Great Lakes Fish and Wildlife Restoration Act

AVIAN MIGRATION WITHIN THE LAKE SUPERIOR COASTAL REGION OF MINNESOTA

***Project Sponsor: USDI Fish and Wildlife Service**

***FWS Agreement Number: 30181AG006**

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Study Objectives:

1. Assessment of the timing, distribution, and relative abundance of fall migrants along the north shore of Lake Superior
2. Examination of fine-scale stopover habitat selection
3. Improvement in understanding large-scale landscape variables on migratory stopover site selection
4. Provide recommendations for conservation priorities to ensure protection of migratory bird populations

Description of Tasks:

Task or Deliverable	Description of activities to complete task
Data collection	Collected bird migration field data during fall of 2010
Data analysis	Data entered into a GIS and analyzed using R software
Interim progress report	Submitted December 31, 2011
Geodatabase	Created with ArcGIS 10 to analyze landscape and habitat variables
Conservation tools	In progress development
Presentation of project results to conservation planning effort or conference	Raptor Research Foundation Meeting, Duluth, MN, 10/2011 AFO/COS/WOS Joint Meeting, Kearney, NE, 3/2011 Great Lakes Wind Collaborative Workshop, Indianapolis, IN, 3/2011
Submission of journal article	In progress
Final report	March 30, 2012

Major findings and accomplishments: Federal guidelines suggest that three years of migration data be gathered prior to any wind farm development, especially within a major migratory corridor. Funding from this study allowed the completion of three years of intensive data gathering within the major migratory corridor of the north shore of Lake Superior, USA. The

results illustrate that this migration corridor is used by a large number of raptor species and a large number of non-raptor species, including many species of greatest conservation need.

Recommendations for migratory birds include the following.

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) 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.
6) Habitats primarily used below canopies by fall migrant birds included wetlands, bogs, deciduous forests, riparian areas, and ridges.
7) 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.
8) 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.

Management implications of your work: There is substantial interest in additional information on migratory birds and potential interactions with wind turbines, communication towers, and other structures potentially affecting migratory birds. These data will be useful for improving our understanding of these interactions.

Additional restoration work needed and/or areas for future research: Satellite telemetry on individual birds migrating along the north shore of Lake Superior would be beneficial. Additional modeling work of bird movements with topography, elevation, weather patterns, and distance from the shoreline would also be useful.

List of presentations delivered and outreach activities:

1) **Raptor Research Foundation Meeting**, Duluth, MN, October 2011; Raptors and Wind Energy Symposia Moderator; Paper - The Conservation of Airspace and Habitat in a Major Migration Corridor

2) **Association of Field Ornithologists/Cooper Ornithological Society/Wilson Ornithological Society - Joint Meeting**, Kearney, NE, March 2011; Paper - Wind turbine development and conservation of airspace in a major migration corridor
3) **Great Lakes Wind Collaborative Workshop on Wind and Wildlife**, Indianapolis, IN, March 2011, Paper: Wind turbine development and conservation of airspace in a major migration corridor

Geographic region project occurred in or effects: North shore of Lake Superior, USA – Duluth MN to MN-US/Canadian border

Publications:

Seeland, H., G. Niemi, R. Regal, A. Peterson, C. Lapin. 2012. Determination of raptor migratory patterns over a large landscape. *Journal of Raptor Research: in press.*

Rationale:

Over the past 50 years there has been increasing urban, exurban, and recreational development along the north shore of Lake Superior, while recently there has been strong interest and plans to develop wind energy along the north shore ridges. During bird migration periods, the Great Lakes are a migration barrier resulting in vast congregations of birds on or near shorelines. Long term studies at Hawk Ridge, MN and a preliminary study along the north shore during fall of 2008 indicate *en route* migratory birds heavily utilize the coastal region of Lake Superior. Hawk Ridge is among the top three raptor migration sites in the US with an average of 94,000 individuals counted per year. Many of these migrants are of high regional and national conservation concern including Bald Eagle, Peregrine Falcon, Golden Eagle, and Northern Goshawk. Migratory birds of the Great Lakes region are included as conservation targets in regional terrestrial conservation plans including the Great Lakes Regional Collaboration's "Strategy to Restore and Protect the Great Lakes," the Upper Mississippi/Great Lakes Region Joint Venture 2007 Implementation Plan, and The Nature Conservancy's "Great Lakes Ecoregional Plan and Conservation Blueprint." However, little is known about bird migration patterns in the western Great Lakes region at scales relevant to land protection, habitat restoration, or for potential placement of wind turbines. Information on migration pathways and stopover habitat use between Grand Portage and Duluth, MN are virtually nonexistent and inadequate to inform implementation of on-the-ground conservation projects to address developmental threats. We completed a spatially explicit, multi-scale assessment of *en route* migratory bird habitat characteristics and use in the Lake Superior coastal region of Minnesota. This information will be useful to local agencies and non-governmental organizations to identify and protect high value conservation areas before further development occurs in the region.

