_H_arcsin	26.936	0.000	0.857
CAWA	0.806 BA_Tree + 0.346 Pole_Ht	23.910	0.000	0.842
CHSP	-0.648 Pole_Ht	7.222	0.023	0.419
DEJU	-0.632 VO	6.665	0.027	0.400
EAPH	0.733 BA_Pole	11.630	0.007	0.538
EASO	0.583 BA_Pole	5.142	0.047	0.340
EATO	-1.144 + BA_Pole + 0.590 DWD_Decay	11.948	0.003	0.726
EAWP	-0.641 GC_S_arcsin	6.965	0.025	0.411
GRCA	1.152 BA_Sapp + -0.405 BA_Tree + -0.289 StndArea	36.737	0.000	0.932
HOWR	-0.726 BA_Pole	11.127	0.008	0.527
LEFL	-0.760 BA_Tree	13.684	0.004	0.578
NAWA	0.550 BA_Tree + 0.499 Pole_Ht(m)	7.451	0.012	0.623
YSFL	0.710 BA_Sapp	10.156	0.100	0.504
OVEN	0.767 BA_Tree + 0.428 Pole_Ht(m)	27.020	0.000	0.857
PIWO	1.152 BA_Sapp + -0.405 BA_Tree + -0.289 BA_Pole	36.737	0.000	0.932
PUFI	0.588 StndArea	5.283	0.044	0.346
RBWO	1.152 BA_Sapp + -0.405 BA_Tree + -0.289 BA_Pole	36.737	0.000	0.932
REVI	0.827 BA_Pole	21.593	0.001	0.683
WBNU	0.800 BA_Sapp	17.724	0.002	0.639
YTVI	0.591 VO	5.374	0.043	0.350
MS_NTM	0.625 BA_Pole	6.408	0.030	0.391
MS_M	-0.802 BA_Pole	18.025	0.002	0.643
MS_R	0.727 BA_Sapp	11.200	0.007	0.528
HU_L	0.745 BA_Pole + -0.376 StndArea	14.009	0.002	0.757
HU_G	-0.859 BA_Pole + -0.343 BA_Tree -0.837 GC_S_arcsin + -0.512 BA_Tree + -0.418 Pole_Ht(m)	23.997	0.000	0.842
NH_Cnpy		25.556	0.000	0.906
NH_Gen	-0.792 BA_Pole + 0.472 GC_S_arcsin	10.927	0.004	0.708

Table 8. Multiple stepwise linear regression results for bird species and macro-level habitat variables for jack pine stands in Cass, Morrison and Wadena Counties, Minnesota, USA.

Bird Species	Macro-level habitat model variables with standardized beta values	<i>F</i>	<i>P</i>	<i>R</i> ²
AMCR	0.787 Near_lk_dist	16.272	0.002	0.619
AMRE	-0.699 CA_for	9.556	0.011	0.489
BCCH	0.694 AREA_CV_for	9.307	0.012	0.482
BHCO	0.631 ACT#	6.619	0.028	0.398
BRCR	0.585 CA_for	5.210	0.046	0.343
BTNW	-0.805 Near_st_dist + 0.616 Near_lk_dist	17.169	0.001	0.792
BWHA	0.693 Lake_area	9.232	0.012	0.480
CAWA	0.544 CA_for + -0.485 AREA_CV_for	18.811	0.001	0.807
CEDW	0.678 AREA_CV_for	8.508	0.015	0.460
CHSP	0.518 AREA_CV_for + -0.512 Near_lk_dist + 0.555 ACT#	19.328	0.001	0.879
DEJU	0.709 Near_lk_dist	10.103	0.010	0.503
DOWO	0.585 PRD	5.199	0.046	0.342
EAPH	-0.728 Near_st_dist	11.295	0.007	0.583
EASO	-0.805 Near_st_dist + 0.616 Near_lk_dist	17.169	0.001	0.792
GRCA	0.914 Lake_area + -0.459 Near_st_dist	13.366	0.002	0.748
GWWA	-1.036 Near_lk_dist + -0.635 CA_for + 0.421 PRD	14.162	0.001	0.842
LEFL	0.610 AREA_CV_for	5.925	0.035	0.372
NAWA	1.009 CA_for + 0.449 Near_st_dist	22.142	0.000	0.831
OVEN	0.877 CA_for	36.995	0.000	0.787
PIWO	0.914 Lake_area + -0.459 Near_st_dist	13.366	0.002	0.748
PUFI	1.065 ACT + 0.463 CA_for	14.371	0.002	0.762
RBWO	0.914 Lake_area + -0.459 Near_st_dist	13.366	0.002	0.748
WAVI	-1.036 Near_lk_dist + -0.635 CA_for + 0.421 PRD	14.162	0.001	0.842
WBNU	0.870 Lake_area + -0.466 Near_st_dist	9.862	0.005	0.687
WITU	0.737 Lake_area + 0.545 PRD	8.779	0.008	0.661
MS_R	0.829 Lake_area + -0.515 Near_st_dist	8.358	0.009	0.650
HU_L	0.591 CA_for	5.364	0.043	0.349
HU_Gen	-0.732 CA_for	11.537	0.007	0.536
NH_BC	0.681 Near_st_dist	8.655	0.015	0.464
NH_Cnpy	-1.130 CA_for + -0.621 ACT#	21.366	0.000	0.826
NH_Gen	0.670 ACT#	8.161	0.017	0.449

Table 9. Multiple stepwise linear regression results for bird species and site-level habitat variables for red pine stands in Oneida County, Wisconsin, USA.

Bird Species	Stand-level habitat model variables with standardized beta values	<i>F</i>	<i>P</i>	<i>R</i> ²
AMCR	0.882 BA_Pole + -0.508	8.019	0.010	0.641
AMGO	0.591 SnagHW_BA	5.367	0.043	0.349
AMRO	0.661 BA_Tree	7.759	0.019	0.437
BAWW	-0.735 Tree_Ht	11.745	0.006	0.540
BLJA	-0.616 Stnd_Perim/Area	6.109	0.033	0.379
CEDW	-0.733 BA_Pole + -0.583 Pole_Ht + -0.438 Snag_Height	29.622	0.000	0.917
CORA	0.622 StndArea	6.313	0.031	0.387
COYE	0.857 SnagHW_BA	27.701	0.000	0.735
CSWA	0.746 Stand_Perim/Area	12.538	0.005	0.556
DEJU	0.753 BA_Tree + 0.318 Vcm3	48.612	0.000	0.915
EABL	0.697 Pole_Ht	9.434	0.012	0.485
EATO	-0.596 BA_Tree	5.518	0.041	0.356
GCKI	-0.804 CC	18.286	0.002	0.646
GRCA	0.857 SnagHW_BA	27.701	0.000	0.735
HETH	0.922 BA_Pole + -0.588 Vcm3 + -0.437 BA_HW	11.494	0.003	0.812
INBU	-0.704 CC	9.808	0.011	0.495
LEFL	0.634 Pole_Ht	6.717	0.027	0.402
MOWA	0.795 SnagHW_BA	17.207	0.002	0.632
YSFL	0.705 SnagHW_BA	9.854	0.011	0.469
PIWO	0.707 BA_Tree + -0.496 Pole_Ht	6.601	0.017	0.595
RBGR	0.544 StndArea + 0.490 SnagHW_BA	6.403	0.019	0.587
REVI	0.651 CC	7.368	0.022	0.424
SCTA	0.697 Pole_Ht	9.434	0.012	0.485
VEER	0.788 BA_Sapp + -0.155 Snag_Height + -0.280 SnagDecay + -0.115 BA_HW + -0.080 CC	2708.8 80	0.000	1.000
WAVI	0.857 SnagHW_BA	27.701	0.000	0.735
WITU	0.633 BA_HW + 0.497 Vcm3	8.908	0.007	0.664
WTSP	0.708 BA_Pole	10.061	0.010	0.502
HU_ES	-0.578 Snag_Decay	5.021	0.049	0.334
HU_OP	-0.601 BA_Tree + -0.489 BA_Pole	6.682	0.017	0.598
NH_BC	0.630 Stnd_Perim/Area	6.591	0.028	0.397
NH_Cnpy	0.635 BA_Tree	6.764	0.026	0.404

