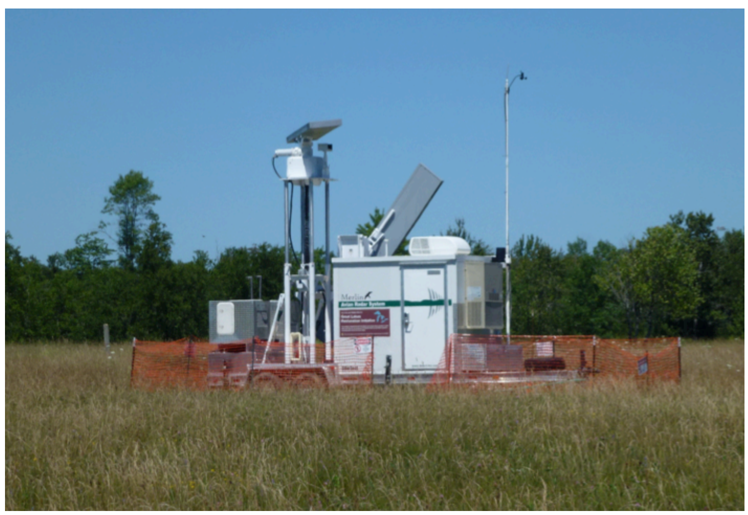
U.S. Fish & Wildlife Service

Great Lakes Avian Radar Technical Report Lake County, MN Bayfield County, WI Keweenaw County, MI

Fall Season 2014

Biological Technical Publication

BTP-R3015-2017



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Great Lakes RESTORATION

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Key words: Great Lakes, Lake Superior, migration, avian radar, wind energy, birds, bats

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Executive Summary

Global wind patterns help move millions of migrating birds and bats through the Great Lakes region, where shorelines provide important stopover habitat. Shorelines are thought to concentrate migrants because they offer the last refuge near a geographic obstacle and are likely used for navigation. Shorelines also offer attractive areas for wind energy development. With this potential for conflicting interests, more information is needed on the aeroecology of the Great Lake shorelines. We used two avian radar systems to identify the activity patterns, timing, and duration of migration that occurred along the shorelines of the Great Lakes, with this season focusing on Lake Superior.

We placed avian radar systems near Lake Superior in Michigan, Minnesota, and Wisconsin, where the automated systems tracked and recorded target (bird and bat) movements continuously from early August to mid-November 2014. We calculated direction of movement, target passage rates, and altitude profiles for the air space above our study areas. We also used a model of our vertical sample volume that allowed us to report an estimate of target density by altitude band.

Migration appeared strong along the shorelines we studied on Lake Superior. The mean nocturnal passage rates were greater than the mean passage rates for dawn, day, and dusk combined at each of our three locations. Nocturnal movement was typically oriented in a southerly direction. We also recorded other behaviors associated with migrants, such as slight dawn ascent and migrants over water returning to land at dawn. Peak density occurred between 100 and 250 m above ground level at each of the sites. Patterns indicating diurnal migration were also observed along the north shore of Lake Superior in Minnesota. The target density may have been underestimated at higher altitudes due to loss of detection at longer ranges and at lower altitudes due to the presence of clutter.

The results of our research highlight the potential role of radar in implementing the USFWS Land-Based Wind Energy Guidelines and how radar may help identify areas where impacts to wildlife could be minimized. We documented migration activity in the air space above our study areas, and our results show that the density of targets at low altitudes may present conservation concerns. The data we collected showed the ebb and flow of migration across the sampling period and that the nocturnal migration of passerines and bats continued into November. Given the amount of time that migration occurred at the sampled sites, it seems that curtailing wind energy operations during nocturnal pulses could result in limited operational time along shorelines during the migration season. Combining the results of radar studies and fatality searches could greatly improve risk assessments and assist with the interpretation of standardized radar studies.

Avian radar is increasingly relied upon to perform surveys for pre-construction risk analysis. While an important tool, few regulatory agencies have experience implementing avian radar or otherwise recognize the strengths and limitations of the technology. This report highlights some considerations about avian radar and reviews some potentially confusing metrics. We also introduce some new metrics to report radar data. In addition to providing information relevant to conservation in the Great Lakes region, the concepts we present in this report are widely relevant to reviews of avian radar studies, and we provide methods that identify components of migration, such as:

- Nocturnal pulses
- Season length
- Estimated density per altitude band
- Migrant behavior near a geographical obstacle

Given the rapid growth of the wind energy sector, our most effective conservation effort may be our ability to identify and avoid development in locations where migrants concentrate.

Introduction

The Great Lakes constitute one of the largest bodies of fresh water on the planet and collectively represent a surface area of nearly 245,000 km^2, with over 17,500 km of shoreline. Global wind patterns help move millions of migrating birds and bats through the Great Lakes region (Rich 2004, Liechti 2006, France et al. 2012), and lake shorelines feature widely recognized Important Bird Areas (Audubon 2013). Migrants passing through the region concentrate near shorelines (Ewert et al. 2011, Peterson and Niemi 2011, Buler and Dawson 2012, France et al. 2012), which provide important stopover habitats—areas used temporarily for rest, refueling, and protection. These shorelines offer increased foraging opportunities relative to inland areas (Smith et al. 2004, 2007; Bonter et al. 2007, 2009) and may be used as a visual cue for navigation or for refuge prior to or after crossing open water (Buler and Moore 2011).

Given their location and size, the Great Lakes likely represent a geographic obstacle (Diehl et al. 2003) that migrants choose to cross, or not, based on environmental and physiological conditions at the time of encounter (Faaborg et al. 2010, Schmaljohann et al. 2011). For migrants that rely on powered flight, it is more efficient to make several short flights than a long flight due to the cost of carrying high fuel loads (Alerstam 1990). This is perhaps one reason why migrants sometimes partially circumnavigate the Great Lakes, which they have the physiological capability of crossing (Alerstam 1990, Alerstam 2001, Ruth 2007). The decision to cross likely represents a trade-off between minimizing costs (e.g., energy and time) and exposure to risk factors (e.g., predation and fatigue) that are associated with migration (McGuire et al. 2012a). In this trade-off, shorelines offer refuge when conditions do not favor flights over water. Lake Superior has the largest surface area and has one of the larger spans of open water that migrants would have to cross in all of the Great Lakes. The size of this lake may make the decision to cross it more of a trade-off compared with some of the other Great Lakes.

Migrants challenged by an obstacle may temporarily reverse or deviate from seasonally appropriate flight directions or return to land to delay or recover from a crossing (Bruderer and Liechti 1998, Akesson 1999, Ewert et al. 2011). Schmaljohann and Naef-Daenzer (2011) found that birds with low fuel loads and/or facing unfavorable weather conditions returned to the shoreline habitat rather than continue across open water in a direction appropriate for migration. For bats, migrants varied their choice to circumnavigate above shorelines or cross lakes, and some long-distance migrants used torpor to postpone migration during periods of unfavorable conditions (McGuire et al. 2012b). These behavioral responses as well as the necessity of using stopover habitat during migration likely contribute to the increased use of shorelines and emphasize the importance of these areas for conservation. A peninsula, such as the Keweenaw Peninsula in Lake Superior, may offer a safe area for migrants due to its location close to the middle of the lake. By extending into the middle of the lake, the peninsula can make a shorter crossing for many migrants and provide a refuge in case of a change in conditions. This refuge area may mitigate some decisions by migrants that may have otherwise been more costly.

Migrants concentrated along shorelines can be very mobile. In addition to immediate refueling and rest, migrants make broad-scale flights among habitat patches, explore wind conditions, and orient themselves for migration. For example, radio-tagged bird and bat migrants on the north shore of Lake Erie made repeated movements among habitat patches. Individuals relocated as far as 18 and 30 km from their capture site (maximum distances tracked for a bat and bird species, respectively) prior to resuming migration (Taylor et al. 2011). Nocturnal migrants such as warblers and other neotropical migrants, regularly engage in morning flights along shorelines (Wiedner et al. 1992). These flights typically occur within 2 hours of sunrise and are thought to represent reorientation along a geographic obstacle or movements among stopover habitats (Able 1977, Moore 1990, Wiedner et al. 1992). Flights of this nature often occur above the tree line (Bingman 1980), while lower heights are associated with nocturnal migration (Harmata et al. 2000, Mabee and Cooper 2004, Newton 2008). Migrants have also been observed initiating nightly exploratory flights at stopover sites (Schmaljohann et al. 2011). These flights are thought to represent normal activity of migrants as they calibrate their internal compass and test wind speed and direction aloft. In addition to these activities while in stopover, migration flights follow north-south-oriented shorelines en route to their destination (Buler and Dawson 2012), while east-west oriented shorelines may be used to circumnavigate open water or find narrow points for crossing (Alerstam 2001, Diehl et al. 2003, France et al. 2012). Additionally, migrant birds may change their altitude many times over the course of a nocturnal migratory flight (Bowlin et. al 2015). Cumulatively, these types of activities indicate that areas near lake shores host a variety of movements at many different altitudes for landscape level, exploratory, and migratory flights. These activities may increase vulnerability to collision risk with tall structures such as communication towers or wind turbines.

Migrant populations may experience the greatest mortality pressure during migration (Newton 2006, 2007; Diehl et al. 2014), and the negative ramifications of compromised stopover habitat for migratory populations are becoming increasingly clear (Sillett and Holmes 2002, Mehlman et al. 2005, Faaborg et al. 2010). Shoreline habitats along the Great Lakes are subject to pressures from urban and energy development, land conversion, and environmental contamination that may limit habitat availability and/or reduce habitat quality (France et al. 2012). Furthermore, White-nose Syndrome is devastating hibernating bat populations and has increased the need to identify conservation areas, as several of these species face the risk of extirpation in the Great Lakes region (Turner et al. 2011). In response to factors such as these, substantial efforts are being made to identify and protect stopover habitat along the Great Lakes shorelines (Buler and Dawson 2012, Ewert et al. 2012, France et al. 2012). With climate change considerations recommending both an increase in renewable energy development and conservation of migratory species, careful planning is needed to balance these demands.

There is a national movement towards a 20% wind energy sector in the U.S. market by 2030 (U.S. DOE 2008). As of 2012, wind energy installation is on target towards achieving this goal (AWEA 2015). If achieved, this would represent a nearly five-fold increase in wind energy capacity during the next 15 years (Loss et al. 2013). Additionally, the U.S. Department of Energy (2015) has conducted a study showing that 35% of the energy demands of the U.S. could be met by wind energy in 2050. Explorations have also been conducted by the National Renewable Energy Laboratory that conclude that over 400 GW of electricity could be produced by wind power in 2050, up from 60 GW in 2012 (Mai et. al 2012, Loss et al. 2013). Coinciding with this national effort, wind energy developments are increasing within the Great Lakes region, where windy shorelines near population centers offer attractive areas for turbine placement (Mageau et al. 2008, Great Lakes Commission 2011).

Utility-grade wind facilities have been associated with mortality events for migrating vertebrates (Newton 2007, Arnett et al. 2008, Smallwood and Thelander 2008), and chronic fatalities across the U.S., particularly for bats, are a concern (Timm 1989, Johnson 2005, Arnett and Baerwald 2013, Hayes 2013, Smallwood 2013). For example, three species of long-distance migratory bats that are impacted by wind energy facilities account for approximately 75% of all bat mortalities (Kunz et al. 2007a, Cryan 2011, Arnett and Baerwald 2013). These migrants, the hoary bat (*Lasiurus cinereus*), eastern red bat (*Lasiurus borealis*), and silver-haired bat (*Lasionycteris noctivagans*) typically make up the majority of bat fatalities at wind facilities in the Upper Midwest (Arnett et al. 2008). Three Wisconsin studies found high fatality rates for these same migrant species but also found that little brown bat (*Myotis lucifugus*) and big brown bat (*Eptesicus fuscus*) fatalities were substantial (Gruver et al. 2009, BHE Environmental 2010, Grodsky et al. 2012). The presence of major hibernacula in the vicinity of these latter three studies may have contributed to the difference in ratios. Many areas along Lake Superior are home to large hibernacula of bats, including the Keweenaw Peninsula in the Upper Peninsula of Michigan, northern Wisconsin, and the north shore of Lake Superior in Minnesota.

Low reproductive rates inhibit the ability of bats to rebound from population decline (Racey and Entwistle 2000), and these declines have already begun for several species (Kunz et al. 2007a, Cryan 2011) and have contributed to the Federal listing of the northern long-eared bat (*Myotis septentrionalis*) as a threatened species under the Endangered Species Act. Cumulative impacts on migrant bird and bat species are a concern, and this concern will increase with the growth of wind energy if methods to avoid or minimize mortality events are not established. Some promising conservation measures have been proposed to reduce mortality levels, such as reduced cut-in speeds; however, the greatest benefit to the conservation of migrants may lie in our ability to identify and avoid future growth in locations where migrants concentrate.

To help meet the needs of both renewable energy development and wildlife conservation, we established this project to identify the activity patterns, timing, and magnitude of migration occurring along shorelines of the Great Lakes. Because bats and many bird species migrate during the nighttime hours throughout the spring and fall, documenting the migration of these animals is challenging due to the difficulty of observing nocturnal movements that occur sporadically throughout the season. To address this challenge, we used two avian radar units that operated 24 hours per day, and each unit simultaneously scanned horizontal and vertical planes. We chose radar because of these and other benefits and to provide an alternative metric to our acoustic monitoring program, which has different strengths and weaknesses (Horton et al. 2015). Avian radar has been shown to reliably track targets that fly through its detection area, although the specific target counts are not indicative of true population counts (Gerringer et al. 2015). Migration traffic on radars has been shown to correlate with the density of birds in stopover habitat during the day (Horton et al. 2016a), indicating that migrants using the airspace are also using stopover habitat in the area. Our objectives for the portion of the study we are reporting on included the following:

- Monitor locations along shorelines and peninsulas of Lake Superior using a consistent methodology.
- Maintain an archive of continuously recorded radar data during the fall migration season;
- Identify activity patterns captured by avian radar that are diagnostic of fall migration on the north shore of a lake and peninsulas extending from the south shore of a lake.
- Estimate the duration of the migration season.
- Document changes in the behavior of migrants under varying conditions and during different parts of the season.

Methods

Study Area and Site Selection

During fall 2014, we selected three sites along the U.S. portion of Lake Superior for radar placement. One radar unit was located along the north shore in Lake County, Minnesota. We collected data at this site throughout the fall migration season (Aug 1 – Nov 11, 2014). The second radar unit was placed at two sites during the migration season, with one site in Bayfield County, Wisconsin (July 31 – Sept 8, 2014) and the other site in Keweenaw County, Michigan (Sept 8 – Nov 2, 2014) (Figure 1). Radar units were placed 1 – 4 km from the shoreline to monitor the airspace above the inland, shoreline, and lake areas.

The Lake County site was located at 47.435760° N, -91.088910° W and was 295 m above mean sea level. It was placed near a ridgeline, in a forest opening, approximately 1.5 km from the shoreline. Deciduous forest and open water were the predominant land cover types within the 3.7 km range of the radar unit, according to our analysis using Esri ArcGIS software and the 2011 National Land Cover Database (Jin et al. 2013). The Bayfield County site was located on the Bayfield Peninsula at 46.915030° N, -90.871950° W and was 234 m above mean sea level. It was placed in a fallow field approximately 4 km from the shoreline, due to lack of suitable sites closer to the lake shore. Deciduous and mixed forest were the predominant land cover types present within range of the radar unit. The Keweenaw County site was located at 47.444820° N, -88.1505680° W and was 205 m above mean sea level. It was placed in a forest opening where a small sandpit had been created and was approximately 2 km from the shoreline. Open water, forest (evergreen, deciduous and mixed) and woody wetlands were the predominant land cover types found within range of the radar unit (Table 1, Figure 2, Appendix 2).

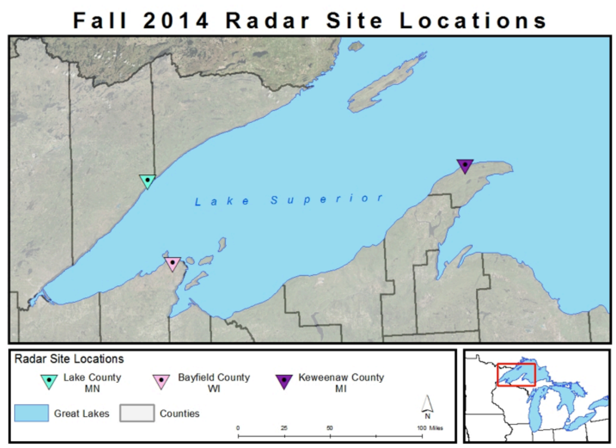


Figure 1. Locations where MERLIN Avian Radar Systems were deployed during the fall 2014 migration season. The map image is the intellectual property of Esri and is used herein under license. Copyright © 2014 Esri and its licensors. All rights reserved.

Table 1. Predominant land cover types found within a 3.7 km radius of the radar locations on Lake Superior during fall 2014.

National Land Cover Class	Lake County	Bayfield County	Keweenaw County
Deciduous Forest	35%	54%	16%
Developed*	2%	4%	4%
Emergent Herbaceous Wetlands	0%	3%	1%
Evergreen Forest	5%	11%	22%
Herbaceous	1%	2%	2%
Mixed Forest	5%	21%	15%
Open water	32%	1%	25%
Shrub/Scrub	16%	4%	1%
Woody Wetlands	4%	0%	15%

* Includes low intensity development and developed open space.

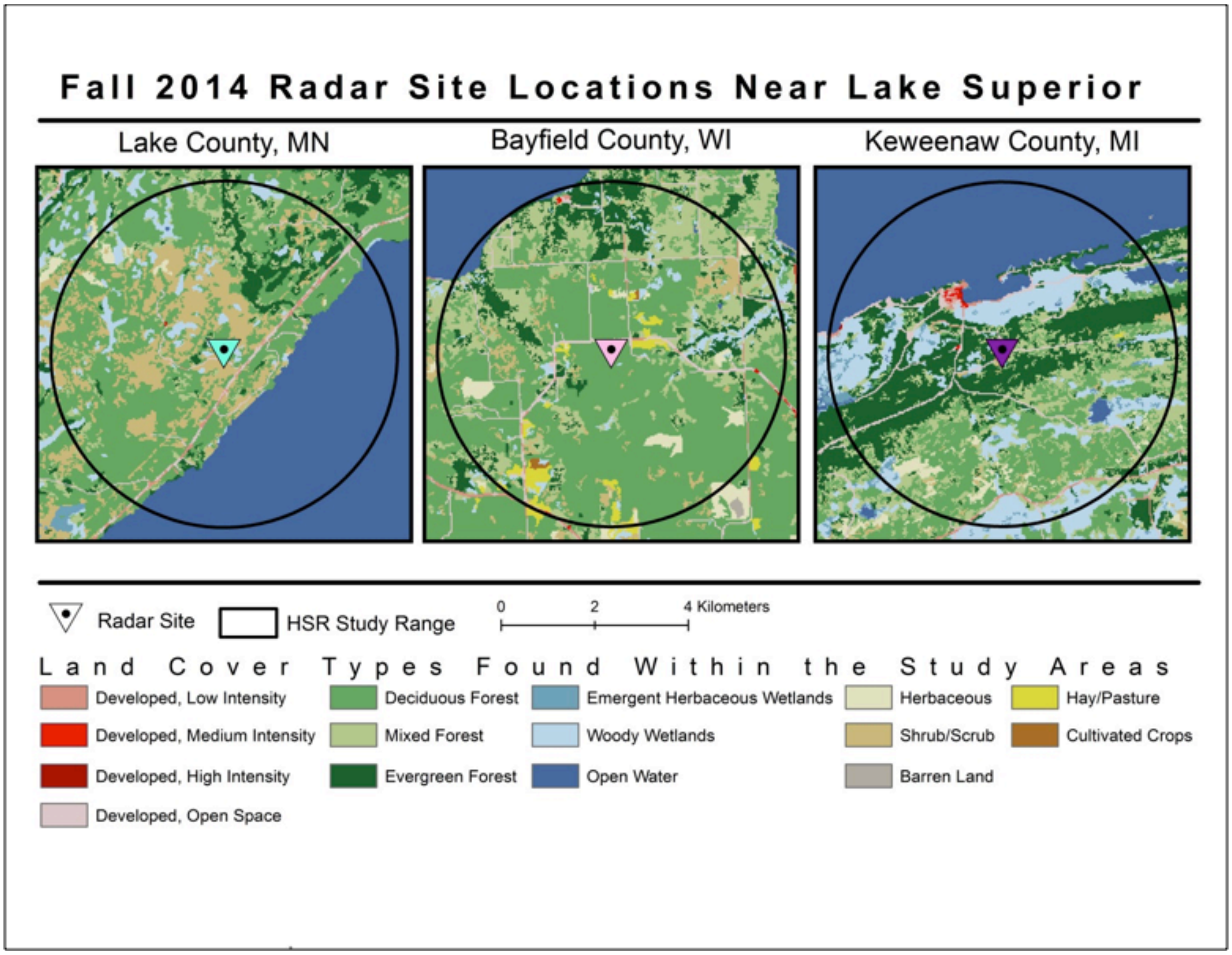


Figure 2. Land cover types found within a 3.7 km radius of the radar locations on Lake Superior during fall 2014. Map information from Jin et al. 2013.

Equipment
We used two model SS200DE MERLIN Avian Radar Systems (DeTect Inc., Panama City, FL) to document migration movements. These systems were selected because they are self-contained mobile units specifically designed to detect, track, and count bird and bat targets. Each system employed two solid-state marine radar antennas that operated simultaneously, one that scanned the horizontal plane while the other scanned vertically (Figure 3). Additionally, each unit contained four computers for real-time automated data processing and a SQL server for processed data storage and review. The units were configured with a wireless router to allow remote access to the computers and automated status updates. The radar units were previously compared against each other and were determined to perform similarly (USFWS unpublished data).

Description of radars – The solid state marine radar antennas (Kelvin Hughes, London, UK) employed by our systems were 3.9 m in length, with 170 W peak power, S-band (10 cm) wavelength, and 2.92 – 3.08 GHz frequency range, and they were configured to operate with both short and medium pulses (0.1 and 5 microseconds, respectively). The horizontal radar was also equipped with Doppler to help filter out stationary targets. The radars emitted a fan-shaped beam that had an approximate 1° horizontal and 25° vertical span when operated in the horizontal plane. S-band radar was selected because the longer wavelength is less sensitive to insect and weather contamination than that of X-band (3 cm wavelength) antenna (Bruderer 1997). It is also less sensitive to signal attenuation from ground clutter such as vegetation and structures (DeTect Inc., unpublished data, 2009). The radars spun perpendicular to each other at a rate of 20 revolutions per minute and were synchronized so as not to emit over one another. The horizontal scanning radar (HSR) was affixed to a telescoping base that was raised to approximately 7 m above ground for operation. This radar rotated in the x-y plane with a 7° tilt to reduce the amount of ground clutter included within its view. While the HSR had the capability to scan large distances, we selected a 3.7 km range setting for data collection in order to have higher resolution and to identify smaller targets such as passerines and bats. The

HSR was primarily used to provide information on target direction. The vertical scanning radar (VSR) rotated in the x-z plane and scanned a 1° x 25° span of the atmosphere. We selected a 2.8 km range setting for this radar for increased resolution and used the VSR to provide information on the number and height of targets.

Extended range horizontal antenna – An extended range horizontal radar and the accompanying two additional computers were installed on the Lake County, MN radar. The addition allowed us to survey out to 11.1 km with this antenna while still continuing our survey efforts at the 3.7 km range. The settings for this antenna were developed independently of the standard range horizontal radar, and all data were analyzed separately for the two different ranges.

Weather Station – Each system was equipped with a weather station (Davis Vantage Pro 2, Hayward, CA) that recorded wind speed and direction, humidity, temperature, precipitation, and barometric pressure. These weather data were summarized and stored every 5 minutes. The anemometer was attached to the radar unit and measured wind speed at a height of approximately 6 m above ground level.

Radar Set Up and Data Collection

The radar systems were deployed on July 31st and August 1st at their respective sites. The radar unit in Lake County was maintained through November 11th to capture the anticipated end date of the nocturnal migration season. The radar unit in Bayfield County was moved on September 8th to the Keweenaw County site, where it was maintained until November 2nd. This radar unit ended data collection earlier than the other unit so that it could be used for a separate ground-truthing study.

Establishing radar systems at a selected site involved several activities, including orienting the VSR, selecting micro-sites, and adjusting to ensure adequate information was captured. Based on the results from previous studies (Peterson and Niemi 2011, Evans et. al 2012), we anticipated that migrants would fly southwest following the shoreline at the Lake County, Minnesota site, and we oriented the radar at 90°. We expected migrants to fly southbound across Lake Superior at the Bayfield and Keweenaw County sites, and the radars were oriented at 75° and 285° at these sites, respectively. These orientations were a compromise between a perpendicular angle that would intercept the greatest number of targets (birds or bats) and a parallel angle that would maximize the amount of travel time within the radar beam. The orientations were also influenced by micro-site selection. Micro-site selection is important because the positioning and orientation of the radar can affect the amount of interference from ground clutter or other sources of noise. In our study, if large areas were obstructed from a radar's view or if substantial amounts of clutter impeded data collection, the system was rotated incrementally to improve the radar's view and/or reduce interference.

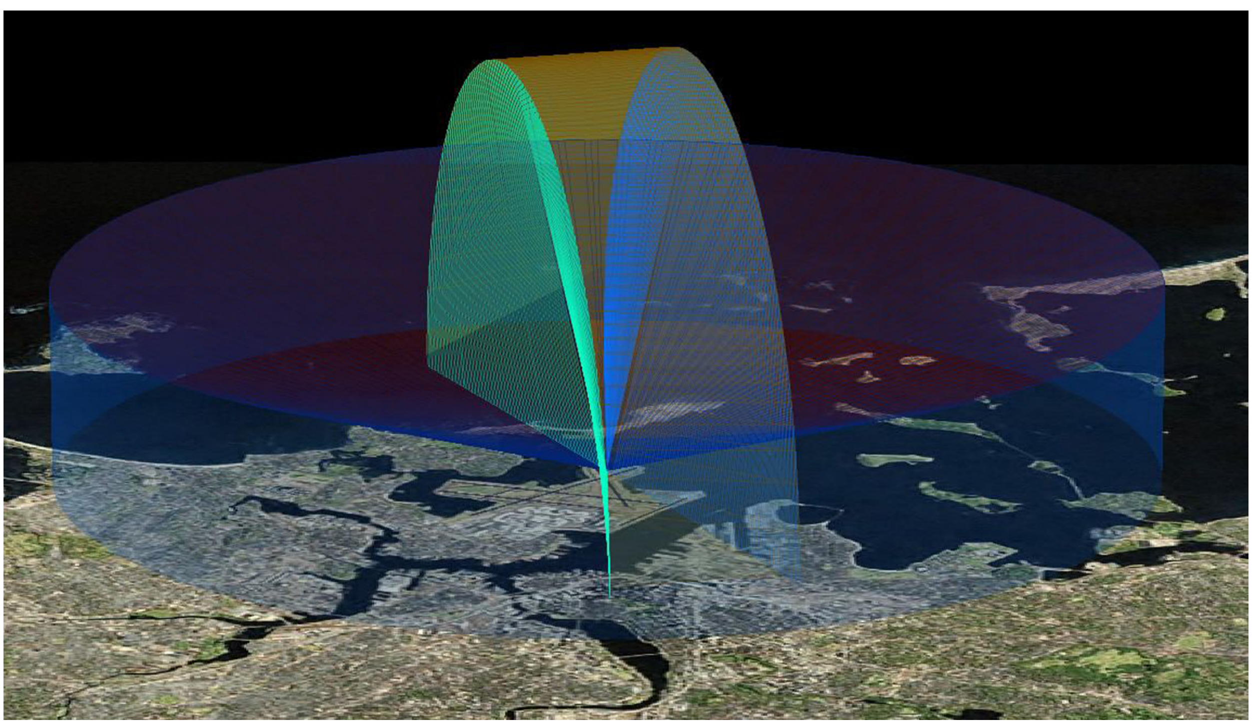


Figure 3. Computer representation of the potential survey volume scanned by horizontal and vertical radars that were used on Lake Superior during fall 2014. Graphic provided by DeTect, Inc.

Once a position was established, clutter maps were generated using 60-scan composite images (Figures 4-5) at time periods with low biological activity to identify areas with constant returns (areas that are white) that were not biological targets, such as tree lines, fencerows, and buildings. These areas were assigned a reflectivity threshold that precluded the constant returns from being included in these data and, as a result, reduced our ability to detect targets in these areas. Transient clutter, such as rain or cloud cover, is not included in these clutter maps.

Following this initial set up, MERLIN software was adjusted to fit the site conditions. The MERLIN software provides real-time processing of raw radar data to identify and track targets while excluding non-targets and rain events. However, the parameters used by the tracking software require adjustments to account for site-specific conditions. DeTect personnel trained our biologists in establishing settings to exclude as many non-biological tracks as possible while retaining the ability to track biological targets. The settings were established by varying the parameters on a small sample of early season data and rerunning the same data repeatedly to determine the optimal settings. The settings were established by one person to ensure consistency and reduce bias in how they are set between units and between seasons. The processed data were stored in a Microsoft Access database and transferred to a SQL database, where they were stored and later queried for data analysis. In addition to processed data, we maintained all raw radar data for potential reprocessing. The raw radar data were temporarily stored in the field on 2 TB external hard drives and were regularly transported back to the Regional Office, where the data were transferred to long-term tape storage. Once set up, the radar systems were monitored remotely, with biologists visiting the sites every few weeks to retrieve the stored data and perform maintenance on the radar units.

Radar System Outputs

The MERLIN software generates more than 30 measurements to describe the size, shape, location, speed, and direction of the movement of targets it tracked. These are the same type of measurements used by biologists when identifying biological targets on a radar screen (DeTect Inc., unpublished data, 2009), and this information was stored in databases for later analysis. To reduce potential false tracking of non-biological targets, the MERLIN tracking algorithm removed tracks with less than five observations. Additionally, when parts of the radar scan were dominated by rain, an automated filter would remove data from those areas.

In addition to storing target attribute data, the DeTect software outputs included a two-dimensional digital display of targets being tracked in real time and static images of tracked targets over a specified period of time (Trackplots) for both vertical and horizontal radars (Figures 9-11). During each site check, we verified that the real-time tracking display

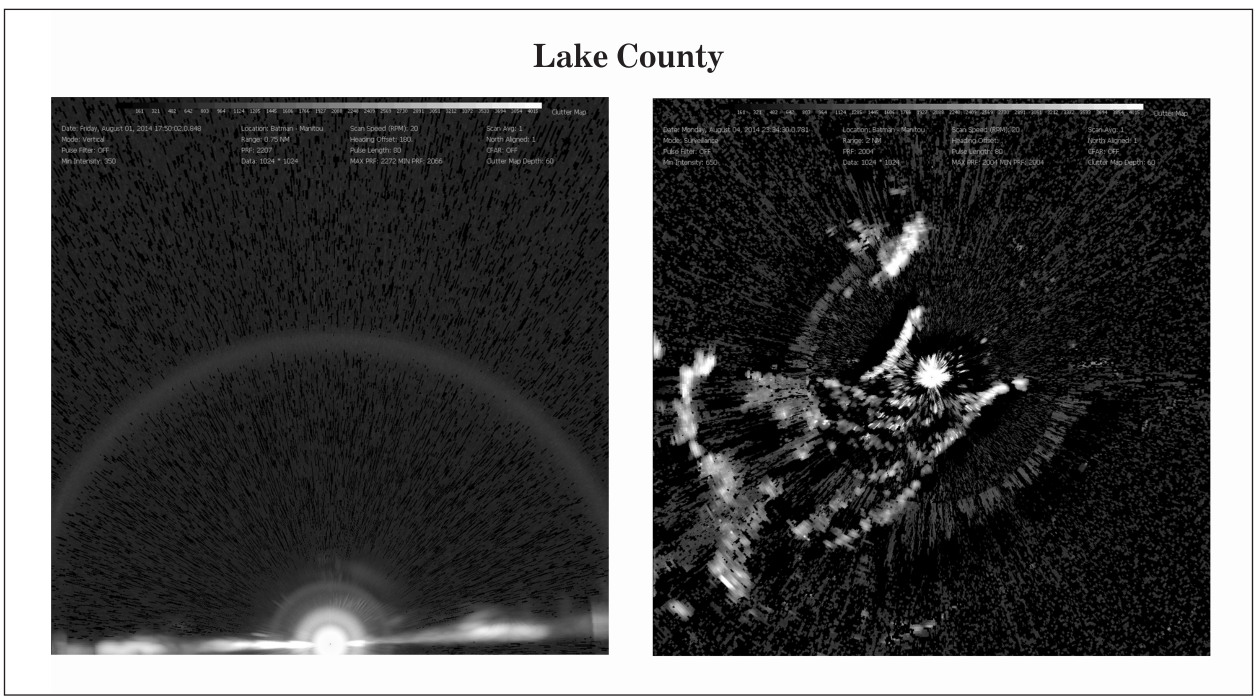


Figure 4. Clutter maps from vertical (left) and horizontal (right) scanning radars from the site in Lake County, MN. Brighter areas represent static returns from stationary objects such as tree lines, fencerows, and ridgelines. Targets may be lost in these areas due to the high radar returns from these stationary objects.