Migration periods represent a critical life-stage that can have impacts on bird species survivorship (Sandberg and Moore 1996, Sillett and Holmes 2002, Smith and Moore 2003). Migration success relies heavily on the quality and quantity of habitats available to migrants to "refuel" and rest (Hutto 2000, Tankersley 2004). While *en route,* migrating birds encounter an array of unfamiliar habitat (Petit 2000), migratory habitat choice is nonrandom (Buler *et al.*

2007). Riparian habitats, large tracts of intact forest, general forest type, ridge lines, and landscape structure may influence habitat use by migrants (Hutto 2000, Ewert et al. 2005, Bonter et al. 2009); however, little is known about migratory bird habitat requirements during migration periods (Petit 2000, Bonter *et al.* 2009). To best develop conservation strategies for protecting important habitat for migrating birds, there is a need for multi-scale assessments of migratory habitat use and characterization throughout entire migration routes (Tankersley and Orvis 2003, Mehlman *et al.* 2005, Heglund and Skagen 2005, Moore *et al.* 2005, Buler *et al.* 2007, Bonter *et al.* 2009).

Approximately 75% of breeding birds in the northern boreal forest of Canada and hemi-boreal forest of Minnesota will migrate (Green 1995, Rich *et al.* 2004). Many of these birds are unique to the boreal forest, are sensitive to landscape change, and are facing substantial declines in population numbers (Niemi *et al.* 2009, Rich *et al.* 2004, Kelly and Hutto 2005). During migration, *en route* migrants travel through the hemi-boreal forests of the western Great Lakes region, stopping to rest and refuel at "stopover" habitats (Diehl *et al.* 2003, Bonter *et al.* 2009). Observations and radar studies show that during fall migration, *en route* birds congregate along the north shore of Lake Superior (Diehl *et al.* 2003, HRBO 2007). Long-term studies at Hawk Ridge, MN and a preliminary study along the north shore during fall of 2008 confirmed that *en route* migratory birds heavily use the Lake Superior coastal region. This region has been identified as a critical landscape for biodiversity protection by the Minnesota Heritage Program, The Nature Conservancy, and the Upper Mississippi & Great Lakes Joint Venture.

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). The study area included an approximate 10-12 km 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. Note identification to species during fall migration is difficult when birds are moving rapidly across the landscape. 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.

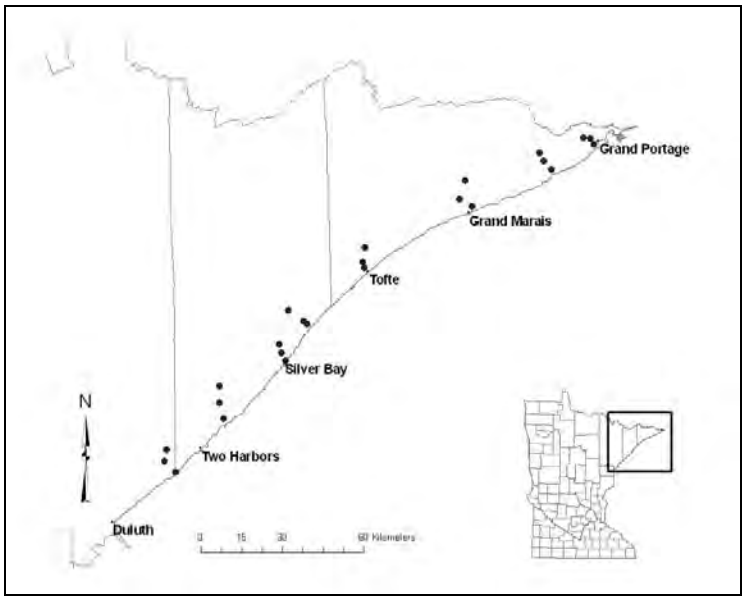

Figure 1. Migratory bird survey transects (8 in total) and site locations (3 sites per transect) in reference to towns along the north shore of Lake Superior, Minnesota (see Appendix A).

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. Identification to species can be difficult when birds are moving through the vegetation during migration and when most birds are relatively quiet. Transect routes were recorded by GPS units and entered into a GIS for further spatial and landscape analysis.