Table 10. Multiple stepwise linear regression results for bird species and macro-level habitat variables for red pine stands in Oneida County, Wisconsin, USA.

Bird Species	Macro-level habitat model variables with standardized beta values	<i>F</i>	<i>P</i>	<i>R</i> ²
AMGO	0.799 Shape_AM_for	17.666	0.002	0.639
BHCO	0.876 CA_for + -0.372 Curvature	33.878	0.000	0.883
BHVI	0.848 Curvature + -0.346 CA_for	20.101	0.000	0.817
BTNW	0.827 Curvature	21.566	0.001	0.683
CORA	0.625 ENN_MN	6.402	0.030	0.390
COYE	0.761 Exposure	13.771	0.004	0.579
CSWA	0.0.866 Exposure + -0.526 CA_for	8.893	0.007	0.664
DEJU	-0.812 CA_for + -0.631 SHAPE_AM_for	22.296	0.000	0.832
DOWO	0.602 CA_for	5.678	0.038	0.362
EABL	-0.767 FRAC_SD_nf + -0.485 Near_lk_dist + -0.356 SHAPE_AM_for	12.369	0.002	0.823
EATO	0.614 CA_for	6.063	0.034	0.377
EAWP	-0.572 Curvature + -0.549 SHAPE_AM_for	9.059	0.007	0.668
GRCA	0.761 Exposure	13.771	0.004	0.579
HETH	0.660 CA_for	7.730	0.019	0.436
INBU	1.058 SHAPE_AM_for + -0.754 ACT# + 0.399 Exposure	15.094	0.001	0.850
MOWA	0.979 Exposure + -0.538 CA_for + -0.363 Curvature	19.126	0.001	0.878
YSFL	0.758 Exposure + -0.462 Curvature	10.119	0.005	0.692
PIWO	0.740 Lake_area(m2)	12.131	0.006	0.548
PUFI	0.868 Curvature	30.456	0.000	0.753
SCTA	-0.767 FRAC_SD_nf + -0.485 Near_lk_dist + -0.356 SHAPE_AM_for	12.369	0.002	0.823
UNKN	-0.608 ENN_MN	5.852	0.036	0.369
SOSP	0.792 ENN_MN	16.843	0.002	0.627
VEER	0.709 ACT	10.136	0.010	0.503
WAVI	0.761 Exposure	13.771	0.004	0.579
WBNU	-1.252 Near_lk_dist + 0.768 ENN_MN + 0.452 ACT#	12.639	0.002	0.826
WITU	1.014 Lake_area(m2) + 0.381 Exposure	47.597	0.000	0.914
WTSP	0.731 Near_lk_dist	11.498	0.007	0.535
YRWA	0.823 SHAPE_AM_for + 0.391 Lake_area	14.922	0.001	0.768
MS_R	0.655 ACT	7.518	0.021	0.429
HU_ES	0.646 Curvature + 0.536 ACT	9.374	0.006	0.676
HU_OP	1.028 SHAPE_AM_for + -0.343 Near_st_dist + -0.362 ACT#	20.553	0.000	0.885
HU_G	-0.723 SHAPE_AM_for	10.953	0.008	0.523
NH_BC	0.811 SHAPE_AM_for	19.152	0.001	0.657
NH_Cnpy	-0.851 SHAPE_AM_for	26.250	0.000	0.724
NH_Cvty	0.710 Lake_area + -0.420 Near_lk_dist	14.437	0.002	0.762
NH_Gen	0.602 CA_for + 0.456 Near_lk_dist	41.616	0.000	0.902

Table 11. Stepwise forward logistic regression results for bat species groups and stand- and macro-level habitat variables for jack pine stands in Cass, Morrison, and Wadena Counties, Minnesota, USA.

Bat Species Group	Year	Habitat Variables	R^2
		Stand-level	
Myotis	2008	- VO	0.553
	2009	- CC	0.462
Hoary	2008	- BA_Sapp	0.468
		Macro-level	
Myotis	2009	+SHAPE_AM_for	1.000

Table 12. Stepwise forward logistic regression results for bat species groups and stand- and macro-level habitat variables for red pine stands in Oneida County, Wisconsin, USA.

Bat Species Group	Year	Habitat Variables	R^2
		<u>Stand-level</u>	
LabuPisu	2009	+BA_Pole	0.875
Hoary	2008	+Vcm3	0.405
		<u>Macro-level</u>	
LabuPisu	2008	+Near_lk_dist	0.513
	2009	+Near_rd_dist	0.619
Hoary	2008	+ENN_MN	0.508
	2009	- ACT_EHW	0.665

Table 13. Multiple stepwise linear regression results for bat species groups and stand-level habitat variables for jack pine stands in Cass, Morrison, and Wadena Counties, Minnesota, USA.

Bat Species Assemblage	Year	Habitat model variables with standardized beta values	$F_{(d.f.)}$	P	R^2
Myotis	2008	0.783 DWD_Decay	14.249	0.004	0.613
	2009	-0.605 BA_Sapp	5.771	0.037	0.366
LabuPisu	2008	0.743 DWD_Decay	11.114	0.009	0.553
	2009	0.582 DWD_Decay	5.132	0.047	0.339
HFG>35	2008	1.336 DWD_Decay + 0.723 Pole_Ht(m)	34.548	0.000	0.896
	2009	-0.670 BA_Sapp	8.138	0.017	0.449
LFG<35	2008	--	--	--	--
	2009	-0.810 BA_Tree	19.048	0.001	0.656
EpfuLano	2008	0.945 StndArea + -0.542 VO + -0.459 CC	11.887	0.004	0.836
	2009	-0.825 BA_Tree	21.298	0.001	0.680
Hoary	2008	--	--	--	--
	2009	0.775 VO	15.065	0.003	0.601
All HFG	2008	1.358 DWD_Decay + 0.751 Pole_Ht(m)	44.540	0.000	0.918
	2009	-0.669 BA_Sapp	8.122	0.017	0.448
All LFG	2008	0.663 StndArea	7.052	0.026	0.439
	2009	-0.877 BA_Tree	33.429	0.000	0.770

Table 14. Multiple stepwise linear regression results for bat species groups and macro-level habitat variables for jack pine stands in Cass, Morrison, and Wadena Counties, Minnesota, USA.

