U.S. Fish & Wildlife Service

Great Lakes Avian Radar Technical Report Delta County, MI Iosco County, MI Huron County, MI

Fall 2012 Season

Biological Technical Publication
BTP-R3016-2017

U.S. Fish & Wildlife Service, Region 3

Funding Provided by the Great Lakes Restoration Initiative

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Great Lakes RESTORATION

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Executive Summary

Global wind patterns help move millions of migrating birds and bats through the Great Lakes region where shorelines provide important stopover habitat. Shorelines are thought to concentrate migrants because they offer the last refuge near a geographic barrier and are likely used for navigation. Shorelines also offer areas attractive for wind energy development. 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 the activity patterns, timing, and duration of migration that occurred along the shorelines of the Great Lakes.

We split the season into two parts and surveyed two sites with avian radar systems in the Upper Peninsula of Michigan near the shorelines of Green Bay, Lake Michigan in August. We then surveyed two sites in the Lower Peninsula of Michigan near the shorelines of Saginaw Bay, Lake Huron for the remainder of the fall migration season (September through early November). While operating at each of the four sites, each of the avian radar systems tracked and recorded target (bird and bat) movements continuously. 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 occurred at all of our study sites; however, by moving locations on the first of September, we likely missed the majority of fall migration at our Upper Peninsula study sites and only captured a few days of what appeared to be heavy migration. We also were not able to document the duration of migration at the Upper Peninsula study sites; however, based on data collected at the study sites in the Lower Peninsula during the second part of our survey season, as well as from past seasons of data (Bowden et al. 2015, Horton et al. 2016c, Rathbun et al. 2016, Rathbun et al. 2017), we suspect that migration at these sites continued through at least October. The mean nocturnal passage rates were greater than the mean passage rates for dawn, day, and dusk combined at all of our locations. Nocturnal movement was generally orientated to the south for all sites. We also recorded other behaviors associated with migrants such as reverse migration, which was especially common at the sites in the Upper Peninsula, dawn ascent, and migrants over water returning to land at dawn. Peak density occurred between 100 - 350 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 identify areas where impacts to wildlife would be minimized. We documented migration activity in the air space above our study areas and suspect 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 periods and that the nocturnal peaks continued through late October. Given the amount of time during which migration occurred, it seems that curtailing wind energy operations during nocturnal pulses could result in limited operational time along shorelines during the migration season. Combining the results of radar studies and fatality searches would greatly improve risk assessments and assist with the interpretation of standardized radar studies.

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

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

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

Introduction

Collectively, the Great Lakes constitute one of the largest bodies of freshwater on the planet, and they have a surface area of nearly 245,000 km^2, and over 17,500 km of shoreline. Global wind patterns help to move millions of migrating birds and bats through the Great Lakes region (Rich et al. 2004, Liechti 2006, France et al. 2012), and globally recognized Important Bird Areas are often located on lake shorelines (Audubon 2013). Migrants passing through the region concentrate near shorelines (Ewert et al. 2011, Peterson and Niemi 2011, Buler and Dawson 2012, France et al. 2012), which provide important stopover habitats, or areas that are used temporarily for refueling, rest, and protection while *en route* to their breeding grounds. Compared with inland areas, these shorelines offer increased foraging opportunities relative to inland areas (Smith et al. 2004, 2007, Bonter et al. 2007, 2009) and may serve as visual cues for navigation or as refuges for migrants before or after they cross open water (Buler and Moore 2011).

Due to their location and size, the Great Lakes likely represent a geographic obstacle that migrants must cross or avoid based on the environmental and physiological conditions at the time they encounter the obstacle (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 single long flight because of the cost of carrying high fuel loads (Alerstam 1990), and this may be one reason why migrants partially circumnavigate the Great Lakes despite being physiologically capable of crossing them (Alerstam 1990, 2001, Ruth 2007). Thus, 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) associated with migration (McGuire et al. 2012a). Shorelines offer refuge when conditions do not favor flights over water.

When challenged by an obstacle, migrants 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 managing low fuel loads and/or unfavorable weather conditions returned to the shoreline habitat rather than continue across open water in the direction of migration. For bats, the migrants varied in their choice to cross over or circumnavigate lakes above the shorelines, and a number of long distance migrants use torpor to postpone migration in unfavorable conditions (McGuire et al. 2012b). These behavioral responses as well as the need to use stopover habitat during migration likely contribute to the increased use of shorelines and demonstrate the importance of these areas for conservation.

Migrants concentrated along shorelines can be very mobile. In addition to using the shoreline habitats for immediate refueling and rest, migrants make broad-scale flights between habitat patches, explore wind conditions, and orient themselves for migration. For example, radio-tagged bird and bat migrants on the north shore of Lake Erie made repeated movements between habitat patches, with individual birds and bats relocating as far as 18 and 30 km from their capture site, respectively, prior to resuming migration (Taylor et al. 2011). Nocturnal migrants, such as warblers and other Neotropical species, regularly engage in morning flights along shorelines (Wiedner et al. 1992). These flights typically occur within two hours of sunrise and likely represent reorientation along a geographic obstacle or movements between stopover habitats (Able 1977, Moore et al. 1990, Wiedner et al. 1992). Flights of this nature often occur above the tree line (Bingman 1980) but at heights lower than those 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), and these flights are considered normal activities aimed at calibrating internal compasses and testing the wind speed and direction aloft. Migrants also follow north-south oriented shorelines *en route* to their destinations (Buler and Dawson 2012), whereas east-west oriented shorelines may be used to circumnavigate open water or find narrow points for crossing (Alerstam 2001, Diehl et al. 2003, France et al. 2012). Additionally, migrant birds may change their altitude many times over the course of a nocturnal migratory flight (Bowlin et al. 2015). Cumulatively, these activities define an area of use near lake shores and include a variety of movements and altitudes for landscape-level, exploratory, and migratory flights. However, these activities may increase the risk of collision 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 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, which may limit habitat availability or reduce habitat quality (France et al. 2012).

Of further concern is the devastation of hibernating bat populations by White-nose Syndrome, which has increased the need for identifying conservation areas as several of these species face extirpation in the Great Lakes region (Turner et al. 2011). The increased number of wind energy installations within the U.S. is further devastating bat populations by causing high numbers of fatalities to long-distance migratory tree bats (Kunz et al. 2007a, Cryan 2011, Arnett and Baerwald 2013, Hayes 2013, Smallwood 2013). In response to such factors, substantial efforts are being made to identify and protect stopover habitat along the shorelines of the Great Lakes (Buler and Dawson 2012, Ewert et al. 2012, France et al. 2012, Johnson, 2013), although careful planning is needed to balance the demands between increased renewable energy development to mitigate climate change and the conservation of migratory species.

There is a national movement towards supplying 20% of the end-use electricity in the U.S. market by wind power by 2030 (U.S. D.O.E. 2008, 2015) and 35% by 2050 (U.S. D.O.E. 2015). As of 2012, wind energy installations were on target to achieve the 2030 goal (AWEA 2015), which would represent a nearly five-fold increase in wind energy capacity over the next 15 years (Loss et al. 2013). Coinciding with this national effort, wind energy development is increasing within the Great Lakes region, where windy shorelines are attractive areas for turbine placement (Mageau et al. 2008, Great Lakes Commission 2011). However, utility-grade wind facilities have been associated with mortality events in migrating vertebrates (Newton 2007, Arnett et al. 2008, Smallwood and Thelander 2008), and chronic fatalities across the U.S., particularly in bats, have become a concern (Timm 1989, Johnson 2005, Arnett and Bearwald 2013, Hayes 2013, Smallwood 2013). For example, approximately 75% of all bat mortalities occur in three species of long-distance migratory bats that are impacted by wind energy facilities (Cryan 2011, Kunz et al. 2007a, Arnett and Baerwald 2013), and these migrants, the hoary bat (*Lasiurus cinereus*), eastern red bat (*Lasiurus borealis*), and silver-haired bat (*Lasionycteris noctivagans*), typically account for 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 as well as substantial fatalities in the little brown bat (*Myotis lucifugus*) and big brown bat (*Eptesicus fuscus)* (Gruver et al. 2009, BHE Environmental 2010, Grodsky et al. 2012), although the presence of major hibernacula in the vicinity of wind facilities may have influenced the results. Additionally, low reproductive rates inhibit the ability of bats to rebound from population declines (Racey and Entwistle 2000), which have already begun in several species (Kunz et al. 2007a, Cryan 2011). The cumulative impacts on migratory birds and bats are a concern that will increase with the growth of wind energy if methods to avoid or minimize mortality events are not implemented. A number of promising conservation measures have been proposed to reduce mortality levels, but the greatest benefit to the conservation of migrants might 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 communities, we established this project to identify the activity patterns, temporal patterns, and magnitude of migration occuring along the shorelines of the Great Lakes. Since bats and many bird species migrate during the night throughout the spring and fall, documenting the migration is challenging because observing sporadic nocturnal movements is difficult. We used a combination of techniques to address this problem. We primarily used two avian radar units that simultaneously scanned the horizontal and vertical planes 24 hours per day, and we used automated ultrasonic/acoustic monitors to record and bat calls. We chose radar because of its ability to collect data on migrants at long range, to return data both at day and night, and to provide an alternative metric to our acoustic monitoring program, which has different strengths and weaknesses (Horton et al. 2015). The results of our acoustic monitoring study will be forthcoming in a separate report. Avian radar has been shown to reliably track targets that fly through its detection area, although the specific target counts are not indicative of true population counts (Gerringer et al. 2015). Migration traffic on radars has been shown to correlate with the density of birds in stopover habitat during the day (Horton et al. 2016a), indicating that migrants using the airspace are also using stopover habitat in the area.

Objectives

Our objectives for the portion of the study we are reporting on included the following:

- Monitor locations along the shorelines of Lake Michigan and Lake Huron using a consistent methodology;
- Maintain an archive of continuously recorded radar data during the fall migration season;
- Identify the activity patterns captured by radar that are diagnostic of migration;
- Document changes in the behavior of migrants under varying conditions and during different parts of the season.

Methods

Study Area and Site Selection

During the fall 2012 season, we selected four sites for radar placement. Two sites were located in the Upper Peninsula of Michigan, and two sites were located in the Lower Peninsula of Michigan (Figure 1). We looked for sites located approximately 0.75 – 3 km from the shoreline in order to monitor airspace above inland, shoreline, and lake areas as well as to investigate movement across large bays.

Both of the sites located in the Upper Peninsula were in Delta County. Our "West Delta County" site was on the western side of Green Bay, south of Escanaba. This site was at 45.6245° N, -87.2274° W and was approximately 175 m above sea level and 1.5 km from the nearest shoreline. The radar was placed in the middle of a grassy field, in an area where, according to our analysis using Esri ArcGIS software and the 2011 National Land Cover Database (Jin et al. 2013), woody wetlands and open water were the predominant land cover types within range of the radar unit (Table 1, Figure 2, Appendix 2). Our "Garden Peninsula" site was located along the eastern side of Green Bay, in approximately the center of the Garden Peninsula at 45.7419° N, -86.5680° W. This site was approximately 180 m above sea level and 2.6 km from the nearest shoreline (Portage Bay). Woody wetlands and evergreen forest were the predominant land cover types present within the range of the radar unit at this study site (Figure 2).

The two sites in the Lower Peninsula were on opposite sides of Saginaw Bay, in Iosco and Huron Counties. Our "Iosco County" site was on the northern side of Saginaw Bay, south of Tawas City. This site was at 44.1852° N, -83.5665° W and was approximately 188 m above sea level and 0.75 km from the nearest shoreline. The radar was placed in a non-active area of a gypsum mine where open water and woody wetlands were the predominant land cover types within range of the radar unit (Figure 2). The second site, "West Huron County," was on the southern side of Saginaw Bay, west of Sebewaing at 43.7999° N, -83.3955° W and was approximately 181 m above sea level and 2.8 km from the nearest shoreline. Cultivated crops constituted the major land cover type present within the range of the radar unit at this study site. Major cultivated crops in this area of Michigan are field beans, sugar beets, corn, and wheat (Huron County, 2015).

Selection of radar sites was achieved by examining areas using aerial imagery in order to identify areas near the shoreline. Areas were considered suitable based on distance to shoreline and distance to forest and man-made structures. Once suitable areas were identified, biologists contacted property owners to obtain permission to visit their land for site visits and radar placement, in order to assess potential sites. This assessment included evaluating the land use, line of sight for the radar units, and accessibility for placement. If additional locations that were not initially identified were discovered during site visits, they were evaluated as well.