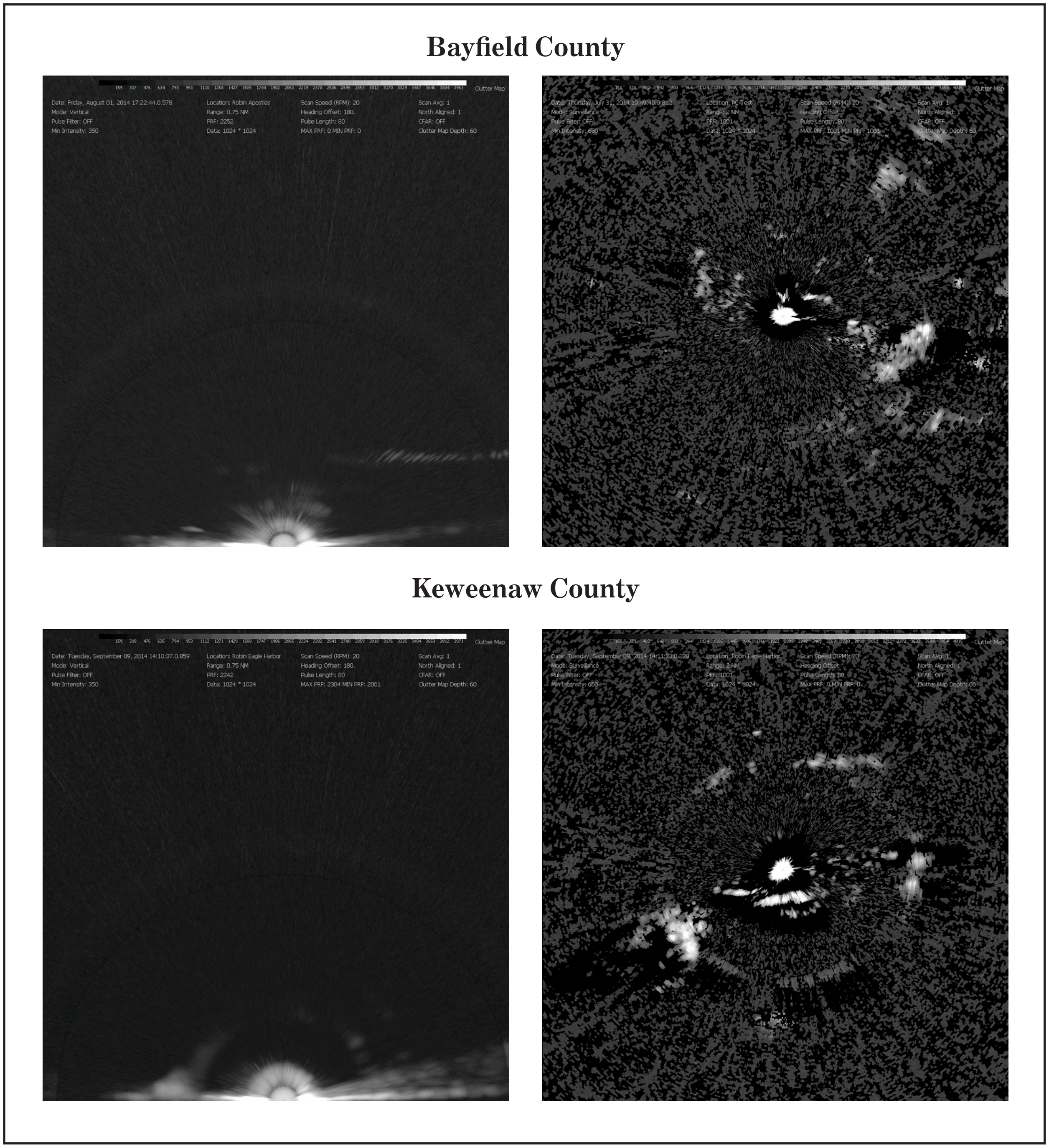


Figure 5. Clutter maps from vertical (left) and horizontal (right) scanning radars from sites in Bayfield County, WI (top) and Keweenaw County, MI (bottom). Brighter areas represent static returns from stationary objects such as tree lines, fencerows, and ridgelines. Targets may be lost in these areas due to the high radar returns from these stationary objects.

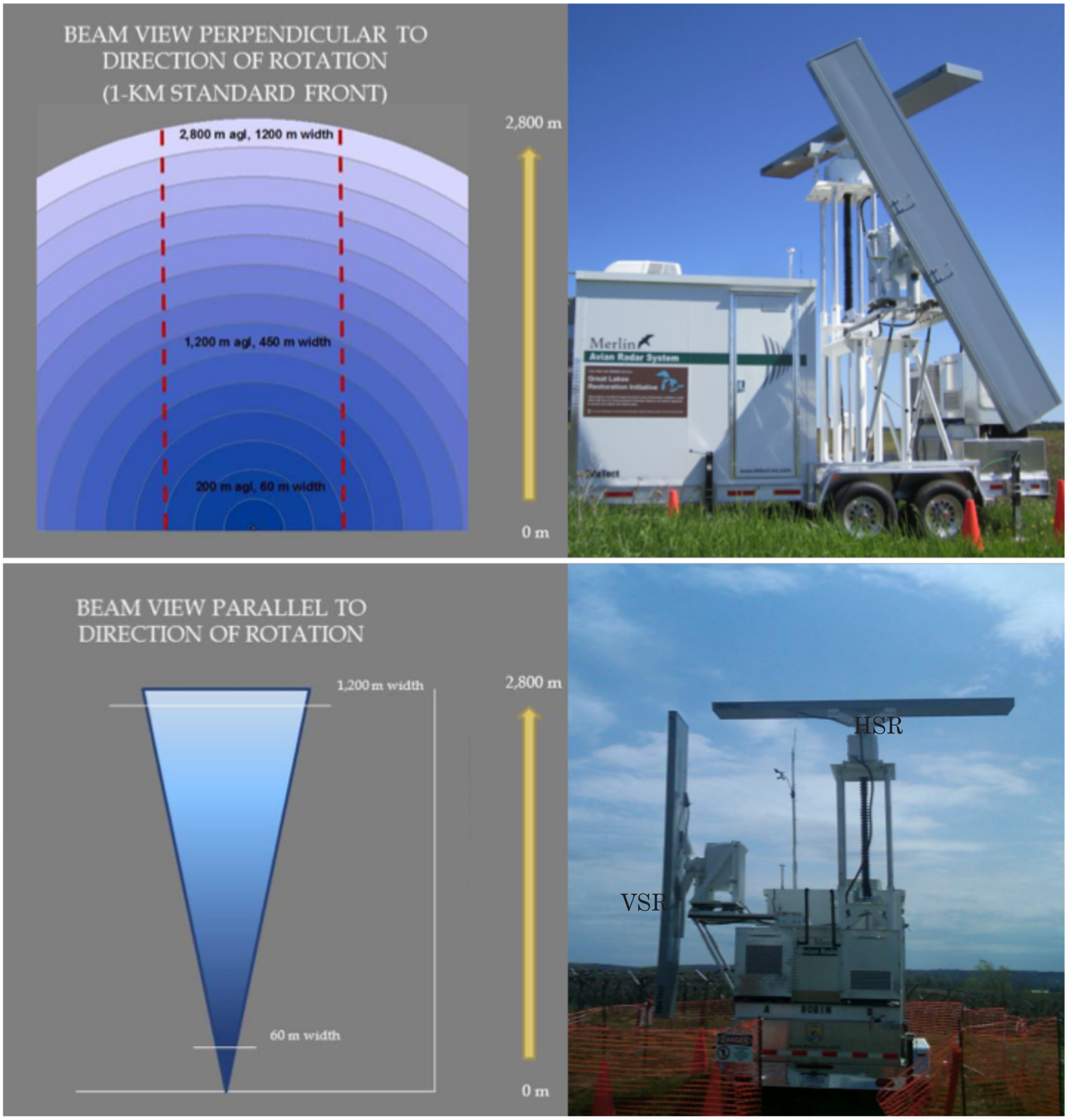


Figure 6. This schematic depicts the vertical scanning radar beam from two different views as well as pictures of the radar unit from those views. The top left graphic identifies the standard front used for data analysis. The standard front extends to 500 m on either side of the radar and up to a height of 2,800 m, as depicted in the top left graphic. In this graphic, the radar is situated at the bottom center, and the red dashed lines represent the lateral limits of the standard front. In the bottom graphic, the radar rotation is suspended so that the beam emits directly upward; this view is an approximation of the beam dispersion as it travels away from the radar unit (schematic not drawn to scale).

agreed with the raw radar display. We also viewed 15 minute and 1 hour Trackplots to assess the previous day's activity.

Data Processing and Quality Control

Prior to data analysis, the data processed by the MERLIN software were further evaluated for potential contamination by false targets. While an automated rain filter was used, during some time periods, it did not remove all rain from the recorded outputs. In addition, insects and other forms of transient clutter may be recorded during data collection. Biologists reviewed all data in 15 minute increments and removed time periods that were dominated by rain, insects, or other forms of transient clutter. We relied on visual inspection of track patterns to discern contamination events. Rain and insect events form diagnostic patterns (Detect Inc., personal communication, 2011) that were readily omitted when present. Additionally, if the number of rain targets constituted only a small part of the overall targets where the reviewer thought that valid conclusions about that time period could be made, then that time period was retained for analysis. Contamination that mimicked the track patterns of the desired targets were not removed from the database, and to the extent that this occurred, it contributed to the error associated with the indices. In addition, we evaluated the initial counts by generating a time series to show the variation in the number of targets per hour across the season for both the HSR and VSR antennas. In general, the HSR and VSR hourly counts are positively correlated, with the HSR also having higher counts. In situations where the VSR resulted in higher counts than the HSR or where peak counts appeared to be outliers, the data were further investigated for evidence of contamination or potential issues with radar performance. On rare occasions when time periods with anomalies appeared to represent artifacts not related to target movement (e.g., rain events or data processing errors), they were removed from further analysis.

Once the contaminated time periods were removed, we summarized the data using SQL queries provided with the MERLIN radar system. Data from the HSR were used to calculate hourly counts and to target movement direction. All targets within 3.7 km of the radar unit were included in the analysis. Data from the VSR were used to calculate hourly counts and height estimates, and these data were truncated to a 1-km front, or "standard front". The standard front was defined by a volume of space that extended 500 m beyond either side of the radar and continued up to the maximum height of data collection (2,800 m) (Figure 6). We adopted this sampling technique because it is the method used by the manufacturer of the MERLIN units, and this metric has also been reported by other researchers (Lowery 1951, Liechti et al. 1995, Kunz et al. 2007b). Using each site location's GPS coordinates, sunrise and sunset times were calculated and target counts were further segregated into four biological time periods: dawn, day, dusk, and night. The dawn time period was 30 minutes before sunrise to 30 minutes after sunrise; day, 30 minutes after sunrise to 30 minutes before sunset; dusk, 30 minutes before sunset to 30 minutes after sunset; and night, 30 minutes after sunset to 30 minutes before sunrise the following day. The dawn and dusk time periods always equaled 60 minutes; however, due to changing sunrise and sunset times, the sampling periods for the day and night time periods varied throughout the season.

Data Summary and Trends Analysis

We used the processed data to assess activity patterns that are associated with migration. Trackplots were viewed to identify changes in activity and to investigate migrant behaviors such as dawn ascent (Myres 1964, Diehl et al. 2003), reverse migration (Akesson 1999), and migrants moving toward or along the shore or stopover habitat at dawn. Target counts represented an index of abundance and we used these indices to identify directional, temporal, and altitudinal trends.

Directional Trends – Mean angle and concentration (r) of target directions were analyzed following the methodology for circular statistics (Zar 1999) provided within DeTect SQL queries. The angular concentration value has a value of 1 when all angles are the same and a value of 0 when all angles cancel each other (e.g., 50% of the vectors are 180° and 50% are 360°), indicating that there is no predominant direction of travel. We reported the mean direction of movement of nocturnal targets and the percent of nights when targets traveled in a direction between south and west (157.5 – 292.5°) for Lake County and between southeast and southwest (112.5 - 247.5°) for Bayfield and Keweenaw counties. These direction bins were chosen because they fit the anticipated direction of movement and contain the mean direction of movement at night. We used radial graphs to plot the number of targets per 8 cardinal directions (i.e., eight groups centered on N, NE, E, SE, S, SW, W, NW) during four biological time periods (i.e., dawn, day, dusk, night).

Temporal Trends – We plotted count indices of targets per hour processed by MERLIN software for both the HSR and VSR antennas as a time series to identify pulses of nocturnal activity, season duration, and changes in patterns of activity over time. We plotted both indices together, as the HSR and VSR have different strengths that complement one another. The HSR index tracks lower-flying targets in a 360° span around the radar unit, and detection is unaffected by the target's direction of travel, as with the VSR. However, this index is much more affected by ground clutter than the VSR, which affects target detection and tracking. Errors caused by ground clutter can lead to both under- and over-counting. This leads to HSR counts that may be more influenced by site conditions than VSR counts. However, the HSR index better captures targets under certain conditions, such as when targets are travelling parallel to the VSR and/or are primarily at low elevation, which may happen more at the beginning and end of the migration season. The HSR is also likely more susceptible to beam bending from dynamic atmospheric conditions than the VSR; beam refraction in the VSR is minimal primarily due to its orientation. The VSR index tracks target activity captured within the standard front and has more-consistent detection than the HSR because it mostly tracks against clear air, except in the lowest altitude bands, where ground clutter and side lobes can affect tracking. The VSR's detection is mainly affected by target movement direction and distance from the radar (Bruderer 1997, Schmaljohann et al. 2008). Plotting these indices together provided a more comprehensive understanding of changes in target activity over time.

We used the VSR index to calculate the target passage rate (TPR). We calculated TPR as the number of targets per standard (1 km) front per hour using DeTect SQL queries. Hours with less than 30 minutes of recording time were omitted from this calculation. For example, after removing all hours with less than 30 minutes of clean data, the nocturnal TPR for a given night (biological time period) was calculated by dividing the target count by the number of nighttime minutes and multiplying by 60 to provide the number of targets per hour during that night. We extended this metric to the season and calculated the mean TPR for biological time periods and hours of the season. The mean nocturnal TPR for the season is the sum of night TPRs divided by the number of nights sampled. Similarly, the mean hourly TPR for the season is the sum of TPRs for an hour period divided by the number times that hour was sampled. We also calculated the mean nocturnal (night biological time period) and diurnal (day biological time period) TPRs for each week during the sampling period. These were calculated in two ways. To show the variability among sampled weeks, we divided the sum of the TPRs for a week (nocturnal or diurnal) by seven and reported the weekly mean TPR and its standard deviation. To better illustrate nocturnal and diurnal trends in TPR across the season, we also plotted 7-day moving means of TPR as line graphs.

Altitudinal Trends – SQL queries provided by DeTect Inc. calculated height estimates from the VSR data of targets tracked within the standard front. Height estimates were calculated based on the range and bearing of the target from the radar unit location using information from the largest radar echo (usually the closest to the center of the radar beam and, therefore, the actual height of the target) and were reported as the height above ground level at the radar unit. We used the estimates of flight height to calculate the mean altitude of targets above ground level by biological time period and hour, and we report the mean and median altitudes for the season. These height estimates were also used to assign each target to a 50-m altitude band. Using these 50-m bands, we also present graphics showing altitudes with the highest frequency of use, a measure that we believe better represents risk.

Density per Altitude Band – To provide information on the density of targets per 50-m altitude band per hour within the standard front, we first estimated the volume of the vertical radar beam's approximate geometric shape. The width of the radar beam expands as it travels from the radar, resulting in increased survey volume with distance from the radar unit. The shape of the survey volume contains the space in which targets have the potential of being detected and represents one of several considerations that define the realized or actual survey volume (Bruderer 1997, Schmaljohann et al. 2008). We calculated the volume contained by the shape of the vertical radar beam and report the density of targets (targets/1,000,000 m^3) per 50-m altitude band per hour for each biological time period. This was calculated by dividing the number of targets per volume of an altitude band by the number of minutes with clean data during the biological time period of interest and multiplying by 60.

To estimate the volume of 50-m altitude bands that are constrained by the standard front, we used Monte Carlo integration (Press et al. 2007). These methods are described in detail elsewhere (manuscript in preparation) and are summarized here. The volume contained by the shape of the radar beam can be calculated using spherical coordinates and multiple integration. However, subjecting this volume to Cartesian constraints (i.e., the standard front and altitude bands) complicates the calculation, and the volume bands are more easily estimated using Monte Carlo integration. Monte Carlo integration is a method to calculate an unknown volume by enclosing it in a known volume and saturating the space with random points. Monte Carlo integration requires rules that determine whether the randomly drawn points are inside or outside of the unknown volume. The proportion of points that fall within these constraints multiplied by the volume of the known space is approximately equal to the unknown volume. As the number of random points approaches infinity, the estimation approaches an exact calculation of the volume in question.

We used R software (R Core Team 2012) to describe a box of known volume that was large enough to enclose the radar beam and then saturated this space with 10 million random points. For the radar beam, we determined two simple rules that defined whether a point was in the survey volume. The first rule was that the distance of the randomly drawn point from the origin was less than 2.8 km. The second rule was that the angle between a randomly drawn point and the vertical plane (the x-z axis in Figure 7) was less than 12.5^{o} (i.e., half the angle of the beam width). The volume of a full sweep of the radar beam, as estimated via Monte Carlo integration, was within 5% of the analytical solution using spherical coordinates. Thus, the number of random points we used provided a reasonable approximation of the volume. With the volume of a full sweep of the radar beam described, we were able to further constrain the Monte Carlo integration to describe the structural volume of the radar beam within a standard front (Figure 7) and within altitude bands (Figure 8).

The number of targets per altitude band is often reported by other researchers, however a volume correction is not often reported. We wanted to compare our correction to the uncorrected method; however, count data and volume data are at different scales. For this reason, we compare our density estimate to a density estimate based on the number of targets per 50-m altitude band per hour while assuming that there is an equal amount of volume within each altitude band (the volume of each altitude band is equal to the total volume divided by the number of altitude bands). An assumption implicit to reporting the number of targets per altitude band is that comparisons among bands can be made directly (i.e., that altitude bands are equal). For our comparison metric, we made this implicit assumption explicit (see Appendix 4). Differences in clutter between these 50-m bands is not accounted for in our correction method, nor is reduction in detection ability due to distance from the radar.

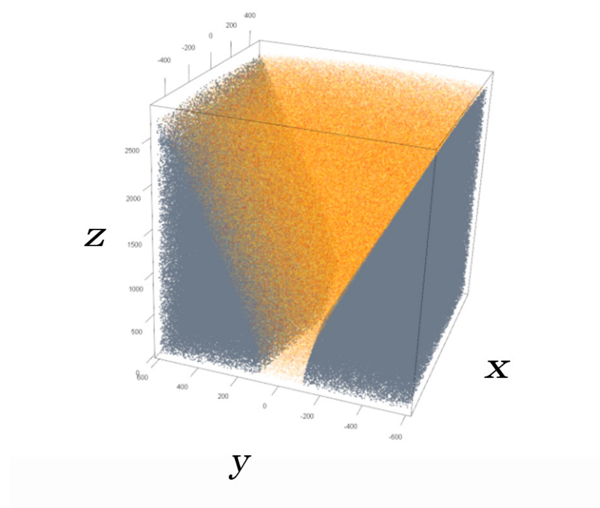


Figure 7. A graphical representation of the structural volume of the vertical scanning radar within the standard front. In this graphic, the radar unit is located at the origin and the radar beam extends to 500 m on either side of the radar unit (x-axis) and up to a maximum height of 2,800 m (z-axis). The y-axis represents the spread of the radar beam as it extends away from the origin. The orange semi-transparent points represent the volume contained by the structure of the radar beam. Dark gray points represent the volume that is within the box but are not included in the volume of the radar beam.

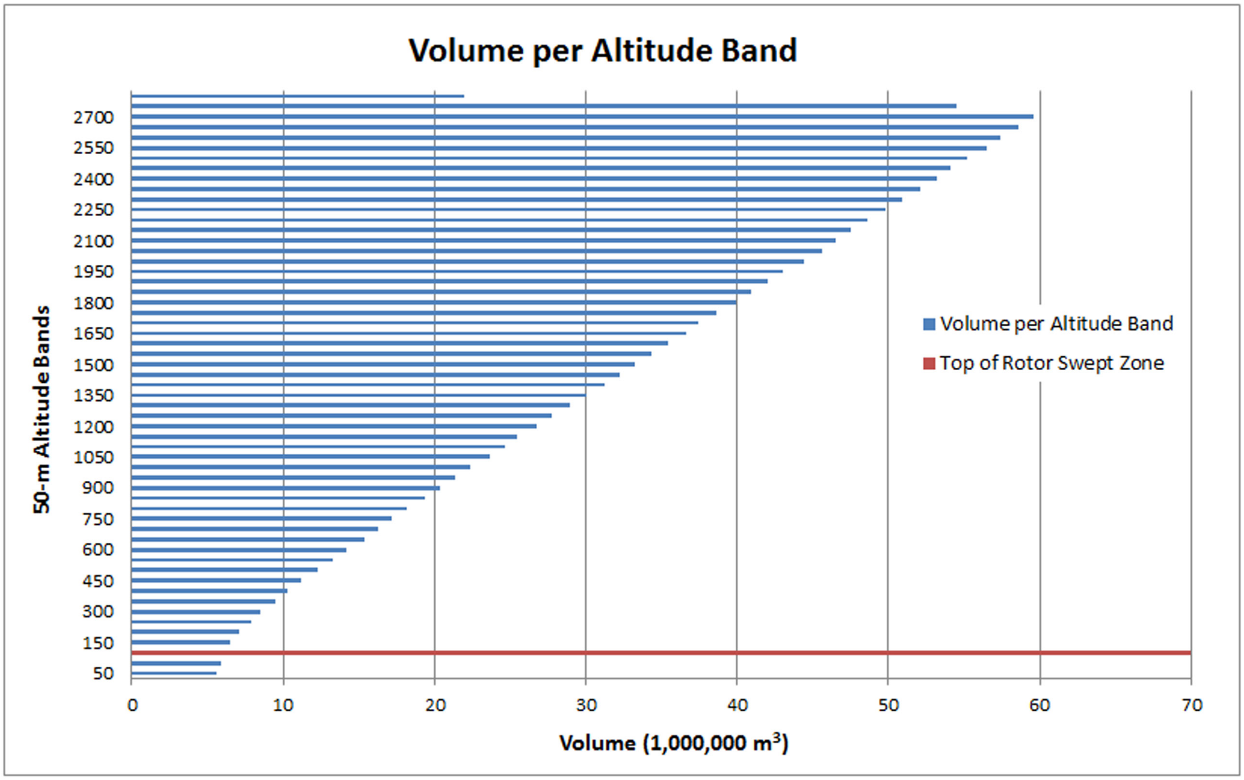


Figure 8. Volume of 50-m altitude bands within the standard front as estimated with Monte Carlo integration. Target counts provided by the vertical scanning radar are limited to the structure of the 1-km standard front. Altitude band labels represent the top of each 50-m band. Red line represents the top of the rotor-swept zone. Radar detections occurred up to 2800 m.

Results

During the fall 2014 season, we began data collection on July 31 and Aug 1 at the Bayfield County, WI and Lake County, MN sites, respectively. We moved the Bayfield County radar unit to Keweenaw County, MI for the second part of the season on September 8. We ended data collection on November 2 at the Keweenaw County site and on November 11 at the Lake County site, which resulted in radars being in place for 2,474 hours at the Lake County site, 937 hours at the Bayfield County site, and 1,345 hours at the Keweenaw County site (Table 2). We recorded data continuously during the survey period while the radar units were operational. Radar downtime occurred when the radar units were non-operational due to maintenance or malfunction. Data with contamination (such as rain) were removed from the analysis, resulting in not all collected data being useable for analysis. Gaps in analyzed data occurred when contaminated data were removed or during radar downtime.

Table 2. Survey effort (hours) by vertical and horizontal scanning radars during fall 2014 in Lake, Bayfield, and Keweenaw counties.

Site	Radar	Survey Period Hours	Radar Downtime	Time Radar Collected Data	Radar Data with Rain	Useable Radar Data	% Survey Period with Collected Data	% Survey Period with Useable Data
Lake	VSR	2474	90	2384	277	2107	96%	85%
Lake	HSR	2474	34	2440	97	2343	99%	95%
Bayfield	VSR	937	29	908	64	844	97%	90%
Bayfield	HSR	937	29	908	4	904	97%	96%
Keweenaw	VSR	1345	25	1320	210	1110	98%	83%
Keweenaw	HSR	1345	23	1322	2	1320	98%	98%

* Vertical and horizontal radars are not equally impacted by rain events or downtime.

Qualitative Assessments

Hourly Trackplots showed images of diurnal and nocturnal migration events at each of the three locations (Figures 9-11). For example, over a 24-hour period, on Sept 22 at the Lake County site, the horizontal radar recorded light activity moving southwest along the shoreline at around 12:00, indicating that a small amount of diurnal migration occurred at this time, which occurred during other days surveyed as well. Activity reduced as the day progressed, with little activity on the horizontal or vertical radars at 17:00. During the 18:00 hour, activity increased, with targets occurring in numbers on both the horizontal and vertical radars. Activity was moving out over the lake and moving south and southeast at this time. During the 22:00 hour, directional movement had shifted southward, and the vertical radar activity increased with more targets at higher altitudes. This level of activity continued throughout the night. At 06:00, when dawn was occurring, the targets shifted their activity and began to travel along the lakeshore or else return to the shoreline by moving west if they were out over the lake. Activity on the vertical radar was also reduced as targets flew at lower altitudes and began to land from their migration flights. By 12:00, diurnal activity had fallen to low levels and no diurnal migration occurred. This pattern of target movement and changes in altitude were indicative of a pulse of nocturnal migratory activity.

A similar pattern can be seen at the other radar sites with lower activity during the day, increasing on both antennas near dusk, peaking around midnight, and decreasing sharply around dawn. Targets also moved in to the shoreline from over the water and along the shoreline at dawn, and activity returned to lower diurnal levels the next day. The target movement directions often also changed between early in the night and times closer to dawn, indicating that the migrants changed their behaviors depending on the time of night they encountered the obstacle of the lake.

Some areas at each site were not well recorded by the radar due to beam blockage from the ground clutter (due to topography, vegetation, buildings, etc.) (Figures 4-5), which resulted in reduced detection in these areas (e.g., the southwest corner of the Lake County horizontal radar scan). Artifacts of the radar unit setup can also be observed in the Trackplots. Examples include rings of decreased detection that occur right next to the radar unit and the ring on the radar where the radar unit switches pulses (Vertical – Sept 22 22:00 Lake County – Figure 9; Horizontal – Aug 31 00:00 Bayfield County – Figure 10).

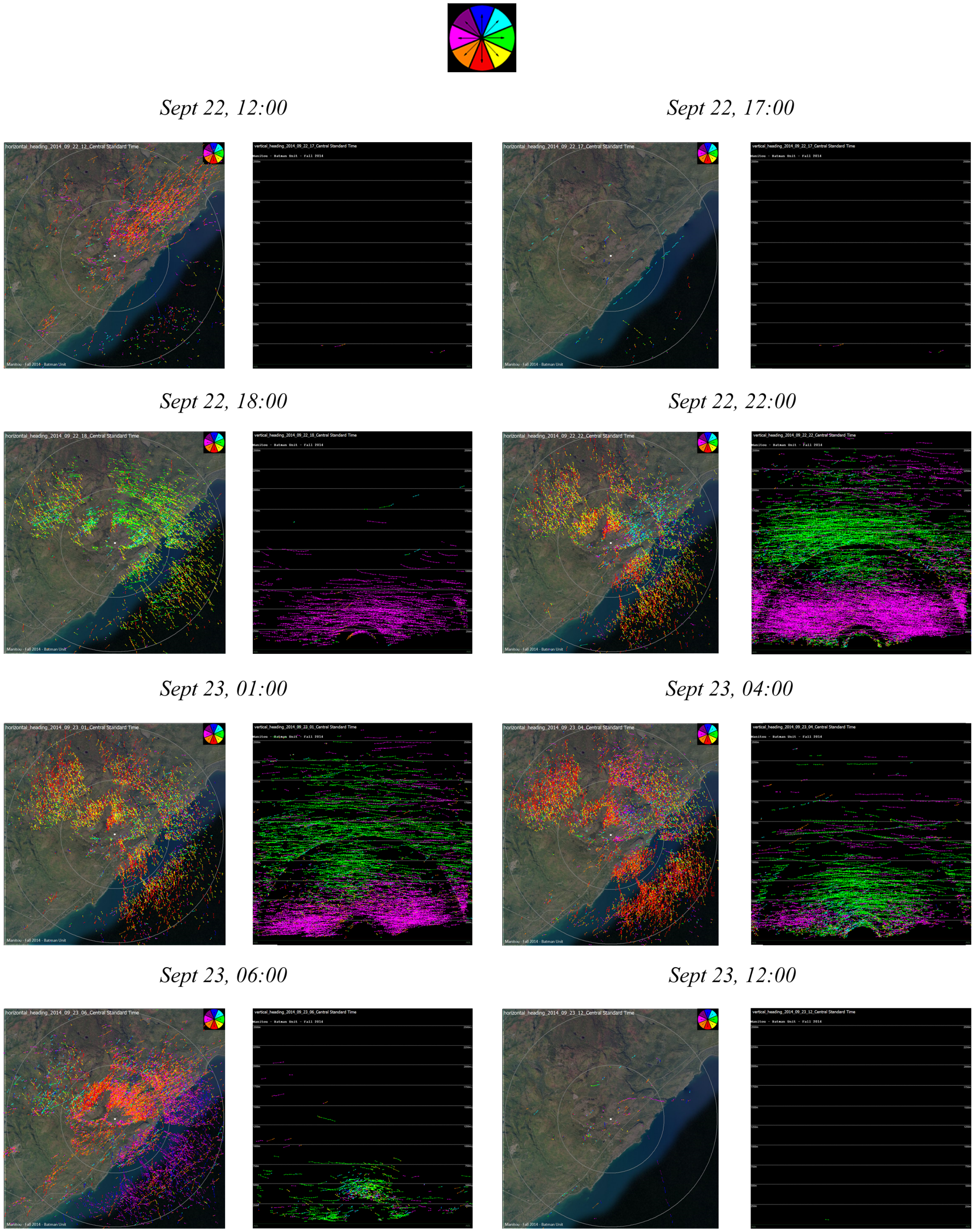


Figure 9. Images of tracks during 1 hour increments recorded by horizontal and vertical scanning radars during a migration event in Lake County, MN. Horizontal radar images (columns 1 and 3) show the direction of targets, as indicated by the color wheel. Vertical radar images (columns 2 and 4) show target heights.