Bat Species Assemblage	Year	Habitat model variables with standardized beta values	$F_{(d.f.)}$	P	R^2
Myotis	2008	--	--	--	--
	2009	0.797 SHAPE_AM_for	17.416	0.002	0.635
LabuPisu	2008	--	--	--	--
	2009	--	--	--	--
HFG>35	2008	--	--	--	--
	2009	--	--	--	--
LFG<35	2008	--	--	--	--
	2009	--	--	--	--
EpfuLano	2008	--	--	--	--
	2009	-0.744 CA_for	12.387	0.006	0.553
Hoary	2008	--	--	--	--
	2009	0.638 Lake_Area(m2)	6.850	0.026	0.407
All HFG	2008	--	--	--	--
	2009	--	--	--	--
ALL LFG	2008	--	--	--	--
	2009	0.801 Lake_area(m2) + 1.134 SHAPE_AM_nf	25.071	0.000	0.848

Table 15. Multiple stepwise linear regression results for bat species groups and stand-level habitat variables for red pine stands in Oneida County, Wisconsin, USA.

Bat Species Assemblage	Year	Stand-level habitat model variables with standardized beta values	$F_{(d.f.)}$	P	R^2
Myotis	2008	--	--	--	--
	2009	0.673 DWD_Vcm3	8.282	0.016	0.453
LabuPisu	2008	--	--	--	--
	2009	-0.585 SnagDecay + 0.437 BA_Pole	44.334	0.000	0.908
HFG>35	2008	0.614 BA_HW	6.041	0.034	0.377
	2009	0.623 DWD_Vcm3	6.345	0.030	0.388
LFG<35	2008	-0.675 Pole_Ht(m) + 0.589 BA_HW	24.547	0.000	0.845
	2009	--	--	--	--
EpfuLano	2008	0.623 SnagDecay	6.347	0.030	0.388
	2009	--	--	--	--
All HFG	2008	0.589 BA_HW 0.601 DWD_Vcm3 + -0.474	5.306	0.044	0.347
	2009	SnagHeight(m)	7.410	0.013	0.622
All LFG	2008	-0.645 CC	7.115	0.024	0.416
	2009	--	--	--	--

Table 16. Multiple stepwise linear regression results for bat species groups and macro-level habitat variables for red pine stands in Oneida County, Wisconsin, USA.

Bat Species Assemblage	Year	Macro-level habitat model variables with standardized beta values	$F_{(d.f.)}$	P	R^2
Myotis	2008	--	--	--	--
	2009	-0.771 Near_lk_dist + 0.675 AREA_AM_for + 0.394 Lake_area(m2) + -0.200 ACT_EHW + -0.206 ENN_CV	47.185	0.000	0.975
LaboPisu	2008	0.863 Near_lk_dist + -0.424 ACT_WW	12.039	0.003	0.728
	2009	0.612 Near_lk_dist	5.990	0.034	0.375
HFG>35	2008	-0.628 CA_for	6.516	0.029	0.395
	2009	-0.673 Near_lk-dist	8.279	0.016	0.453
LFG<35	2008	--	--	--	--
	2009	0.586 Lake_area(m2) + -0.542 AREA_AM_for + 0.310 ENN_CV + 0.212 Near_rd_dist + -0.254 ACT_MF + -0.118 ACT_WW	206.693	0.000	0.996
Hoary	2008	0.857 Near_rd_dist + 0.513 ACT_WW + 0.326 Lake_area(m2)	16.76	0.001	0.863
	2009	Near_rd_dist	11.498	0.007	0.535
ALL_HFG	2008	--	--	--	--
	2009	-0.656 Near_lk_dist	7.550	0.021	0.430
ALL_LFG	2008	--	--	--	--
	2009	0.793 Lake_area(m2) + 0.543 Near_rd_dist	10.255	0.005	0.695

Table 17. Principal Components Analysis (PCA) results describing variation between jack pine and red pine stands according to stand-level habitat variables measured in 2009 in Cass, Wadena, and Morrison Counties in Minnesota and Oneida County of Wisconsin, USA.

Site-level habitat variable	First PC	Second PC	Third PC	Fourth PC	Fifth PC	Sixth PC	Seventh PC
BA_HW	0.861	-0.288	-0.183	0.132	0.134	-0.017	-0.255
BA_Shrub	0.850	-0.174	0.228	-0.079	0.021	-0.063	0.091
Vcm3	0.844	0.025	-0.046	0.211	0.149	-0.103	-0.197
BA_Sapp	0.817	-0.285	0.116	-0.032	-0.006	-0.122	0.325
BA_Pole	0.734	-0.419	-0.203	-0.035	0.095	0.093	-0.178
VO	0.709	0.170	0.338	0.028	-0.349	0.045	0.346
Shrub_Ht	0.693	-0.227	0.266	-0.424	-0.225	0.124	0.083
GC_WD_arcsin	0.682	0.054	-0.063	0.415	0.025	0.079	0.268
Sapp_Ht(m)	0.618	-0.285	-0.243	-0.355	0.025	-0.222	0.081
CC	0.517	-0.065	0.143	0.284	0.234	-0.386	-0.295
GC_O_arcsin	0.194	0.775	-0.019	0.062	0.101	-0.254	-0.190
Stnd_Perim/Area	0.334	0.766	-0.026	-0.149	0.163	0.199	0.285
SnagDecay	0.225	0.732	0.330	-0.077	0.311	0.295	-0.039
Tree_Ht(m)	0.454	-0.676	0.171	0.131	0.385	0.211	0.043
StndPerim(m)	0.079	0.674	-0.353	0.165	0.344	-0.007	0.481
StndAge	-0.206	-0.637	0.393	0.413	0.085	0.310	0.021
Cavities	0.282	0.620	0.464	-0.154	0.115	0.174	-0.236
Height(m)	0.300	0.618	0.321	-0.021	0.482	0.088	-0.181
Tree_HtCnpy(m)	-0.394	-0.548	0.527	-0.083	0.290	0.191	0.291
GC_S_arcsin	-0.091	0.070	-0.685	0.049	0.015	0.590	-0.158
SnagHW_BA(m2)	0.553	-0.205	-0.580	0.160	0.026	0.470	-0.055
DECAY	0.219	0.080	-0.139	0.709	-0.130	-0.251	0.037
GC_L_arcsin	0.042	-0.399	-0.335	-0.687	0.330	-0.224	0.062
BA_Tree	-0.421	-0.371	0.357	0.494	0.338	-0.001	-0.057
GC_H_arcsin	0.268	0.260	0.112	0.338	-0.736	0.088	0.004
StndArea	-0.315	0.021	-0.395	0.377	0.397	-0.223	0.305
Eigen values	6.969	5.064	2.659	2.411	1.956	1.407	1.197
% Variation	26.803	19.475	10.225	9.273	7.523	5.410	4.604

^a Values greater than 0.4 indicate significant loading for PC axis

Table 18. Principal Components Analysis (PCA) results describing variation between jack pine and red pine stands according to macro-level avian habitat variables measured in 2009 in Cass, Morrison and Wadena Counties, Minnesota and Oneida County Wisconsin, USA.