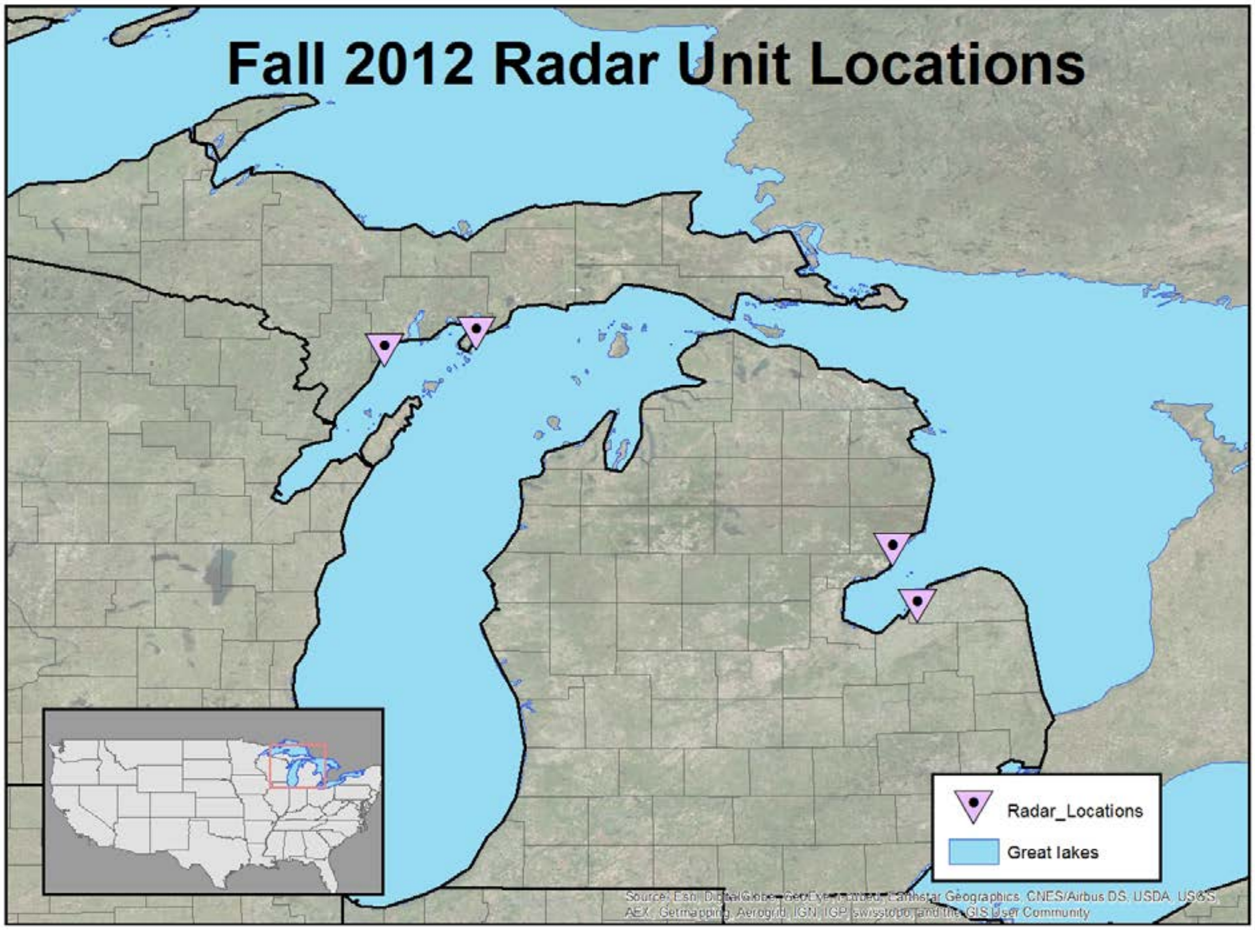


Figure 1. Locations where MERLIN Avian Radar Systems were deployed during the fall 2012 migration season. The basemap is the intellectual property of Esri and is used herein under license. Copyright © 2014 Esri and its licensors. All rights reserved.

Table 1. Predominant land cover types found within a 3.7 km radius of the fall 2012 radar locations.

	Percent Land Cover			
Land Cover Class	**West Delta County**	**Garden Peninsula**	**Iosco County**	**West Huron County**
Cultivated crops/Hay pasture	3%	21%	5%	61%
Deciduous forest	6%	10%	10%	6%
Deveoloped[1]	4%	4%	8%	6%
Emergent herbaceous wetlands	2%	1%	7%	6%
Evergreen Forest	7%	18%	4%	0%
Mixed Forest	8%	10%	2%	0%
Open water	24%	7%	35%	10%
Other[2]	7%	8%	10%	1%
Woody wetlands	39%	22%	19%	9%

[1] Includes low, medium, and high intensity development and developed open space.

[2] Includes barren land, herbaceous, and shrub/scrub.

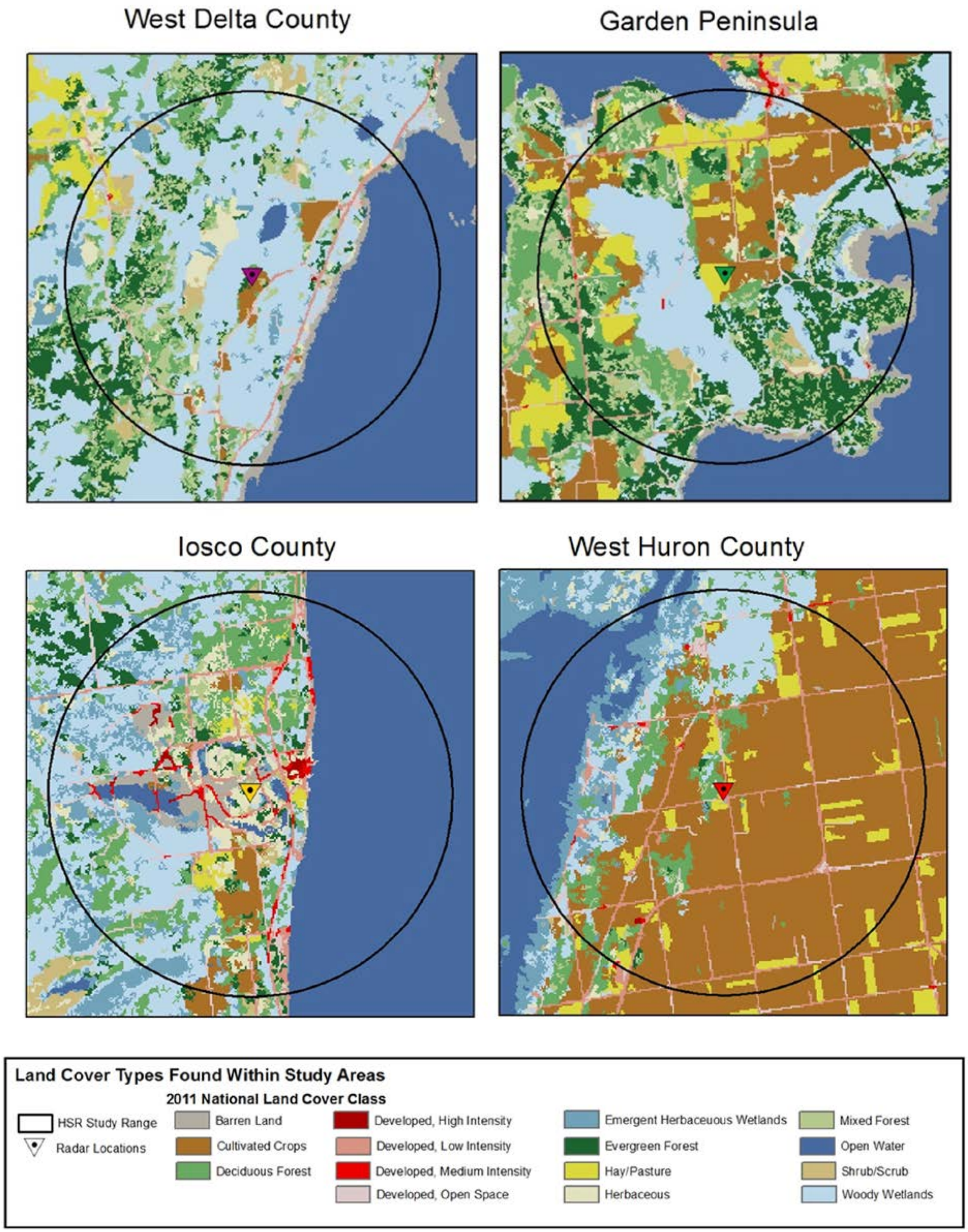


Figure 2. Land cover types (Jin et al. 2013) found within a 3.7 km radius of our West Delta County, Garden Peninsula, Iosco County, and West Huron County radar sites.

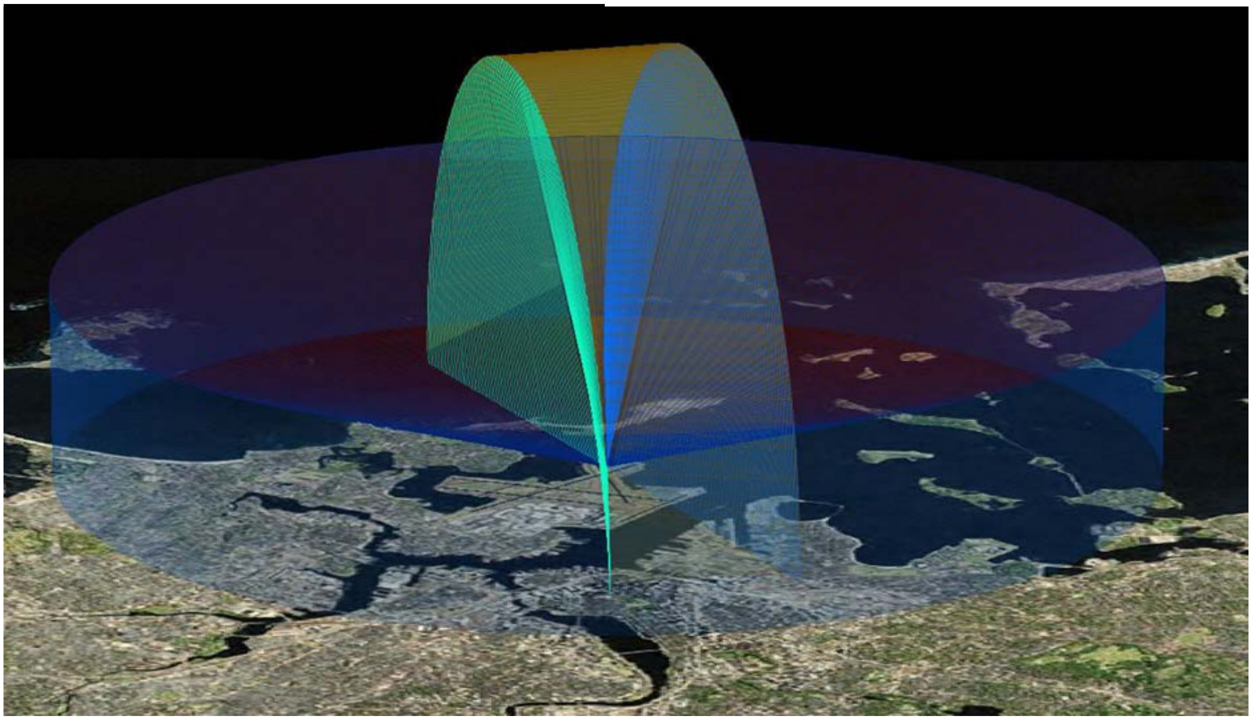


Figure 3. Computer representation of the potential survey volume scanned by the horizontal and vertical radars used by the U.S. Fish and Wildlife Service. Graphic provided by DeTect, Inc.

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 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. The solid state marine radar antennas (Kelvin Hughes, London, UK) employed by our systems were 3.9 m in length, with 170 W peak power, S-band (10 cm) wavelength, and 2.92 – 3.08 GHz frequency range, and they were configured to operate with both short and medium pulses (0.1 and 5 microseconds, respectively). The horizontal radar was also equipped with Doppler to help filter stationary targets. The radars emanated a fan-shaped beam that 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 that of X-band (3 cm wavelength) antenna (Bruderer 1997). It is also less sensitive to signal attenuation from ground clutter such as vegetation and structures (DeTect Inc., unpublished data, 2009). The radars spun perpendicular to each other at a rate of 20 revolutions per minute and were synchronized so as not to emit over one another. The horizontal scanning radar (HSR) was affixed to a telescoping base that was raised to approximately 7 m above ground for operation. This radar rotated in the x-y plane with a 7° tilt to reduce the amount of ground clutter included within its view. While the 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 to identify smaller targets such as passerines and bats. The HSR was primarily used to provide information on target direction. The vertical scanning radar (VSR) rotated in the x-z plane and scanned a 1° x 25° span of the atmosphere. We selected a 2.8 km range setting for this radar for increased resolution and used the VSR to provide information on the number and height of targets.

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

Radar Set Up and Data Collection

The radar systems were deployed to the Upper Peninsula of Michigan during the last week of July; however, due to radar malfunction full data collection did not begin until early August. Data collection continued through September 1 in the Upper Peninsula. We then moved to two new sites in the Lower Peninsula of Michigan, where data collection occurred from the first week of September through the first week of November.

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 southbound direction of migration during the fall season and orientated vertical scanning radars to an angle that was slightly off of perpendicular to the 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 noise. In our study, if large areas were obstructed from the radar's view or if substantial amounts of clutter impeded data collection, the 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 the data collection, clutter maps were generated using 60-scan composite images (Figures 4-5) during time periods with low biological activity to identify areas with constant returns (white areas) 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, thus reducing our ability to detect targets in these areas.