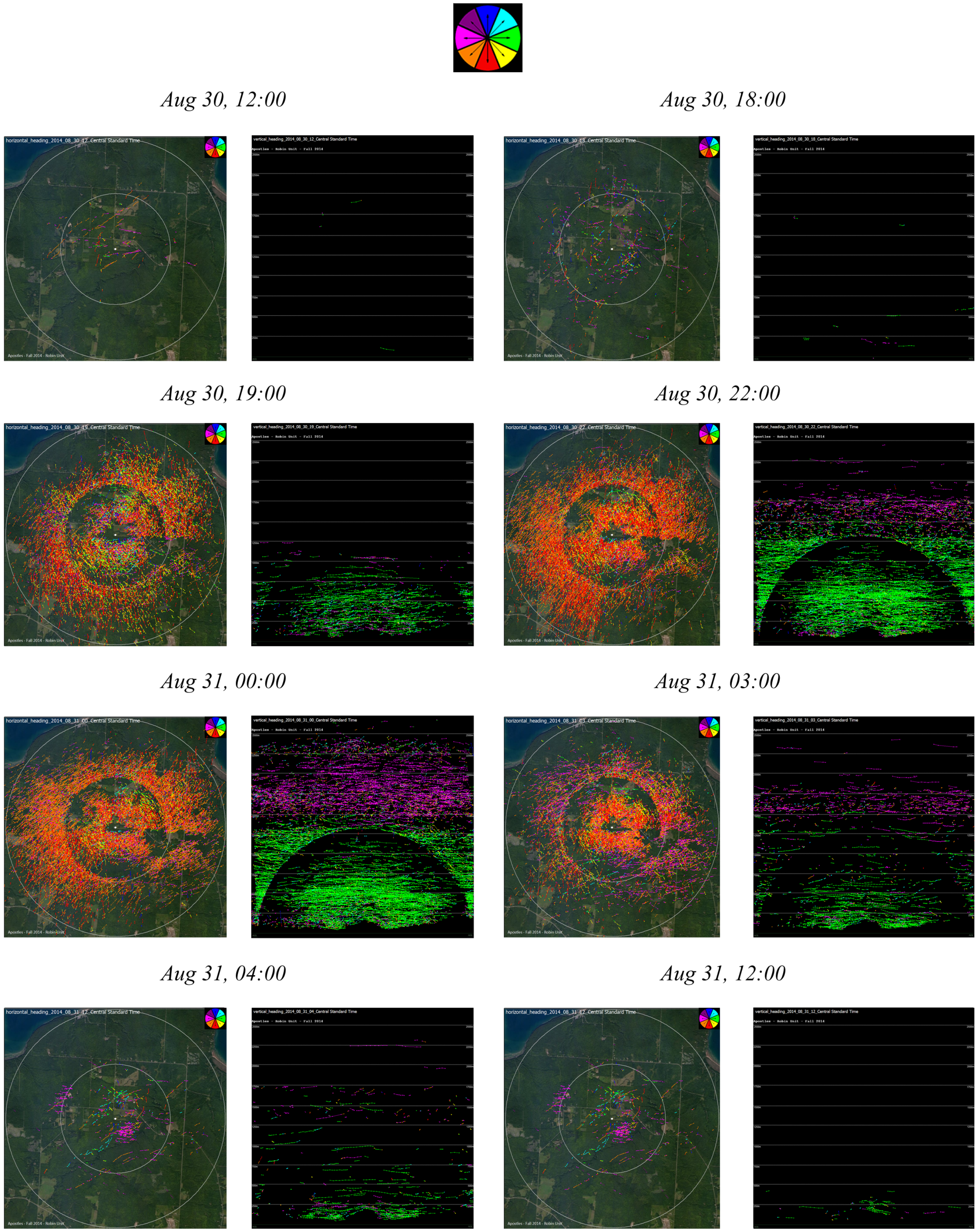


Figure 10. Images of tracks during 1 hour increments recorded by horizontal and vertical scanning radars during a migration event in Bayfield County, WI. Horizontal radar images (columns 1 and 3) show the direction of targets indicated by the color wheel. Vertical radar images (columns 2 and 4) show target heights.

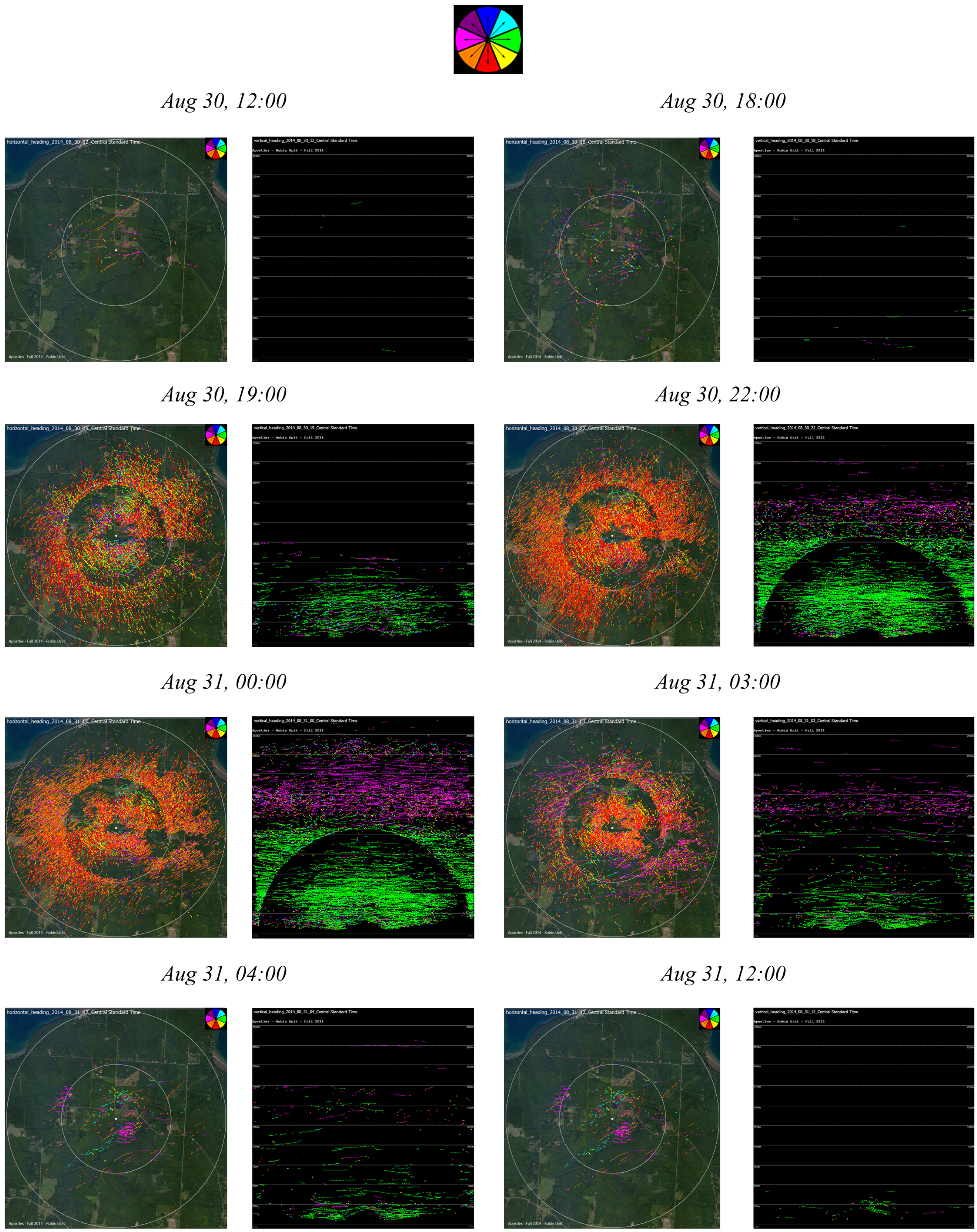


Figure 11. Images of tracks during 1 hour increments recorded by horizontal and vertical scanning radars during a migration event in Keweenaw County, MI. Horizontal radar images (columns 1 and 3) show the direction of targets indicated by the color wheel. Vertical radar images (columns 2 and 4) show target heights.

Directional Trends

During the fall 2014 season, the nocturnal target movement direction was generally between southeast and west (112.5-292.5°) at all sampled locations (Figures 12-13, Tables 3-4). At the Lake County site, the mean nocturnal direction was 210°, with an angular concentration (r) of 0.55 (n = 3,986,149 targets), and during 85% of nights, the mean target direction was between south and west (157.5-292.5°), showing movement along the lakeshore. The diurnal mean direction was similar at 226°, with an angular concentration of 0.57 (n = 1,137,367 targets), and during 90% of days, the mean target direction was between south and west, indicating strong diurnal directionality along the lakeshore as well.

The direction at the Bayfield County site was slightly more variable during most time periods and had a mean nocturnal direction of 170° (r = 0.45, n = 1,399,938), with 78% of nights having a mean direction between southwest and southeast (112.5-247.5°). The diurnal movement direction was even more variable, with a mean direction of 160° and an angular concentration of 0.21 (n = 180,003 targets). During 65% of the days, the mean target direction was between southeast and southwest.

The Keweenaw County site had a mean nocturnal direction of 170° (r=0.55, n=1,341,917), with 70% of nights having a mean direction between southwest and southeast. The diurnal movement was similar, with an average movement direction of 159° with an angular concentration of 0.4 (n=111,638 targets). During 72% of days, the mean target direction was between southeast and southwest. There was some evidence for onshore movement at dawn at each of the 3 sites (Figures 9-13).

Overall, the general directional trends observed on the extended range (11.1 km) horizontal radar at the Lake County, MN site matched what we observed on the normal (3.7 km) horizontal radar at that site. The total counts on the extended range radar were higher due to the increased area surveyed, but the temporal pattern of when the high and low numbers were observed as well as the general direction of movement were similar between the normal and extended range radars. We do not present the extended range data in this report due to its similarity to the standard range horizontal radar.

Table 3. Mean direction, angular concentration (r), and percent of biological time periods with strong directionality (r ≥ 0.5) of targets during these periods in Lake County, MN. This table is meant to give information about the direction of movement of the targets, not overall counts, as the amount of time sampled for each biological period is different.

	Lake County			
Biological Period	**Mean Direction (degrees)**	**r**	**% Time Periods r ≥ 0.5**	**n**
Dawn	235	0.51	68.3%	243,146
Day	226	0.57	62.6%	1,137,367
Dusk	203	0.52	65.3%	62,695
Night	210	0.55	86.0%	3,986,149

Target DirectionPer Hour for Four Biological Time Periods

Lake County, MN

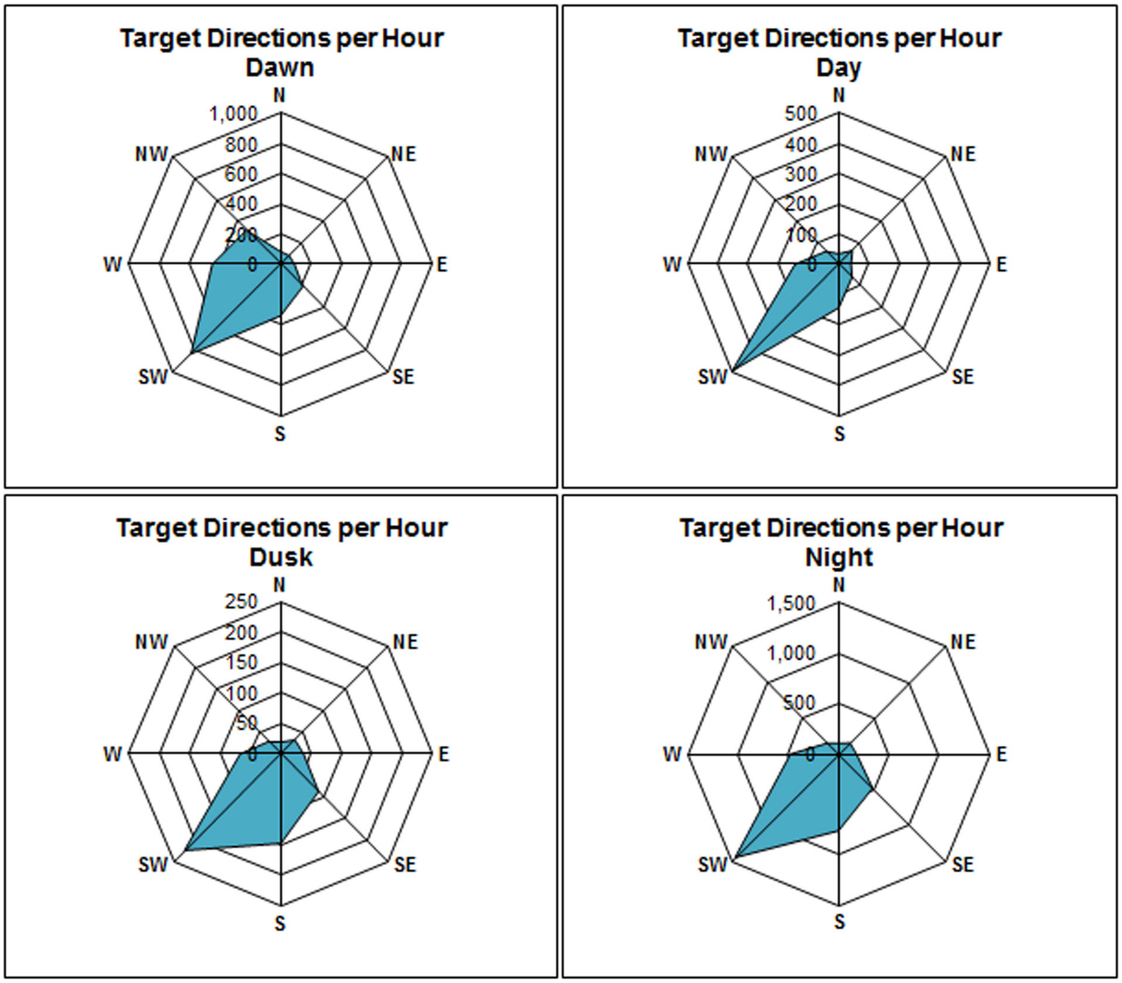


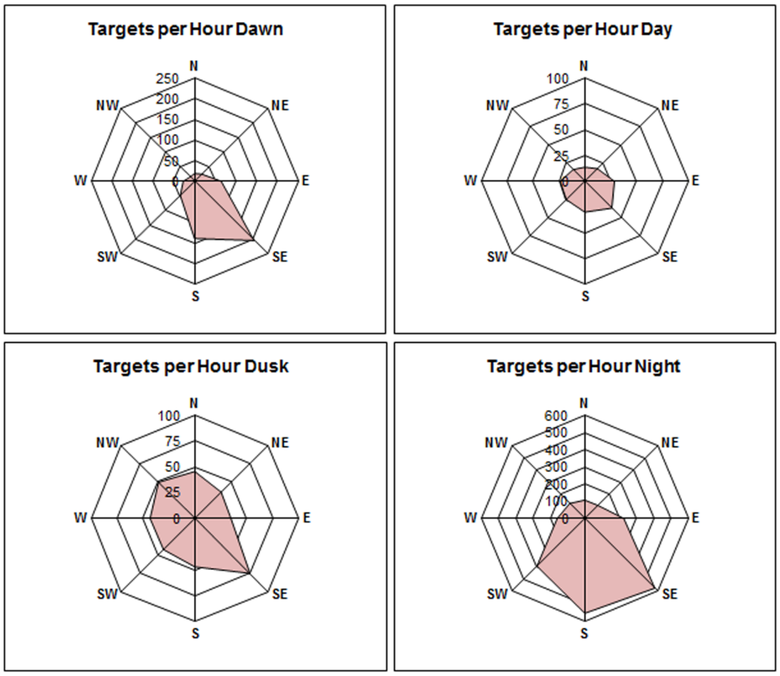
Figure 12. Target direction per hour during four biological time periods during fall 2014 in Lake County, MN

Table 4. Mean direction, angular concentration (r), and percent of biological time periods with strong directionality (r ≥ 0.5) of targets during biological time periods in Bayfield County, WI and Keweenaw County, MI. This table is meant to give information about the direction of movement of the targets, not overall counts, as the amount of time sampled for each biological period is different.

	Bayfield County				Keweenaw County			
Biological Period	**Mean Direction (degrees)**	**r**	**% Time Periods r ≥ 0.5**	**n**	**Mean Direction (degrees)**	**r**	**% Time Periods r ≥ 0.5**	**n**
Dawn	151	0.59	63.2%	38,372	157	0.70	75.9%	62,276
Day	160	0.21	23.7%	180,003	159	0.40	34.5%	111,638
Dusk	170	0.07	39.5%	27,264	178	0.32	65.5%	5,196
Night	170	0.45	71.1%	1,399,938	170	0.55	81.8%	1,341,917

Target DirectionPer Hour for Four Biological Time Periods

Bayfield County, WI



Keweenaw County, MI

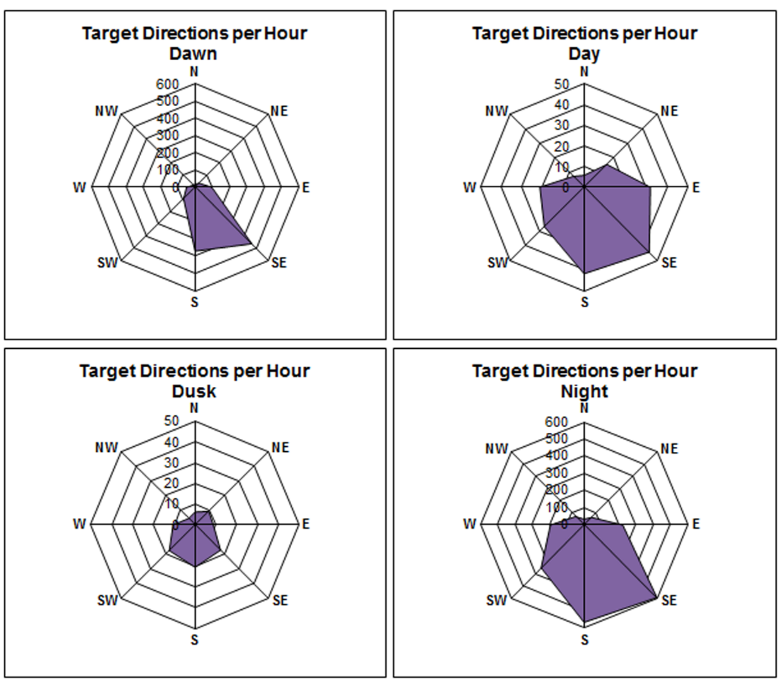


Figure 13. Target direction per hour during four biological time periods during fall 2014 at Bayfield County, WI (left) and Keweenaw County, MI (right).

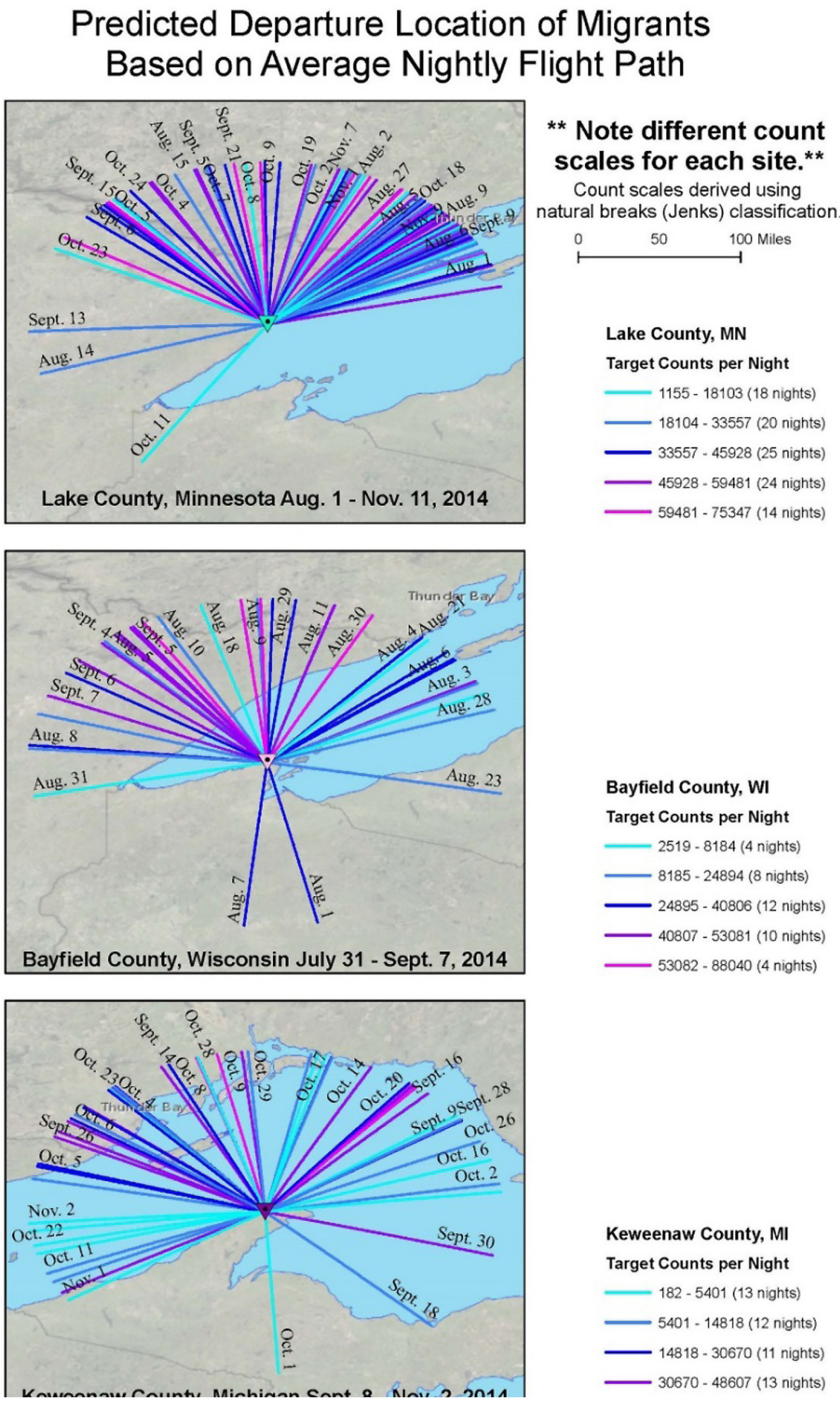


Figure 14. Movement direction of targets for each night over the entire season. Each line represents the average movement direction targets were coming from for one night during the season. These directions assume that migrants move in a straight line for an entire night, which is not the case, but it helps to show where the general direction of migrant movement originates. These directions provide evidence that nocturnal migrants are flying across the open water of the Great Lakes and along the shorelines. The color of the lines indicates the magnitude of migration on that night. Count categories are derived using natural breaks (Jenks) classification. Date labels are missing for some lines that were too closely clumped together.

Temporal Trends

Time Series Plots – Hourly target counts provided by horizontal and vertical radars showed pulses of elevated nocturnal activity with peaks near or slightly after midnight at the three study sites. Across the sampling period, these events were often clustered into groups of several sequential nights, and repeated groups of peaks were observed as soon as we deployed the radar units for the season at both of the first set of sites (Figures 15-16). These clusters of peaks of activity occurred up through when we moved one of the radar units to Keweenaw County on September 8, reaching their highest counts at Bayfield County near the end of August and in early September. The peaks occurred from near the start of our time at Keweenaw County and ended around the middle of October at this site (Figure 17). For the Lake County site, nocturnal peaks were observed consistently from the start of the season through mid-October, with sporadic peaks observed after this date up through when we ended our surveying season in mid-November. Diurnal peaks on the horizontal radar were also evident at this site, occurring with regularity from mid-September through early November, indicating heavy use of the area by diurnal migrants.

Different patterns of activity are apparent as the season progresses, with the differences being the most obvious at our Lake County site. For example, in early August, most of the activity occurs only at night. Near the end of August, higher activity during the day starts to occur occasionally, but the overall numbers are still much less than at night. In the middle of September, however, daytime HSR numbers begin to rival nocturnal HSR numbers, and days with activity occurring in the morning hours increase in frequency. In mid to late October, nocturnal activity began to drop off, leaving the diurnal activity as the main cause of many of the peaks in activity (Figure 15). These diurnal peaks were almost always moving along the shoreline to the southwest, indicating that they were likely diurnal migrants and not simply gulls or other birds moving back and forth between roosting and feeding grounds, as we have observed at some of the locations we surveyed during previous seasons. These observations match other studies of diurnal raptor migration along the coastline of Lake Superior in Minnesota (Peterson and Niemi 2011, Evans et. al 2012, Seeland et al. 2012, Peterson et al. 2015).

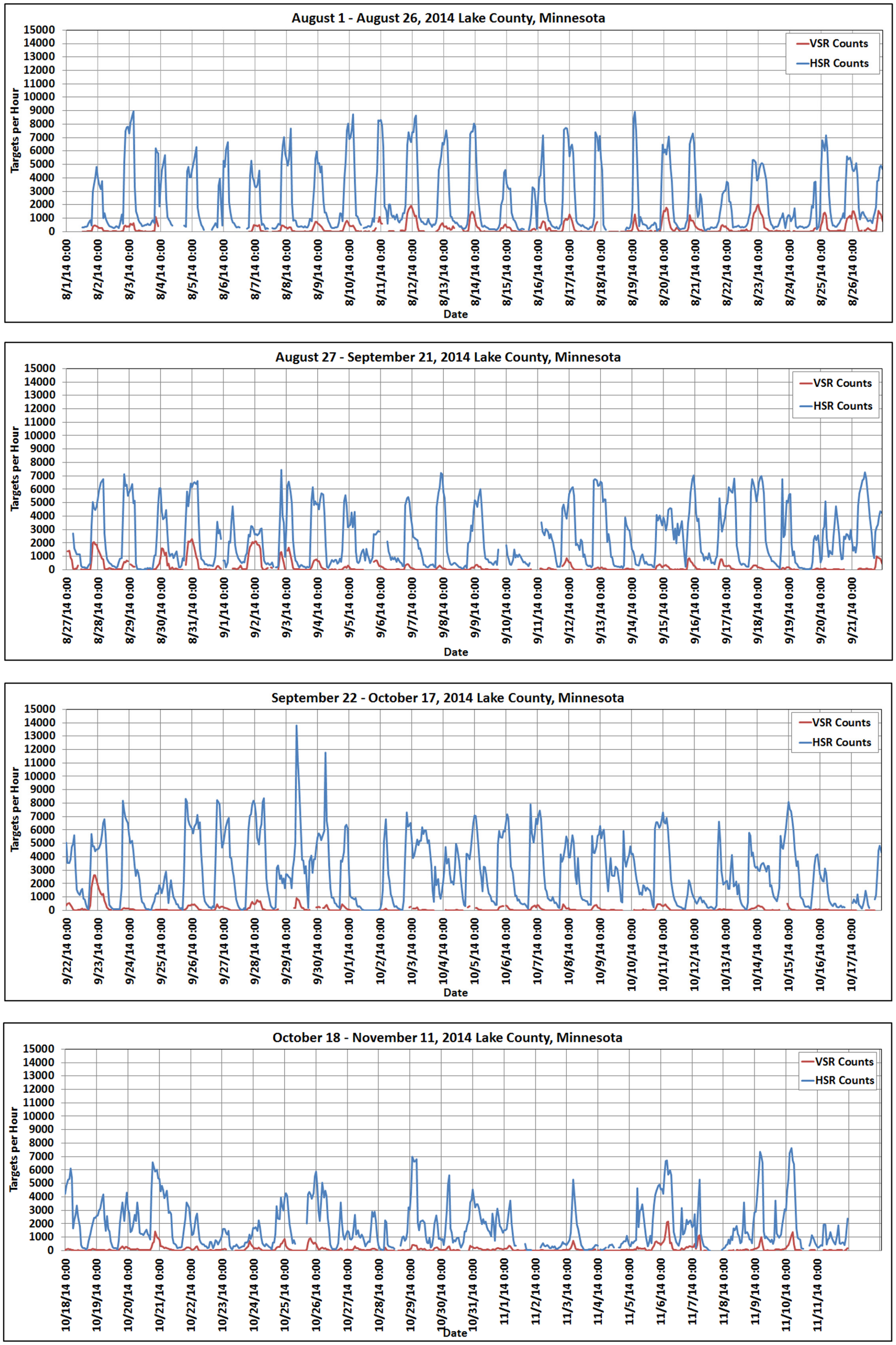


Figure 15. Hourly counts by the horizontal radar and the vertical radar's standard front from August 1 – November 11, 2014, at Lake County, Minnesota. Light gray vertical lines represent midnight.

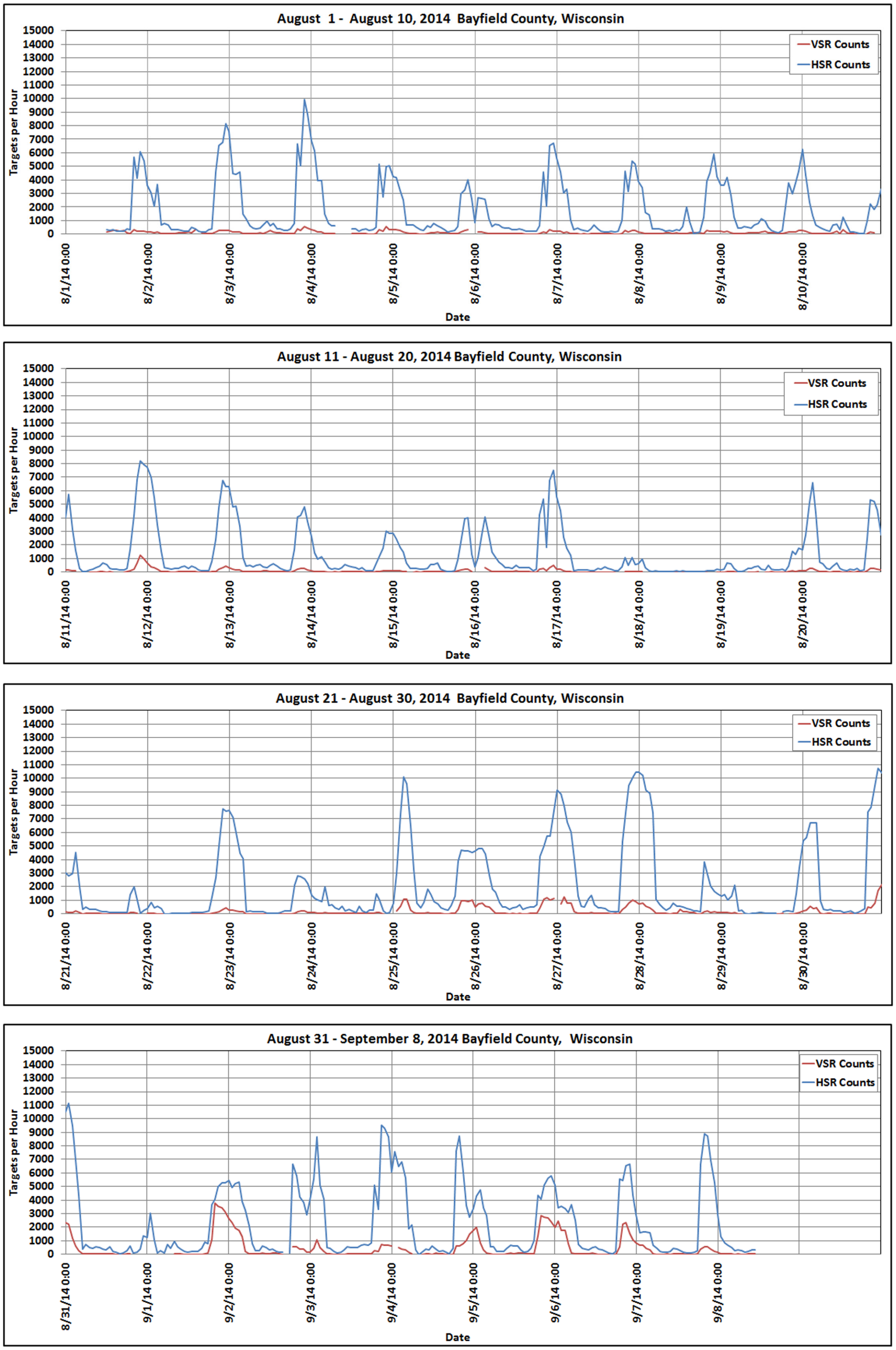


Figure 16. Hourly counts by the horizontal radar and the vertical radar's standard front from August 1 – September 8, 2014, at Bayfield County, Wisconsin. Light gray vertical lines represent midnight.