Macro-level habitat variables	First PC	Second PC	Third PC	Fourth PC	Fifth PC	Sixth PC	Seventh PC
TE_for	0.938	0.133	-0.088	0.122	-0.006	0.124	0.129
CONTAG	-0.895	0.056	0.332	0.164	0.040	-0.189	-0.122
SHAPE_AM_nf	0.845	-0.074	-0.361	0.282	-0.049	0.123	0.053
AREA_CV_for	0.770	-0.117	-0.148	-0.346	0.222	0.203	-0.226
CA_for (ha)	-0.761	0.384	0.177	-0.335	0.166	0.015	-0.054
SIDI	0.744	-0.170	-0.476	-0.350	-0.074	0.215	0.084
ENN_MN	-0.744	0.298	-0.160	0.393	0.144	0.194	0.009
FRAC_SD_for	0.739	-0.075	0.335	-0.278	0.152	-0.310	-0.086
FRAC_AM_for	0.682	0.579	0.281	0.126	0.162	0.002	-0.008
ACT_EHW	0.640	0.213	0.108	0.428	-0.052	-0.285	0.146
SHAPE_SD_nf	0.624	-0.451	-0.399	0.422	0.124	-0.037	-0.067
ENN_CV	-0.620	0.371	-0.084	0.286	0.394	0.309	-0.106
SHAPE_SD_for	0.607	0.300	0.545	-0.302	0.184	-0.220	-0.092
Near_lk_dist	-0.556	0.443	-0.177	0.375	-0.321	-0.232	0.113
ACT_D-OS	0.060	0.839	-0.315	0.178	-0.216	0.042	-0.114
Adj_CvrTyp(ACT)#	0.221	0.799	-0.206	0.309	0.030	-0.038	0.130
SHAPE_AM_for	0.462	0.739	0.270	-0.053	0.195	0.060	-0.117
Total_rd_L	0.048	0.698	-0.493	0.090	0.254	0.236	0.299
NP_nf	-0.031	0.628	0.575	-0.421	0.033	-0.020	0.218
AREA_CV_nf	0.528	0.625	0.137	-0.262	-0.270	0.057	0.315
ACT_D-LI	0.239	0.566	-0.158	0.203	0.198	0.117	-0.522
Exposure	-0.141	0.545	-0.213	-0.367	0.020	-0.531	0.065
Near_rd_dist	0.052	-0.282	0.782	0.210	-0.081	0.177	0.342
Curvature	-0.019	-0.045	0.732	0.043	0.493	0.313	0.020
ACT_MF	-0.365	0.145	-0.643	-0.138	0.338	-0.100	0.355
Total_st_L	-0.105	-0.241	-0.387	-0.741	-0.037	0.203	0.160
Near_st_dist	0.189	-0.273	0.372	0.726	0.058	0.069	0.367
ACT_WW	0.212	0.275	0.223	0.280	-0.676	0.160	-0.291
FRAC_SD_nf	0.330	-0.357	-0.224	0.425	0.474	-0.458	-0.039
Eigen values	8.506	5.535	4.076	3.357	1.781	1.351	1.206
% Variation	29.332	19.086	14.055	11.577	6.141	4.658	4.158

^a Values greater than 0.40 indicate significant loading for PC axis

Table 19. Multiple stepwise linear regression of stand-level PCs on avian abundance in Cass, Wadena, and Morrison Counties, Minnesota and Oneida County, Wisconsin, USA.

Bird species assemblage	Habitat PC with standardized beta	<i>F</i>	<i>P</i>	<i>R</i> ²
MS_NTM	0.433 StndPC_4 + 0.404 StndPC_1	5.668	0.011	0.351
MS_M	-0.650 StndPC_1 + 0.358 StndPC_6	12.875	0.000	0.551
HU_ES	-0.429 StndPC_1	4.958	0.371	0.184
HU_LS	0.530 StndPC_1 + -0.379 StndPC_6	7.734	0.003	0.421
HU_OS	-0.431 StndPC_1	5.013	0.036	0.421
NH_BC	0.414 StndPC_7	4.551	0.044	0.414
NH_Cnpy	-0.426 StndPC_7 + 0.422 StndPC_3	11.22	0.000	0.627

Table 20. Multiple stepwise linear regression of macro-level PCs on bird abundance in Cass, Wadena, and Morrison Counties, Minnesota and Oneida County, Wisconsin, USA.

Bird species assemblage	Habitat PC with standardized beta	<i>F</i>	<i>P</i>	<i>R</i> ²
MS_M	-0.588 MacroBrdPC_4	6.858	0.021	0.345
HU_ES	-0.579 MacroBrdPC_4	6.545	0.024	0.335
HU_OS	0.552 MacroBrdPC_4	5.694	0.033	0.305
HU_LS	0.824 MacroBrdPC_2	27.559	0.000	0.679
HU_Gen	-0.572 MacroBrdPC_2	6.336	0.026	0.328
NH_BC	0.853 MacroBrdPC_2	34.605	0.000	0.727
NH_Cnpy	-0.692 MacroBrdPC_2 + -0.494 MacroBrdPC_4	15.691	0.000	0.723
NH_Gen	-0.767 MacroBrdPC_1 + 0.393 MacroBRdPC_7 + -0.302 MacroBrdPC_2 + 0.267 MacroBrdPC_4	23.843	0.000	0.905

Table 21. Principal Components Analysis (PCA) results describing variation between jack pine and red pine stands according to macro-level bat habitat variables measured in 2009 in Cass, Morrison and Wadena Counties, Minnesota and Oneida County Wisconsin, USA.