Following this initial set up, MERLIN software was adjusted to fit the site conditions. The MERLIN software provided real-time processing of raw radar data to identify and track targets while excluding non-targets and rain events. However, the parameters used by the tracking software required adjustments to account for site specific conditions and biologists established 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. Despite the radar system's ability to be operated remotely for extended periods of time, biologists remained on site during the data collection period to ensure continuous function, monitor raw (unprocessed analog radar returns) and processed radar outputs, provide routine maintenance (such as fueling and oil changes), and manage data storage. In addition to processed data, we maintained all raw radar data for potential reprocessing. Raw radar data were temporarily stored in the field on 2 TB external hard drives and regularly transported back to the USFWS Regional Office (Region 3) on ruggedized external drives where data were transferred to long term tape storage.

Radar System Outputs

The MERLIN software generated more than 30 measurements to describe target size, shape, location, speed, and direction of movement. These data were 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 fewer 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, the DeTect software outputs included a two-dimensional digital display of targets being tracked in real-time and static images of tracked targets over a specified period of time (Trackplots) for both vertical and horizontal radars. During each site check, we viewed the real-time digital display to ensure that it was consistent with the raw radar display, and we later viewed 15-minute and 1-hour Trackplots to assess the target direction and height during the previous day's activity.

Data Processing and Quality Control

Prior to the data analysis, the data processed by the MERLIN software were further evaluated for potential contamination by non-targets. Although an automated rain filter was used, it did not remove all of the rain from the recorded outputs during certain time periods. Additionally, insects and other forms of transient clutter may have

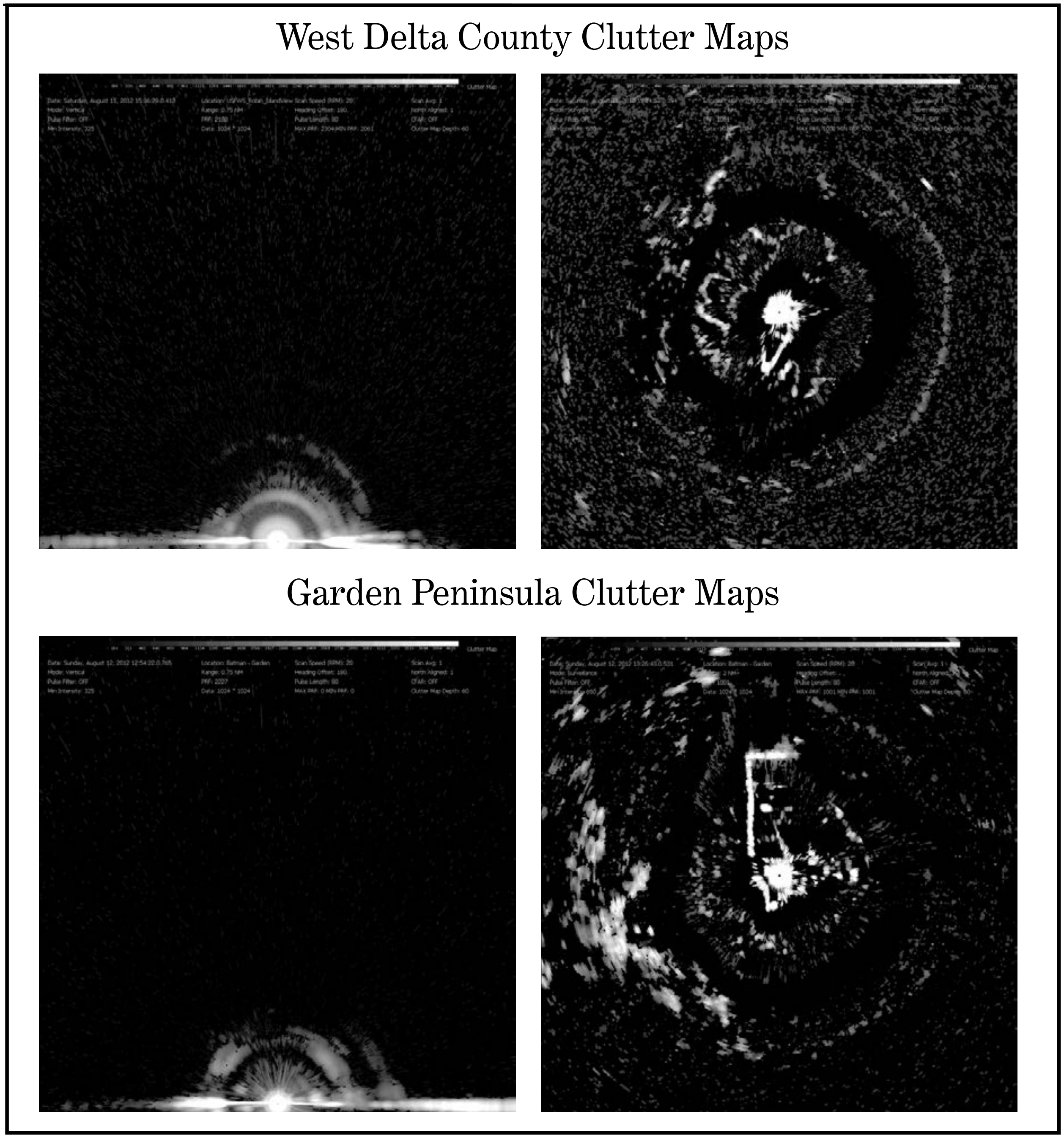


Figure 4. Clutter maps from vertical (left) and horizontal (right) scanning radars at study sites at our West Delta County (top) and Garden Peninsula (bottom) study sites, during the fall 2012 migration season. Brighter areas represent static returns from stationary objects, such as tree lines and fencerows. Target detection may be obscured in these areas because of obstructions from the objects.

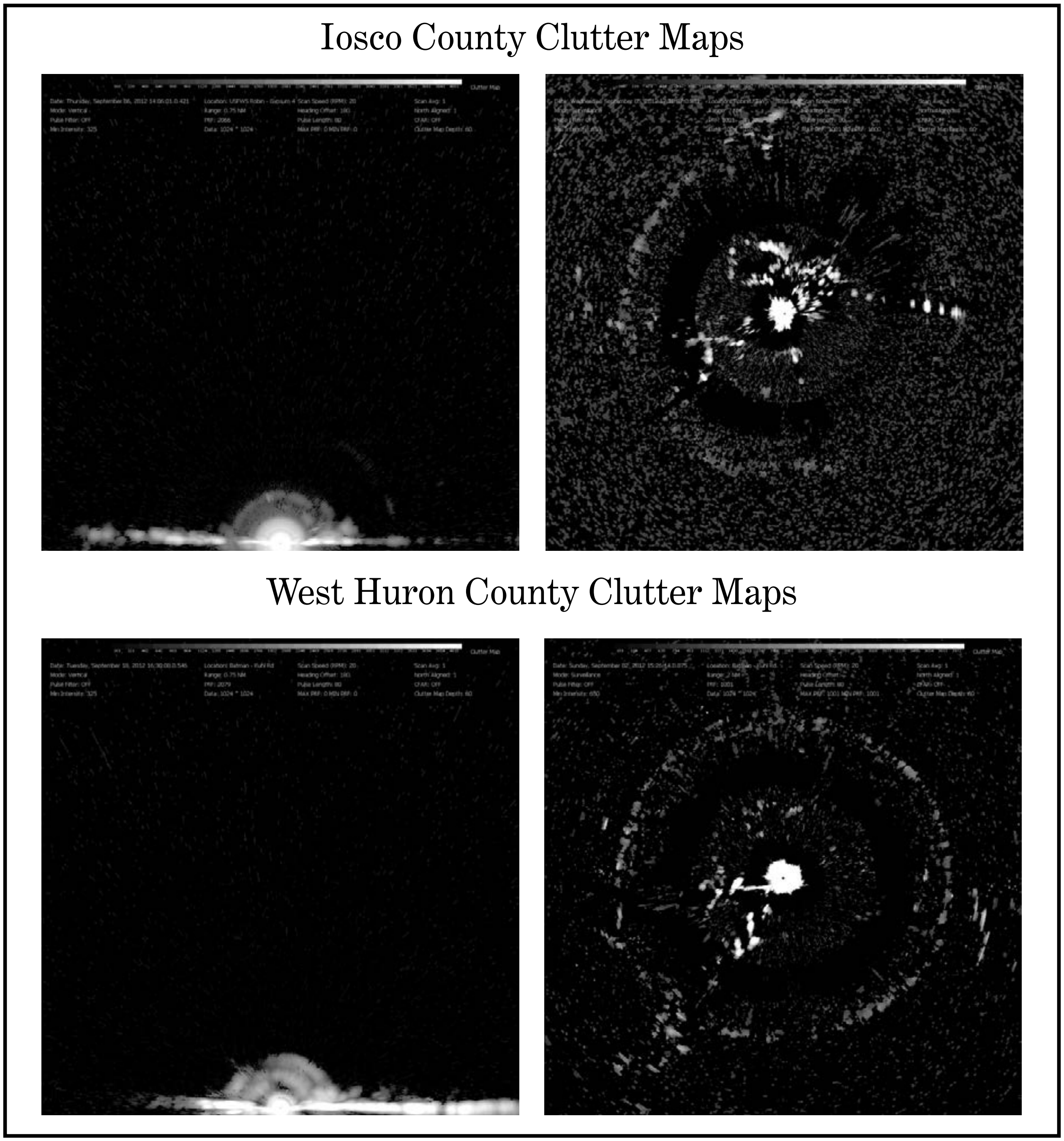


Figure 5. Clutter maps from vertical (left) and horizontal (right) scanning radars at study sites at our Iosco County (top) and West Huron County (bottom) study sites, during the fall 2012 migration season. Brighter areas represent static returns from stationary objects, such as tree lines and fencerows. Target detection may be obscured in these areas because of obstructions from the objects.

been recorded during data collection. Therefore, biologists reviewed all of the data in 15-minute time increments and removed the time periods that were dominated by rain, although there were no time periods dominated by other forms of transient clutter that needed to be removed.

We relied on visual inspections of the 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. Unknown contamination that mimicked the patterns of desired targets was not removed from the database and contributed to the error associated with the indices. In addition, we evaluated initial counts by generating a time series of the variation in the number of targets per hour throughout the season for the HSR and VSR radars. In general, the HSR and VSR hourly counts were positively correlated with higher HSR counts, and in situations where the VSR counts were higher than the HSR counts or where the peak counts appeared to be outliers, the data were further investigated for evidence of contamination or potential issues with radar performance. On the rare occasions when time periods with anomalies appeared to represent artifacts that were unrelated to target movement (e.g., rain events, insects, or data processing errors), these periods were removed from further analysis.

Once the contaminated time periods were removed, we summarized the data using SQL queries provided with the MERLIN radar system. Data from the HSR were used to calculate hourly counts and target movement direction. All targets within 3.7 km of the radar unit were included in the analysis. Data from the VSR were used to calculate hourly counts and height estimates, and these data were truncated to a 1-km front, or "standard front". We adopted this sampling technique as it is the method used by the manufacturer of the MERLIN units (DeTect Inc., unpublished data, 2009) and has also been used 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 6). Counts were further segregated into four biological time periods: dawn, day, dusk, and night. Dawn represented 30 minutes before sunrise to 30 minutes after sunrise; day represented 30 minutes after sunrise to 30 minutes before sunset; dusk represented 30 minutes before sunset to 30 minutes after sunset, and night represented 30 minutes after sunset to 30 minutes before sunrise.

Data Summary and Trends Analysis

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

Directional Trends. The mean angle and concentration (r) of the target movement directions were analyzed following the methodology for circular statistics (Zar 1999) included in the DeTect SQL queries. The angular concentration value has a value of 1 when all of the angles are the same and a value of 0 when all of the angles cancel each other out, indicating that there is no predominant direction of travel (e.g., if 50% of the vectors are 180° and 50% are 360°, then no direction is predominant because there were as many targets heading south as there were heading north). We anticipated a generally southward direction of movement by the nocturnal targets during the fall migration season and reported the mean direction and the percent of nocturnal targets that traveled in a direction between southwest and southeast (112.5° – 247.5°). We used radial graphs to plot the number of targets per eight cardinal directions (i.e., eight groups centered on N, NE, E, SE, S, SW, W, and NW) during the four biological time periods (i.e., dawn, day, dusk, and night).

Temporal Trends. We plotted the counts of targets per hour processed by the MERLIN software for both the HSR and VSR antennas as a time series to identify pulses of nocturnal activity, the duration of the season, and changes in activity patterns over time. The HSR and VSR radars have different strengths that complement one another and were plotted together. The HSR index tracks low flying targets in a 360° span around the radar unit, and compared with the VSR, detection is unaffected by the target's direction of travel, although the HSR index is much more affected by ground clutter, which impacts target detection and tracking, and errors caused by ground clutter lead to both under- and over-counting. Targets blocked by ground clutter may not be counted, and targets that fly in and out of areas with ground clutter may be counted multiple times. Such issues lead to HSR counts that are more influenced by site characteristics relative to the VSR counts; however, the HSR index better captures targets under certain conditions, such as when targets are primarily at low elevations and/or traveling parallel to the VSR. The HSR is also more susceptible to beam-bending from dynamic atmospheric conditions relative to the VSR, which presents minimal beam refraction primarily because of its orientation. The VSR index was used to track targets captured within the standard front, and it exhibited more consistent detection than the HSR because it mostly tracked against clear air except in the lowest altitude bands. Detection by the VSR index was affected by target direction and distance from the radar (Bruderer 1997, Schmaljohann et al. 2008), and it was impacted by ground clutter, particularly at low elevations. Plotting these indices together provided a more comprehensive understanding of changes in target activity over time.