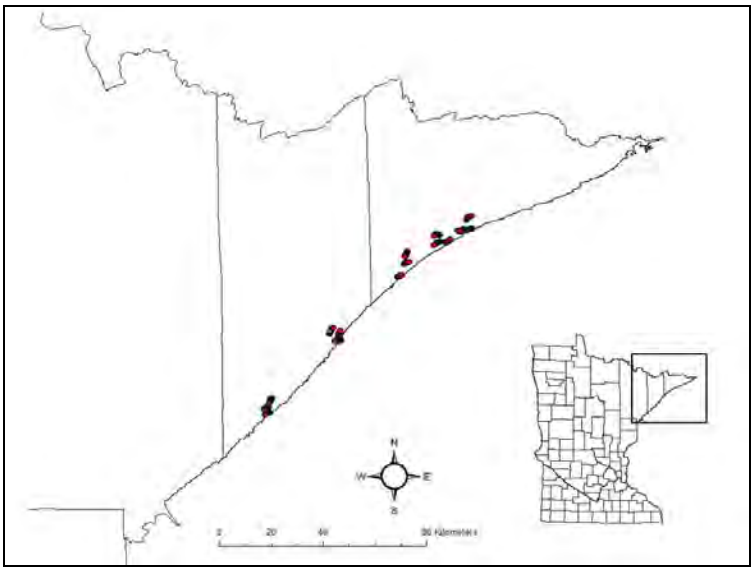

Figure 2. Locations of below canopy transect sites along Lake Superior's north shore in Minnesota, USA.

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. Linear regression (R software) was used to compare birds per hour to distance from shore and distance from Duluth.

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.

Results:

Above Canopy. A total of 18,037 raptors (Appendix A) and 160,421 non-raptors (Appendix B) 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	Non-raptors/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 Shoreline. 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. The number of nonraptors observed per hour significantly decreased when moving away from Duluth (northeast) along the north shore towards Grand Portage (F-stat=4.78, r^2=0.14, p-value<0.05; Fig. 3). Raptors did not exhibit a significant trend when moving away from Duluth. The observation of both raptors (F-stat=11.43, r^2=0.34, p-value<0.01) and nonraptors (F-stat=6.76, r^2=0.24, p-value<0.5) per hour significantly decreased when moving away from the Lake Superior shoreline (Figs. 4 and 5, respectively).

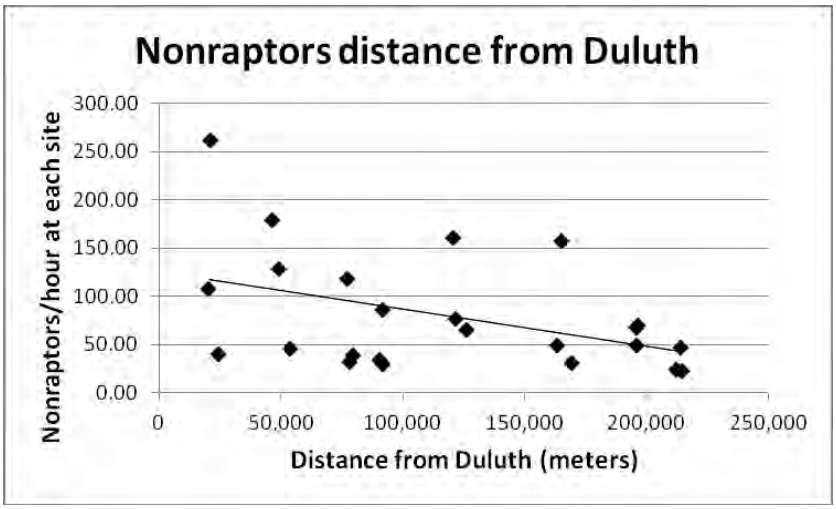

Figure 3. Mean number of non-raptors (mostly songbirds) observed per hour during fall migration 2008-2010 along the north shore of Lake Superior.

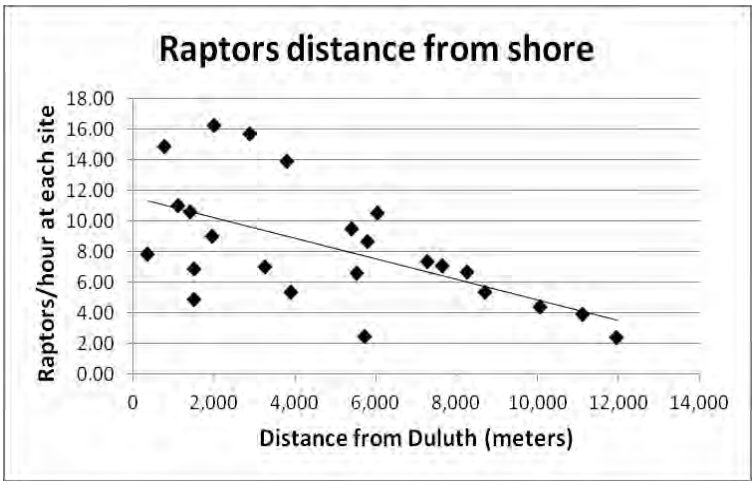

Figure 4. Mean number of raptors per hour recorded at each site within each transect along the north shore of Lake Superior.

