Development of a Comprehensive Conservation Strategy for the North Shore Highlands Region of Minnesota in the Context of Future Wind Power Development

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Introduction

Each autumn, millions of birds migrate from their breeding grounds in the northern hemisphere to wintering areas in the continental United States, Mexico, Central America, and South America (Rich 2004, Bildstein 2006). The North Shore Highlands parallels the Lake Superior shoreline from Duluth through Grand Portage, Minnesota to the US border with Canada. This region's prominent ridgelines and Lake Superior coastline funnel migrating birds into this migration corridor (Hofslund 1966, Mueller and Berger 1967, Bildstein 2006). As a result, the North Shore Highlands hosts the largest migratory route for birds of prey in Minnesota and is among the highest in the US. In addition, recent data suggest that the numbers of non-raptor bird species moving along the north shore of Lake Superior are orders of magnitude larger than those for raptors.

Migration periods constitute a critical life-stage for these birds as mortality rates may be higher during migration than during breeding or over wintering periods (Sillett and Holmes 2002, Smith and Moore 2003). Large bodies of water and other major topographical features cause a nonrandom distribution of migrating birds on the landscape in both periods of active flight and rest (Goodrich and Smith 2008). Landscape features that define the North Shore Highlands (Lake Superior, ridgelines, river valleys) result in a major congregation of migratory birds (raptors and passerines) that are both actively flying and resting within the region.

With the current emphasis on renewable energy (Great Lakes Commission 2011), the North Shore Highlands region has become a focal point for potential wind power, with many plans already in progress (Mageau et al. 2008). Besides wind turbines there is also increased activity in the development of communication towers in the region. The North Shore Highlands region is recognized as one of the top tourist destinations in Minnesota and the upper Midwestern US. Over the past twenty years, the area has experienced increased developmental pressure from recreation, tourism, and exurban housing (MNDNR 2006).

Conservation strategies aimed at the protection of migratory birds are incomplete without the focus on migratory bird flyway and stopover habitat preservation (Petit 2000, Mehlman et al. 2005). To develop conservation strategies to protect *en route* migratory birds within this region, there is a need to understand the cues by which migrants choose migratory flight paths and stopover habitats (Ewert et al. 2011, Buler et al. 2007, Bonter et al. 2009). Our overall goal is to provide data and mapping products that will contribute to a comprehensive conservation plan for migratory birds highlighting the potential risks of wind energy development within the North Shore Highlands region. We have worked closely with several community groups in the region (e.g., Grand Portage Indian Reservation, Cook County Local Energy Project, and Lutsen Mountains Resort) who have expressed an interest in wind energy development. Our purpose will be to eliminate or minimize interactions with migratory birds if wind turbines are placed in the North Shore Highlands region.

OBJECTIVES (July 2010 – December 2011)

I. Telemetry -
   a. During fall 2010 and 2011, 25 radio-collared Sharp-shinned Hawks and/or Northern Goshawk will be followed through the North Shore Highlands region to compare these movements with those observed and mapped along the North Shore of Lake Superior during the fall of 2008, 2009, and 2010.

II. Conservation Recommendations

a. Analyze data and develop recommendations for migratory bird conservation in the context of future wind energy development for the North Shore Highlands ecological subsection.

We note that in 2008 and 2009 data were gathered on migratory bird movements in the North Shore Highlands under funding from the Minnesota Coastal Zone Management program (Peterson et al. 2010, Peterson and Niemi 2011, Seeland et al. ms). In 2010 data for migratory bird movements along the north shore of Lake Superior were gathered as part of a project funded by the USDI Fish and Wildlife Service (Project No. 00010606). Compilation and analysis of these data were a part of this current project under objective 2.

Methods

Study Area. The general location of the study includes the broad area from Duluth to the US-Canada border in extreme northeast Minnesota (Figs. 1 and 2, Appendix A). The study area included an approximate 10-12 kilometer swath from the Lake Superior shoreline landward.

Above Canopy Movement. Migratory bird data were gathered at 24 survey points organized in eight transects (three sites per transect) established between Duluth and Grand Portage, Minnesota (Fig. 1). During the fall migration (August – November) bird surveys were conducted three to four times each year (2008, 2009, and 2010). All daily counts at each of the three survey points along transects were gathered simultaneously by three researchers. Survey sites were established at locations with optimum views of the surrounding landscape and at three distances perpendicular to the Lake Superior shoreline (approximately 2, 5, 10 km). These sites included natural overlooks, clearings with the aid of a tree-stand (e.g., gravel pits and clear-cuts), fire towers (Finland, Grand Portage), and a 45-foot lift. All birds actively migrating were recorded for 7 hours each day between sunrise and 1600. Each bird was identified to the lowest taxonomic group possible, assigned a flight height, flight direction, and recorded at the point on the landscape where first detected. All bird locations and data were entered into a geographic information system (ArcGIS 10). All observations were summarized as the number of birds recorded per hour of observation.

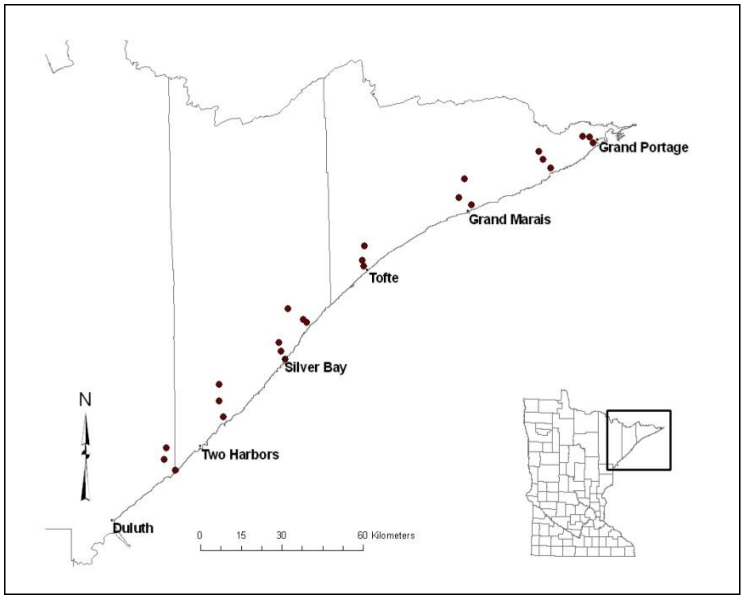

Figure 1. Migratory bird survey transects (8 in total) and site locations (3 sites per transect) in reference to towns along the North Shore of Lake Superior, Minnesota (see Appendix A).

Below Canopy Habitat Use. A total of fifteen survey sites were established to gather data on bird use within habitats along the north shore of Lake Superior. Each site consisted of six - 500 meter survey transects defined by a parallel distance to the Lake Superior shoreline (<1, 1-3, 3-6 km; Figure 2). All transect surveys occurred on public recreational trails (hiking, skiing, and snowmobile) with an average 50% closed canopy. Sites were surveyed from sunrise to 4 hours after sunrise and followed the Hanowski et al. (1990) transect survey protocol. Surveys were conducted at each site simultaneously by three observers each at one of the three sites parallel from shore. All birds heard or observed inside and outside 50-m on either side of the transect were identified to the lowest taxonomic group possible and recorded at the location first detected. Transect routes were recorded by GPS units and entered into a GIS for further spatial and landscape analysis.