We used the VSR index to calculate the target passage rate (TPR), which is the number of targets

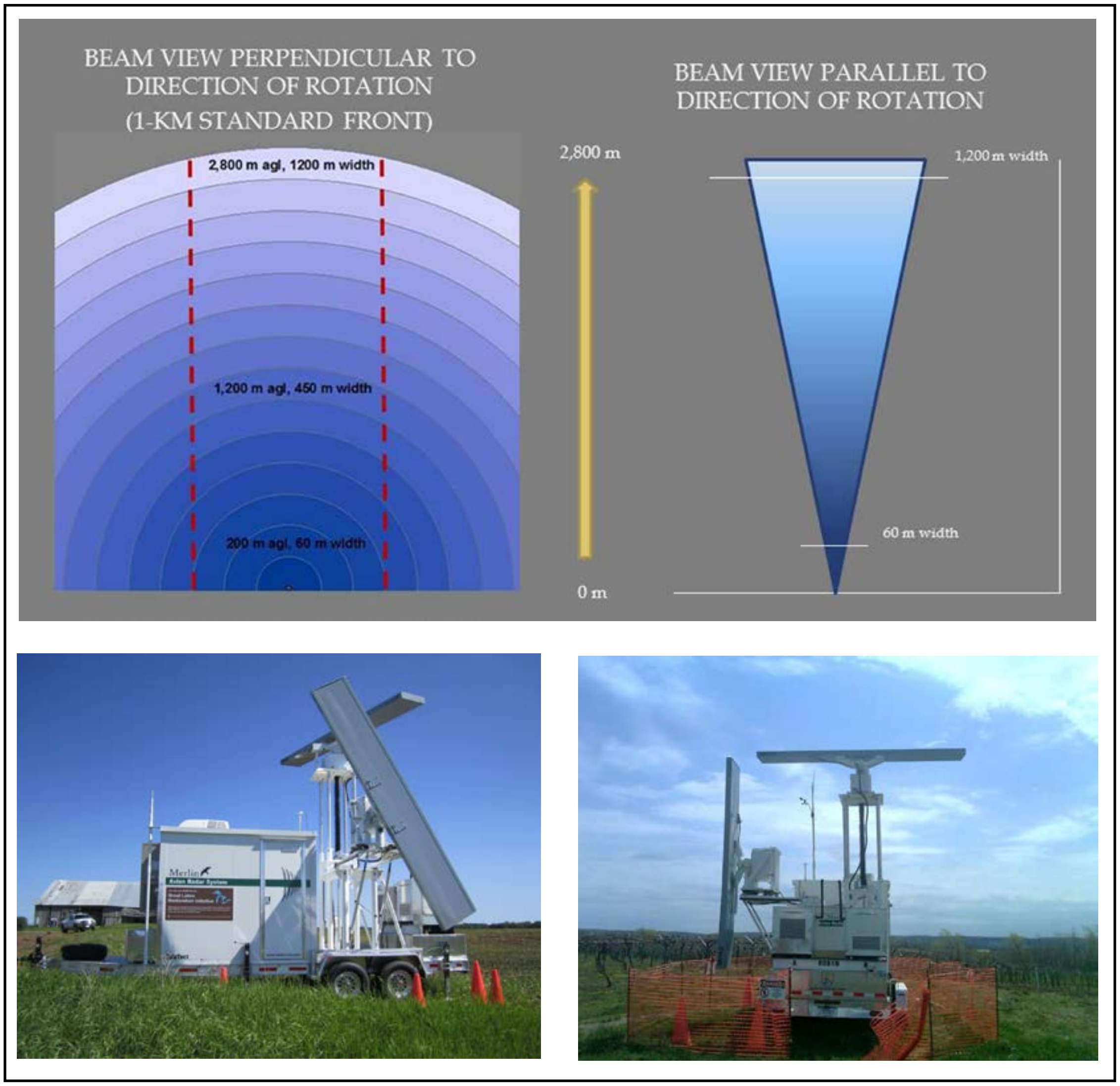


Figure 6. This schematic depicts the vertical scanning radar beam from two different views and pictures of the radar unit associated with those views. The top left graphic identifies the standard front used for data analysis, which extends to 500 m on either side of the radar and up to a height of 2800 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 top right graphic, the radar rotation is suspended so that the beam is emitting directly upward; this view is an approximation of the beam dispersion as it travels away from the radar unit (schematic not drawn to scale).

per standard front per hour, using the DeTect SQL queries, and hour intervals with less than 30 minutes of recording time were omitted from this calculation. For example, after removing all of the hours with less than 30 minutes of clean data, the nocturnal TPR for a given night (biological time period) was calculated by dividing the target count by the number of nighttime minutes and multiplying the value by 60 to yield the number of targets per hour during that night. We extended this metric to the season and calculated the mean TPR for the four biological time periods and hours of the season. The mean nocturnal TPR for the season is the sum of the night TPRs divided by the number of nights sampled. Similarly, the mean hourly TPR for the season is the sum of the TPRs for an hour-long period divided by the number times that hour was sampled. We also calculated mean nocturnal (night biological period) and diurnal (day biological period) TPR weekly during the sampling period using two methods. First, to demonstrate the variability among the 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. Second, to better illustrate the nocturnal and diurnal trends in TPR across the season, we plotted 7-day moving TPR means as line graphs.

Altitudinal Trends. The DeTect SQL queries were used to estimate the height of the targets tracked within the standard front from the VSR data. The 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 the ground as measured at the radar unit; this measurement did not consider changes in topography across the landscape. We used these estimates to calculate the mean altitude of the targets above the ground according to biological time period and hour, and we reported the 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 expanded as it traveled from the radar, resulting in increased survey volume with distance from origin. The shape of the survey volume contained the space in which targets had the potential of being detected and represented 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 the density of targets (targets/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 (uncluttered) data during the biological time period of interest and multiplied by 60.

To estimate the volume of the 50-m altitude bands that were constrained by the standard front, we used Monte Carlo integration (Press et al. 2007), which is described in detail elsewhere (manuscript in preparation) and summarized here. The volume contained by the shape of the radar beam was calculated using spherical coordinates and multiple integration. However, subjecting this volume to Cartesian constraints (i.e., the standard front and the altitude bands) complicated the calculation, so the volume bands were more easily estimated using Monte Carlo integration, which is a method used 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, and 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, the estimate approaches the true value as the number of random points approaches infinity.

We used R software (R Core Team 2012) to describe a box of known volume that was large enough to enclose the radar beam and then saturated this space with 10 million random points, and 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 had to be less than 2.8 km. The second rule was that the angle between a randomly drawn point and the vertical plane (the x-z axis in Figure 7) had to be less than 12.5º (i.e., half the angle of the width of the beam). The volume of a full sweep of the radar beam, which was estimated by Monte Carlo integration, was within 5% of the analytical solution using spherical coordinates. Therefore, the number of random points we used provided a reasonable approximation of the volume. By determining the volume of a full sweep of the radar beam, we were able to further constrain the Monte Carlo integration to describe the structural volume of the radar beam within a standard front (Figure 7) and within altitude bands (Figure 8).

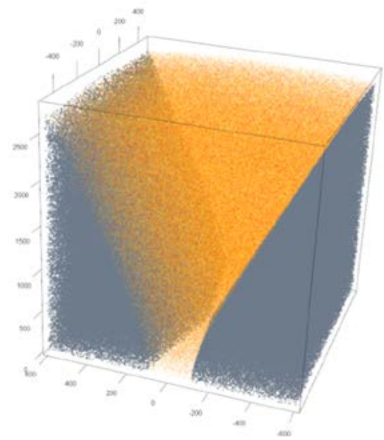


Figure 7. A graphical representation of the structural volume of the vertical scanning radar within the standard front. In this graphic the radar unit is located at the origin, and the radar beam extends to 500 m on either side of the radar unit (x-axis) and up to a maximum height of 2800 m (z-axis). 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 is not included in the volume of the radar beam.

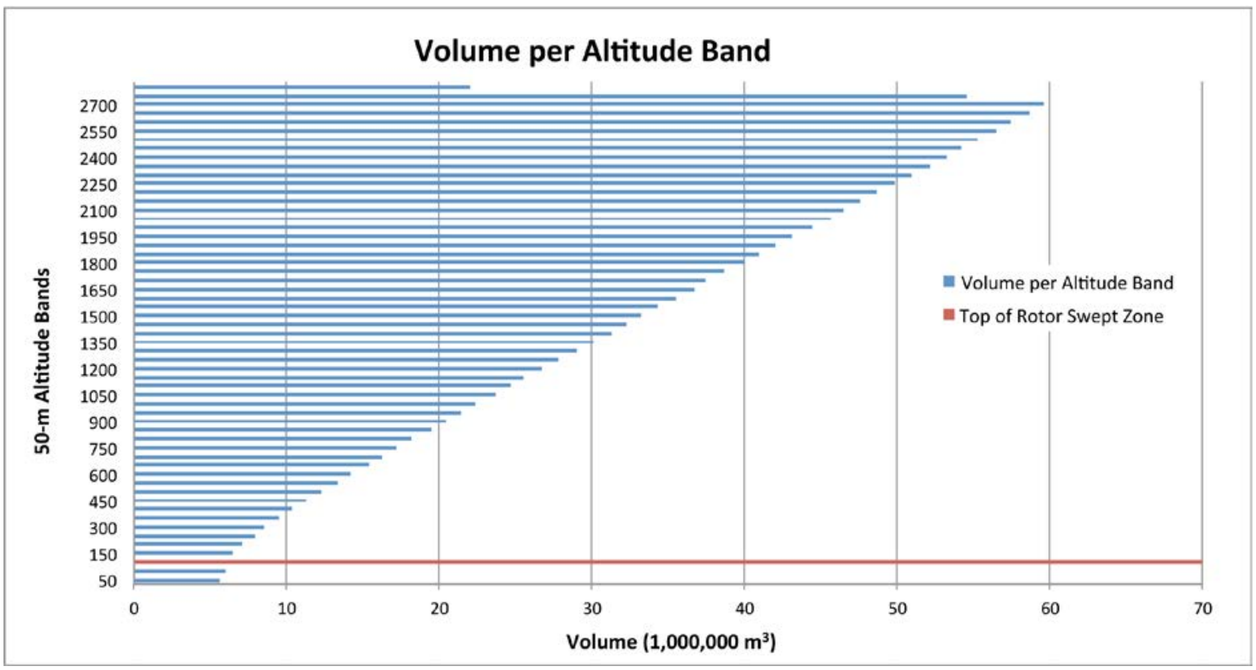


Figure 8. Volume of 50-m altitude bands within the standard front as estimated with Monte Carlo integration. Altitude band intervals represent the upper band limit. Target counts provided by the vertical scanning radar are limited to the structure of the standard front. The red line represents the top of the rotor swept zone at 130 m.

The number of targets per altitude band is often reported without providing a volume correction. We wanted to compare our correction to the uncorrected method; however, count data and volume data are at different scales. For this reason, we compared 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).

Results

Upper Peninsula of Michigan - Green Bay, Lake Michigan

During the fall 2012 season we began data collection at the West Delta County site on July 29 using the horizontal scanning radar. Due to water intrusion into the vertical scanning radar, which resulted in the radar's malfunction and inability to collect data, we were not able to start collecting vertical scanning radar data until August 11. Water intrusion issues in the antenna also occurred with the radar unit that was placed at the Garden Peninsula site. Therefore, data collection from both vertical and horizontal radars started on August 9 at this site. Data collection ended at both sites on September 1, 2012. Our survey period at the West Delta County and Garden Peninsula sites captured migration activity; however, our survey period did not overlap with what is generally the peak of the fall migration season (generally September – October), so our results may not be indicative of what occurs during the height of migration. Data were recorded continuously while the radar units were operational, although gaps in the data collection occurred during rain events and when the radar units were not operational due to maintenance or malfunction (radar downtime). When correcting for radar downtime and removing the periods with rain, the vertical and horizontal radars collected usable data for 88% and 87% of the study period at the West Delta County site, and for 90% and 87% of the season at the Garden Peninsula site, respectively (Table 2).

Table 2. Survey effort (hours) by vertical and horizontal scanning radars during fall 2012 at our radar sites in West Delta County (WDC) and Garden Peninsula (GP).