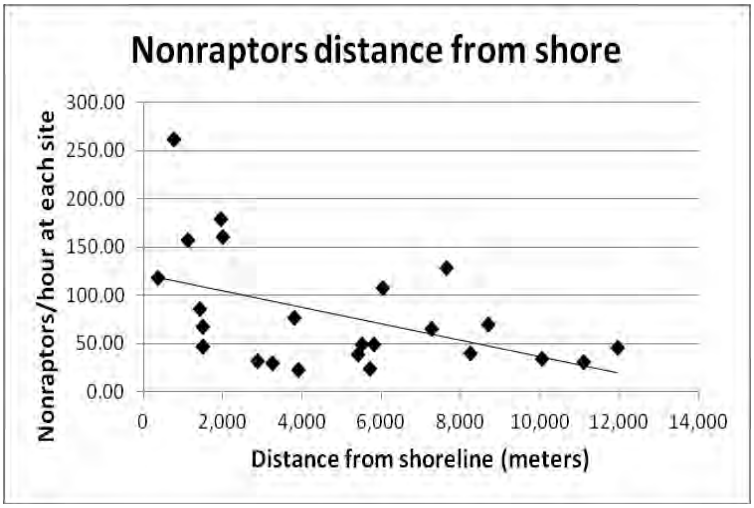

Figure 5. Mean number of non-raptors per hour recorded at each site within each transect along the north shore of Lake Superior.

Flight Height. – The airspace occupied by raptors differed between raptor groups (Fig. 6). 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. 6). 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.

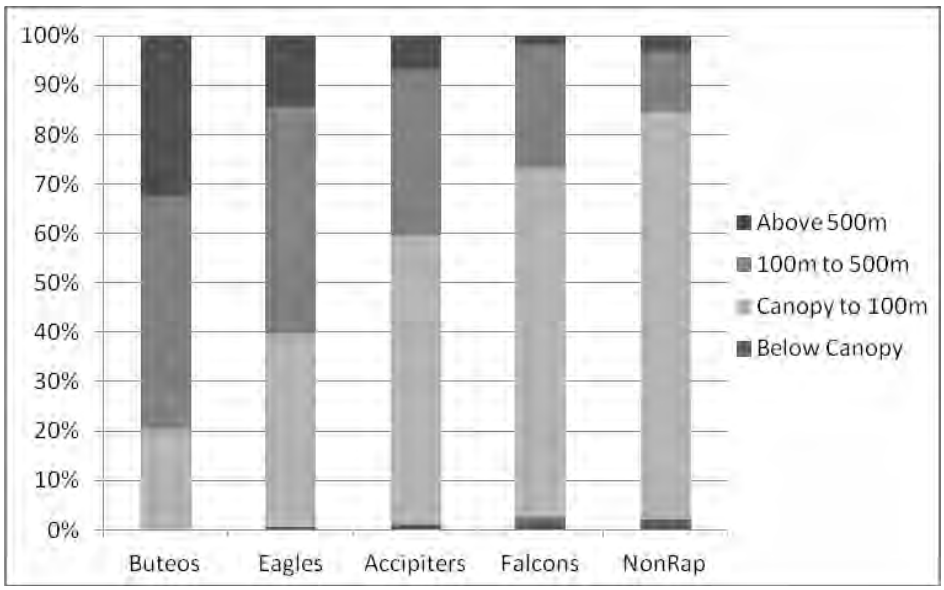

Figure 6. Proportions of the major raptor groups and all nonraptors (NonRap) in each flight height category recorded during the north shore migration surveys 2008-2010.

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. 7). 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.

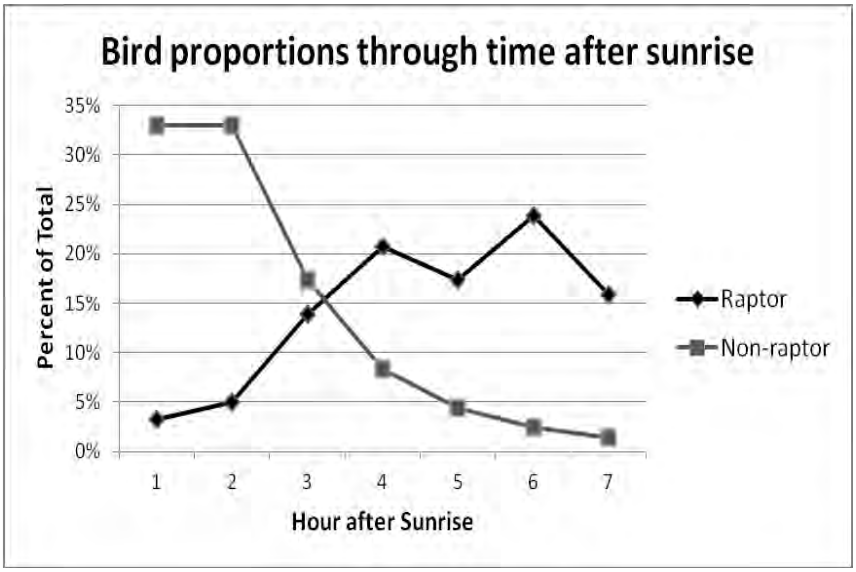

Figure 7. Proportion of total non-raptors and raptors recorded during each hour of observation. Hour 1 begins at 1-1.5 hours after sunrise; hour 7 is the seventh hour after the start of the survey.