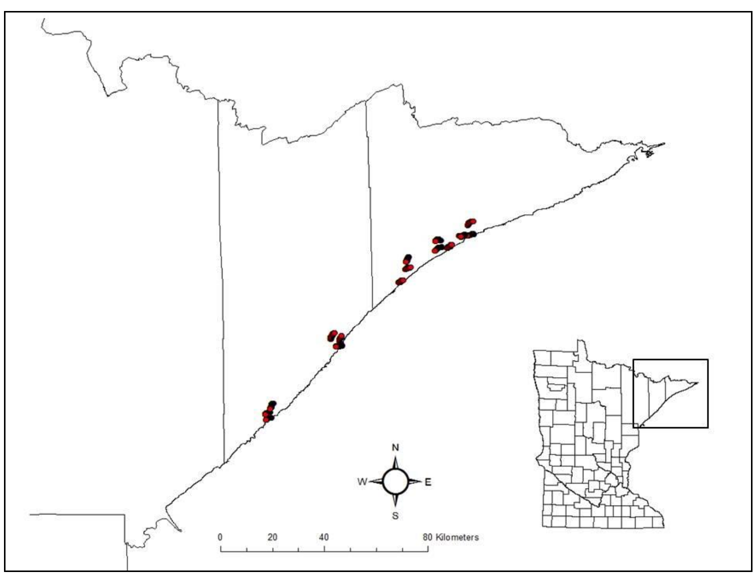

Figure 2. Locations of below canopy transect sites along Lake Superior's north shore in Minnesota, USA.

Telemetry. The portion of the project was initiated and approved by the Institutional Animal Care and Use Committee (IACUC) of the University of Minnesota (IACUC Code Number 1106A00641). Approval was also received from the US Fish and Wildlife Service for capture, banding, and placement of transmitters on Sharp-shinned Hawks or Northern Goshawks (Permit Number 20583 to David L. Evans). Transmitters were purchased ($173 each) from Advanced Telemetry Systems in Isanti, MN. They were tail-mounted A4540 transmitters weighing 2.8 grams, with Pulsar R (40 ppm), Pulsar W (20 ms), and with a warranty life of 48 days. They also included an activity switch to determine whether the individuals were active or resting.

Capture stations for Sharp-shinned Hawks or Northern Goshawks were established at a gravel pit owned by SJ Bautch Construction Company, Grand Marais, MN located at the mid-distance site of the above canopy Grand Marais transect and in an open farm field located near Grand Marais. This former location had an average of 19 Sharp-shinned Hawks observed per day over 12 days of sampling at this site from 2008-2010. Individuals captured were attempted to be located every 15 minutes during daylight hours and tracked for as long as possible while in the study region or until they migrated past Hawk Ridge in Duluth. An antenna system at Hawk Ridge was installed to identify whether an individual with a transmitter passed by the site. This antenna system should identify if a radioed bird passed Hawk Ridge within a 5 km swath.

Statistical Methods.

Above Canopy. We performed exploratory data analysis for the above canopy data using R software. All data tables were exported from ArcGIS into Microsoft Excel and then imported into R. For summary statistics, birds were divided into raptor and nonraptor categories. Raptors were further broken down into the groups: eagles, falcons, accipiters, and buteos. By reporting in birds per hour, we standardized the data by time spent observing at each site.

Below Canopy. Mean bird observations were calculated for each 500m by 100m transect segment using data from all three collection seasons (2008-2010). Bird means were analyzed by migration strategy (long, short, and permanent resident) and major guilds represented. The long distance and short distance migration groups were generated by adding all appropriate identified and unidentified passerines that were observed before (long) and after (short) a natural break in the seasonal timing of the identified long and short distance migrants. Landscape variables were averaged for each transect segment and included distance from shore, elevation, and change in slope. The categorical presence of a ridgeline was also included. Habitat variables included proportion of deciduous, conifer, mixed tree types, and brush-wetland in each study segment. Linear regression (R software) was used to compare bird parameters to individual, and combinations of, landscape and habitat variables.

Telemetry. All detections of each individual were entered into a GIS for each 15-minute interval when the bird was located. Analyses of these detections were completed using standard software for wildlife telemetry observations. We summarized the movement patterns for each individual captured.

Results

Above Canopy. A total of 18,037 raptors (Appendix B) and 160,421 non-raptors were recorded during the three fall migration seasons of 2008-2010. Each study transect was visited at least three times each season with a total of 623 observation hours. Over all years, the highest numbers of raptors per hour were observed at the Silver Bay transect while the highest numbers of non-raptors per hour were observed at the Knife River transect (Table 1). The largest raptor migration day was on 20 October 2008 at the Knife River transect (911 raptors). The largest nonraptor migration day was on 7 October 2010 also at the Knife River transect (13,363 non-raptors). The most common species/guilds of birds observed in decreasing order (% of total) were unidentified passerines (songbird; 22%), unidentified warblers (11%), American Robins (9%), Blue Jays (8%), American Crows (7%), unidentified blackbirds (4%), Cedar Waxwings (4%), Purple Finches (3%), Common Grackles (3%), and Broad-winged Hawks (2%). Of the raptors observed, Broad-winged Hawks (22% of total), Sharp-shinned Hawks (19%), and Bald Eagles (17%) were the most common. All non-raptors combined (mostly passerines) represented nearly 90% of the total migrants utilizing the north shore region.

Table 1. Mean number of raptors, nonraptors, and total birds counted per hour of observation at each above canopy transect during fall migration 2008-2010.

Sites	Raptors/Hr	Nonraptors/Hr	Total Birds/Hr
Knife River	31	410	441
Encampment	18	346	364
Silver Bay	33	183	215
Finland	21	159	180
Tofte	32	284	317
Grand Marais	22	254	276
Hovland	16	190	206
Grand Portage	14	88	102

Distances from Duluth and Shore. Distance measurements for each site (3 sites per transect) were obtained using the distance tool in ArcGIS to represent the point where each bird or group of birds were observed, not the distance to actual birds. We recorded a decreasing trend in raptors and nonraptors observed per hour when moving away from Duluth (northeast) along the North Shore towards Grand Portage (Figs. 3 and 4, respectively). The observation of raptors and nonraptors per hour also decreased when moving away from the Lake Superior shoreline (Figs. 5 and 6, respectively).

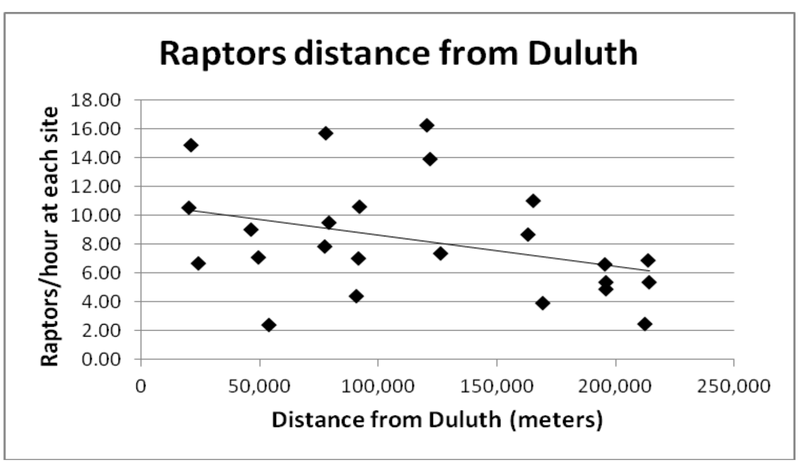

Figure 3. Mean number of raptors observed per hour during fall migration 2008-2010 along the north shore of Lake Superior.

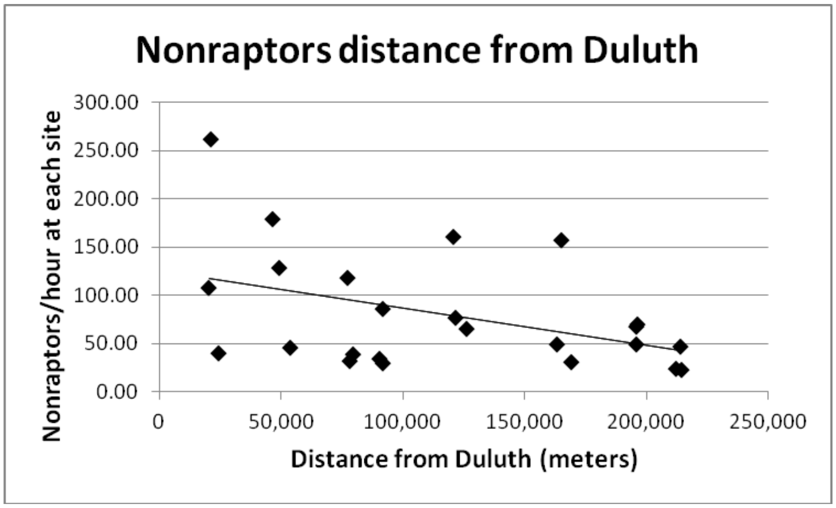

Figure 4. Mean number of non-raptors (mostly songbirds) observed per hour during fall migration 2008-2010 along the north shore of Lake Superior.

