U.S. Fish & Wildlife Service

Great Lakes Avian Radar Technical Report

Lake Huron Shoreline:
Presque Isle County and Alcona County, MI
Fall 2015 and Spring 2016

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Funding Provided by Great Lakes Restoration Initiative
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Principle Investigator

Jeff Gosse, Regional Energy Coordinator, USFWS Region 3

Authors

Michael Wells, Fish and Wildlife Biologist, USFWS Region 3

Kevin Heist, Fish and Wildlife Biologist, USFWS Region 3

Rebecca Horton, Fish and Wildlife Biologist, USFWS Region 3

Daniel Nolfi, Fish and Wildlife Biologist, USFWS Region 3

Erik Olson, Fish and Wildlife Biologist (GIS), USFWS Region 3

Nathan Rathbun, Fish and Wildlife Biologist, USFWS Region 3

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Corresponding Authors

Michael T. Wells, PhD.
Fish and Wildlife Biologist
Ecological Services
5600 American Blvd. West, Suite 990
Bloomington, MN 55437
612/713 5336
michael_wells@fws.gov

Authors' Complete Contact Information

Jeffrey C. Gosse, PhD
Regional Energy Coordinator
Ecological Services
5600 American Blvd. West, Suite 990
Bloomington, MN 55437
612/713 5138
jeff_gosse@fws.gov

Rebecca L. Horton
Fish and Wildlife Biologist
Ecological Services
5600 American Blvd. West, Suite 990
Bloomington, MN 55437
612/713 5196
rebecca_horton@fws.gov

Kevin W. Heist, PhD.
Fish and Wildlife Biologist
Ecological Services
5600 American Blvd. West, Suite 990
Bloomington, MN 55437
Phone: 612/713 5196
Email: kevin_heist@fws.gov

Daniel C. Nolfi
Fish and Wildlife Biologist
Ecological Services
5600 American Blvd. West, Suite 990
Bloomington, MN 55437
612/713 5195
daniel_nolfi@fws.gov

Erik C. Olson
Fish and Wildlife Biologist (GIS)
Ecological Services
5600 American Blvd. West, Suite 990
Bloomington, MN 55437
612/713 5488
erik_olson@fws.gov

Nathan A. Rathbun
Fish and Wildlife Biologist
Ecological Services
5600 American Blvd. West, Suite 990
Bloomington, MN 55437
612/713 5182
nathan_rathbun@fws.gov

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Executive Summary

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

We placed avian radar systems on the Western shore of Lake Huron where the automated systems tracked and recorded target (bird and bat) movements continuously from early August to late October, 2015, and from late March to Mid-June 2016. We calculated direction of movement, target passage rates, and altitude profiles for the air space above our study areas. We also developed 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 western Lake Huron shoreline at both study sites. Mean nocturnal passage rates were greater than mean passage rates for dawn, day, and dusk combined at both of our locations. Nocturnal movement was typically oriented in a northerly direction; however, we also recorded other behaviors associated with migrants such as reverse migration, dawn ascent, and migrants over water returning to land at dawn. After correction, peak density occurred between 50—150 m above ground level; however, density may have been underestimated at higher and lower altitudes.

The results of our research highlight the potential role of radar in implementing the Land-Based Wind Energy Guidelines and help to identify areas where impacts to wildlife could be minimized. We documented migration activity in the air space above our study areas, which indicates 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 document that nocturnal peaks continued through early June for the spring and late October for the fall. Given the amount of time that migration occurred in the sampled sites, it seems that curtailing wind energy operations to minimize bird and bat mortality during nocturnal pulses could result in limited operational time along the shoreline during the migration season. Combining the results of radar studies and fatality searches would greatly improve risk assessments and assist with interpretation of standardized radar studies.

Avian radar is often 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. In addition to providing information relevant to wildlife conservation in the Great Lakes region, the concepts we present in this report are widely relevant to reviews of avian radar studies and 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 might be our ability to identify and avoid development in locations where migrants concentrate. Our use of commercial-grade avian radar to document migration is a broad-scale effort toward that end. To our knowledge, this effort represents the first of its kind by the U.S. Fish and Wildlife Service.

Introduction

The Great Lakes support one of the largest bodies of freshwater 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 to move millions of migrating birds through the Great Lakes region (Rich et al. 2004, Liechti 2006, France et al. 2012) and lake shorelines feature widely recognized Important Bird Areas (Audubon 2013). Bat migration is less studied but findings suggest similar patterns of wind use (Dechmann et al. 2017). Migrants passing through the region concentrate near shorelines (Dzal et al. 2009, Ewert et al. 2011, Peterson and Niemi 2011, Buler and Dawson 2012, France et al. 2012), which provide important stopover habitats—*en route* areas used temporarily for refueling, rest, 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 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 partially circumnavigate the Great Lakes, which they have the physiological capability of crossing (Alerstam 1990, 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, 2012b). In this trade-off, shorelines offer refuge when conditions do not favor flights over water.

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 shoreline habitat rather than continue across open water in a direction appropriate for migration. For bats, available studies suggest 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.

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 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 distance tracked for a bat and bird species, respectively) prior to resuming migration (Taylor et al. 2011). Nocturnal migrants such as warblers and other neotropical birds 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 et al. 1990, Wiedner et al. 1992). Flights of this nature often occur above tree line (Bingman 1980) but lower than heights 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 migrant birds and possibly bats 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). Cumulatively, these types of activities define a use area near lake shores that include a variety of movements and altitudes for landscape level, exploratory, and migratory flights. These activities may increase vulnerability to collision risk with tall structures such as buildings, communication towers, or wind turbines.

Migrant populations may experience the greatest mortality pressure during migration (Newton 2006, 2007; Sillett and Holmes 2002, Diehl et al. 2014) and the negative ramifications of compromised stopover habitat to 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, Johnson, 2013). With climate change considerations calling for 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). Wind energy installation is currently on target towards achieving this goal (U.S. EIA 2017). 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).

Low reproductive rates inhibit the ability of bats to rebound from population decline (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 (Frick et al. 2017). 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 (Bonter et al. 2009), 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 of Lake Huron using consistent methodology.

- Maintain an archive of continuously recorded radar data during the fall and spring migration seasons.

- Identify activity patterns captured by radar that are diagnostic of migration.

- Estimate the duration of the migration season.

- Document changes in the behavior of migrants under varying environmental conditions and during different parts of the season.

- Document changes in behavior between fall and spring migration seasons.

Methods

Study Area and Site Selection

During the fall 2015 season, we selected two sites along Lake Huron for radar placement; one site was towards the northwest end of the lake in Michigan (Figure 1). We located sites within 1.5 km from the Lake Huron shoreline to monitor airspace above inland, shoreline and lake areas. The northern site, located in Presque Isle County, Michigan at 45.396318° N, -83.720929° W was approximately 1.5 km from the shoreline and 171 m above sea level. Here, the radar unit was placed in a hayfield in an area where wetlands and forest were the predominant land cover types within range of the radar unit according to our analysis using Esri ArcGIS software and the 2006 National Land Cover Database (Fry et al. 2011) (Table 1, Figure 2, Appendix 2). The southern site, located in Alcona County, Michigan at 44.67620° N, -83.29481° W was approximately 1.0 km from the shoreline and 285 m above sea level. This radar was also placed in a hayfield in an area where forest was the primary land cover type within range of the radar unit (Table 1, Figure 2, Appendix 2).

Selection of radar monitoring sites was achieved through a combination of geographic modeling and on-site assessment to locate areas near shorelines with unimpeded views. First, large sections of Great Lakes shorelines were identified as potential study areas for the migration season. Esri ArcGIS software was used to model the areas of interest to find locations that could be suitable for radar siting. This suitability modeling incorporated datasets describing elevation, land cover, and shorelines of the Great Lakes. Additional landscape characteristics were derived from these datasets (elevation below local maximum elevation, percent forested, distance to forest, distance from shoreline, etc.) and ranked to create a continuous raster surface within the area of interest with estimated suitability values. Contiguous areas with high suitability identified through the GIS modeling process were targeted for on-site assessment.

Biologists were dispatched to areas of interest to do a more thorough assessment of potential sites identified by the modeling effort. This assessment included evaluating the land use, line of sight to shorelines, and accessibility for placement of radar units. Additional locations not identified through the modeling were frequently discovered through this process and evaluated as well. When a location was determined by field biologists to be highly suitable relative to the other locations visited in the field, contact was initiated with property owners to obtain permission to set up the radar units.

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 marine radars that operated simultaneously, one that scanned the horizontal plane while the other scanned

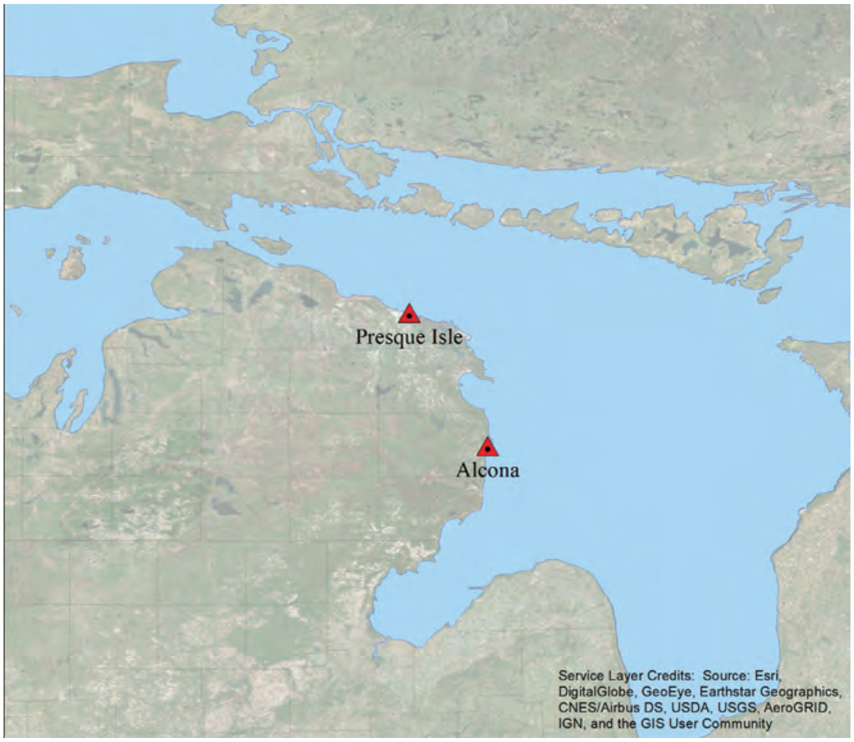


Figure 1. *Locations where MERLIN Avian Radar Systems were deployed during the fall 2015/spring 2016 migration seasons. Map image is the intellectual property of Esri and is used herein under license. Copyright© 2014 Esri and its licensors. All rights reserved.*

Table 1. Predominant land cover types found within a 3.7 km radius of the radar locations located in Presque Isle and Alcona Counties during the fall of 2015 and spring of 2016.

National Land Cover Class	*Presque Island County*	*Alcona County*
Open Water	35.42%	33.79%
Developed[1]	4.48%	7.76%
Barren Land	10.22%	1.60%
Forest[2]	19.81%	36.12%
Grassland/Shrubland	7.08%	4.33%
Planted/Cultivated[3]	0.12%	4.27%
Wetlands[4]	22.87%	12.12%

1 Includes low, medium, and high intensity developed land and developed open space
2 Includes deciduous, evergreen, and mixed forest
3 Includes pasture/hay and cultivated crops
4 Includes woody wetlands and emergent herbaceous wetlands

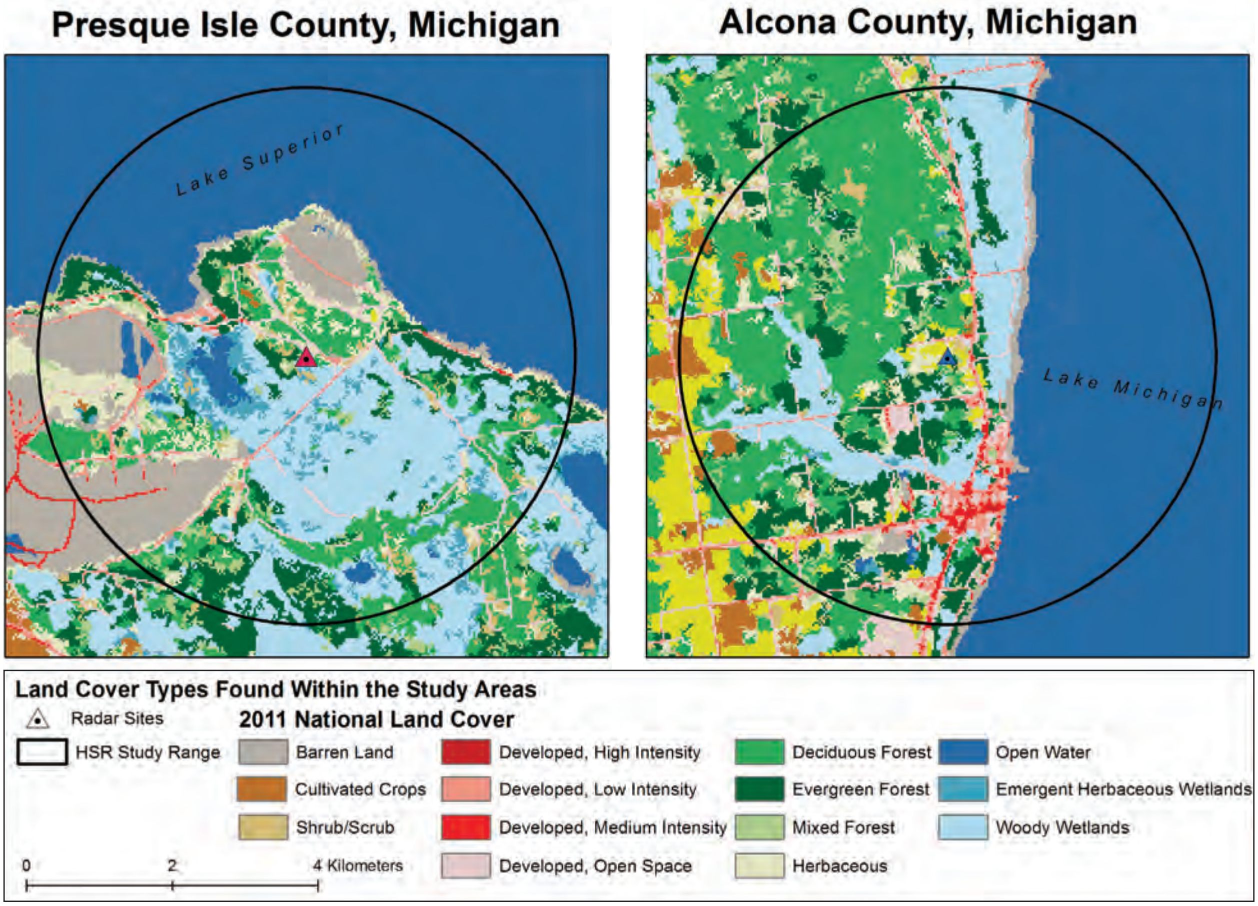


Figure 2. *Land cover types found within a 3.7 km radius of the radar units located in Presque Isle and Alcona Counties during fall of 2015 and spring of 2106. Map image is the intellectual property of Esri and is used herein under license. Copyright © 2014 Esri and its licensors. All rights reserved.*

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.

Description of radars—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, 2.92–3.08 GHz frequency range, and were configured to operate with both short and medium pulse (0.1 and 5 microseconds, respectively). The horizontal radar was also equipped with Doppler to help filter stationary targets. The radars emanated a fan-shaped beam, which had an approximate 1° horizontal and 25° vertical span when operated in the horizontal plane. The S-band radar was selected because the longer wavelength is less sensitive to insect and weather contamination than 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 spin 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 radar 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 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.

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. 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 about 6 m above ground level.

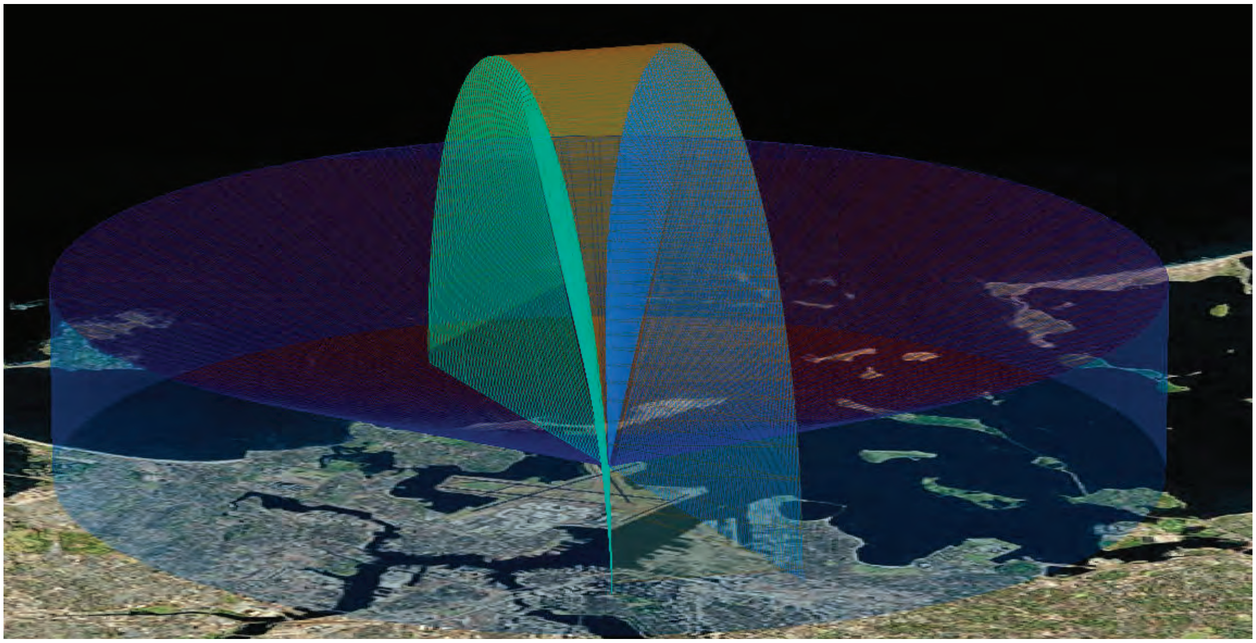


Figure 3. *Computer representation of the potential survey volume scanned by horizontal and vertical radars used by the U.S. Fish and Wildlife Service during the fall 2015 and spring 2016. Graphic provided by DeTect, Inc.*

Radar Set Up and Data Collection

Radar systems were deployed during the fall season from the first week of August to the last week of October of 2015. We continued our study for the spring season from the last week of March to the second week of June.

Establishing radar systems at a selected site involved several activities including orienting the VSR, micro-site selection, and adjusting to ensure adequate information was captured. We anticipated a primarily north-south axis of migration along the shoreline of Lake Huron during the fall and spring seasons, and oriented vertical scanning radars to an angle that was slightly off of perpendicular to anticipated direction of traffic. This orientation was 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 orientation was also influenced by micro-site selection. Micro-site selection is important in that positioning the radar can affect the amount of interference from ground clutter or other sources of radar interference. If large areas were obstructed from the radar view or if substantial amounts of clutter impeded data collection, systems were rotated incrementally to improve the radar's view and/or reduce interference.

Once a position was established, clear-air thresholds and the radar's built-in sensitivity time control (STC) filters were employed to reduce small non-target returns and improve tracking of distant targets. These settings are needed as an object reflects more energy at close range than it does when it is further from the radar. For example, an object at a 50-m range will return about 16 times more energy than when it is at 100-m range (Bruderer 1997, Schmaljohann et al. 2008). To further improve data collection, clutter maps were generated using 60-scan composite images (Figure 4) at time periods with low biological activity in order 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 the data and, as a result, also reduced our ability to detect targets in these areas.

Following this initial set up, MERLIN software was fitted to site conditions. The MERLIN software provides real-time processing of raw radar data to locate and track targets while excluding non-targets and rain events. However, parameters used by the tracking software require adjustments to account for site-specific conditions. DeTect personnel trained our biologists in establishing these settings with the goal of minimizing inclusion of non-targets while maximizing cohesive tracks of targets. Processed data were stored in an Access database and transferred daily to a SQL database where they were stored and later queried for data analysis.

Biologists returned to the site periodically during the data collection period to ensure continuous function, monitor raw (unprocessed analog radar returns) and processed radar outputs, provide routine maintenance (such as re-fueling and oil changes), and manage data storage. In addition to processed data, we maintained all raw radar data for potential reprocessing until the end of the season.

Radar System Outputs

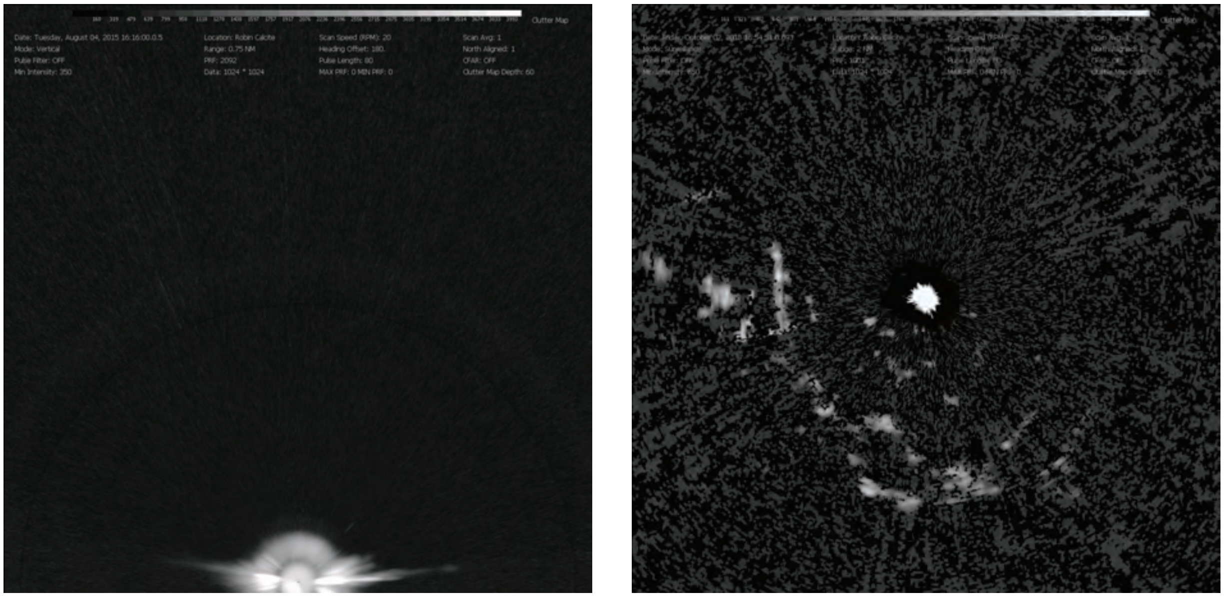
The MERLIN software generates more than 30 measurements to describe target size, shape, location, speed, and direction of movement. These data are of the same type used by biologists when identifying biological targets on a radar screen (DeTect Inc., unpublished data, 2009) and this information was stored to the database for later analysis. To reduce potential false tracking, the MERLIN tracking algorithm removed tracks with less than five observations. As well, an automated filter was used to remove sectors of the sample volume that were dominated by rain.

In addition to storing target attribute data, 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. During each site check, we viewed the real-time digital display to ensure it agreed with the raw radar display. We later viewed 15-minute and 1-hour Trackplots to assess target direction and height both on site and remotely on a regular basis during the season.

Data Processing and Quality Control

Prior to data analysis, data processed by MERLIN software were further evaluated for potential contamination by non-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 time increments and removed time periods that were dominated by rain; data were also reviewed for time periods dominated by insects or other forms of transient clutter; however, there were no time periods where these types of non-desirable targets needed to be removed from the dataset. We relied on visual inspection of track patterns to discern contamination events. Rain and insect events form diagnostic patterns (Detect Inc., personal communication, 2011) and time periods with these types of track patterns can be removed when present. Unknown contamination that mimicked patterns of desired targets was not removed from the database and, to the extent that this occurred, contributed to error associated with indices. In addition, we evaluated initial counts by generating a time series to show the variation in the number of targets per hour across the season for both HSR and VSR radars. In general, the HSR and VSR hourly counts are positively correlated, with the HSR having higher counts due to a larger sampled area. In situations where the VSR

Presque Isle County, MI Fall 2015 Cluster Maps



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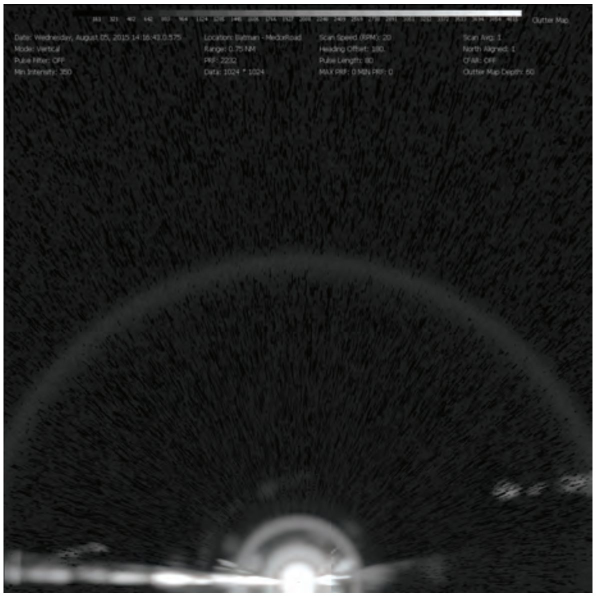
Alcona County, MI Fall 2015 Cluster Maps



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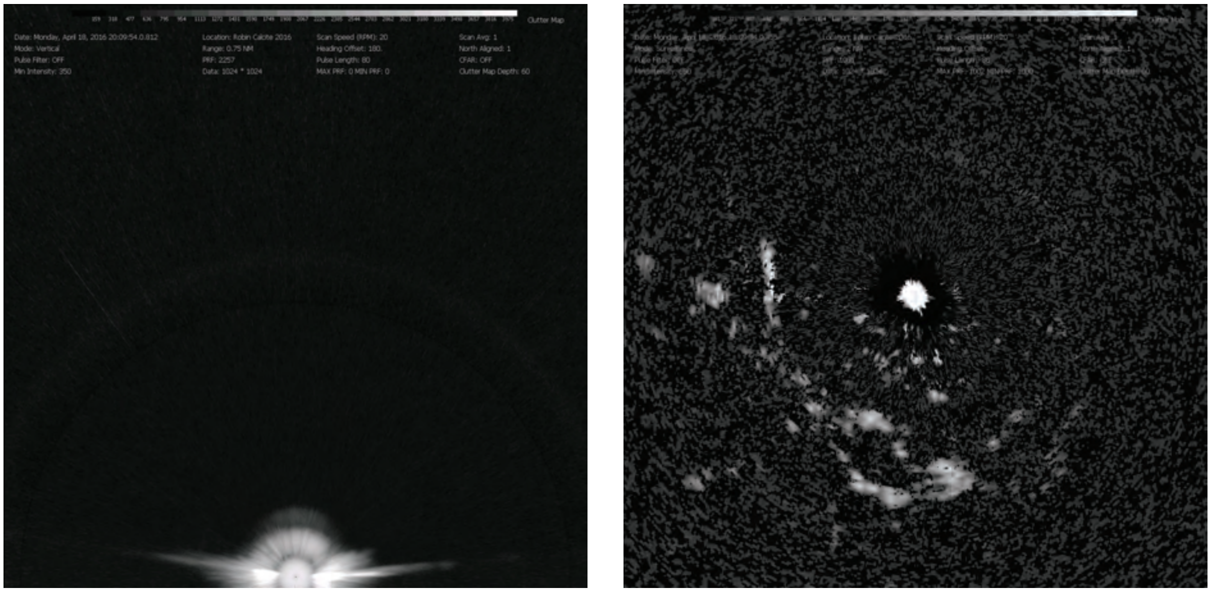
MAX PRF: 0 MIN PRF: 0
Scan Avg: 1
North Aligned: 1
CFAR: OFF
Clutter Map Depth: 60

Figure 4a. *Clutter maps from vertical (left) and horizontal (right) scanning radars at study sites in Presque Isle and Alcona Counties during the fall of 2015 migration season. Due to loss of motor and gearbox, the horizontal radar was not present at the Alcona County site. Brighter areas represent static returns from stationary objects such as tree lines and fencerows. Detection of targets may be lost in these areas due to obstruction from these objects.*

Presque Isle County, MI Spring 2016 Cluster Maps



Alcona County, MI Spring 2016 Cluster Maps

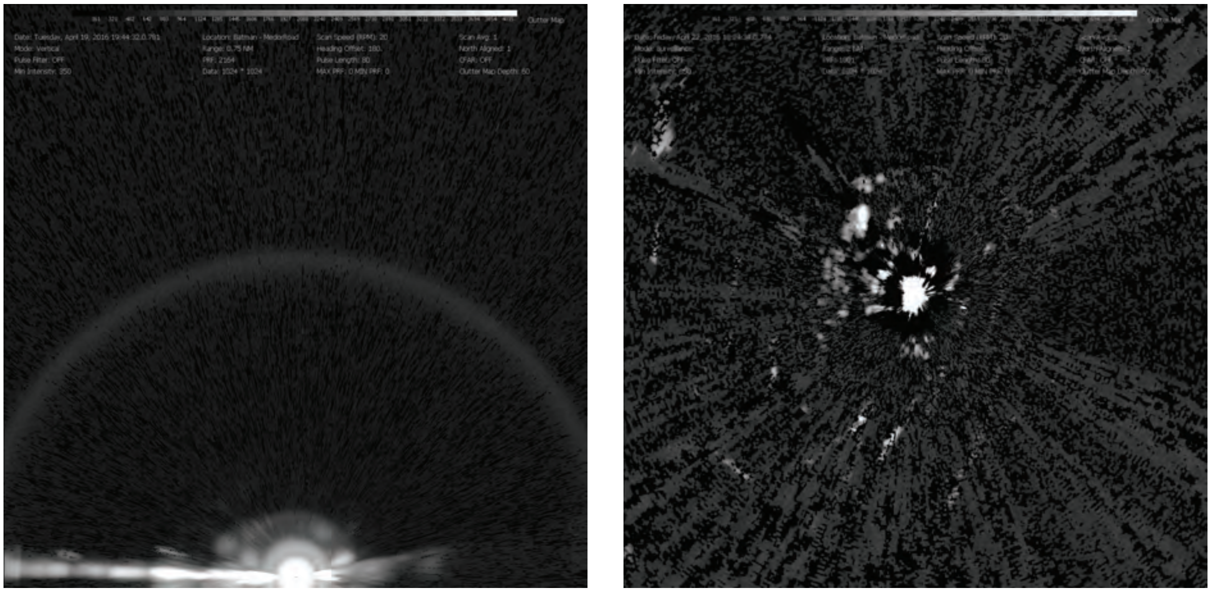


Figure 4b. *Clutter maps from vertical (left) and horizontal (right) scanning radars at study sites in Presque Isle and Alcona Counties during the spring of 2016 migration season.*

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, insects or data processing errors) they were removed from further analysis.

Once contaminated time periods were removed, we summarized data using SQL queries provided with the MERLIN radar system. Data from the HSR were used to calculate hourly counts and target 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". We adopted this sampling technique as it is the method used by the manufacturer of the MERLIN units and this metric is also reported by other researchers (Lowery 1951, Liechti et al. 1995, Kunz et al. 2007b). The standard front was defined by a volume of space that extended 500 m to either side of the radar and continued up to the maximum height of data collection (2800 m) (Figure 5).

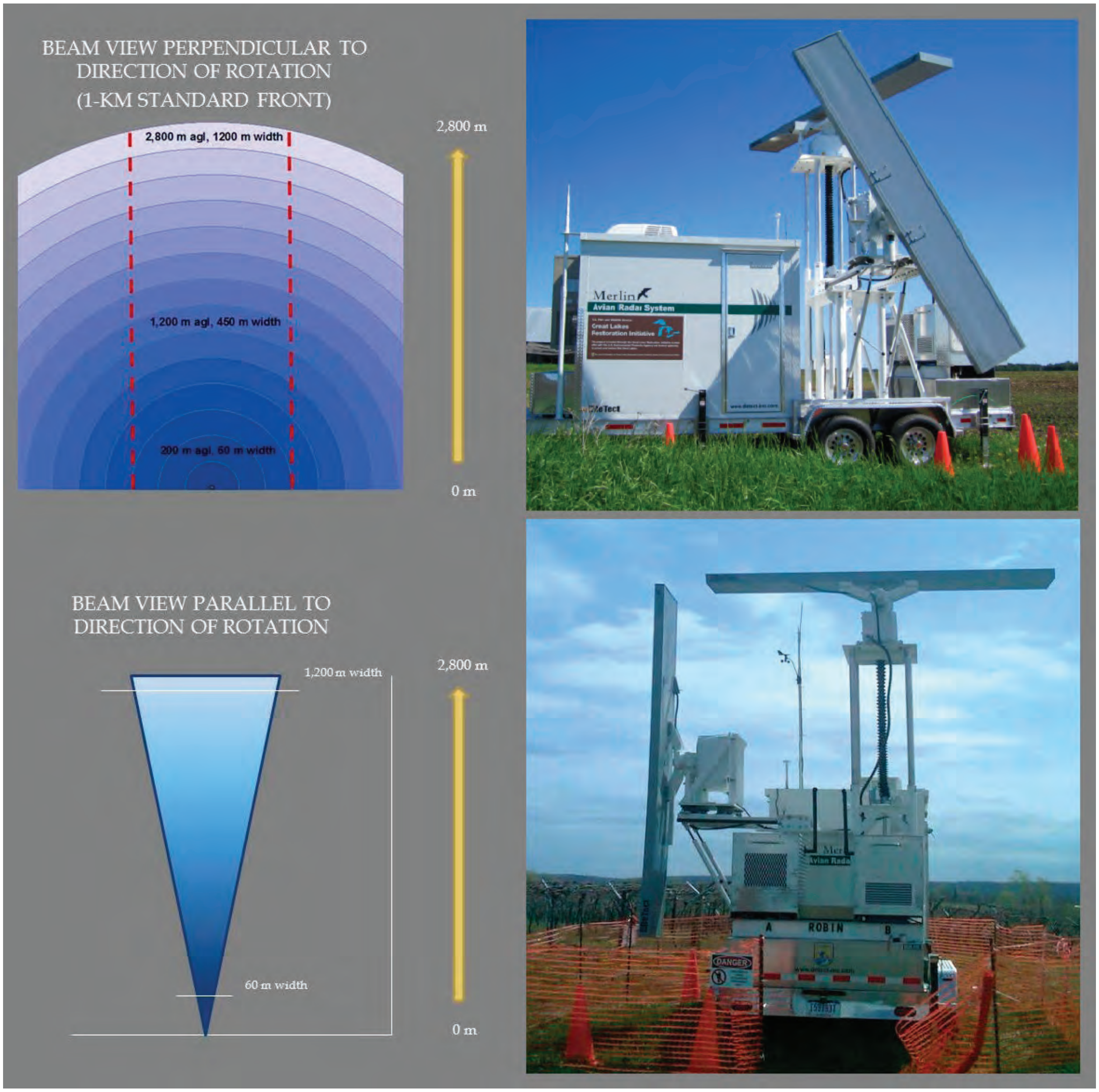


Figure 5. *This schematic depicts the vertical scanning radar beam from two different views and pictures of the radar unit from those views. The top left graphic identifies the standard front used for data analysis. The standard front extends to 500 m on either side of the radar and up to a height of 2800 m. 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).*

Biological Time Periods

For each site location, sunrise and sunset times were calculated and target counts were further segregated into four biological time periods: dawn, day, dusk, and night; with dawn representing 30 minutes before sunrise to 30 minutes after sunrise, day representing 30 minutes after sunrise to 30 minutes before sunset, dusk representing 30 minutes before to sunset to 30 minutes after sunset, and night representing 30 minutes after sunset to 30 minutes before sunrise.

Data Summary and Trends Analysis

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

Directional Trends—Mean angle and concentration (r) of target directions were analyzed following 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., if 50% of the vectors are 180° and 50% are 360°, then there is not a predominate direction because there were as many targets heading south as there were heading north and thus the angular concentration is 0), indicating that there is no predominant direction of travel. We anticipated a generally southwards direction of movement from nocturnal targets during the fall migration season, and northwards direction in spring. We report the mean direction of nocturnal targets and the percent of nights targets traveled in a direction between northwest or southwest and northeast or southeast for spring (315°—45°) and fall (135°—225°), respectively. 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 counts of targets per hour processed by MERLIN software for both HSR and VSR antennas as a time series to identify pulses of nocturnal activity, season duration, and changes in patterns of activity over time. The HSR and VSR radars have different strengths that complement one another; these indices were plotted together. The HSR index tracks low-flying targets in a 360˚ span around the radar unit and detection is not affected 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 lead to both under- and over-counting; targets blocked by ground clutter may not get counted, and targets that fly in and out of areas with ground clutter may get counted multiple times. This leads to HSR counts that are more influenced by site conditions than VSR counts. However, the HSR index better captures targets under certain conditions, such as when targets are primarily at low elevation and/or traveling parallel to the VSR. The HSR is also much more susceptible than the VSR to beam bending from dynamic atmospheric conditions; beam refraction in the VSR is minimal primarily due to its orientation. The VSR index was used to track targets captured within the standard front and has more consistent detection than HSR as it mostly tracks against clear air, except in the lowest altitude bands. Its detection is affected by target direction and distance from the radar (Bruderer 1997, Schmaljohann et al. 2008). The VSR is also impacted by ground clutter. Plotting these indices together provided a more comprehensive understanding of changes in target activity over time.