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. Unidentified passerine and warbler 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, respectively.

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 river or stream. These migrants were also more common in brush-wetland habitats. 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. 8a) in areas with low deciduous trees and high coniferous trees. Thrushes were most significantly associated with increasing distance from shore (Fig. 8b). Ovenbirds were most significantly related to the presence of hardwood trees and higher elevations as well as the combination of an increasing distance from shore, increasing elevation, and the presence of a river or stream. Short distance migrants were not significantly related to any variables in this model.

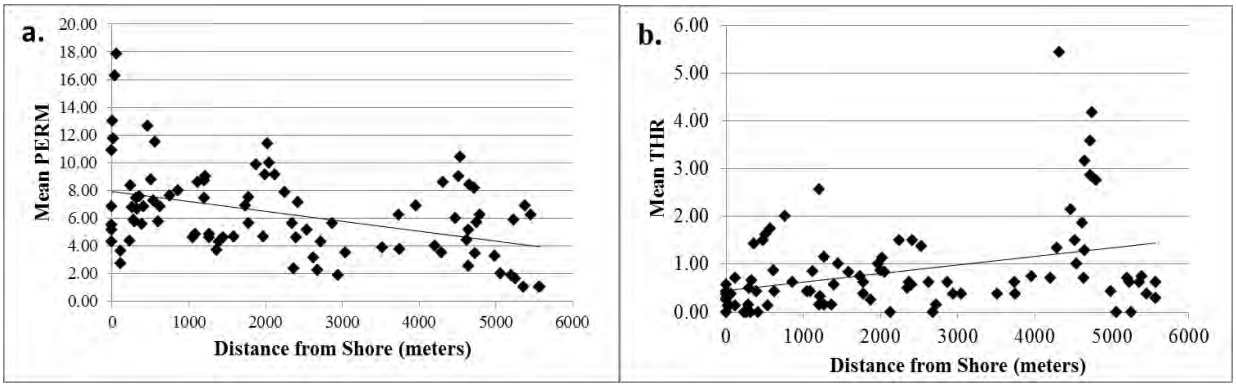

Figure 8a and b. The relationship of (a) permanent residents (PERM) and (b) Thrush spp. (THR) with increasing distance from the shoreline of Lake Superior during fall migration.

Table 2. Results of regression analyses testing the ability of landscape and habitat variables to explain mean abundance of long (LONG) distance migrants, Thrush spp. (THR), Ovenbirds (OVEN) and permanent residents (PERM) along the north shore of Lake Superior during fall migration. Variables include distance from shore (Dist), average elevation (Elev), presence of a ridgeline (Rdgln), presence of a river or stream (RS), proportion of brush and wetland habitat (Brsh_Wtld), deciduous trees (Decid), conifer trees (Conif), and mixed stands of aspen-birch (AspnBrch), northern hardwoods (NHard), spruce, and cedar. 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***.

Variables	LONG	THR	OVEN	PERM
Dist		**0.11****	0.14***	**(-) 0.67****
Elev		0.08**	0.16***	(-) 0.24***
Rdgln				
RS	0.05*			
Elev+Rdln		0.07*	0.15***	(-) 0.25***
Dist+Elev	0.10**	0.10**	0.15***	(-) 0.23***
Dist+Rdln		0.11**	0.14***	(-) 0.16***
Dist+Elev+Rdln	0.11**	0.11**	0.14**	(-) 0.25***
Dist+RS+Elev	**0.14****	0.09*	0.16***	(-) 0.23***
Brsh_Wtld	0.03*			
Decid			0.06*	(-) 0.24***
Conif				0.16***
AspnBrch		0.09**	0.05*	
NHard			**0.17****	(-) 0.27***
Spruce				0.31***
Cedar	0.06*			

Discussion:

General observations. We observed thousands of raptors and tens of thousands of nonraptors (mostly passerines) 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 Northern Goshawk, and 103 Osprey. Examples of observations of nonraptors during below and above canopy surveys included 2365 Rusty Blackbirds, 7 Olive-sided Flycatchers, 109 Winter Wrens, 55 Canada Warblers, 152 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 and through the air. 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 coastal region of Minnesota. For 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 cited 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), although we did not observe a significant difference in numbers of raptors moving away from Duluth.

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 (e.g., 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 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 that 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.