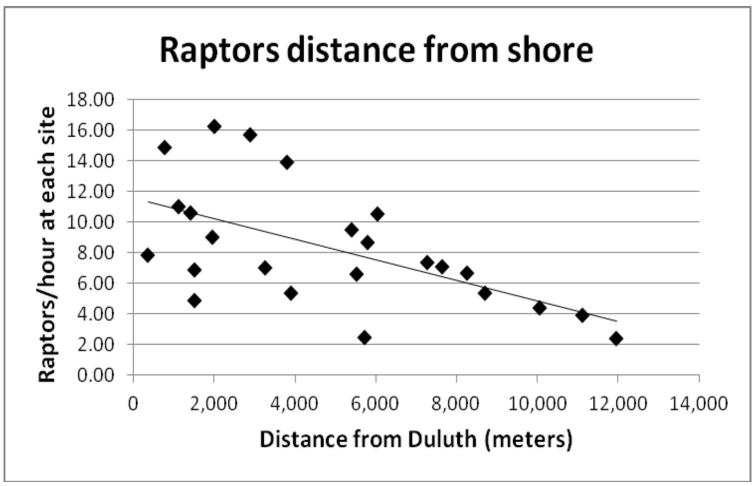

Figure 5. Mean number of raptors per hour recorded at each site within each transect along the north shore of Lake Superior.

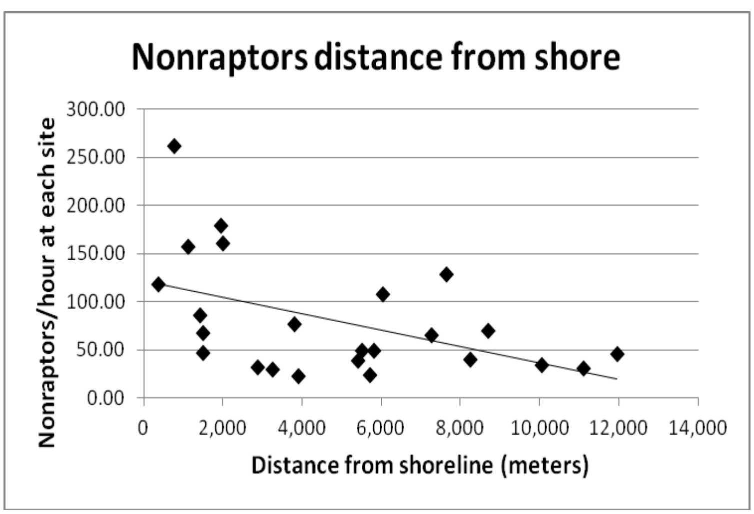

Figure 6. Mean number of non-raptors per hour recorded at each site within each transect along the north shore of Lake Superior.

Flight Height. – The airspace occupied by raptors differed between raptor groups (Fig. 7). Accipiters (Sharp-shinned Hawks, Cooper's Hawks, and Northern Goshawks) and falcons (American Kestrels, Merlins, and Peregrine Falcons) were more often observed flying at lower altitudes as compared to Buteos (Broad-winged Hawks, Red-Tailed Hawks, and Rough-Legged Hawks) and Eagles (Bald and Golden). The proportion of Sharp-shinned Hawks and American Kestrels was highest within 100 m of the canopy. Higher proportions of Red-tailed Hawks, Broad-winged Hawks, Bald Eagles, and Turkey Vultures were flying at heights between 100 and 500 m. The raptors observed above 500 m were largely Broad-winged Hawks and Bald Eagles.

Non-raptors were mostly observed flying between the tree canopy and 100 m above the canopy (Fig. 7). The proportion of passerine species was greatest within 100 m of the canopy. Cranes, ravens, geese, and other waterfowl made up the majority of non-raptors above 100 m in altitude in the nonraptor group.

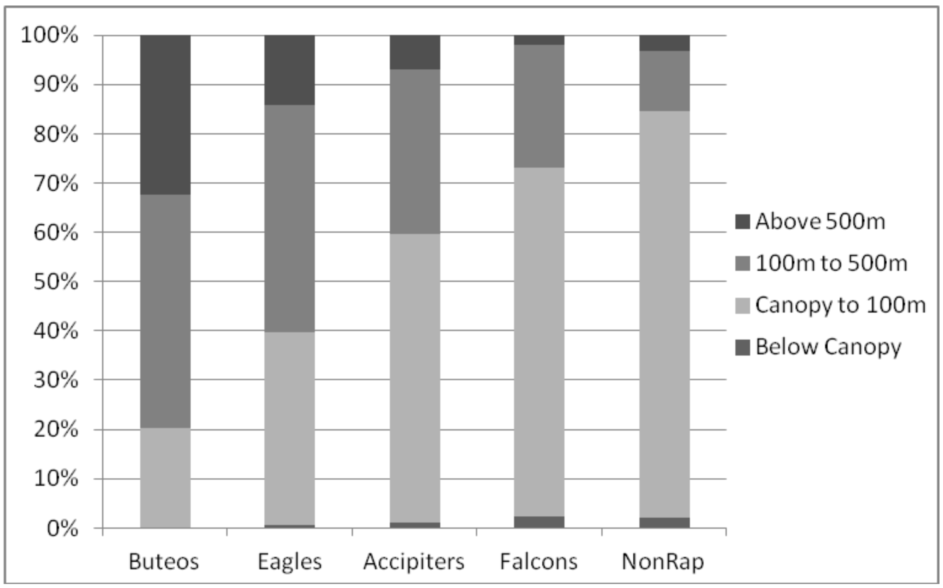

Figure 7. Proportions of the major raptor groups and all nonraptors in each flight height category recorded during the North Shore migration surveys 2008-2010.

Temporal Factors. –Non-raptors were most active during the first two hours of surveys (1-1.5 hours after sunrise to 3-3.5 hours after sunrise) then activity dropped off rapidly throughout the remainder of the day (Fig. 8). Raptor activity increased during the third and fourth hours of daily surveys, peaked around the sixth hour, and then displayed a decrease as the survey continued.

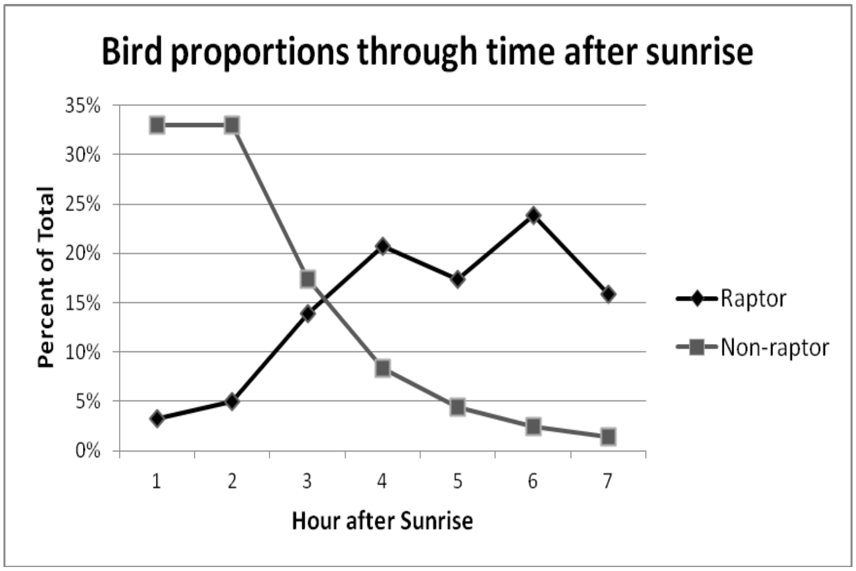

Figure 8. Proportion of total non-raptors and raptors recorded during each hour of observation. Hour 1 begins at 1-1.5 hours after sunrise, hour 7 is the seventh hour after the start of the survey.