We used the VSR index to calculate target passage rate (TPR). We calculated TPR as the number of targets per standard 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, 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 mean TPR for biological time periods and hours of the season. Mean nocturnal TPR for the season is the sum of night TPRs divided by the number of nights sampled. Similarly, 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 mean nocturnal (night biological period) and diurnal (day biological period) TPR for weeks 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 plotted 7-day moving means of TPR as line graphs.

Altitudinal Trends—DeTect SQL queries 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 location with the largest radar echo and reported as the height above ground level as measured at the radar unit; this measurement does not take into account changes in topography as you move across the landscape. Both sites were in areas with generally flat topography, and little distortion due to topography was expected. We used these estimates to calculate mean altitude of targets above ground level by biological time period and hour and report mean and median altitudes for the season.

Density per Altitude Band—In order 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 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 origin. 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 radar beam and report density of targets (targets per 1,000,000 m^3) per 50-m altitude band per hour for each biological 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). 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. In Monte Carlo integration, as the number of random points approaches infinity, the estimation approaches truth (an exact calculation).

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 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 6) was less than 12.5° (i.e., half the angle of beam width). The volume of a full sweep of the radar beam as estimated via Monte Carlo integration was within 0.5% of the analytical solution using spherical coordinates; thus, the number of random points that 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 6) and within altitude bands (Figure 7).

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 on 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).

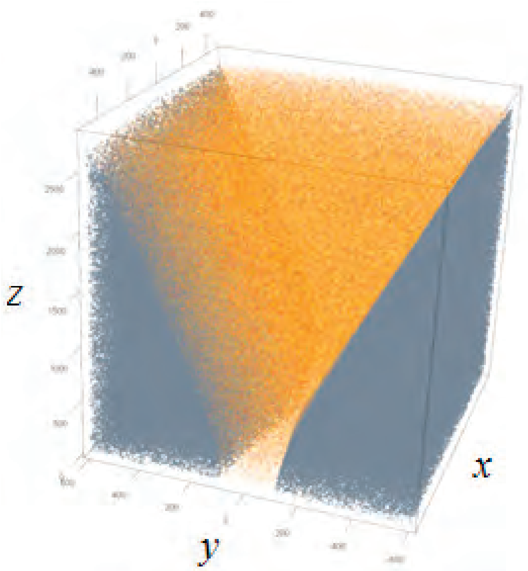


Figure 6. *A graphical representation of the structural volume of the vertical scanning radar within the standard front. In this graphic the radar unit is located at the origin and the radar beam extends to 500 m on either side of the radar unit (x-axis) and up to a maximum height of 2800 m (z-axis). 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.*

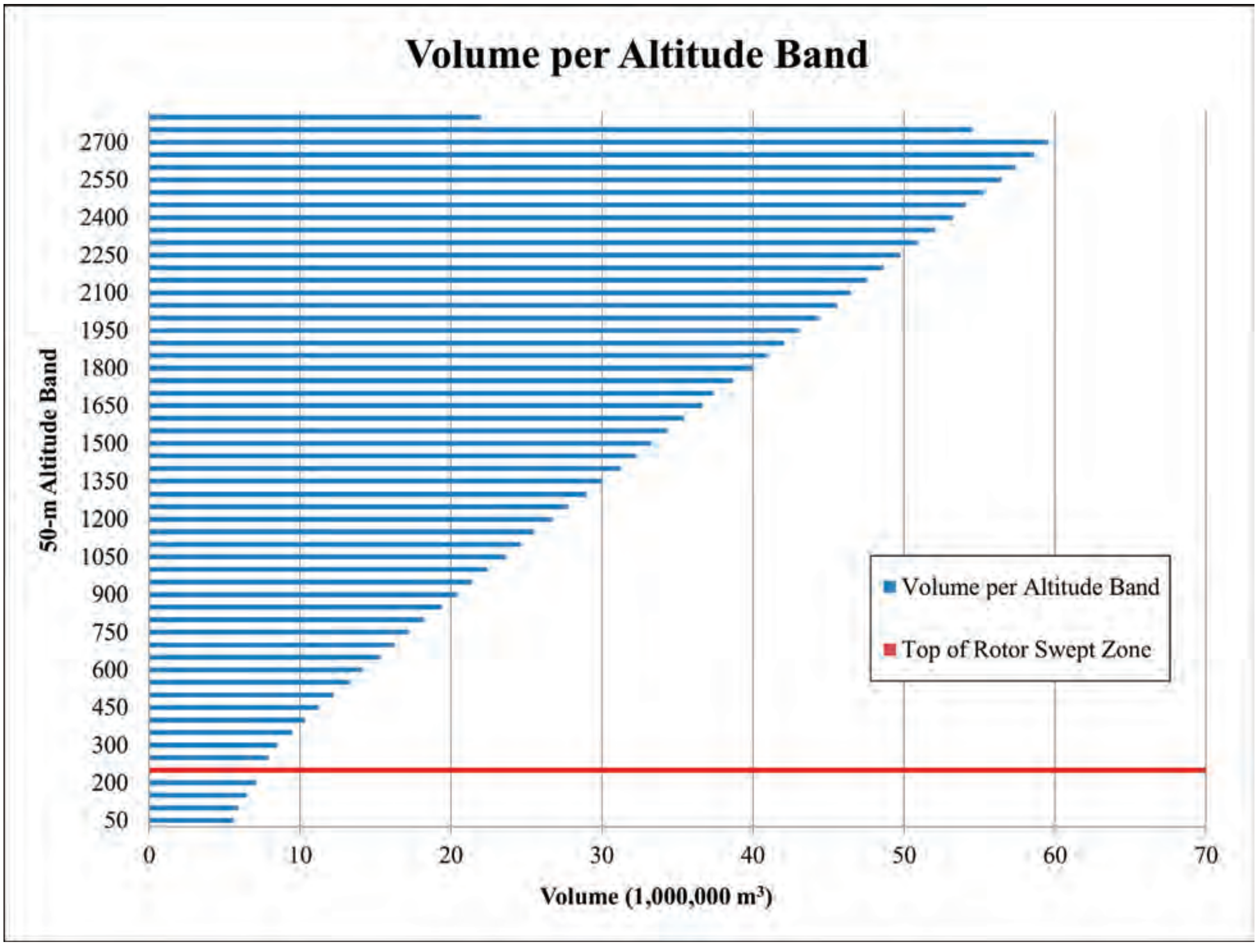


Figure 7. *Volume of 50-m altitude bands within the standard front as estimated with Monte Carlo integration. Altitude band intervals represent the upper band limit. Target counts provided by the vertical scanning radar are limited to the structure of the standard front. The red line represents the top of the rotor swept zone at 200 m.*

Results-Fall 2015

During the fall 2015 season, we began data collection August 3 and 4 at the Presque Isle and Alcona County sites, respectively. Data collection ended on October 27, 2015 at both sites, resulting in a survey period of 2042 hours at Presque Isle County and Alcona County sites (Table 2). Data were recorded continuously while the radar units were operational. Gaps in analyzed data occurred during rain events and when the radar units were not operational due to maintenance or malfunction (radar downtime). The motor and gearbox for the HSR were lost at the beginning of the season for the Alcona County site, and due to lack of available parts, could not be fixed during the fall 2015 season; subsequently, no HSR data was collected at this site. When correcting for radar downtime and removal of periods with rain, the radars collected useable data 85.5% and 70.3% of the season in Presque Isle County for vertical and horizontal radars, respectively, and 88.6% of the fall season for vertical radars in Alcona County. As mentioned above, no data were collected for the Alcona County HSR. There we no usable data from horizontal radar in Alcona County, MI.

Qualitative Assessments

Plots of tracked targets showed images of nocturnal migration events at both locations (Figure 8 and 9). For example, on October 9 at the Presque Isle County site (Figure 8), the horizontal radar recorded scattered activity and low numbers from 12:00-18:00. During the 18:00 hour, there was an increase in southward movement recorded on the horizontal radar, but still relatively few targets are recorded on the vertical radar at a relatively low altitude. During the 20:00 hour, most targets were oriented in a southern direction, and vertical radar recorded significantly more targets with a greater range of altitudes being used. Targets continued south during the 23:00 hour, with some shifts to the southeast and southwest. Vertical radar continued to record large numbers of targets and a wide range of heights at this time. By 04:00 on October 10, target directions began to scatter in multiple directions and continued to 05:00, possibly as migrants began to search for suitable stopover habitat near dawn. Vertical radar recorded a decline in activity in the 04:00 and 05:00 hours compared with the peak of the last several hours. By 12:00, the activity had returned to the low activity levels seen the previous day from 12:00-18:00. The patterns here (directionality changes, changes in height and density of targets) are indicative of a pulse of migration activity.

While the Alcona County site did not record horizontal data, the vertical radar also showed a pattern of migratory activity. From 12:00-18:00 on October 13, there were few targets moving, and they were generally low in altitude. During the 18:00 hour, the number of targets rose, and increased in height. Further increases in number and altitude use continued at 20:00, with airspace below 750 m saturated with targets and with considerable numbers up to 2000 m. Migratory activity peaked between 23:00 and 01:00 on October 14, with heavy use of airspace up to 1500 m and continued common use up to 2000 m. Numbers of targets declined during the pre-dawn and dawn hours of 04:00-0:600, but continued to use wide altitude bands. By 12:00, the densities returned to the same levels as the previous daytime, generally following the pattern of the Presque Isle County site and indicative of a migratory pulse.

Table 2. Survey effort (hours) by vertical and horizontal scanning radars during fall 2015 at our radar sites in Presque Isle and Alcona Counties.

Site	*Radar*	*Survey Period*	*Radar Downtime*[1]	*Time Radar Collected Data*	*Radar Data w/Rain*	*Usable Radar Data*	*% Usable Data*
Presque Isle	VSR	2042	160	1882	135	1747	86%
Presque Isle	HSR	2042	199	1843	407	1435	70%
Alcona	VSR	2042	87	1955	147	1808	89%
Alcona	HSR2	2042	2042	0	0	0	0%

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

2 The Horizontal radar malfunctioned and did not collect data for the survey period.

Also apparent on the Trackplots from both sites are areas not well recorded by the radar due to beam blockage from ground clutter (due to topography, vegetation, buildings, etc.; Figure 4), resulting in reduced detection in the air space that was within the range of data collection (e.g., ~500 m altitude on the right side of the Alcona County VSR (Figure 9). Rings of decreased detection near the radar unit and where the radar switched from short to medium pulse are also evident in both the horizontal (October 9, 23:00) and vertical (October 9, 23:00) Trackplots (seen at a range of about 1,400—2,000 m).

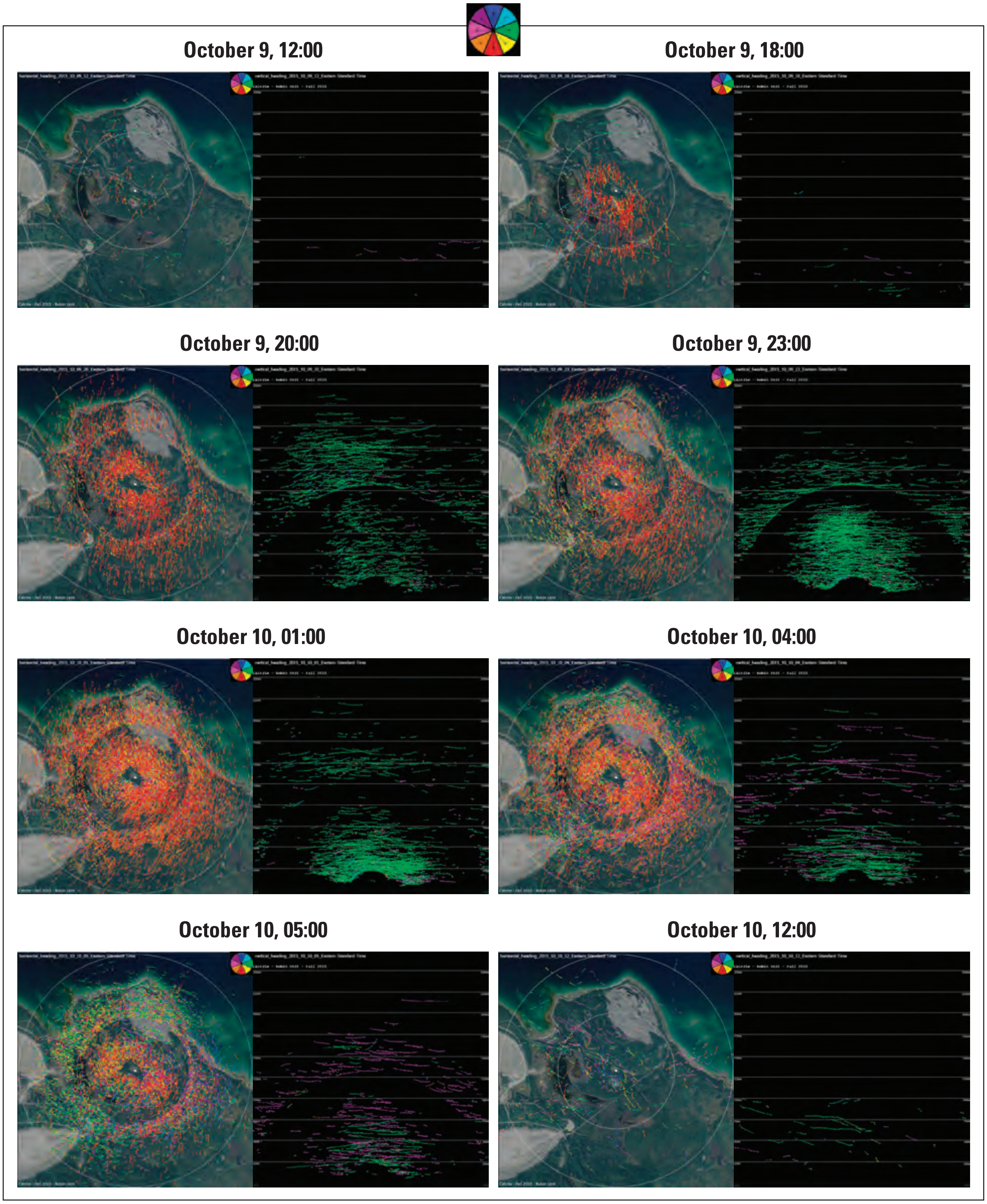


Figure 8. *Images of tracks during 1-hour increments recorded by horizontal and vertical scanning radars during a migration event at our radar site in Presque Isle County. Horizontal radar images (columns 1 and 3) show direction of targets as indicated by the color wheel (dark blue indicates a direction of travel to the north and red travel to the south). Vertical radar images (columns 2 and 4) show target heights.*

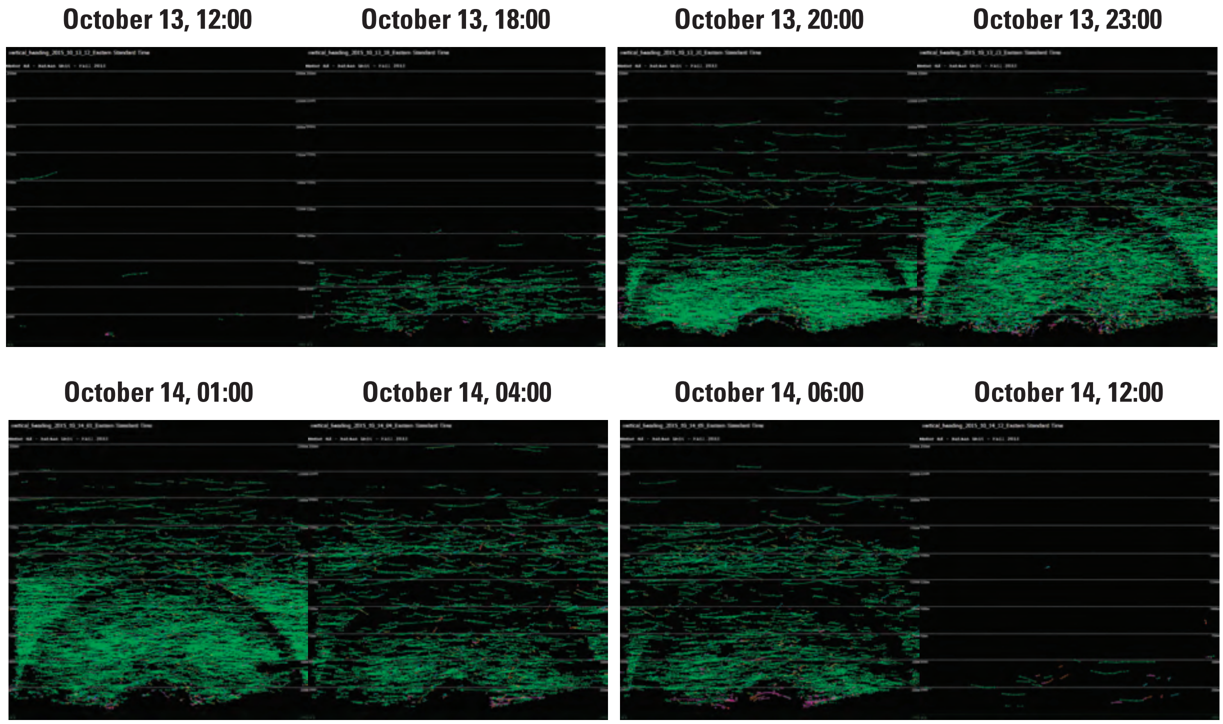


Figure 9. *Images of tracks during 1-hour increments recorded by vertical scanning radar during a migration event at our radar site in Alcona County, MI. Vertical radar images show target heights. Due to malfunction of the radar motor, horizontal radar was not functional.*

Directional Trends

During the fall 2015 season, nocturnal target direction was generally south at the Presque Isle County site (Figure 10). At the Presque Isle County site, mean nocturnal direction was 174° with an angular concentration (r) of 0.60 (n = 2,344,277 targets), and during 65% of nights, mean target direction was between southwest and southeast (112.5°—247.5°). Onshore movement to the west at dawn was visible (Figure 10). Mean nightly direction at Presque Isle County came from all directions, but included vectors over substantial stretches of open water (Figure 28).

Temporal Trends

Time Series Plots—Hourly target counts provided by horizontal and vertical radars showed pulses of elevated nocturnal activity with peaks occurring a few hours before midnight at our study sites. Across our sampling period, these events were often clustered into groups of several nights and were first observed on September 1 and September 19 at the Presque Isle County and Alcona County sites, respectively (Figures 11 and 12). At both sites, the occurrence and magnitude of nocturnal pulses continued through the season's end.

Presque Isle County, Mi Target Direction per Hour During Four Biological Time Periods Fall 2015

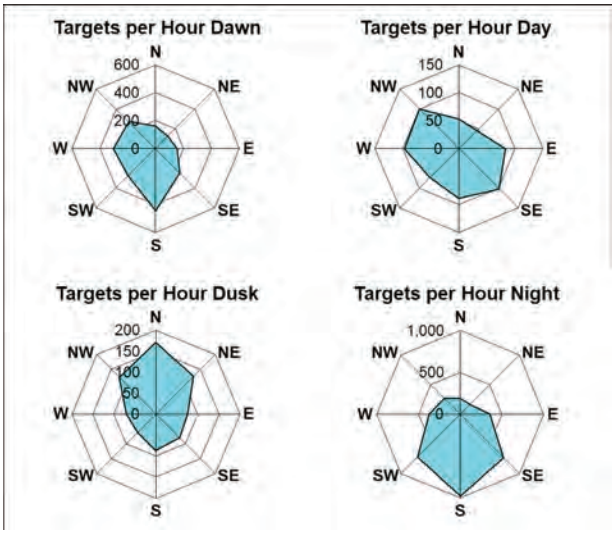


Figure 10. *Target direction per hour during four biological periods during fall 2015 at our sites in Presque Isle County, MI. Due to the malfunction of the horizontal radar, we could not present data from our Alcona County, MI site.*

Table 3. Mean direction, angular concentration (r), and percent of biological time periods with strong directionality (r ≥ 0.5) of targets during biological time periods at our sites in Presque Isle County during the fall 2015 season.

	Presque Isle			
Biological Period	*Mean Direction (degrees)*	*r*	*% time r ≥ 0.5*	*n*
Dawn	217	0.24	56.9%	118975
Day	208	0.10	23.1%	449342
Dusk	8	0.21	38.5%	47509
Night	184	0.41	78.8%	2344277

The HSR of Alcona County was nonfunctional during the fall 2015 season.

Different patterns of activity are apparent as the season progresses at our study sites. For example, beginning in early September activity patterns become dominated by nocturnal pulses that are seen on both horizontal and vertical radars in Presque Isle County; this pattern is apparent on the vertical radar for Alcona County as well (the horizontal radar malfunctioned during this season at our unit in Alcona County; Figures 11, 12). This pattern continues until the end of the recorded season in late October, indicating a continued migration through the end of the month and potentially beyond. Also apparent are differences in detection capability of the vertical and horizontal scanning radars. For instance, the shift to south-oriented targets at 18:00 on October 9 is not detected by the vertical radar (Figure 8).

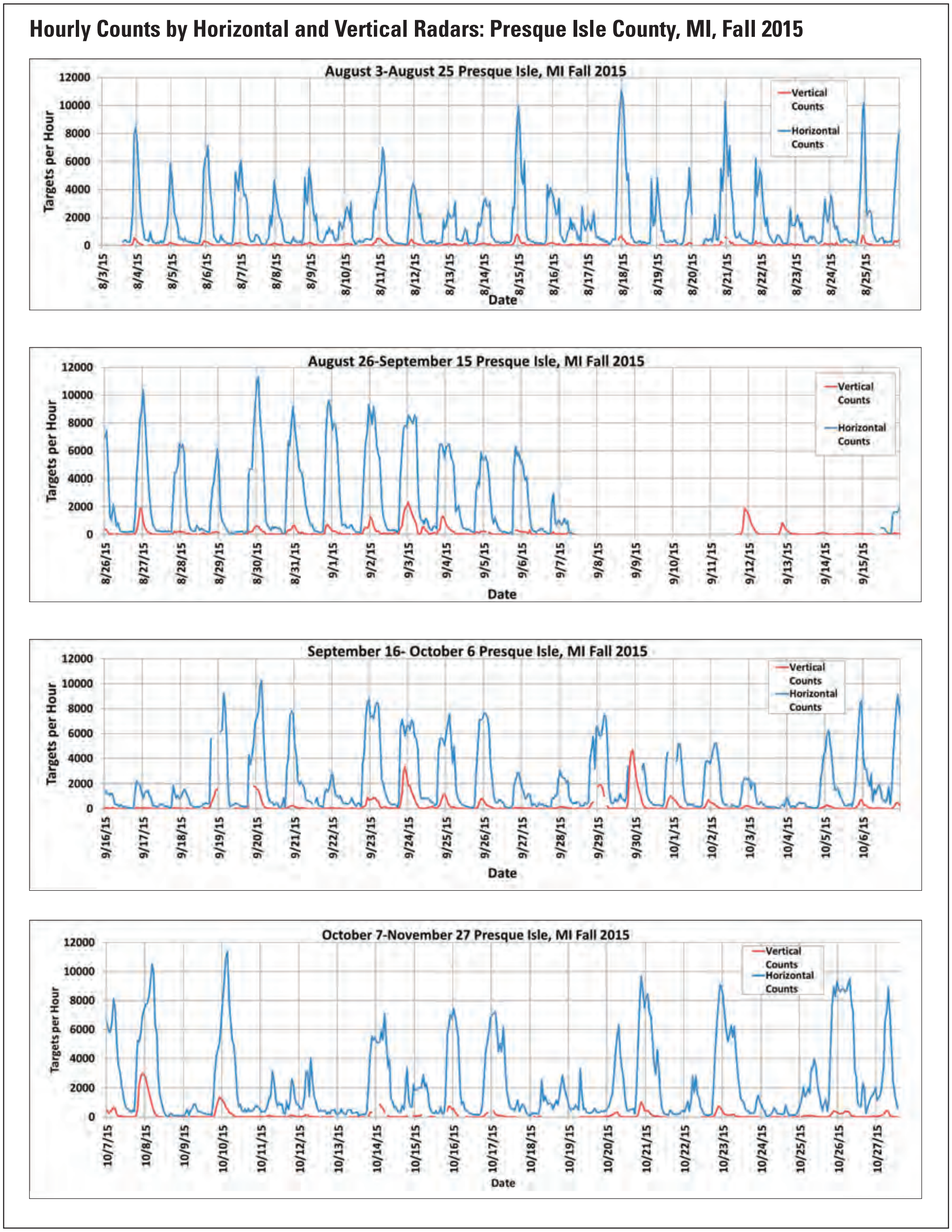
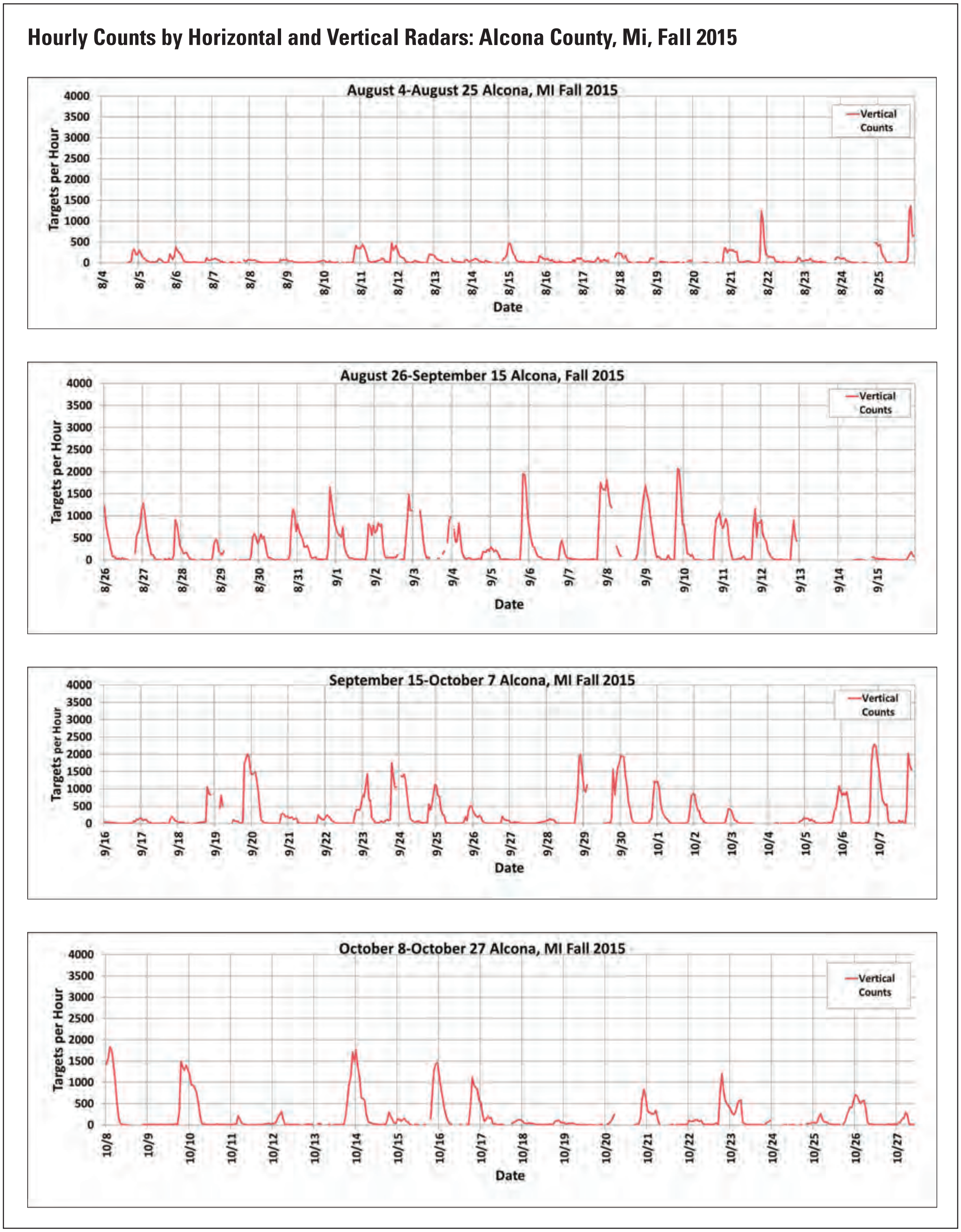


Figure 11. *Hourly counts by horizontal and vertical radars from August 3–October 27, 2015 at the Presque Isle County site, MI. Light gray vertical lines represent midnight.*



Hourly Counts by Horizontal and Vertical Radars: Alcona County, Mi, Fall 2015

August 4-August 25 Alcona, MI Fall 2015

August 26-September 15 Alcona, Fall 2015

September 15-October 7 Alcona, MI Fall 2015

October 8-October 27 Alcona, MI Fall 2015

Figure 12. *Hourly counts by vertical radar from Alcona County, MI in fall 2015. Light gray vertical lines represent midnight. Note differing scale from Figure 11.*

Target Passage Rate—The pattern of mean TPR among the four biological time periods was similar between the two study sites (Figure 13) with mean TPR at night being greater than the combined means of the other three biological time periods (Table 4). Mean nocturnal TPR was 343± 428 SD (n = 84 nights) and 434 ± 430 SD (n=85 nights) at the Presque Isle County and Alcona County sites, respectively. Mean TPR varied by hour with peak numbers reached during the 20:00 and 23:00 hours (approximately dusk through an hour after sunset). Peak timing differed by site, with the more northern Presque Isle County site having a peak near 22:00-23:00, and the Southern Alcona County site at 21:00-22:00. This difference is likely due to migrants needing to cross open water to reach the northern site, as discussed below. At both locations, mean TPR gradually decreased as the night progressed, with the most drastic decline occurring around 06:00 and 07:00, which roughly corresponds with dawn (Figure 14).

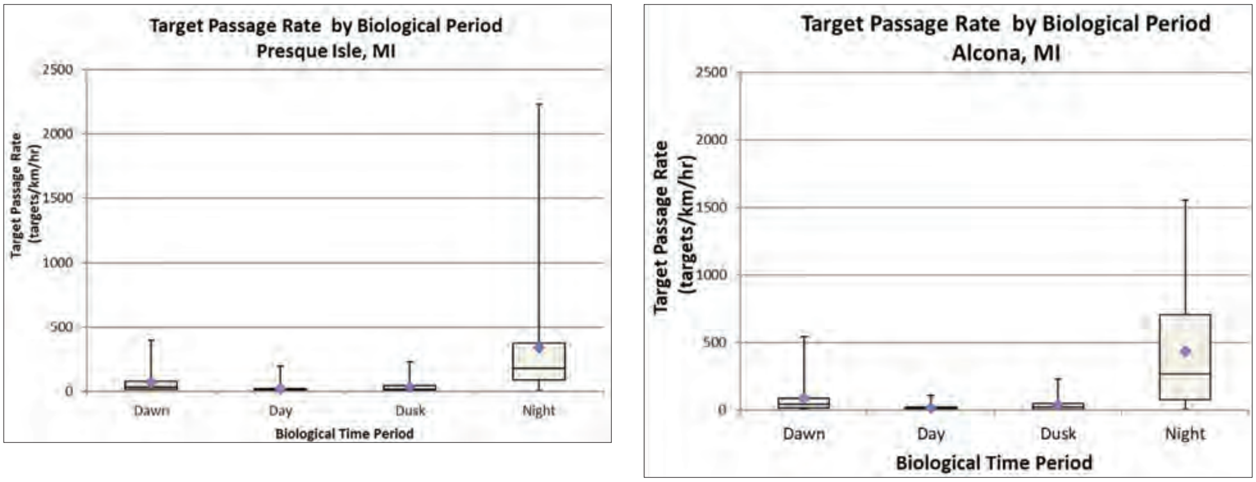


Figure 13. *Box plots showing variability in target passage rate (targets/km/hr) during four biological periods for fall 2015 in Presque Isle County and Alcona County. Whiskers represent the 1st and 4th quartiles, boxes represent the 2nd and 3rd quartiles (with the line between indicating the median), and blue diamonds represent seasonal mean for the time.*

Table 4. Mean target passage rate (TPR) with standard deviations during four biological periods in Presque Isle County and Alcona County during fall 2015.

Biological Period	*Calcite Mean TPR*	*Medor Rd. Mean TPR*
Dawn	64 ± 82	86 ± 114
Day	18 ± 25	18 ± 20
Dusk	32 ± 41	37 ± 44
Night	343 ± 428	434 ± 430

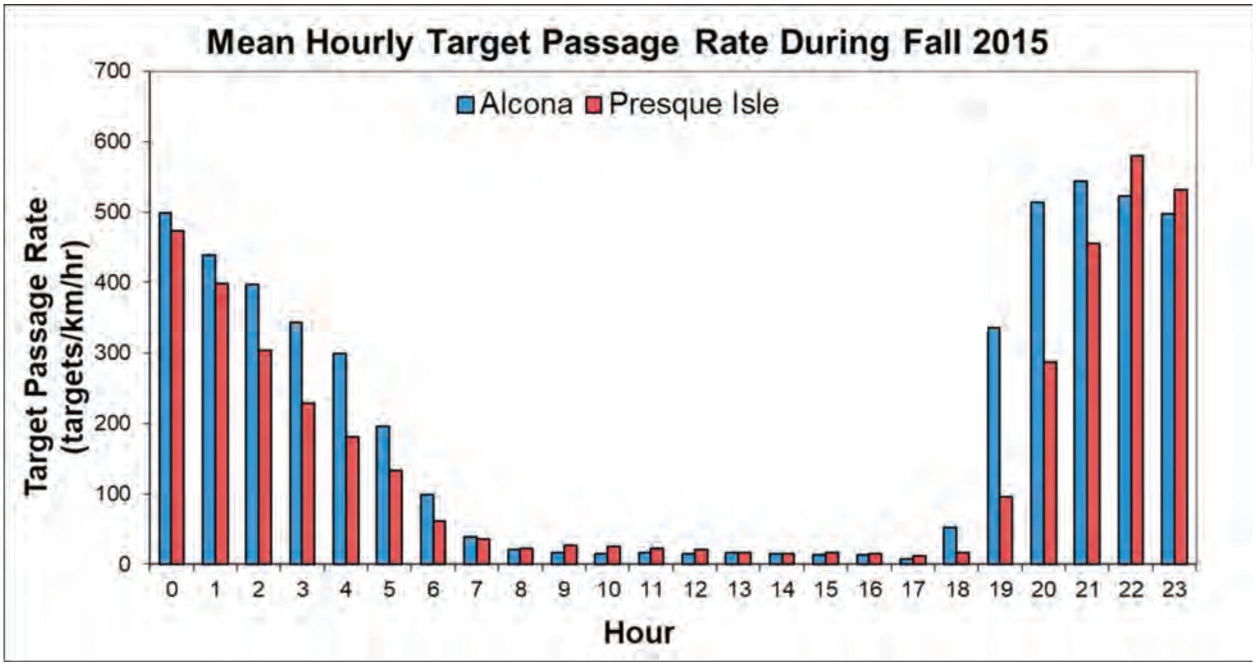


Figure 14. *Mean hourly target passage rate (targets/km/hr) during fall, 2015 at sites in Presque Isle and Alcona Counties, MI.*

Weekly Mean of Target Passage Rates—At both sites, weekly means of nocturnal target passage rates were relatively high compared to diurnal target passage rates and both sites showed a generally increasing mean through mid-October. After mid-October, nocturnal migration rates declined. Weekly means of nocturnal TPR were consistently higher than weekly means of diurnal TPR (Figures 15). As the recorded migration season began, there was less difference between the nocturnal and diurnal target passage rates (Figures 15 and 16), but the difference at the end of the recorded migration season was still substantial. Trends in both nocturnal and diurnal TPRs (7-day moving means) were similar at both sites (Figure 17).