Macro-level habitat variables	First PC	Second PC	Third PC	Fourth PC	Fifth PC	Sixth PC	Seventh PC
Total_st_L	0.969	0.013	0.030	-0.090	-0.137	-0.071	0.063
ENN_MN	-0.957	0.205	-0.114	0.021	0.094	0.004	-0.092
FRAC_SD_nf	0.922	-0.063	0.091	-0.081	-0.158	-0.217	0.131
SHAPE_AM_nf	0.881	0.320	-0.207	0.122	0.050	0.143	-0.079
Near_st_dist	-0.829	0.237	0.090	-0.331	-0.012	0.046	-0.158
ACT_MF	0.726	-0.082	0.212	-0.036	-0.328	-0.015	-0.343
TE_for	0.677	-0.444	0.270	0.216	0.035	0.286	-0.126
AREA_CV_nf	0.565	0.500	-0.260	0.456	0.265	0.054	-0.056
ACT_EHW	-0.555	0.404	-0.043	0.369	-0.359	-0.345	0.148
Adj_CvrTyp(ACT)#	-0.121	0.766	0.510	0.232	-0.227	0.047	0.052
Near_rd_dist	-0.576	-0.667	0.109	0.139	0.248	0.076	0.223
ACT_D-OS	0.275	0.652	0.483	-0.235	0.064	-0.119	0.152
ACT_WW	-0.084	0.634	-0.041	0.199	0.279	-0.433	0.403
ACT_D-LI	0.005	0.626	0.462	-0.248	0.031	0.297	0.078
CA_for	0.531	-0.619	0.416	-0.079	-0.062	-0.175	0.262
AREA_AM_for	-0.603	-0.609	0.456	0.070	-0.001	-0.112	0.048
ACT_Past-Hay	-0.221	0.470	0.238	0.030	-0.346	0.462	0.300
Curvature	-0.055	-0.473	0.629	0.022	0.195	-0.288	0.009
Near_lk_dist	0.215	0.388	0.413	0.253	0.309	-0.109	-0.289
ACT_OW	-0.081	-0.003	0.150	0.785	0.212	-0.165	-0.261
ACT_DF	-0.420	-0.189	0.234	0.458	-0.328	0.437	-0.167
Exposure	0.254	-0.111	0.014	0.132	0.645	0.505	0.395
ACT_CultCrps	-0.166	0.336	0.205	-0.474	0.500	-0.004	-0.428
Eigen values	7.228	4.581	2.102	1.907	1.634	1.402	1.142
% Variance	31.426	19.917	9.140	8.293	7.105	6.095	4.965

^a Values greater than 0.650 indicate significant loading for PC axis

Table 22. Multiple stepwise linear regression of stand-level PCs on bat activity index in Cass, Wadena, and Morrison Counties, Minnesota and Oneida County, Wisconsin, USA.

Bat species group	Year	Habitat PC with standardized beta	<i>F</i>	<i>P</i>	<i>R</i> ²
Myotis	2008	--	--	--	--
	2009	--	--	--	--
LabuPisu	2008	--	--	--	--
	2009	--	--	--	--
HFG>35	2008	--	--	--	--
	2009	-0.733 StndPC_3	25.611	0.000	0.538
LFG<35	2008	-0.580 StndPC_3 + 0.507 StndPC_1 + 0.323 StndPC_6 + 0.299 StndPC_2 + 0.247 StndPC_7	18.242	0.000	0.843
	2009	-0.680 StndPC_3 + 0.415 StndPC_1 + 0.260 Stnd_PC 2	15.719	0.000	0.702
EpfuLano	2008	0.425 StndPC_7	4.620	0.043	0.180
	2009	-0.631 StndPC_3 + 0.384 StndPC_2 + 0.356 StndPC_1	13.685	0.000	0.672
Hoary	2008	-0.493 StndPC_3 + -0.459 StndPC_4	7.787	0.003	0.438
	2009	-0.520 StndPC_3 + 0.464 StndPC_1 + 0.441 StandPC_2	14.179	0.000	0.632
All HFG	2008	--	--	--	--
	2009	-0.606 StndPC_3	12.748	0.002	0.367
All LFG	2008	-0.532 StndPC_3 + 0.424 StndPC_1 + 0.381 StndPC_7 + 0.342 StndPC_6 + 0.308 StndPC_2	13.808	0.000	0.802
	2009	-0.687 StndPC_3 + 0.406 StndPC_1 + 0.353 StndPC_2	21.316	0.000	0.762

Table 23. Multiple stepwise linear regression of macro-level PCs on bat activity index in Cass, Wadena, and Morrison Counties, Minnesota and Oneida County, Wisconsin, USA.

Bat species group	Year	Habitat PC with standardized beta	<i>F</i>	<i>P</i>	<i>R</i> ²
		0.433 MacroBtPC_1 + 0.412			
Myotis	2008	MacroBTPC_5	5.173	0.015	0.341
	2009	-0.442 MacroBtPC_2	5.356	0.03	0.196
HFG>35	2008	0.423 MacroBtPC_6	4.569	0.044	0.179
		-0.637 MacroBtPC_1 + 0.469			
LFG<35	2008	MacroBtPC_4 + 0.302 MacroBtPC_6	13.959	0.000	0.688
	2009	-0.722 MacroBtPC_1	23.992	0.000	0.522
EpfuLano	2008	-0.469 MacroBtPC_1	5.916	0.024	0.220
		-0.772 MacroBtPC_1 + 0.318			
	2009	MacroBtPC_4	24.135	0.000	0.697
	2009	-0.748 MacroBtPC_1	27.912	0.000	0.559
		-0.588 MacroBtPC_1 + 0.394			
All LFG	2008	MacroBtPC_4 + 0.342 MacroBtPC_6	9.179	0.001	0.592
		-0.833 MacroBtPC_1 + 0.292			
	2009	MacroBtPC_4	37.017	0.000	0.779

Table 24. Mann-Whitney U-test results of stand-level habitat variable comparison between jack pine and red pine stands.

Habitat Variable	Jack Pine		Red Pine		<i>P</i>
StndAge	52 ^b	[48, 62] ^c	62.500	[46, 74]	0.008
Stnd_Perim/Area	0.020	[0.01, 0.03]	0.010	[0.01-0.02]	0.011
GC_L_arcsin	64.3	[49.8, 77.8]	76.8	[25.4, 83.0]	0.009
GC_H_arcsin	33.7	[22.5, 43]	25.6	[11.5, 58.8]	0.007
GC_O_arcsin	27.6	[10.7, 40.1]	11.4	[5.0, 24.0]	0.001
BA_Tree	0.7	[0.4, 1.0]	0.9	[0.7, 1.4]	0.003
BA_Pole	0.02	[0.00, 0.04]	0.01	[0.0, 0.03]	0.024
BA_Sapp	0.01	[0.01, 0.04]	0.00	[0.01, 0.03]	0.007
BA_Con	0.6	[0.3, 0.8]	0.9	[0.7, 1.4]	0.000
BA_HW	0.10	[0.01, 0.3]	0.01	[0.00, 0.06]	0.002
BA_Shruh	0.01	[0.00, 0.03]	0.00	[0.00, 0.01]	0.003
VO	7.4	[5.3, 12.3]	4.8	[1.6, 11.8]	0.009
CC	10.1	[4.3, 27]	7.2	[3.5, 9.1]	0.039
Shrub_Stem	109.2	[79.4, 219.4]	50.9	[11.0, 192.3]	0.004
DWD_Vcm3	153366.3	[69842.7, 443002.4]	13374.4	[0.0, 59913.7]	0.000
Tree_HtCnpy(m)	9.8	[8.3, 12.2]	12.5	[8.6, 14.3]	0.001
SnagHeight(m)	10.6	[7.2, 34]	7.2	[0.0, 16.2]	0.008
SnagCon_BA(m 2)	0.3	[0.1, 0.4]	0.0	[0.0, 0.07]	0.000

^aMann-Whitney U-test

^bMedian

^c[Min, Max]

Table 25. Mann-Whitney U-test results of bird species relative abundance comparison between jack pine and red pine stands.