Below Canopy. A total of 28,131 individual birds of 95 different species, were observed using habitats within the north shore region during the fall 2008-2010 below canopy surveys. Sites were visited at least twice during each migration season. The most common bird observations were unidentified passerines and unidentified warblers (Appendix C). Identification to species for all individuals is difficult or impossible when birds are migrating in flocks or groups through the vegetation. Individuals were identified to species whenever possible, but this was only possible when clear views were made. These two bird groups likely represent a high proportion of long distance migrants. The most common species observed were permanent residents (Black-capped Chickadees, Red-breasted Nuthatches, and Downy Woodpeckers) and short distance migrants (White-throated Sparrows and Cedar Waxwings). The most common bird guilds represented include Thrush spp., Warbler spp., and Sparrow spp. The most common species identified in these groups were American Robin, American Redstart, and White-throated Sparrow.

Mean bird parameters exhibited normal distributions (Johnson 1995) justifying use of linear regression analysis and models. Linear regression results are exhibited in Table 2. Long distance migrants were most significantly explained by a combination of an increasing distance from shore, increasing elevation, and the presence of a ridgeline. These migrants were also more common in brush-wetland habitats with low mixed tree species. Short distance migrants were slightly related to an increase in the change of the slope of a site and distance from shore. Permanent residents and thrushes were most significantly related to distance from shore, although in opposite patterns. Permanent residents were most commonly found near shore and (Fig. 9a) in areas with low deciduous trees. Thrushes were most significantly associated with increasing distance from shore (Fig. 9b). Warblers were not strongly related to any measured variables but were slightly more common in areas with a higher proportion of brush and wetland habitat. Sparrow species were not strongly associated with any measured variables but were slightly related to a decrease in the proportion of conifer trees.

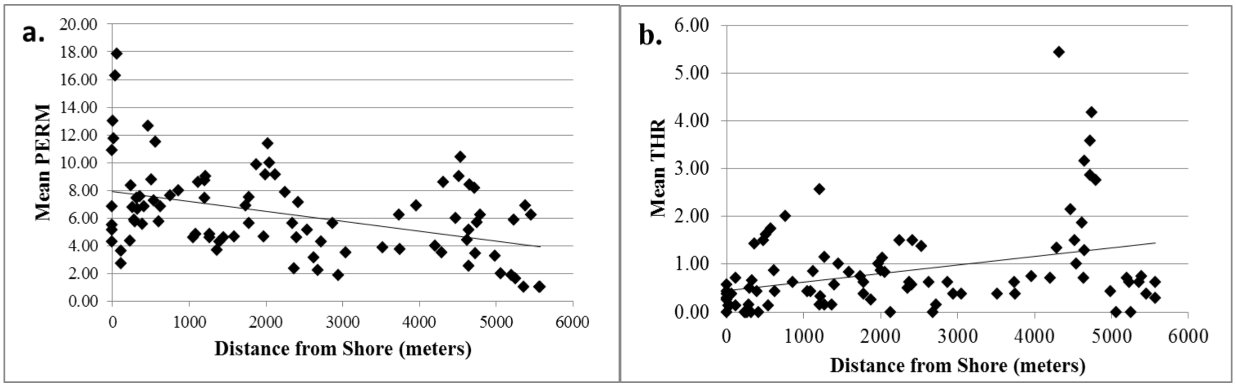

Figure 9a and b. The relationship of (a) permanent residents (PERM) and (b) Thrush spp. (THR) with increasing distance from the shoreline of Lake Superior during fall migration.

Table 2. Results of regression analyses testing the ability of landscape and habitat variables to explain mean abundance of long (LONG) and short (SHRT) distance migrants, permanent residents, Thrush spp., Warbler spp. (WAR), and Sparrow spp. (SPA) along the north shore of Lake Superior during fall migration. Variables include distance from shore (Dist), Average Elevation (Elev), Presence of a ridgeline (Rdgln), Change in slope (ChngSlp), proportion of brush and wetland habitat (Brsh_Wtld), deciduous trees (Decid), conifer trees (Conif), and mixed tree types (Mix). Cells containing no values did not exhibit significant relationships. (-) depicts a negative direction of the relationship, all others are positive with P-values <0.05*, <0.01**, <0.001***.

	LONG	**SHRT**	**PERM**	**THR**	**WAR**	**SPA**
Variables:	**adj R^2**	**adj R^2**	**adj R^2**	**adj R^2**	**adj R^2**	**adj R^2**
Dist	--		(-) 0.67***	0.11***	--	--
Elev	--	--	(-) 0.24***	0.08**	--	--
Rdgln	--	--	--	--	--	--
ChngSlp	--	0.05*	(-) 0.04*	--	--	--
Dist+ChngSlp	--	0.05*	(-) 0.19***	0.11**	--	--
Elev+Rdln	--	--	(-) 0.25***	0.07*	--	--
Dist+Elev	0.10**	--	(-) 0.23***	0.10**	--	--
Dist+Rdln	--	--	(-) 0.16***	0.11**	--	--
Dist+Elev+Rdln	0.12**	--	(-) 0.25***	0.11**	--	--
Brsh_Wtld	0.03*	--	--	--	0.05*	--
Decid	--	--	(-) 0.24***	--	--	--
Conif	--	--	0.16***	--	--	(-) 0.03*
Mix	(-) 0.04*	--	0.09**	--	--	--

Telemetry. A total of eight individual Sharp-shinned Hawks were caught, banded, and transmitters mounted. No Northern Goshawks were caught. The Sharp-shinned Hawks with transmitters included those summarized below.

1) Hatch year female (transmitter frequency – 164.012) caught on 9/7/2011 and signal lost on 9/9/2011 – individual generally stayed in the Grand Marais area after capture,
2) Hatch year female (164.294) caught on 9/13/11 – signal lost near Caribou Trail on 9/15/11 – individual was tracked for approximately 30 km,
3) Second year female (164.393) caught on 9/14/11 – signal lost south of Moose Mountain near Lutsen on 9/15/11, individual was tracked for approximately 40 km,
4) Hatch year female (164.434) caught on 9/16/11 – found dead near Hwy 61 9/20/11 – individual had lost a substantial amount of weight,
5) Second year female (164.473) caught on 9/21/11 – signal was lost on 9/24/11 south of Lookout Mountain in Cascade State Park – individual was tracked for approximately 23 km,
6) Second year female (164.484) caught on 9/23/11 – signal was lost on 10/9/11 – the individual continued to move in various areas around Grand Marais until it was lost,
7) Hatch year female (164.642) caught on 10/4/11 – signal was lost that evening on 10/4/11, and
8) Second year female (164.743) caught on 10/5/11 – signal was lost at noon on 10/5/11 due to a malfunction on the receiver.

The antenna system at Hawk Ridge did not detect any of the Sharp-shinned Hawks with radio transmitters moving past the Ridge. In addition, on 19 October 2011 an airplane reconnaissance was used to determine the location of the seven Sharp-shinned Hawks with transmitters that had been lost. None of the individual Sharp-shinned Hawks were detected during the flight along the entire North Shore from Cloquet, MN (30 km west of Duluth, MN) to Grand Marais, MN. The detection distance of test transmitters placed on the ground was 2.5 km.

The primary trapping site was located between the eastern end of Devil's Track Lake and Grand Marais, while the secondary trapping site was located north of Grand Marais. A summary of the five Sharp-shinned Hawks tracked for more than one day are shown in Figure 10. They are number 2 (as defined above with a red track), 3 (light yellow with blue dots), 4 (white), 5 (black), and 6 (yellow with black dots). The number of days that each of the five individuals were tracked are as follows: 2 for three days, 3 for two days, 4 for five days, 5 for four days, and 6 for 17 days. Based on three of the individuals, migratory pathways appear to be southwest and in a direction near the shoreline. Signals for each of these individuals were lost in the extensive forested areas along the North Shore that are typified by few roads, plus substantial topography. A combination of limitations in distance of detection and the lack of access were the primary reasons that the signals were lost.