Altitudinal Trends

Our density estimate that accounted for the geometric shape of the sampled space resulted in a substantially different density estimate than assuming an equal amount of sample volume per altitude band. Altitude profiles for dawn and night differed between our two locations, with density at low elevation being greater at our Presque Isle County site (Figures 18 and 19). Hourly altitude profiles at night revealed considerable variation in use of altitude bands (Figures 20 and 21); however, over the course of the season, the 100—150 m altitude band was observed to be the most densely used at both sites (Figure 22), with a total of 4.60 targets per 1,000,000 m^3 per night-hour and 3.45 targets per 1,000,000 m^3 per night-hour, at Presque Isle County and Alcona County, respectively. The maximum density of targets was below 150 m during 79.7% and 65.1% of the nights at the Presque Isle County and Alcona County, respectively (Figure 23). A similar pattern, although with more variation, occurred if the hours from 20:00—04:00, with the maximum density of targets occurring at less than 150 m during 51.1% and 49.6% of these night hours at the Presque Isle County and Alcona County, respectively (Figure 24).

At both sites, targets were observed within the entire range of altitude bands sampled. Mean altitude of nocturnal targets was 528 m ± 435 m SD and 681 m ± 502 m SD above ground level at our Presque Isle County and Alcona County sites, respectively. Median altitude at night was 377 m and 533 m above ground level at the Presque Isle County and Alcona County sites, respectively. Median altitude was greatest during the night and dawn biological time periods. While many radar reports include estimates of mean and median altitude of targets, we found that these estimates were poor indicators of maximum density (Table 5) due to the difference in volume of sampled air space at various altitude bands.

Mean altitude per hour during the season showed a similar pattern at the two locations (Figure 25). Mean altitude increased following dusk, tapered around the 20:00 and 22:00 hours, and decreased following midnight. A spike in mean altitude occurred during the 06:00 hour, which corresponds to the dawn or near dawn during at least a portion of the survey period. Density of targets was highest during the nighttime hours. However, the highest density of targets was below 500 m for the Presque Isle County site (Figure 26), and below 800 m for the Alcona County site (Figure 27). These density findings show the distribution of migrants is most dense at lower altitudes. Importantly, density distributions are skewed and mean altitude measures do not accurately reflect the underlying distribution of migrants at these sites.

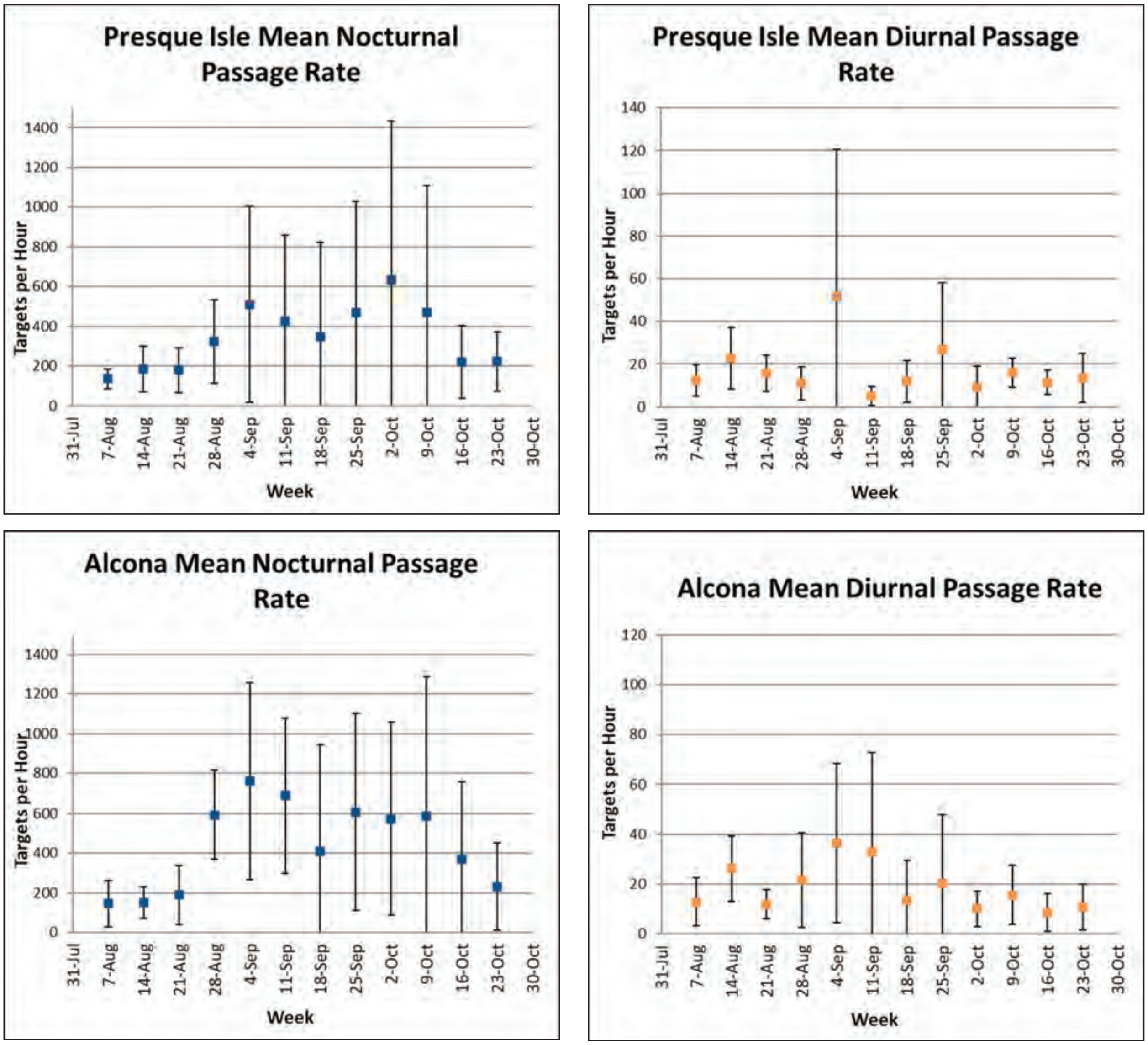
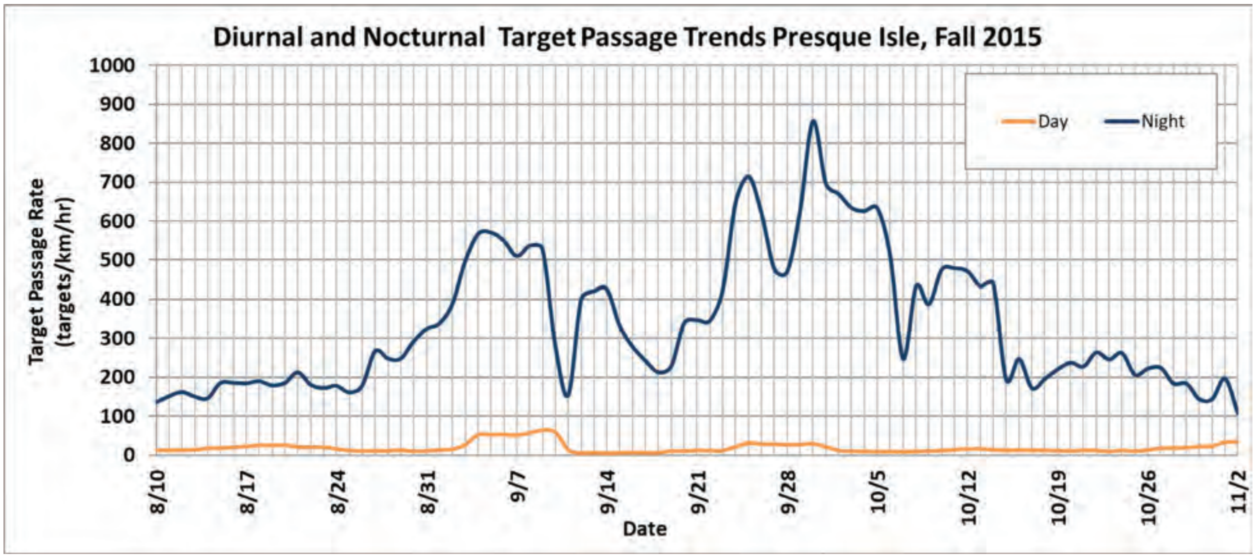


Figure 15. *Weekly mean of nocturnal and diurnal target passage rates (targets/km/hr) in Presque Isle County (top row) and Alcona County (bottom row) from August 7-October 23, 2015. Error bars represent one standard deviation. Note different scales on nocturnal and diurnal plots.*



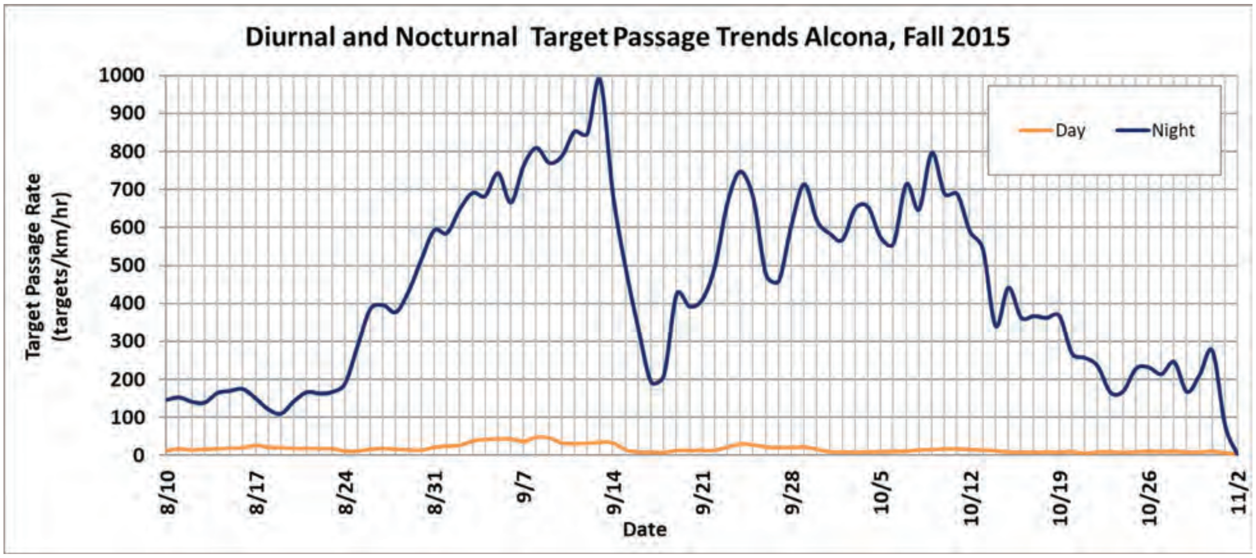


Figure 16. *Comparison of nocturnal and diurnal target passage trends (based on a moving 7-day mean) during fall 2015 in Presque Isle County (top row) and Alcona County (bottom row).*

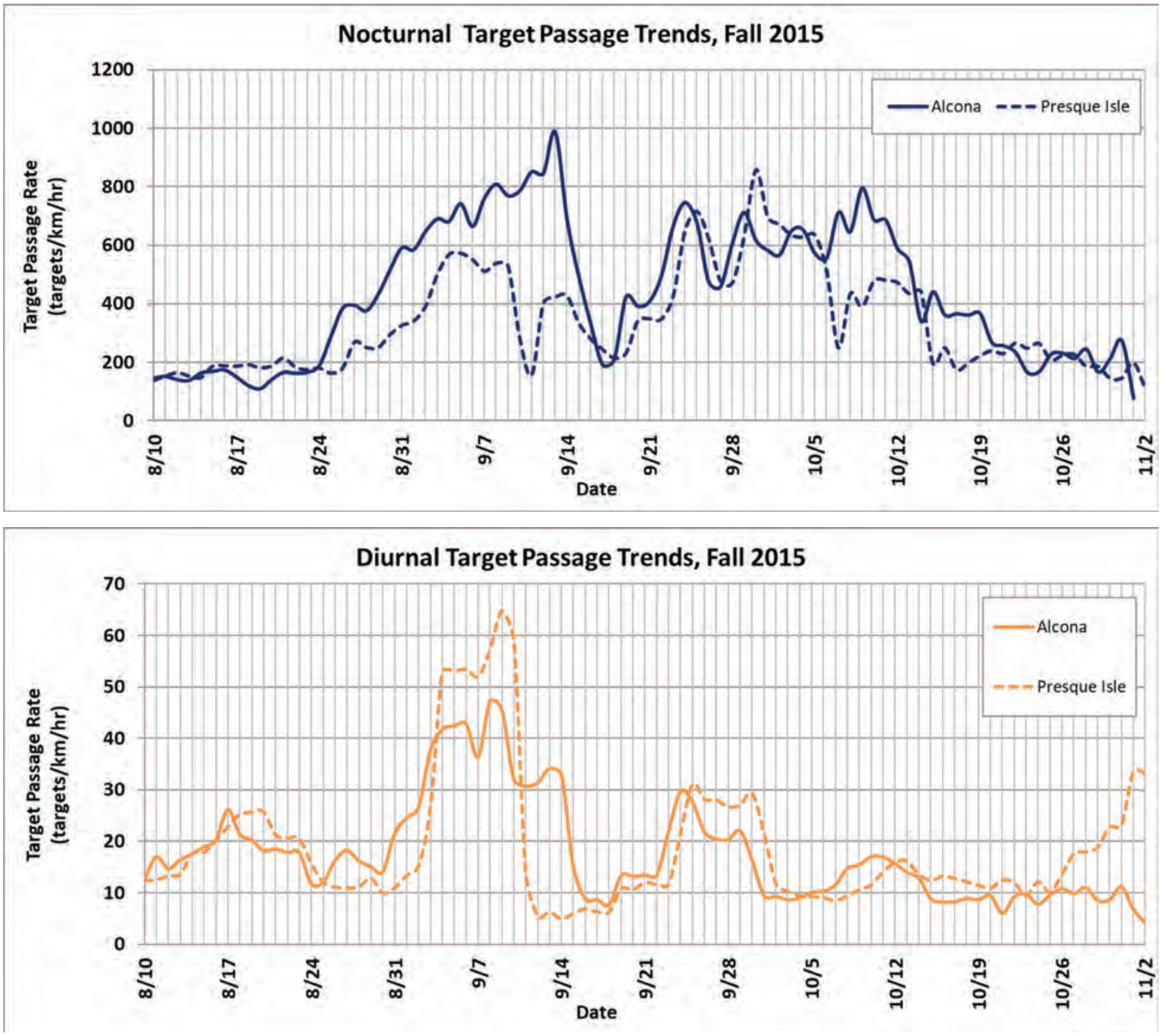


Figure 17. *Comparison of nocturnal (top row) and diurnal (bottom row) target passage trends (based on a moving 7-day mean) during fall 2015 in Presque Isle County and Alcona County, MI.*

Table 5. Comparison of mean altitude (m) with standard deviations, median altitude, and altitude band (50 m bands) that contained the maximum target density during four biological periods at our sites in Presque Isle County and Alcona County during fall, 2015. Max band densities represent the top of the altitude band.

	Presque Isle			**Alcona**		
Biological Period	*Mean*	*Median*	*Max Band Density*	*Mean*	*Median*	*Max Band Density*
Dawn	594 ± 491	401.27	250	680 ± 544	486.92	350
Day	392 ± 340	292.61	300	475 ± 445	344.12	350
Dusk	314 ± 331	237.44	150	365 ± 364	269.90	250
Night	528 ± 435	377.34	150	681 ± 502	533.40	150

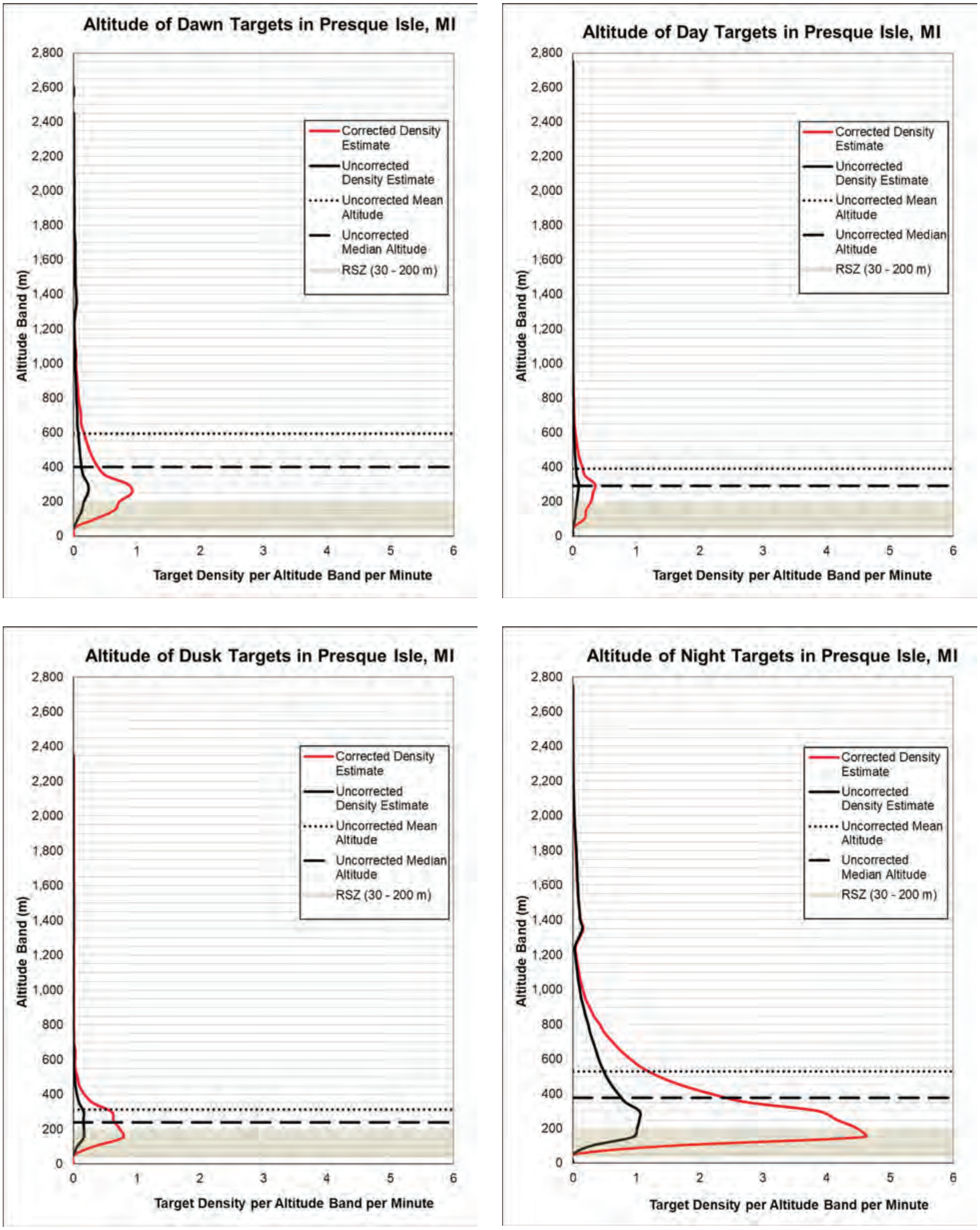


Figure 18. *Altitude profile of targets at our site in Presque Isle County, MI. Corrected lines depict target density (targets/1,000,000 m*^{3}*) per 50-m altitude band per hour after adjusting for the structure of the sample volume. Uncorrected lines depict target density per 50-m altitude band per hour, with an assumed uniform volume distribution (volume of each band is equal to the total volume divided by the number of bands). Tan band represents the rotor swept zone (RSZ) between 30—200 m. Y-axis labels represent the top of the altitude band.*

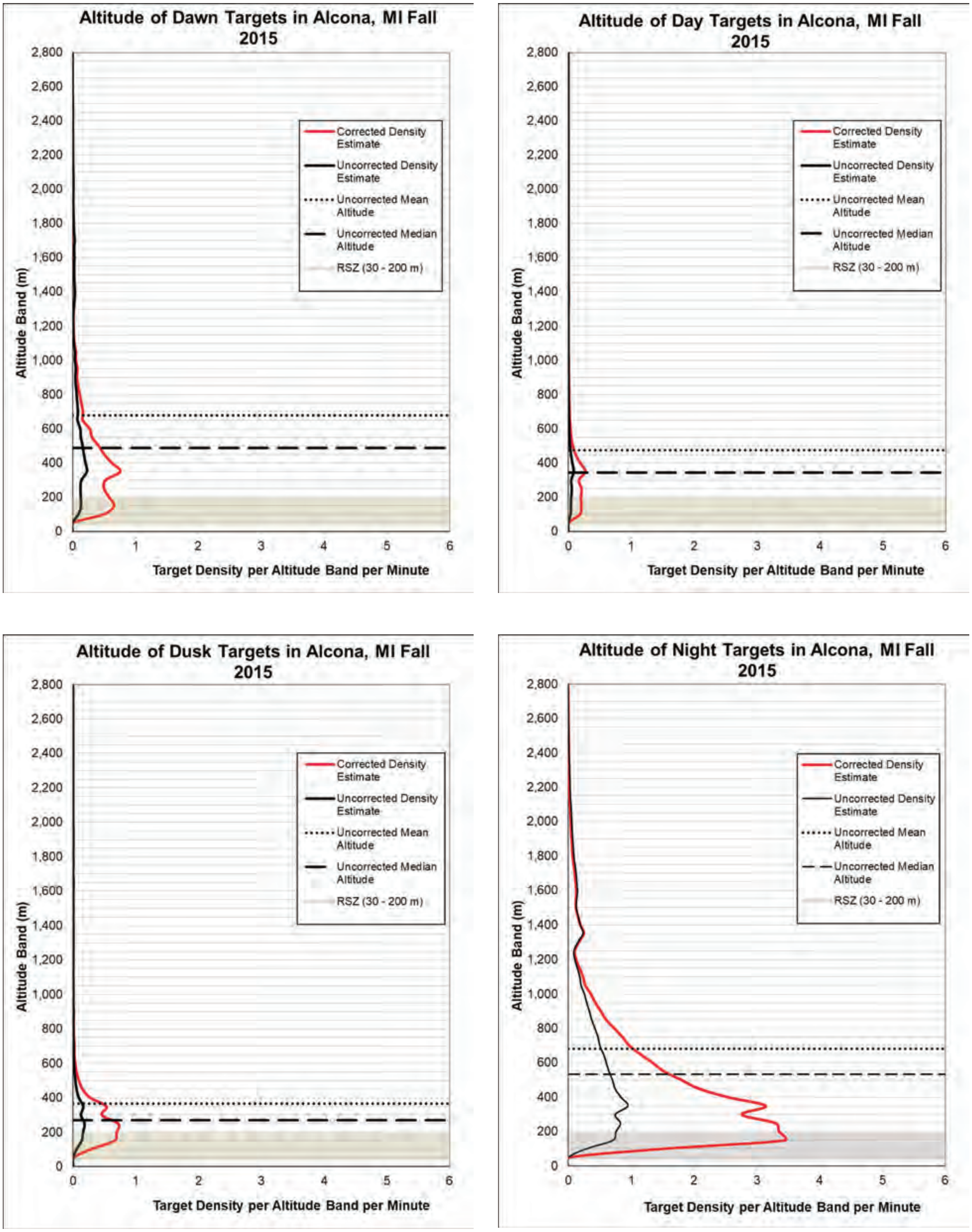


Figure 19. *Altitude profile of targets at our site in Alcona County, MI. Corrected lines depict target density (targets/1,000,000 m^3) per 50-m per hour altitude band after adjusting for the structure of the sample volume. Uncorrected lines depict target density per 50-m altitude band per hour with an assumed uniform volume distribution (volume of each band is equal to the total volume divided by the number of bands). Tan band represents the rotor swept zone (RSZ) between 30—200 m. Y-axis labels represent the top of the altitude band.*

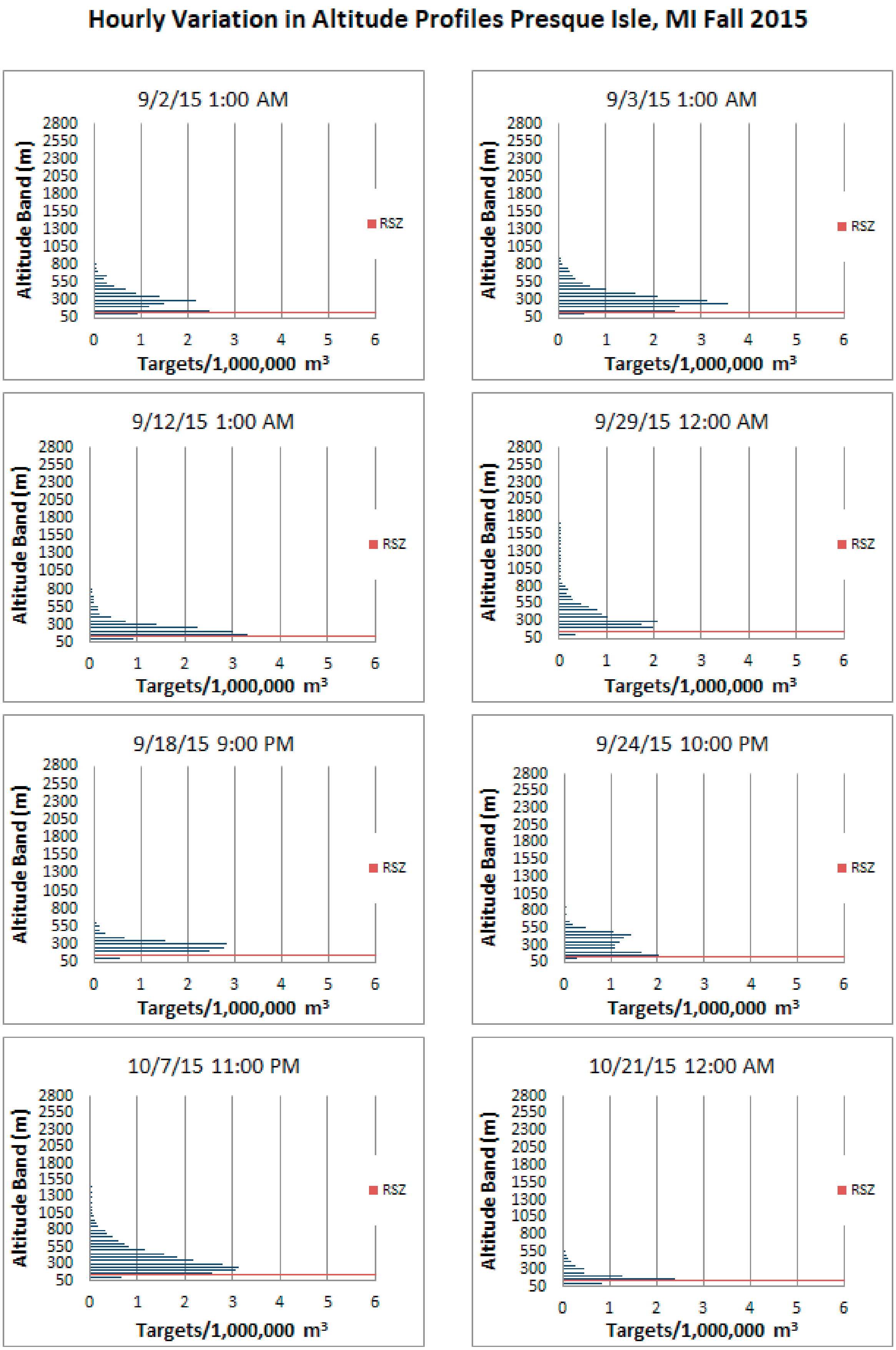


Figure 20. *A sample of hourly altitude profiles corrected for the shape of the sample volume at our site in Presque Isle County, during fall 2015. Hours were selected to portray the variability in density per altitude band of passing targets. The x-axis represents target density. The red line represents the top of the rotor swept zone at 200 m. Y-axis labels represent the top of the altitude band.*

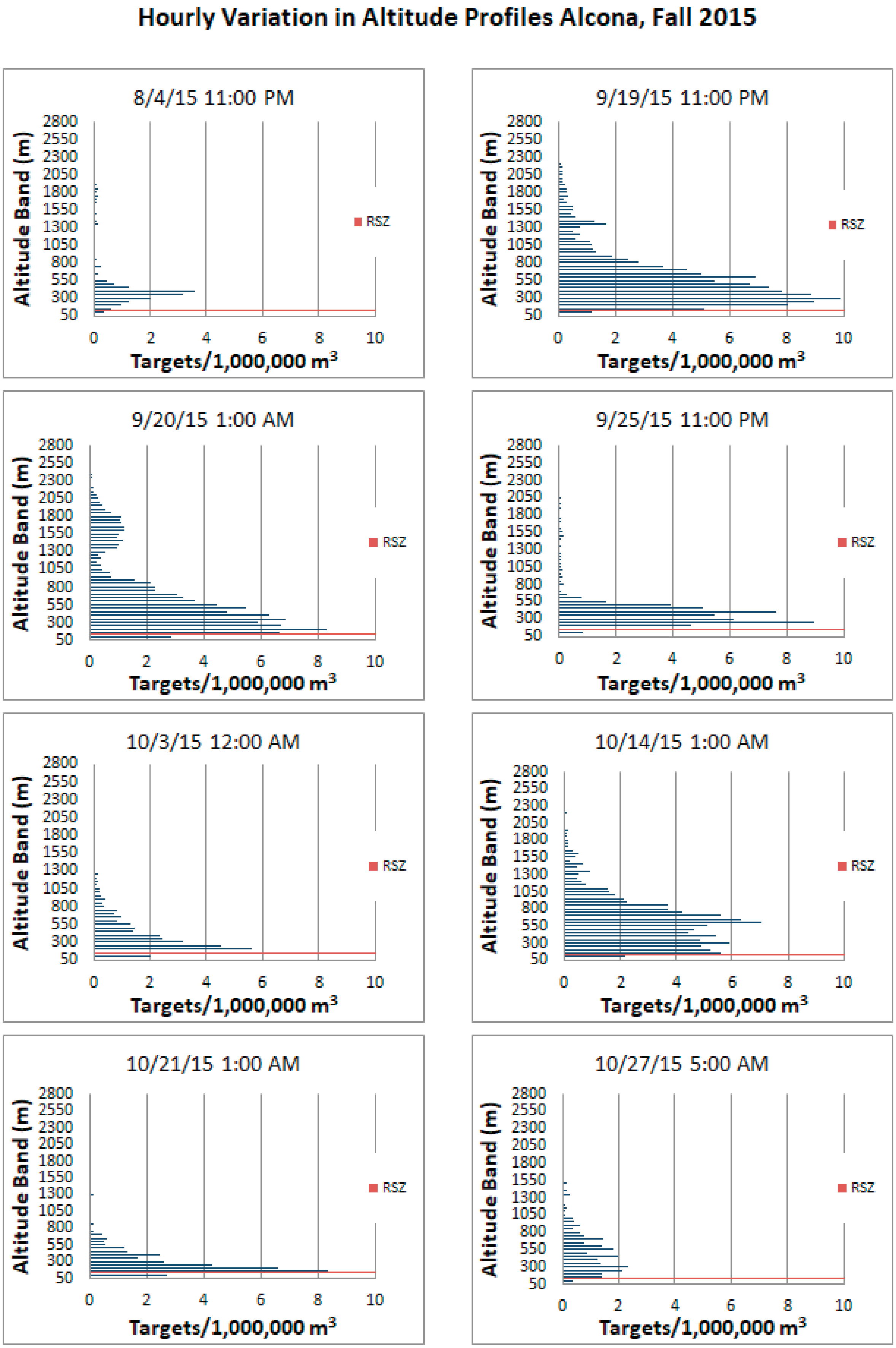


Figure 21. *A sample of hourly altitude profiles corrected for the shape of the sample volume at our site in Alcona County during fall, 2015. Hours were selected to portray the variability in density per altitude band of passing targets. The x-axis represents target density. Y-axis labels represent the top of the altitude band.*

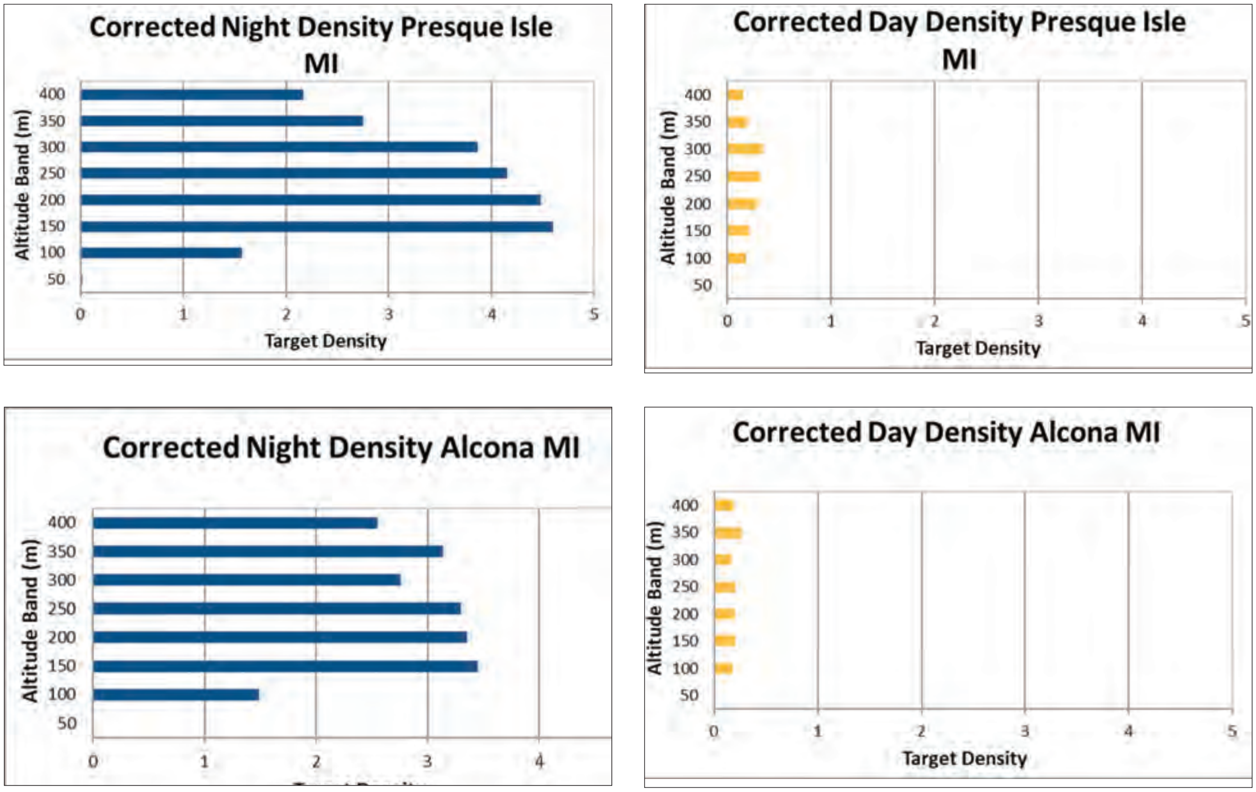


Figure 22. *Altitude profile of corrected target density below 400 meters in Presque Isle County and Alcona County, MI. The x-axis represents target density (targets/1,000,000 m*^{3}*) per 50-m altitude band. Y-axis labels represent the top of the altitude band.*

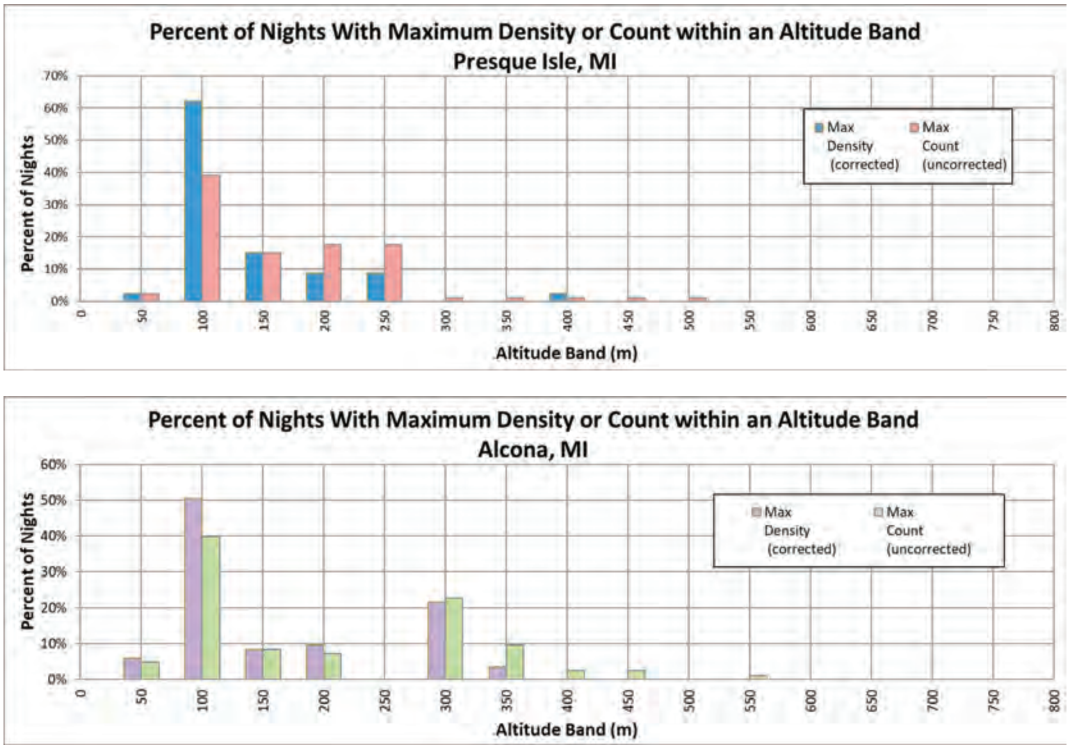


Figure 23. *Percent of nights when the maximum density (targets/1,000,000 m³/ altitude band) or count (targets/altitude band) occurred within 50-m altitude bands in Presque Isle County and Alcona County, during fall 2015. X-axis labels represent the top of the altitude band.*