Site	Radar	Survey Period	Radar Downtime	Time Radar Collected Data	Radar Data w/Rain	Useable Radar Data	% Survey Period with Collected Data	% Survey Period with Useable Data
WDC	VSR[1]	570	52	518	15	503	91%	88%
WDC	HSR	878	112	766	1	765	87 %	87%
GP	VSR	562	37	525	17	508	93%	90%
GP	HSR	562	72	490	1	488	87%	87%

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

Qualitative Assessments

Plots of tracked targets showed images of nocturnal migration events at both locations (Figures 9 and 10). For example, on August 27 at the West Delta County site, the horizontal radar recorded scattered activity and the vertical radar recorded a low number of targets from 12:00 – 17:00 (Eastern Standard Time). During the 17:00 hour, a more directional movement of targets to the south and southwest began to occur, and vertical counts increased slightly. During the 20:00 hour, directional movement to the south and southwest continued and targets began moving to the southeast as well; vertical counts increased at this time, with more targets at higher altitudes. A general southward movement continued throughout the night, with some western movement beginning around 01:00 on August 28. As the night progressed, overall target counts tapered off, and target flight heights moved lower in altitude. At 06:00, some targets moved west off of the lake, and by 10:00 diurnal activity appeared similar to the proceeding day at 12:00 (Figure 9). This pattern of target movement and changes in flight altitude were indicative of a pulse of migratory activity.

A similar pattern of low target activity and flight heights during the day and increased directional activity and higher flight heights at night was also seen at the Garden Peninsula site (Figure 10). On August 26, targets moved southeast and east at 20:00 and shifted to a mainly southeast direction by 23:00. By 05:00 on August 27, the direction of target movement shifted again towards the south and west. This continued until after dawn, and by 11:00 target activity returned to non-directional diurnal movement. At the Garden Peninsula site, we also observed many

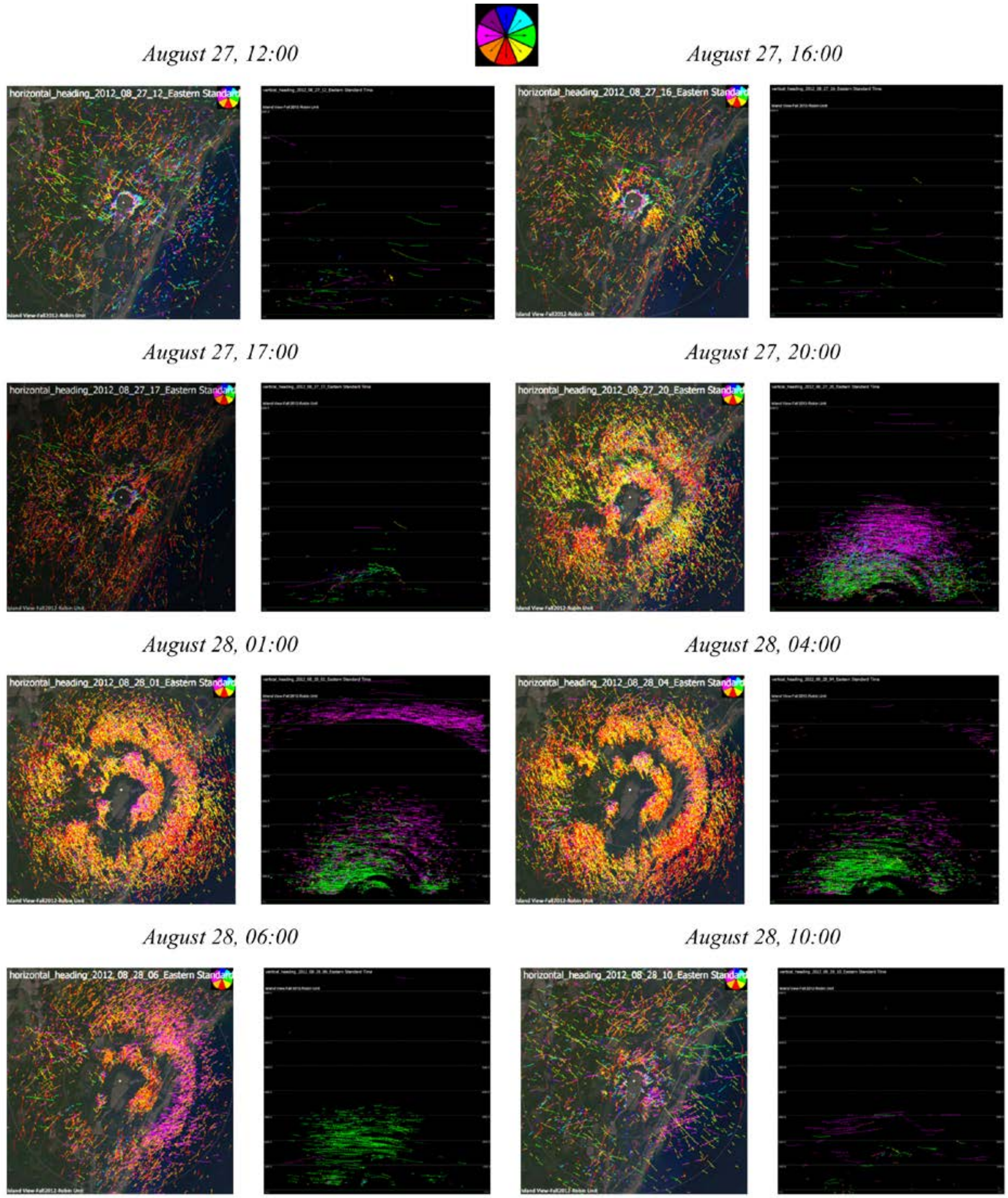


Figure 9. Images of tracks during one hour increments recorded by horizontal and vertical scanning radars during a migration event at our West Delta County radar site. Horizontal radar images (columns 1 and 3) show direction of targets as indicated by the color wheel (dark blue indicates travel to the north and red indicates travel to the south). Vertical radar images (columns 2 and 4) show target heights.

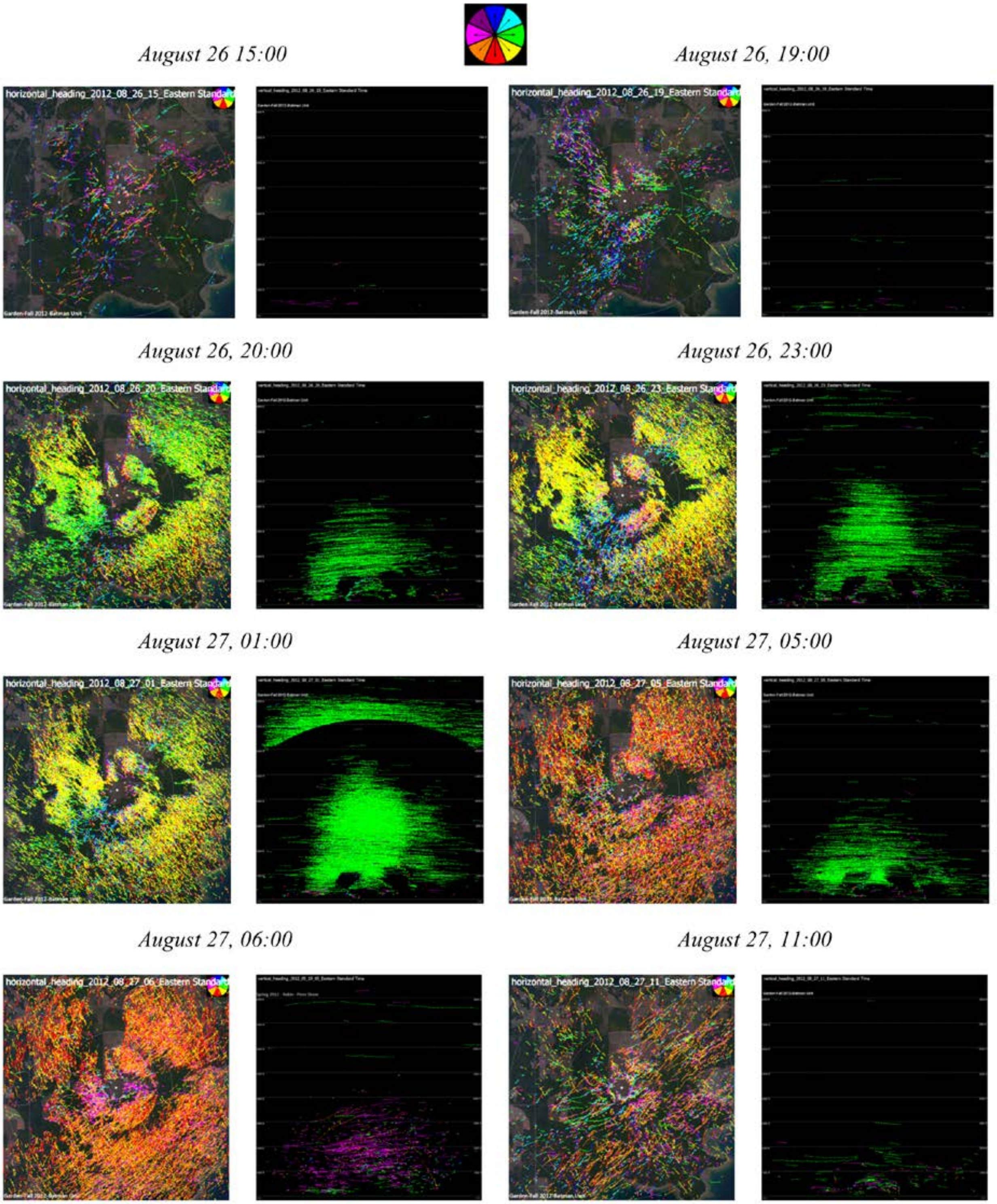


Figure 10. Images of tracks during one hour increments recorded by horizontal and vertical scanning radars during a migration event at our Garden Peninsula radar site. Horizontal radar images (columns 1 and 3) show direction of targets as indicated by the color wheel (dark blue indicates travel to the north and red indicates travel to the south). Vertical radar images (columns 2 and 4) show target heights.

nights with reverse migration, with targets moving to the northeast. We attributed this to the early sampling dates that we had for this season.

Also apparent on the Trackplots from both sites are areas not well recorded by the radar due to beam blockage from ground clutter (i.e., topography, vegetation, buildings, etc.) (Figure 4), thus resulting in reduced detection in the air space within the data collection range (e.g., south and west of the radar unit at the West Delta County site and north, east and west of the radar unit at the Garden Peninsula site, as observed in the horizontal Trackplots in Figures 9 and 10). 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 (August 28, 01:00) and vertical Trackplots (observed at a range of about 1,400 – 2,000 m).

Directional Trends

During the fall 2012 season, the nocturnal target direction was generally south at West Delta County and southwest and southeast at the Garden Peninsula site (Figure 11). At our West Delta County site, the mean nocturnal direction was 152° (r = 0.17, n = 2,681,116 targets) (Table 3) and during 52% of the nights the mean target direction was between the southeast and southwest (113.5° – 247.5°). Direction at the Garden Peninsula site had a mean nocturnal direction of 155° (r = 0.24, n = 1,634,581) with 62% of nights having a mean direction between southeast and southwest (Figure 11 and 12, Figure 3).

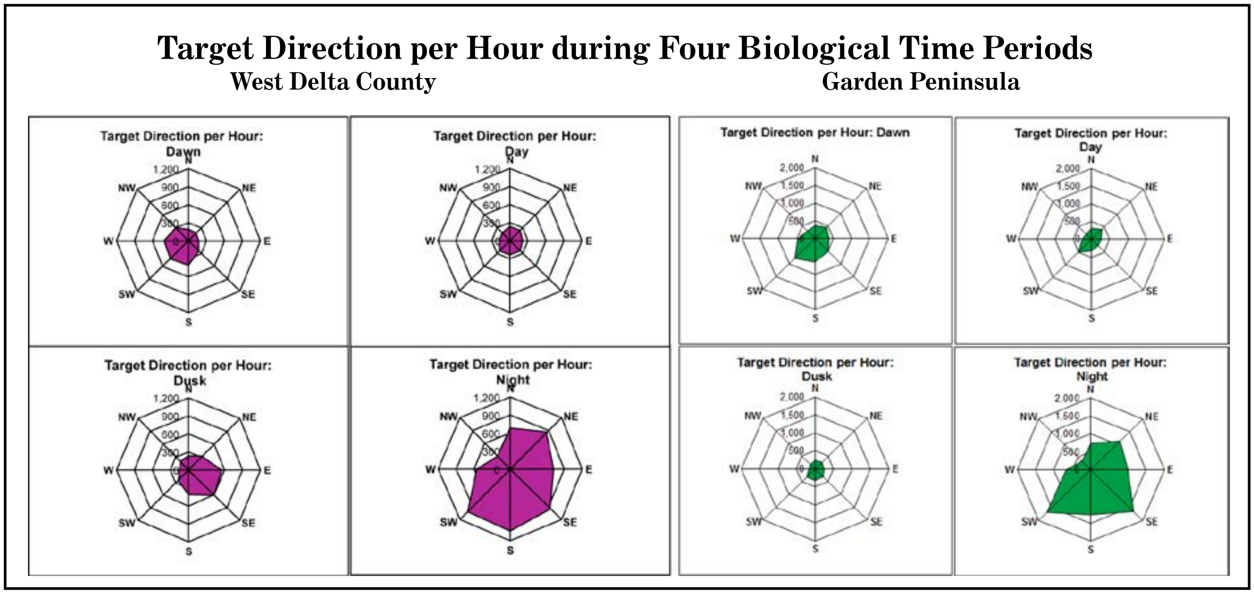


Figure 11. Target direction per hour during four biological periods during fall 2012 at our West Delta County (left) and Garden Peninsula (right) sites. Note different axis scales between the sites.