It was surprising that many of the individuals (e.g., numbers 1, 4, and 6) spent considerable time in areas surrounding the trap site or even in the case of number 4 that moved to the northeast from the trap site. This individual was the one that was found dead after five days in the general area. We have no evidence that the transmitter caused any harm to this individual because its weight was more than adequate to mount the transmitter (165.5 g or transmitter was 1.7 % of body weight), but the individual had lost considerable weight when it was found dead (128.0 g). This female was a first year bird and mortality rates are known to be high for these species.

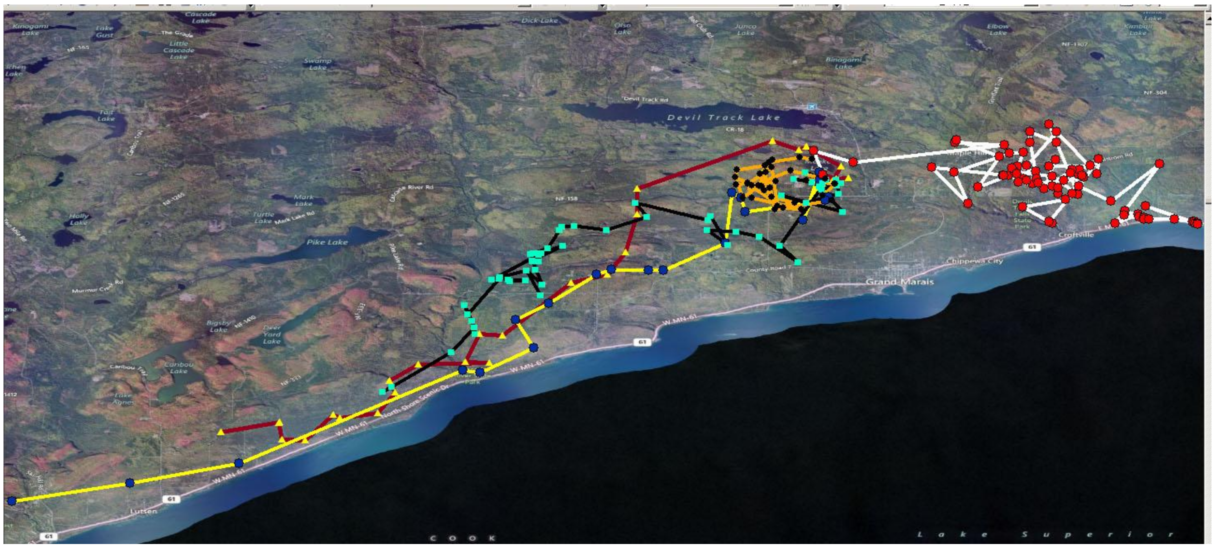

Figure 10. Movement patterns for five Sharp-shinned hawk individuals within the North Shore highlands region during September and early October 2011.

Presentations. In addition to this report, the results of the project have been presented at several professional conferences. They included 1) The Wildlife Society Meeting, Fargo, ND, February 2012, 2) Raptor Research Foundation National Meeting, Duluth, MN, October 2011, 3) Joint Annual Meeting of Association of Field Ornithologists, Cooper Ornithological Society, and Wilson Ornithological Society, Kearney, NE, March 2011, and 4) Great Lakes Wind and Wildlife Workshop, Indianapolis, IN, March 2011.

Discussion

General observations. We observed thousands of raptors and tens of thousands of nonraptors during our sampling of migrating birds both above and below the canopy of the north shore of Lake Superior. Clearly these represent a small percentage of the actual numbers of birds migrating along the north shore because we did not sample every day or every daylight hour during the migration season.

A considerable number of species of concern and species of greatest conservation need were also observed. For example, we observed 3021 bald eagles, 127 golden eagles, 66 peregrine falcons, 56 North goshawk, and 103 osprey. Examples of observations of nonraptors during below-canopy counts included 100 rusty blackbirds, 7 olive-sided flycatchers, 109 winter wrens, 55 Canada warblers, 13 red crossbill, 2 scarlet tanagers, and 1 golden-winged warbler. It is important to note that species identification can be difficult while conducting counts because of the large number of individuals and their rapid movements through the vegetation. This activity is much more difficult than simply observing birds when extra time can be spent in species identification. Standard counts of both raptors and nonraptors at Hawk Ridge in Duluth MN have averaged over 80,000 raptors and several hundred thousand nonraptors during fall migration (www.hawkridge.org).

Above-canopy. Distance from Duluth and Distance from Shore. These data confirmed that thousands of raptors and tens of thousands of nonraptors migrate within the North Shore Highlands region of Minnesota. For all raptors and nonraptors, a decreasing trend was observed moving northeastward along the shore from Duluth and moving inland from the Lake Superior shoreline. A funneling effect caused by the position of Lake Superior and ridges running parallel to the shore is often sited as the mechanism that causes raptors to concentrate near shore and near Duluth, MN (the end of the Lake Superior 'barrier' when traveling south; Hofslund 1966, Mueller and Berger 1967).

Nonraptors (mostly passerines) also exhibited this trend of movement along the north shore of Lake Superior. In general, passerines make much less or no use of thermal lift and ridge lift as raptors do during migration periods. In addition, many of the passerines observed are known to be nocturnal migrants and were observed mostly during the early morning hours when thermals have yet to develop. The concentration of nonraptors near the shoreline of Lake Superior as well as an increased abundance near Duluth are likely due in part to the same ‘wind drift’ mechanism that funnel raptors within this corridor: ridges along the coast and the 'barrier' presented by Lake Superior. During daylight hours, passerines and other nonraptors are unlikely to cross Lake Superior so they follow the coastline southwest towards Duluth. During nighttime hours, these same birds may use the coastline as a guide keeping them near the shore. In the early morning hours, migrants caught over water were observed re-orientating themselves towards shore.

Flight Height*.* – All bird groups migrating along the north shore of Lake Superior occupied the airspace within 100 m of the forest canopy at some level. This is the area that directly corresponds with communication tower and wind turbine blade sweep heights. The majority of nonraptors (mostly passerines) traveled within this airspace. As passerines are not built to utilize thermals, the majority of these birds migrate at low flight heights observed as flights just above the canopy. Among the raptors, higher proportions of accipiters and falcons were observed flying between the canopy and 100m above compared to buteos and eagles. Niles et al. (1996) found that raptors fly lower over habitats they occupy during the remainder of the year, perhaps for foraging purposes while on migration. The majority of the landscape along the north shore is forested, and as many nonraptors fly at this height, it is likely that accipiters and falcons take advantage of these prey opportunities while migrating through the region. Buteos and eagles, on the other hand, are built to soar and are often observed either gaining altitude on thermals or gliding from high altitudes between thermals (Kerlinger and Gauthreaux 1985).

Below-canopy**.** Bird use of areas along the coastline of Lake Superior varied among migratory groups and bird guilds. Thrushes, represented by both long and short distance species, and long-distance migrants were more common at areas further from the shoreline. The landscape features define areas inland from the Lake Superior include higher elevations and ridgelines. Whereas permanent residents, mostly black-capped chickadees and red-breasted nuthatches, exhibited an opposite response and were more commonly found near shore and at lower elevations. In this study, permanent residents represented the most abundant bird group. Had we examined landscape and habitat use by bird abundance alone, actual migrant use of areas would have been overshadowed by permanent resident abundance and ultimately overlooked the migrant use of these other landscape features. It is a possibility that permanent residents are attracted to the shoreline and the greater number of human dwellings and bird feeders close to the shoreline.

Many stopover habitat restoration and protection efforts occur in close proximity to, or directly adjacent to, coastlines. These data illustrate the importance of protecting areas used by migrating birds at locations such as ridgelines as well as coastal areas. In addition, bird abundance alone cannot be the only measurement used to represent migratory bird use of areas along the north shore.