Conservation Priorities:
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 to avoid the unforested prairies of central Canada and the U.S., evolutionary instinct, and because they are pushed by westerly winds (Fig. 9). 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 devoid 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.

Identifying and prioritizing habitats and airspace important for migratory birds within Lake Superior's coastal zone must include an evaluation of daytime and nighttime use, as well as early and late season assessment. Here we present key factors in identifying important areas for daytime 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 outside the scope of the habitat use portion of this study.

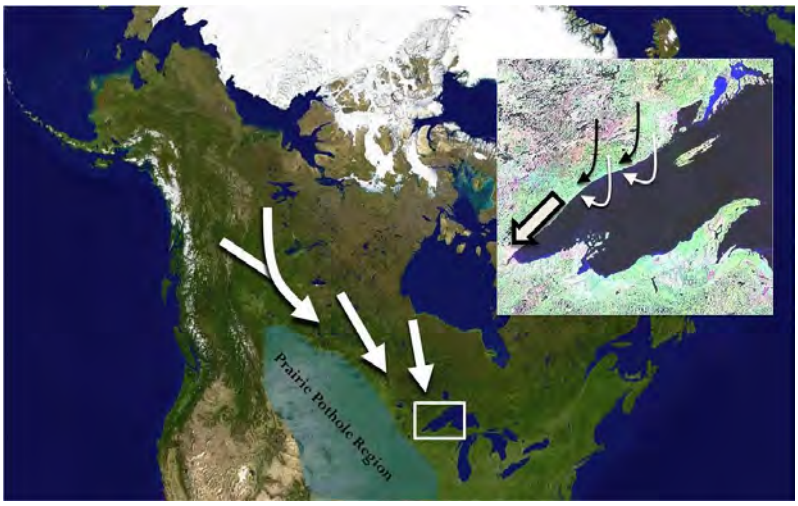

Figure 9. Illustration of migratory bird movement in relation to the Great Lakes region and the north shore of Lake Superior.

Airspace Use. The use of airspace by diurnally migrating of birds within the coastal zone of Lake Superior varies 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 groups of birds also follow lead-lines that take the form of both ridgelines and *river valleys*. Many small birds use river corridors as lead lines away from Lake Superior (drift compensation). In addition river valleys can create their own ridge-lift as many are accompanied by *steep slopes*.

In summary, areas of heavy airspace use include (but are not limited to) the following (Figs. 10 and 11):
1. Airspace between the shoreline and first prominent ridgeline (~1000m from shore)
2. Prominent ridgelines within 6000km of the shoreline (lead lines and ridge-lift)
3. General topography of steep slopes and deep valleys (providing ridge-lift and lead lines)

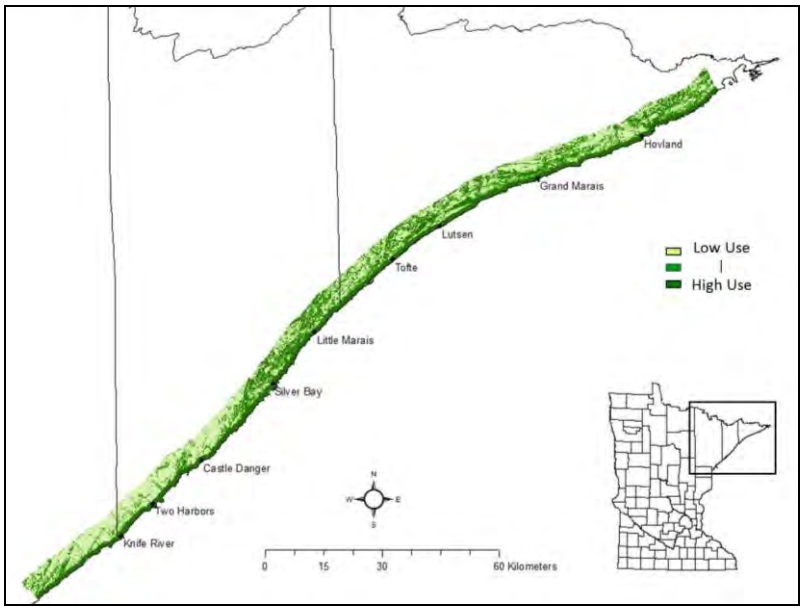

Figure 10. Map of diurnal migratory bird airspace use (low to high) within the Lake Superior coastal zone of Minnesota.