Table 3. Mean direction, angular concentration (r), and percentage of biological time periods with strong directionality (r ≥ 0.5) of targets during biological time periods at our West Delta County and Garden Peninsula sites.

	West Delta County				Garden Peninsula			
Biological Period	Mean Direction (degrees)	r	% Time $r \geq 0.5$	n	Mean Direction (degrees)	r	% Time $r \geq 0.5$	n
Dawn	233	0.25	54.8%	77,220	196	0.18	66.7%	82,478
Day	142	0.06	3.2%	720,070	199	0.05	5.0%	645,619
Dusk	123	0.31	40.0%	87,478	149	0.13	28.6%	43,036
Night	152	0.17	77.4%	1,796,348	155	0.24	78.9%	1,634,581

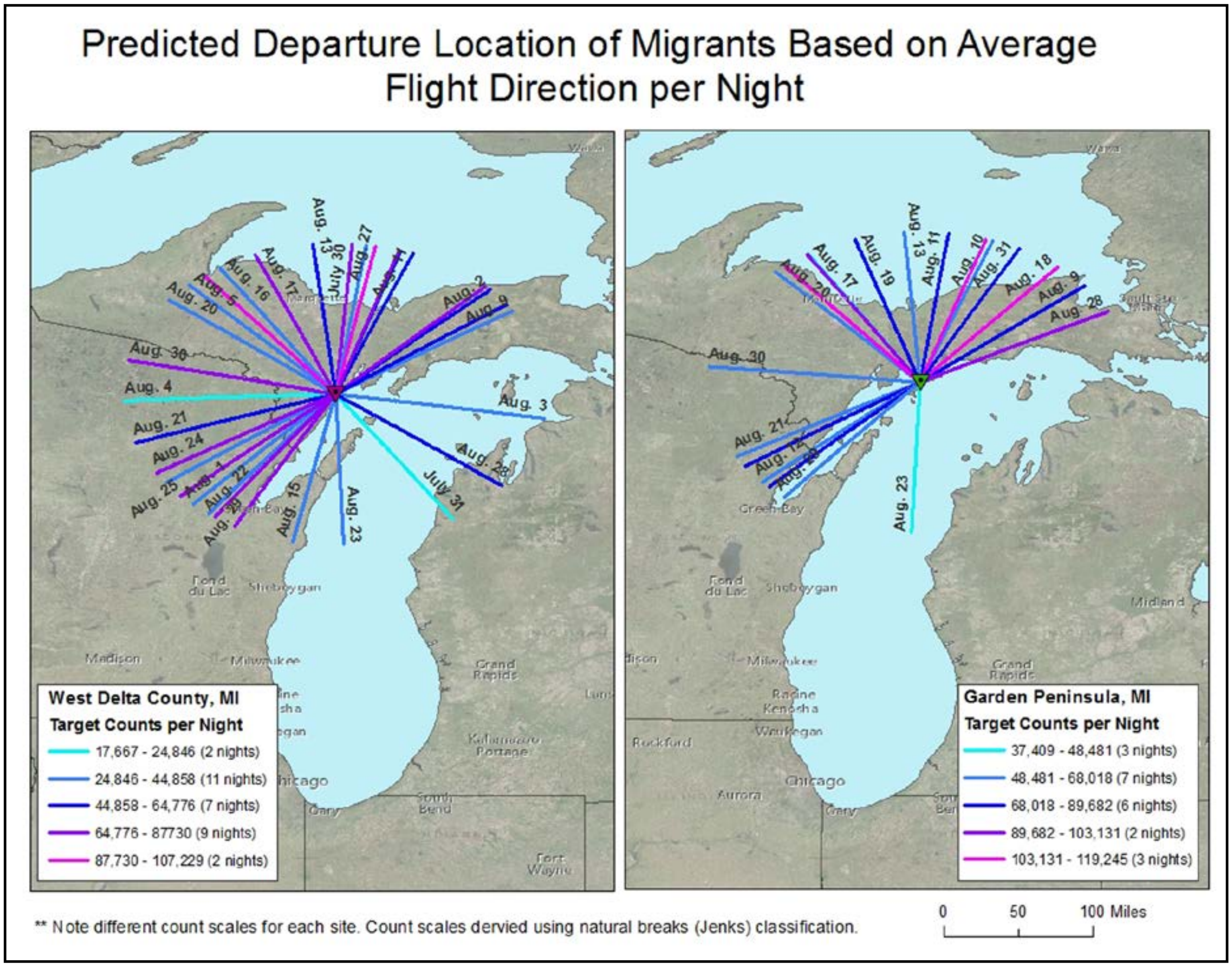


Figure 12. Movement direction of targets for each night over the first part of the season. Each line represents the average movement direction targets were coming from for one night during the season. These directions assume that migrants move in a straight line, which is not the case, but it helps to show where the general direction of movement that migrants were coming from was located. These directions provide evidence that migrants fly along the Garden Peninsula and along the shoreline of Green Bay. The color of the lines indicates the magnitude of migration on that night. Count categories were derived using natural breaks (Jenks) classification. Date labels are missing for some lines that were too closely clumped together.

Temporal Trends

Time Series Plots. Hourly target counts provided by horizontal and vertical radars showed pulses of elevated nocturnal activity with nocturnal peaks occurring a few hours before and a few hours after midnight. Typically, we've seen this elevated nocturnal activity clustered into groups of several nights for many of our survey periods (see Figures 13 and 14) (Bowden et al. 2015, Horton et al. 2016c, Rathbun et al. 2016, Rathbun et al. 2017).

Elevated nocturnal activity occurred at the West Delta County and Garden Peninsula sites on August 27 and continued through the last day of our survey period, September 1, with a lull in activity occurring on August 30 (Figures 13 and 14). Though at a lower magnitude, nocturnal activity occurred at these sites during the early parts of August as well.

Differences in detection capability of the vertical and horizontal scanning radars can be observed in Figures 13 and 14. For example, the horizontal radar at West Delta County shows an afternoon peak on August 20 at 13:00; however, this peak in activity is not represented by the counts obtained by the vertical scanning radar. This is possibly due to the flight path and lower altitudes of these targets.

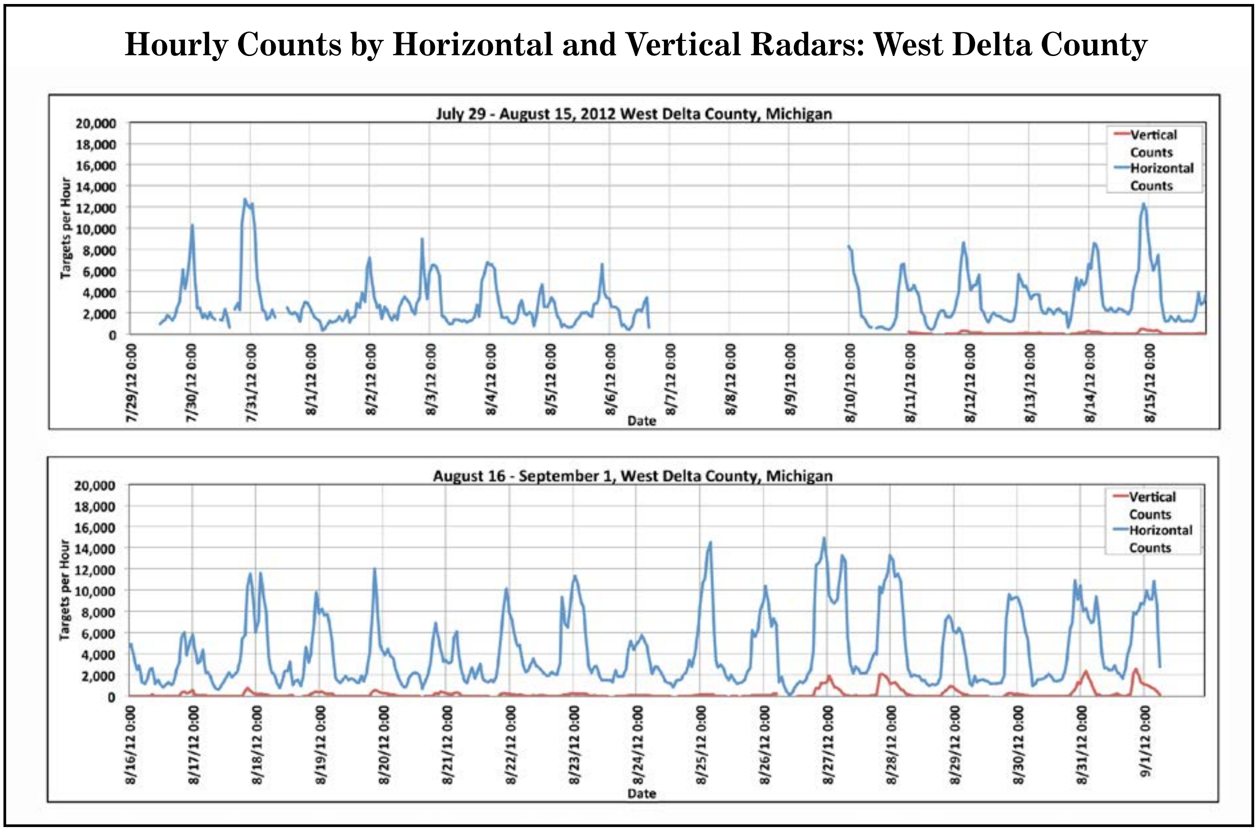


Figure 13. Hourly counts by horizontal and vertical radars from July 29 – September 1, 2012, West Delta County. Due to water intrusion into the vertical scanning radar, resulting in the radar's malfunction and inability to collect data, data collection from the vertical scanning radar began after repairs were made, on August 11. Light gray vertical lines represent midnight.

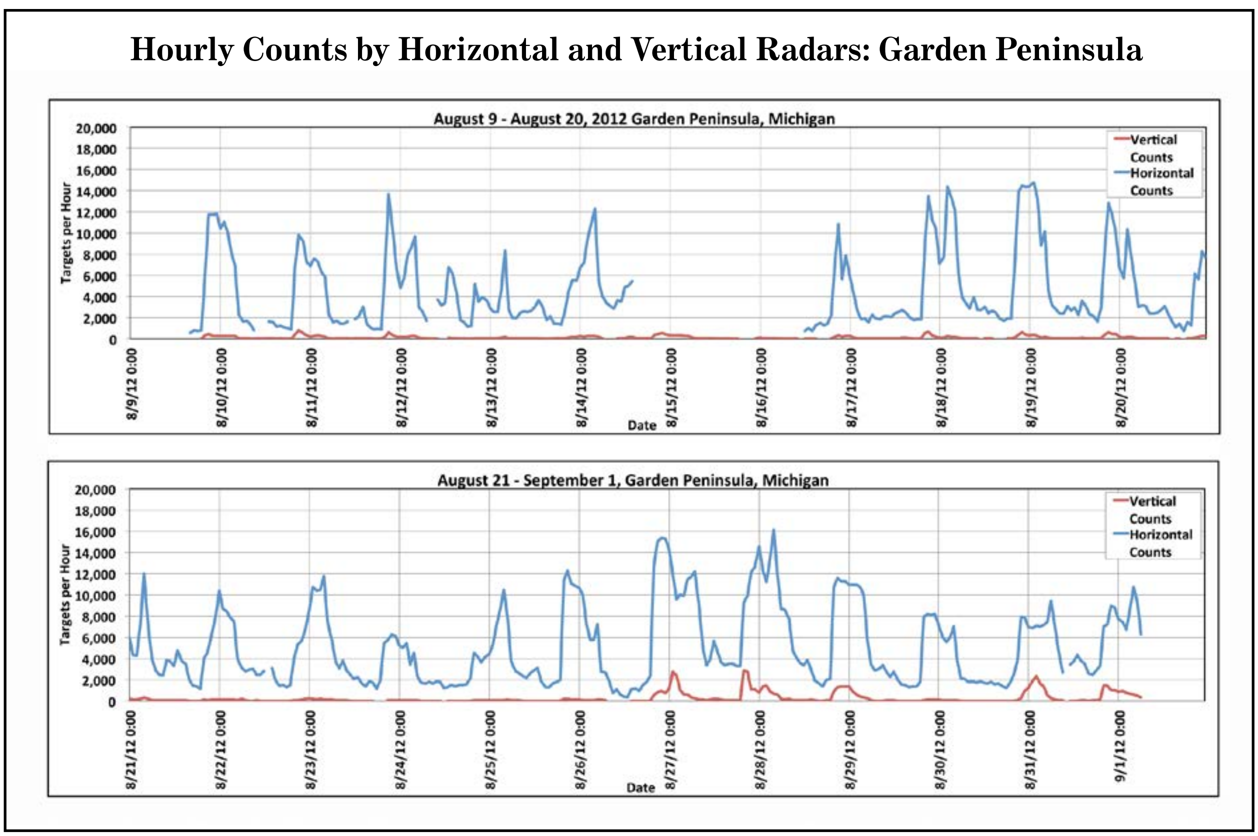


Figure 14. Hourly counts by horizontal and vertical radars from August 9 – September 1, 2012, Garden Peninsula. Light gray vertical lines represent midnight.