Telemetry. The ability to trap and follow raptors with radios proved to be very difficult in the rugged landscape of the north shore of Lake Superior. Despite the fact that we had observed an average of 19 sharp-shinned hawks per day at the trap site during three previous years of observations at the site, the fall of 2011 was very warm with a considerable number of days with west winds, so migration movements were low. Trapping was continuously run from early September through early October 2011, yet we were only able to capture eight individuals that were suitable for the placement of radio transmitters. For instance, many males were too small for the placement of a 2.8 g transmitter.

It was interesting how many of the sharp-shinned hawks stayed within the immediate trapping area or around the area north of Grand Marais after trapping. The three individuals that we were able to follow for more than 20 km did move in the anticipated direction to the southwest and tended to follow the shoreline area. What is surprising is that none of the individual sharp-shinned hawks with transmitters that we were unable to follow were recorded at Hawk Ridge in Duluth. The migratory pathways of these birds are surprising, but we suspect that these individuals moved to the northern side of Hawk Ridge where the mounted antenna systems were unable to pick them up over the ridge. The other possibility is that the individuals either moved very close to the shoreline or they flew across Lake Superior. Our personal observations during this study indicate that birds were observed moving along the shoreline in a pathway along the shoreline of Lake Superior. Several observers, however, did note seeing birds move away from the shore out toward the lake but quickly lost sight of the birds. We note that this was a very rare occurrence. Hawk Ridge in Duluth records an average of 16,000 sharp-shinned hawks each fall. Our data would suggest that this number may be very conservative if many of the sharp-shinned hawks are moving farther to the north of Hawk Ridge, moving close to the shoreline, or are moving across Lake Superior before reaching Hawk Ridge.

Summary - Conservation Issues and Recommendations

The coastal zone of Lake Superior is heavily utilized by migrating birds during the fall migration season. During migration, many boreal forest birds of Canada, Alaska, and northern MN, rather than heading due south, begin their fall migration by heading in a more easterly direction, for reasons that presumably include a) avoiding the unforested prairies of central Canada and the U.S., b) evolutionary instinct, and c) they are pushed by westerly winds (Fig. 11). As a result of this trajectory, a significant proportion of these migrants encounter the Great Lakes region. The Great Lakes are “barriers” to migrating birds because they are void of safe places to land and require much energy to cross. Dominant ridges and valleys paralleling Lake Superior's inhospitable waters act as topographical cues that concentrate and funnel birds along the north shore.

Identification and prioritization of habitats and airspace important for migratory birds within Lake Superior's coastal zone should include an evaluation of day-time and night-time use, as well as early and late season assessment. Here we present key factors in identifying important areas for day-time migrants (airspace) and long-distance migrants (landscape and habitat) only. We present important features within 6000 meters (3.7 miles) of the shoreline as distances beyond this reach were outside the scope of the below-canopy habitat use portion of this study.

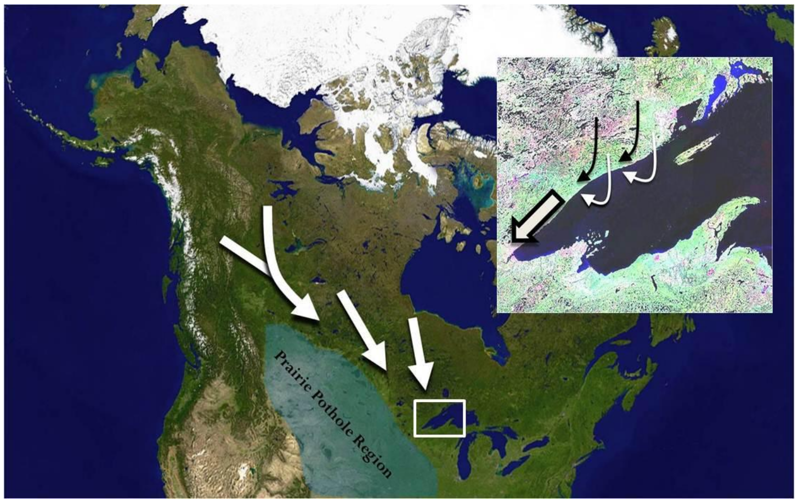

Figure 11. Illustration of migratory bird movement in relation to the Great Lakes region and the north shore of Lake Superior.

Airspace Use. The use of airspace by diurnal migrating birds within the coastal zone of Lake Superior varied with time of day, time of season, weather, and the presence of major topographical features. There is a difference in airspace use between smaller birds (mostly passerines) and the larger soaring birds (mostly raptors). The smaller birds observed during the daylight hours included both diurnal and nocturnal migrants. As these birds are susceptible to wind drift, westerly and southerly winds push these birds towards the north shore. Around sunrise, there is a large movement of small birds in the airspace *between the coastline and the first major ridgeline*. The movement includes birds that are heading to land from over Lake Superior, birds that have stopped along the coastline during the night, and birds that have stopped along the coastline the previous day. As many raptors rely on thermals and ridge-lift, their movement does not start until mid- to late-morning. Raptors are also heavily using the same near shore airspace as the smaller birds but their reliance on ridge-lift creates important airspace use along *prominent ridgelines* at various distances from shore. All birds also follow lead-lines that form from both ridgelines and *river valleys*. Many small birds use river corridors as lead lines away from Lake Superior (e.g., drift compensation). In addition river valleys can create their own ridge-lift as many are accompanied by *steep slopes*.

In summary, the primary recommendations for conservation of migratory bird airspace use include the following and are illustrated in Figs. 10 and 11.

1) The airspace between the shoreline and first prominent ridgeline (~1000m from shore) is an area intensively used by both fall migrating raptorial and non-raptorial birds.
2) Prominent ridgelines within 6000km of the shoreline also are used as leading lines and provide lift for migratory birds during migration, especially raptors. Use of these ridgelines tends to decrease landward from the first, highest ridgeline.
3) The airspace between the canopy and 100 m above the canopy are used extensively by eagles, falcons, accipiters, and non-raptors during their fall migration that corresponds with the airspace where wind turbines and communication towers are found.
4) Several mitigation measures are possible in order to minimize collisions with migratory birds including a) avoiding the peak migration seasons in September and early October, b) migration movements are most intense when winds have a westerly component (southwest, west, and northwest), c) migratory movements for non-raptors occur within the first two hours of sunrise, while the timing of migration of raptors is most intense three to seven hours after sunrise in combination with favorable westerly winds.
5) Based on additional data from Hawk Ridge, Duluth, MN, there are significant movements (tens of thousands) shoreline movements by Common Nighthawks (*Chordeiles minor*) at dusk, especially during the last two weeks of August, and large numbers of nocturnal movements by owls during late September and October (Evans et al. 2012). There is no information on migratory pathways used by owls along the north shore of Lake Superior.
6) Diurnal movements by fall migrating birds over water near the shoreline were minimal, except for movements by gulls, small numbers of corvids, and relatively low numbers of waterfowl.

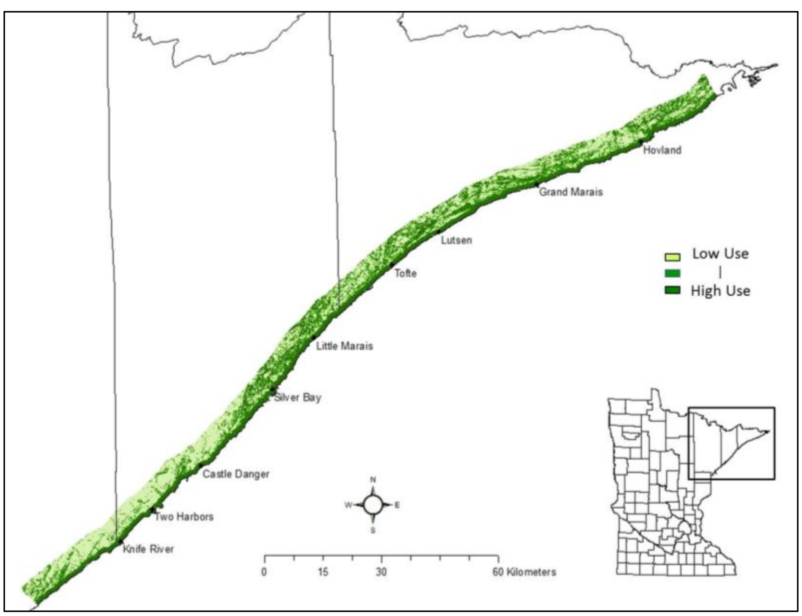

Figure 12. Map of diurnal migratory bird airspace use (low to high) within the Lake Superior coastal zone of Minnesota