Avian Species and Species Assemblage	Jack Pine		Red Pine		<i>P</i>
AMCR	0.000 ^b	[0, 0.02] ^c	0.002	[0, 0.895]	0.007
AMRE	0.020	[0.003, 0.4]	0.000	[0, 0.001]	0.000
AMRO	0.002	[0, 0.007]	0.009	[0, 0.02]	0.013
BAWW	0.007	[0, 0.015]	0.000	[0, 0.05]	0.002
BHCO	0.010	[0.005, 0.033]	0.004	[0, 0.024]	0.018
CHSP	0.006	[0, 0.021]	0.011	[0.001, 0.028]	0.038
GCFL	0.008	[0, 0.017]	0.001	[0, 0.009]	0.001
GCKI	0.000	[0, 0]	0.000	[0, 0.005]	0.037
HOWR	0.004	[0, 0.021]	0.000	[0, 0.003]	0.003
PIWA	0.006	[0, 0.016]	0.029	[0.007, 0.041]	0.000
RBGR	0.005	[0, 0.010]	0.000	[0, 0.003]	0.000
REVI	0.014	[0, 0.030]	0.003	[0, 0.011]	0.004
SCTA	0.004	[0, 0.017]	0.000	[0, 0.001]	0.000
VEER	0.005	[0, 0.013]	0.000	[0, 0.003]	0.000
WTSP	0.000	[0, 0]	0.000	[0, 0.003]	0.033
MS_NTM	0.139	[0.089, 0.175]	0.113	[0, 0.137]	0.003
MS_R	0.089	[0.073, 0.105]	0.116	[0.008, 0.172]	0.003
HU_ES	0.062	[0.045, 0.084]	0.083	[0.014, 0.126]	0.021
HU_LS	0.098	[0.053, 0.130]	0.053	[0.011, 0.092]	0.002
NH_BC	0.067	[0.056, 0.088]	0.055	[0.006, 0.072]	0.002
NH_Cnpy	0.051	[0.023, 0.069]	0.075	[0.006, 0.096]	0.005

^aMann-Whitney U-test

^bMedian

^c[Min, Max]

* significant at $p \leq 0.05$

Table 26. Mann-Whitney U-test results of macro-level avian habitat characteristics between jack pine and red pine stands.

Macro- Habitat Variable	Jack Pine		Red Pine		P
CA_for (ha)	84.6 ^b	[64.1, 275.7] ^c	178.9	[132.7, 246.6]	0.050 ¹
PLAND_for	28.2	[21.4, 91.8]	59.7	[44.3, 82.4]	0.050 ¹
NP_for	28.0	[1.0, 36.0]	11.5	[1.0, 21.0]	0.060
LPI_for	10.8	[4.2, 91.8]	42.2	[18.1, 82.4]	0.083
TE_for	35685.0	[13380.0, 51240.0]	27510.0	[17010.0, 45750.0]	0.184
ED_for	119.0	[44.6, 171.0]	91.8	[56.9, 152.5]	0.184
AREA_AM_for	20.0	[5.5, 275.7]	97.4	[32.6, 246.6]	0.083
AREA_CV_for	171.5	[0.0, 327.6]	228.3	[0.0, 328.9]	0.165
SHAPE_AM_for	3.5	[2.9, 9.4]	3.8	[2.9, 6.4]	0.419
SHAPE_SD_for	1.0	[0.0, 2.4]	1.1	[0.0, 1.5]	1.000
SHAPE_CV_for	52.2	[0.0, 107.4]	52.8	[0.0, 79.9]	1.000
FRAC_AM_for	1.2	[1.2, 1.3]	1.2	[1.2, 1.3]	0.273
FRAC_SD_for	0.1	[0.0, 0.1]	0.1	[0.0, 0.1]	0.272
FRAC_CV_for	6.5	[0.0, 8.3]	6.1	[0.0, 8.1]	0.355
CA_nf (ha)	215.6	[24.7, 235.8]	120.8	[52.6, 166.8]	0.050 ¹
PLAND_nf	71.8	[8.2, 78.6]	40.3	[17.6, 55.7]	0.050 ¹
NP_nf	5.5	[2.0, 24.0]	8.5	[3.0, 20.0]	0.325
LPI_nf	71.4	[2.0, 77.7]	32.2	[9.5, 54.6]	0.083
TE_nf	35685.0	[13380.0, 51240.0]	27510.0	[17010.0, 45750.0]	0.184
ED_nf	119.0	[44.6, 171.0]	91.8	[56.9, 152.5]	0.184
AREA_AM_nf	213.4	[2.7, 230.4]	78.8	[18.7, 160.2]	0.094
AREA_CV_nf	171.2	[99.9, 222.4]	192.9	[140.5, 350.3]	0.204
SHAPE_AM_nf	6.6	[1.8, 8.8]	5.5	[2.8, 8.6]	0.356
SHAPE_SD_nf	2.2	[0.5, 3.4]	1.4	[0.7, 2.7]	0.166
SHAPE_CV_nf	79.7	[33.3, 117.7]	70.6	[42.5, 109.4]	0.603
FRAC_AM_nf	1.3	[1.1, 1.3]	1.2	[1.2, 1.3]	0.603
FRAC_SD_nf	0.1	[0.1, 0.1]	0.1	[0.0, 0.1]	0.106
FRAC_CV_nf	8.6	[5.6, 12.4]	7.8	[3.8, 10.2]	0.094
ENN_MN	72.8	[65.8, 149.6]	73.0	[61.9, 135.5]	0.817
ENN_CV	29.9	[18.1, 62.8]	28.3	[5.0, 79.6]	0.729
CONTAG	26.3	[8.6, 65.0]	21.6	[10.9, 47.1]	0.453
PRD	0.7	[0.7, 0.7]	0.7	[0.7, 0.7]	0.059
SIDI	0.4	[0.2, 0.5]	0.5	[0.3, 0.5]	0.057
SIEI	0.8	[0.3, 1.0]	1.0	[0.6, 1.0]	0.057

^aMann-Whitney U-test^bMedian^c[Min, Max]¹Independent means test failed

Table 26 (cont'd). Mann-Whitney U-test results of macro-level avian habitat characteristics between jack pine and red pine stands.