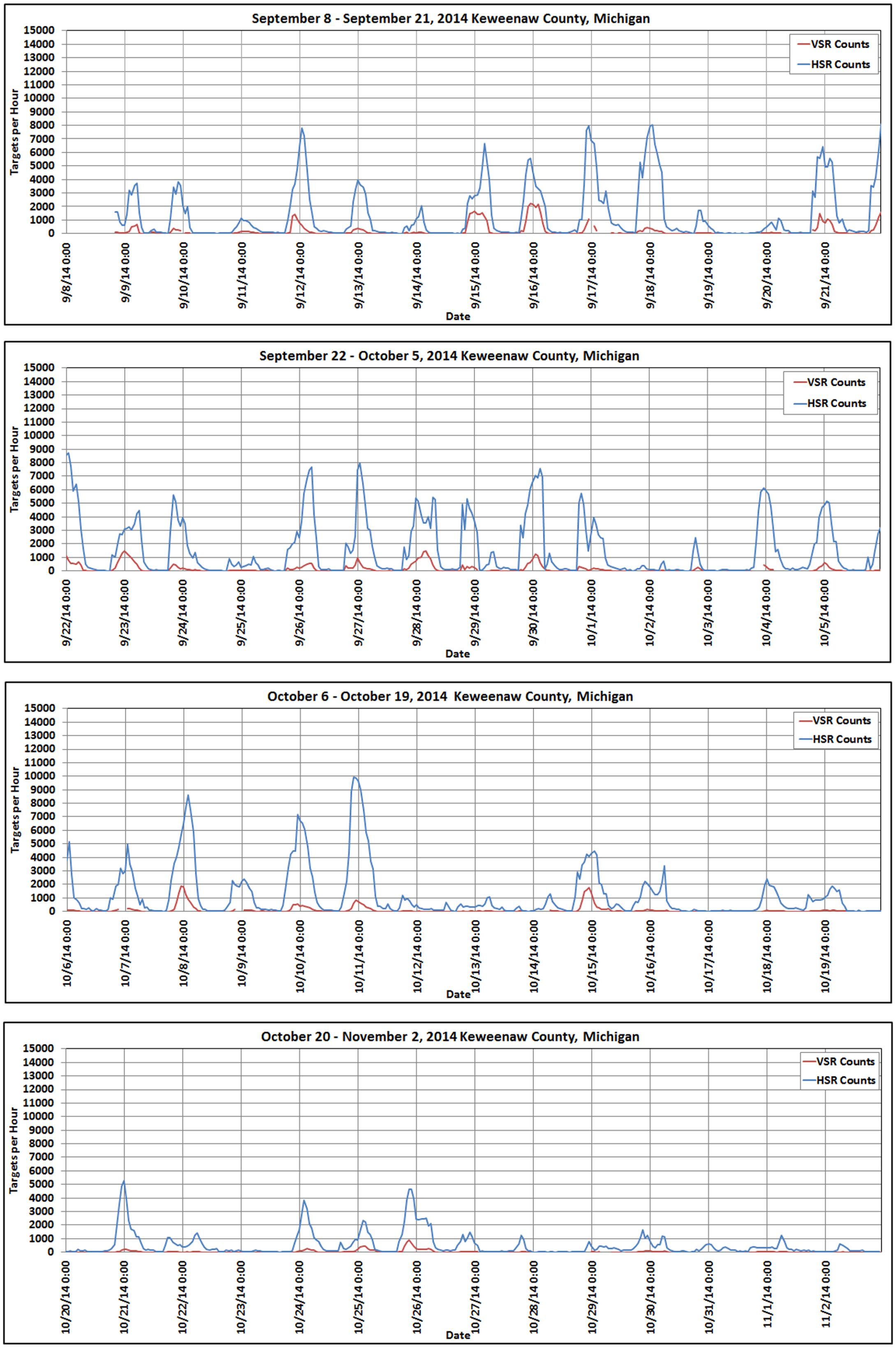


Figure 17. Hourly counts by the horizontal radar and the vertical radar's standard front from September 8 – November 2, 2014, at Keweenaw County, Michigan. Light gray vertical lines represent midnight.

Target Passage Rate – The pattern in mean TPR among the four biological time periods was similar among the four study sites (Figure 17), with the mean TPR at night being the greatest (Table 5). The mean nocturnal TPR was 398 ± 421 SD (n = 91 nights) at Lake County, MN, and at Bayfield and Keweenaw counties, it was 450 ± 555 (n= 37 nights) and 266 ± 319 (n=51 nights), respectively. The mean TPR varied by the hour, with peak numbers achieved near midnight, with a decline afterwards at each of the locations (Figure 18).

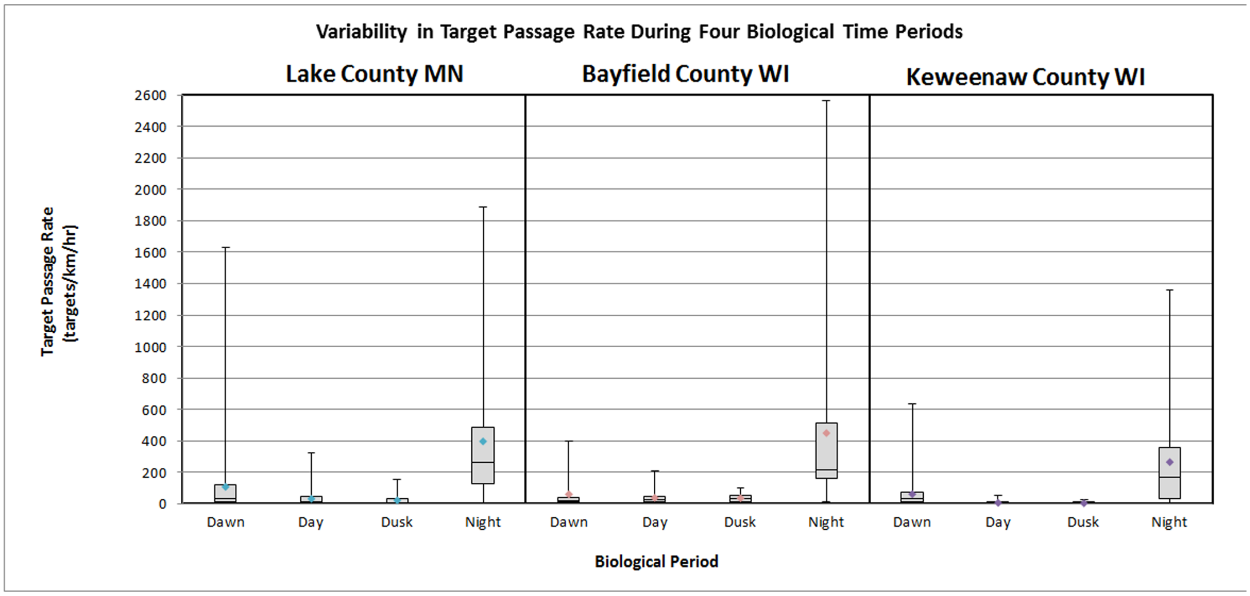


Figure 18. Box plots showing variability in target passage rate (targets/km/hr) during four biological time periods for fall 2014 in three counties along Lake Superior: Lake County, MN, Bayfield County, WI, and Keweenaw County, MI. Whiskers represent the 1st and 4th quartiles, boxes represent the 2nd and 3rd quartiles (with the line between indicating the median), and colored diamonds represent the seasonal mean for the time period at that site.

Table 5. Mean target passage rate (targets/km/hour) with standard deviations during four biological time periods in Lake, Bayfield, and Keweenaw counties during fall 2014.

Biological Period	Lake Mean TPR	Bayfield Mean TPR	Keweenaw Mean TPR
Dawn	109 ± 209	61 ± 99	62 ± 103
Day	32 ± 45	38 ± 39	7 ± 8
Dusk	23 ± 31	36 ± 26	4 ± 6
Night	398 ± 422	450 ± 555	266 ± 319

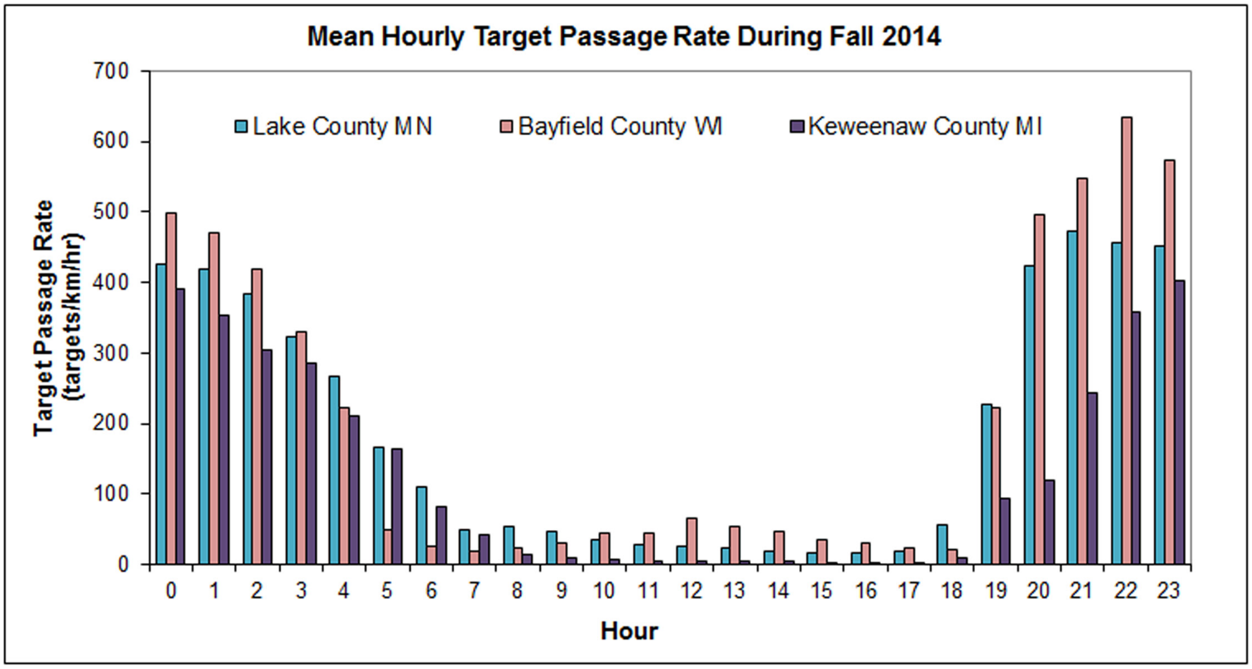


Figure 19. Mean hourly target passage rate (targets/km/hr) during fall 2014 at Lake, Bayfield, and Keweenaw counties.

Weekly Mean of Target Passage Rates – The weekly means of nocturnal TPR rose quickly during the first part of our season at both Lake County and Bayfield County (Figure 20). Around the time the Bayfield County radar unit was moved to Keweenaw County, a drastic drop-off in weekly mean TPR was observed at Lake County. This drop-off also occurred at a similar time at Keweenaw County, indicating that the drop-off may not have been due to the change in site (Figure 20). A change in species that were moving through (long-distance vs. short-distance migrants) may have also been responsible for the differences in numbers observed. Weekly means of nocturnal TPR were consistently higher than weekly means of diurnal TPR (Figure 20). However, as the recorded migration season subsided, there was less difference between these passage rates (Figures 20-22). Patterns in nocturnal TPR (7-day moving means) and diurnal TPR were similar among the sites, although diurnal and nocturnal movements seemed to be less correlated at these sites than at others we have surveyed (Bowden et. al 2014, USFWS unpublished data). Early in the season, there was high weekly mean nocturnal activity. This activity declined near the time when we moved the radar unit, at both the site we moved to (Keweenaw County) and the site that stayed in a constant location (Lake County). Diurnal weekly means matched the high early season nocturnal activity, but they did not match up as well later in the season. For instance, a peak in diurnal activity in early October did not seem to match up with nightly activity during the same time, and increased diurnal activity levels near the end of the season did not match the nocturnal activity levels (Figures 21-22).

Weekly Mean Nocturnal Passage Rate **Weekly Mean Diurnal Passage Rate**

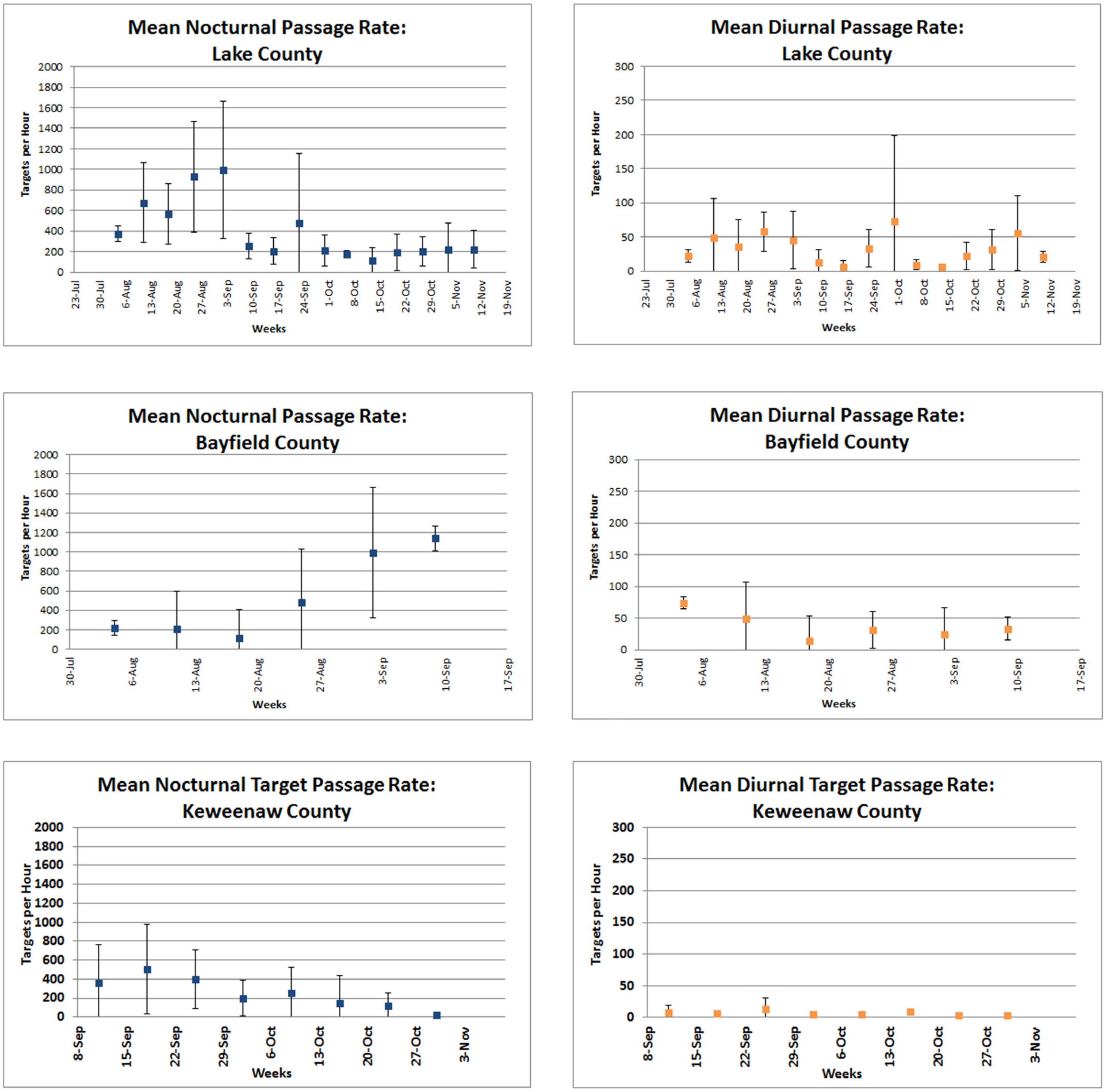
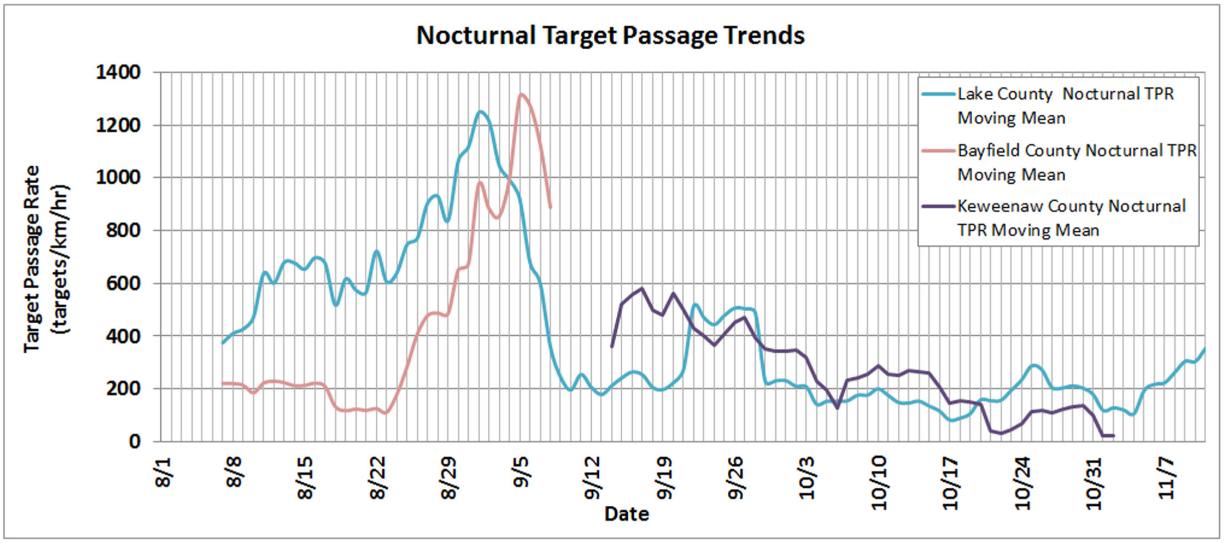


Figure 20. Weekly mean of nocturnal (left column) and diurnal (right column) target passage rates (targets/km/hr) at Lake, Bayfield, and Keweenaw counties. Error bars represent one standard deviation. Note different scales on nocturnal and diurnal plots.

Moving 7-Day Mean Target Passage Rates – Between Sites



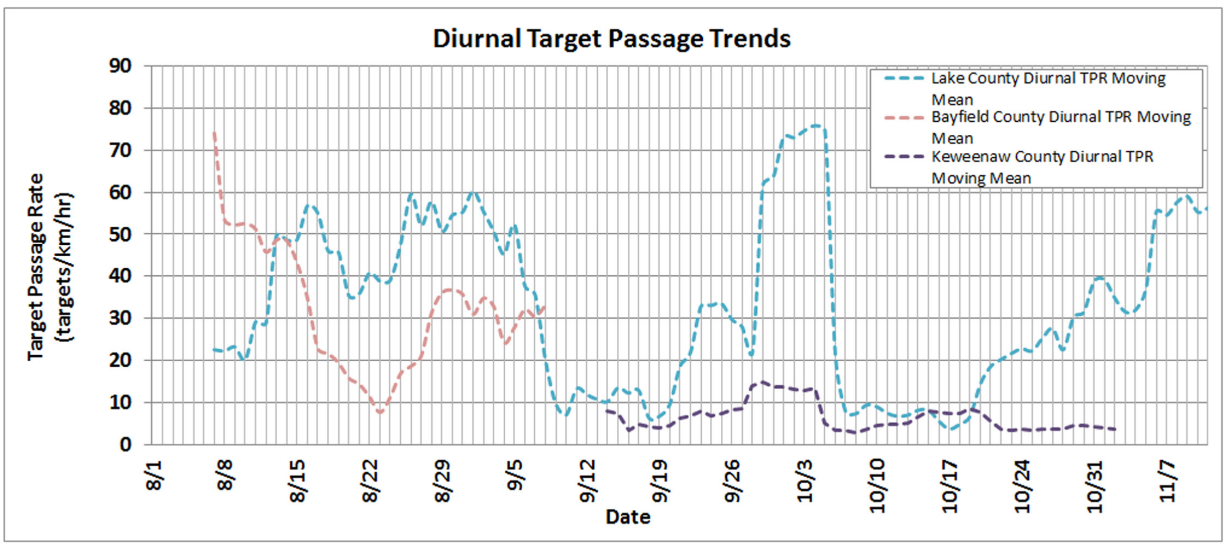
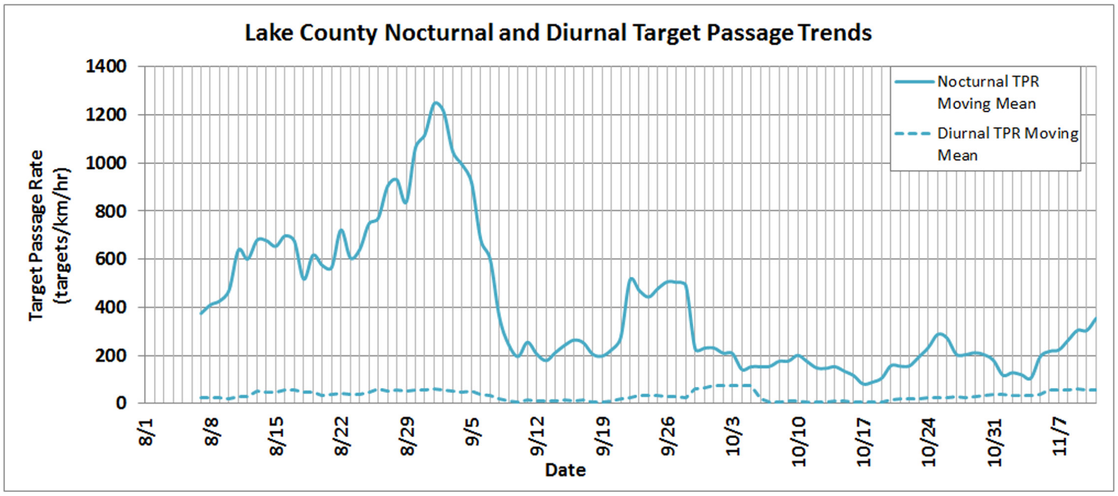
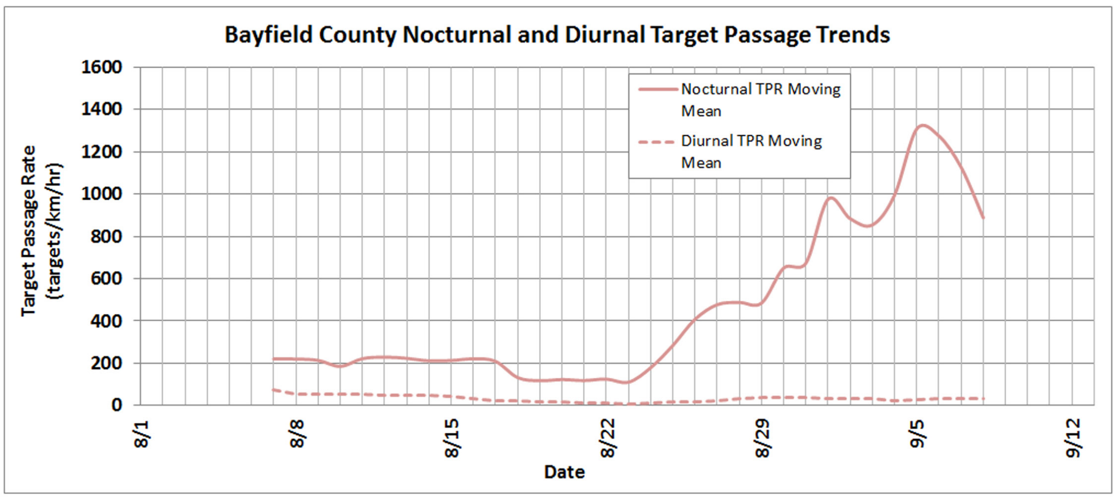


Figure 21. Between site comparison (based on a moving 7-day mean) of nocturnal (top graph) and diurnal (bottom graph) target passage rate trends (targets/km/hr) during fall 2014 in Lake, Bayfield, and Keweenaw counties. Note the different scales on the nocturnal and diurnal graphs.

Moving 7-Day Mean Target Passage Rates – Between Sites





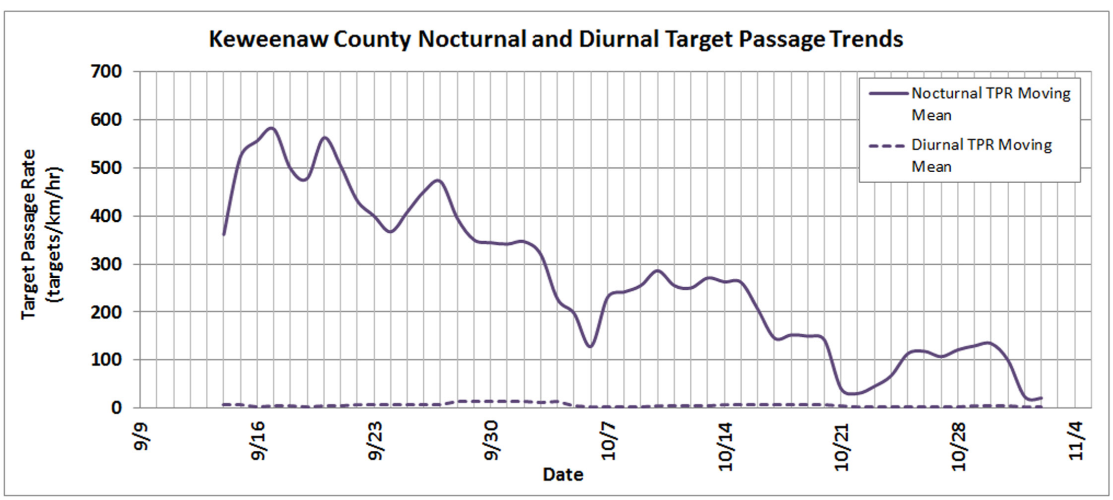


Figure 22. Within site comparison (based on a moving 7-day mean) of nocturnal (solid lines) and diurnal (dashed lines) target passage rate trends (targets/km/hr) during fall 2014 in Lake, Bayfield, and Keweenaw counties. Note the different scales for each site.

Altitudinal Trends

Altitude patterns are important for determining the risk wind turbines pose to migrating birds and bats, making the use of density estimates critical to examining the data while examining wind farm locations. Our density estimate that accounted for the geometric shape of the sampled space resulted in a substantially different density estimate and a higher estimate of risk to migrants than assuming an equal amount of sample volume per altitude band. The rotor-swept zone is the area the rotor blades spin through as the turbine turns. To produce more power, larger turbine blades are needed, meaning the rotor-swept zone is larger and stretches higher into the air. An approximate rotor-swept zone for a 1.5 megawatt (MW) turbine is 40-120 m and for a 2.5 MW turbine is 50-150 m. There has also been interest in building turbines with rotor-swept zones extending up to 200 m in the Great Lakes region.

Altitude profiles for the dawn biological time period were consistent among sites and between the two parts of the season, with a high amount of activity within the rotor-swept zone at all sites (Figures 23-25). The altitude profile for the night period had much more activity than the other time periods at all of the sites and included high concentrations within or near the rotor-swept zone. For the day and dusk periods, Lake County and Bayfield County both had concentrations approximately equal to the dawn period, with the highest concentrations within or near the rotor-swept zone. Keweenaw County however, had much lower activity during the day and dusk periods than at dawn, although the highest concentrations still remained in or near the rotor-swept zone.

Hourly altitude profiles at night revealed considerable variation in use of altitude bands (Figures 26-28). However, over the course of the season, the lower altitude bands (50-250 m) were the most densely used bands at each of the sites during each of the biological time periods (Figure 29). In Lake County, the 100-150 m altitude band was the most densely populated (Figure 29), with a total of 4.31 targets/1,000,000 m^3/night-hour occurring in that band. At Bayfield County, the 100-150 m altitude band was the most densely populated, with 4.02 targets/1,000,000 m^3/night-hour. Keweenaw County had the 150-200 m altitude band as the most densely populated, with 6.88 targets/1,000,000 m^3/night-hour.

The maximum density of the corrected target estimates was below 200 m during 77.6%, 65.8%, and 63.0% of the nights for Lake, Bayfield, and Keweenaw counties, respectively (Figure 30). A similar pattern occurred when the hours from 20:00 to 04:00 were considered individually, with the maximum density of targets occurring at less than 200 m during 74.2%, 51.7%, and 56.1% of the night hours for Lake, Bayfield, and Keweenaw counties, respectively (Figure 31). The maximum density was below 200 m during 78.0% of days and 68.6% of day hours (07:00-17:00) at the Lake County, MN site (Figure 32). This analysis was only performed for the Lake County site due to the observed high numbers of diurnal migrants at this site.

At each of the three sites, targets were observed within the entire range of altitude bands sampled. The mean altitude of nocturnal targets was 612 m ± 531 SD above ground level at the Lake County site, with a median target altitude at night of 421 m. At the Bayfield County site, the mean altitude of nocturnal targets was 664 m ± 514 SD, and the median altitude was 501 m. In Keweenaw County, the nocturnal mean altitude of targets was 605 m ± 451 SD, with a median altitude of 473 m. At two of the three sites (Lake and Bayfield counties), the mean and median altitudes were greatest during the night biological time period with the dawn period being the next highest. At the Keweenaw County site, however, the mean and median altitudes at dawn were much higher than at night.

Estimates of the mean and median altitudes were poor indicators of the altitude band with the highest density, and we believe there are metrics that better represent the distribution of targets, such as volume-corrected measures and 50-m band analysis (Table 6). Using mean or median estimates for altitude tends to underestimate the risk to migrants. This under-representation would have occurred at all of the sites during all of the time periods sampled. By examining the density of each altitude band across the 24-hour cycle, we can see that there are particular times where the highest densities are within or near the rotor-swept zone for each of the sites (Figure 33). The night hours at all three sites had the highest density of flight activity, and the range of flight altitudes increased during the night as well. Many targets fly well within the rotor-swept zone during the night, and mean and median altitudes do not reflect peak density altitudes. These metrics can misrepresent collision risk if not used carefully. At the Lake County site, the density within the rotor-swept zone was much higher than outside it, and this pattern continued even throughout the daytime hours. Other studies have also observed the greatest amount of movement within 100 m of the tree canopy (Peterson et al. 2015). This further indicates a high amount of use of the airspace above this site by diurnal migrants. In Bayfield County, there were also indications of diurnal use by migrants (Figure 33).

The mean altitude per hour during the season showed a similar pattern at two of the three locations (Lake and Keweenaw counties). At these locations, the mean altitude increased following dusk, tapered toward midnight, and decreased following midnight (Figure 34). A spike in mean altitude occurred during the 06:00 hour, representing slight dawn ascent. At the Bayfield County site, however, there was no increase in mean altitude near dawn, but otherwise, the overall pattern was similar to those of the other sites. At the Keweenaw County site, the dawn mean and median altitudes were the highest of all the time periods.

Table 6. Comparison of mean altitude (m) with standard deviations, median altitude, and volume corrected altitude band (50-m bands) that contained the maximum target density during four biological time periods in Lake, Bayfield, and Keweenaw counties during fall 2014. The max density category is the top of the 50-m altitude band. Keweenaw counties. Note the different scales for each site.