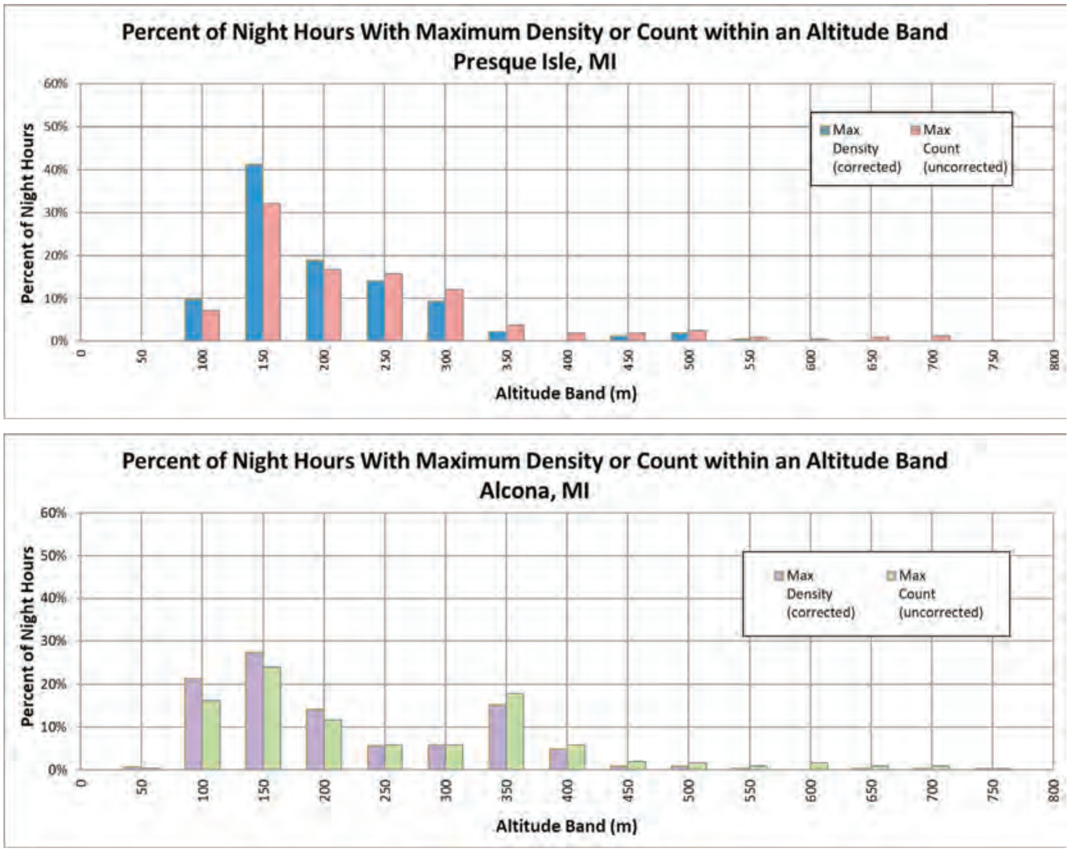
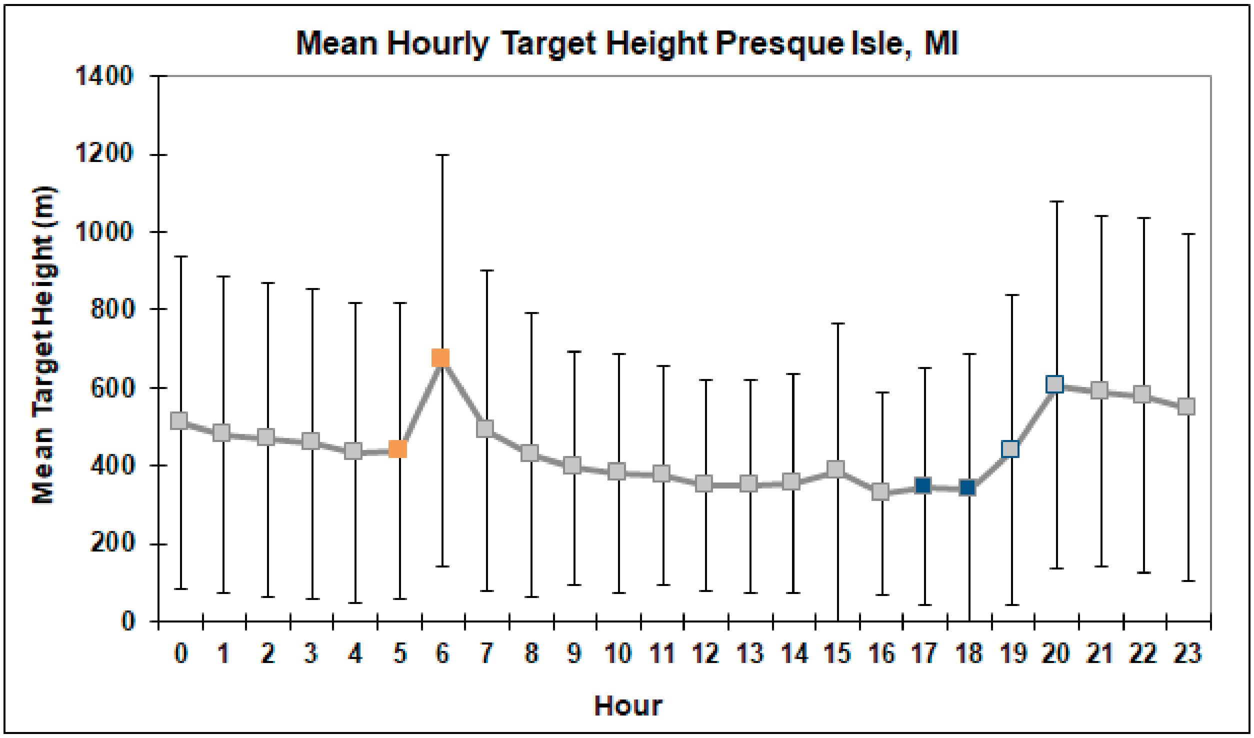


Figure 24. *Percent of night hours (20:00—04:00) when the maximum density (targets/1,000,000 m³/ altitude band) or count (targets/altitude band) occurred within 50-m altitude bands in Presque Isle County and Alcona County, during fall 2015. X-axis labels represent the top of the altitude band.*



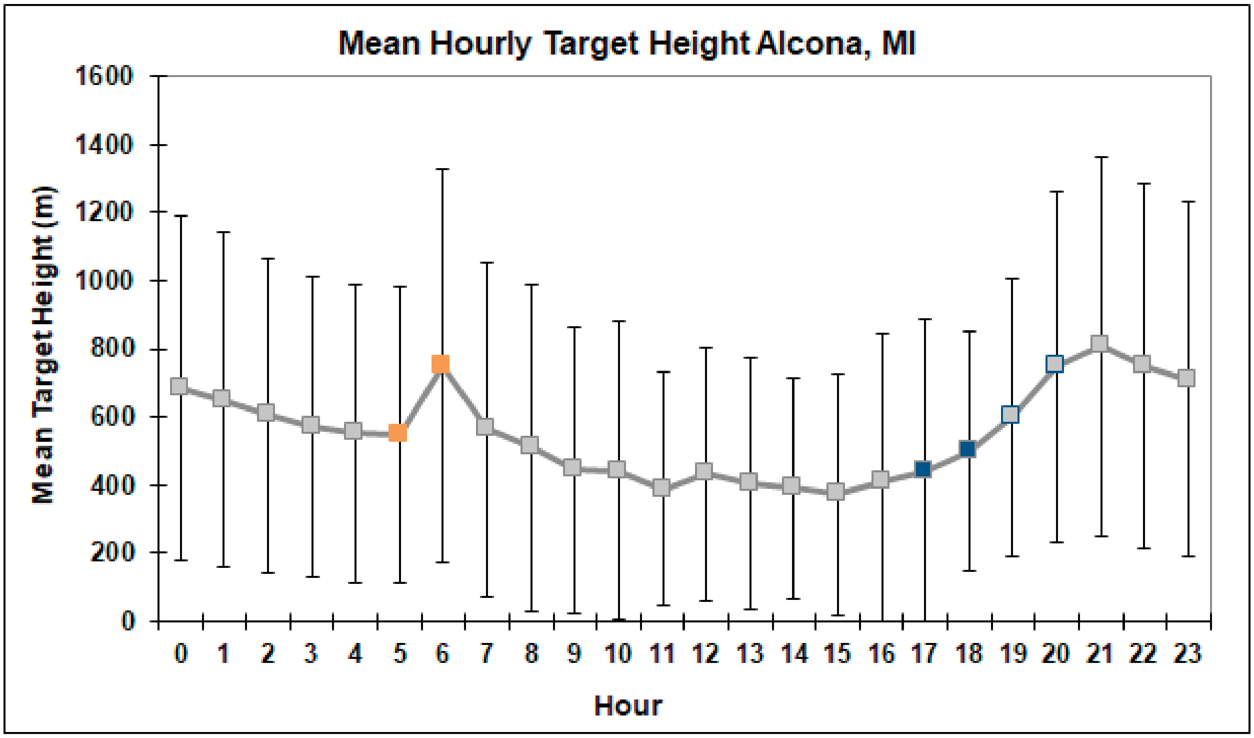


Figure 25. *Mean hourly target heights (m) in fall 2015 in Presque Isle and Alcona Counties, Michigan. Orange and blue markers indicate the hours in which sunrise and sunset occurred during the season, respectively. Error bars represent one standard deviation.*

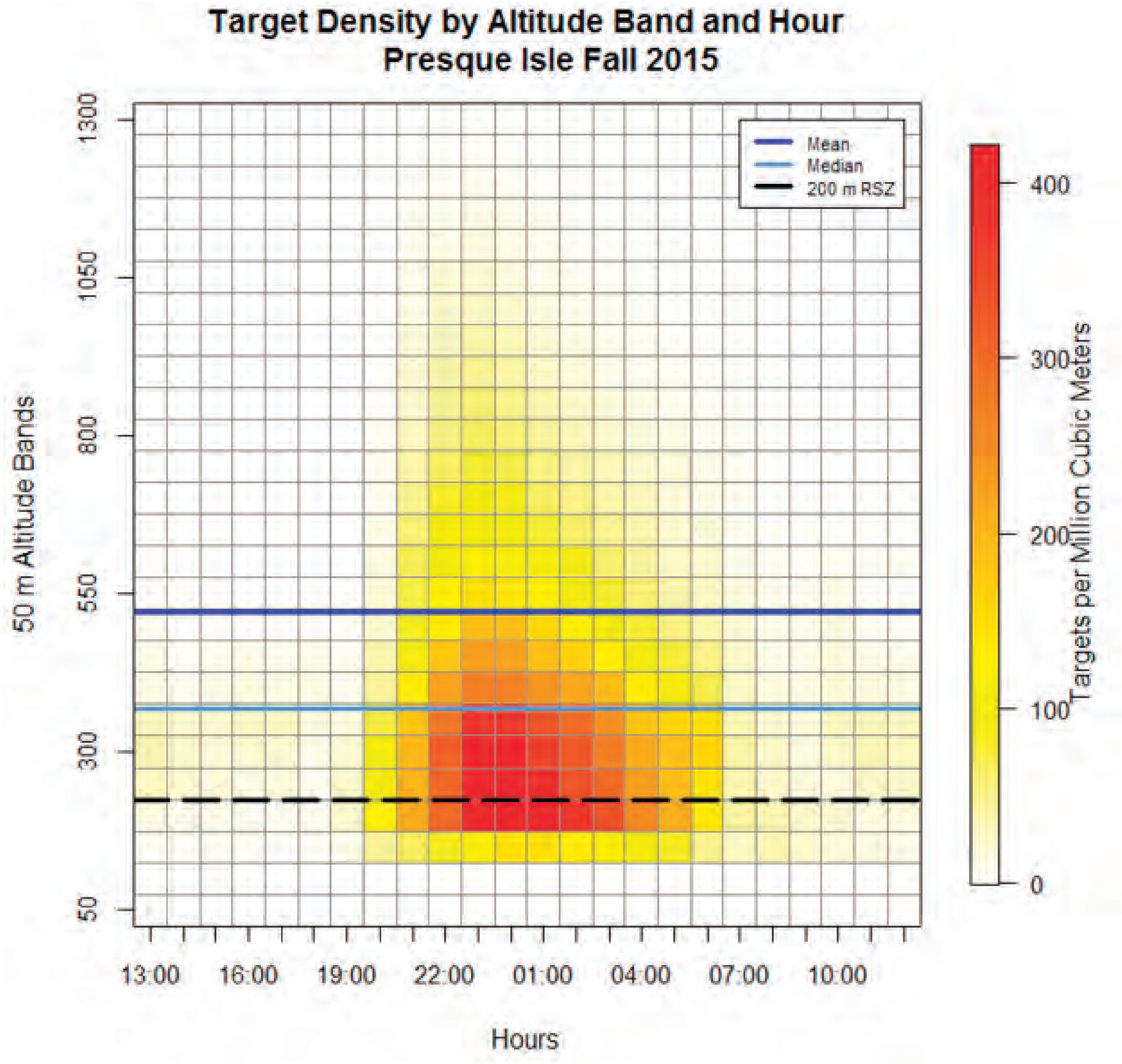


Figure 26. *Variation in flight Altitudes based on target density (targets per million cubic m) at our site in Presque Isle County, Michigan throughout the fall study period. Altitude bands are in meters and labels represent the max value of each altitude band. Density of targets is in targets per million cubic meters. Colors shown in each rectangle indicate the relative density observed for that altitude (key shown on the right) and time. The dark blue and light blue lines represent the nocturnal mean and median target heights, respectively. The black dotted line at 200 m represents maximum height of a turbine with a rotor-swept zone of 30-200 m. Note difference in density scale used in Figure 27.*

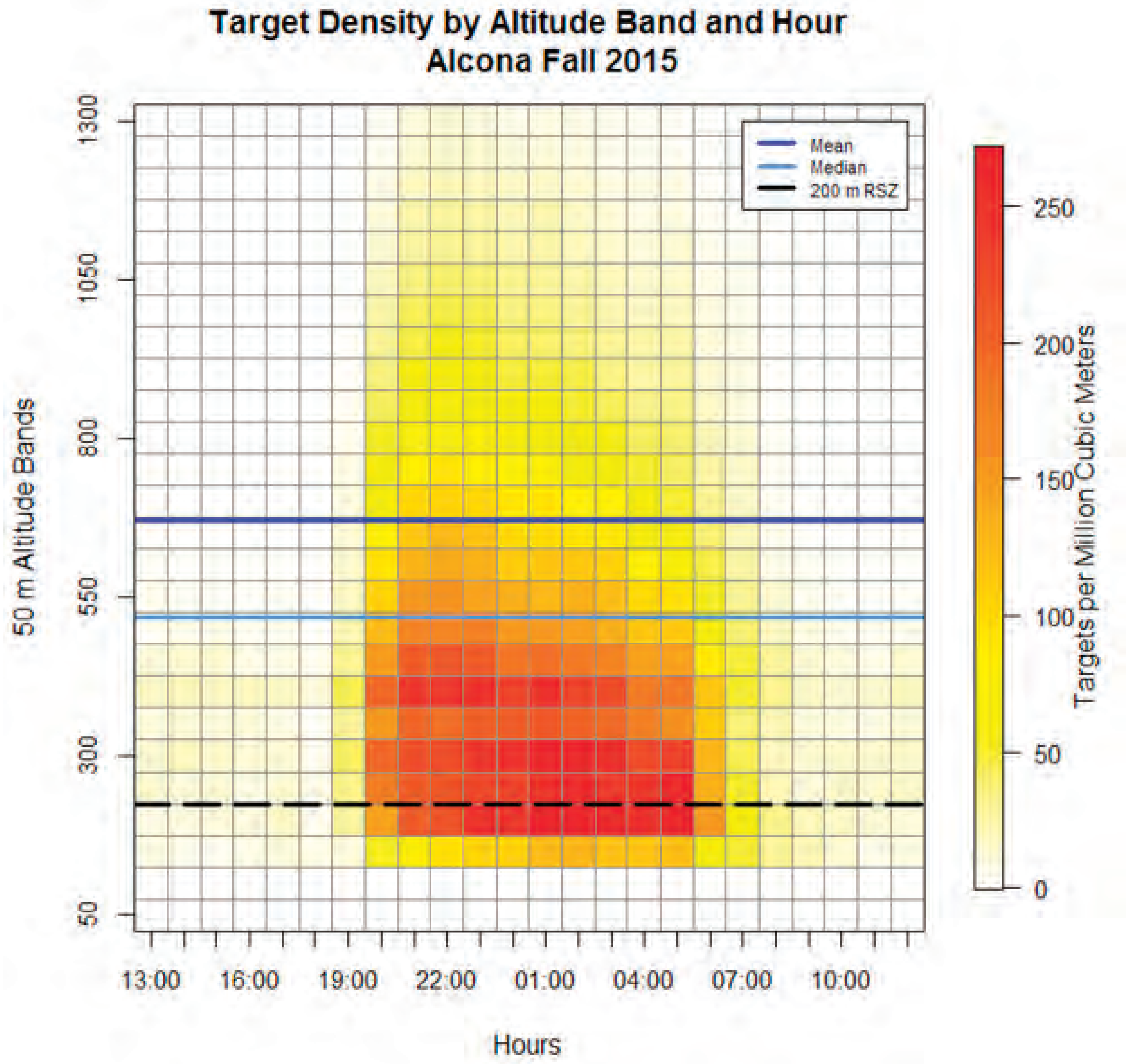


Figure 27. *Variation in flight Altitudes based on target density (targets per million cubic m) at our site in Alcona County, Michigan throughout the fall study period. Altitude bands are in meters and labels represent the max value of each altitude band. Density of targets is in targets per million cubic meters. Colors shown in each rectangle indicate the relative density observed for that altitude (key shown on the right) and time. The dark blue and light blue lines represent the nocturnal mean and median target heights, respectively. The black dotted line at 200 m represents maximum height of a turbine with a rotor-swept zone of 30-200 m. Note difference in density scale used in Figure 26.*

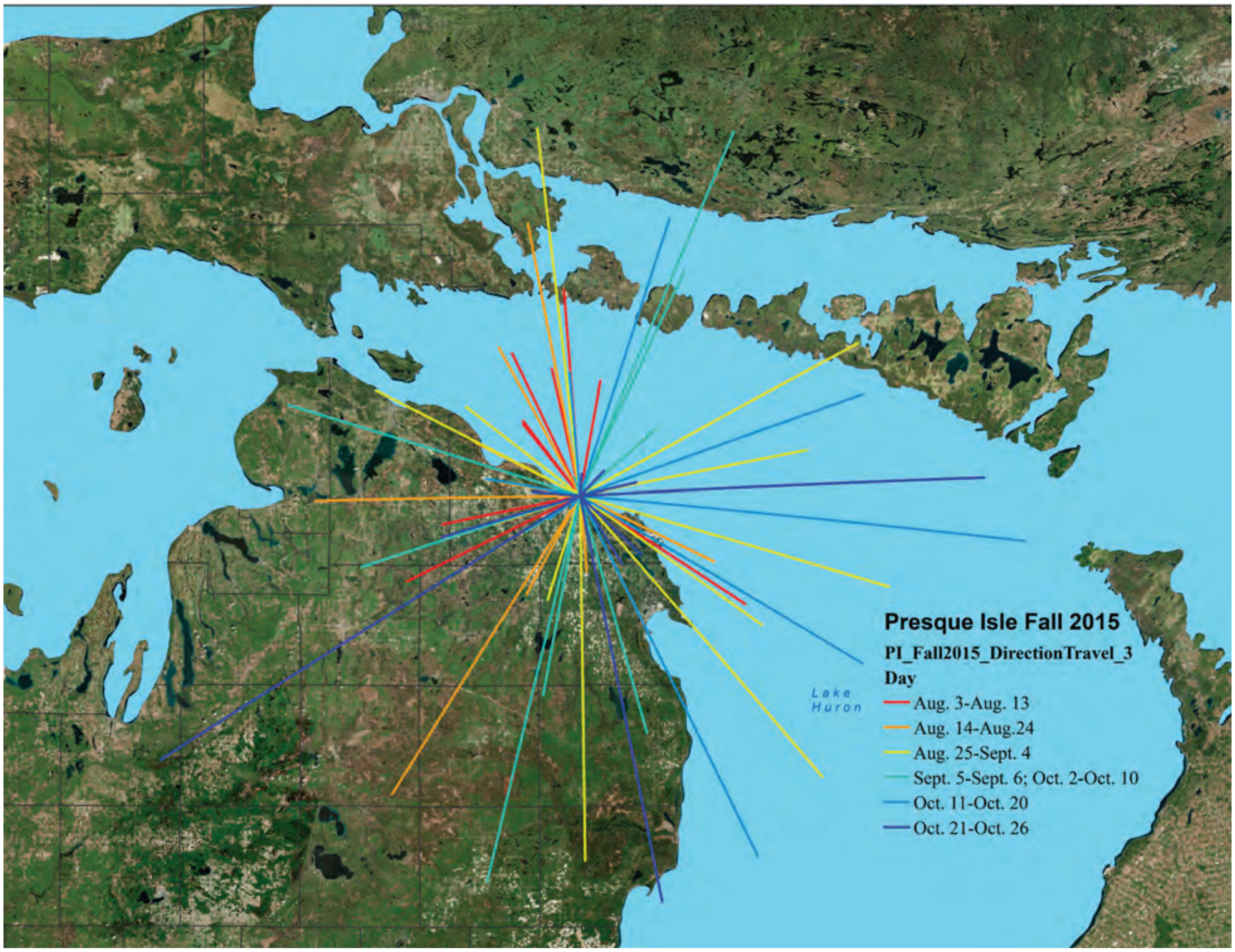


Figure 28. *Movement direction of targets for each night over the spring 2015 migration season for Presque Isle site. Each line represents the average origin direction of targets during one night. These directions are averaged across the night, and while orientation changes throughout the night, provide a general direction of flight. Line length is proportional to number of targets moving through the area. Line color denotes the time within the season, with cooler colors denoting later dates in the season. Note the variety of origin directions, and the relatively common movements from the east across open waters of Lake Huron.*

Results-Spring 2016

During the spring 2016 season we began data collection March 29 at both sites. Data collection ended on June 13, and June 14 at Presque Isle County and Alcona County, respectively, resulting in a survey period of 1870 hours at the Presque Isle County site and 1847 hours at the Alcona County site (Table 2). Data were recorded continuously while the radar units were operational. Gaps in analyzed data occurred during rain events and when the radar units were not operational due to maintenance or malfunction (radar downtime). Horizontal radar at Alcona County site was lost due to motor and gear damage from March 29-April 22. When correcting for radar downtime and removal of periods with rain, the radars collected useable data 77% and 95% of the season in Presque Isle County and 84% and 65% in Alcona County with the vertical and horizontal radars, respectively.

Qualitative Assessments

Plots of tracked targets showed images of nocturnal migration events at both locations (Figure 29-30). For example, on May 9 at the Presque Isle County site (Figure 29), the horizontal radar recorded scattered activity, and low activity was present on the vertical radar between 12:00 and 18:00. During 20:00-21:00, the horizontal radar recorded a direction shift to north and northeast, and the vertical radar recorded many more targets in the air, especially at and below 1250 m. The direction stayed consistently northward through 01:00 on May 10th, while the vertical radar recorded a second dense band of migrants from 1750-2250 m beginning at 23:00 on May 9th. The number of migrants recorded on the vertical radar began to decline after this point, continuing through 04:00. The horizontal radar recorded a shift in direction at 04:00 towards the west, chiefly among migrants over water, indicating a dawn return towards shore. This pattern continued and strengthened through 05:00. The number of targets recorded by vertical radar continued to decline over this time. By 12:00 on May 10th, the pattern had returned to a similar pattern as the previous day, with few targets moving in no clear direction. The pattern from May 9-10 is consistent with previously observed nocturnal migratory activity in the spring.

Migratory activity in Alcona County on the night of 29 April-30 April (Figure 30) are broadly similar to those at Presque Isle County, including low number of migrants with little directionality recorded at 12:00, and increase in number of targets and directionality starting at 20:00 and peaking at 01:00 on April 30, then declining during the rest of the night and returning to low numbers and no directionality by 12:00. During 05:00 of April 30th, we recorded a very clear dawn turn towards shore, with all individuals over water turning west, while targets at the shore demonstrated a strong north-south pattern, indicative of targets following the shoreline, presumably searching for suitable stopover habitat.

Also apparent on the Trackplots from both sites are areas not well recorded by the radar due to beam blockage from ground clutter (due to topography, vegetation, buildings, etc.; Figure 4b) resulting in reduced detection in the air space that was within the range of data collection (e.g., southwest of the radar unit at the Presque Isle County site and in the areas in the northwest areas of the Alcona County radar site as seen in the horizontal Trackplots;

Table 6. Survey effort (hours) by vertical and horizontal scanning radars during spring 2016 at our radar sites in Presque Isle County and Alcona County.

Site	*Radar*	*Survey Period*	*Radar Downtime*[1]	*Time Radar Collected Data*	*Radar Data w/Rain*	*Usable Radar Data*	*% Usable Data*
Presque Isle	VSR	1870	255	1615	186	1429	76%
Presque Isle	HSR	1777	0	1777	22	1755	99%
Alcona	VSR	1847	45	1801	254	1548	84%
Alcona	HSR	1847	607	1240	47	1193	65%

[1] Vertical and horizontal radars are not equally impacted by rain events or downtime.

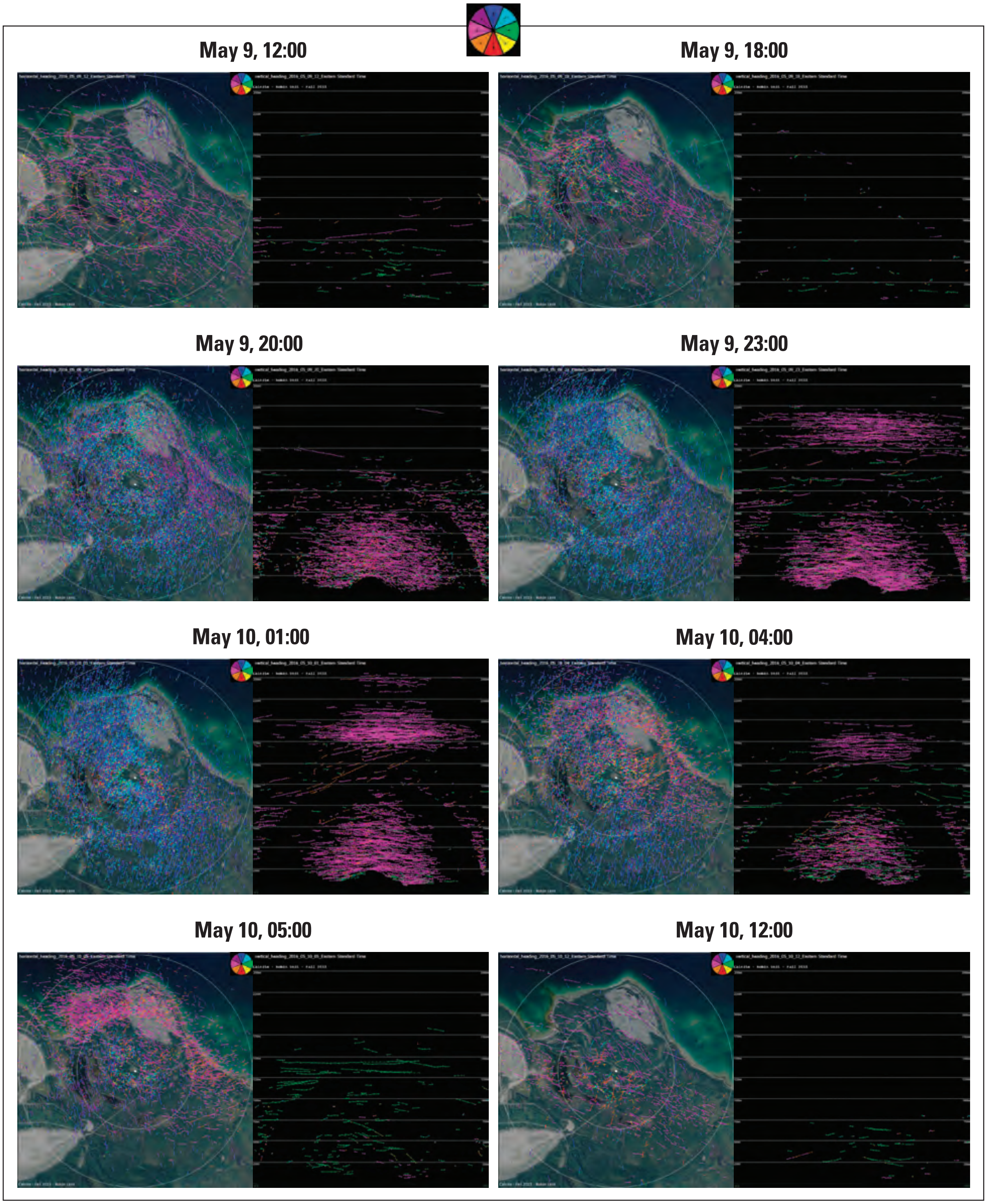
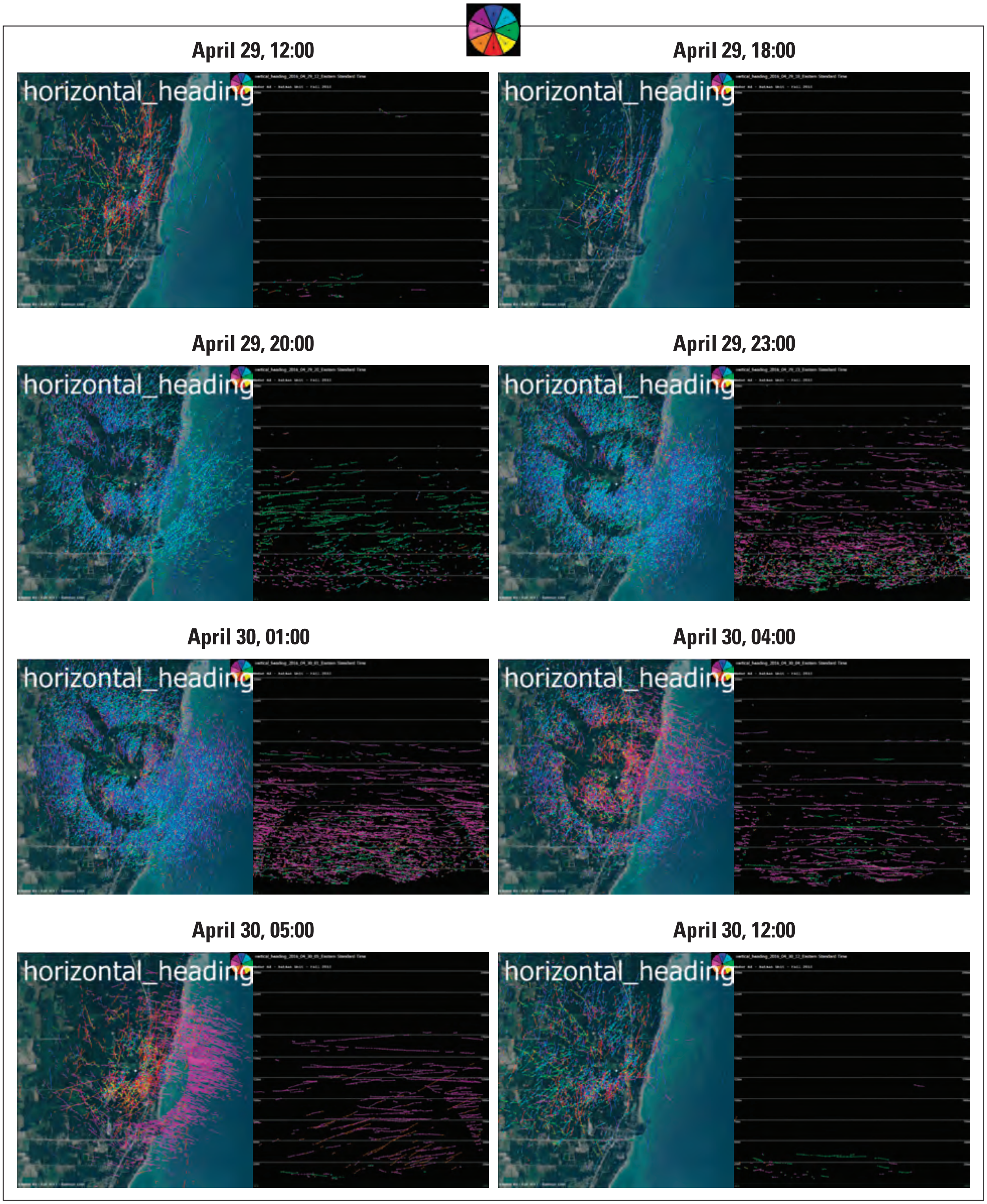


Figure 29. *Images of tracks during 1-hour increments recorded by horizontal and vertical scanning radars during a migration event at our radar site in Presque Isle County. Horizontal radar images (columns 1 and 3) show direction of targets as indicated by the color wheel (dark blue indicates a direction of travel to the north and red travel to the south). Vertical radar images (columns 2 and 4) show target heights.*

Figures 29 and 30). Rings of decreased detection near the radar unit and where the radar switched from short to medium pulse are also evident in both the horizontal (e.g., April 29-30, 20:00-05:00. Figure 29) and vertical (e.g., May 9th, 23:00. Figure 28) Trackplots (seen at a range of about 1,400—2,000 m). Additionally, there was low-elevation clutter on one side of the Alcona County's VSR, reducing detection on lakeward side of the radar.



April 29, 12:00

April 29, 18:00

April 29, 20:00

April 29, 23:00

April 30, 01:00

April 30, 04:00

April 30, 05:00

April 30, 12:00

Figure 30. Images of tracks during 1-hour increments recorded by horizontal and vertical scanning radars during a migration event at our radar site in Alcona County. Horizontal radar images (columns 1 and 3) show direction of targets as indicated by the color wheel (dark blue indicates a direction of travel to the north and red travel to the south). Vertical radar images (columns 2 and 4) show target heights.

Directional Trends

During the spring 2016 season, nocturnal target movement direction was generally north/northeast at both sampled locations (Figure 31). At the Presque Isle County site, mean nocturnal direction was 18° with an angular concentration (r) of 0.47 (n = 2,265,807 targets) and during 59.3% of nights mean target direction was between northwest and northeast (292.5°—67.5°). Direction at the Alcona County site had a mean nocturnal direction of 9° (r = 0.39, n = 2,324,169) with 67% of nights having a mean direction between northwest and northeast. Onshore movement to the west and south at dawn was visible at Presque Isle County, while onshore movement to the west was visible at dawn at Alcona County (Figure 30). Uniform directionality at night was slightly stronger at our Presque Isle site than in our Alcona site (Table 7). Directional trends also reflect movement towards shore at dawn. The Presque Isle site is located on a northwest to southeast oriented shoreline, while Alcona is located on a north-south oriented shoreline (Figure 1). During the dawn time period, Presque Isle shows a substantial movement to the south and southwest, reflecting the movements of migrants from open water to the north or the site to shore, whereas the Alcona site shows migrants oriented to the north and northwest, consistent with migrants' movement into shore from the open waters to the east. Migrants appear to be moving from the south directly across the lake at the Presque Isle site (Figure 49), while they tend to follow the western shore of Lake Huron at our Alcona site (Figure 50).