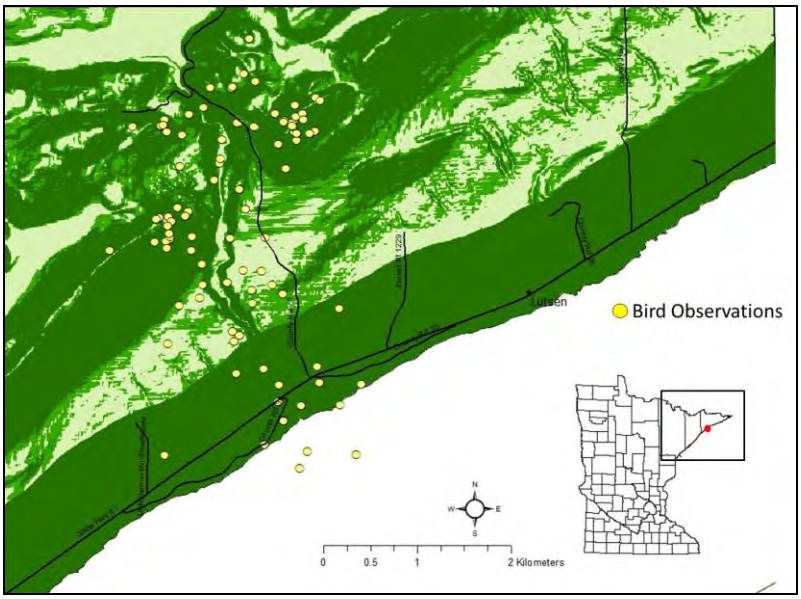

Figure 11. Airspace use by diurnal migratory birds near Lutsen, Minnesota, and recorded bird observation locations during 2009 and 2010 surveys. Darker areas predicted to be high use.

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. Areas *near the Lake Superior shoreline* are heavily used by short distance migrants and long-distance migrants, as well as permanent residents. Long-distance migrants were also using landscapes defined by an *increase in distance from shore and increase in elevation*. In general, these areas were at least 3000 meters from the shoreline and over 300 meters in elevation. Many heavily used areas were also defined by proximity to *ridgelines and rivers*. Habitats most heavily

utilized by long distance migrants included both *deciduous forests*, which commonly occurred at higher elevations, and *wetland and bog habitats*.

In summary, characteristics that define areas of heavy habitat use include (but are not limited to) the following (Figs. 12 and 13):
1. All land within 1000m of the shoreline
2. Landscapes beyond 3000m from the shoreline with elevations above 300 meters
3. Wetlands and bogs
4. Deciduous forest stands
5. Presence of river (not included in map)
6. Presence of ridgeline

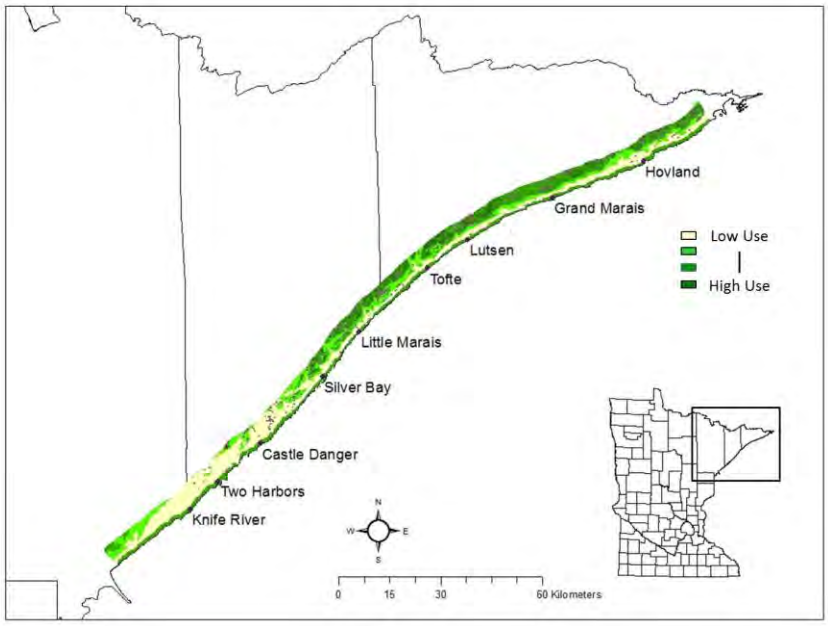

Figure 12. Map of migratory bird habitat use (low to high) within the Lake Superior coastal zone of Minnesota.