Target Passage Rate. The pattern of mean TPR among the four biological time periods was similar between the two study sites (Figure 15) with the mean TPR at night being greater than the combined means of the other three biological time periods (Table 4). The mean nocturnal TPR was 407 ± 430 SD (n = 22 nights) and 392 ± 406 SD (n=23 nights) at the West Delta County and Garden Peninsula sites, respectively. The mean TPR varied by hour with peak numbers reached during the 21:00 and 22:00 hours at the West Delta County site and the 21:00 hour at the Garden Peninsula sight. An additional nighttime peak occurred after midnight at both sites and occurred at 01:00 at the West Delta County site and at 01:00 and 02:00 at the Garden Peninsula site (Figure 16). At both locations, the mean TPR gradually decreased as the night progressed, with a more pronounced decline occurring between 05:00 and 06:00, which corresponds with the dawn time period.

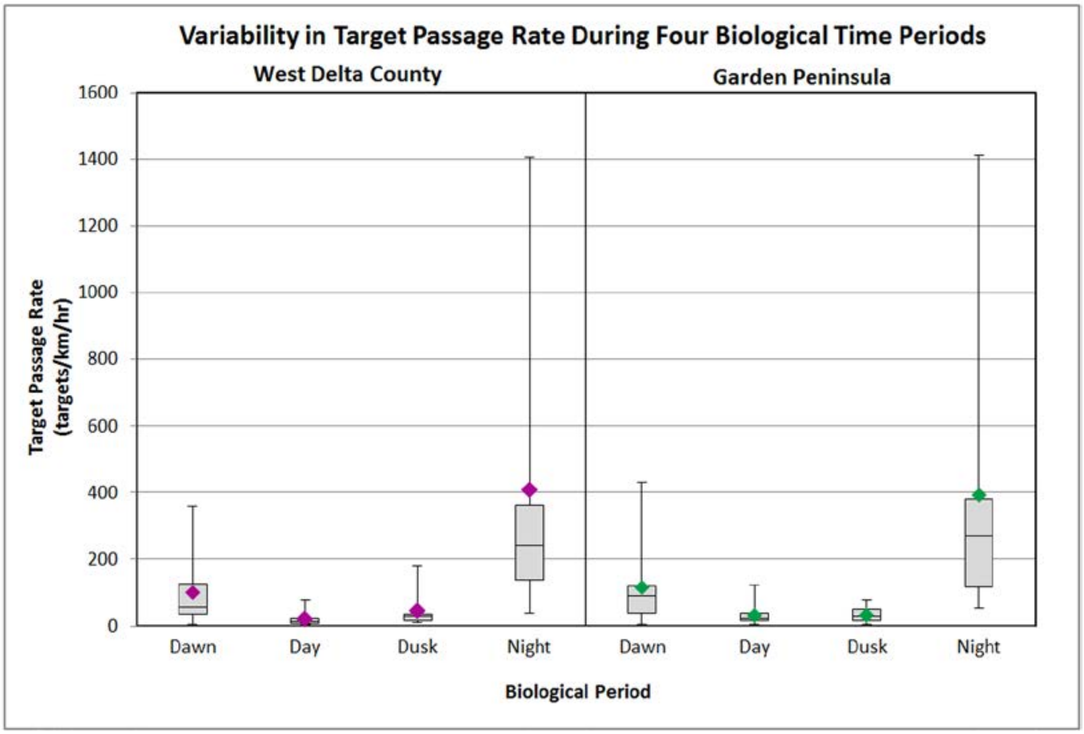


Figure 15. Box plots showing variability in target passage rate (targets/km/hr) during four biological periods for fall 2012 in West Delta County and Garden Peninsula. Whiskers represent the 1st and 4th quartiles; boxes represent the 2nd and 3rd quartiles (with the line between indicating the median); the colored diamonds represent seasonal mean for the biological time period.

Table 4. Mean target passage rate (TPR) with standard deviations during four biological periods in West Delta County and Garden Peninsula during fall 2012.

Biological Period	West Delta County Mean TPR	Garden Peninsula Mean TPR
Dawn	100 ± 98	116 ± 117
Day	20 ± 17	32 ± 27
Dusk	44 ± 46	32 ± 21
Night	407 ± 430	392 ± 406

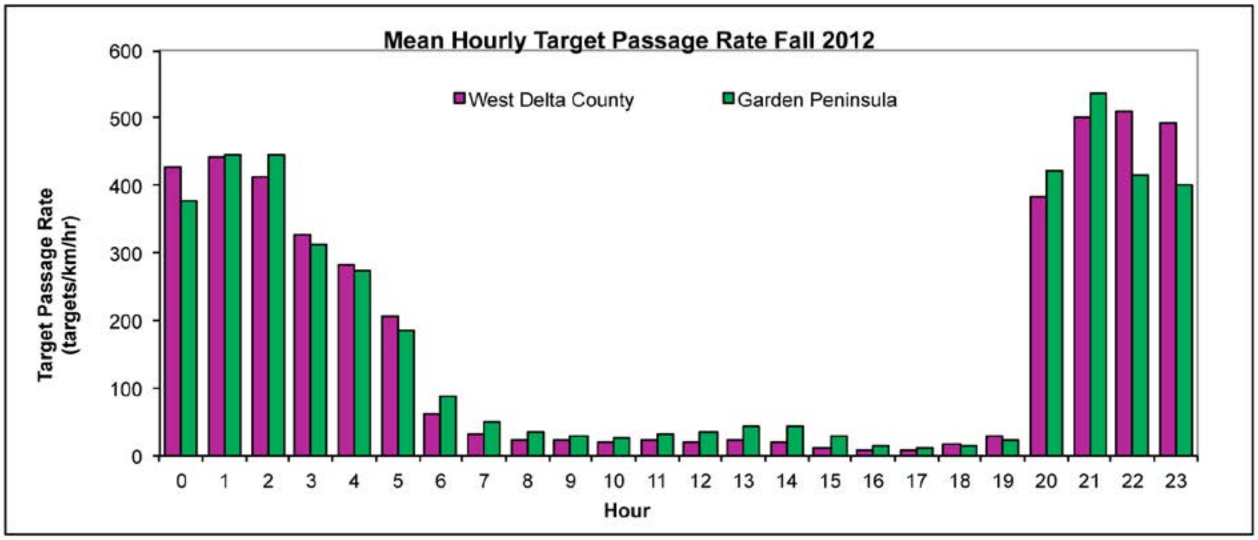


Figure 16. Mean hourly target passage rate (targets/km/hr) during fall 2012 at sites in West Delta County and Garden Peninsula.

Weekly Mean of Target Passage Rates. Patterns of weekly means of nocturnal and diurnal target passage rates were similar at both sites (Figures 17, 18 and 19). Weekly means of nocturnal TPR were consistently higher than weekly means of diurnal TPR. Nocturnal target passage rates were lower the first two weeks of the study period and increased during the third week of the study period, suggesting we left these sites just as migration was increasing.

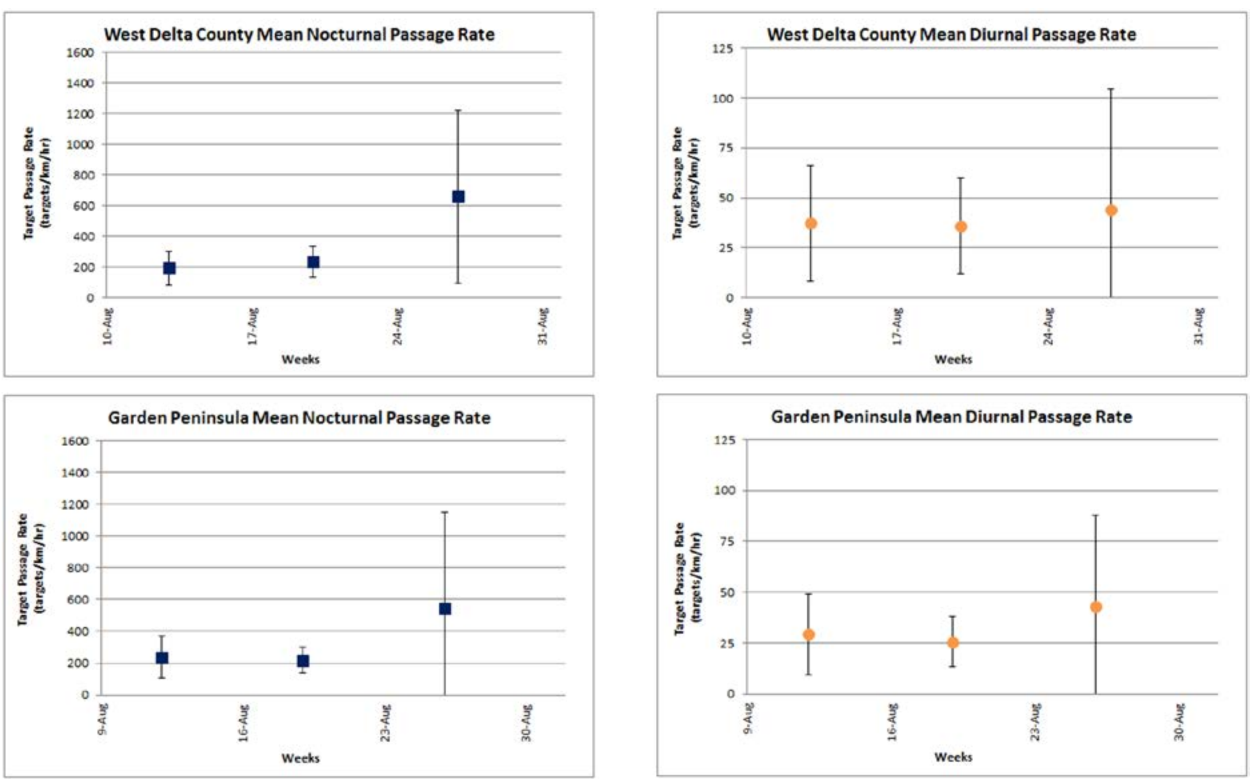


Figure 17. Weekly mean of nocturnal and diurnal target passage rates (targets/km/hr) in West Delta County (top row) (August 11 – September 1, 2012) and Garden Peninsula (bottom row) (August 9 – September 1, 2012). Error bars represent one standard deviation. Note different scales on nocturnal and diurnal plots.