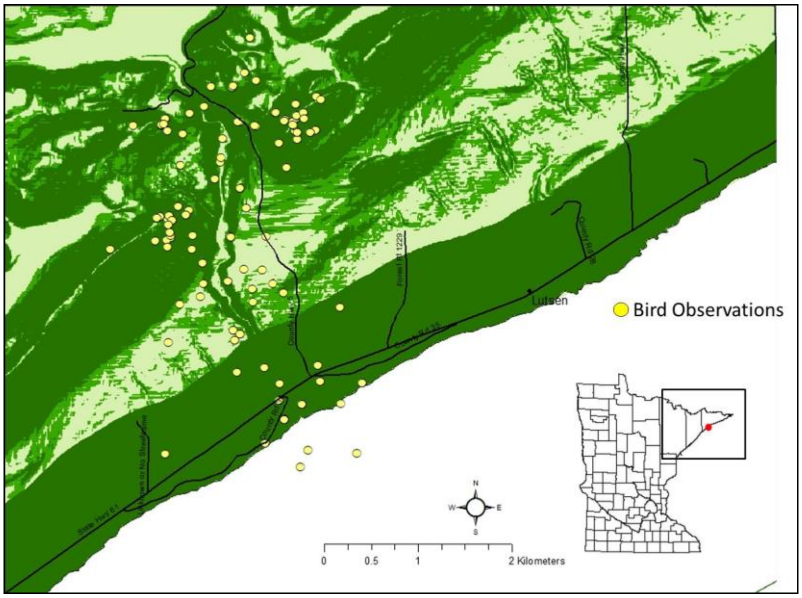

Figure 13. Airspace use by diurnal migratory birds near Lutsen, Minnesota, and recorded bird observation locations during 2009 and 2010 surveys. Darker areas predicted to be high use.

Habitat Use. As long distance migratory birds forage and rest in habitats within the coastal zone of Lake Superior, areas of heavy use are defined by both landscape and habitat characteristics. A summary of the major areas of use by migratory birds in below-canopy counts are the following and are illustrated in Figs. 14 and 15.

1) Below canopy movements of migratory birds were most intense within 1000 m of the shoreline and at distances away from the shoreline above 300 m elevation.
2) Habitats primarily used below canopies by fall migrant birds included wetlands, bogs, and deciduous forests, especially within the coastal zones described above.
3) Many heavily used areas were also defined by proximity to *ridgelines and rivers (e.g., riparian areas).*

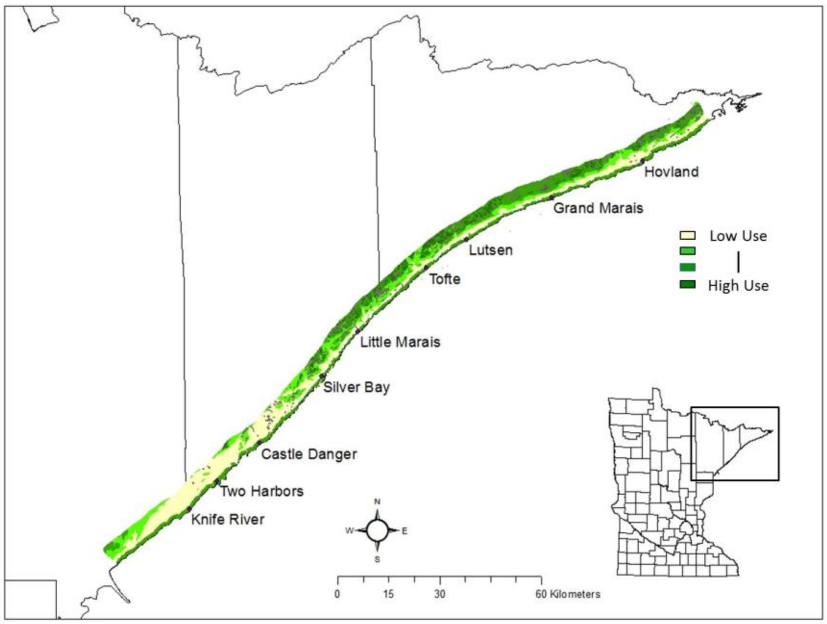

Figure 14. Map of migratory bird habitat use (low to high) within the Lake Superior coastal zone of Minnesota

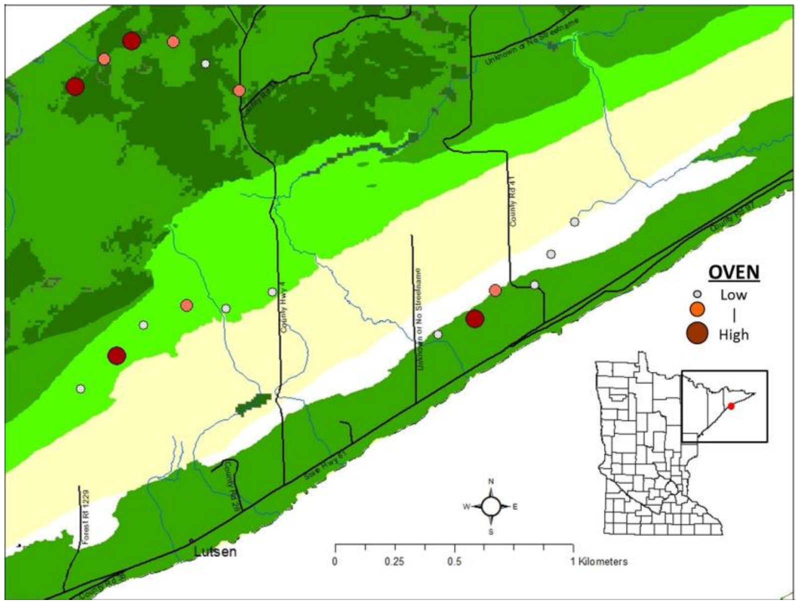

Figure 15. Habitat use by migratory birds near Lutsen, Minnesota, and mean Ovenbird (OVEN) abundance during below canopy surveys, 2008-2010. Darker colors indicate areas predicted to be high use.

Applications/Future Needs. - The survey approach used in this study has proven to be exceptionally productive for studying migratory movements and stopover habitat use. Visual methods of studying migratory movements are useful where detailed observations or large sample sizes are limited using other methods, as is the case along the north shore of Lake Superior. The topography of the region limits the use of radar to detect diurnal movement or nocturnal stopover use because the ridgelines block radar beams from the primary Doppler radar unit in Duluth. The methods utilized for this study can be tailored to any region where a more detailed understanding of the migratory pathways is desired. A series of vantage points with a wide view of the landscape and transect surveys through various landscape and habitat give a more detailed picture of a migration corridor. This information can be especially useful in siting new tower and wind power developments. Future work with tracking individual raptor species will likely need to rely on satellite transmitters that do not rely on individuals attempting to track individuals through heavily wooded areas with few roads and considerable topography.

Several sets of guidelines on the construction of new wind power developments have been developed to minimize impacts on birds. A common thread among these guidelines is the importance of identifying potential conflicts, and to avoid placing development in areas highly important to birds, including migratory pathways (US Fish and Wildlife Service 2003). The results of this and future studies can be used in combination with guidelines that are currently evolving. Using the methods described here, regional maps of migratory pathways can be produced and used to identify the areas that are the most sensitive to development. With the increasing popularity of wind power, the cumulative impacts on birds are of immediate conservation concern, considering direct mortality resulting from collisions has been documented at wind farms (Smallwood and Thelander 2008). It is vital that migratory pathways be identified in detail over large regions to avoid cumulative negative effects on migrating birds.