Macro- Habitat Variable	Jack Pine		Red Pine		<i>P</i>
Near_lk_dist	952.4	[228.7, 1691.6]	1027.4	[474.4, 2116.0]	0.729
Lake_area(m2)	1314.7	[831.7, 222826.2]	1246.5	[233.7, 1184845.9]	0.685
Near_st_dist	1296.5	[292.1, 1898.5]	381.1	[210.1, 794.7]	0.000 ¹
Total_st_L	1126.2	[324.0, 5905.1]	2046.8	[666.2, 3943.3]	0.332
Near_rd_dist	959.8	[275.1, 2472.4]	410.3	[154.2, 1063.0]	0.043*
Total_rd_L	2419.6	[237.6, 4617.6]	4469.6	[1178.5, 5942.4]	0.076
Adj_CvrTyp(ACT)#	4.0	[2.0, 8.0]	3.0	[2.0, 6.0]	0.477
Curvature	0.001	[-0.002, 0.012]	0.000	[-0.002, 0.005]	0.149
Exposure	1.4	[0.3, 3.2]	3.0	[1.8, 5.4]	0.001 ¹ *

^aMann-Whitney U-test

^bMedian

¹Independent means test failed

Table 27. Mann-Whitney U-test results of stand-level bat habitat characteristics between jack pine and red pine stands.

Bat Species and Species Assemblage	Year	Jack Pine	Red Pine	<i>P</i>	
Myotis	2008	0.0 ^b	[0.0, 0.6] ^c	0.2 [0.1, 3.8]	0.018
LFG<35kHz	2008	0.3	[0.1, 1.2]	0.1 [0, 0.2]	0.000
	2009	0.7	[0.2, 1.4]	0.3 [0.1, 0.7]	0.001
EpfuLano	2009	1.5	[0.2, 2.2]	0.4 [0.1, 0.7]	0.001
Hoary	2009	0.2	[0.1, 0.3]	0.1 [0.0, 0.1]	0.000
ALL_HFG	2008	0.5	[0.0, 10.7]	0.6 [0.3, 8.9]	0.003
ALL_LFG	2008	0.8	[0.2, 3.5]	0.2 [0.1, 0.4]	0.001
	2009	2.5	[0.5, 3.0]	0.6 [0.4, 1.4]	0.000

^aMann-Whitney U-test

^bMedian

^c[Min, Max]

Table 28. Mann-Whitney U-test results of macro-level bat habitat characteristics between jack pine and red pine stands.

Macro- Habitat Variable	Jack Pine		Red Pine		P^a
CA_for (ha)	79127.28 ^b	[73801.0, 114808.9] ^c	108126.7	[95632.4, 108126.7]	0.007 ^{1,*}
PLAND_for	40.3	[37.6, 58.5]	55.1	[48.7, 55.1]	0.007 ^{1,*}
NP_for	5761.0	[2891.0, 6045.0]	3468.5	[3259.0, 3468.5]	0.004 ^{1,*}
LPI_for	17.8	[14.0, 45.7]	11.4	[10.6, 11.4]	0.000 ^{1,*}
TE_for	16999230.0	[16700610.0, 18182490.0]	17717430.0	[17525460.0, 17717430.0]	0.003 ^{1,*}
ED_for	86.6	[85.1, 92.6]	90.2	[89.3, 90.2]	0.003 ^{1,*}
AREA_AM_for	15789.1	[12596.4, 70389.9]	9880.2	[6593.0, 9880.2]	0.008 ^{1,*}
AREA_CV_for	3406.8	[2653.5, 4486.2]	1999.8	[1707.6, 1999.8]	0.000 ^{1,*}
SHAPE_AM_for	25.8	[22.3, 70.6]	26.0	[20.6, 26.0]	0.954
SHAPE_SD_for	1.5	[1.4, 2.0]	1.9	[1.7, 1.9]	0.004 ^{1,*}
SHAPE_CV_for	74.2	[71.5, 108.0]	97.2	[87.8, 97.2]	0.004 ^{1,*}
FRAC_AM_for	1.3	[1.3, 1.4]	1.3	[1.3, 1.3]	0.326
FRAC_SD_for	0.1	[0.1, 0.1]	0.1	[0.1, 0.1]	0.000 ^{1,*}
FRAC_CV_for	5.9	[5.8, 6.0]	6.4	[6.4, 6.4]	0.000 ^{1,*}
CA_nf (ha)	117221.8	[81539.8, 122547.2]	88220.9	[86877.5, 88220.9]	0.007 ^{1,*}
PLAND_nf	59.7	[41.5, 62.4]	44.9	[44.2, 44.9]	0.007 ^{1,*}
NP_nf	2630.0	[2351.0, 4981.0]	2841.5	[2286.0, 2841.5]	0.525
LPI_nf	52.6	[18.3, 57.6]	39.0	[37.3, 39.0]	0.043 ^{1,*}
TE_nf	16999230.0	[16700610.0, 18182490.0]	17717430.0	[17525460.0, 17717430.0]	0.003 ^{1,*}
ED_nf	86.6	[85.1, 92.6]	90.2	[89.3, 90.2]	0.003 ^{1,*}
AREA_AM_nf	91894.1	[21834.8, 104439.3]	66656.0	[61903.7, 66656.0]	0.073
AREA_CV_nf	4507.4	[3650.8, 5105.4]	4667.5	[4503.2, 4667.5]	0.013 ^{1,*}
SHAPE_AM_nf	92.9	[50.3, 103.3]	110.4	[107.0, 110.4]	0.000 ^{1,*}
SHAPE_SD_nf	2.2	[1.6, 2.2]	2.5	[2.4, 2.5]	0.000 ^{1,*}
SHAPE_CV_nf	125.6	[92.3, 130.1]	143.8	[141.0, 143.8]	0.000 ^{1,*}
FRAC_AM_nf	1.4	[1.4, 1.4]	1.4	[1.4, 1.4]	0.000 ^{1,*}
FRAC_SD_nf	0.1	[0.1, 0.1]	0.1	[0.1, 0.1]	0.000 ^{1,*}
FRAC_CV_nf	5.3	[5.2, 5.4]	6.0	[5.9, 6.0]	0.000 ^{1,*}
ENN_MN	88.3	[85.9, 89.3]	78.5	[77.2, 78.5]	0.000 ^{1,*}
ENN_CV	64.4	[56.1, 66.8]	52.1	[50.7, 52.1]	0.000 ^{1,*}
CONTAG	23.6	[21.1, 25.0]	21.9	[20.6, 21.9]	0.000 ^{1,*}
PRD	0.0	[0.0, 0.0]	0.0	[0.0, 0.0]	1.000
SIDI	0.5	[0.5, 0.5]	0.5	[0.5, 0.5]	0.004 ^{1,*}
SIEI	1.0	[0.9, 1.0]	1.0	[1.0, 1.0]	0.004 ^{1,*}

^aMann-Whitney U-

test

^bMedian; ^c[Min, Max]* significant at $p \leq 0.05$ ¹independent- samples median test significant at $p \leq 0.05$

Table 28 (cont'd.). Mann-Whitney U-test results of macro-level bat habitat characteristics between jack pine and red pine stands.