Target Direction per Hour During Four Biological Time Periods

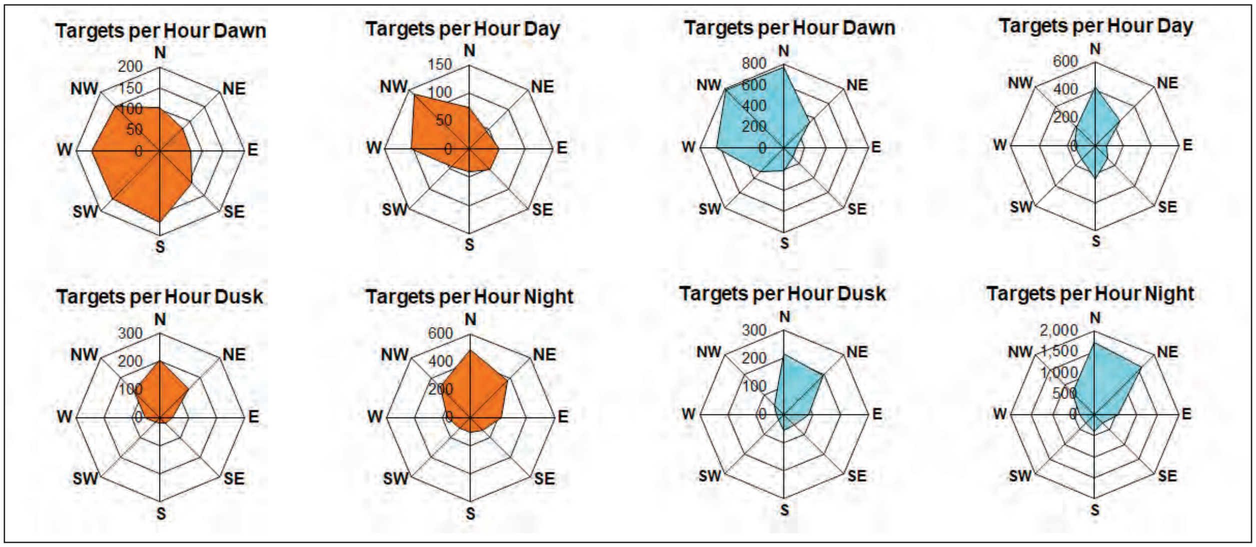


Figure 31. *Target direction per hour during four biological periods during spring 2016 at our sites in Presque Isle (left) and Alcona Counties (right). Note the different scales on each of the graphs.*

Table 7. Mean direction, angular concentration (r), and percent of biological time periods with strong directionality (r ≥ 0.5) of targets during biological time periods at our sites in Presque Isle and Alcona counties.

	Presque Isle				**Alcona**			
Biological Period	*Mean Direction*	*r*	*% time r ≥ 0.5 (degrees)*	*n*	*Mean Direction*	*r*	*% time r ≥ 0.5 (degrees)*	*n*
Dawn	243	0.20	32.9%	146,863	318	0.44	61.3%	165,023
Day	311	0.27	17.3%	1,090,186	357	0.21	18.8%	1,116,667
Dusk	1	0.55	54.1%	95,352	35	0.49	46.9%	37,494
Night	9	0.39	27.8%	2,324,169	18	0.47	59.3%	2,265,807

Temporal Trends

Time Series Plots—Hourly target counts provided by horizontal and vertical radars showed pulses of elevated nocturnal activity with peaks occurring around midnight at our study sites. Across our sampling period these events were often clustered into groups of several nights and were first observed on April 14 and April 16 at the Presque Isle and Alcona counties, respectively (Figures 32 and 33). At both sites, the occurrence and magnitude of nocturnal pulses decreased substantially after May 30, 2016.

Different patterns of activity are apparent as the season progresses at our study sites. For example, beginning in mid-April activity patterns become dominated by nocturnal pulses that are seen on both horizontal and vertical radars in Presque Isle County, and in Alcona County to a lesser extent. This pattern continues until late May when activity patterns begin to shift with activity levels decreasing overall.

Hourly Counts by Horizontal and Vertical Radars: Presque Isle County, MI

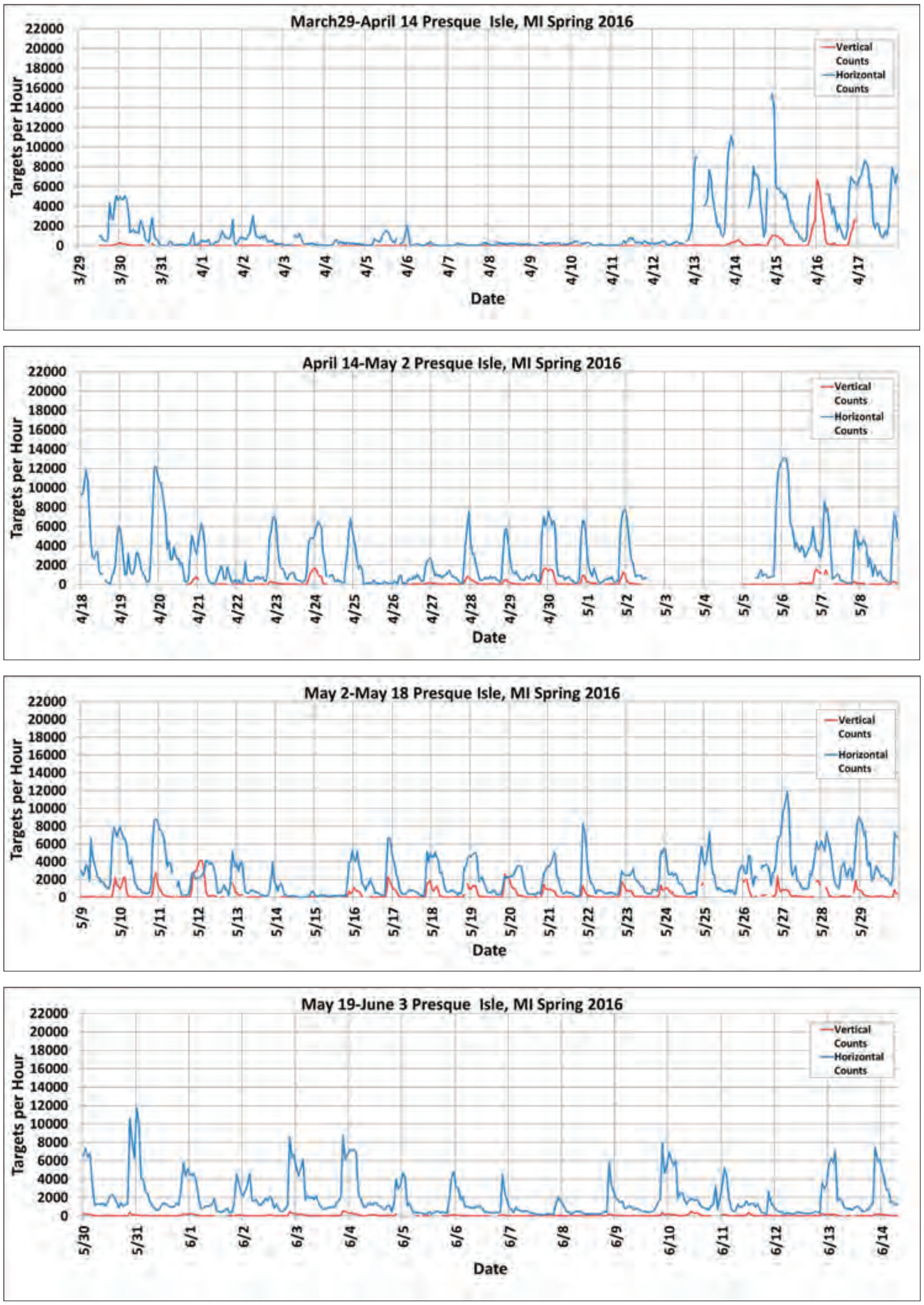


Figure 32. *Hourly counts by horizontal and vertical radars from March 29-June 3, 2016 Presque Isle County, MI. Light gray vertical lines represent midnight. figure 32 title: Hourly Counts by Horizontal and Vertical Radars: Presque Isle County, MI*

Hourly Counts by Horizontal and Vertical Radars: Alcona County, MI

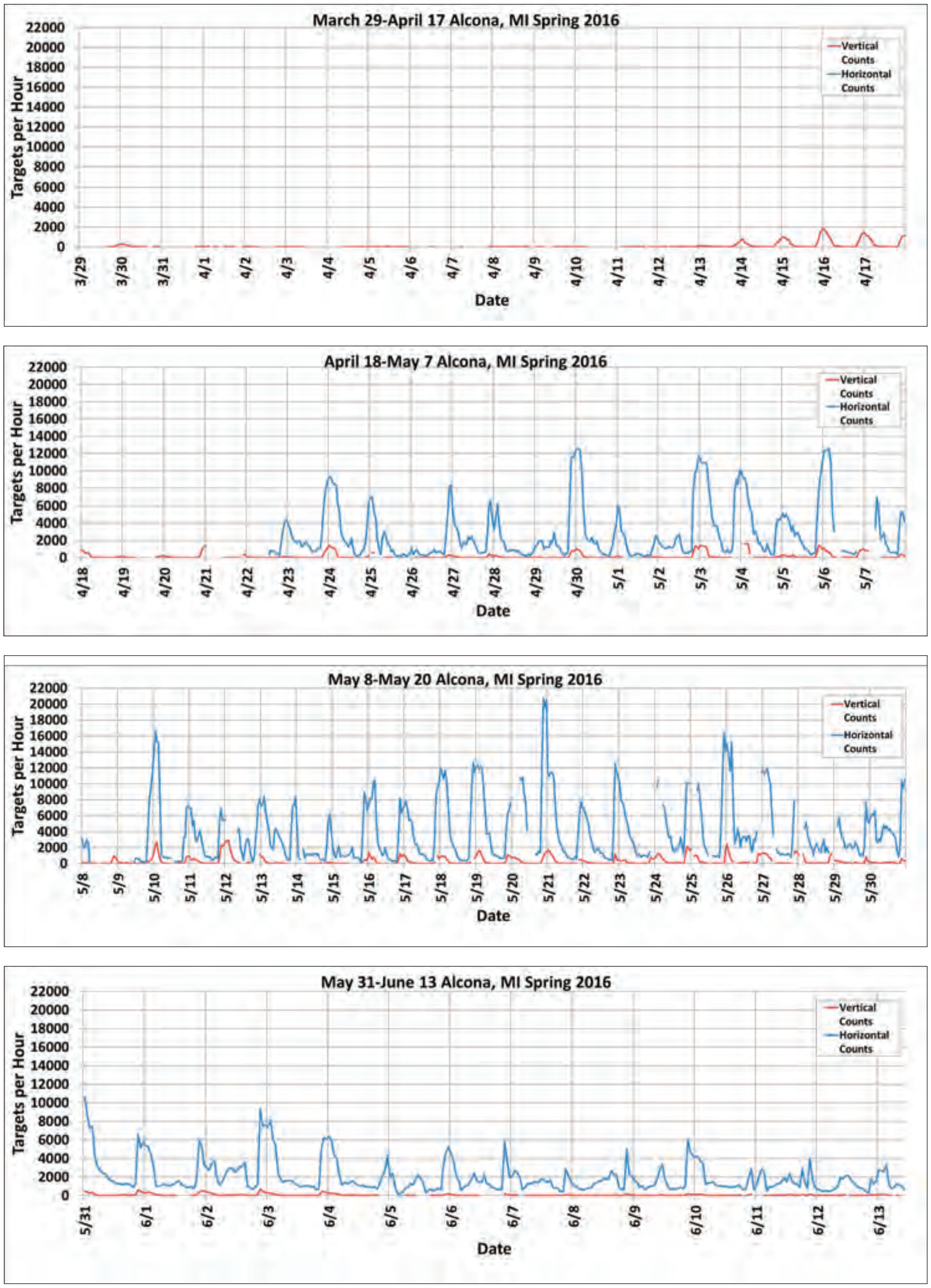


Figure 33. *Hourly counts by horizontal and vertical radars from March 29-June 13, 2016 in Alcona County, MI. Light gray vertical lines represent midnight.*

Target Passage Rate—The pattern of mean TPR among the four biological time periods was similar between the two study sites (Figure 33), with mean TPR at night being greater than the combined means of the other three biological time periods (Table 8). Mean nocturnal TPR was 583.6 ± 737.5 SD (n = 58 nights) and 461.7 ± 488.0 SD (n = 74 nights) at the Presque Isle and Alcona counties, respectively. Mean TPR varied by hour with peak numbers reached during the 21:00 and 00:00 hours (approximately dusk through three hours after sunset) at both sites. At both locations, mean TPR gradually decreased as the night progressed, with the most drastic decline occurring around 04:00 and 05:00, which corresponds with dawn (Figure 35).

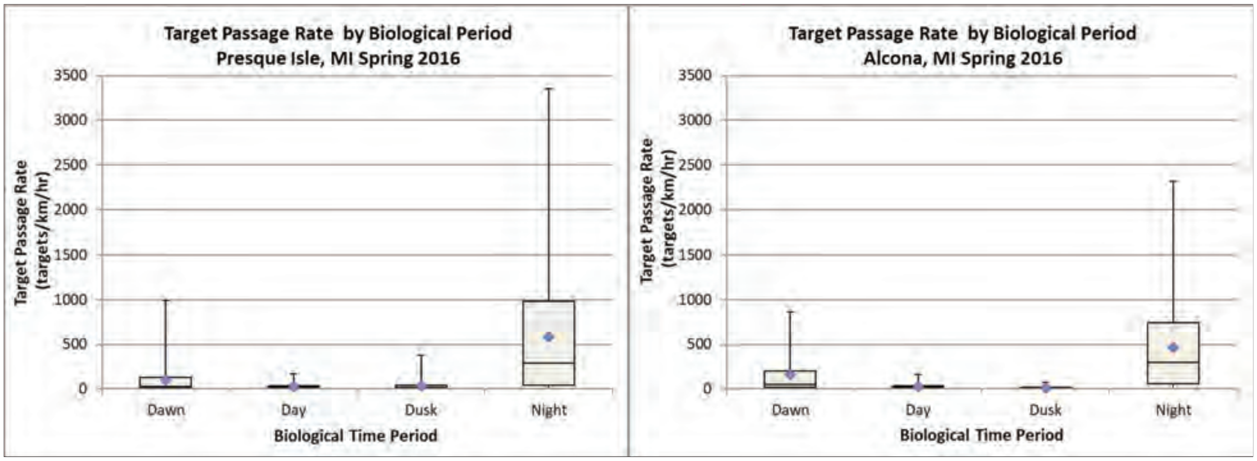


Figure 34. *Box plots showing variability in target passage rate (targets/km/hr) during four biological periods for spring 2016 in Presque Isle and Alcona counties, Michigan. Whiskers represent the 1st and 4th quartiles, boxes represent the 2nd and 3rd quartiles (with the line between indicating the median), and blue diamonds represent seasonal mean for the time.*

Table 8. Mean target passage rate (TPR) with standard deviations during four biological periods in Presque Isle and Alcona Counties during spring 2016.

Biological Period	*Presque Isle Mean TPR*	*Alcona Mean TPR*
Dawn	43 ± 71	160 ± 222
Day	155 ± 212	30 ± 29
Dusk	38 ± 75	15 ± 14
Night	404 ± 736	462 ± 488

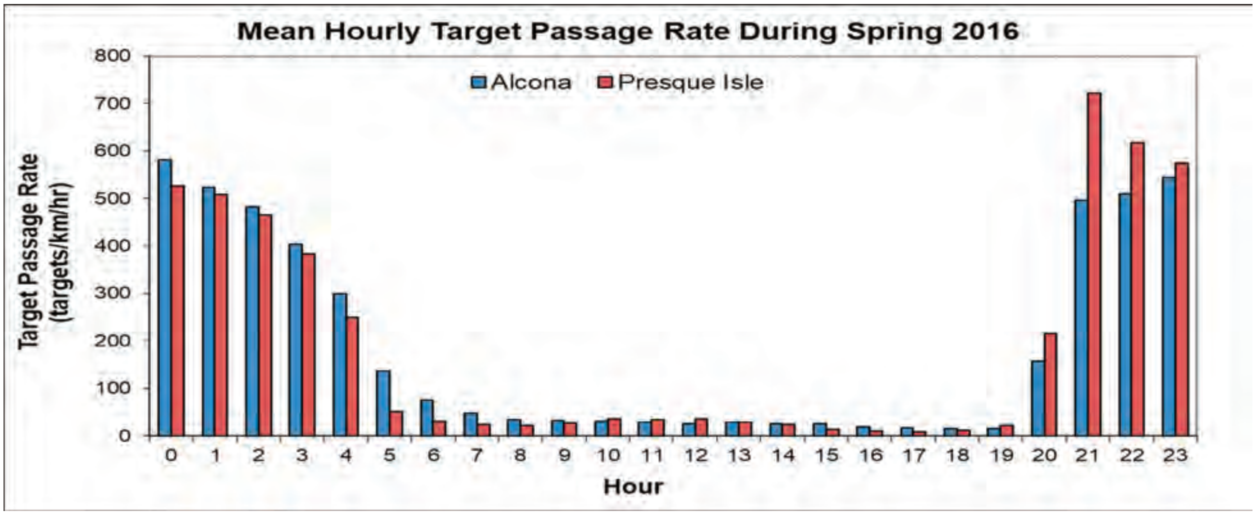


Figure 35. *Mean hurly target passage rate (targets/km/hr) during spring 2016 at sites in Presque Isle and Alcona counties, MI.*

Weekly Mean of Target Passage Rates—At both sites weekly means of nocturnal target passage rates were relatively high compared to diurnal target passage rates and both sites showed a generally increasing mean throughout the season. In mid-to-late May nocturnal mean TPRs began to decrease (Figure 36). Weekly means of nocturnal TPR were consistently higher than weekly means of diurnal TPR (Figures 36). As the recorded migration season subsided there was less difference between the nocturnal and diurnal target passage rates (Figures 36 and 37). Trends in both nocturnal and diurnal TPRs (7 day moving means) were similar in pattern, but not magnitude at both sites (Figure 37). Presque Isle County had a slightly higher target passage rate during migration peaks, especially night migration peaks than Alcona County (Figures 34, 38).

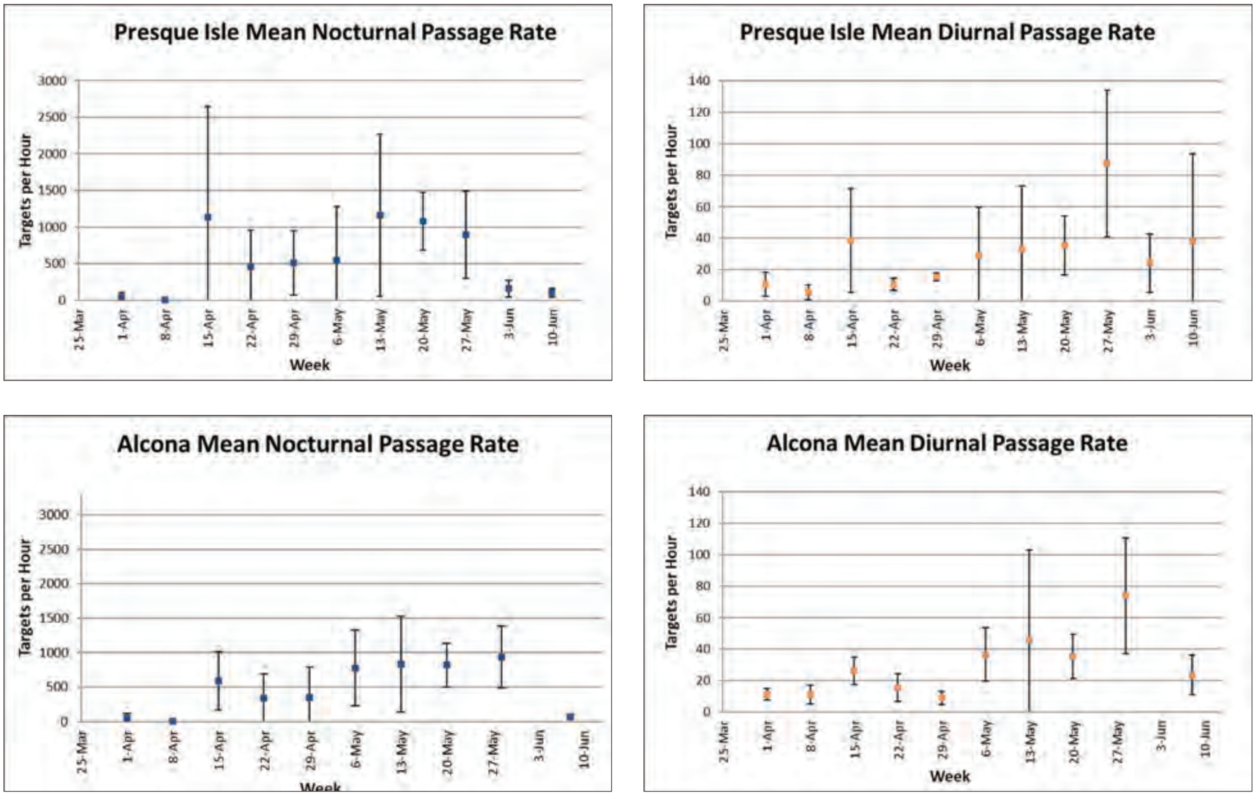
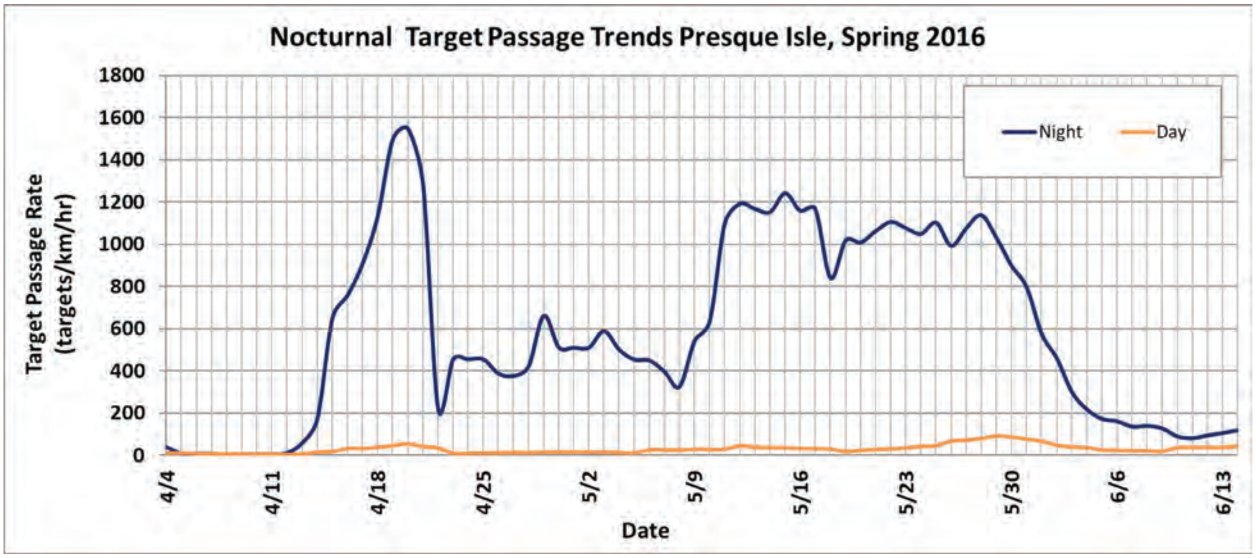


Figure 36. *Weekly mean of nocturnal and diurnal target passage rates (targets/km/hr) in Presque Isle (top row) and Alcona (bottom row) counties from April 1-June 10, 2016. Error bars represent one standard deviation. Error on 9-June for Alcona's nocturnal passage rate is too small to be graphed with the other weeks. Note different scales on nocturnal and diurnal plots.*



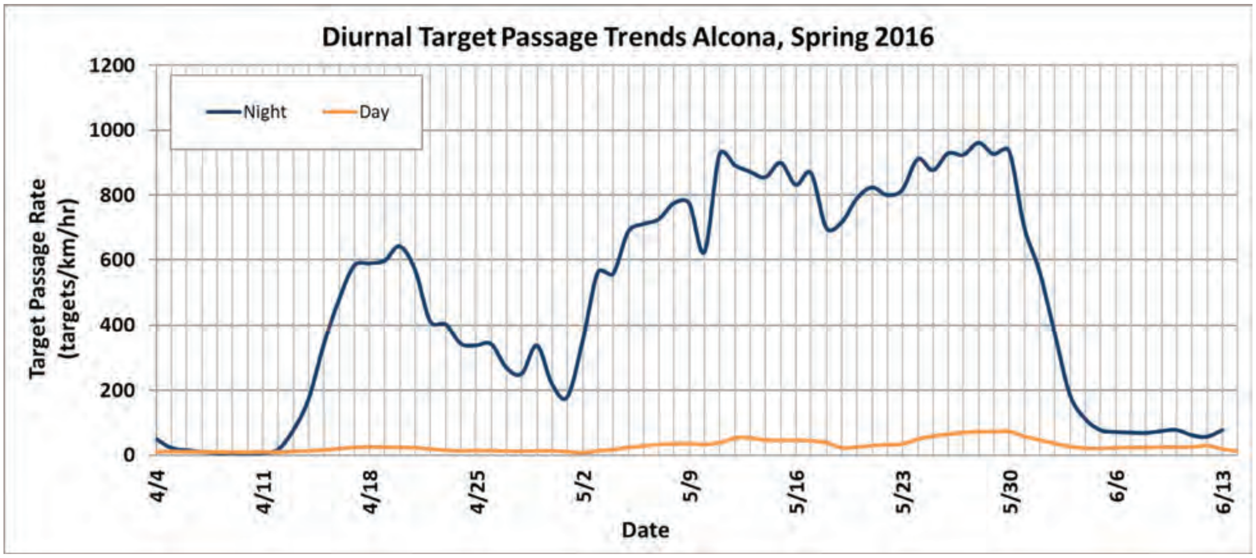


Figure 37. *Comparison of nocturnal and diurnal target passage trends (based on a moving 7-day mean) during spring 2016 in Presque Isle (top row) and Alcona (bottom row) counties.*

Altitudinal Trends

Our density estimate that accounted for the geometric shape of the sampled space resulted in a substantially different density estimate than assuming an equal amount of sample volume per altitude band, as is the case with reporting uncorrected counts. Altitude profiles for dawn and night differed between our two locations with density at low elevation being greater at our Alcona site (Figures 39 and 40). Hourly altitude profiles at night revealed considerable variation in use of altitude bands (Figures 41 and 42); however, over the course of the season the 150 m altitude band was observed to be the most densely used at the Presque Isle and Alcona counties (Figure 43) with a total of 2.15 targets per 1,000,000 m^3 per night-hour and 3.56 targets per 1,000,000 m^3 per night-hour, respectively. The maximum density of targets was below 150 m during 85.3% and 71.6% of the nights at the Presque Isle and Alcona sites, respectively (Figure 44). A similar pattern, although with more variation, occurred if the hours from 20:00—04:00 were considered individually, with the maximum density of targets occurring at less than 200 m during 56.3% and 43.2% of these night hours at the Presque Isle and Alcona site, respectively (Figure 45).

At both sites, targets were observed within the entire range of altitude bands sampled. Mean altitude of nocturnal targets was 790 m ± 401 m SD and 731 m ± 533 m SD above ground level at our Presque Isle and Alcona sites, respectively. Median altitude at night was 618m and 577 m above ground level at the Presque Isle and Alcona sites, respectively. Median altitude was greatest during the night and dawn biological time periods. While many radar reports include estimates of mean and median altitude of targets, we found that these estimates were poor indicators of maximum density (Table 9) due to the difference in volume of sampled air space at various altitude bands.

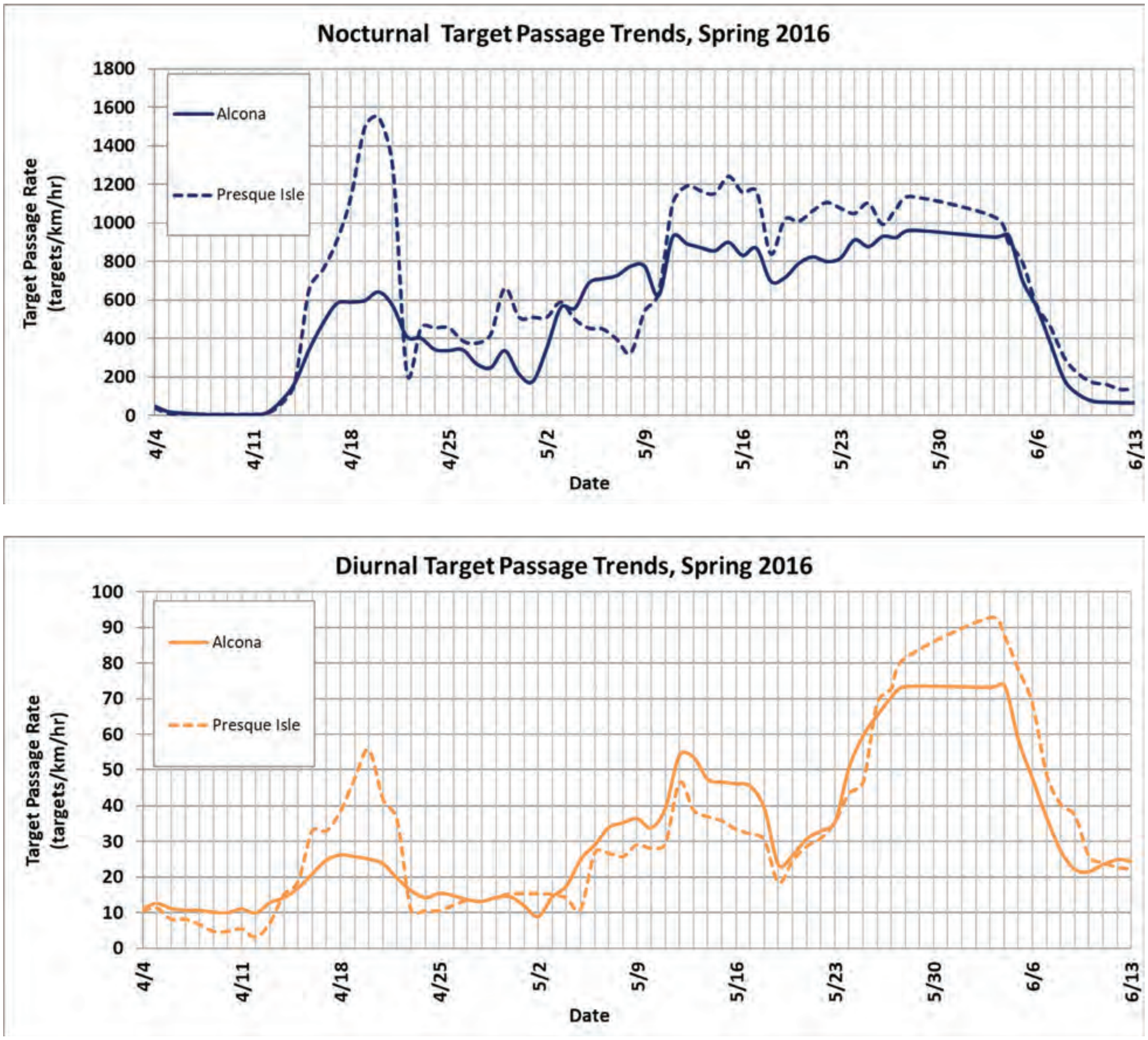


Figure 38. *Comparison of nocturnal (top row) and diurnal (bottom row) target passage trends (based on a moving 7-day mean) during spring 2016 in Presque Isle and Alcona counties, Michigan.*

Mean altitude per hour during the season showed a similar pattern at the two locations (Figure 46). Mean altitude increased following dusk, tapered around the 21:00 and 22:00 hours, and decreased following midnight. A spike in mean altitude occurred during the 05:00 and 06:00 hour in at both sites. These time periods occur during or near dawn during at least a portion of the survey period (Figure 46). Altitude also varied in density among time across the season. At the Presque Isle site (Figure 47), the greatest density of migrants occurred during the nocturnal hours, and migrants generally were most dense at less than 300 meters, suggesting heavy use of the lower airspace. High migrant density expanded to higher altitudes during dawn and dusk periods, suggesting that migrants may fly higher during these times to orient for nightly migration at dusk and towards safe habitat at dawn. Likewise, the Alcona site had the highest density of migrants during nocturnal hours and migrant density was highest below 350m (Figure 48). However, there is no expansion of high density at dawn and dusk at Alcona. One possible explanation for this difference is the presence of a water crossing north of the Presque Isle site that may require migrants to inspect and orient to the crossing, while they can follow the shoreline at the Alcona site.

Table 9. Comparison of mean altitude (m) with standard deviations, median altitude, and altitude band (50 m bands) that contained the maximum target density during four biological periods at our sites in Presque Isle and Alcona Counties during spring 2016. Max band densities represent the top of the altitude band.