	Biological Period	Mean	Median	Max Density
Lake	Dawn	574 ± 483	422	100
	Day	364 ± 321	301	100
	Dusk	419 ± 423	280	250
	Night	612 ± 531	424	200
Bayfield	Dawn	561 ± 428	458	100
	Day	339 ± 294	282	200
	Dusk	484 ± 503	298	150
	Night	664 ± 514	501	150
Keweenaw	Dawn	817 ± 557	688	250
	Day	549 ± 538	316	150
	Dusk	392 ± 419	230	150
	Night	605 ± 451	473	200

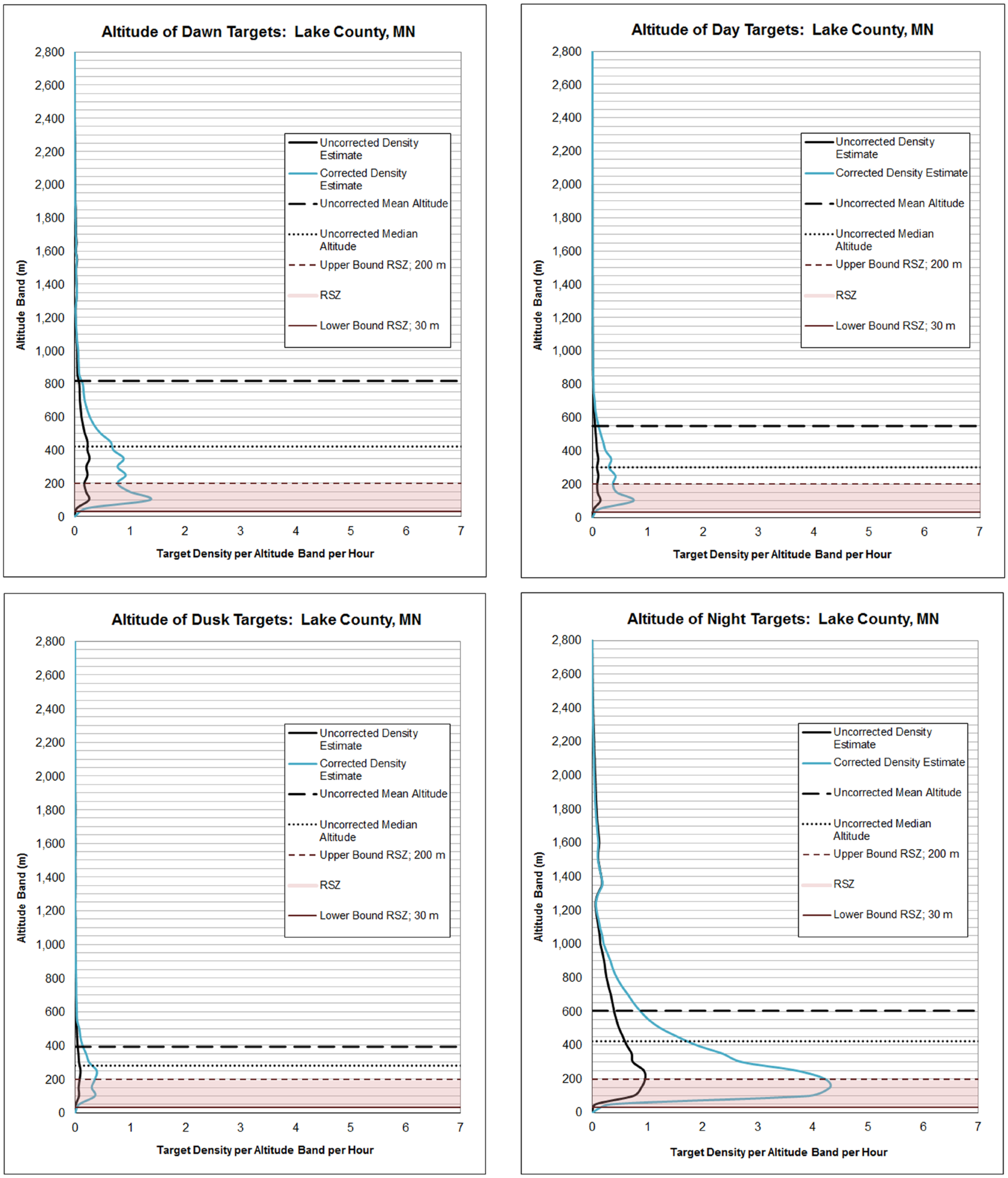


Figure 23. Altitude profile of targets in Lake County, MN. Corrected lines (blue) depict target density (targets/1,000,000 m^3) per 50-m altitude band per hour after adjusting for the structure of the sample volume. Uncorrected lines (black) depict target density per 50-m altitude band per hour with an assumed uniform volume distribution (volume of each band is equal to the total volume divided by the number of bands). The red band represents the rotor-swept zone (RSZ) between 30 and 200 m. Y-axis labels represent the top of the altitude band.

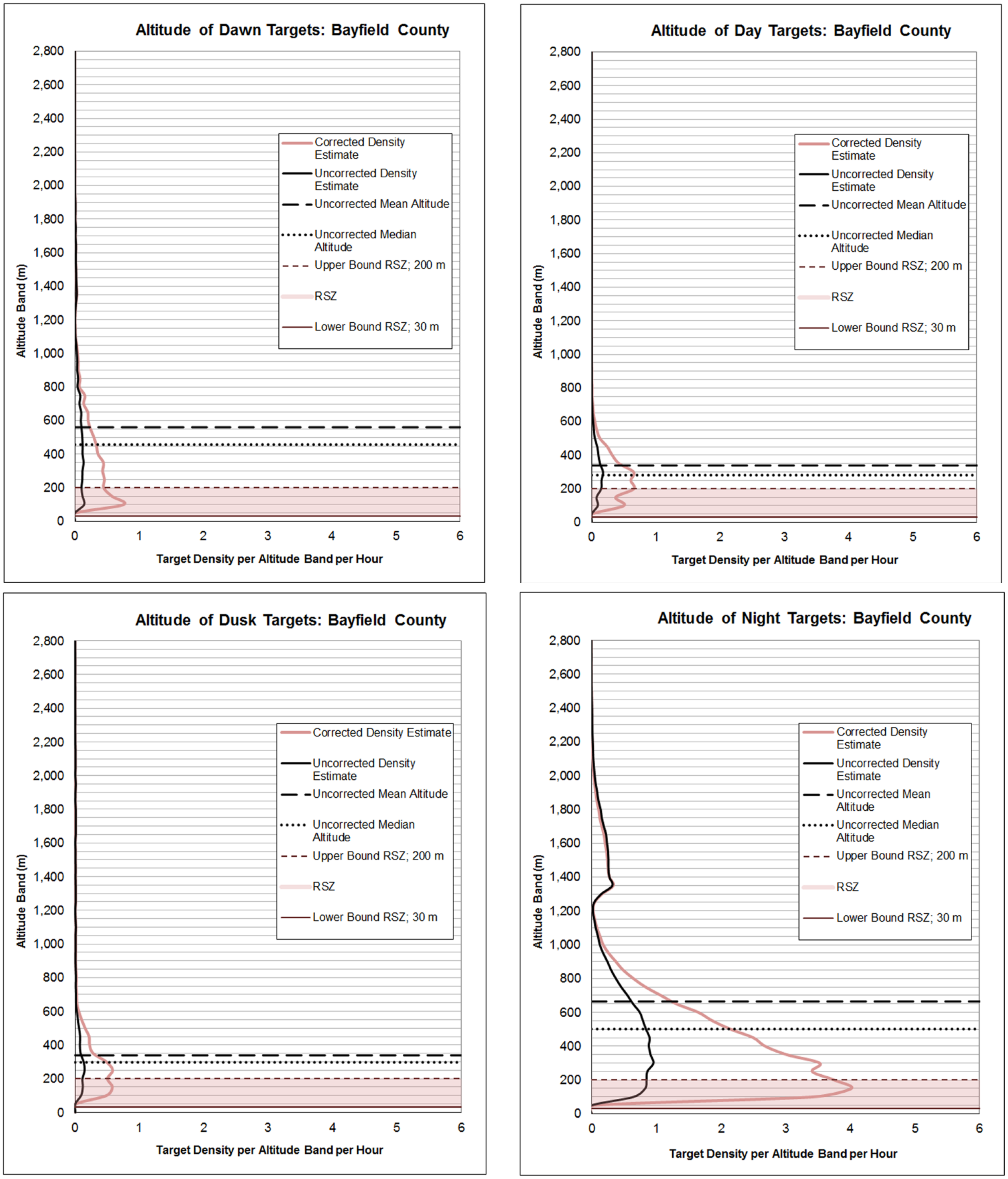


Figure 24. Altitude profile of targets in Bayfield County, WI. Corrected lines (pink) depict target density (targets/1,000,000 m³) per 50-m altitude band per hour after adjusting for the structure of the sample volume. Uncorrected lines (black) depict target density per 50-m altitude band per hour with an assumed uniform volume distribution (volume of each band is equal to the total volume divided by the number of bands). The red band represents the rotor-swept zone (RSZ) between 30 and 200 m. Y-axis labels represent the top of the altitude band.

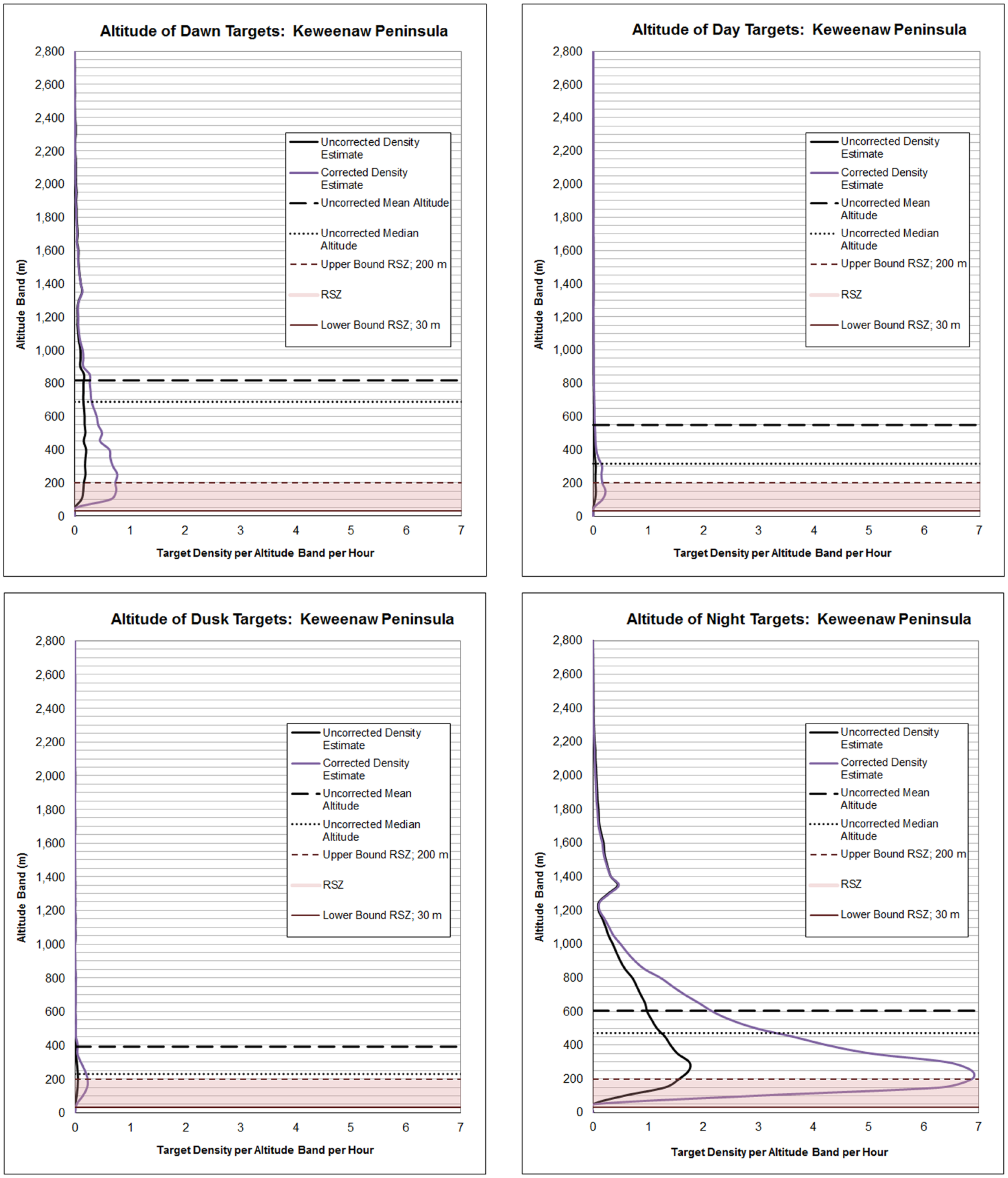


Figure 25. Altitude profile of targets in Keweenaw County, MI. Corrected lines (purple) depict target density (targets/1,000,000 m³) per 50-m altitude band per hour after adjusting for the structure of the sample volume. Uncorrected lines (black) depict the target density per 50-m altitude band per hour with an assumed uniform volume distribution (volume of each band is equal to the total volume divided by the number of bands). The red band represents the rotor-swept zone (RSZ) between 30 and 200 m. Y-axis labels represent the top of the altitude band.

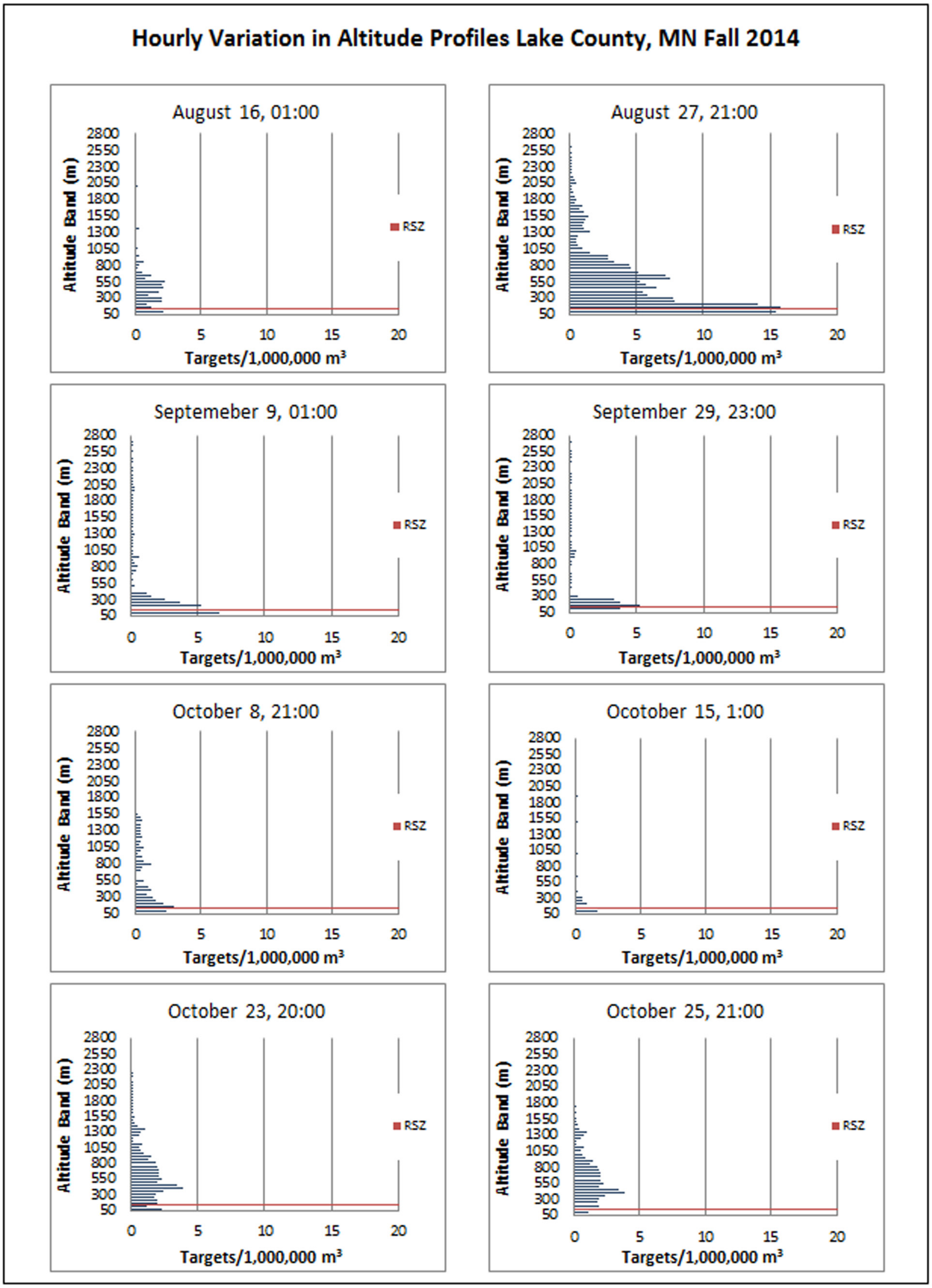


Figure 26. A sample of nocturnal hourly altitude profiles corrected for the shape of the sample volume in Lake County, MN during fall 2014. Hours were selected to portray the variability in density per altitude band of passing targets during the night and early morning hours. The x-axis represents the uncorrected target density (targets/1,000,000 m^3) per 50-m altitude band. The y-axis labels represent the top of each altitude band in meters. The red line represents the top of the rotor-swept zone at 200 m.

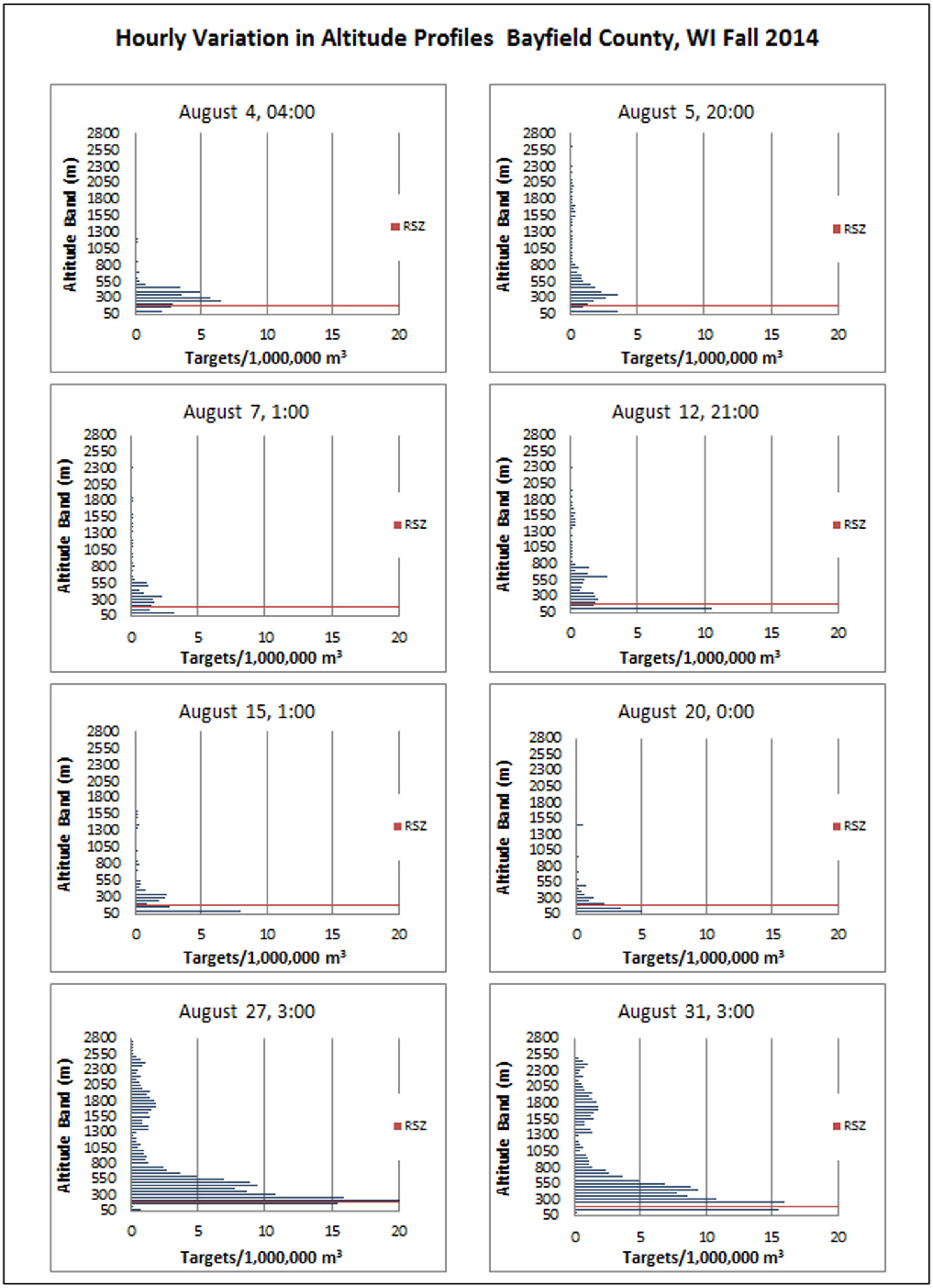


Figure 27. A sample of nocturnal hourly altitude profiles corrected for the shape of the sample volume in Bayfield County, WI during fall 2014. Hours were selected to portray the variability in density per altitude band of passing targets during the night and early morning hours. The x-axis represents the uncorrected target density (targets/1,000,000 m^3) per 50-m altitude band. The y-axis labels represent the top of each altitude band in meters. The red line represents the top of the rotor-swept zone at 200 m.

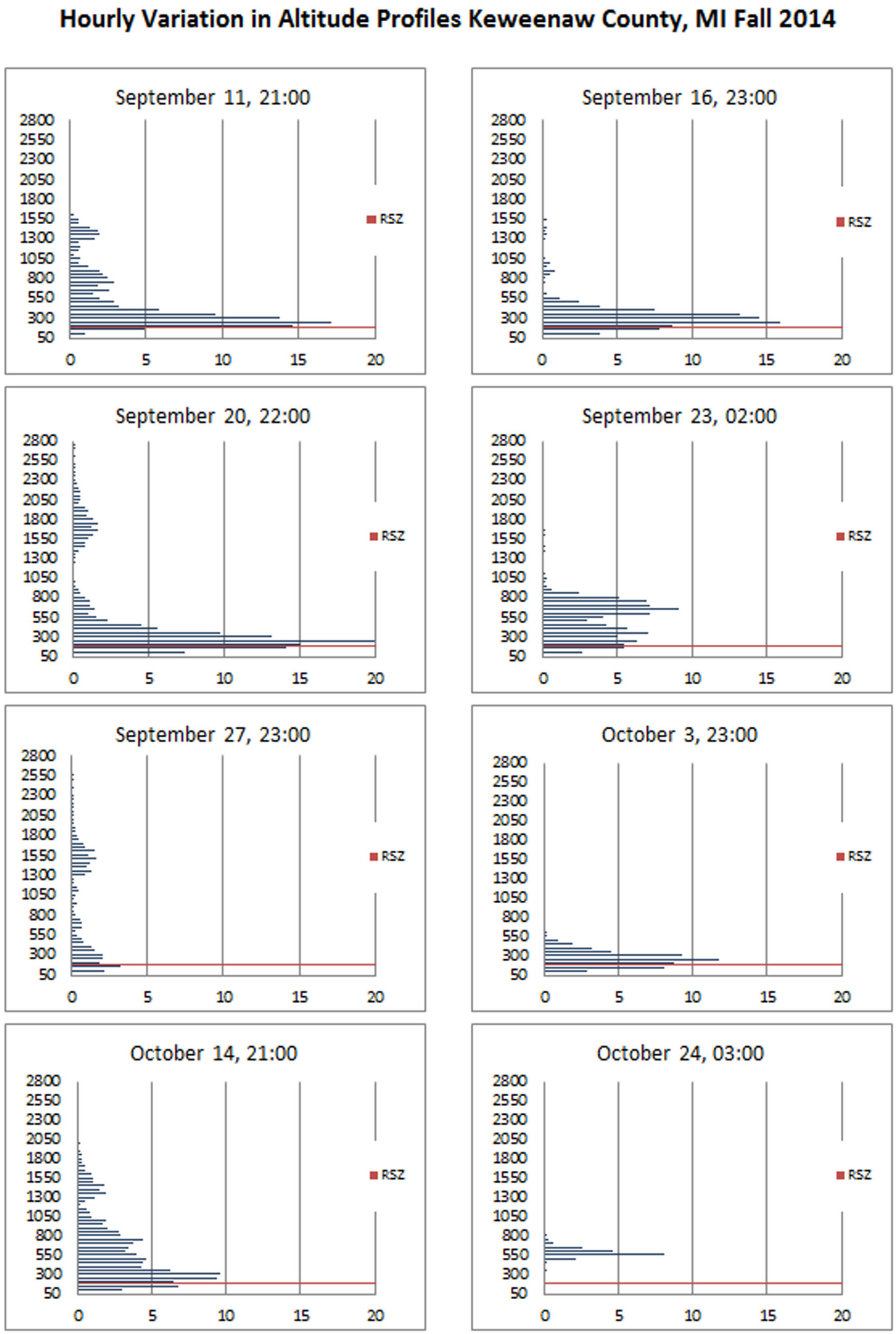


Figure 28. A sample of nocturnal hourly altitude profiles corrected for the shape of the sample volume in Keweenaw County, MI during fall 2014. Hours were selected to portray the variability in density per altitude band of passing targets during the night and early morning hours. The x-axis represents the uncorrected target density (targets/1,000,000 m^3) per 50-m altitude band. The y-axis labels represent the top of each altitude band in meters. The red line represents the top of the rotor-swept zone at 200 m.

Altitude Profile of Target Density Below 400 m

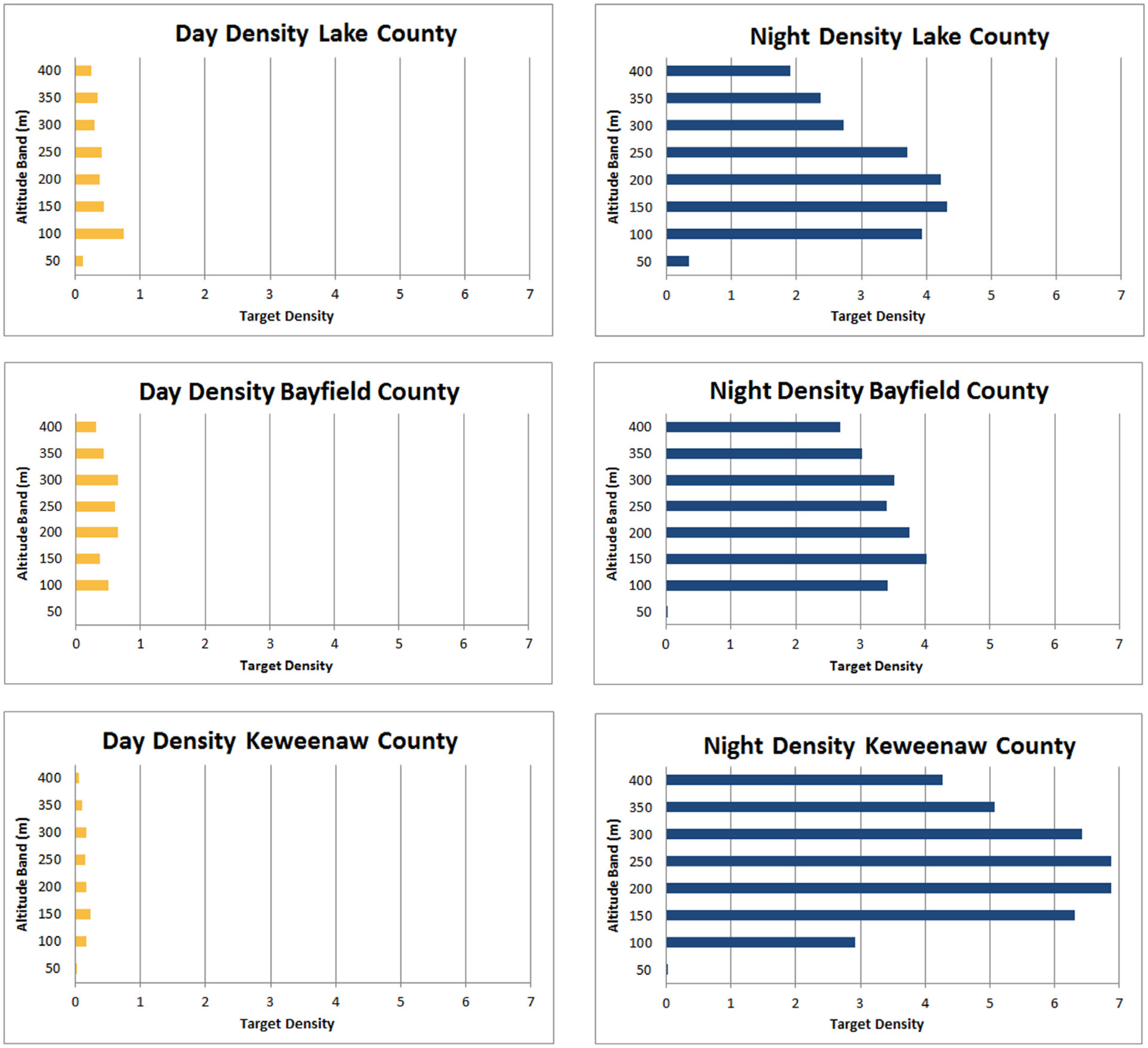
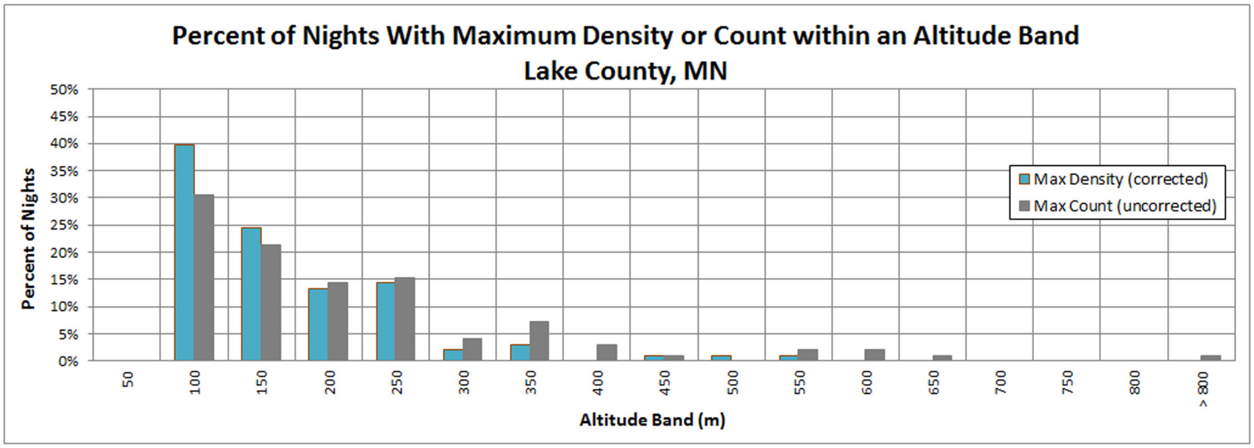
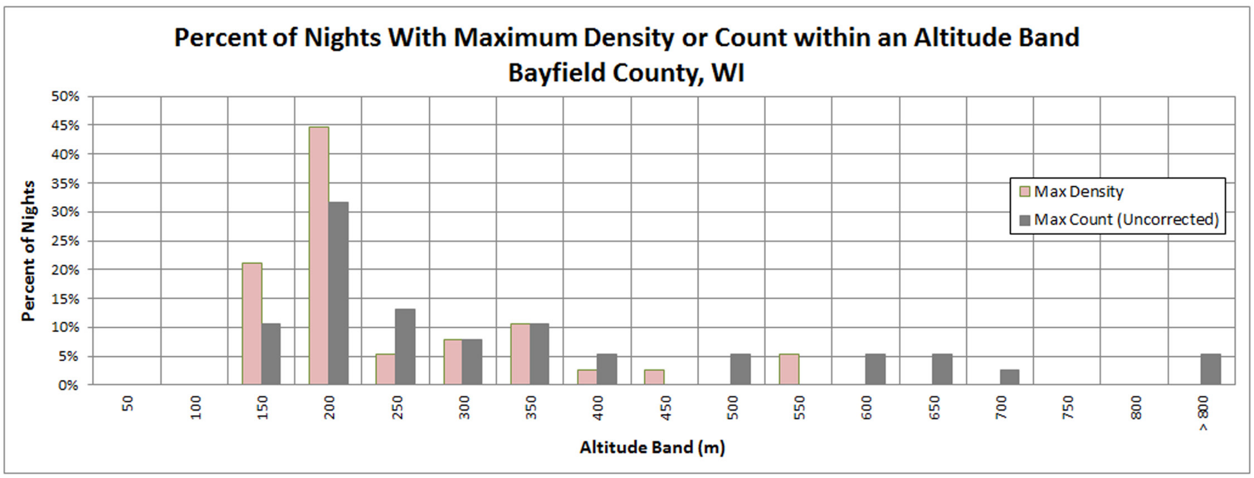


Figure 29. Altitude profile of target density below 400 meters in Lake, Bayfield, and Keweenaw counties. These graphs show the altitude band where the maximum corrected density occurred during fall 2014. The x-axis represents target density (targets/1,000,000 m^3) per 50-m altitude band. The y-axis labels represent the top of each altitude bands in meters. The lowest altitude band is often the most affected by ground clutter, greatly reducing the ability to detect targets in this area.