Macro- Habitat Variable	Jack Pine		Red Pine		<i>P</i> ^a
Near_lk_dist	840.8	[228.7, 1691.6]	1027.4	[474.4, 1027.4]	0.729
Lake_area(m2)	1444.6	[831.7, 222826.2]	1246.5	[233.7, 1246.5]	0.685
Near_st_dist	1257.1	[292.1, 1898.5]	381.1	[210.1, 381.1]	0.000 ^{1,*}
Total_st_L	1398664.5	[948742.5, 1438927.2]	3146520.5	[2961539.2, 3146520.5]	0.000 ^{1,*}
Near_rd_dist	1004.5	[299.7, 2472.4]	410.3	[154.2, 410.3]	0.043*
Total_rd_L	1641019.0	[1442172.7, 1998452.6]	2504574.7	[2431580.2, 2504574.7]	0.000 ^{1,*}
Adj_CvrTyp(ACT)#	4.0	[2.0, 5.0]	3.0	[2.0, 3.0]	0.477
Curvature	0.0	[0, 0]	0.0	[0.0, 0.0]	0.954
Exposure	0.7	[0.1, 3.8]	1.1	[0.6, 1.1]	0.273

^aMann-Whitney U-test

^bMedian; ^c[Min, Max]

* significant at $p \leq 0.05$

¹independent- samples median test significant at $p \leq 0.05$

Table 29. Stand-level habitat characteristics measured at each of 24 study stands, included in logistic and linear regressions explaining habitat relationships to wildlife metrics as well as Mann-Whitney U-test comparisons between jack pine and red pine stands Minnesota and Wisconsin, USA, 2009.

Variable label	Variable	Units
StndAge	Stand age	years
StndArea	Stand area	ha
StndPerim	Stand perimeter	m
Stnd_Perim/Area	Stand perimeter to area ratio	m/m ²
Shrub_Ht	Shrub height	cm
GC_S_arcsin	Ground cover- soil	%
GC_L_arcsin	Ground cover- litter	%
GC_H_arcsin	Ground cover-herbaceous	%
GC_WD_arcsin	Ground cover- woody debris	%
GC_O_arcsin	Ground cover- other	%
BA_Tree	Basal area- tree	m ²
BA_Pole	Basal area- pole	m ²
BA_Sapp	Basal area- sapling	m ²
BA_Con	Basal area- conifer	m ²
BA_HW	Basal area- hardwood	m ²
BA_Shruh	Basal area- shrub	m ²
VO	Visual obscurity	none
CC	Canopy closure	none
Stem_cnt	Shrub stem count	none
Vcm3	Downed woody debris (DWD) volume	cm ³
DECAY	DWD decay	none
Tree_Ht(m)	Tree height	m
Tree_HtCnpy(m)	Tree height to bottom of canopy	m
Pole_Ht(m)	Pole height	m
Sapp_Ht(m)	Sapling height	m
Height(m)	Snag height	m
SnagDecay	Snag decay	none
Cavities	Snag- number of cavities	none
SnagCon_BA(m2)	Snag- basal area of conifer	m ²
SnagHW_BA(m2)	Snag- basal area of hardwood	m ²

Table 30. Macro-level habitat characteristics measured from 24 study stands, included in logistic and linear regressions explaining habitat relationships to wildlife metrics as well as Mann-Whitney U-test comparisons between jack pine and red pine stands Minnesota and Wisconsin, USA.

Variable label	Variable	Units	Additional description
CA_for, nf	Total (Class) Area- forest, non-forest	ha	
PLAND_for, nf	Percentage of Landscape- forest, non-forest	%	
NP_for, nf	Number of Patches- forest, non-forest	none	
LPI_for, nf	Largest Patch Index- forest, non-forest	%	area of largest patch/ total landscape area
TE_for, nf	Total Edge- forest, non-forest	m	sum of all patch edges
ED_for, nf	Edge Density- forest, non-forest	m/ha	sum of all patch edges/ total landscape area
AREA_AM ^a , CV for, nf	Patch Area- forest, non-forest	ha	area of patch
SHAPE_AM, SD, CV_for, nf	Shape Index Distribution- forest, non-forest	none	patch perimeter/ minimum perimeter of patch possible for maximally compact patch
FRAC_AM, SD, CV_for, nf	Fractal Index Distribution- forest, non-forest		$2 \ln \text{patch perimeter (m)} / \ln \text{patch area (m}^2\text{)}$
ENN_MN, CV	Euclidean Nearest Neighbor	m	distance to nearest neighboring patch of same type
CONTAG	Contagion	%	index of landcover interspersion
PRD	Patch Richness Diversity	#/100 ha	# of different patch types/total landscape area (ha)
SIDI	Simpson's Diversity Index	none	$1 - \sum(\text{across all patch types}) \text{proportional abundance of each patch type squared}$
SIEI	Simpson's Evenness Index	none	$[1 - \sum(\text{across all patch types}) \text{proportional abundance of each patch type squared}] / [1 - (1/\#\text{patches})]$
Near_lk_dist	Distance to nearest lake	m	
Lake_area	area of nearest lake	m ²	
Near_st_dist	Distance to nearest stream	m	
Total_st_L	Length of nearest stream	m	
Near_rd_dist	Distance to nearest road	m	
Total_rd_L	Total length of all roads	m	

^a Area weighted mean (AM), Coefficient of variation (CV), Standard Deviation (SD), Mean (MN)

Table 30 (cont'd.). Macro-level habitat characteristics measured from 24 study stands, included in logistic and linear regressions explaining habitat relationships to wildlife metrics as well as Mann-Whitney U-test comparisons between jack pine and red pine stands Minnesota and Wisconsin, USA.

Variable label	Variable	Units	Additional description
ACT#	Count of adjacent cover types	none	
ACT_	Adjacent cover type	none	OW-Open water; D-OS-Developed open space; D-LI-Developed low intensity; DF-deciduous forest; EF- Evergreen forest; MF-Mixed forest; Shr-Scrb-Shrub Scrub; Past-Hay- Pasture Hay; CultCrps-Cultivated crops; WW-Wooded wetland; EHW-Emergent herbaceous wetland
Curvature	degree to which landscape is concave/convex		second derivative of slope
Exposure	extent to which terrain is exposed or sheltered from the elements		$(\text{mean elevation} + \text{elevation at sampling point}) / \text{standard deviation of } (\text{mean elevation} + \text{elevation at sampling point})$ across the landscape

^a Area weighted mean (AM), Coefficient of variation (CV), Standard Deviation (SD), Mean (MN)