	Presque Isle, MI			**Alcona, MI**		
Biological Period	*Mean*	*Median*	*Max Density Band*	*Mean*	*Median*	*Max Density Band*
Dawn	763 ± 551	595	150	737 ± 501	610	150
Day	437 ± 398	316	150	527 ± 478	376	100
Dusk	395 ± 401	244	200	731 ± 466	177	150
Night	790 ± 574	618	150	731 ± 533	577	200

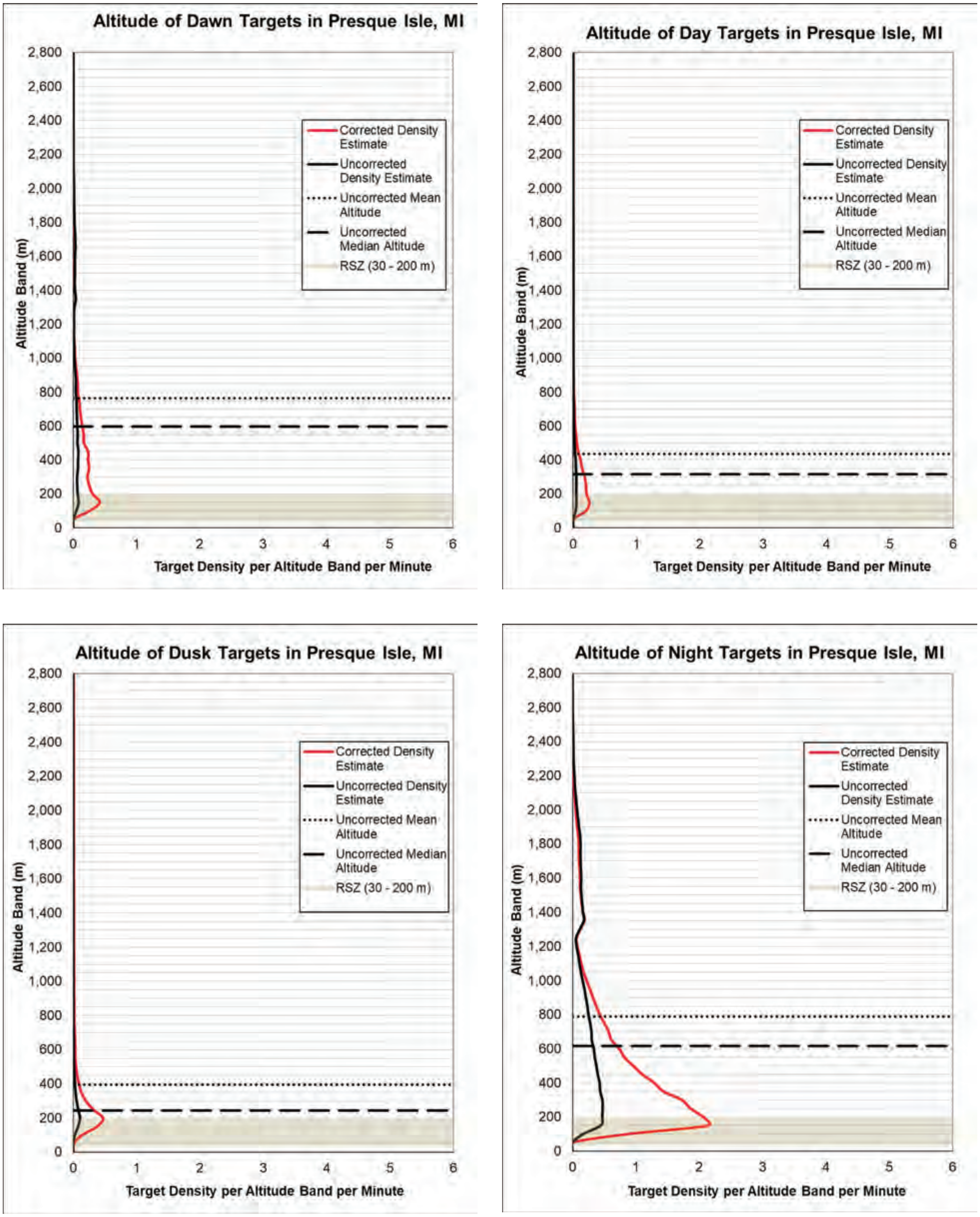


Figure 39. *Spring altitude profile of targets at our site in Presque Isle County. Corrected lines depict target density (targets/1,000,000* m^3*) per 50-m altitude band per hour after adjusting for the structure of the sample volume. Uncorrected lines depict target density per 50-m altitude band per hour with an assumed uniform volume distribution Tan band represents the rotor swept zone (RSZ) between 30—200 m. Y-axis labels represent the top of the altitude band.*

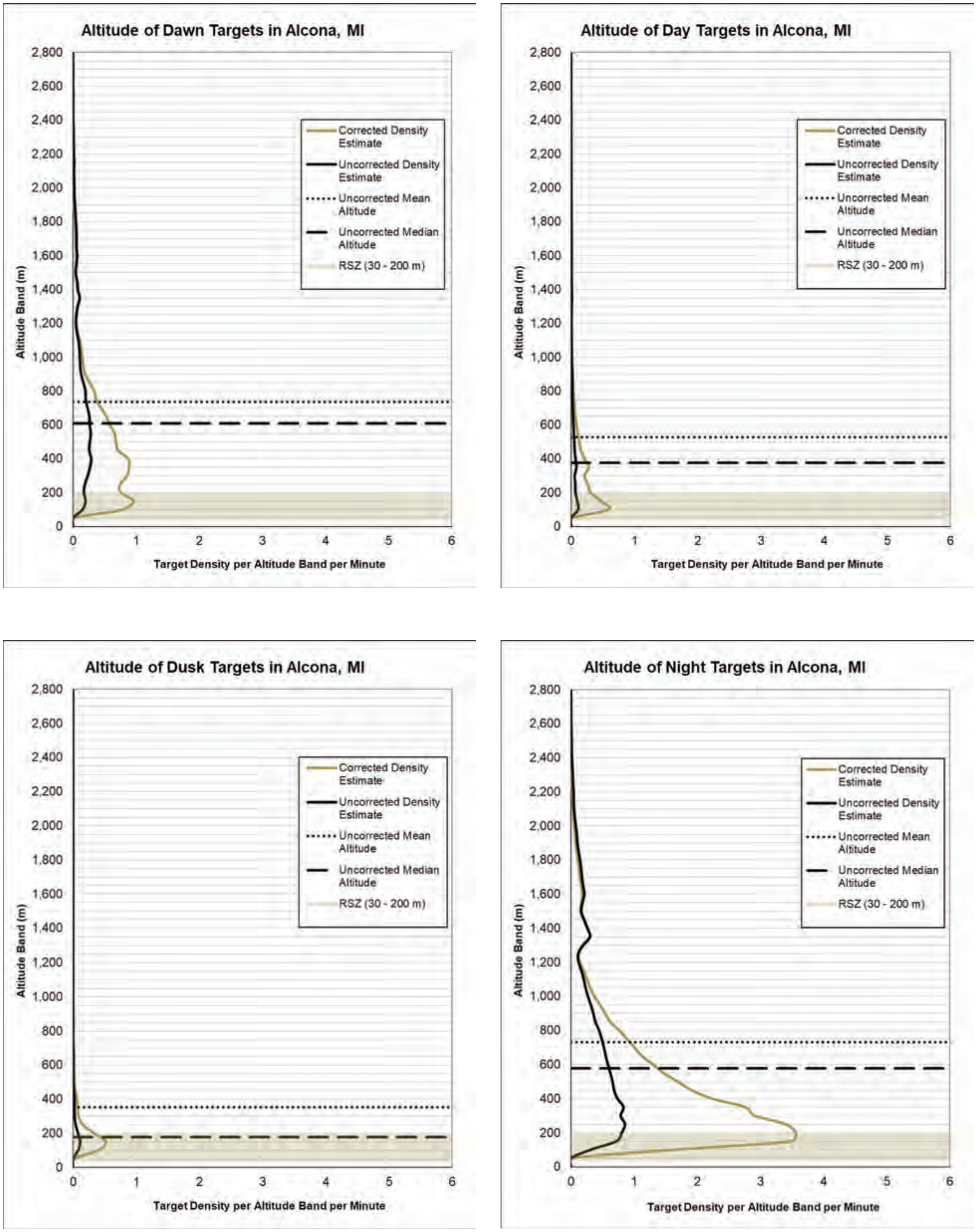


Figure 40. *Spring altitude profile of targets at our site in Alcona County. Corrected lines depict target density (targets/1,000,000 m3) per 50-m per hour altitude band after adjusting for the structure of the sample volume. Uncorrected lines depict target density per 50-m altitude band per hour with an assumed uniform volume distribution (volume of each band is equal to the total volume divided by the number of bands). Tan band represents the rotor swept zone (RSZ) between 30—200 m. Y-axis labels represent the top of the altitude band.*

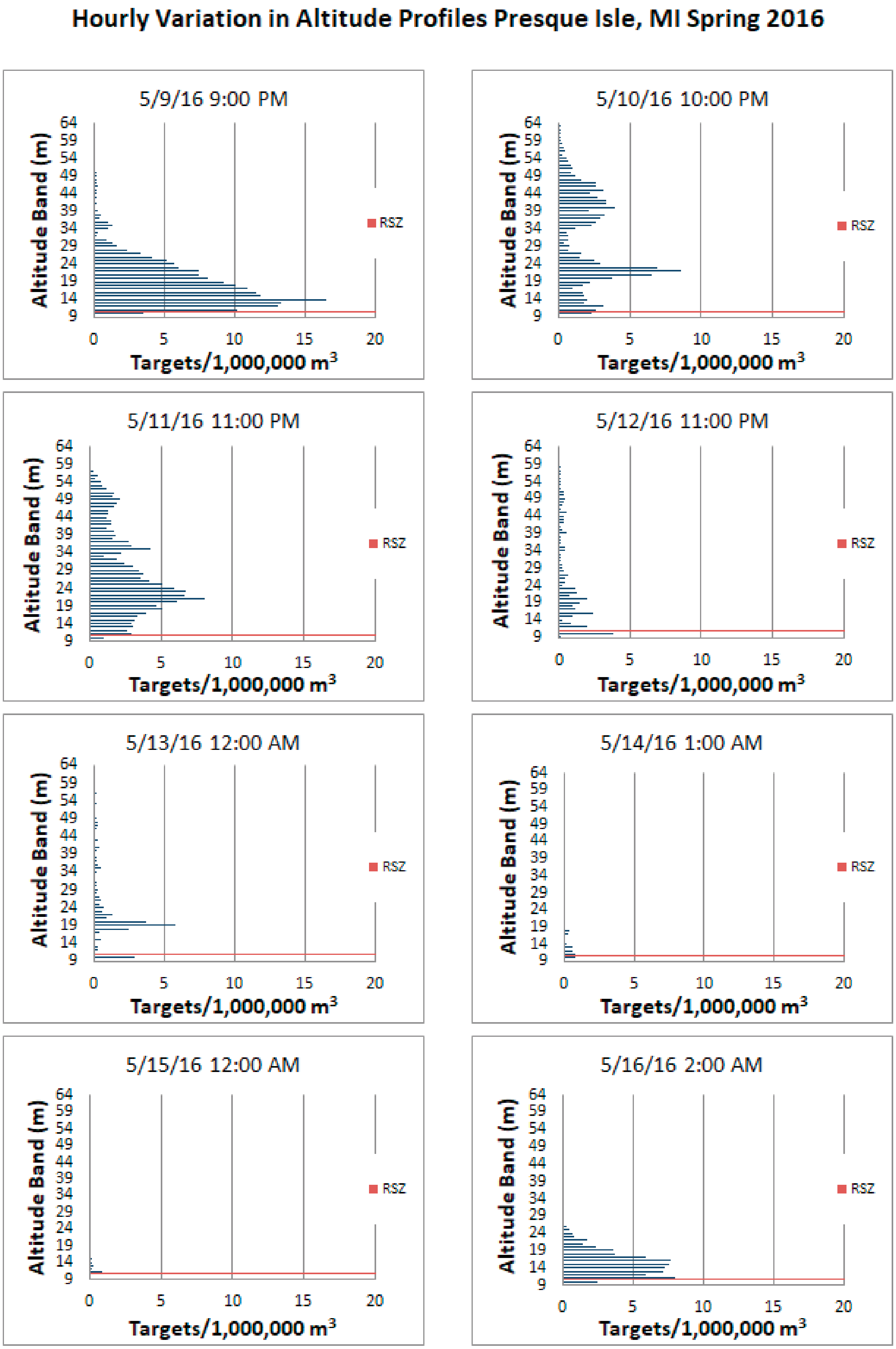


Figure 41. *A sample of hourly profiles corrected for the shape of the sample volume at our site in Presque Isle Co. during spring 2016. Hours were selected to portray the variability in density per altitude band of passing targets. The X-axis represents target density.The red line represents the top of the rotor swept zone at 200 meters. The Y-axis represents the top altitude.*

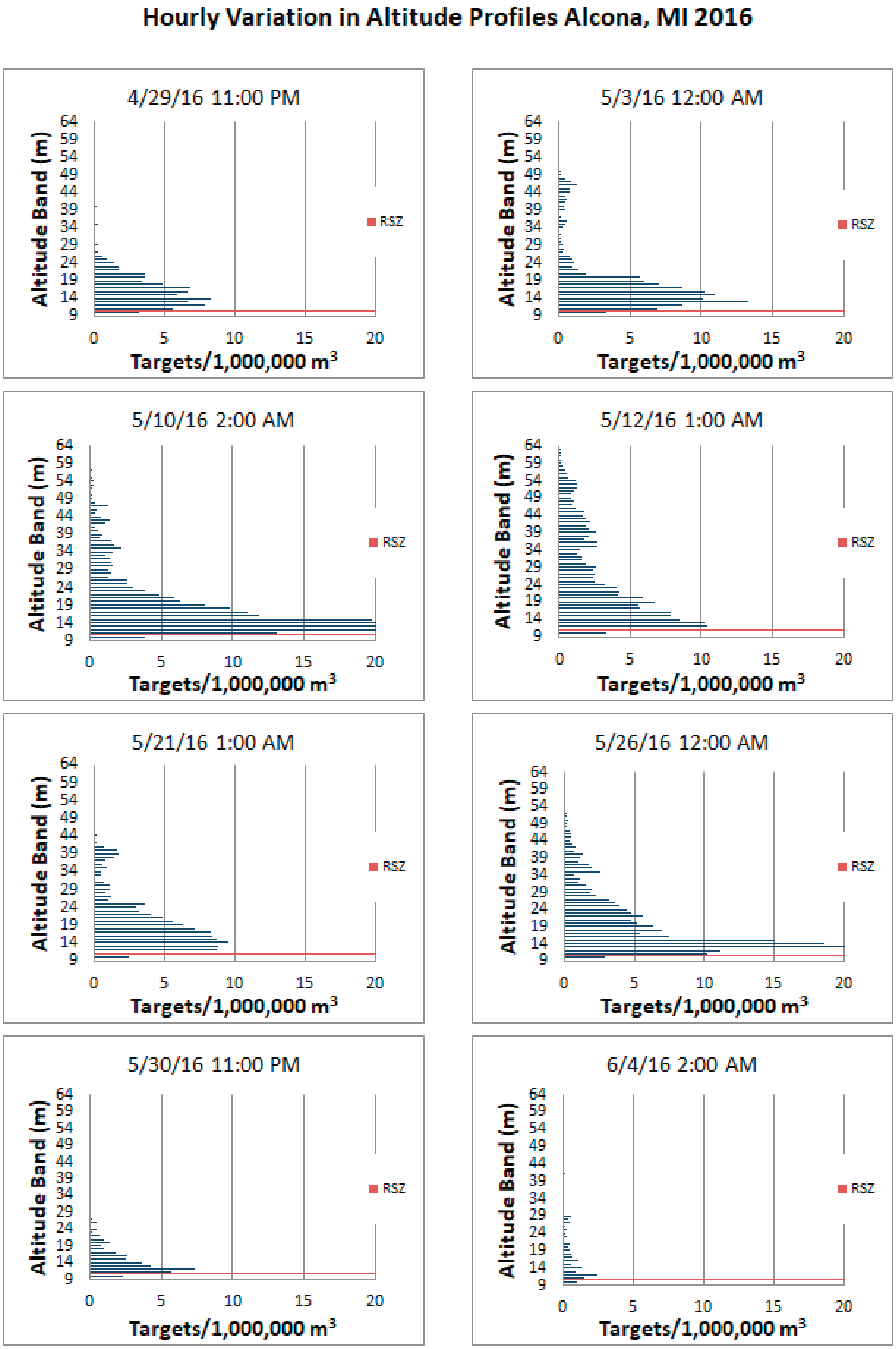


Figure 42. *A sample of hourly altitude profiles corrected for the shape of the sample volume at our site in Alcona counties during spring 2016. Hours were selected to portray the variability in density per altitude band of passing targets. The x-axis represents target density. The red line represents the top of the rotor swept zone at 200 m. Y-axis labels represent the top of the altitude band.*

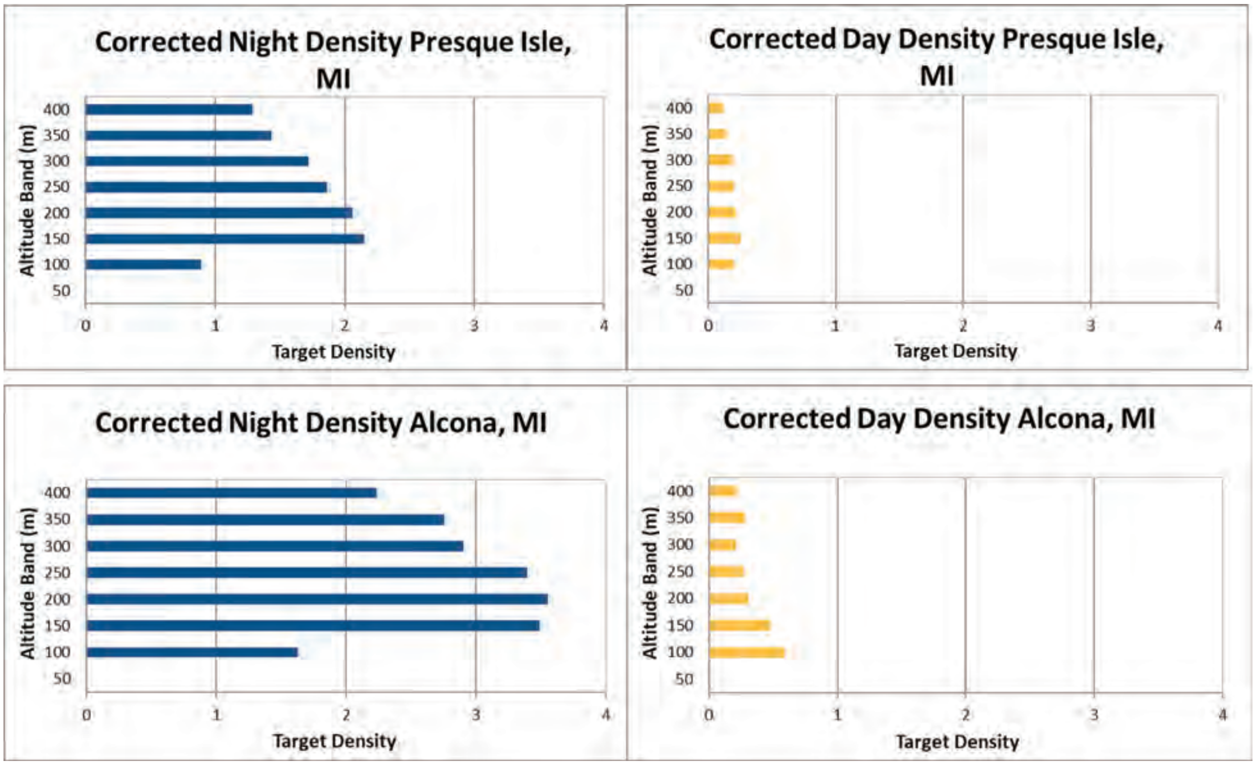


Figure 43. Altitude profile of corrected target density below 400 meters in Presque Isle and Alcona counties. The x-axis represents target density (targets/1,000,000 m3) per 50-m altitude band. Y-axis labels represent the top of the altitude band.

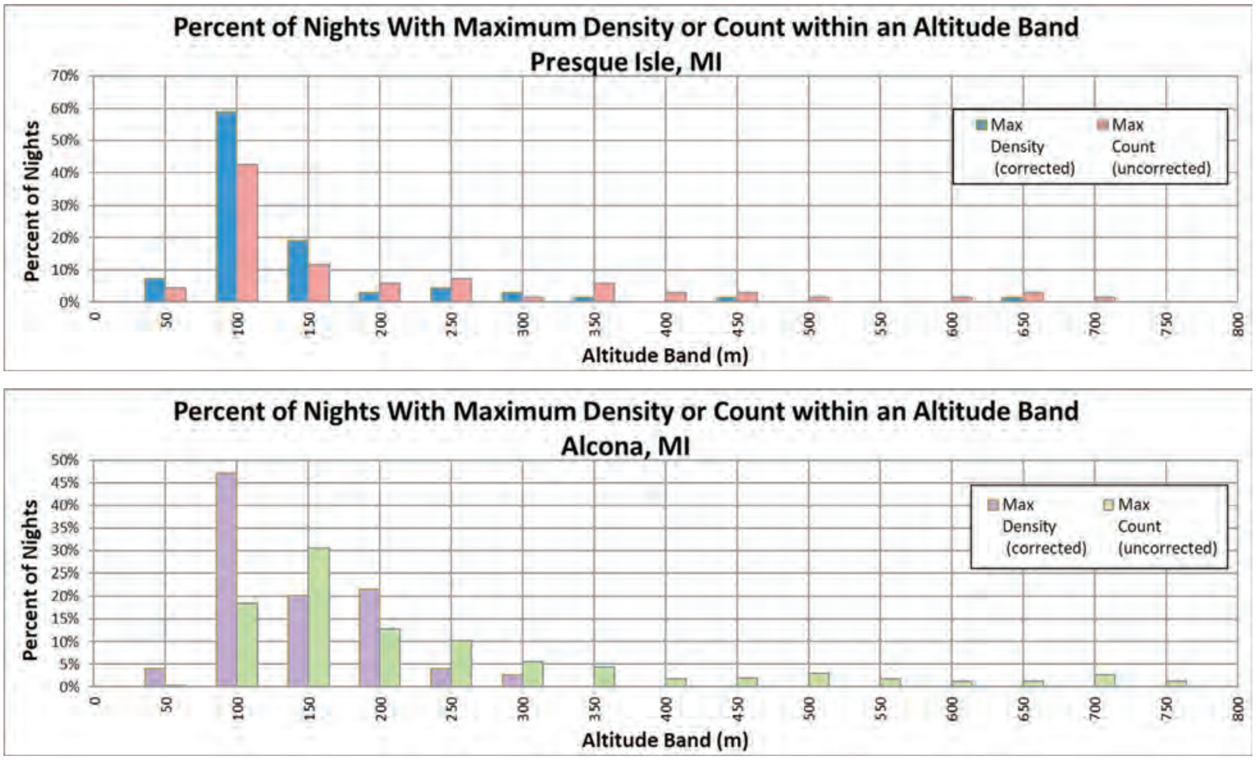


Figure 44. *Percent of nights when the maximum density (targets/1,000,000 m3/ altitude band) or count (targets/altitude band) occurred within 50-m altitude bands in Presque Isle and Alcona counties, during spring 2016. X-axis labels represent the top of the altitude band.*

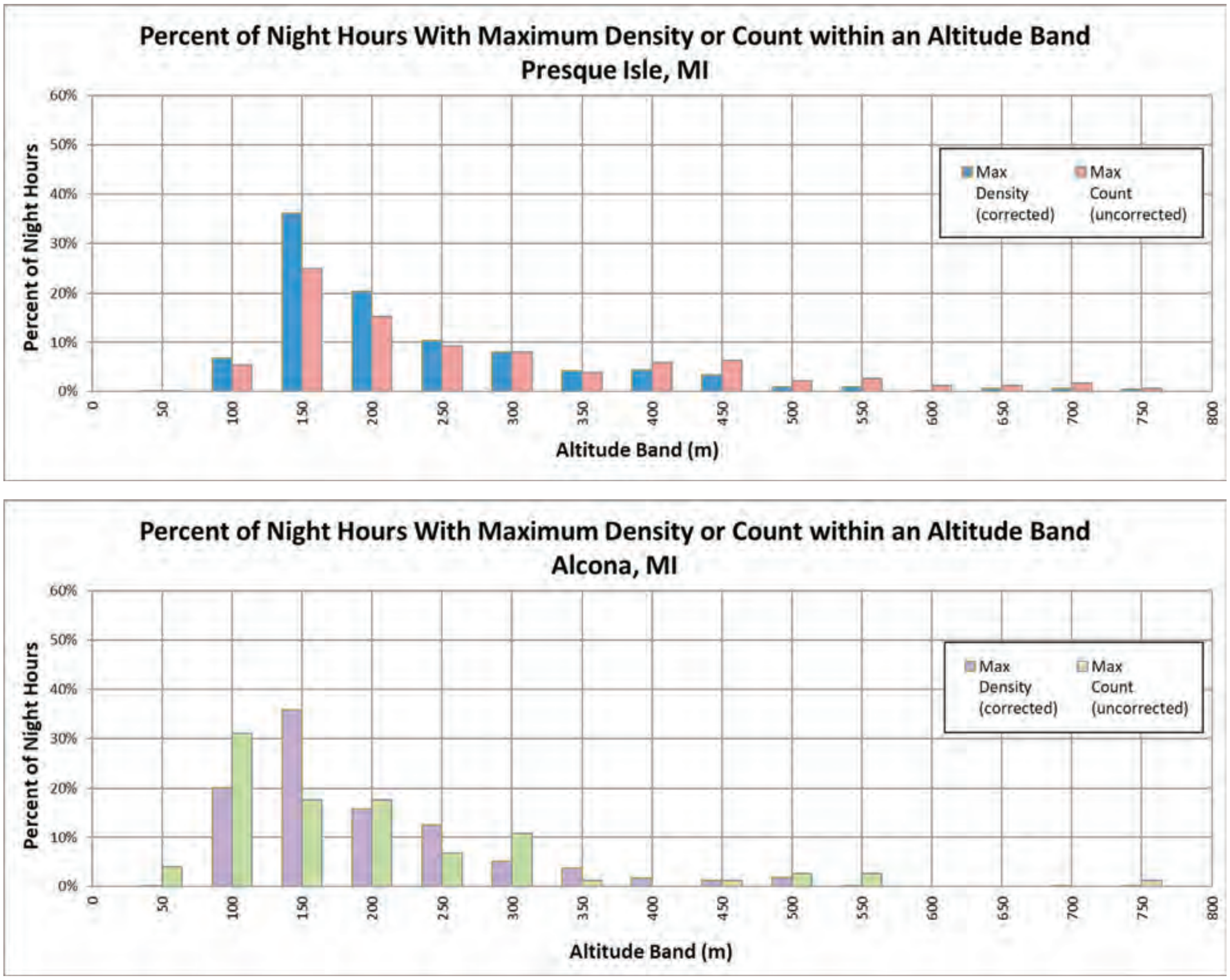
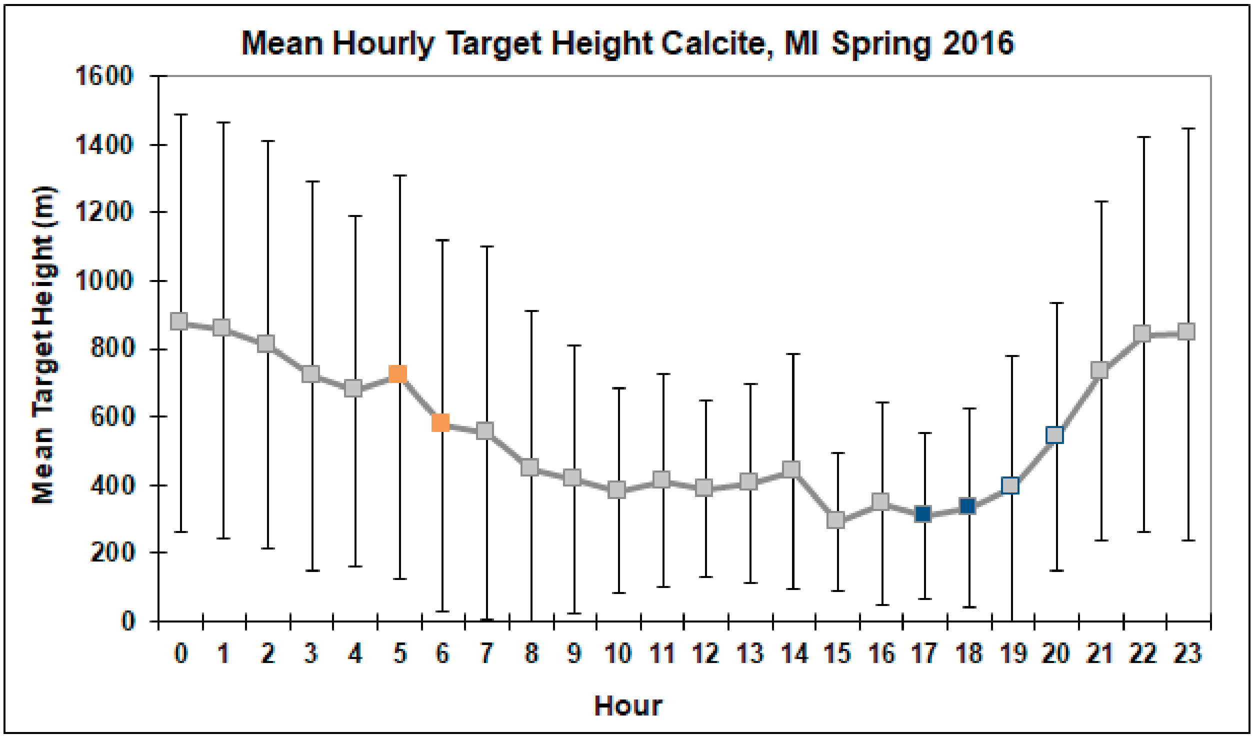


Figure 45. *Percent of night hours (20:00–04:00) when the maximum density (targets/1,000,000 m*^{3}*/ altitude band) or count (targets/altitude band) occurred within 50-m altitude bands in Presque Isle and Alcona Counties, during spring 2016. X-axis labels represent the top of the altitude band.*



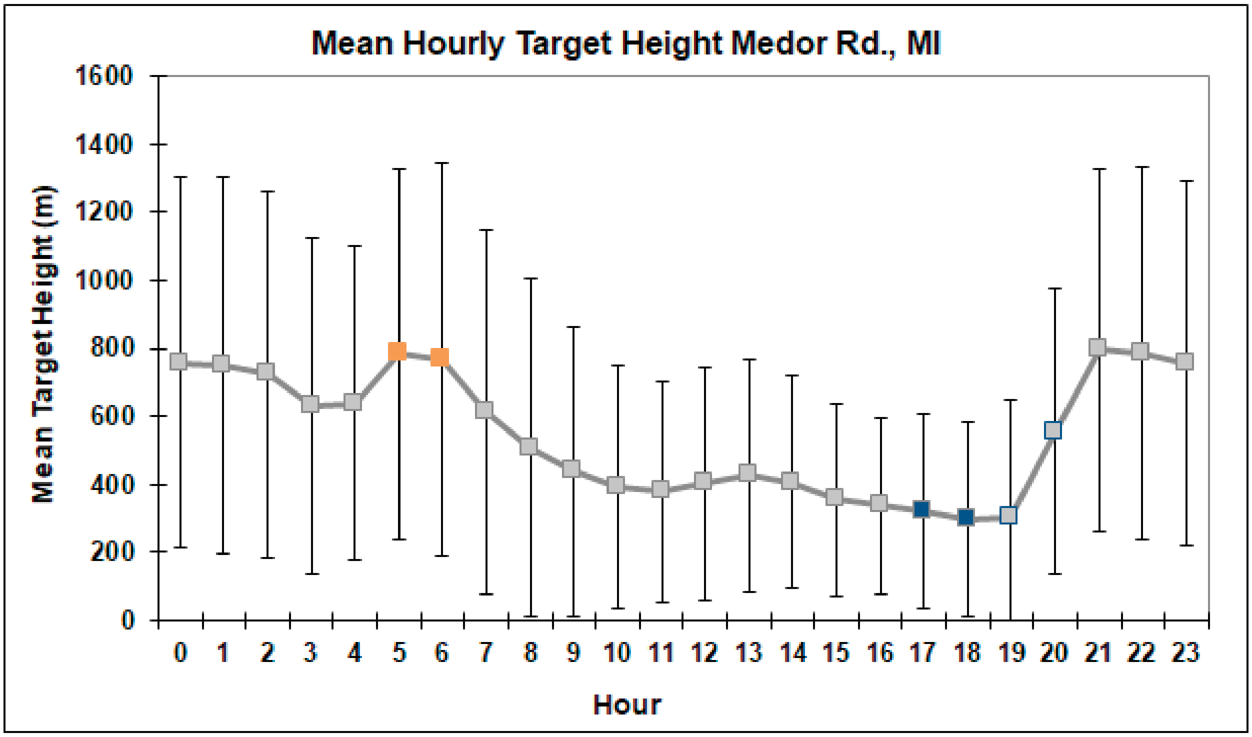


Figure 46. *Mean hourly target height (m) during spring 2016 in Presque Isle and Alcona Counties. Orange and blue markers indicate the hours in which sunrise and sunset occurred during the season, respectively. Error bars represent one standard deviation.*

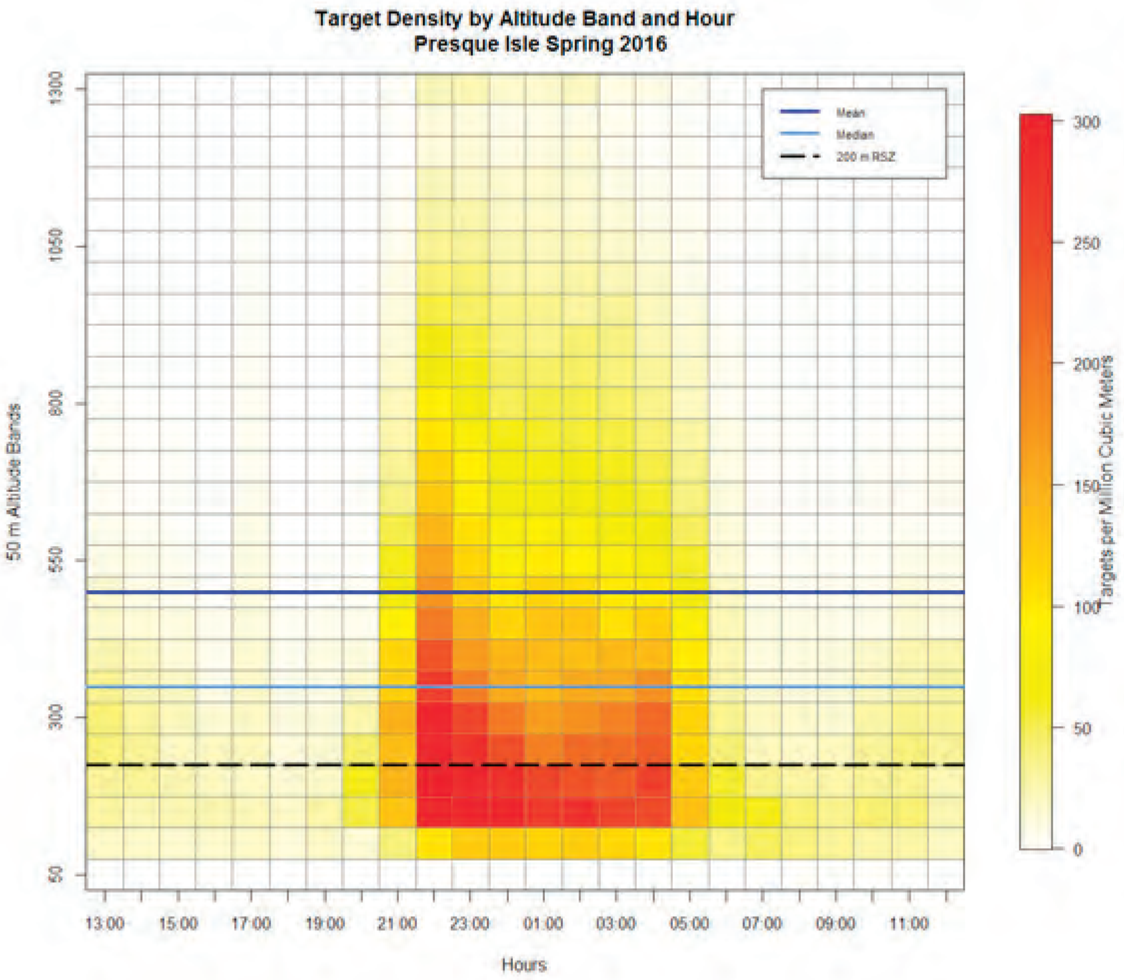


Figure 47. *Variation in flight altitudes based on target density (targets per million cubic m) at our site in Presque Isle throughout the spring study period. Altitude bands are in meters and labels represent the max value of each altitude band. Density of targets is in targets per million cubic meters. Colors shown in each rectangle indicate the relative density observed for that altitude (key shown on the right) and time. The dark blue and light blue lines represent the nocturnal mean and median target heights, respectively. The black dotted line at 200 m represents the maximum height of a turbine with a rotor-swept zone of 70-200 m. Note difference in density scale used in Figure 48.*

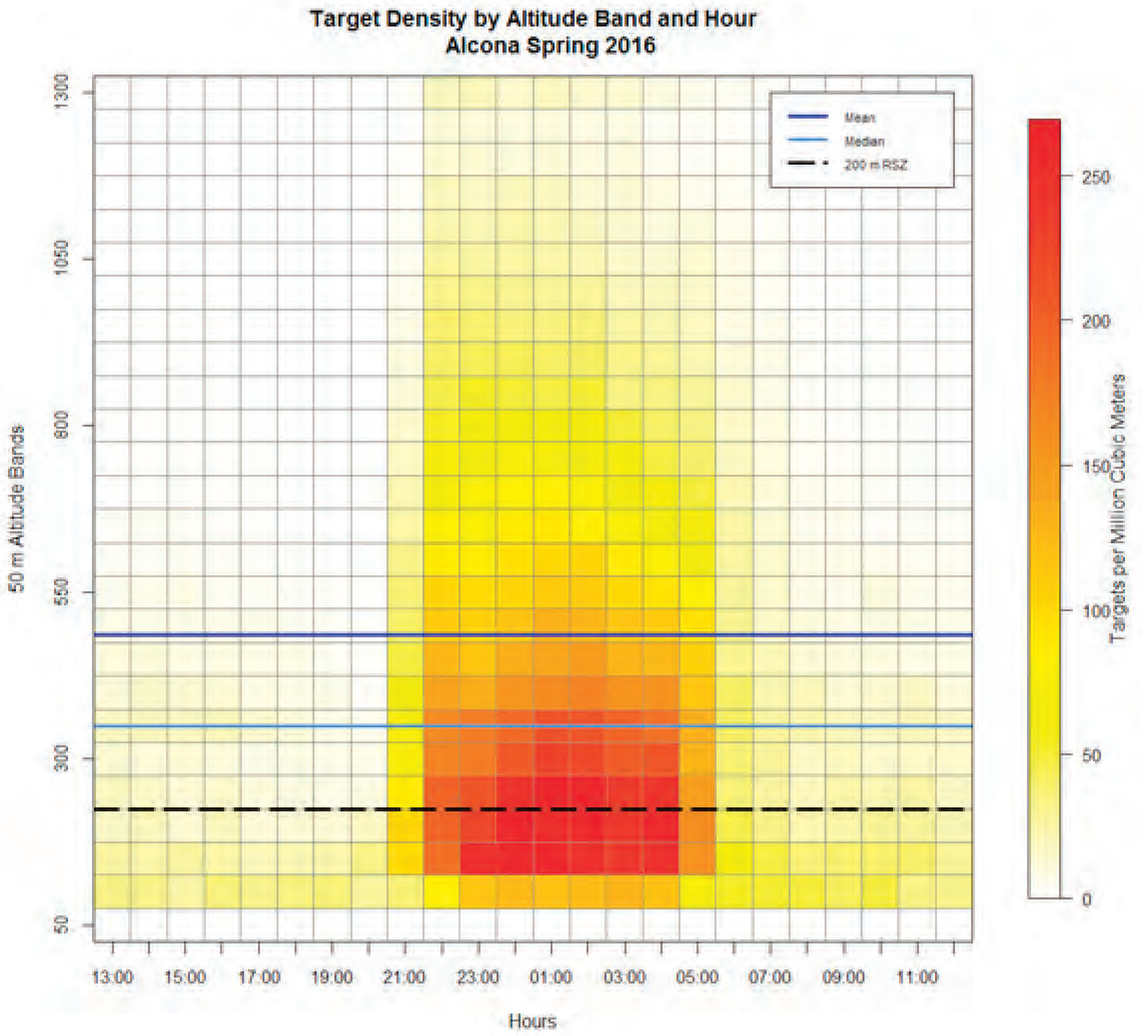


Figure 48. *Variation in flight altitudes based on target density (targets per million cubic m) at our site in Alcona County throughout the spring study period. Altitude bands are in meters and labels represent the max value of each altitude band. Density of targets is in targets per million cubic meters. Colors shown in each rectangle indicate the relative density observed for that altitude (key shown on the right) and time. The dark blue and light blue lines represent the nocturnal mean and median target heights, respectively. The black dotted line at 200 m represents the maximum height of a turbine with a rotor-swept zone of 70-200 m. Note difference in density scale used in Figure 47.*