Comparison of Max Density and Max Counts Per Night





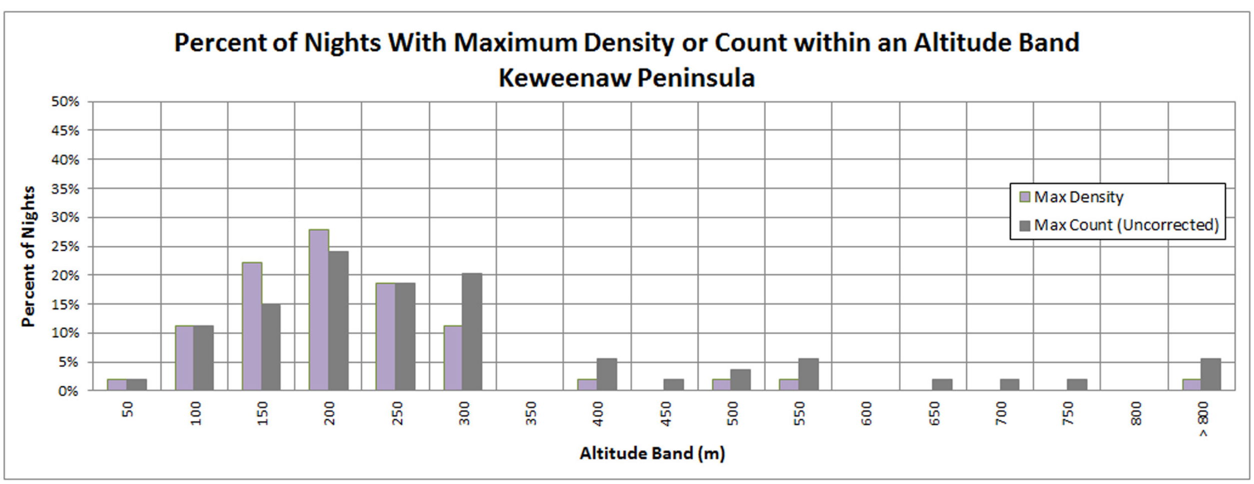
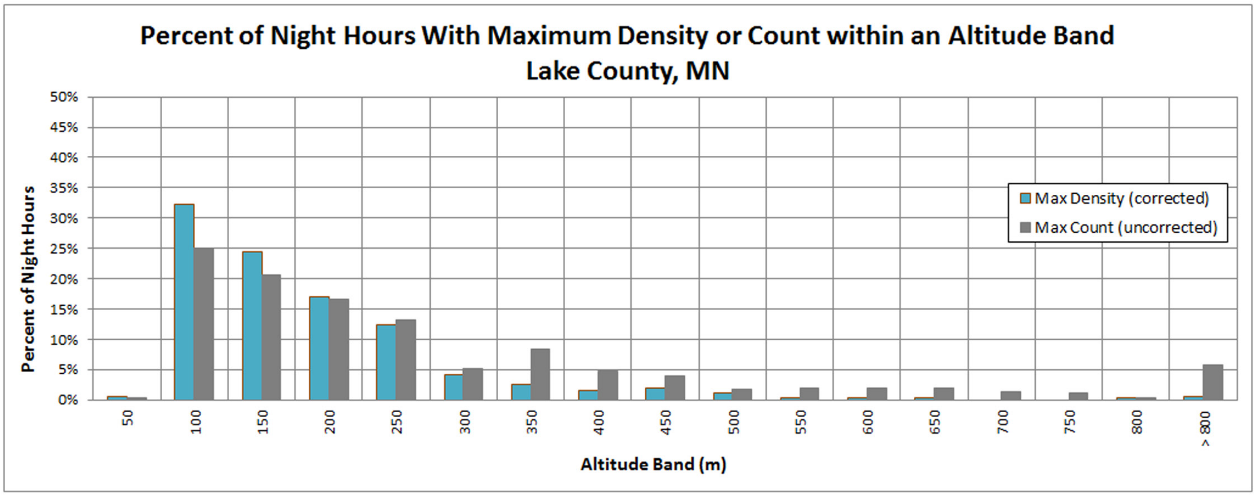
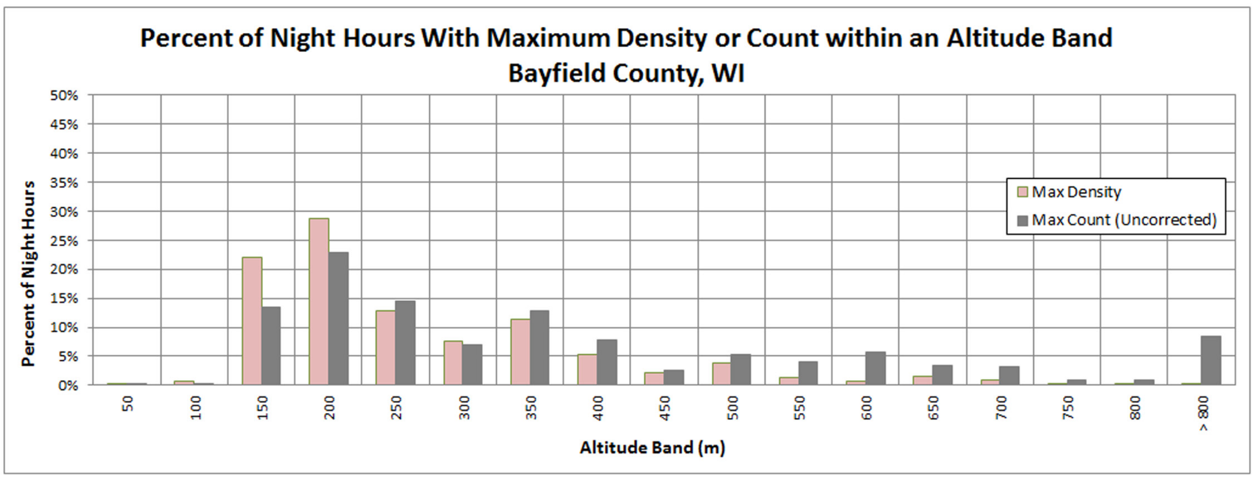


Figure 30. These graphs show the percent of nights surveyed when the maximum density (targets/1,000,000 m^3/ altitude band) or count (targets/altitude band) occurred within 50-m altitude bands in Lake, Bayfield, and Keweenaw counties during fall 2014. The x-axis labels represent the top of each altitude band.

Comparison of Max Density and Max Counts Per Hour





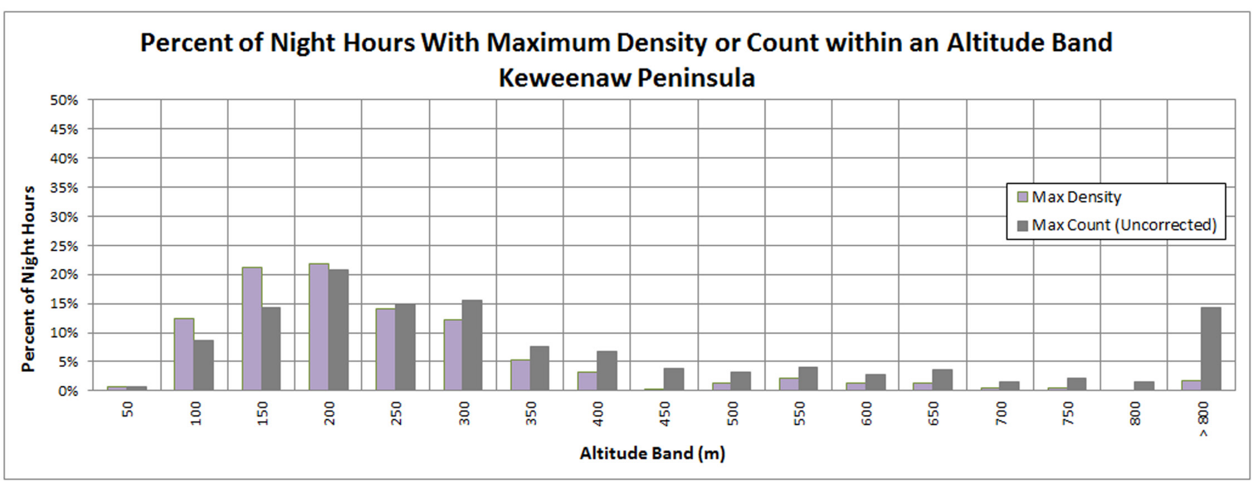
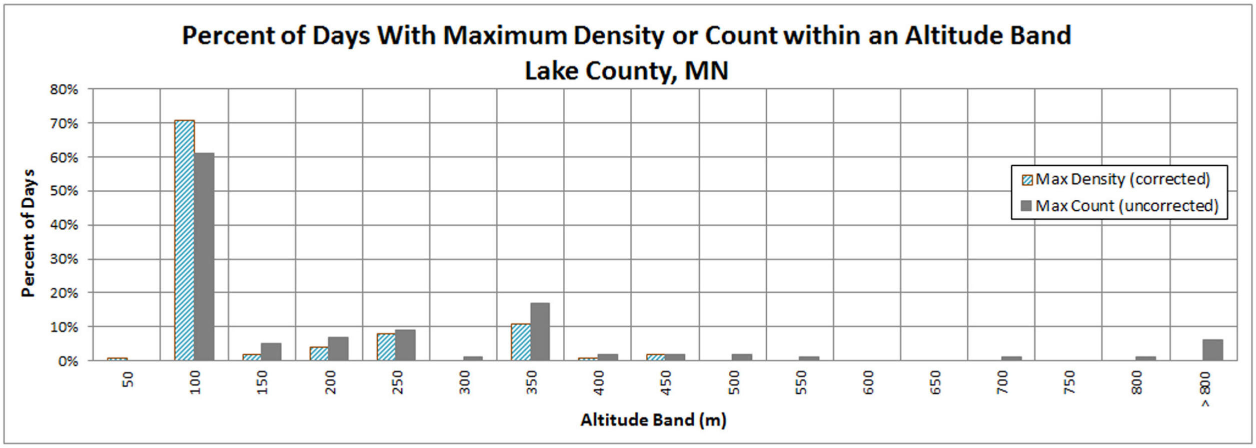


Figure 31. These graphs show the percent of night hours (20:00 – 04:00) surveyed when the maximum density (targets/1,000,000 m^3/ altitude band) or count (targets/altitude band) occurred within 50-m altitude bands in Lake, Bayfield, and Keweenaw counties during fall 2014. The x-axis labels represent the top of each altitude band.

Maximum Density Per Day and Day Hour



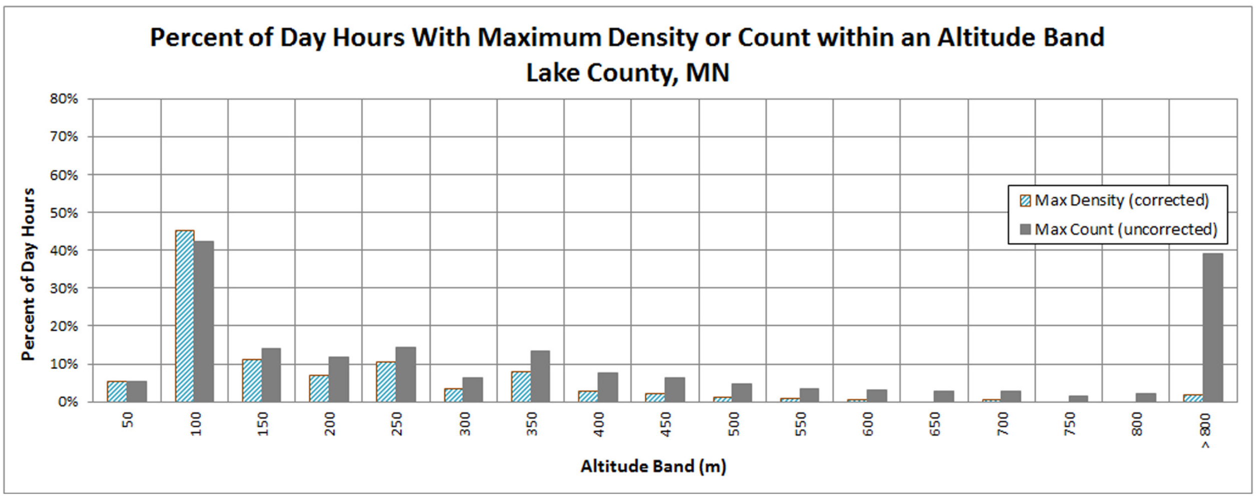


Figure 32. These graphs show the percent of days and day hours (07:00 – 17:00) surveyed when the maximum density (targets/1,000,000 m^3/ altitude band) or count (targets/altitude band) occurred within 50-m altitude bands in Lake County, MN during fall 2014. This figure was only completed for this site due to the high numbers of diurnal migrants observed. The x-axis labels represent the top of each altitude band. The large percentage of Max Count targets above 800 m when only looking at the Day Hours likely comes from hours with only a few targets present.

Target Density by Altitude Band Averaged Over Each of the Daily 24 Hours during Fall 2014

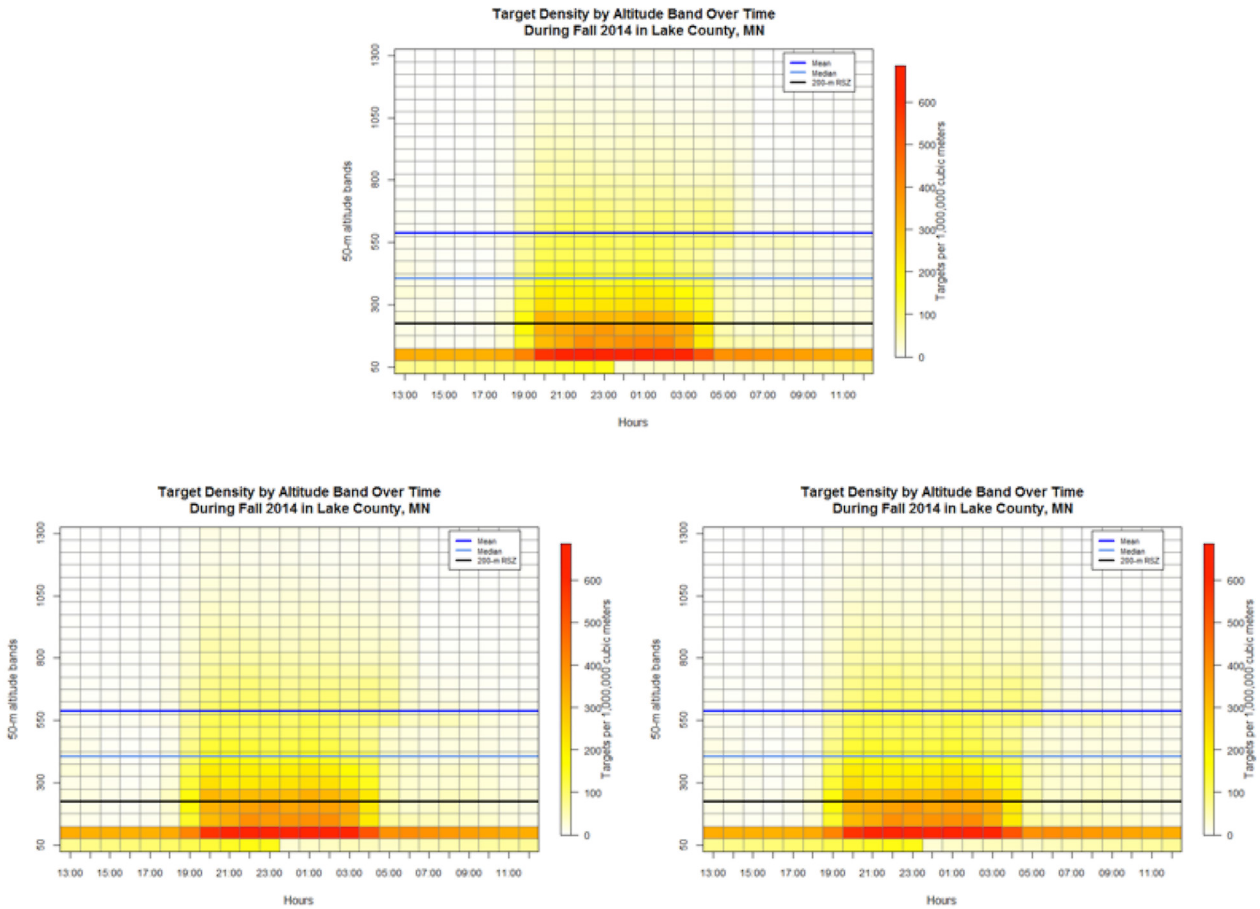
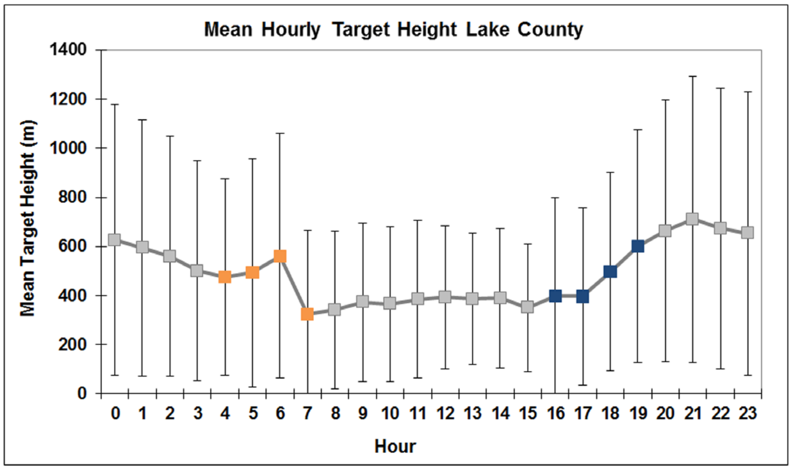
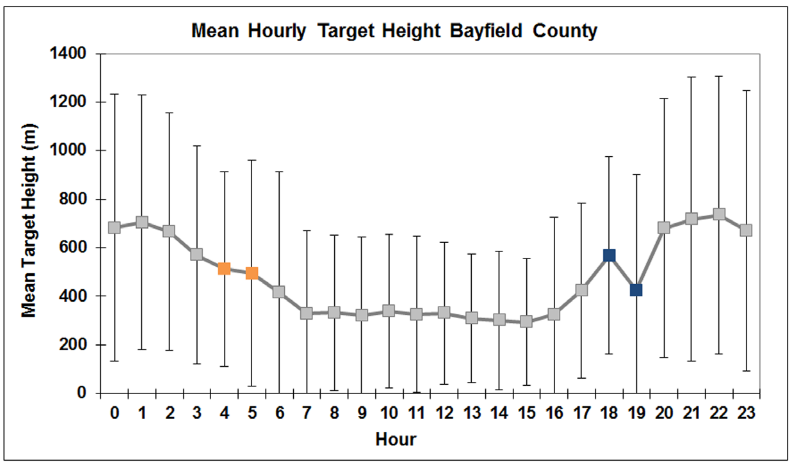


Figure 33. These graphs present the density of targets that occurred within each 50-m altitude band in Lake, Bayfield, and Keweenaw counties in fall 2014 over each of the 24 hours in a day. Please note the different scales for each of the heat maps, especially for Lake County, MN. Deep red areas on one graph may be equivalent in density to yellow areas on another heat map. This is at least partially due to differences in detection ability due to clutter and target movement direction, which makes comparisons between sites difficult. Dark blue lines represent the mean altitude, and light blue lines represent the median altitude across all hours. The black lines represent the top of the 200-m rotor-swept zone. The graphs only extend up to 1300 m and not to the full height of the radar scan to better show detail of the lower altitude bands.

Hourly Mean Heights of Targets during Fall 2014





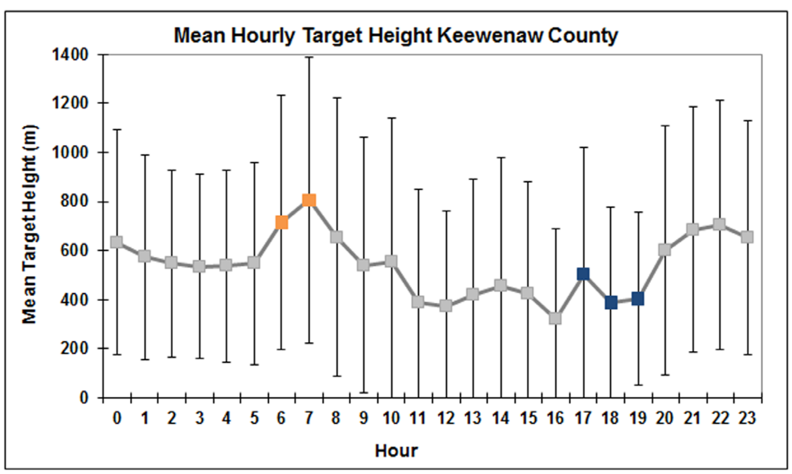


Figure 34. Mean hourly target height (m) during fall 2014 at Lake County, Bayfield County, and Keweenaw County. Orange and blue markers indicate the hours in which sunrise and sunset occurred during the season, respectively. Due to the different locations and times surveyed, hours where sunrise and sunset occurred were not equal for each of the sites across the season. Error bars represent one standard deviation.

Discussion

We undertook this study to document migration along the shorelines of the Great Lakes. The 2014 season was the first time we stationed the radar units along Lake Superior and was the first time we stationed a radar unit on the northern shore of an east-west oriented lake (the Lake County site). What we found during this season indicates that migration was common along Lake Superior's U.S. shorelines where we established our study sites. We also believe that our data can be extrapolated to represent much of the rest of the shores of the western part of Lake Superior. Our research contributes to a growing body of literature that documents various aspects of migration and identifies the Great Lakes shorelines as areas that are important for the conservation of migratory species of birds and bats. Our data provide unique observations about the magnitude and timing of nocturnal migration that could not be observed without the aid of radar.

The sites sampled this season were sampled for different periods of time, with one site (Lake County) sampled for the entire season and the other two sampled for a portion of the season, with the first part occurring at Bayfield County and the second occurring at Keweenaw County. Due to these different time periods and lengths sampled, our aggregate summary statistics may not be comparable between sites. Additionally, each of these sites was affected to varying degrees by clutter on the horizontal and vertical radars, further emphasizing the need for caution when making comparisons between sites and time periods. When examining the numbers and patterns between sites, it is important to remember that these site-specific factors can make comparisons between sites potentially misleading.

Patterns of diurnal migration were evident at the Lake County, MN site. The migration direction was strongly southwest along the lakeshore during the day period (Figure 12). Activity often continued into the morning hours after a nocturnal pulse as well (Figures 15 and 19). These results support conclusions made by other researchers that the shoreline of Lake Superior in Minnesota is a migratory pathway for raptors and other diurnal migrants (Peterson and Niemi 2011, Evans et. al 2012, Seeland et al. 2012, Peterson et al. 2015).

The Keweenaw County site had some interesting patterns that may have arisen due to the site location near the tip of the peninsula. At this site, it seemed that the peaks of migration occurred slightly less often than at other sites; however, when they did occur, they seemed to be as large or larger in magnitude. This could indicate that large numbers of migrants were reluctant to cross the large expanse of Lake Superior unless conditions were favorable, but when favorable conditions did occur, migrants moved across en masse and freely and may have been attracted to the Keweenaw Peninsula that extends out into the lake. There were some migrants that crossed over Lake Superior every night. However, we have not yet analyzed the weather data in relation to radar counts to determine their relationship at this site. Qualitatively, however, our biologists in the field believe that there appears to be a strong relationship between wind direction and migration across Lake Superior.

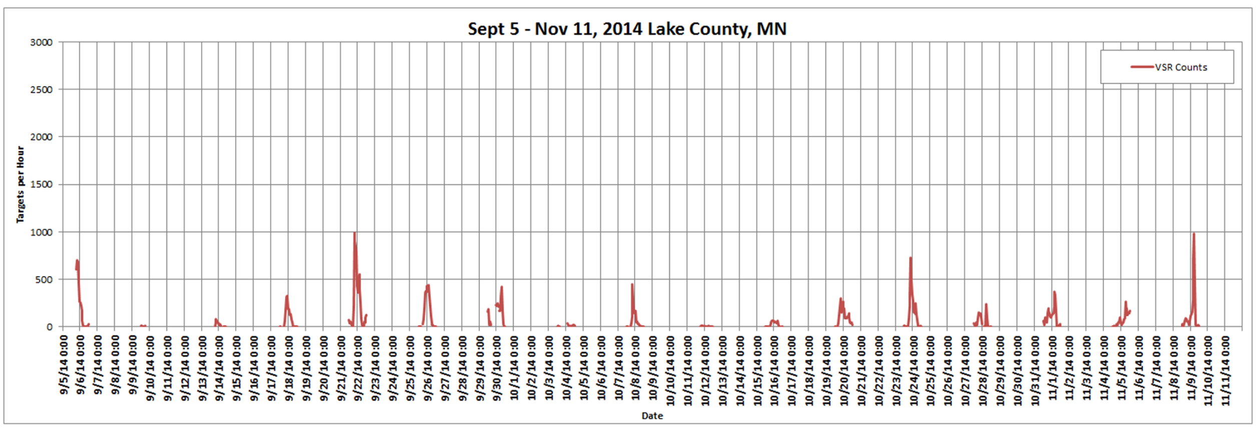
Additionally, many of the timing patterns were slightly different at the Keweenaw County site. For instance, the migration numbers were slower to increase after dusk at this site than the other two sites (Figure 19), and the mean altitude did not increase until after dusk (Figure 34). This is likely due to the length of time it would take migrants to cross over the lake and reach the Keweenaw Peninsula. For instance, a few migrants would start flying from habitat located on the peninsula, but once those had passed by the radar location, it could be an hour or more before migrants that started flying at dusk from the north shore of Lake Superior in Canada reached the peninsula. This delay would create the difference in the pattern of hourly TPR we observed when comparing the Keweenaw site to our other sites this season. Migrants that were still moving at dawn continued longer into the morning at the Keweenaw County site than the Bayfield County site, and dawn mean altitudes were the highest at the Keweenaw County site (Figures 19 and 34). Migrants that were still crossing over the lake at dawn may have traveled to higher altitudes to scout for a place to land, and the Keweenaw Peninsula could have been an attractive place for them to take refuge. Due to the varying distances the migrants may have been away from the peninsula, this would cause a slow trickle of migrants to continue into the post-dawn hours. It is difficult to compare the morning hours at the Keweenaw County site to the Lake County site due to the high numbers of diurnal migrants that used the Lake County site, possibly obscuring the patterns of the end of nocturnal migration.

Sampling Regime

The sampling regime is an important consideration for migration studies. Migratory movements are guided, in part, by environmental conditions and occur in pulses across the migratory season (Alerstam 1990). Our continuous sampling scheme captured the timing of migration events and provided a more complete picture of migration than a systematic or random sampling scheme, which may miss pulses of activity, even when sampling as frequently as every four days (Figure 35). In this figure, the interpretation could be made from the periodic sampling method that there is a constant low amount of migration that occurs during this time period, which may not actually represent a time of risk to migrants. In fact, there were additional larger peaks than were observed using the partial sampling method, and the peaks that did occur happened more regularly than would be concluded based on the partial sampling data alone.

We used diurnal radar observations to provide a baseline for comparing nocturnal activity, and including this time period in the sampling scheme helped us distinguish the magnitude of migration events (Figure 15-17). In addition, at the Lake County site, we observed high levels of diurnal migration that are consistent with data gathered by other studies along the shoreline of Lake Superior in Minnesota (Peterson and Neimi 2011, Peterson et al. 2015), including observations from a hawk watch station in Duluth, MN (Evans et. al 2012). This heavy diurnal migration may confound the use of daytime data to provide a baseline of activity of non-migrants to compare with nocturnal migrant activity for this site. Our sampling regime was also useful in showing that the nocturnal migration season was active even when we deployed our radar units in early August and continued regularly through the middle of October.

Effect of Sampling Schedule on Data



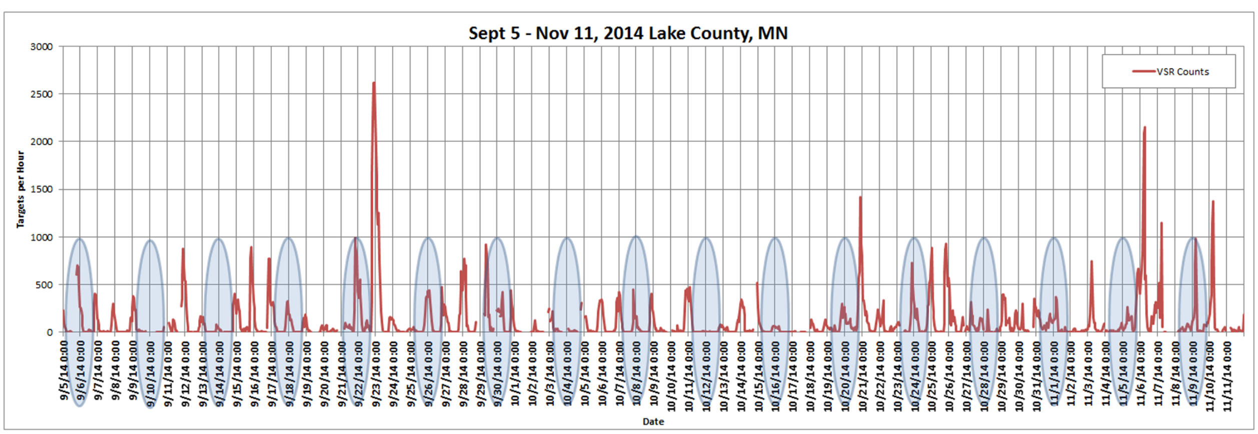


Figure 35. Example of a hypothetical sampling schedule where data were collected once every four days (top graphic) versus the actual continuous sampling schedule (bottom graphic). Red lines represent the number of targets counted per km per hour by the vertical scanning radar from the middle to the end of the sampling season (Sept 5 to Nov 11, 2014) at Lake County, Minnesota. Blue circles on the bottom graphic represent times that would have been sampled during the top graphic, missing many of the larger migration peaks.

After this time, there were still apparent peaks of migration, but they occurred with less regularity. Although we moved sites with one radar unit in the middle of the season to cover more area, we believe that our locations were similar enough to represent the approximate peak and end dates for fall migration in the Lake Superior area. Activity appeared to have begun before our start date, so estimating the start date of fall migration from our data is more difficult. As more data are collected and we examine the general patterns of migration at different locations, we will be able to better describe the migration season and how it varies with location and year. This information will help conservation efforts to be tailored to appropriate time frames for migratory birds and bats.

Target Counts

Target counts provided by radar are influenced by radar type and calibration, filtering of non-intended targets, count algorithms, frequency band, antenna orientation, sampling scheme, and how researchers account for variation in detection probability and sample volume (Bruderer 1997, Harmata et al. 1999, Schmaljohann et al. 2008). Even when the same equipment and methodology are used among sites or studies, comparisons should be made cautiously if the probability of detection and sampling volume are ignored (Schmaljohan et al. 2008). Recognizing that our counts represent an index of target passage and not a true population count that is relative to a site, we are cautious in making comparisons among sites or studies. Rather than relying solely on the magnitude of the target passage as an indication of airspace usage, we assess the general patterns of activity among sites to compare the relative strength of migration. For example, a site with a nocturnal passage rate that shows peaks that are many times larger than nocturnal lulls for the majority of the sampling period would be considered as having more migration than a site with less of a discrepancy between nocturnal peaks and lulls. A site that had a nocturnal passage rate that only occasionally spiked above a baseline of low nocturnal passage rates may be indicative of an area with low amounts of migration, although this may not be the case for all areas. The presence of behaviors such as dawn movement to or along the shoreline, change in movement direction during the course of the night, and other indicators of an obstacle to migration may indicate risk to migrants in a given area, along with more specific measures such as the density of targets in the rotor-swept zone.

Migration Patterns

The patterns of movement we recorded were consistent with other observations of migration (Newton 2008), and they indicated that nocturnal migratory flights occurred regularly during fall 2014 at each of our three surveyed locations along Lake Superior. The nocturnal activity we observed was typically oriented along the shoreline at the Lake County site (Figures 12 and 14) and generally towards the south at the Bayfield and Keweenaw county sites (Figures 13 and 14). There was also evidence that targets regularly crossed over large expanses of the open water of Lake Superior to the Keweenaw Peninsula (Figure 14). The crossing of migrants over this large expanse of open water (175 km) suggests that they are capable of and willing to fly over any expanse of water in the Great Lakes. Care should be taken to evaluate migrants that fly over the lakes when siting offshore wind facilities in this area. Activity occurred in pulses across the season, as captured by horizontal and vertical radars (Figures 15-17). We also observed targets flying over water return to shorelines near dawn (Figure 9-13). Movement towards shore at dawn may be due to migrants drifting with the wind as they migrate and adjusting their position at dawn to find suitable stopover habitat to rest and refuel (Anna Peterson, pers. communication, Horton et al. 2016b). The target passage rate (mean for the season) was greatest during the nocturnal biological time period at each location, with the dawn biological time period having the next highest mean target passage rate at each location (Table 5, Figure 18).