When we considered the topography of the region, it appears that at least for migration raptors, the first two major ridgelines along the shore act as leading lines, concentrating these birds along these ridgelines and along the shore. In addition, migratory songbirds appear to be targeting these ridgelines for stopovers as well. Wind energy feasibility studies have identified such ridgelines as having a potential for wind turbine development (Mageau et al. 2008). In this context, it is crucial that we understand the flight behaviors and stopover habitats of birds that migrate along the north shore of Lake Superior. Proper wind turbine and tower siting within this migration corridor will help to preserve one of the largest migrations in the Midwest and among the largest in the US.

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Appendix A. Latitude, longitude, and altitude of each observation point. Observation points were arranged in eight transects numbered 1 through 8. Each transect contained three study sites lettered a through c in increasing distance from the Lake Superior shoreline.

Transect	**Site**	**Latitude**	**Longitude**	**Altitude (M)**
1	a	46° 56' 51.139" N	91° 47' 33.295" W	201
	b	46° 58' 53.453" N	91° 50' 46.611" W	319
	c	47° 1' 9.709" N	91° 50' 1.754" W	419
2	a	47° 6' 49.788" N	91° 33' 28.610" W	303
	b	47° 9' 57.789" N	91° 34' 31.449" W	381
	c	47° 13' 2.399" N	91° 34' 22.797" W	449
3	a	47° 17' 44.159" N	91° 15' 3.884" W	231
	b	47° 19' 15.967" N	91° 16' 7.836" W	387
	c	47° 20' 49.688" N	91° 16' 40.233" W	454
4	a	47° 24' 34.317" N	91° 8' 21.727" W	417
	b	47° 25' 13.863" N	91° 9' 29.304" W	430
	c	47° 27' 22.718" N	91° 13' 55.762" W	572
5	a	47° 35' 5.542" N	90° 51' 22.566" W	430
	b	47° 36' 11.096" N	90° 51' 46.135" W	355
	c	47° 38' 59.079" N	90° 50' 53.595" W	402
6	a	47° 46' 14.099" N	90° 19' 0.108" W	361
	b	47° 47' 39.649" N	90° 22' 46.267" W	490
	c	47° 51' 13.416" N	90° 20' 48.117" W	538
7	a	47° 52' 36.279" N	89° 55' 13.225" W	372
	b	47° 54' 19.759" N	89° 57' 33.903" W	452
	c	47° 55' 53.025" N	89° 58' 42.471" W	457
8	a	47° 57' 10.729" N	89° 42' 26.569" W	256
	b	47° 58' 17.484" N	89° 43' 25.632" W	441
	c	47° 58' 28.447" N	89° 45' 33.521" W	520

Appendix B. Raptor species observed and total number counted during fall migration surveys in 2008, 2009, and 2010.

Species Name	**Count**	**Species Name**	**Count**
American Kestrel	617	Red-tailed Hawk	1238
Bald Eagle	3021	Rough-legged Hawk	343
Cooper's Hawk	42	Sharp-shinned Hawk	3413
Golden Eagle	127	Turkey Vulture	1294
Merlin	144	Unidentified Accipiter	385
Northern Goshawk	56	Unidentified Buteo	1271
Northern Harrier	170	Unidentified Eagle	108
Osprey	103	Unidentified Falcon	220
Peregrine	66	Unidentified Raptor	1489
Red-shouldered Hawk	**1**		

Appendix C. Bird species, migration guild (Guild) and number of species observed (Count) at below canopy sites during fall migration surveys along Lake Superior's north shore 2008-2010. (Guild: LONG = Long distance migrant, SHRT = Short distance migrant, PERM = Permanent resident, MIG = General migrant (Long or Short), NA = Not enough information to determine migration guild).

Species Name	Guild	Count
Alder Flycatcher	LONG	2
American Crow	PERM	101
American Goldfinch	SHRT	110
American Kestrel	SHRT	1
American Pipit	SHRT	8
American Redstart	LONG	441
American Robin	SHRT	335
Bald Eagle	SHRT	6
Black-and-white Warbler	LONG	130
Black-backed Woodpecker	PERM	5
Black-capped Chickadee	PERM	1944
Belted Kingfisher	LONG	11
Blue-headed Vireo	LONG	5
Blackburnian Warbler	LONG	18
Blue Jay	SHRT	410
Blackpoll Warbler	LONG	7
Boreal Chickadee	PERM	1
Brown Creeper	SHRT	215
Black-throated Blue Warbler	LONG	9
Black-throated Green Warbler	LONG	69
Broad-winged Hawk	LONG	8
Canada Goose	SHRT	1
Canada Warbler	LONG	55
Cedar Waxwing	SHRT	649
Chipping Sparrow	SHRT	12
Common Grackle	**SHRT**	**22**
Common Merganser	SHRT	25
Common Raven	PERM	58
Common Yellowthroat	SHRT	63
Chestnut-sided Warbler	LONG	63
Dark-eyed Junco	SHRT	263
Downy Woodpecker	PERM	855
Eastern Bluebird	SHRT	5
Eastern Kingbird	LONG	1
Eastern Phoebe	SHRT	5
Eastern Wood Pewee	LONG	14
Evening Grosbeak	PERM	9
Fox Sparrow	SHRT	10
Great-crested Flycatcher	LONG	1
Golden-crowned Kinglet	SHRT	416
Gray-cheeked Thrush	LONG	3
Gray Jay	PERM	2
Gray Catbird	LONG	4
Golden-winged Warbler	LONG	1
Hairy Woodpecker	PERM	118
Hermit Thrush	SHRT	42
House Wren	SHRT	3
Least Flycatcher	LONG	103
Lincoln's Sparrow	SHRT	1
Magnolia Warbler	LONG	40
Merlin	SHRT	13
Mourning Warbler	LONG	78

Species Name	Guild	Count
Nashville Warbler	LONG	139
Northern Flicker	SHRT	127
Northern Goshawk	SHRT	1
Northern Oriole	LONG	1
Northern Parula	LONG	11
Northern Waterthrush	LONG	14
Olive-sided Flycatcher	LONG	7
Ovenbird	LONG	146
Peregrine Falcon	LONG	2
Pine Siskin	PERM	239
Pileated Woodpecker	PERM	38
Purple Finch	PERM	114
Rose-breasted Grosbeak	LONG	47
Red-breasted Nuthatch	PERM	1944
Ruby-crowned Kinglet	SHRT	188
Red Crossbill	PERM	13
Red-eyed Vireo	LONG	291
Ruby-throated Hummingbird	LONG	32
Rusty Blackbird	SHRT	100
Ruffed Grouse	PERM	86
Savannah Sparrow	SHRT	1
Scarlet Tanager	LONG	2
Sedge Wren	SHRT	2
Song Sparrow	SHRT	30
Spotted Sandpiper	LONG	6
Sharp-shinned Hawk	SHRT	19
Swamp Sparrow	SHRT	3
Swainson's Thrush	LONG	127
Tennessee Warbler	LONG	48

Species Name	Guild	Count
Turkey Vulture	SHRT	2
Unidentified Blackbird	SHRT	31
Unidentified Finch	SHRT	110
Unidentified Flycatcher	LONG	88
Unidentified Goose	MIG	1
Unidentified Kinglet	SHRT	213
Unidentified Non-Passerine	NA	20
Unidentified Passerine	MIG	7167
Unidentified Raptor	MIG	9
Unidentified Shorebird	LONG	3
Unidentified Sparrow	SHRT	233
Unidentified Thrush	LONG	128
Unidentified Vireo	LONG	8
Unidentified Warbler	MIG	6104
Unidentified Woodpecker	NA	152
Unidentified Wren	SHRT	5
Veery	LONG	21
White-breasted Nuthatch	PERM	16
White-crowned Sparrow	LONG	5
Wilson's Warbler	LONG	8
Winter Wren	SHRT	109
Palm Warbler	LONG	10
White-throated Sparrow	SHRT	2771
White-winged Crossbill	PERM	3
Yellow-bellied Flycatcher	LONG	12
Yellow-bellied Sapsucker	SHRT	55
Yellow-rumped Warbler	SHRT	294
Yellow-throated Vireo	LONG	1
Yellow Warbler	LONG	3