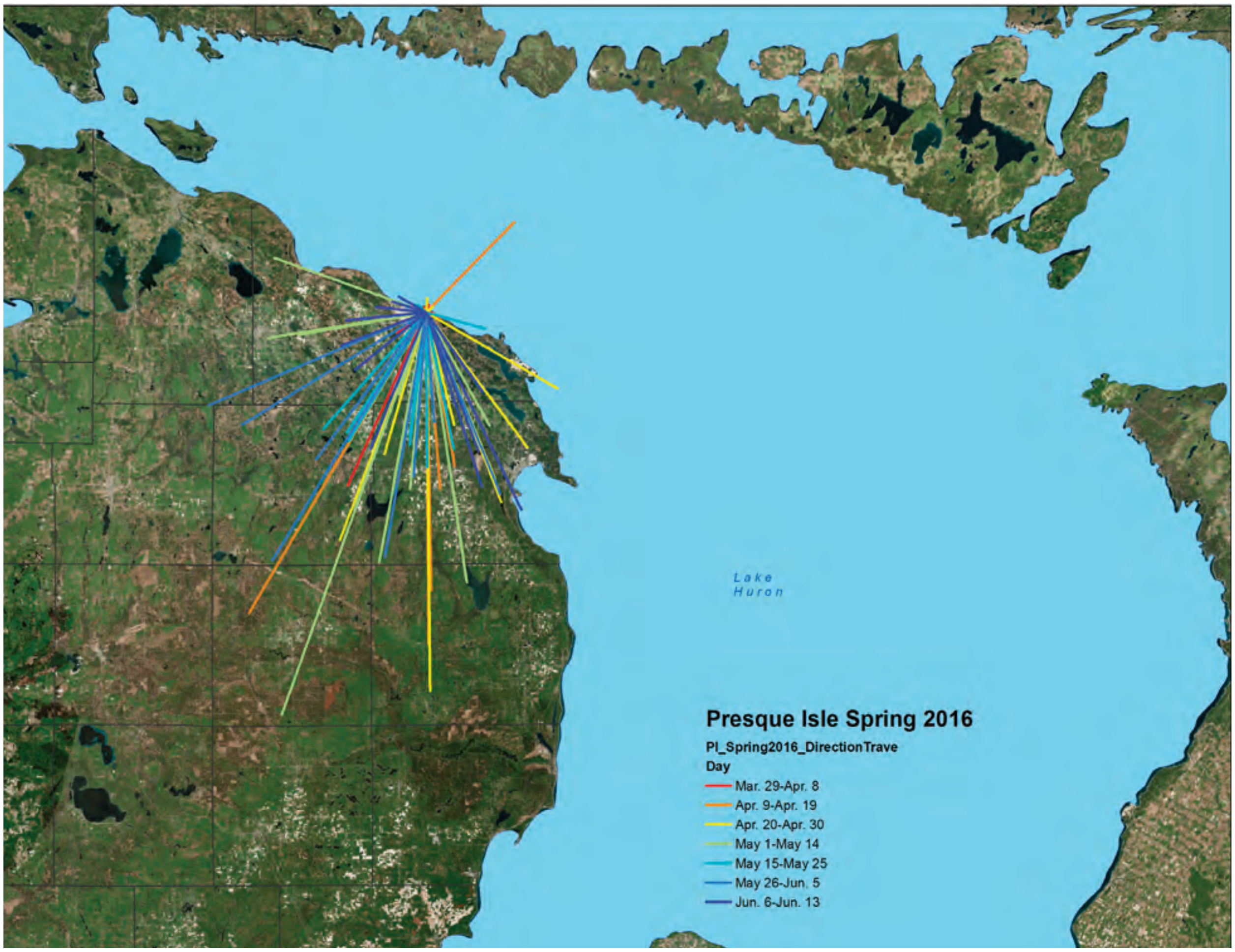


Figure 49. *Movement direction of targets for each night over the spring 2015 migration season for Presque Isle site. Each line represents the average origin direction of targets during one night. These directions are averaged across the night, and while orientation changes throughout the night, provide a general direction of flight. Line length is proportional to number of targets moving through the area. Line color denotes the time within the season, with cooler colors denoting later dates in the season. Note the more consistent direction of travel during the spring season compared to the fall (Figure 28).*

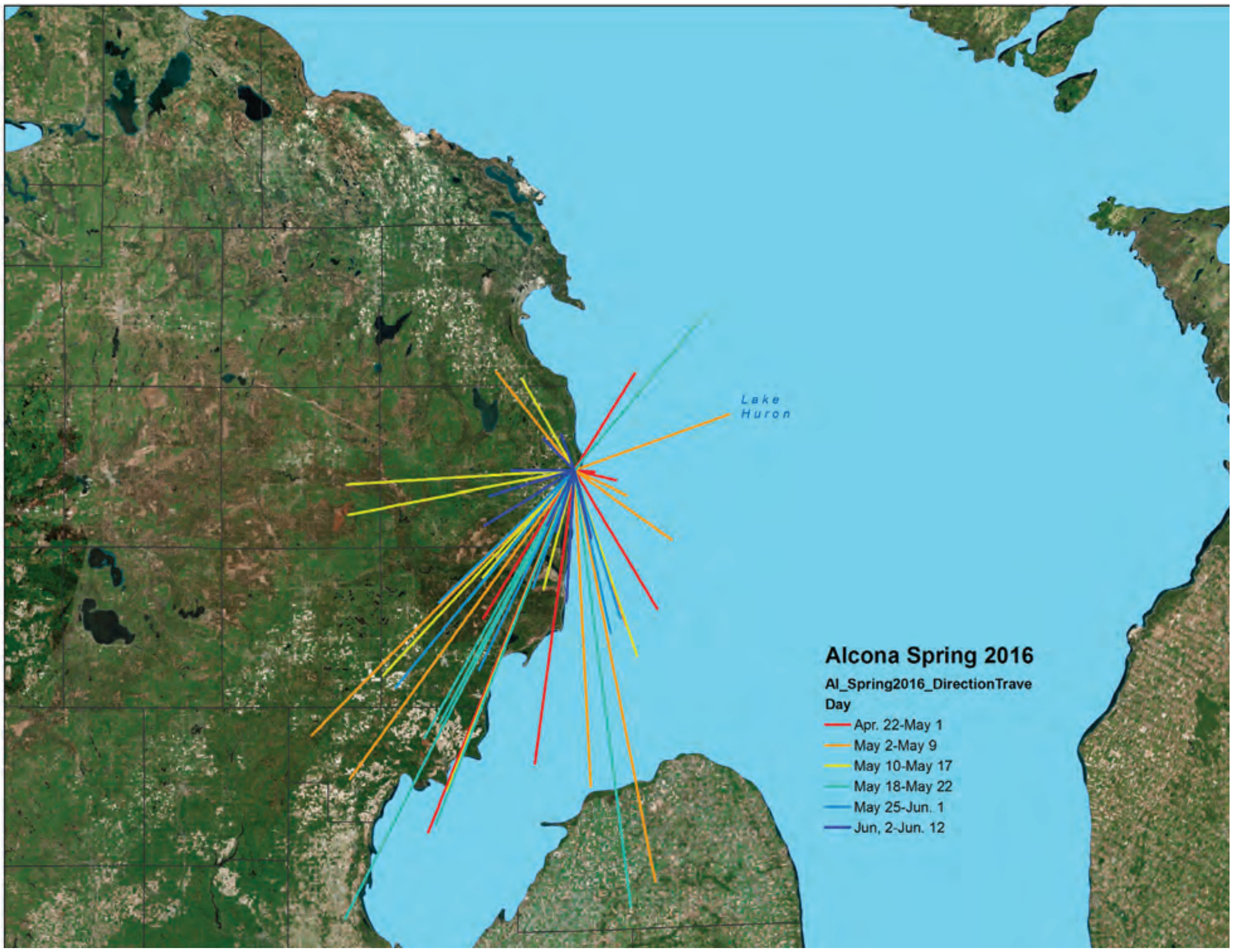


Figure 50. *Movement direction of targets for each night over the spring 2015 migration season for Alcona County. Each line represents the average origin direction of targets during one night. These directions are averaged across the night, and while orientation changes throughout the night, provide a general direction of flight. Line length is proportional to number of targets moving through the area. Line color denotes the time within the season, with cooler colors denoting later dates in the season. Note the majority of migrants are following the western shoreline of Lake Huron north.*

Discussion

We undertook this study to document migration along the shorelines of the Great Lakes. The fall 2015/spring 2016 seasons were the first time we stationed the radar units at the same sites for two consecutive migration seasons. By placing radars at the same sites for two consecutive seasons, we can more closely compare the similarities and differences between spring and fall migration. Overall, what we found indicates migration movements were common along the northwestern shorelines of Lake Huron, where we established our study sites. In addition, we believe that data collected at these two sites are representative of migration along the rest of the Lake Huron shorelines in the United States. Our research contributes to a growing body of literature that documents various aspects of migration and identifies Great Lake shorelines as important areas for the conservation of migratory species. Our data provide unique observations about the magnitude and timing of nocturnal migration that could not be observed without the aid of radar.

Loss of the horizontal radar at our Alcona County site limited observations to only the vertical radar for the duration of the fall 2015 season and the first 3.5 weeks of the spring 2016 season. However, vertical radar still provided substantial information on migration onset and conclusion, accurate counts of the number of targets observed, and altitudinal distribution of targets at the Alcona County site.

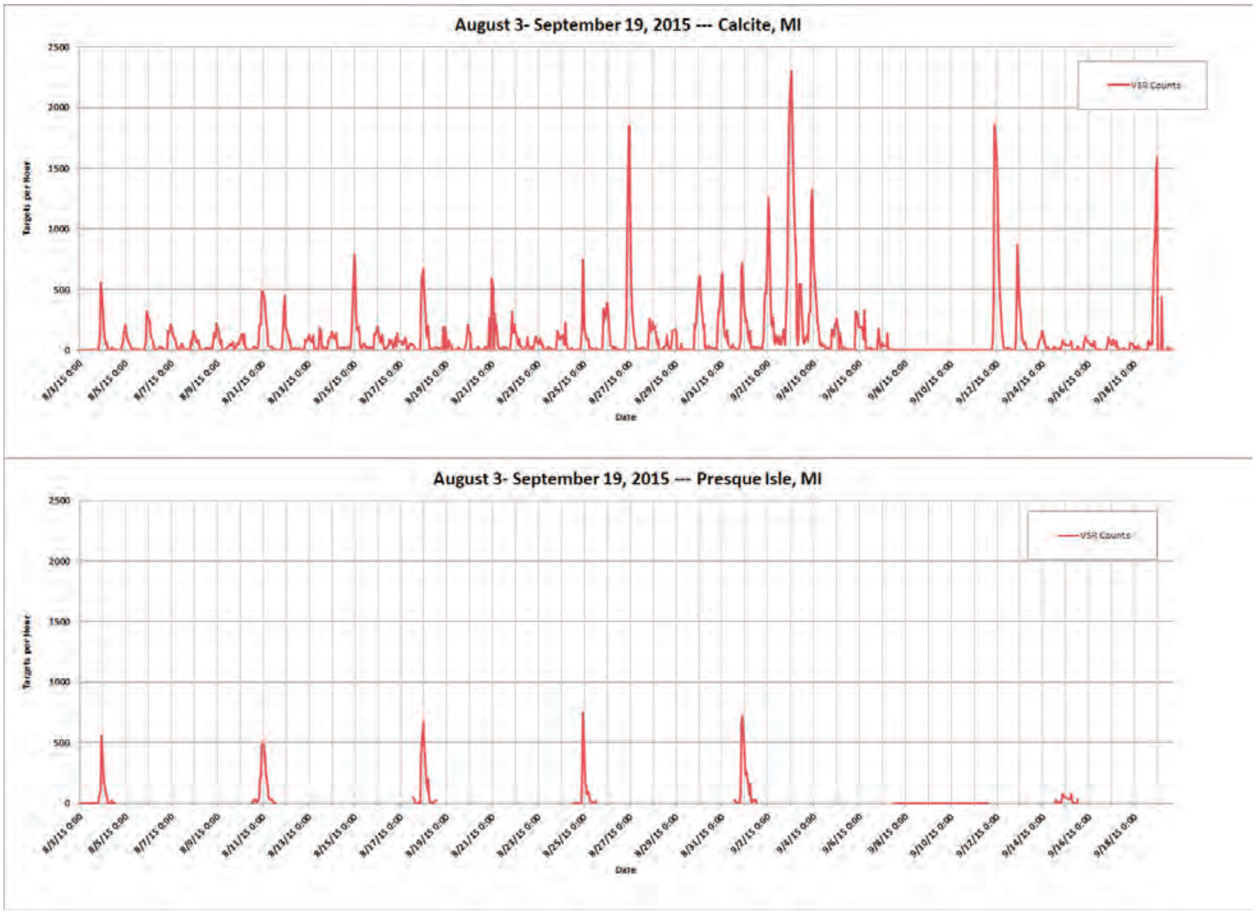


Figure 51. *Example of a hypothetical sampling schedule where data were collected once per week (top graphic) versus the actual continuous sampling schedule (bottom graphic). Red lines represent the number of targets counted per hour by the vertical scanning radar from August 3-October 27, 2015 in Presque Isle, Michigan.*

Sampling Regime

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, McGuire et al, 2012b). Our continuous sampling scheme captured the timing of migration events and provided a more complete picture of the migratory season than a systematic (e.g., once per week) or random sampling scheme, which may have missed pulses of activity, even at relatively high resolution (e.g., sampling once every four days, Figure 48). We used diurnal radar observations to provide a baseline for comparing nocturnal activity, and including this time period in the sampling scheme helped to distinguish the magnitude of migration events (Figures 11-12; 31-32). Our sampling regime in fall 2015 indicated that migration season began in late August, peaked in mid to late-September and declined by mid-October, although migration continued to occur sporadically through the end of sampling. In spring 2016, the migration occurred mainly during the month of May, although sporadic migration events also occurred during April and June as well. This information will help to tailor conservation efforts 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, tracking 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 that is relative to a site we are cautious in making comparisons among sites or studies. Rather than relying solely on the magnitude of target passage as an indication of migration, we assess the patterns of activity among sites to compare the relative strength of migration. For example, a site with nocturnal passage rates showing peaks much larger than the nocturnal lulls for most of the sampling period may be considered to have stronger migration than sites with less discrepancy between the peaks and lulls. A site where there were only occasional spikes of activity rather than more common spikes may be indicative of an area with lower migration, although this method may not be appropriate for all sites. The presence of behavioral indicators of obstacles, including movement to or along shore during dawn, and changes in direction of movement during the night suggest that these shorelines may indicate a risk to migrants in the area, along with more specific measures such as density of targets in the rotor-swept zone.

Migration Patterns

Patterns of movement we recorded were consistent with other observations of migration (Newton 2008) and indicated that nocturnal migratory flights occurred regularly during both fall 2015 and spring 2016 at both of our surveyed locations. During the fall season, the nocturnal activity we observed was typically oriented in a north/northeast direction (Figures 10 and 31) and occurred in pulses across the season that were captured by horizontal and vertical radars (Figures 11, 12, 32, 33).

We also observed targets returning to shore from open water at dawn (Figure 8, 29, 30). This movement to shore may be due to migrants drifting with the wind as they migrate and adjusting their position at dawn to locate suitable stopover habitat to rest a refuel (A. Peterson, pers. communication, Horton et al. 2016). Target passage rate (mean for the season) was greatest during the nocturnal biological time period at both locations (Tables 4, 8; Figures 13, 34). At each of our sites, mean hourly heights showed a pattern consistent with migration (Harmata et al. 2000, Mabee and Cooper 2004), with heights that increased near dusk, peaked a few hours before midnight, and began to decrease prior to dawn. Presque Isle County's mean hourly height pattern was similar to other locations we have investigated; however, the highest mean altitudes were recorded during dawn and not midnight (Figure 25). This could be driven by the location of the coastline at the site, which may act as a refuge point both for migrants moving south from the open water to the north, as well as individuals turning west towards shore from open water to the east. Targets at the Alcona County site in the fall and both Alcona County and Presque Isle County sites during the spring increased in mean height near dawn (Figures 25 and 26), 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. However, this may also be an artifact of averaging the dawn hours across the season. We are undertaking further studies to tease this apart. Taken together, we attribute these nocturnal observations to migrants and suggest that the shorelines we studied are important for their conservation.

During the fall season, nocturnal migrants moved across the landscape in several major waves. For Presque Isle County, three major waves moved through, centered on the dates of September 24, September 30, October 8, and October 10. The Alcona County showed slightly different timing of waves at September 20, September 30, October 8 and October 16. In all cases, the Presque Isle County events tended to occur on a single night or very few nights with little or no buildup, while the Alcona County site showed more gradual buildups to the peak dates. The differences between these sites may be due to optimal conditions in crossing the water barriers to the north of the Presque Isle County, which would suggest that migrants concentrate along the north edge of Lake Huron before moving across *en masse* during only the most favorable conditions, while migrants may continue to move south along the shore during times when weather conditions are still favorable, but not necessarily optimal.

During the spring season, fluxes of night migrants moved more consistently than the fall, with fewer pulses. At our Presque Isle County site, there was a large spike of migrants May 10–12, followed by a lower, but consistent set of peaks from May 16–29. Our Alcona County site did not demonstrate a spike of migration, and instead had consistent nightly migration from May 10 to June 4. We speculate the spike in migration at the Presque Isle County site may be due to migrants waiting for favorable conditions early in the season, but this explanation does not account for the consistent pattern of migration afterward.

Flight Altitude

Altitude profiles indicated that most nocturnal targets passed below 800 m with peak density in the 150-250 m altitude bands (Figures 18, 19, 21, 39, 40, and 43). 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 (Schmaljohan et al. 2008); in addition, our vertical scanning radars had reduced detection at a range of about 1,400–2,000 m where the radar transitioned from the short to medium pulse. For these reasons, our estimates likely under-represent density as altitude increases. There is a minor increase around 1,400 m that might be undercounted during night migrations (e.g. Figure 18), but is unlikely to change the overall picture.

Altitude profiles that we report varied considerably among nocturnal hours at our sites in Alcona and Presque Isle Counties (Figures 19, 20, 41, 42). Migrants adjust flight altitude with wind direction, 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). As well, 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 or 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.

Comparison of Spring and Fall Migratory Seasons

Migration rates were different in the spring and fall at these sites. While fall migration appeared to occur in more episodic fashion, spring migration was continuous and stable. There are a number of potential reasons for these differences. First, fall migration strategies could reap benefits by waiting for more favorable weather. Second, this strategy could be increased by an overall higher body condition from ample food resources on the breeding grounds. In contrast, this episodic nature could be due to more difficult crossings of ecological obstacles in the fall, necessitating more favorable weather conditions for crossing, or due to other behavioral factors (e.g., fall mating seasons in the case of migratory bats; Cryan and Brown 2007). Naïve migrants (e.g., young of the year) may also use different strategies than experienced migrants, causing larger pulses. Spring migrants, especially male birds, are often attempting to reach breeding ground early in order to attempt to acquire the best possible territory for the breeding season, which may motivate migrants to cross ecological obstacles during less than optimal conditions (Francis and Cooke 1986, Dierschke et al. 2005). Combined with females following the males during warmer periods, this could produce the more consistent migration pattern we observe in the spring. What drives differences in migration tempo between spring and fall migration season merits further attention.

For horizontal radar directionality, we can only compare the Presque Isle County site between the seasons. We found that direction was oriented broadly south in the fall and north in the spring (Figures 8-10; 29-31). However, the mean circular concentration, *r*; providing a measure of uniformity of movement showed that during day and dusk, the *r* of movement directions was much higher in spring than in fall (Tables 3, 7). While the reasons for the stronger daytime concentration are unclear, the dusk concentration may indicate faster navigational orientation. Studies of migrants and homing birds found that juvenile birds tend to orient less accurately than adults, which could reduce concentration (Moore 1984). Thus, the spring increase in mean angular concentration could be due to the lack of naive birds in the population in spring compared to the fall.

We found that altitudes at both sites were on average similar in densities among altitude bands at both sites for most of the night (Presque Isle: Figures 26 and 47; Alcona: Figures 27 and 48) among seasons. However, during the spring season at Presque Isle we found a strong increase in density across altitude bands at dusk hours. Additionally, during the fall season we observed a more modest increase in density across altitude bands at the Alcona site. We speculate that for both sites, this phenomenon may be due to migrants increasing flight altitudes in order to orient and determine crossing lengths across open water. At Presque Isle, for instance, there is a high density of migrants at dusk to ~400-m altitude, with density gradually reducing above this altitude. At 400 m, the horizon is calculated to be at 71 km (assuming no diffraction), well past the 60 or so km to the northern coastline of Lake Huron. Likewise, the Alcona site data shows a similar increase in the fall, which could be due to migrants orienting to cross either Lake Huron (133 km across) or Saginaw Bay (76 km across). Future work comparing spring and fall density spikes at other crossings could help establish if this is a widespread pattern.

We emphasize that these findings are from only two sites for two seasons, and should not be generalized without caution. Site-specific attributes (e.g., Presque Isle County's two large water crossings), anomalous weather in one or both seasons, and interannual variation in migration patterns, singly or together could be driving a large amount of what we perceive as the interseasonal patterns. In addition, differences in migratory behavior among species and taxa (e.g., birds vs. bats) cannot be disentangled solely with radar data. Finally, differences in detectability among sites make it difficult to directly compare sites in a quantitative manner. Additional work needs to be done to quantify and correct detectability differences so further comparisons with a larger sample of data across multiple sites and years in can be undertaken to tease apart the differences between spring and fall migrations.

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. 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 these 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 (Tables 5 and 9; also see Figures 26–27 and 47-48). 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 23-27; Figures 44-48). 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 which we 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 migrant birds and bats.

Management Considerations

These data provide a large picture of migration that we need to put in perspective. Our radars were located along the shoreline, which is the area where we can gain the best picture of many migrant behaviors. The general patterns along the shorelines of Lake Huron reveal that these areas are used heavily by nocturnal migrants during both spring and fall migration. This pattern of migration is evident from our sample Trackplots as well as the timelines from each of the sites. Beginning in late August, migration occurs on many if not most nights, and continued through the end of our observations in late October. We observed migrants coming over the open water to the shore in our Presque Isle County site, and following the shore south at both sites. spring migration season began in mid-April and continued until early June. We observed migrants following the shore of Lake Huron crossing the open water between Michigan's lower and Upper Peninsula. 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 the shoreline area may be encountered by more than just migrants moving from the areas directly to the north or south.

A close look at the different biological time periods also reveals information about the importance of the shoreline area. The high levels of activity at both sites during dusk may represent birds and bats leaving their stopover habitat to continue with their migratory journey. High activity levels at dawn may be due to new migrants moving into land in the stopover habitat after moving into the area at night or coming in from flying over the water. These newly arriving birds and bats may be in different guilds, may be heading to different wintering areas, may be arriving from different breeding grounds, may 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 22-24; 26-27;44, 45, 47, 48). Nocturnal and diurnal migrants change altitudes depending on environmental conditions, and thus, migrants in altitude bands that are near the rotor-swept zone may also be at risk. In addition, our analysis only shows a typical rotor-swept zone for turbines constructed at the time of this study. Wind turbines are already being constructed to higher altitudes (Eller 2015), with larger rotor-swept zones extending into the altitude bands above where turbine blades currently reach, which will likely impact more migrants (Figures 26, 27, 47, 48).

Our data demonstrate that the shoreline areas of Lake Huron 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 highlights the need to avoid development in these migration corridors as recommended in the USFWS wind energy guidelines (USFWS 2012).

The results of our research highlight the potential role of radar in implementing recommendations from the USFWS 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 Huron, 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 Huron 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, UK.

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/. (accessed May 2015)

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

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 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. Environmental Law 41:355-370.

Cryan, P. M. and A. C. Brown. 2007. Migration of bats past a remote island offers clues toward the problem of bat fatalities at wind turbines. Biological Conservation 139:1–11.

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

Dechmann, D. K., M. Wikelski, D. Ellis-Soto, K. Safi, and M. T. O'Mara. 2017. Determinants of spring migration departure decision in a bat. Biology letters 13:20170395.

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. M. Bates, D. E. Willard, and T. P. Gnoske. 2014. Bird mortality during nocturnal migration over Lake Michigan: a case study. Wilson Journal of Ornithology 126:19–29.

Dierschke V., B. Mendel, and H. Schmaljohann. 2005. Differential timing of spring migration in northern wheatears Oenanthe oenanthe: hurried males or weak females? Behavioral Ecology and Sociobiology 57:470–480.

Dzal, Y., L. A. Hooton, E. L. Clare, and M. B. Fenton. 2009. Bat activity and genetic diversity at Long Point, Ontario, an important bird stopover site. Acta Chiropterologica, 11:307–315.

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.

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.

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).

Francis, C, M. and F. Cooke. 1986. Differential timing of spring migration in wood warblers (Parulinae). The Auk 103:548–556.

Frick, W. F., E. F. Baerwald, J. F. Pollock, R. M. R. Barclay, J. A. Szymanski, T. J. Weller, A. L. Russell, S. C. Loeb, R. A. Medellin, and L. P. McGuire. 2017. Fatalities at wind turbines may threaten population viability of a migratory bat. Biological Conservation 209:172–177.

Fry, J., Xian, G., Jin, S., Dewitz, J., Homer, C., Yang, L., Barnes, C., Herold, N., and Wickham, J., 2011. Completion of the 2006 National Land Cover Database for the Conterminous United States, PE&RS, Vol. 77(9):858–864.

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, and T. L. DeVault. 2016. Evaluation of an avian radar system in a midwestern landscape. Wildlife Society Bulletin 40:150–159.

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 36:773–783.

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): 390–410

Horton, K. G., B. M. Van Doren, P.M. Stepanian, W.M. Hochachka, A. Farnsworth, and J.F. Kelly. 2016. 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.

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

Johnson, P. L. 2013. Migratory Stopover of Songbirds in the Western Lake Erie Basin. Doctoral dissertation, Ohio State University.

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: 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. Journal of Field Ornithology 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. University of Kansas Publications Museum of 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.

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. 1984. Age-Dependent Variability in the Migratory Orientation of the Savannah Sparrow (Passerculus sandwichensis). Auk 101:875–880.

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. Elsevier, London, 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.

Press, W. H., S. A. Teukolsky, W. T. Vetterling, and B. P. Flannery. 2007. Numerical recipes: the art of scientific computing. 3rd ed. Cambridge University Press, Cambridge, UK.

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. Pages 363-414 in E. G. Crichton and P. H. Krutzsch, editors. Reproductive biology of bats. Academic Press, Cambridge, MA, USA.

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, 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.

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: e27054

Timm, R. M. 1989. Migration and molt patterns of red bats, Lasiurus borealis (Chiroptera: Vespertilionidae). Illinois Bulletin of the Chicago Academy of Science 14:1–7.

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 (DOE). 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. www.nrel.gov/docs/fy08osti/41869.pdf (accessed May 2015).

U.S. Department of Energy (DOE). 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. www.energy.gov/sites/prod/files/WindVision_Report_final.pdf (accessed May 2015)

U.S. Energy Information Administration (EIA). 2017. Wind turbines provide 8% of U.S. generating capacity, more than any other renewable source. www.eia.gov/todayinenergy/detail.php?id=31032. (accessed March 2018).

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. Crossley. 1992. Visible morning flights of neotropical landbird migrants at Cape May, New Jersey. Auk 109:500–510.

Zar, J. H. 1999. Biostatistical Analysis, 4th ed. Prentice Hall, New Jersey, USA. 662 pp.

Appendices

Appendix 1: **Fall 2015 and Spring 2016 Report Summary**

Appendix 2: **Percent Land Cover Associated with Study Sites and the 2006 National Land Cover Database Classification**

Appendix 3: **Corrected Density per Hour by Biological Period**

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Appendix 1

Fall 2015 and Spring 2016 Report Summary

- Migration occurred on the western shoreline of Lake Huron during fall 2015 and spring 2016.
  - Migration was identified by uniformity of movement of direction (south in the fall, north in the spring) 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
    - Three main waves of nocturnal migration in the fall with highest concentrations near September 20, September 30, and October 8–16
    - Consistent nightly migration but no waves or pulses May 10–June 4, with a pulse at one site May 10–12
- Date range of pulses that occurred during the fall migration season
  - Began on August 27 in Presque Isle County, MI and August 26 in Alcona County, MI
  - Ended on October 27 in Presque Isle County, MI and Alcona County, MI
- Date range of migration that occurred during the spring migration season
  - Began on April 15 in Presque Isle County, MI and April 16 in Alcona County, MI
  - Ended on May 29 in Presque Isle County, MI and May 28 Alcona 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
    - 65% of nights surveyed the mean direction of travel was between S and SW during fall at Presque Isle County, MI
    - 59% of nights surveyed the mean direction of travel was between NE and NW during spring at Presque Isle County, MI
    - 67% of nights surveyed the mean direction of travel was between NE and NW during spring at Alcona County, MI
  - Movement in towards and/or along the shore at dawn
    - Observed at both sites during both seasons
  - Highest target passage rate at night
  - Dawn ascent
    - Slight increase in height around dawn hours observed at all sites
- Peak density of targets in volume corrected counts
  - Max density below 150 m during 79.7% of fall nights and 51.1% of fall night hours at Presque Isle County, MI
  - Max density below 150 m during 65.1% of fall nights and 49.6% of fall night hours at Alcona County, MI
  - Max density below 150 m during 85.3% of spring nights and 56.3% of spring night hours at Presque Isle County, MI
  - Max density below 150 m during 71.6% of spring nights and 43.2% of spring night hours at Alcona County, MI

- 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 band graphics 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 at Presque Isle and Alcona County sites during fall 2015 and spring 2016 migration seasons

	Percent Land Cover	
National Landcover Class	*Presque Isle County %*	*Alcona County %*
Open Water	35%	34%
Developed, Open Space	3%	4%
Developed, Low Intensity	1%	3%
Developed, Medium Intensity	0%	1%
Developed, High Intensity	0%	0%
Barren Land	10%	2%
Deciduous Forest	10%	22%
Evergreen Forest	7%	10%
Mixed Forest	3%	4%
Shrub/Scrub	1%	1%
Herbaceuous	6%	3%
Hay/Pasture	0%	3%
Cultivated Crops	0%	1%
Woody Wetlands	19%	12%
Emergent Herbaceuous Wetlands	4%	0%

Classification Description for the 2006 National Land Cover Database (taken from http://www.mrlc.gov/nlcd06_leg.php; accessed 5/5/2014).

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 spring biological time periods (dawn, day, dusk, night) in Presque Isle County, fall 2015 (targets/1,000,000 m^3/time period).

Altitude Band	*Dawn*	*Day*	*Dusk*	*Night*
50	0.0	0.0	0.0	0.0
100	0.3	0.2	0.3	1.6
150	0.6	0.2	0.8	4.6
200	0.7	0.3	0.7	4.5
250	0.9	0.3	0.6	4.2
300	0.9	0.3	0.6	3.9
350	0.5	0.2	0.3	2.7
400	0.4	0.1	0.2	2.2
450	0.3	0.1	0.1	1.7
500	0.2	0.1	0.1	1.3
550	0.2	0.1	0.0	1.1
600	0.2	0.0	0.0	0.9
650	0.1	0.0	0.0	0.7
700	0.1	0.0	0.0	0.6
750	0.1	0.0	0.0	0.5
800	0.1	0.0	0.0	0.4
850	0.1	0.0	0.0	0.3
900	0.1	0.0	0.0	0.3
950	0.0	0.0	0.0	0.2
1000	0.0	0.0	0.0	0.2

Estimated density of targets by altitude band during spring biological time periods (dawn, day, dusk, night) in Alcona County, fall 2015 (targets/1,000,000 m^3/time period).

Altitude Band	*Dawn*	*Day*	*Dusk*	*Night*
50	0.0	0.0	0.0	0.0
100	0.5	0.2	0.3	1.5
150	0.7	0.2	0.7	3.4
200	0.6	0.2	0.7	3.4
250	0.5	0.2	0.7	3.3
300	0.5	0.2	0.5	2.8
350	0.8	0.3	0.5	3.1
400	0.6	0.2	0.3	2.5
450	0.5	0.1	0.2	2.1
500	0.4	0.1	0.1	1.8
550	0.3	0.0	0.1	1.5
600	0.3	0.0	0.0	1.3
650	0.2	0.0	0.0	1.2
700	0.2	0.0	0.0	1.0
750	0.1	0.0	0.0	0.9
800	0.1	0.0	0.0	0.7
850	0.1	0.0	0.0	0.6
900	0.1	0.0	0.0	0.5
950	0.1	0.0	0.0	0.4
1000	0.1	0.0	0.0	0.4

Estimated density of targets by altitude band during spring biological time periods (dawn, day, dusk, night) in Presque Isle County, Spring 2016 (targets/1,000,000 m^3/time period).

Altitude Band	*Dawn*	*Day*	*Dusk*	*Night*
50	0.0	0.0	0.0	0.0
100	0.3	0.2	0.1	0.9
150	0.4	0.3	0.4	2.1
200	0.3	0.2	0.5	2.1
250	0.3	0.2	0.3	1.9
300	0.2	0.2	0.2	1.7
350	0.3	0.1	0.1	1.4
400	0.2	0.1	0.1	1.3
450	0.2	0.1	0.1	1.1
500	0.2	0.1	0.0	1.0
550	0.2	0.0	0.0	0.8
600	0.1	0.0	0.0	0.7
650	0.1	0.0	0.0	0.6
700	0.1	0.0	0.0	0.6
750	0.1	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	0.0	0.0	0.0	0.3
1000	0.0	0.0	0.0	0.2

Estimated density of targets by altitude band during spring biological time periods (dawn, day, dusk, night) in Alcona County, spring 2016 (targets/1,000,000 m^3/time period).

Altitude Band	*Dawn*	*Day*	*Dusk*	*Night*
50	0.0	0.0		0.0
100	0.8	0.6	0.4	1.6
150	1.0	0.5	0.5	3.5
200	0.8	0.3	0.3	3.6
250	0.7	0.3	0.2	3.4
300	0.9	0.2	0.1	2.9
350	0.9	0.3	0.1	2.8
400	0.9	0.2	0.1	2.2
450	0.7	0.2	0.0	1.9
500	0.7	0.1	0.0	1.7
550	0.7	0.1	0.0	1.5
600	0.6	0.1	0.0	1.3
650	0.5	0.1	0.0	1.1
700	0.4	0.1	0.0	1.0
750	0.4	0.0	0.0	0.9
800	0.3	0.0	0.0	0.8
850	0.3	0.0	0.0	0.6
900	0.2	0.0	0.0	0.5
950	0.2	0.0	0.0	0.5
1000	0.1	0.0	0.0	0.4

Appendix 4

Comparison of Static and Corrected Density Estimates

Comparison of methods to estimate target density by altitude band during the dawn biological period in Presque Isle County, fall 2015.

Altitude Band (m)	*Target Count*	*Running Total Target Count*[1]	*Static Volume*	*Corrected Volume*	*Static Target Density per Hour*	*Corrected Target Density per Hour*[2]	*% Total Targets*	*% Static Density*	*% Corrected Density*
50	8	8	31.3	5.6	0.0	0.0	0.2%	0.2%	0.3%
100	154	162	31.3	5.9	0.1	0.3	3.0%	3.0%	5.6%
150	308	470	31.3	6.5	0.1	0.6	6.0%	6.0%	10.2%
200	381	851	31.3	7.1	0.2	0.7	7.4%	7.4%	11.5%
250	537	1,388	31.3	7.9	0.2	0.9	10.4%	10.4%	14.6%
300	539	1,927	31.3	8.5	0.2	0.9	10.4%	10.4%	13.6%
350	358	2,285	31.3	9.5	0.2	0.5	6.9%	6.9%	8.1%
400	293	2,578	31.3	10.3	0.1	0.4	5.7%	5.7%	6.1%
450	252	2,830	31.3	11.2	0.1	0.3	4.9%	4.9%	4.8%
500	221	3,051	31.3	12.2	0.1	0.2	4.3%	4.3%	3.9%
550	196	3,247	31.3	13.3	0.1	0.2	3.8%	3.8%	3.2%
600	168	3,415	31.3	14.1	0.1	0.2	3.3%	3.3%	2.5%
650	132	3,547	31.3	15.3	0.1	0.1	2.6%	2.6%	1.8%
700	137	3,684	31.3	16.2	0.1	0.1	2.7%	2.7%	1.8%
750	118	3,802	31.3	17.2	0.1	0.1	2.3%	2.3%	1.5%
800	97	3,899	31.3	18.2	0.0	0.1	1.9%	1.9%	1.1%
850	93	3,992	31.3	19.4	0.0	0.1	1.8%	1.8%	1.0%
900	76	4,068	31.3	20.4	0.0	0.1	1.5%	1.5%	0.8%
950	66	4,134	31.3	21.4	0.0	0.0	1.3%	1.3%	0.7%
1000	52	4,186	31.3	22.4	0.0	0.0	1.0%	1.0%	0.5%

[1] Total target counts recorded up to 2,800 m band during the dawn time period was 5,158.