Mean hourly heights showed a pattern previously associated with migration at each of our sites (Harmata et al. 2000, Mabee and Cooper 2004, Bowden et. al 2015), with heights increasing near dusk, peaking around midnight, and decreasing prior to dawn. Keweenaw County's mean hourly height pattern was similar to the pattern we observed at other locations; however, the highest mean altitudes were recorded at dawn and not at midnight (Figure 33). The slight increase in mean height near dawn (Figure 33) at Lake and Keweenaw counties is consistent with a migratory behavior described as dawn ascent (Myres 1964, Diehl et al. 2003). This behavior is attributed to migrants increasing altitude to gain a broader view of the surrounding landscape before selecting stopover habitat or returning to the shoreline if they were flying over water. This phenomenon of dawn ascent did not appear to occur at the Bayfield County site, but because only the first part of the season was sampled, we cannot say with certainty that it does not occur there. In previous seasons where we have moved the radar units, we have noticed that early season sites tend to show less of the pattern of dawn ascent than later-season or full-season sites (USFWS unpublished data). The Bayfield County site was also further inland than the other sites, providing another possible explanation for the difference. The dawn ascent was also more pronounced at the Keweenaw County site than many other sites we have seen. The Keweenaw County site was near the tip of a large peninsula that reaches into the middle of Lake Superior. Migrants crossing over the middle of the lake at dawn may fly to even higher altitudes to find a spot to land, likely being attracted to the peninsula as a safe refuge. Taken together, we attribute nocturnal observations to migrants and suggest that the areas we studied are important for their conservation. High levels of diurnal activity with directional movement also occurred at the Lake County site, confirming results of other studies that show diurnal migration of raptors and other birds along the north shore of Lake Superior.

At each of our three sample locations, nocturnal targets appeared to move across the landscape in four waves, with peaks near August 14, September 4, September 22, and October 15 (Figures 21-22). Diurnal targets also appeared to move in 4 waves, with the peaks occurring near August 16, September 3, October 3, and November 7. These fluctuations may be related to broad-scale weather fronts, variation in timing among guilds of migrants, or a combination of these and other factors (Newton 2009). The similarity in the pattern of these waves when compared between sites reveals broad-scale influences and could indicate that further investigation into their cause would allow prediction of high migration events and adjustment of wind turbine operations accordingly.

The weekly mean estimates of nocturnal TPR were consistently higher than the weekly mean diurnal TPR across all weeks of data collection (Figures 20-22). Although the nocturnal TPR was always greater, the difference between the nocturnal and diurnal time periods was the smallest during the beginning and end of the migration season. This shift from time periods with orders of magnitude more nocturnal activity to time periods with much more similar diurnal and nocturnal activity indicate that nocturnal migration added substantially to the aeroecology above our study areas, although this measure may not be appropriate for all areas.

Flight Attitude

Altitude profiles indicated that most nocturnal targets passed below 800 m with peak density in the 100 - 250 m altitude bands for each of the sites we surveyed this season (Figures 26-31). We believe that analysis of altitude bands with the highest densities is a better representation of the data than uncorrected mean or median flight altitudes. We corrected for the approximate shape of the survey volume and included this correction in our density estimates. This correction is based on the manufacturer's estimate of beam geometry, which may not be precise, and beam propagation is not consistent over time. Beam propagation is affected by side lobes, target size and distance, and atmospheric conditions. Nonetheless, we think the correction was an improvement over altitude profiles that ignore beam geometry and sampling effort. We were not able to correct for the loss of detection with distance from the radar (Schmaljohann et al. 2008), and our vertical scanning radars lost detection in the region where the radar transitioned from the short to medium pulse, at a range of approximately 1,200 m. For these reasons, our estimates likely under-represent density as altitude increases.

The altitude profiles we report varied considerably among nocturnal hours at our sites along Lake Superior (Figures 22-24). Migrants adjust flight altitude with wind direction and speed, visibility, time, and landscape below flight trajectory (Alerstam 1990, Hueppop et al. 2006, Liechti 2006). For example, head winds aloft have resulted in migrants moving en masse to lower altitudes where wind speeds were reduced (Gauthreaux 1991). Also, migrants are typically on land at least twice during every 24-hour period. Changes in flight altitude can occur at various times over the course of the night and are associated with targets ascending from and descending to stopover sites. Depending on location, these altitude changes may place migrants at risk of collision with wind turbines and other tall human-made structures.

Radar Study Considerations

While radar may be the best tool available for gathering large amounts of data on nocturnal migration, the interpretation of radar data can be challenging. Also, the metrics reported in these types of surveys can be misleading to someone unfamiliar with avian radar. Marine radar is the most common type used to track bird and bat movements (Larkin 2005), and its use to assess risk will likely increase with the increase in wind energy development. Despite this growing trend, standard methodologies for establishing radar settings, ground truthing biological targets, and processing data have not been adopted. These considerations can substantially affect the quality of data and the interpretations that are derived from thoese data. This presents a challenge that is not easily solved. Yet, without standards, comparisons among studies may be more reflective of differences in equipment, methodology, and site conditions rather than differences in migration activity.

An example of a potentially misleading metric, mean altitude of target passage, is often reported to be above the rotor-swept zone and has been interpreted as an indication of low risk. However, the mean altitude can be well above the rotor-swept zone even when there is a high rate of targets passing within it. This is due to the long range at which radars collect altitude data, up to 3 km above ground level in our study, where high flying targets inflate the mean altitude. This bias is apparent in our data and can be seen by comparing the mean altitude of nocturnal targets to the most densely populated altitude band (Table 6 and Figures 23-25 and 30-32). We do not recommend using mean and median altitudes as indicators of risk to migrants.

It is also misleading to compare the percent of targets below, within, and above the height of the rotor-swept zone without addressing the difference in sampling effort between these categories. Within our sampling framework, there are four 50-m altitude bands below 200 m (an estimate for the height of the rotor-swept zone) and 52 altitude bands above 200 m. Based on our model, we estimated that approximately 2 percent of the potential survey volume is below 200 m. Given that information, we would expect a small percentage of targets to be recorded at or below the rotor-swept zone, but this does not necessarily indicate low risk. If targets were spread evenly throughout the survey volume, we would expect to have a tiny percentage of targets within the rotor-swept zone. Uncorrected numbers such as 5-10% of targets in the rotor-swept zone are often reported and classified as "low risk" due to the low percentage of targets in the rotor-swept zone, even though this means that this area is many times more concentrated with targets than we would expect from a random distribution of targets throughout the survey volume. When using estimates of target counts that are corrected for volume, we often see a much higher concentration in the rotor-swept zone than if the numbers do not take sampling volume into account (Figures 23-25). For these reasons, we also do not recommend using percentages of targets below, within, or above the rotor-swept zone as indicators of risk to migrants.

In this report, we provide examples of methodology and analyses that we find helpful in interpreting radar data and have used in other seasons. We suggest that the patterns of activity and the relative change in counts at a site indicate the level of migration activity and that this is a better indicator than comparing the magnitude of counts among studies. Careful attention should be given to how these indices fluctuate over fine temporal scales, such as hourly, as opposed to monthly or seasonal summaries. These fine-scale measures may show more times when risk to migrants could be high. The clutter maps we include provided information about our ability to detect targets at various altitudes, and it is important, particularly for risk assessment, that radar operators address their ability to detect targets at low altitude. We provide a concept for a method to account for the structure of the sample volume that, while not without limitations, provides a partial solution rather than ignoring the biases associated with sampling effort. Overall, we found that radar provides insight into nocturnal migration that would otherwise be unattainable, while continued development and careful interpretation will result in valuable contributions to the management and conservation of migrants.

Management Considerations

These data provide a larger picture of migration that we need to put in perspective. Our radars were primarily located along the shoreline, which is the area where we can gain the best picture of migrant behavior. The general patterns along the shorelines of Lake Superior reveal that these areas are used heavily by nocturnal and diurnal migrants during fall migration. This pattern of migration is evident from our sample Trackplots as well as the timelines from each of the sites. Beginning in early August, migration occurs on many if not most nights. Birds and bats likely began migrating prior to this date, as we saw large movements almost immediately after we set up the radar units. We observed migrants beginning on the lake shore and traveling out over the open water to cross to the south shore of Lake Superior. At other locations, we saw targets arriving at the south shore after traveling in from out over the water. From our directional analysis, we concluded that migrants were crossing over Lake Superior to the Keweenaw Peninsula (Figure 14). This expanse of water, at nearly 100 miles (175 km), is one of the largest spans in the Great Lakes. If migrants are willing and able to cross this expanse, they are likely willing and able to cross at any area of the Great Lakes, provided the weather conditions are appropriate. We often observed migrants following along the shoreline. They likely used the shoreline for navigation or were funneled through the area by geographical features. The movement of migrants along the shoreline implies that a wind energy facility or communication tower constructed in shoreline areas may be encountered by more than just migrants moving down from the areas directly to the north.

A close look at the different biological time periods also reveals information about the importance of the shoreline area. At many of the sites, the high levels of activity at dusk may represent birds and bats leaving their stopover habitat to continue migrating. High activity levels at dawn may be due to new migrants moving into land in the stopover habitat after migrating into the area at night or coming in from flying over the water. These newly arriving birds and bats may be in different guilds, be heading to different wintering areas, be arriving from different breeding grounds, have different physical conditions, or may represent different sex or age groups than those that previously migrated through the same area. Consequently, impacts to the shoreline area from development, habitat loss, or other factors may have impacts on all parts of the population for a wide variety of bird and bat species.

At the survey locations this season, our risk analysis revealed that during a large proportion of nocturnal hours or nights overall, the numbers and densities of birds and bats flying in or near the rotor-swept zone were high (Figures 30-33). At the Lake County site, there were high densities of targets in the rotor-swept zone even throughout the daytime hours (Figures 32-33). The Lake County site had some of the highest daytime migrant activity we have seen around the Great Lakes (Bowden et al. 2015, Rathbun et al.

2016, USFWS unpublished data). Nocturnal and diurnal migrants will change altitudes depending on environmental conditions, and thus, targets in altitude bands that are near the rotor-swept zone may also be at risk. In addition, our analysis only shows the rotor-swept zone for turbines that were constructed at the time of the study. Wind turbines are already being constructed to higher altitudes (Eller 2015), with larger rotor-swept zones extending into the altitude bands just above where turbine blades currently reach, which will likely impact more migrants (Figure 33).

Our data demonstrate that the shoreline areas of Lake Superior are important for migrating birds and bats. We have identified behaviors that concentrate migrants along the shoreline, demonstrated that these behaviors occur regularly throughout the season, and established that migrants are flying at altitudes that place them at risk of collision with current or future wind energy development in the area. The importance of shoreline areas, as revealed by our study, highlights the need to avoid development in these migration corridors as recommended in the wind energy guidelines (USFWS 2012).

In this report, we provide examples of methodologies and analyses that are helpful in the interpretation of radar data. We suggest that relative changes in the counts at a single site indicate the level of migration activity and that these data provide a better indicator than comparisons among the magnitude of counts recorded in different studies. Careful attention should be given to how these indices fluctuate over fine temporal scales, such as hourly compared with monthly or seasonal scales. Our clutter maps provided information on our ability to detect targets at various altitudes, and we believe that it is important for radar operators to address their ability to detect targets at low altitudes, particularly for risk assessments. We provide the basis for a method of accounting for the structure of the sample volume that offers a partial solution, albeit with limitations, instead of ignoring the biases associated with sampling effort. Overall, we found that radar provides insights into nocturnal migration that would be otherwise unattainable, and we believe that its continued development and careful interpretation will result in valuable contributions to the management and conservation of migrating birds and bats.

The results of our research highlight the potential role of radar in implementing recommendations from the wind energy guidelines (USFWS 2012) to identify areas where impacts to wildlife would be minimized. We documented clear examples of migrant activity along studied shorelines on Lake Superior, and the density of targets at lower altitudes is a potential concern. The data we collected may be of interest to public and private entities that are involved with wind energy development and its potential placement in the Lake Superior area as well as the entire Great Lakes region. Coupling avian radar systems with other forms of research or using radar in conjunction with acoustic and ultrasonic monitors, as well as post construction fatality searches, may broaden the utility in making risk assessments and assessing wind energy developments.

Literature Cited

Able, K. P. 1977. The flight behaviour of individual passerine nocturnal migrants: a tracking radar study. Animal Behaviour 25:924–935.

Akesson, S. 1999. Do passerine migrants captured at an inland site perform temporary reverse migration in autumn? Ardea 87:129-138.

Alerstam, T. 1990. Bird Migration. Cambridge University Press, Cambridge.

Alerstam, T. 2001. Detours in bird migration. Journal of Theoretical Biology 209:319-331.

Arnett, E. B., and E. F. Baerwald. 2013. Impacts of wind energy development on bats: Implications for conservation. Pages 435–456 *in* R. A. Adams and S. C. Pederson. Editors. Bat Ecology, Evolution and Conservation. Springer Science Press, New York, USA.

Arnett, E. B., W. K. Brown, W. P. Erickson, J. K. Fiedler, B. L. Hamilton, T. H. Henry, A. Jain, G. D. Johnson, J. Kerns, R. R. Koford, C. P. Nicholson, T. J. O'Connell, M. D. Piorkowski, and R. D. Tankersley, Jr. 2008. Patterns of bat fatalities at wind energy facilities in North America. Journal of Wildlife Management 72:61-78.

Audubon. 2013. Important Bird Areas Program. http://web4.audubon.org/bird/iba/. Last accessed August 2013.

AWEA. 2015. American Wind Energy Association. http://www.awea.org/Issues/Content.aspx?ItemNumber=4437. Last accessed January 2015.

BHE Environmental, Inc. 2010. Post-construction bird and bat mortality study Cedar Ridge wind farm Fond Du Lac County, Wisconsin. Unpublished interim report. www.bheenvironmental.com

Bingman, V. P. 1980. Inland morning flight behavior of nocturnal passerine migrants in eastern New York. Auk 97: 465-472.

Bonter, D., T. Donovan, and E. Brooks. 2007. Daily mass changes in landbirds during migration stopover on the south shore of Lake Ontario. Auk 124:122–133.

Bonter, D., S. A. Gauthreaux, Jr., and T. M. Donovan. 2009. Characteristics of important stopover locations for migrating birds: remote sensing with radar in the Great Lakes Basin. Conservation Biology 23:440-448.

Bowden, T. S., E. C. Olson, N. A. Rathbun, D. C. Nolfi, R. L. Horton, D. J. Larson, and J. C. Gosse. 2015. Great Lakes Avian Radar Technical Report Huron and Oceana Counties, Michigan. U.S. Department of Interior, Fish and Wildlife Service, Biological Technical Publication FWS/BTP-2015

Bowlin, M.S., D.A. Enstrom, B.J. Murphy, E. Plaza, P. Jurich, and J. Cochran. 2015. Unexplained altitude changes in a migrating thrush: Long-flight altitude data from radio-telemetry. The Auk: Ornithological Advances 132: 808-816.

Bruderer, B. 1997. The study of bird migration by radar, Part 1: The technical basis. Naturwissenschaften 84: 1-8.

Bruderer, B., and F. Liechti. 1998. Flight behaviour of nocturnally migrating birds in coastal areas - crossing or coasting. Journal of Avian Biology 29:499-507.

Buler, J. J. and R. H. Diehl. 2009. Quantifying Bird Density During Migratory Stopover Using Weather Surveillance Radar. IEEE Transactions on Geoscience and Remote Sensing 47:2741-2751.

Buler, J. J. and F. Moore. 2011. Migrant-habitat relationships during stopover along an ecological barrier: extrinsic constraints and conservation implications. Journal of Ornithology 152:101-112.

Buler, J. J. and D. K. Dawson. 2012. Radar analysis of fall bird migration stopover sites in the Northeast U.S. Final Report. Cooperative Agreement USGS and University of Delaware.

Cryan, P.M. 2011. Wind turbines as landscape impediments to the migratory connectivity of bats. Environ Law. 41:355-370.

DeTect, Inc. 2009. MERLIN avian radar survey for a proposed wind project. Unpublished technical report. Panama City, FL.

Diehl, R. H., R. P. Larkin, and J. E. Black. 2003. Radar observations of bird migration over the Great Lakes. Auk 120:278-290.

Diehl, R.H., J.E. Bates, D.E. Willard, and T.P. Gnoske. 2014. The hazards of nocturnal migration over Lake Michigan: a case study. Wilson Journal of Ornithology. 126:19-29.

Evans, D.L., G.J. Niemi, and M.A. Etterson. 2012. Autumn raptor banding at Hawk Ridge, Duluth, Minnesota, U.S.A., 1972-2009: an overview. Journal of Raptor Research 46:36-49.

Ewert, D. N., M. J. Hamas, R. J. Smith, M. E. Dallman, and S. W. Jorgensen. 2011. Distribution of migratory landbirds along the northern Lake Huron shoreline. Wilson Journal of Ornithology 123:536-547.

Ewert, D.N., P.J. Doran, K.R. Hall, A. Froelich, J. Cannon, J.B. Cole, and K.E. France. 2012. On a wing and a (GIS) layer: Prioritizing migratory bird stopover habitat along Great Lakes Shorelines. Final report to the Upper Midwest/Great Lakes Landscape Conservation Cooperative.

Faaborg, J., R. T. Holmes, A. D. Anders, K. L. Bildstein, K. M. Dugger, S. A. Gauthreaux, Jr., P. Heglund, K. A. Hobson, A. E. Jahn, D. H. Johnson, S. C. Latta, D. J. Levey, P. P. Marra, C. L. Merkord, E. Nol, S. I. Rothstein, T. W. Sherry, T. S. Sillett, F. R. Thompson, III, and N. Warnock. 2010. Conserving migratory land birds in the New World: Do we know enough? Ecological Applications 20:398-418.

France, K. E., M. Burger, T. G. Howard, M. D. Schlesinger, K. A. Perkins, M. MacNeil, D. Klein, and D. N. Ewert. 2012. Final report for Lake Ontario Migratory Bird Stopover Project. Prepared by The Nature Conservancy for the New York State Department of Environmental Conservation, in fulfillment of a grant from the New York Great Lakes Protection Fund (C303907).

Gauthreaux, S. A. 1991. The flight behavior of migrating birds in changing wind fields – radar and visual analyses. American Zoologist 31:187-204.

Gerringer, M.B., S.L. Lima, T. L. DeVault. 2015. Evaluation of an avian radar system in a Midwestern landscape. Wildlife Society Bulletin 1-10.

Great Lakes Commission. 2011. State of the science: an assessment of research on the ecological impacts of wind energy in the Great Lakes Region. Report by the Great Lakes Wind Collaborative, Great Lakes Commission, 19 p.

Grodsky, S. M., C.S. Jennelle, D. Drake, and T. Virizi. 2012. Bat mortality at a wind-energy facility in southeastern Wisconsin. Wildlife Society Bulletin 36(4):773-783.

Gruver, J., M. Sonnenburg, K. Bay, and W. Erickson. 2009. Post-construction bat and bird fatality study at the Blue Sky Green Field Wind Energy Center, Fond Du Lac County, Wisconsin. Western EcoSystems Technology, Inc. Unpublished final report.

Harmata, A. R., K. M. Podruzny, J. R. Zelenak, and M. L. Morrison. 1999. Using marine surveillance radar to study bird movements and impact assessment. Wildlife Society Bulletin 27:44-52.

Harmata, A. R., K. M. Podruzny, J. R. Zelenak, and M. L. Morrison. 2000. Passage rates and timing of bird migration in Montana. American Midland Naturalist 143:30-40.

Hayes, M. 2013. Bats killed in large numbers at United States Wind Energy Facilities. Bioscience 63: 975-979.

Horton, K.G., W.G. Shriver, and J.J. Buler. 2015. A comparison of traffic estimates of nocturnal flying animals using radar, thermal imaging, and acoustic recording. Ecological Applications 25(2): 390-401.

Horton, K.G., W.G. Shriver, and J.J. Buler. 2016a. An assessment of spatio-temporal relationships between nocturnal bird migration traffic rates and diurnal bird stopover density. Movement Ecology 4: 1.

Horton, K.G., B.M. Van Doren, P.M. Stepanian, W.M. Hochachka, A. Farnsworth, and J.F. Kelly. 2016b. Nocturnally migrating songbirds drift when they can and compensate when they must. Scientific Reports 6: 1-8.

Hueppop, O., J. Dierschke, K. M. Exo, E. Fredrich, and R. Hill. 2006. Bird migration studies and potential collision risk with offshore wind turbines. Ibis 148:90-109.

Jin, S., Yang, L., Danielson, P., Homer, C., Fry, J., and Xian, G. 2013. A comprehensive change detection method for updating the National Land Cover Database to circa 2011. Remote Sensing of Environment 132: 159 – 175.

Johnson, G.D. 2005. A review of bat mortality at wind-energy developments in the United States. Bat Research News 46: 45-49.

Kunz, T. H., E. B. Arnett, W. P. Erickson, A. Hoar, G. Johnson, R. Larkin, M.D. Strickland, R. Thresher, and M. Tuttle. 2007a. Ecological impacts of wind energy development on bats: questions, research needs, and hypotheses. Frontiers of Ecology and the Environment 5(6):315-324.

Kunz, T. H., E. B. Arnett, B. M. Cooper, W. P. Erickson, R. P. Larkin, T. Mabee, M. L. Morrison, M. D. Strickland, and J. M. Szewczak. 2007b. Assessing impacts of wind-energy development on nocturnally active birds and bats: a guidance document. Journal of Wildlife Management 71: 2449–2486.

Larkin, R.P. 2005. Radar techniques for wildlife biology. Pages 448-464 In: C. E. Braun, editor Techniques for wildlife investigations and management, 6th Edition. The Wildlife Society, Bethesda, Maryland, USA.

Liechti, F., B. Bruderer, and H. Paproth. 1995. Quantification of nocturnal bird migration by moonwatching: comparison with radar and infrared observations. J. Field Ornithol. 66: 457–468.
Liechti, F. 2006. Birds: blowin' by the wind? Journal of Ornithology 147:202-211.
Loss, S., T. Will, and P. Marra. 2013. Estimates of bird collision mortality at wind facilities in the contiguous United States. Biological Conservation, 168: 201-209.
Lowery, G.H. Jr. 1951. A quantitative study of the nocturnal migration of birds. Univ. Kansas Publ. Mus. Natural History 3: 361–472.
Mabee, T. J. and B. A. Cooper. 2004. Nocturnal bird migration in northeastern Oregon and southeastern Washington. Northwestern Naturalist 85:39-47.
Mageau, M., B. Sunderland, and S. Stark. 2008. Minnesota's Lake Superior coastal program wind resource development in the Minnesota coastal zone. University of Minnesota Center for Sustainable Community Development. Project No. 306-02-08. Contract No. A92528.
Mai, T.; R. Wiser, D. Sandor, G. Brinkman, G.Heath, P. Denholm, D.Hostick, N. Darghouth, A. Schlosser, K. Strzepek. 2012. Exploration of High-Penetration Renewable Electricity Futures. Vol. 1 of Renewable Electricity Futures Study. <http://www.nrel.gov/analysis/staff/trieu_mai.html> (accessed November 2013).
McGuire, L. P., K. A. Jonasson, and C. G. Guglielmo. 2012a. Torpor-assisted migration in bats. In: The Society for Integrated & Comparative Biology; January 4, 2012; Charleston, SC. Session 20.
McGuire, L. P., C. G. Guglielmo, S. A. Mackenzie, and P. D. Taylor. 2012b. Migratory stopover in the long-distance migrant silver-haired bat, *Lasionycteris noctivagans*. Journal of Animal Ecology 81: 377–385.
Mehlman, D. W., S. E. Mabey, D. N. Ewert, C. Duncan, B. Abel, D. Cimprich, R. D. Sutter, and M. Woodrey. 2005. Conserving stopover sites for forest-dwelling migratory landbirds. Auk 122:1281-1290.
Moore, F.R., P. Kerlinger, T. R. Simons. 1990. Stopover on a Gulf Coast Barrier Island by spring trans-Gulf migrants. Wilson Bulletin. 102: 487-501.
Myres, M. T. 1964. Dawn ascent and reorientation of Scandanavian thrushes (Turdus spp.) migrating at night over the northeastern Atlantic Ocean in autumn. Ibis 106:7–51.
Newton, I. 2006. Can conditions experienced during migration limit the population levels of birds? Journal of Ornithology 147:146-166.
Newton, I. 2007. Weather-related mass-mortality events in migrants. Ibis 149:453-467.
Newton, I. 2008. Migration ecology of birds. Academic Press, Elsevier. UK. 975 pp.
Peterson, A. and G. J. Niemi. 2011. Development of a comprehensive conservation strategy for the North Shore Highlands Region of Minnesota in the context of future wind development. Final Report. Natural Resources Research Institute technical report: NRRI/TR-2012/13.
Peterson, A., G. Niemi, and D. Johnson. 2015. Patterns in diurnal airspace use by migratory landbirds along an ecological barrier. Ecological Applications 25:673-684.
Press, W. H., S. A. Teukolsky, W. T. Vetterling, and B. P. Flannery. 2007. Numerical Recipes: The Art of Scientific Computing (3rd ed.). New York: Cambridge University Press.
R Core Team. (2012). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org/.
Racey, P., and A. Entwistle. 2000. Life-history and reproductive strategies of bats. Reproductive biology of bats, 363-414.
Rathbun N. A., T. S. Bowden, R. L. Horton, D. C. Nolfi, E. C. Olson, D. J. Larson, and J. C. Gosse. 2016. Great Lakes Avian Radar Technical Report; Niagara, Genesee, Wayne, and Jefferson Counties, New York; Spring 2013. U.S. Department of Interior, Fish and Wildlife Service, Biological Technical Publication FWS/BTP-R3013-2016
Rich, T. D., C. J. Beardmore, H. Berlanga, P. J. Blancher, M. S. W. Bradstreet, G. S. Butcher, D. W. Demarest, E. H. Dunn, W. C. Hunter, E. E. Iñigo-Elias, J. A. Kennedy, A. M. Martell, A. O. Panjabi, D. N. Pashley, K. V. Rosenberg, C. M. Rustay, J. S. Wendt, and T. C. Will. 2004. Partners in Flight North American Landbird Conservation Plan. Cornell Lab of Ornithology. Ithaca, NY.
Ruth, J. M., editor. 2007. Applying radar technology to migratory bird conservation and management: strengthening and expanding a collaborative. Fort Collins, CO, U. S. Geological Survey, Biological Resources Discipline. Open-File Report 2007 – 1361, 84p.
Schmaljohann, H., P. J. J. Becker, H. Karaardic, F. Liechti, B. Naef-Daenzer, and C. Grande. 2011. Nocturnal exploratory flights, departure time, and direction in a migratory songbird. Journal of Ornithology 152:439-452.

Schmaljohann, H., F. Liechti, E. Baechler, T. Steuri, and B. Bruderer. 2008. Quantification of bird migration by radar - a detection probability problem. Ibis 150:342-355.

Schmaljohann, H. and B. Naef-Daenzer. 2011. Body condition and wind support initiate the shift of migratory direction and timing of nocturnal departure in a songbird. Journal of Animal Ecology 80:1115-1122.

Seeland, H., G.Niemi, R.Regal, A. Peterson, C. Lapin. 2012. Determination of raptor migratory patterns over a large landscape. Journal of Raptor Research 46:283-295.

Sillett, T. S. and R. T. Holmes. 2002. Variation in survivorship of a migratory songbird throughout its annual cycle. Journal of Animal Ecology 71:296-308.

Smallwood, K.S. 2013. Comparing bird and bat fatality-rate estimates among North American wind-energy projects. Wildlife Society Bulletin 37: 19-33.

Smallwood, K. S. and C. Thelander. 2008. Bird mortality in the Altamont Pass wind resource area, California. Journal of Wildlife Management 72:853-853.

Smith, R. J., M. J. Hamas, D. N. Ewert, and M. E. Dallman. 2004. Spatial foraging differences in American redstarts along the shoreline of northern Lake Huron during spring migration. Wilson Bulletin 116:48-55.

Smith, R. J., F. R. Moore, and C. A. May. 2007. Stopover habitat along the shoreline of northern Lake Huron, Michigan: Emergent aquatic insects as a food resource for spring migrating landbirds. Auk 124:107-121.

Taylor, P. D., S. A. Mackenzie, B. G. Thurber, A. M. Calvert, A. M. Mills, L. P. McGuire, and C. G. Guglielmo. 2011. Landscape Movements of Migratory Birds and Bats Reveal an Expanded Scale of Stopover. Plos One 6.

Timm, R.M. 1989. Migration and molt patterns of red bats. Illinois Bull. Chicago Academy of Science.

Turner, G. G., D. M. Reeder, and J. T. H. Coleman. 2011. A Five-year Assessment of Mortality and Geographic Spread of White-Nose Syndrome in North American Bats, with a Look at the Future. Update of White-Nose Syndrome in bats. Bat Research News, 52:13-27.

U.S. Department of Energy. 2008. 20% Wind energy by 2030: increasing wind energy's contribution to U.S. electricity supply. U.S. Department of Energy, Office of Scientific and Technical Information, Oak Ridge, Tennessee. <http://www.nrel.gov/docs/fy08osti/41869.pdf> (accessed November 2013).

U.S. Department of Energy. 2015. Wind Vision: A New Era for Wind Power in the United States. U.S. Department of Energy, Office of Scientific and Technical Information, Oak Ridge, Tennessee. http://www.energy.gov/sites/prod/files/WindVision_Report_final.pdf (accessed August 2015)

USFWS. 2012. U.S. Fish and Wildlife land-based wind energy guidelines. OMB Control No. 1018-0148.

Wiedner, D. S., P. Kerlinger, D. A Sibley, P. Holt, J. Hough, and R. Cmssley. 1992. Visible morning flights of neotropical landbird migrants at Cape May, New Jersey. Auk 109 (3): 500-510.

Zar, J.H. 1999. Biostatistical Analysis, 4th ed. Prentice Hall, Upper Saddle River, NJ. 662 pp.

Appendices

Appendix 1

Fall 2014 Report Summary

■ Migration occurred on both the northwest and south the shorelines of Lake Superior during fall 2014
- Migration was identified by uniformity of movement of direction (south/southwest) at night, high target passage rate, and typically a peaking of numbers near midnight
- General patterns and timing of migration were similar between the sites sampled during the same period
  - 4 main waves of nocturnal migration with highest concentrations near Aug 14, Sept 4, Sept 22, and Oct 15
  - 4 main waves of diurnal migration with the peaks near Aug 16, Sept 3, Oct 3, and Nov 7

■ Date range of pulses that occurred during the migration season
- Began on August 3 in Lake County, MN and Bayfield County, WI
- Ended on November 10 in Lake County, MN and on October 26 in Keweenaw County, MI

■ Patterns of activity were different between Dawn, Day, Dusk, and Night time periods
- Movement between southeast and west during the night at all locations
  - 85% of nights surveyed the mean direction of travel was between S and W in Lake County, MN
  - 78% of nights surveyed the mean direction of travel was between SE and SW in Bayfield County, WI
  - 72% of nights surveyed the mean direction of travel was between SE and SW in Keweenaw County, MI
- Movement in towards and/or along the shore at dawn
  - Observed at all three sites
- Highest target passage rate at night
- Dawn ascent
  - Slight increase in height around dawn hours observed at two sites

■ Peak density of targets in volume corrected counts
- Max density below 200 m 77.6% of nights and 74.2% of night hours at Lake County, MN
- Max density below 200 m 65.8% of nights and 51.7% of night hours at Bayfield County, WI

■ Standards for radar studies need to be established and recommendations are included in this report
- Using radar counts as an index of activity and not a population estimate
- Surveying continuously over the whole migration season
- Examining smaller time periods (Dawn/Day/Dusk/Night or Hourly) rather than seasonal metrics
- Using volume corrected counts on the vertical radar to better estimate use of low altitudes and the rotor swept zone
- Using 50-m altitude bands to represent height distributions rather than mean or median heights
- Examining the most densely populated altitude bands rather than comparing numbers or percentages of targets below, within, and above the rotor swept zone
- Recognizing that migrants change altitude for various reasons over time and that targets flying several altitude bands above the rotor swept zone may still be at risk

Appendix 2

Percent Land Cover Associated with Study Sites and the 2006 National Land Cover Database Classification

Percent landcover found within 3.7 km of radar locations along Lake Superior in fall 2014.

National Landcover Class	Lake County	Bayfield County	Keweenaw County
Deciduous Forest	35%	54%	16%
Developed*	2%	4%	4%
Emergent Herbaceous Wetlands	0%	3%	1%
Evergreen Forest	5%	11%	22%
Herbaceous	1%	2%	2%
Mixed Forest	5%	21%	15%
Open water	32%	1%	25%
Shrub/Scrub	16%	4%	1%
Woody Wetlands	4%	0%	15%

* Includes low intensity development and developed open space.

Classification Description for the 2011 National Land Cover Database (http://www.mrlc.gov/nlcd2011.php).