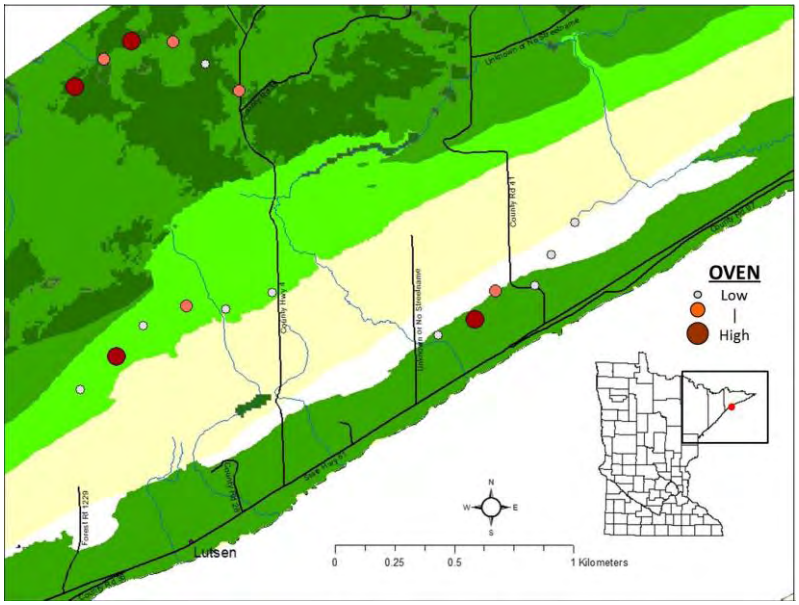

Figure 13. Habitat use by migratory birds near Lutsen, Minnesota, and mean Ovenbird (OVEN) abundance during below canopy surveys, 2008-2010. Darker colors indicate areas predicted to be high use.

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 2012). 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. Raptor species and **number of individuals observed (Count) at above canopy sites during fall migration surveys along Lake Superior's north shore 2008-2010.**

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

Appendix B. Nonraptor species and number of individuals observed (count) at above canopy sites during fall migration surveys along Lake Superior's north shore 2008-2010.

Species Name	Count	Species Name	Count	Species Name	Count	Species Name	Count
American Blackduck	1	Common Merganser	3	Pine Grosbeak	88	Unidentified Flycatcher	3
American Crow	11815	Common Nighthawk	11	Pine Siskin	3906	Unidentified Goose	575
American Goldfinch	1321	Common Raven	2474	Purple Finch	6004	Unidentified Gull	350
American Pipit	3011	Common Redpoll	1865	Red Crossbill	152	Unidentified Kinglet	724
American Redstart	37	Dark-eyed Junco	1568	Red-bellied Woodpecker	1	Unidentified Loon	1
American Robin	16760	Dickcissel	1	Red-breasted Nuthatch	187	Unidentified Nonpasserine	487
American Tree Sparrow	4	Double-creasted Cormorant	17	Red-eyed Vireo	12	Unidentified Passerine	39362
American White Pelican	3	Downy Woodpecker	57	Red-winged Blackbird	323	Unidentified Shorebird	47
American Widgeon	1	Eastern Bluebird	547	Ring-billed Gull	1	Unidentified Sparrow	108
American Woodcock	1	Eastern Kingbird	10	Rock Dove	12	Unidentified Swallow	33
Baltimore Oriole	1	European Starling	22	Rose-breasted Grosbeak	170	Unidentified Thrush	32
Belted Kingfisher	15	Evening Grosbeak	65	Ruby-crowned Kinglet	47	Unidentified Vireo	1
Black-backed Woodpecker	46	Fox Sparrow	3	Ruby-throated Hummingbird	14	Unidentified Warbler	19463
Black-capped Chickadee	345	Golden-crowned Kinglet	180	Rusty Blackbird	2365	Unidentified Waxwing	30
Black-throated Green Warbler	1	Gray Jay	4	Sandhill Crande	645	Unidentified Woodpecker	24
Blue Jay	13767	Great Blue Heron	15	Semipalmated Plover	1	Upland Sandpiper	12
Bobolink	8	Hairy Woodpecker	32	Short-eared Owl	1	White-breasted Nuthatch	2
Bohemian Waxwing	54	Hermit Thrush	3	Snow Bunting	897	White-crowned Sparrow	2
Boreal Chickadee	1	Herring Gull	1	Snow Goose	26	White-throated Sparrow	431
Brown Creeper	16	Horned Lark	438	Solitary Sandpiper	2	White-winged Crossbill	1789
Brown-headed Cowbird	16	Lapland Longspur	574	Song Sparrow	2	Wilson's Snipe	4
Cackling Goose	4	Least Sandpiper	1	Spotted Sandpiper	1	Yellow Warbler	65
Canada Goose	3273	Magnolia Warbler	1	Swainson's Thrush	170	Yellow-bellied Sapsucker	3
Cape May Warbler	4	Mallard	45	Townsend's Solitaire	2	Yellow-shafted Flicker	194
Cedar Waxwing	6308	Mourning Dove	3	Tree Swallow	11		
Chimney Swift	11	Myrtle Warbler	2386	Tundra Swan	2		
Chipping Sparrow	10	Northern Shrike	6	Unidentified Blackbird	7009		
Cliff Swallow	4	Northern Waterthrush	2	Unidentified Corvid	47		
Common Grackle	5522	Palm Warbler	11	Unidentified Duck	487		
Common Loon	267	Pileated Woodpecker	17	Unidentified Finch	1105		

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