[2] Total density of targets per hour recorded up to the 2,800 m band during the dawn time period was 6.28.

Comparison of methods to estimate target density by altitude band during the day biological period in Presque Isle County, fall 2015.

Altitude Band (m)	*Target Count*	*Running Total Target Count*[1]	*Static Volume*	*Corrected Volume*	*Static Target Density per Hour*	*Corrected Target Density per Hour*[2]	*% Total Targets*	*% Static Density*	*% Corrected Density*
50	42	42	31.3	5.6	0.0	0.0	0.3%	0.3%	0.4%
100	929	971	31.3	5.9	0.0	0.2	5.6%	5.6%	8.8%
150	1,148	2,119	31.3	6.5	0.0	0.2	7.0%	7.0%	10.0%
200	1,738	3,857	31.3	7.1	0.1	0.3	10.6%	10.6%	13.8%
250	2,143	6,000	31.3	7.9	0.1	0.3	13.0%	13.0%	15.2%
300	2,528	8,528	31.3	8.5	0.1	0.3	15.4%	15.4%	16.7%
350	1,536	10,064	31.3	9.5	0.1	0.2	9.3%	9.3%	9.1%
400	1,321	11,385	31.3	10.3	0.0	0.1	8.0%	8.0%	7.2%
450	971	12,356	31.3	11.2	0.0	0.1	5.9%	5.9%	4.9%
500	788	13,144	31.3	12.2	0.0	0.1	4.8%	4.8%	3.6%
550	632	13,776	31.3	13.3	0.0	0.1	3.8%	3.8%	2.7%
600	459	14,235	31.3	14.1	0.0	0.0	2.8%	2.8%	1.8%
650	307	14,542	31.3	15.3	0.0	0.0	1.9%	1.9%	1.1%
700	245	14,787	31.3	16.2	0.0	0.0	1.5%	1.5%	0.8%
750	209	14,996	31.3	17.2	0.0	0.0	1.3%	1.3%	0.7%
800	166	15,162	31.3	18.2	0.0	0.0	1.0%	1.0%	0.5%
850	130	15,292	31.3	19.4	0.0	0.0	0.8%	0.8%	0.4%
900	103	15,395	31.3	20.4	0.0	0.0	0.6%	0.6%	0.3%
950	68	15,463	31.3	21.4	0.0	0.0	0.4%	0.4%	0.2%
1000	70	15,533	31.3	22.4	0.0	0.0	0.4%	0.4%	0.2%

1 Total target counts recorded up to 2,800 m band during the day time period was 16,446.

2 Total density of targets per hour recorded up to the 2,800 m band during the day time period was 2.07.

Comparison of methods to estimate target density by altitude band during the dusk biological period in Presque Isle County, fall 2015.

Altitude Band (m)	*Target Count*	*Running Total Target Count*[1]	*Static Volume*	*Corrected Volume*	*Static Target Density per Hour*	*Corrected Target Density per Hour*[2]	*% Total Targets*	*% Static Density*	*% Corrected Density*
50	1	1	31.3	5.6	0.0	0.0	0.0%	0.0%	0.1%
100	128	129	31.3	5.9	0.1	0.3	5.9%	5.9%	8.1%
150	347	476	31.3	6.5	0.2	0.8	15.9%	15.9%	20.3%
200	362	838	31.3	7.1	0.2	0.7	16.6%	16.6%	19.3%
250	348	1,186	31.3	7.9	0.2	0.6	16.0%	16.0%	16.6%
300	356	1,542	31.3	8.5	0.2	0.6	16.3%	16.3%	15.8%
350	204	1,746	31.3	9.5	0.1	0.3	9.4%	9.4%	8.1%
400	124	1,870	31.3	10.3	0.1	0.2	5.7%	5.7%	4.5%
450	70	1,940	31.3	11.2	0.0	0.1	3.2%	3.2%	2.4%
500	50	1,990	31.3	12.2	0.0	0.1	2.3%	2.3%	1.5%
550	20	2,010	31.3	13.3	0.0	0.0	0.9%	0.9%	0.6%
600	20	2,030	31.3	14.1	0.0	0.0	0.9%	0.9%	0.5%
650	27	2,057	31.3	15.3	0.0	0.0	1.2%	1.2%	0.7%
700	5	2,062	31.3	16.2	0.0	0.0	0.2%	0.2%	0.1%
750	7	2,069	31.3	17.2	0.0	0.0	0.3%	0.3%	0.2%
800	1	2,070	31.3	18.2	0.0	0.0	0.0%	0.0%	0.0%
850	2	2,072	31.3	19.4	0.0	0.0	0.1%	0.1%	0.0%
900	2	2,074	31.3	20.4	0.0	0.0	0.1%	0.1%	0.0%
950	1	2,075	31.3	21.4	0.0	0.0	0.0%	0.0%	0.0%
1000	4	2,079	31.3	22.4	0.0	0.0	0.2%	0.2%	0.1%

[1] Total target counts recorded up to 2,800 m band during the dusk time period was 2,181.

Comparison of methods to estimate target density by altitude band during the night biological period in Presque Isle County, fall 2015.

Altitude Band (m)	*Target Count*	*Running Total Target Count*[1]	*Static Volume*	*Corrected Volume*	*Static Target Density per Hour*	*Corrected Target Density per Hour*[2]	*% Total Targets*	*% Static Density*	*% Corrected Density*
50	69	69	31.3	5.6	0.0	0.0	0.0%	0.0%	0.0%
100	7,026	7,095	31.3	5.9	0.3	1.6	2.7%	2.7%	4.7%
150	22,402	29,497	31.3	6.5	1.0	4.6	8.5%	8.5%	13.8%
200	23,950	53,447	31.3	7.1	1.0	4.5	9.1%	9.1%	13.5%
250	24,761	78,208	31.3	7.9	1.1	4.2	9.4%	9.4%	12.5%
300	24,762	102,970	31.3	8.5	1.1	3.9	9.4%	9.4%	11.6%
350	19,593	122,563	31.3	9.5	0.8	2.7	7.4%	7.4%	8.3%
400	16,850	139,413	31.3	10.3	0.7	2.2	6.4%	6.4%	6.5%
450	14,367	153,780	31.3	11.2	0.6	1.7	5.5%	5.5%	5.1%
500	12,411	166,191	31.3	12.2	0.5	1.3	4.7%	4.7%	4.1%
550	10,875	177,066	31.3	13.3	0.5	1.1	4.1%	4.1%	3.3%
600	9,587	186,653	31.3	14.1	0.4	0.9	3.6%	3.6%	2.7%
650	8,591	195,244	31.3	15.3	0.4	0.7	3.3%	3.3%	2.2%
700	7,544	202,788	31.3	16.2	0.3	0.6	2.9%	2.9%	1.9%
750	6,440	209,228	31.3	17.2	0.3	0.5	2.4%	2.4%	1.5%
800	5,738	214,966	31.3	18.2	0.2	0.4	2.2%	2.2%	1.3%
850	4,708	219,674	31.3	19.4	0.2	0.3	1.8%	1.8%	1.0%
900	3,963	223,637	31.3	20.4	0.2	0.3	1.5%	1.5%	0.8%
950	3,091	226,728	31.3	21.4	0.1	0.2	1.2%	1.2%	0.6%
1000	2,620	229,348	31.3	22.4	0.1	0.2	1.0%	1.0%	0.5%

1 Total target counts recorded up to 2,800 m band during the night time period was 263,613.

2 Total density of targets per hour recorded up to the 2,800 m band during the night time period was 33.23.

Comparison of methods to estimate target density by altitude band during the dawn biological period in Alcona County, fall 2015.

Altitude Band (m)	*Target Count*	*Running Total Target Count*[1]	*Static Volume*	*Corrected Volume*	*Static Target Density per Hour*	*Corrected Target Density per Hour*[2]	*% Total Targets*	*% Static Density*	*% Corrected Density*
50	5	5	31.3	5.6	0.0	0.0	0.1%	0.1%	0.2%
100	227	232	31.3	5.9	0.1	0.5	3.5%	3.5%	7.1%
150	323	555	31.3	6.5	0.1	0.7	4.9%	4.9%	9.3%
200	313	868	31.3	7.1	0.1	0.6	4.8%	4.8%	8.2%
250	301	1,169	31.3	7.9	0.1	0.5	4.6%	4.6%	7.1%
300	340	1,509	31.3	8.5	0.1	0.5	5.2%	5.2%	7.4%
350	544	2,053	31.3	9.5	0.2	0.8	8.3%	8.3%	10.7%
400	491	2,544	31.3	10.3	0.2	0.6	7.5%	7.5%	8.9%
450	429	2,973	31.3	11.2	0.2	0.5	6.6%	6.6%	7.1%
500	387	3,360	31.3	12.2	0.2	0.4	5.9%	5.9%	5.9%
550	315	3,675	31.3	13.3	0.1	0.3	4.8%	4.8%	4.4%
600	294	3,969	31.3	14.1	0.1	0.3	4.5%	4.5%	3.9%
650	191	4,160	31.3	15.3	0.1	0.2	2.9%	2.9%	2.3%
700	205	4,365	31.3	16.2	0.1	0.2	3.1%	3.1%	2.4%
750	185	4,550	31.3	17.2	0.1	0.1	2.8%	2.8%	2.0%
800	159	4,709	31.3	18.2	0.1	0.1	2.4%	2.4%	1.6%
850	131	4,840	31.3	19.4	0.1	0.1	2.0%	2.0%	1.3%
900	107	4,947	31.3	20.4	0.0	0.1	1.6%	1.6%	1.0%
950	128	5,075	31.3	21.4	0.1	0.1	2.0%	2.0%	1.1%
1000	91	5,166	31.3	22.4	0.0	0.1	1.4%	1.4%	0.8%

1 Total target counts recorded up to 2,800 m band during the dawn time period was 6,526.

2 Total density of targets per hour recorded up to the 2,800 m band during the dawn time period was 7.10.

Comparison of methods to estimate target density by altitude band during the day biological period in Alcona County, fall 2015.

Altitude Band (m)	*Target Count*	*Running Total Target Count*[1]	*Static Volume*	*Corrected Volume*	*Static Target Density per Hour*	*Corrected Target Density per Hour*[2]	*% Total Targets*	*% Static Density*	*% Corrected Density*
50	40	40	31.3	5.6	0.0	0.0	0.3%	0.3%	0.5%
100	933	973	31.3	5.9	0.0	0.2	6.0%	6.0%	10.0%
150	1,115	2,088	31.3	6.5	0.0	0.2	7.2%	7.2%	11.0%
200	1,202	3,290	31.3	7.1	0.0	0.2	7.8%	7.8%	10.8%
250	1,392	4,682	31.3	7.9	0.1	0.2	9.0%	9.0%	11.3%
300	1,218	5,900	31.3	8.5	0.0	0.2	7.9%	7.9%	9.2%
350	2,167	8,067	31.3	9.5	0.1	0.3	14.0%	14.0%	14.6%
400	1,649	9,716	31.3	10.3	0.1	0.2	10.7%	10.7%	10.2%
450	1,079	10,795	31.3	11.2	0.0	0.1	7.0%	7.0%	6.1%
500	732	11,527	31.3	12.2	0.0	0.1	4.7%	4.7%	3.8%
550	511	12,038	31.3	13.3	0.0	0.0	3.3%	3.3%	2.5%
600	407	12,445	31.3	14.1	0.0	0.0	2.6%	2.6%	1.8%
650	306	12,751	31.3	15.3	0.0	0.0	2.0%	2.0%	1.3%
700	248	12,999	31.3	16.2	0.0	0.0	1.6%	1.6%	1.0%
750	230	13,229	31.3	17.2	0.0	0.0	1.5%	1.5%	0.9%
800	165	13,394	31.3	18.2	0.0	0.0	1.1%	1.1%	0.6%
850	144	13,538	31.3	19.4	0.0	0.0	0.9%	0.9%	0.5%
900	126	13,664	31.3	20.4	0.0	0.0	0.8%	0.8%	0.4%
950	99	13,763	31.3	21.4	0.0	0.0	0.6%	0.6%	0.3%
1000	102	13,865	31.3	22.4	0.0	0.0	0.7%	0.7%	0.3%

1 Total target counts recorded up to 2,800 m band during the day time period was 1,542.

2 Total density of targets per hour recorded up to the 2,800 m band during the day time period was 1.83.

Comparison of methods to estimate target density by altitude band during the dusk biological period in Alcona County, fall 2015.

Altitude Band (m)	*Target Count*	*Running Total Target Count*[1]	*Static Volume*	*Corrected Volume*	*Static Target Density per Hour*	*Corrected Target Density per Hour*[2]	*% Total Targets*	*% Static Density*	*% Corrected Density*
50	2	2	31.3	5.6	0.0	0.0	0.1%	0.1%	0.1%
100	121	123	31.3	5.9	0.1	0.3	4.5%	4.5%	6.7%
150	315	438	31.3	6.5	0.1	0.7	11.8%	11.8%	16.0%
200	366	804	31.3	7.1	0.2	0.7	13.7%	13.7%	17.0%
250	422	1,226	31.3	7.9	0.2	0.7	15.8%	15.8%	17.6%
300	290	1,516	31.3	8.5	0.1	0.5	10.9%	10.9%	11.2%
350	372	1,888	31.3	9.5	0.2	0.5	13.9%	13.9%	12.9%
400	211	2,099	31.3	10.3	0.1	0.3	7.9%	7.9%	6.7%
450	126	2,225	31.3	11.2	0.1	0.2	4.7%	4.7%	3.7%
500	85	2,310	31.3	12.2	0.0	0.1	3.2%	3.2%	2.3%
550	54	2,364	31.3	13.3	0.0	0.1	2.0%	2.0%	1.3%
600	37	2,401	31.3	14.1	0.0	0.0	1.4%	1.4%	0.9%
650	23	2,424	31.3	15.3	0.0	0.0	0.9%	0.9%	0.5%
700	25	2,449	31.3	16.2	0.0	0.0	0.9%	0.9%	0.5%
750	15	2,464	31.3	17.2	0.0	0.0	0.6%	0.6%	0.3%
800	12	2,476	31.3	18.2	0.0	0.0	0.4%	0.4%	0.2%
850	10	2,486	31.3	19.4	0.0	0.0	0.4%	0.4%	0.2%
900	17	2,503	31.3	20.4	0.0	0.0	0.6%	0.6%	0.3%
950	3	2,506	31.3	21.4	0.0	0.0	0.1%	0.1%	0.0%
1000	8	2,514	31.3	22.4	0.0	0.0	0.3%	0.3%	0.1%

1 Total target counts recorded up to 2,800 m band during the dusk time period was 2,668.

2 Total density of targets per hour recorded up to the 2,800 m band during the dusk time period was 4.12.

Comparison of methods to estimate target density by altitude band during the night biological period in Alcona County, fall 2015.

Altitude Band (m)	*Target Count*	*Running Total Target Count*[1]	*Static Volume*	*Corrected Volume*	*Static Target Density per Hour*	*Corrected Target Density per Hour*[2]	*% Total Targets*	*% Static Density*	*% Corrected Density*
50	14	14	31.3	5.6	0.0	0.0	0.0%	0.0%	0.0%
100	7,119	7,133	31.3	5.9	0.3	1.5	2.0%	2.0%	4.2%
150	17,945	25,078	31.3	6.5	0.7	3.4	5.1%	5.1%	9.8%
200	19,158	44,236	31.3	7.1	0.8	3.4	5.4%	5.4%	9.5%
250	21,010	65,246	31.3	7.9	0.8	3.3	5.9%	5.9%	9.3%
300	18,893	84,139	31.3	8.5	0.7	2.8	5.3%	5.3%	7.8%
350	23,950	108,089	31.3	9.5	1.0	3.1	6.8%	6.8%	8.9%
400	21,211	129,300	31.3	10.3	0.8	2.5	6.0%	6.0%	7.2%
450	18,851	148,151	31.3	11.2	0.7	2.1	5.3%	5.3%	5.9%
500	17,809	165,960	31.3	12.2	0.7	1.8	5.0%	5.0%	5.1%
550	16,385	182,345	31.3	13.3	0.7	1.5	4.6%	4.6%	4.3%
600	15,337	197,682	31.3	14.1	0.6	1.3	4.3%	4.3%	3.8%
650	14,215	211,897	31.3	15.3	0.6	1.2	4.0%	4.0%	3.3%
700	12,731	224,628	31.3	16.2	0.5	1.0	3.6%	3.6%	2.8%
750	11,975	236,603	31.3	17.2	0.5	0.9	3.4%	3.4%	2.4%
800	10,779	247,382	31.3	18.2	0.4	0.7	3.0%	3.0%	2.1%
850	9,477	256,859	31.3	19.4	0.4	0.6	2.7%	2.7%	1.7%
900	8,552	265,411	31.3	20.4	0.3	0.5	2.4%	2.4%	1.5%
950	7,450	272,861	31.3	21.4	0.3	0.4	2.1%	2.1%	1.2%
1000	6,556	279,417	31.3	22.4	0.3	0.4	1.9%	1.9%	1.0%

[1] Total target counts recorded up to 2,800 m band during the night time period was 353,586.

[2] Total density of targets per hour recorded up to the 2,800 m band during the night time period was 35.29.

Comparison of methods to estimate target density by altitude band during the dawn biological period in Presque Isle County, spring 2016.

Altitude Band (m)	*Target Count*	*Running Total Target Count*[1]	*Static Volume*	*Corrected Volume*	*Static Target Density per Hour*	*Corrected Target Density per Hour*[2]	*% Total Targets*	*% Static Density*	*% Corrected Density*
50	2	2	31.3	5.6	0.00	0.0	0.0%	0.0%	0.1%
100	181	183	31.3	5.9	0.05	0.3	3.2%	3.2%	7.0%
150	323	506	31.3	6.5	0.09	0.4	5.7%	5.7%	11.5%
200	260	766	31.3	7.1	0.07	0.3	4.6%	4.6%	8.4%
250	240	1,006	31.3	7.9	0.06	0.3	4.2%	4.2%	7.0%
300	229	1,235	31.3	8.5	0.06	0.2	4.0%	4.0%	6.2%
350	282	1,517	31.3	9.5	0.08	0.3	4.9%	4.9%	6.9%
400	290	1,807	31.3	10.3	0.08	0.2	5.1%	5.1%	6.5%
450	315	2,122	31.3	11.2	0.08	0.2	5.5%	5.5%	6.5%
500	249	2,371	31.3	12.2	0.07	0.2	4.4%	4.4%	4.7%
550	264	2,635	31.3	13.3	0.07	0.2	4.6%	4.6%	4.6%
600	239	2,874	31.3	14.1	0.06	0.1	4.2%	4.2%	3.9%
650	221	3,095	31.3	15.3	0.06	0.1	3.9%	3.9%	3.3%
700	203	3,298	31.3	16.2	0.05	0.1	3.6%	3.6%	2.9%
750	198	3,496	31.3	17.2	0.05	0.1	3.5%	3.5%	2.7%
800	149	3,645	31.3	18.2	0.04	0.1	2.6%	2.6%	1.9%
850	162	3,807	31.3	19.4	0.04	0.1	2.8%	2.8%	1.9%
900	139	3,946	31.3	20.4	0.04	0.1	2.4%	2.4%	1.6%
950	105	4,051	31.3	21.4	0.03	0.0	1.8%	1.8%	1.1%
1000	71	4,122	31.3	22.4	0.02	0.0	1.2%	1.2%	0.7%

[1] Total target counts recorded up to 2,800 m band during the dawn time period was 5,697.

[2] Total density of targets per hour recorded up to the 2,800 m band during the dawn time period was 3.65.

Comparison of methods to estimate target density by altitude band during the day biological period in Presque Isle County, spring 2016.

Altitude Band (m)	*Target Count*	*Running Total Target Count*[1]	*Static Volume*	*Corrected Volume*	*Static Target Density per Hour*	*Corrected Target Density per Hour*[2]	*% Total Targets*	*% Static Density*	*% Corrected Density*
50	32	32	31.3	5.6	0.0	0.0	0.1%	0.1%	0.2%
100	1,918	1,950	31.3	5.9	0.0	0.2	7.5%	7.5%	12.0%
150	2,657	4,607	31.3	6.5	0.1	0.3	10.5%	10.5%	15.3%
200	2,403	7,010	31.3	7.1	0.0	0.2	9.5%	9.5%	12.6%
250	2,551	9,561	31.3	7.9	0.1	0.2	10.0%	10.0%	12.0%
300	2,519	12,080	31.3	8.5	0.1	0.2	9.9%	9.9%	11.1%
350	2,155	14,235	31.3	9.5	0.0	0.1	8.5%	8.5%	8.5%
400	1,963	16,198	31.3	10.3	0.0	0.1	7.7%	7.7%	7.1%
450	1,415	17,613	31.3	11.2	0.0	0.1	5.6%	5.6%	4.7%
500	1,160	18,773	31.3	12.2	0.0	0.1	4.6%	4.6%	3.5%
550	916	19,689	31.3	13.3	0.0	0.0	3.6%	3.6%	2.6%
600	693	20,382	31.3	14.1	0.0	0.0	2.7%	2.7%	1.8%
650	581	20,963	31.3	15.3	0.0	0.0	2.3%	2.3%	1.4%
700	574	21,537	31.3	16.2	0.0	0.0	2.3%	2.3%	1.3%
750	449	21,986	31.3	17.2	0.0	0.0	1.8%	1.8%	1.0%
800	314	22,300	31.3	18.2	0.0	0.0	1.2%	1.2%	0.6%
850	266	22,566	31.3	19.4	0.0	0.0	1.0%	1.0%	0.5%
900	240	22,806	31.3	20.4	0.0	0.0	0.9%	0.9%	0.4%
950	198	23,004	31.3	21.4	0.0	0.0	0.8%	0.8%	0.3%
1000	159	23,163	31.3	22.4	0.0	0.0	0.6%	0.6%	0.3%

[1] Total target counts recorded up to 2,800 m band during the day time period was 25,425.

[2] Total density of targets per hour recorded up to the 2,800 m band during the day time period was 1.67.

Comparison of methods to estimate target density by altitude band during the dusk biological period in Presque Isle County, spring 2016.

Altitude Band (m)	*Target Count*	*Running Total Target Count*[1]	*Static Volume*	*Corrected Volume*	*Static Target Density per Hour*	*Corrected Target Density per Hour*[2]	*% Total Targets*	*% Static Density*	*% Corrected Density*
50	1	1	31.3	5.6	0.0	0.0	0.0%	0.0%	0.1%
100	92	93	31.3	5.9	0.0	0.1	4.5%	4.5%	6.7%
150	285	378	31.3	6.5	0.1	0.4	13.8%	13.8%	18.9%
200	396	774	31.3	7.1	0.1	0.5	19.2%	19.2%	24.0%
250	295	1,069	31.3	7.9	0.1	0.3	14.3%	14.3%	16.0%
300	198	1,267	31.3	8.5	0.1	0.2	9.6%	9.6%	10.0%
350	137	1,404	31.3	9.5	0.0	0.1	6.6%	6.6%	6.2%
400	106	1,510	31.3	10.3	0.0	0.1	5.1%	5.1%	4.4%
450	73	1,583	31.3	11.2	0.0	0.1	3.5%	3.5%	2.8%
500	54	1,637	31.3	12.2	0.0	0.0	2.6%	2.6%	1.9%
550	37	1,674	31.3	13.3	0.0	0.0	1.8%	1.8%	1.2%
600	40	1,714	31.3	14.1	0.0	0.0	1.9%	1.9%	1.2%
650	40	1,754	31.3	15.3	0.0	0.0	1.9%	1.9%	1.1%
700	28	1,782	31.3	16.2	0.0	0.0	1.4%	1.4%	0.7%
750	18	1,800	31.3	17.2	0.0	0.0	0.9%	0.9%	0.4%
800	17	1,817	31.3	18.2	0.0	0.0	0.8%	0.8%	0.4%
850	19	1,836	31.3	19.4	0.0	0.0	0.9%	0.9%	0.4%
900	20	1,856	31.3	20.4	0.0	0.0	1.0%	1.0%	0.4%
950	12	1,868	31.3	21.4	0.0	0.0	0.6%	0.6%	0.2%
1000	22	1,890	31.3	22.4	0.0	0.0	1.1%	1.1%	0.4%

1 Total target counts recorded up to 2,800 m band during the dusk time period was 2,065.

2 Total density of targets per hour recorded up to the 2,800 m band during the dusk time period was 1.95.

Comparison of methods to estimate target density by altitude band during the night biological period in Presque Isle County, spring 2016.

Altitude Band (m)	*Target Count*	*Running Total Target Count*[1]	*Static Volume*	*Corrected Volume*	*Static Target Density per Hour*	*Corrected Target Density per Hour*[2]	*% Total Targets*	*% Static Density*	*% Corrected Density*
50	18	18	31.3	5.6	0.0	0.0	0.0%	0.0%	0.0%
100	5,383	5,401	31.3	5.9	0.2	0.9	1.9%	1.9%	4.3%
150	14,085	19,486	31.3	6.5	0.4	2.1	5.0%	5.0%	10.3%
200	14,835	34,321	31.3	7.1	0.5	2.1	5.3%	5.3%	9.9%
250	14,937	49,258	31.3	7.9	0.5	1.9	5.3%	5.3%	9.0%
300	14,865	64,123	31.3	8.5	0.5	1.7	5.3%	5.3%	8.3%
350	13,756	77,879	31.3	9.5	0.4	1.4	4.9%	4.9%	6.9%
400	13,509	91,388	31.3	10.3	0.4	1.3	4.8%	4.8%	6.2%
450	12,549	103,937	31.3	11.2	0.4	1.1	4.5%	4.5%	5.3%
500	11,899	115,836	31.3	12.2	0.4	1.0	4.2%	4.2%	4.6%
550	11,044	126,880	31.3	13.3	0.3	0.8	3.9%	3.9%	3.9%
600	10,613	137,493	31.3	14.1	0.3	0.7	3.8%	3.8%	3.6%
650	9,592	147,085	31.3	15.3	0.3	0.6	3.4%	3.4%	3.0%
700	9,405	156,490	31.3	16.2	0.3	0.6	3.3%	3.3%	2.7%
750	8,779	165,269	31.3	17.2	0.3	0.5	3.1%	3.1%	2.4%
800	7,953	173,222	31.3	18.2	0.3	0.4	2.8%	2.8%	2.1%
850	7,407	180,629	31.3	19.4	0.2	0.4	2.6%	2.6%	1.8%
900	6,648	187,277	31.3	20.4	0.2	0.3	2.4%	2.4%	1.5%
950	5,965	193,242	31.3	21.4	0.2	0.3	2.1%	2.1%	1.3%
1000	5,031	198,273	31.3	22.4	0.2	0.2	1.8%	1.8%	1.1%

1 Total target counts recorded up to 2,800 m band during the night time period was 281,577.

2 Total density of targets per hour recorded up to the 2,800 m band during the night time period was 20.76.

Comparison of methods to estimate target density by altitude band during the dawn biological period in Alcona County, spring 2016.

Altitude Band (m)	*Target Count*	*Running Total Target Count*[1]	*Static Volume*	*Corrected Volume*	*Static Target Density per Hour*	*Corrected Target Density per Hour*[2]	*% Total Targets*	*% Static Density*	*% Corrected Density*
50	4	4	31.3	5.6	0.0	0.0	0.0%	0.0%	0.1%
100	313	317	31.3	5.9	0.1	0.8	2.9%	2.9%	6.4%
150	415	732	31.3	6.5	0.2	1.0	3.8%	3.8%	7.8%
200	361	1,093	31.3	7.1	0.2	0.8	3.3%	3.3%	6.2%
250	396	1,489	31.3	7.9	0.2	0.7	3.6%	3.6%	6.1%
300	489	1,978	31.3	8.5	0.2	0.9	4.5%	4.5%	7.0%
350	564	2,542	31.3	9.5	0.3	0.9	5.1%	5.1%	7.3%
400	606	3,148	31.3	10.3	0.3	0.9	5.5%	5.5%	7.2%
450	538	3,686	31.3	11.2	0.3	0.7	4.9%	4.9%	5.9%
500	560	4,246	31.3	12.2	0.3	0.7	5.1%	5.1%	5.6%
550	590	4,836	31.3	13.3	0.3	0.7	5.4%	5.4%	5.4%
600	554	5,390	31.3	14.1	0.3	0.6	5.0%	5.0%	4.8%
650	544	5,934	31.3	15.3	0.3	0.5	5.0%	5.0%	4.3%
700	484	6,418	31.3	16.2	0.2	0.4	4.4%	4.4%	3.6%
750	424	6,842	31.3	17.2	0.2	0.4	3.9%	3.9%	3.0%
800	413	7,255	31.3	18.2	0.2	0.3	3.8%	3.8%	2.8%
850	346	7,601	31.3	19.4	0.2	0.3	3.2%	3.2%	2.2%
900	268	7,869	31.3	20.4	0.1	0.2	2.4%	2.4%	1.6%
950	238	8,107	31.3	21.4	0.1	0.2	2.2%	2.2%	1.4%
1000	222	8,329	31.3	22.4	0.1	0.1	2.0%	2.0%	1.2%

1 Total target counts recorded up to 2,800 m band during the dawn time period was 10,972.

2 Total density of targets per hour recorded up to the 2,800 m band during the dawn time period was 12.16.

Comparison of methods to estimate target density by altitude band during the day biological period in Alcona County, spring 2016.

Altitude Band (m)	*Target Count*	*Running Total Target Count*[1]	*Static Volume*	*Corrected Volume*	*Static Target Density per Hour*	*Corrected Target Density per Hour*[2]	*% Total Targets*	*% Static Density*	*% Corrected Density*
50	41	41	31.3	5.6	0.0	0.0	0.1%	0.1%	0.3%
100	3,005	3,046	31.3	5.9	0.1	0.6	10.6%	10.6%	18.1%
150	2,667	5,713	31.3	6.5	0.1	0.5	9.4%	9.4%	14.8%
200	1,882	7,595	31.3	7.1	0.1	0.3	6.6%	6.6%	9.5%
250	1,810	9,405	31.3	7.9	0.1	0.3	6.4%	6.4%	8.2%
300	1,539	10,944	31.3	8.5	0.1	0.2	5.4%	5.4%	6.5%
350	2,264	13,208	31.3	9.5	0.1	0.3	8.0%	8.0%	8.6%
400	1,896	15,104	31.3	10.3	0.1	0.2	6.7%	6.7%	6.6%
450	1,497	16,601	31.3	11.2	0.1	0.2	5.3%	5.3%	4.8%
500	1,374	17,975	31.3	12.2	0.1	0.1	4.8%	4.8%	4.0%
550	1,175	19,150	31.3	13.3	0.0	0.1	4.1%	4.1%	3.2%
600	1,056	20,206	31.3	14.1	0.0	0.1	3.7%	3.7%	2.7%
650	894	21,100	31.3	15.3	0.0	0.1	3.1%	3.1%	2.1%
700	737	21,837	31.3	16.2	0.0	0.1	2.6%	2.6%	1.6%
750	633	22,470	31.3	17.2	0.0	0.0	2.2%	2.2%	1.3%
800	547	23,017	31.3	18.2	0.0	0.0	1.9%	1.9%	1.1%
850	516	23,533	31.3	19.4	0.0	0.0	1.8%	1.8%	1.0%
900	449	23,982	31.3	20.4	0.0	0.0	1.6%	1.6%	0.8%
950	331	24,313	31.3	21.4	0.0	0.0	1.2%	1.2%	0.6%
1000	264	24,577	31.3	22.4	0.0	0.0	0.9%	0.9%	0.4%

1 Total target counts recorded up to 2,800 m band during the day time period was 28,472.

2 Total density of targets per hour recorded up to the 2,800 m band during the day time period was 3.24.

Comparison of methods to estimate target density by altitude band during the dusk biological period in Alcona County, spring 2016.

Altitude Band (m)	*Target Count*	*Running Total Target Count*[1]	*Static Volume*	*Corrected Volume*	*Static Target Density per Hour*	*Corrected Target Density per Hour*[2]	*% Total Targets*	*% Static Density*	*% Corrected Density*
50		0	31.3	5.6			0.0%	0.0%	0.0%
100	147	147	31.3	5.9	0.1	0.4	16.2%	16.2%	21.9%
150	214	361	31.3	6.5	0.1	0.5	23.6%	23.6%	29.3%
200	152	513	31.3	7.1	0.1	0.3	16.8%	16.8%	18.9%
250	80	593	31.3	7.9	0.0	0.2	8.8%	8.8%	8.9%
300	47	640	31.3	8.5	0.0	0.1	5.2%	5.2%	4.9%
350	44	684	31.3	9.5	0.0	0.1	4.9%	4.9%	4.1%
400	42	726	31.3	10.3	0.0	0.1	4.6%	4.6%	3.6%
450	25	751	31.3	11.2	0.0	0.0	2.8%	2.8%	2.0%
500	12	763	31.3	12.2	0.0	0.0	1.3%	1.3%	0.9%
550	14	777	31.3	13.3	0.0	0.0	1.5%	1.5%	0.9%
600	9	786	31.3	14.1	0.0	0.0	1.0%	1.0%	0.6%
650	14	800	31.3	15.3	0.0	0.0	1.5%	1.5%	0.8%
700	8	808	31.3	16.2	0.0	0.0	0.9%	0.9%	0.4%
750	2	810	31.3	17.2	0.0	0.0	0.2%	0.2%	0.1%
800	3	813	31.3	18.2	0.0	0.0	0.3%	0.3%	0.1%
850	8	821	31.3	19.4	0.0	0.0	0.9%	0.9%	0.4%
900	4	825	31.3	20.4	0.0	0.0	0.4%	0.4%	0.2%
950	4	829	31.3	21.4	0.0	0.0	0.4%	0.4%	0.2%
1000	1	830	31.3	22.4	0.0	0.0	0.1%	0.1%	0.0%

1 Total target counts recorded up to 2,800 m band during the dusk time period was 906.

2 Total density of targets per hour recorded up to the 2,800 m band during the dusk time period was 1.76.

Comparison of methods to estimate target density by altitude band during the night biological period in Alcona County, spring 2016.

Altitude Band (m)	*Target Count*	*Running Total Target Count*[1]	*Static Volume*	*Corrected Volume*	*Static Target Density per Hour*	*Corrected Target Density per Hour*[2]	*% Total Targets*	*% Static Density*	*% Corrected Density*
50	13	13	31.3	5.6	0.0	0.0	0.0%	0.0%	0.0%
100	5,359	5,372	31.3	5.9	0.3	1.6	2.1%	2.1%	4.6%
150	12,493	17,865	31.3	6.5	0.7	3.5	4.9%	4.9%	9.8%
200	13,961	31,826	31.3	7.1	0.8	3.6	5.5%	5.5%	10.0%
250	14,852	46,678	31.3	7.9	0.9	3.4	5.8%	5.8%	9.5%
300	13,676	60,354	31.3	8.5	0.8	2.9	5.4%	5.4%	8.1%
350	14,436	74,790	31.3	9.5	0.8	2.8	5.7%	5.7%	7.7%
400	12,773	87,563	31.3	10.3	0.7	2.2	5.0%	5.0%	6.3%
450	11,839	99,402	31.3	11.2	0.7	1.9	4.7%	4.7%	5.3%
500	11,437	110,839	31.3	12.2	0.7	1.7	4.5%	4.5%	4.7%
550	10,814	121,653	31.3	13.3	0.6	1.5	4.3%	4.3%	4.1%
600	10,174	131,827	31.3	14.1	0.6	1.3	4.0%	4.0%	3.6%
650	9,553	141,380	31.3	15.3	0.6	1.1	3.8%	3.8%	3.2%
700	9,069	150,449	31.3	16.2	0.5	1.0	3.6%	3.6%	2.8%
750	8,447	158,896	31.3	17.2	0.5	0.9	3.3%	3.3%	2.5%
800	7,753	166,649	31.3	18.2	0.4	0.8	3.0%	3.0%	2.2%
850	6,704	173,353	31.3	19.4	0.4	0.6	2.6%	2.6%	1.7%
900	6,157	179,510	31.3	20.4	0.4	0.5	2.4%	2.4%	1.5%
950	5,461	184,971	31.3	21.4	0.3	0.5	2.1%	2.1%	1.3%
1000	4,644	189,615	31.3	22.4	0.3	0.4	1.8%	1.8%	1.0%

1 Total target counts recorded up to 2,800 m band during the night time period was 254,368.

2 Total density of targets per hour recorded up to the 2,800 m band during the night time period was 35.71.

Department of the Interior
U.S. Fish and Wildlife Service

Fall 2015 & Spring 2016

Great Lakes
RESTORATION