Classification Description
Water
Open Water - areas of open water, generally with less than 25% cover of vegetation or soil.
Perennial Ice/Snow - areas characterized by a perennial cover of ice and/or snow, generally greater than 25% of total cover.
Developed
Developed, Open Space - areas with a mixture of some constructed materials, but mostly vegetation in the form of lawn grasses. Impervious surfaces account for less than 20% of total cover. These areas most commonly include large-lot single-family housing units, parks, golf courses, and vegetation planted in developed settings for recreation, erosion control, or aesthetic purposes.
Developed, Low Intensity - areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 20% to 49% percent of total cover. These areas most commonly include single-family housing units.
Developed, Medium Intensity – areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 50% to 79% of the total cover. These areas most commonly include single-family housing units.
Developed High Intensity -highly developed areas where people reside or work in high numbers. Examples include apartment complexes, row houses and commercial/industrial. Impervious surfaces account for 80% to 100% of the total cover.

Barren
Barren Land (Rock/Sand/Clay) - areas of bedrock, desert pavement, scarps, talus, slides, volcanic material, glacial debris, sand dunes, strip mines, gravel pits and other accumulations of earthen material. Generally, vegetation accounts for less than 15% of total cover.
Forest
Deciduous Forest - areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75% of the tree species shed foliage simultaneously in response to seasonal change.
Evergreen Forest - areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75% of the tree species maintain their leaves all year. Canopy is never without green foliage.
Mixed Forest - areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. Neither deciduous nor evergreen species are greater than 75% of total tree cover.
Shrubland
Dwarf Scrub - Alaska only areas dominated by shrubs less than 20 centimeters tall with shrub canopy typically greater than 20% of total vegetation. This type is often co-associated with grasses, sedges, herbs, and non-vascular vegetation.
Shrub/Scrub - areas dominated by shrubs; less than 5 meters tall with shrub canopy typically greater than 20% of total vegetation. This class includes true shrubs, young trees in an early successional stage or trees stunted from environmental conditions.
Herbaceous
Grassland/Herbaceous - areas dominated by gramanoid or herbaceous vegetation, generally greater than 80% of total vegetation. These areas are not subject to intensive management such as tilling, but can be utilized for grazing.
Sedge/Herbaceous - Alaska only areas dominated by sedges and forbs, generally greater than 80% of total vegetation. This type can occur with significant other grasses or other grass like plants, and includes sedge tundra, and sedge tussock tundra.
Lichens - Alaska only areas dominated by fruticose or foliose lichens generally greater than 80% of total vegetation.
Moss - Alaska only areas dominated by mosses, generally greater than 80% of total vegetation.
Planted/Cultivated
Pasture/Hay – areas of grasses, legumes, or grass-legume mixtures planted for livestock grazing or the production of seed or hay crops, typically on a perennial cycle. Pasture/hay vegetation accounts for greater than 20% of total vegetation.
Cultivated Crops – areas used for the production of annual crops, such as corn, soybeans, vegetables, tobacco, and cotton, and also perennial woody crops such as orchards and vineyards. Crop vegetation accounts for greater than 20% of total vegetation. This class also includes all land being actively tilled.
Wetlands
Woody Wetlands - areas where forest or shrubland vegetation accounts for greater than 20% of vegetative cover and the soil or substrate is periodically saturated with or covered with water.
Emergent Herbaceous Wetlands - Areas where perennial herbaceous vegetation accounts for greater than 80% of vegetative cover and the soil or substrate is periodically saturated with or covered with water.

Appendix 3

Corrected Density per Hour by Biological Period

Estimated density of targets by altitude band during all biological periods in Lake, Bayfield, and Keweenaw counties during fall 2014 (targets/1,000,000 m³/time period).

Lake County

Altitude Band	Dawn	Day	Dusk	Night
50	0.2	0.1	0.1	0.3
100	1.4	0.7	0.4	3.9
150	1.0	0.4	0.3	4.3
200	0.8	0.4	0.4	4.2
250	0.9	0.4	0.4	3.7
300	0.8	0.3	0.3	2.7
350	0.9	0.3	0.2	2.4
400	0.7	0.2	0.1	1.9
450	0.7	0.2	0.1	1.6
500	0.5	0.1	0.1	1.2
550	0.4	0.1	0.0	1.0
600	0.3	0.1	0.0	0.9
650	0.2	0.0	0.0	0.8
700	0.2	0.0	0.0	0.6
750	0.2	0.0	0.0	0.5
800	0.1	0.0	0.0	0.4
850	0.1	0.0	0.0	0.4
900	0.1	0.0	0.0	0.3
950	0.1	0.0	0.0	0.3
1000	0.1	0.0	0.0	0.2

Bayfield County

Altitude Band	Dawn	Day	Dusk	Night
50	0.0	0.0	0.0	0.0
100	0.8	0.5	0.5	3.4
150	0.6	0.4	0.6	4.0
200	0.4	0.7	0.5	3.8
250	0.5	0.6	0.6	3.4
300	0.4	0.7	0.5	3.5
350	0.4	0.4	0.3	3.0
400	0.4	0.3	0.2	2.7
450	0.3	0.2	0.2	2.5
500	0.3	0.1	0.2	2.2
550	0.2	0.1	0.1	1.9
600	0.2	0.1	0.1	1.7
650	0.2	0.0	0.0	1.3
700	0.1	0.0	0.0	1.1
750	0.2	0.0	0.0	0.8
800	0.1	0.0	0.0	0.6
850	0.1	0.0	0.0	0.5
900	0.1	0.0	0.0	0.4
950	0.1	0.0	0.0	0.3
1000	0.0	0.0	0.0	0.2

Keweenaw County

Altitude Band	Dawn	Day	Dusk	Night
50	0.0	0.0	0.0	0.0
100	0.7	0.2	0.1	2.9
150	0.8	0.2	0.2	6.3
200	0.7	0.2	0.2	6.9
250	0.8	0.1	0.2	6.9
300	0.7	0.2	0.1	6.4
350	0.6	0.1	0.0	5.1
400	0.6	0.1	0.0	4.3
450	0.5	0.0	0.0	3.6
500	0.5	0.0	0.0	3.0
550	0.4	0.0	0.0	2.5
600	0.4	0.0	0.0	2.2
650	0.3	0.0	0.0	1.9
700	0.3	0.0	0.0	1.7
750	0.3	0.0	0.0	1.4
800	0.3	0.0	0.0	1.2
850	0.3	0.0	0.0	0.9
900	0.2	0.0	0.0	0.8
950	0.2	0.0	0.0	0.6
1000	0.1	0.0	0.0	0.5

Appendix 4

Comparison of Static and Corrected Density Estimates

Comparison of methods to estimated target density by altitude band during the *dawn* biological period in Lake County, Minnesota.

Altitude Band	Running Total	Count per Band	Static Volume	Corrected Volume	Static Density per Hour	Corrected Density per Hour	% Total per Band	% Static Density	% Corrected Density
50	113	113	31.3	5.6	0.0	0.2	1.2%	1.2%	2.2%
100	844	731	31.3	5.9	0.3	1.4	7.5%	7.5%	13.7%
150	1,424	580	31.3	6.5	0.2	1.0	6.0%	5.9%	10.0%
200	1,922	498	31.3	7.1	0.2	0.8	5.1%	5.1%	7.8%
250	2,582	660	31.3	7.9	0.2	0.9	6.8%	6.8%	9.3%
300	3,178	596	31.3	8.5	0.2	0.8	6.1%	6.1%	7.8%
350	3,938	760	31.3	9.5	0.3	0.9	7.8%	7.8%	8.9%
400	4,594	656	31.3	10.3	0.2	0.7	6.7%	6.7%	7.1%
450	5,254	660	31.3	11.2	0.2	0.7	6.8%	6.8%	6.5%
500	5,778	524	31.3	12.2	0.2	0.5	5.4%	5.4%	4.8%
550	6,204	426	31.3	13.3	0.2	0.4	4.4%	4.4%	3.6%
600	6,555	351	31.3	14.1	0.1	0.3	3.6%	3.6%	2.8%
650	6,862	307	31.3	15.3	0.1	0.2	3.2%	3.1%	2.2%
700	7,128	266	31.3	16.2	0.1	0.2	2.7%	2.7%	1.8%
750	7,381	253	31.3	17.2	0.1	0.2	2.6%	2.6%	1.6%
800	7,620	239	31.3	18.2	0.1	0.1	2.5%	2.4%	1.5%
850	7,773	153	31.3	19.4	0.1	0.1	1.6%	1.6%	0.9%
900	7,913	140	31.3	20.4	0.0	0.1	1.4%	1.4%	0.8%
950	8,048	135	31.3	21.4	0.0	0.1	1.4%	1.4%	0.7%
1000	8,180	132	31.3	22.4	0.0	0.1	1.4%	1.4%	0.7%

Comparison of methods to estimated target density by altitude band during the *day* biological period in Lake County, Minnesota.

Altitude Band	Running Total	Count per Band	Static Volume	Corrected Volume	Static Density per Hour	Corrected Density per Hour	% Total per Band	% Static Density	% Corrected Density
50	618	618	31.3	5.6	0.0	0.1	1.9%	1.9%	3.0%
100	4,977	4,359	31.3	5.9	0.1	0.7	13.5%	13.5%	20.1%
150	7,801	2,824	31.3	6.5	0.1	0.4	8.7%	8.7%	12.0%
200	10,402	2,601	31.3	7.1	0.1	0.4	8.0%	8.0%	10.0%
250	13,643	3,241	31.3	7.9	0.1	0.4	10.0%	10.0%	11.2%
300	16,145	2,502	31.3	8.5	0.1	0.3	7.7%	7.7%	8.1%
350	19,329	3,184	31.3	9.5	0.1	0.3	9.8%	9.8%	9.2%
400	21,768	2,439	31.3	10.3	0.1	0.2	7.5%	7.5%	6.5%
450	23,931	2,163	31.3	11.2	0.1	0.2	6.7%	6.7%	5.3%
500	25,734	1,803	31.3	12.2	0.1	0.1	5.6%	5.6%	4.0%
550	27,133	1,399	31.3	13.3	0.0	0.1	4.3%	4.3%	2.9%
600	28,169	1,036	31.3	14.1	0.0	0.1	3.2%	3.2%	2.0%
650	28,905	736	31.3	15.3	0.0	0.0	2.3%	2.3%	1.3%
700	29,520	615	31.3	16.2	0.0	0.0	1.9%	1.9%	1.0%
750	29,870	350	31.3	17.2	0.0	0.0	1.1%	1.1%	0.6%
800	30,212	342	31.3	18.2	0.0	0.0	1.1%	1.1%	0.5%
850	30,469	257	31.3	19.4	0.0	0.0	0.8%	0.8%	0.4%
900	30,665	196	31.3	20.4	0.0	0.0	0.6%	0.6%	0.3%
950	30,848	183	31.3	21.4	0.0	0.0	0.6%	0.6%	0.2%
1000	31,006	158	31.3	22.4	0.0	0.0	0.5%	0.5%	0.2%

Comparison of methods to estimated target density by altitude band during the *dusk* biological period in Lake County, Minnesota.

Altitude Band	Running Total	Count per Band	Static Volume	Corrected Volume	Static Density per Hour	Corrected Density per Hour	% Total per Band	% Static Density	% Corrected Density
50	37	37	31.3	5.6	0.0	0.1	1.8%	1.8%	3.0%
100	229	192	31.3	5.9	0.1	0.4	9.5%	9.4%	14.5%
150	404	175	31.3	6.5	0.1	0.3	8.6%	8.5%	12.1%
200	633	229	31.3	7.1	0.1	0.4	11.3%	11.2%	14.4%
250	911	278	31.3	7.9	0.1	0.4	13.7%	13.6%	15.7%
300	1,104	193	31.3	8.5	0.1	0.3	9.5%	9.4%	10.2%
350	1,274	170	31.3	9.5	0.1	0.2	8.4%	8.3%	8.0%
400	1,397	123	31.3	10.3	0.0	0.1	6.1%	6.0%	5.3%
450	1,493	96	31.3	11.2	0.0	0.1	4.7%	4.7%	3.8%
500	1,575	82	31.3	12.2	0.0	0.1	4.0%	4.0%	3.0%
550	1,616	41	31.3	13.3	0.0	0.0	2.0%	2.0%	1.4%
600	1,652	36	31.3	14.1	0.0	0.0	1.8%	1.8%	1.1%
650	1,687	35	31.3	15.3	0.0	0.0	1.7%	1.7%	1.0%
700	1,715	28	31.3	16.2	0.0	0.0	1.4%	1.4%	0.8%
750	1,746	31	31.3	17.2	0.0	0.0	1.5%	1.5%	0.8%
800	1,773	27	31.3	18.2	0.0	0.0	1.3%	1.3%	0.7%
850	1,796	23	31.3	19.4	0.0	0.0	1.1%	1.1%	0.5%
900	1,816	20	31.3	20.4	0.0	0.0	1.0%	1.0%	0.4%
950	1,827	11	31.3	21.4	0.0	0.0	0.5%	0.5%	0.2%
1000	1,841	14	31.3	22.4	0.0	0.0	0.7%	0.7%	0.3%

Comparison of methods to estimated target density by altitude band during the *night* biological period in Lake County, Minnesota.

Altitude Band	Running Total	Count per Band	Static Volume	Corrected Volume	Static Density per Hour	Corrected Density per Hour	% Total per Band	% Static Density	% Corrected Density
50	1,805	1,805	31.3	5.6	0.1	0.3	0.5%	0.5%	1.0%
100	23,646	21,841	31.3	5.9	0.7	3.9	6.3%	6.3%	11.6%
150	49,699	26,053	31.3	6.5	0.9	4.3	7.5%	7.5%	12.7%
200	77,713	28,014	31.3	7.1	1.0	4.2	8.1%	8.1%	12.5%
250	105,071	27,358	31.3	7.9	0.9	3.7	7.9%	7.9%	10.9%
300	126,677	21,606	31.3	8.5	0.7	2.7	6.2%	6.2%	8.0%
350	147,611	20,934	31.3	9.5	0.7	2.4	6.0%	6.0%	7.0%
400	165,908	18,297	31.3	10.3	0.6	1.9	5.3%	5.3%	5.6%
450	182,194	16,286	31.3	11.2	0.6	1.6	4.7%	4.7%	4.6%
500	196,448	14,254	31.3	12.2	0.5	1.2	4.1%	4.1%	3.7%
550	209,252	12,804	31.3	13.3	0.4	1.0	3.7%	3.7%	3.0%
600	220,865	11,613	31.3	14.1	0.4	0.9	3.3%	3.3%	2.6%
650	231,629	10,764	31.3	15.3	0.4	0.8	3.1%	3.1%	2.2%
700	241,475	9,846	31.3	16.2	0.3	0.6	2.8%	2.8%	1.9%
750	250,110	8,635	31.3	17.2	0.3	0.5	2.5%	2.5%	1.6%
800	257,717	7,607	31.3	18.2	0.3	0.4	2.2%	2.2%	1.3%
850	264,572	6,855	31.3	19.4	0.2	0.4	2.0%	2.0%	1.1%
900	270,871	6,299	31.3	20.4	0.2	0.3	1.8%	1.8%	1.0%
950	276,255	5,384	31.3	21.4	0.2	0.3	1.5%	1.5%	0.8%
1000	280,603	4,348	31.3	22.4	0.1	0.2	1.3%	1.3%	0.6%

Comparison of methods to estimated target density by altitude band during the *dawn* biological period in Bayfield County, Wisconsin.

Altitude Band	Running Total	Count per Band	Static Volume	Corrected Volume	Static Density per Hour	Corrected Density per Hour	% Total per Band	% Static Density	% Corrected Density
50	1	1	31.3	5.6	0.0	0.0	0.0%	0.0%	0.1%
100	159	158	31.3	5.9	0.1	0.8	7.2%	7.2%	13.5%
150	290	131	31.3	6.5	0.1	0.6	6.0%	6.0%	10.3%
200	402	112	31.3	7.1	0.1	0.4	5.1%	5.1%	8.0%
250	530	128	31.3	7.9	0.1	0.5	5.9%	5.9%	8.2%
300	659	129	31.3	8.5	0.1	0.4	5.9%	5.9%	7.7%
350	807	148	31.3	9.5	0.1	0.4	6.8%	6.8%	7.9%
400	938	131	31.3	10.3	0.1	0.4	6.0%	6.0%	6.4%
450	1,071	133	31.3	11.2	0.1	0.3	6.1%	6.1%	6.0%
500	1,199	128	31.3	12.2	0.1	0.3	5.9%	5.9%	5.3%
550	1,313	114	31.3	13.3	0.1	0.2	5.2%	5.2%	4.3%
600	1,415	102	31.3	14.1	0.1	0.2	4.7%	4.7%	3.7%
650	1,523	108	31.3	15.3	0.1	0.2	5.0%	5.0%	3.6%
700	1,601	78	31.3	16.2	0.1	0.1	3.6%	3.6%	2.4%
750	1,694	93	31.3	17.2	0.1	0.2	4.3%	4.3%	2.7%
800	1,739	45	31.3	18.2	0.0	0.1	2.1%	2.1%	1.3%
850	1,794	55	31.3	19.4	0.0	0.1	2.5%	2.5%	1.4%
900	1,832	38	31.3	20.4	0.0	0.1	1.7%	1.7%	0.9%
950	1,873	41	31.3	21.4	0.0	0.1	1.9%	1.9%	1.0%
1000	1,906	33	31.3	22.4	0.0	0.0	1.5%	1.5%	0.7%

Comparison of methods to estimated target density by altitude band during the *day* biological period in Bayfield County, Wisconsin.

Altitude Band	Running Total	Count per Band	Static Volume	Corrected Volume	Static Density per Hour	Corrected Density per Hour	% Total per Band	% Static Density	% Corrected Density
50	23	23	31.3	5.6	0.0	0.0	0.1%	0.1%	0.2%
100	1,398	1,375	31.3	5.9	0.1	0.5	8.2%	8.2%	12.1%
150	2,513	1,115	31.3	6.5	0.1	0.4	6.6%	6.6%	9.0%
200	4,656	2,143	31.3	7.1	0.1	0.7	12.8%	12.7%	15.7%
250	6,880	2,224	31.3	7.9	0.2	0.6	13.2%	13.2%	14.7%
300	9,437	2,557	31.3	8.5	0.2	0.7	15.2%	15.2%	15.7%
350	11,299	1,862	31.3	9.5	0.1	0.4	11.1%	11.1%	10.3%
400	12,830	1,531	31.3	10.3	0.1	0.3	9.1%	9.1%	7.7%
450	14,092	1,262	31.3	11.2	0.1	0.2	7.5%	7.5%	5.9%
500	14,823	731	31.3	12.2	0.1	0.1	4.4%	4.3%	3.1%
550	15,313	490	31.3	13.3	0.0	0.1	2.9%	2.9%	1.9%
600	15,644	331	31.3	14.1	0.0	0.1	2.0%	2.0%	1.2%
650	15,839	195	31.3	15.3	0.0	0.0	1.2%	1.2%	0.7%
700	15,974	135	31.3	16.2	0.0	0.0	0.8%	0.8%	0.4%
750	16,036	62	31.3	17.2	0.0	0.0	0.4%	0.4%	0.2%
800	16,105	69	31.3	18.2	0.0	0.0	0.4%	0.4%	0.2%
850	16,148	43	31.3	19.4	0.0	0.0	0.3%	0.3%	0.1%
900	16,198	50	31.3	20.4	0.0	0.0	0.3%	0.3%	0.1%
950	16,220	22	31.3	21.4	0.0	0.0	0.1%	0.1%	0.1%
1000	16,246	26	31.3	22.4	0.0	0.0	0.2%	0.2%	0.1%

(Appendix 4 continued)

Comparison of methods to estimated target density by altitude band during the *dusk* biological period in Bayfield County, Wisconsin.

Altitude Band	Running Total	Count per Band	Static Volume	Corrected Volume	Static Density per Hour	Corrected Density per Hour	% Total per Band	% Static Density	% Corrected Density
50	2	2	31.3	5.6	0.0	0.0	0.2%	0.2%	0.3%
100	104	102	31.3	5.9	0.1	0.5	7.7%	7.7%	12.3%
150	236	132	31.3	6.5	0.1	0.6	9.9%	9.9%	14.6%
200	362	126	31.3	7.1	0.1	0.5	9.5%	9.5%	12.7%
250	525	163	31.3	7.9	0.1	0.6	12.2%	12.3%	14.8%
300	671	146	31.3	8.5	0.1	0.5	11.0%	11.0%	12.3%
350	765	94	31.3	9.5	0.1	0.3	7.1%	7.1%	7.1%
400	847	82	31.3	10.3	0.1	0.2	6.2%	6.2%	5.7%
450	933	86	31.3	11.2	0.1	0.2	6.5%	6.5%	5.5%
500	1,000	67	31.3	12.2	0.1	0.2	5.0%	5.0%	3.9%
550	1,047	47	31.3	13.3	0.0	0.1	3.5%	3.5%	2.5%
600	1,075	28	31.3	14.1	0.0	0.1	2.1%	2.1%	1.4%
650	1,089	14	31.3	15.3	0.0	0.0	1.1%	1.1%	0.7%
700	1,103	14	31.3	16.2	0.0	0.0	1.1%	1.1%	0.6%
750	1,113	10	31.3	17.2	0.0	0.0	0.8%	0.8%	0.4%
800	1,126	13	31.3	18.2	0.0	0.0	1.0%	1.0%	0.5%
850	1,135	9	31.3	19.4	0.0	0.0	0.7%	0.7%	0.3%
900	1,140	5	31.3	20.4	0.0	0.0	0.4%	0.4%	0.2%
950	1,147	7	31.3	21.4	0.0	0.0	0.5%	0.5%	0.2%
1000	1,155	8	31.3	22.4	0.0	0.0	0.6%	0.6%	0.3%

Comparison of methods to estimated target density by altitude band during the *night* biological period in Bayfield County, Wisconsin.

Altitude Band	Running Total	Count per Band	Static Volume	Corrected Volume	Static Density per Hour	Corrected Density per Hour	% Total per Band	% Static Density	% Corrected Density
50	36	36	31.3	5.6	0.0	0.0	0.0%	0.0%	0.1%
100	6,418	6,382	31.3	5.9	0.7	3.4	4.2%	4.2%	8.5%
150	14,561	8,143	31.3	6.5	0.8	4.0	5.4%	5.4%	10.0%
200	22,911	8,350	31.3	7.1	0.9	3.8	5.5%	5.5%	9.3%
250	31,376	8,465	31.3	7.9	0.9	3.4	5.6%	5.6%	8.5%
300	40,777	9,401	31.3	8.5	1.0	3.5	6.2%	6.2%	8.8%
350	49,739	8,962	31.3	9.5	0.9	3.0	5.9%	5.9%	7.5%
400	58,435	8,696	31.3	10.3	0.9	2.7	5.8%	5.8%	6.7%
450	67,243	8,808	31.3	11.2	0.9	2.5	5.8%	5.8%	6.2%
500	75,507	8,264	31.3	12.2	0.8	2.2	5.5%	5.5%	5.4%
550	83,317	7,810	31.3	13.3	0.8	1.9	5.2%	5.2%	4.7%
600	90,643	7,326	31.3	14.1	0.7	1.7	4.8%	4.8%	4.1%
650	96,962	6,319	31.3	15.3	0.6	1.3	4.2%	4.2%	3.3%
700	102,436	5,474	31.3	16.2	0.6	1.1	3.6%	3.6%	2.7%
750	106,947	4,511	31.3	17.2	0.5	0.8	3.0%	3.0%	2.1%
800	110,656	3,709	31.3	18.2	0.4	0.6	2.5%	2.5%	1.6%
850	113,643	2,987	31.3	19.4	0.3	0.5	2.0%	2.0%	1.2%
900	116,063	2,420	31.3	20.4	0.2	0.4	1.6%	1.6%	0.9%
950	117,843	1,780	31.3	21.4	0.2	0.3	1.2%	1.2%	0.7%
1000	119,113	1,270	31.3	22.4	0.1	0.2	0.8%	0.8%	0.4%

Comparison of methods to estimated target density by altitude band during the *dawn* biological period in Keweenaw County, Michigan.

Altitude Band	Running Total	Count per Band	Static Volume	Corrected Volume	Static Density per Hour	Corrected Density per Hour	% Total per Band	% Static Density	% Corrected Density
50	3	3	31.3	5.6	0.0	0.0	0.1%	0.1%	0.3%
100	86	83	31.3	5.9	0.1	0.7	2.8%	2.8%	6.5%
150	190	104	31.3	6.5	0.2	0.8	3.5%	3.5%	7.5%
200	302	112	31.3	7.1	0.2	0.7	3.7%	3.7%	7.4%
250	433	131	31.3	7.9	0.2	0.8	4.4%	4.4%	7.8%
300	559	126	31.3	8.5	0.2	0.7	4.2%	4.2%	6.9%
350	690	131	31.3	9.5	0.2	0.6	4.4%	4.4%	6.5%
400	829	139	31.3	10.3	0.2	0.6	4.6%	4.6%	6.3%
450	940	111	31.3	11.2	0.2	0.5	3.7%	3.7%	4.6%
500	1,070	130	31.3	12.2	0.2	0.5	4.3%	4.3%	5.0%
550	1,191	121	31.3	13.3	0.2	0.4	4.0%	4.0%	4.3%
600	1,312	121	31.3	14.1	0.2	0.4	4.0%	4.0%	4.0%
650	1,425	113	31.3	15.3	0.2	0.3	3.8%	3.8%	3.5%
700	1,529	104	31.3	16.2	0.2	0.3	3.5%	3.5%	3.0%
750	1,636	107	31.3	17.2	0.2	0.3	3.6%	3.6%	2.9%
800	1,743	107	31.3	18.2	0.2	0.3	3.6%	3.6%	2.8%
850	1,858	115	31.3	19.4	0.2	0.3	3.8%	3.8%	2.8%
900	1,926	68	31.3	20.4	0.1	0.2	2.3%	2.3%	1.6%
950	1,998	72	31.3	21.4	0.1	0.2	2.4%	2.4%	1.6%
1000	2,068	70	31.3	22.4	0.1	0.1	2.3%	2.3%	1.5%

Comparison of methods to estimated target density by altitude band during the *day* biological period in Keweenaw County, Michigan.

Altitude Band	Running Total	Count per Band	Static Volume	Corrected Volume	Static Density per Hour	Corrected Density per Hour	% Total per Band	% Static Density	% Corrected Density
50	10	10	31.3	5.6	0.0	0.0	0.3%	0.3%	0.5%
100	257	247	31.3	5.9	0.0	0.2	7.5%	7.4%	12.7%
150	620	363	31.3	6.5	0.0	0.2	11.0%	10.9%	17.1%
200	913	293	31.3	7.1	0.0	0.2	8.9%	8.8%	12.6%
250	1,207	294	31.3	7.9	0.0	0.1	8.9%	8.8%	11.3%
300	1,547	340	31.3	8.5	0.0	0.2	10.3%	10.2%	12.2%
350	1,772	225	31.3	9.5	0.0	0.1	6.8%	6.7%	7.2%
400	1,908	136	31.3	10.3	0.0	0.1	4.1%	4.1%	4.0%
450	2,017	109	31.3	11.2	0.0	0.0	3.3%	3.3%	3.0%
500	2,121	104	31.3	12.2	0.0	0.0	3.1%	3.1%	2.6%
550	2,214	93	31.3	13.3	0.0	0.0	2.8%	2.8%	2.1%
600	2,293	79	31.3	14.1	0.0	0.0	2.4%	2.4%	1.7%
650	2,383	90	31.3	15.3	0.0	0.0	2.7%	2.7%	1.8%
700	2,461	78	31.3	16.2	0.0	0.0	2.4%	2.3%	1.5%
750	2,529	68	31.3	17.2	0.0	0.0	2.1%	2.0%	1.2%
800	2,578	49	31.3	18.2	0.0	0.0	1.5%	1.5%	0.8%
850	2,622	44	31.3	19.4	0.0	0.0	1.3%	1.3%	0.7%
900	2,657	35	31.3	20.4	0.0	0.0	1.1%	1.0%	0.5%
950	2,692	35	31.3	21.4	0.0	0.0	1.1%	1.0%	0.5%
1000	2,733	41	31.3	22.4	0.0	0.0	1.2%	1.2%	0.6%

Comparison of methods to estimated target density by altitude band during the *dusk* biological period in Keweenaw County, Michigan

Altitude Band	Running Total	Count per Band	Static Volume	Corrected Volume	Static Density per Hour	Corrected Density per Hour	% Total per Band	% Static Density	% Corrected Density
50	3	3	31.3	5.6	0.0	0.0	1.5%	1.5%	2.3%
100	20	17	31.3	5.9	0.0	0.1	8.6%	8.7%	12.5%
150	49	29	31.3	6.5	0.0	0.2	14.7%	14.9%	19.7%
200	82	33	31.3	7.1	0.1	0.2	16.8%	17.0%	20.4%
250	111	29	31.3	7.9	0.0	0.2	14.7%	14.9%	16.1%
300	129	18	31.3	8.5	0.0	0.1	9.1%	9.3%	9.3%
350	137	8	31.3	9.5	0.0	0.0	4.1%	4.1%	3.7%
400	147	10	31.3	10.3	0.0	0.0	5.1%	5.1%	4.2%
450	150	3	31.3	11.2	0.0	0.0	1.5%	1.5%	1.2%
500	153	3	31.3	12.2	0.0	0.0	1.5%	1.5%	1.1%
550	157	4	31.3	13.3	0.0	0.0	2.0%	2.1%	1.3%
600	158	1	31.3	14.1	0.0	0.0	0.5%	0.5%	0.3%
650	161	3	31.3	15.3	0.0	0.0	1.5%	1.5%	0.9%
700	164	3	31.3	16.2	0.0	0.0	1.5%	1.5%	0.8%
750	167	3	31.3	17.2	0.0	0.0	1.5%	1.5%	0.8%
800	173	6	31.3	18.2	0.0	0.0	3.0%	3.1%	1.4%
850	174	1	31.3	19.4	0.0	0.0	0.5%	0.5%	0.2%
900	175	1	31.3	20.4	0.0	0.0	0.5%	0.5%	0.2%
950	175	0	31.3	21.4	0.0	0.0	0.0%	0.0%	0.0%
1000	175	0	31.3	22.4	0.0	0.0	0.0%	0.0%	0.0%

(Appendix 4 continued)

Comparison of methods to estimated target density by altitude band during the *night* biological period in Keweenaw County, Michigan.

Altitude Band	Running Total	Count per Band	Static Volume	Corrected Volume	Static Density per Hour	Corrected Density per Hour	% Total per Band	% Static Density	% Corrected Density
50	13	13	31.3	5.6	0.0	0.0	0.0%	0.0%	0.0%
100	3,426	3,413	31.3	5.9	0.6	2.9	2.4%	2.4%	4.6%
150	11,471	8,045	31.3	6.5	1.3	6.3	5.6%	5.6%	10.0%
200	21,086	9,615	31.3	7.1	1.6	6.9	6.7%	6.7%	10.9%
250	31,799	10,713	31.3	7.9	1.7	6.9	7.4%	7.4%	10.9%
300	42,560	10,761	31.3	8.5	1.7	6.4	7.5%	7.5%	10.2%
350	52,021	9,461	31.3	9.5	1.5	5.1	6.6%	6.6%	8.1%
400	60,694	8,673	31.3	10.3	1.4	4.3	6.0%	6.0%	6.8%
450	68,755	8,061	31.3	11.2	1.3	3.6	5.6%	5.6%	5.8%
500	75,904	7,149	31.3	12.2	1.2	3.0	5.0%	5.0%	4.7%
550	82,469	6,565	31.3	13.3	1.1	2.5	4.6%	4.6%	4.0%
600	88,514	6,045	31.3	14.1	1.0	2.2	4.2%	4.2%	3.5%
650	94,327	5,813	31.3	15.3	0.9	1.9	4.0%	4.0%	3.1%
700	99,654	5,327	31.3	16.2	0.9	1.7	3.7%	3.7%	2.6%
750	104,530	4,876	31.3	17.2	0.8	1.4	3.4%	3.4%	2.3%
800	108,924	4,394	31.3	18.2	0.7	1.2	3.1%	3.1%	1.9%
850	112,531	3,607	31.3	19.4	0.6	0.9	2.5%	2.5%	1.5%
900	115,585	3,054	31.3	20.4	0.5	0.8	2.1%	2.1%	1.2%
950	118,198	2,613	31.3	21.4	0.4	0.6	1.8%	1.8%	1.0%
1000	120,408	2,210	31.3	22.4	0.4	0.5	1.5%	1.5%	0.8%

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