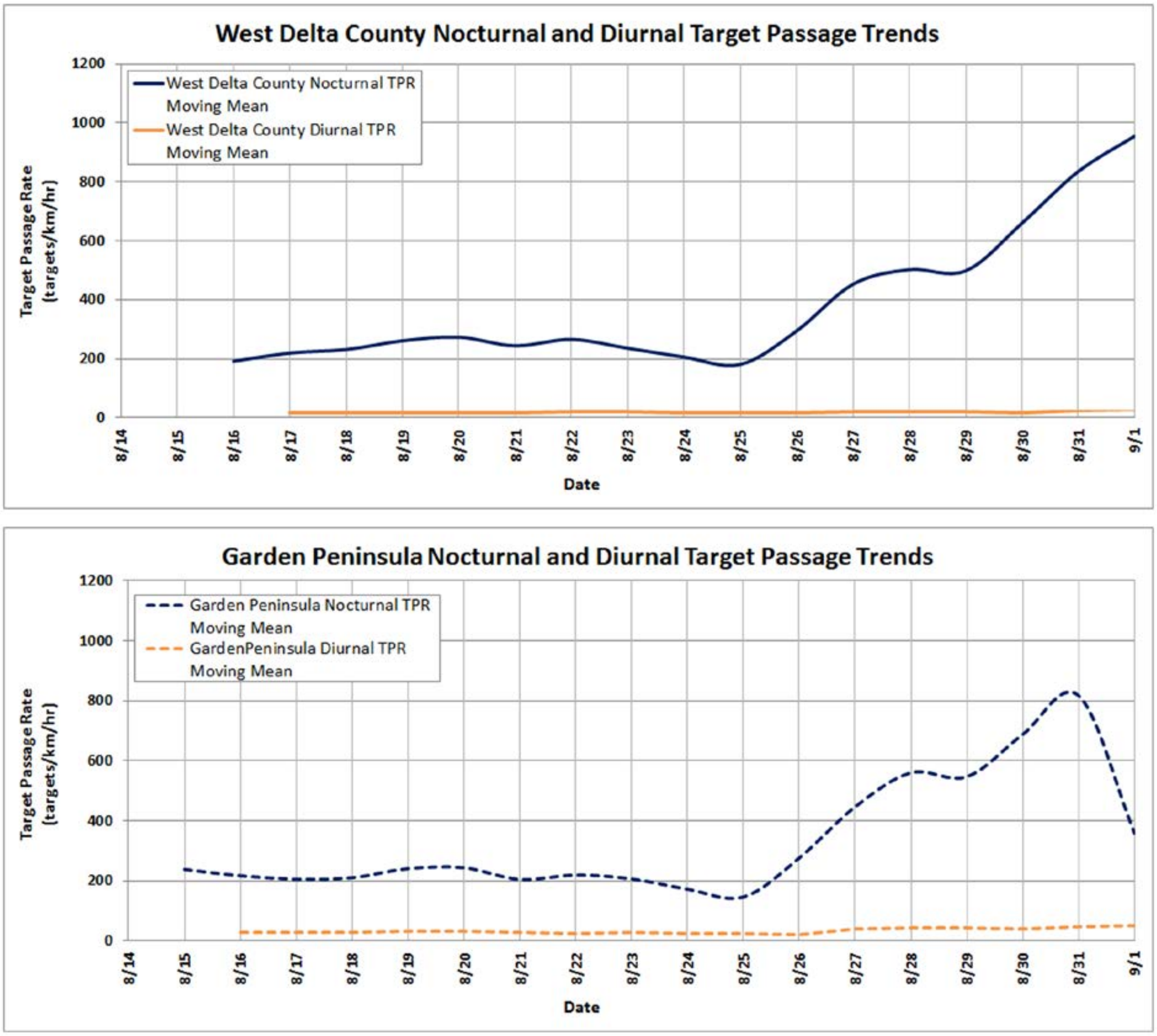
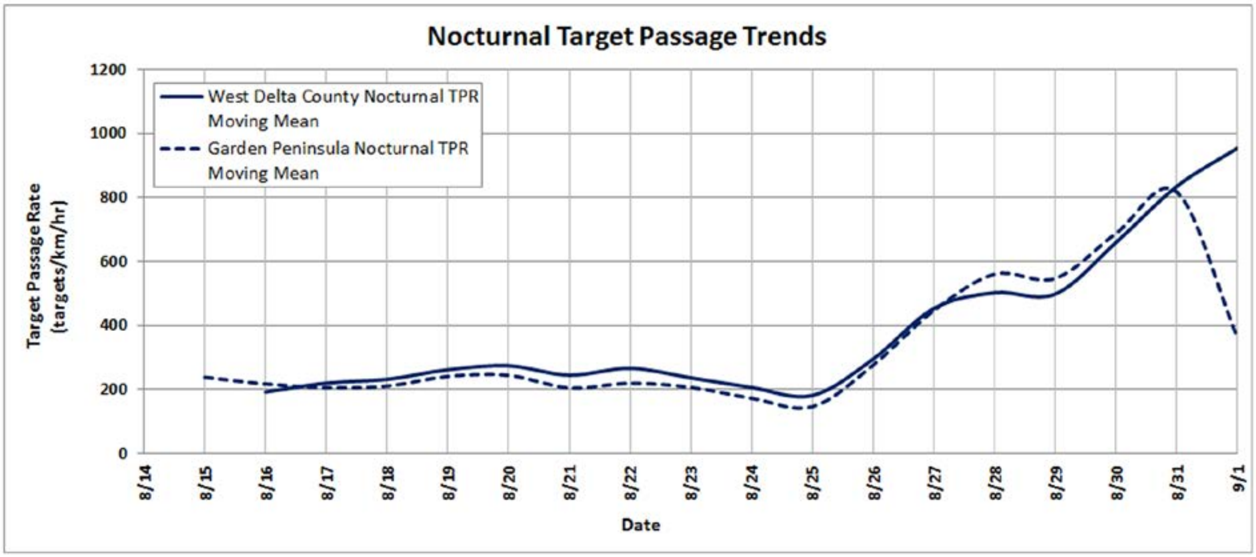


Figure 18. Comparison of nocturnal and diurnal target passage trends (based on a moving 7-day mean) during fall 2012 at our West Delta County (top row) and Garden Peninsula (bottom row) radar sites.



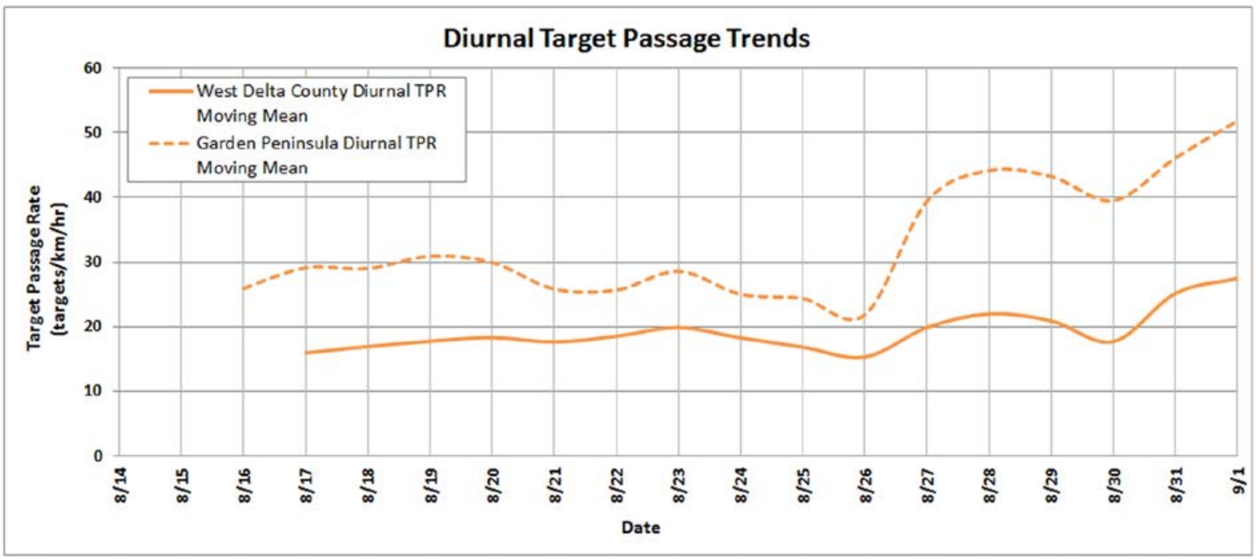


Figure 19. Comparison of nocturnal (top row) and diurnal (bottom row) target passage trends (based on a moving 7-day mean) during fall 2012 at our West Delta County and Garden Peninsula radar sites.

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 (Figures 20 and 21). Hourly altitude profiles at night revealed considerable variation in use of altitude bands (Figures 22 and 23); however, over the course of the season, the 200 – 250 m altitude band was the most densely used at both sites (Figure 24), with a total of 3.26 targets/1,000,000 m^3/night-hour and 3.22 targets/1,000,000 m^3/night-hour, respectively. The maximum density of targets was below 150 m during 13.6% and 56.5% of the nights at the West Delta County and Garden Peninsula sites, respectively (Figure 25). A similar pattern occurred if the hours from 20:00 – 04:00 were considered individually, with the maximum density of targets occurring at less than 150 m during 17.0% and 55.4% of these night hours at the West Delta County and Garden Peninsula site, respectively (Figure 26).

At both sites, targets were observed within the entire range of altitude bands sampled. The mean altitude of nocturnal targets during the study period was 580 m ± 371 m SD and 526 m ± 370 m SD above the ground at our West Delta County and Garden Peninsula sites, respectively. Median altitude at night for the study period was 516 m and 459 m above ground at the West Delta County and Garden Peninsula sites, respectively. Mean and median altitudes were greatest during the dawn and night biological time periods (Table 5). The mean altitude per hour during the study period showed a similar pattern at both sites (Figure 27), where the mean altitude increased following dusk, peaked at 21:00, and generally decreased as the night progressed. An increase in mean altitude occurred near dawn at both sites.

Although many radar reports include estimates of the mean and median target altitudes, we found that these estimates were poor indicators of maximum density because of differences in the volume of air space sampled at various altitude bands. Figures 28 and 29 are based on target density and show the variation in flight altitudes used by birds and bats that were counted by our vertical scanning radars throughout our survey period (August 11 – September 1, 2012 at the West Delta County site and August 9 – September 1, 2012 at the Garden Peninsula site). These graphics show the altitude bands of 0 – 1,300 m where most targets were counted (targets were counted up to 2,750 m, which is the extent of our sampling range). These graphics show that night hours at both sites had the highest density of flight activity and that the range of flight altitudes increased during the night hours. The graphics also show that many targets flew within, or just outside of a 30 – 130 m RSZ and that the mean and median altitudes do not reflect peak density altitudes, demonstrating how these values can misrepresent flight risk.

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 West Delta County and Garden Peninsula during fall 2012.

	West Delta County			Garden Peninsula		
Biological Period	Mean	Median	Max Band Density	Mean	Median	Max Band Density
Dawn	632 ± 319	640	750	562 ± 338	515	300
Day	470 ± 387	400	200	341 ± 338	234	150
Dusk	400 ± 310	346	200	379 ± 351	297	150
Night	580 ± 371	516	200	526 ± 370	459	200

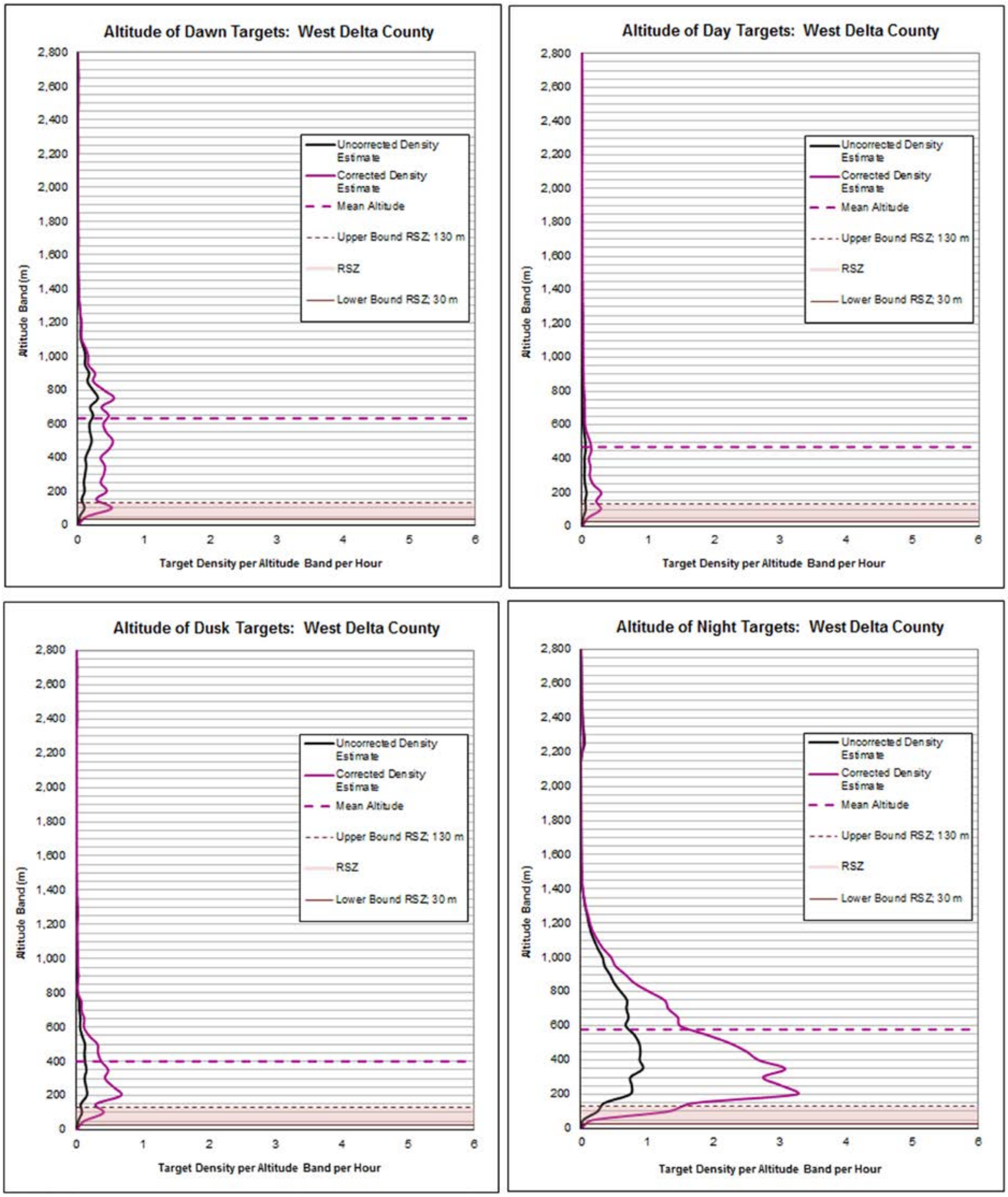


Figure 20. Altitude profile of targets at our site in West Delta County. Corrected lines depict target density (targets/1,000,000 m^3) per 50-m altitude band per hour after adjusting for the structure of the sample volume. Uncorrected lines depict target density per 50-m altitude band per hour with an assumed uniform volume distribution (volume of each band is equal to the total volume divided by the number of bands). The red band represents the rotor swept zone (RSZ) between 30 – 130 m and the y-axis labels represent the top of the altitude band.

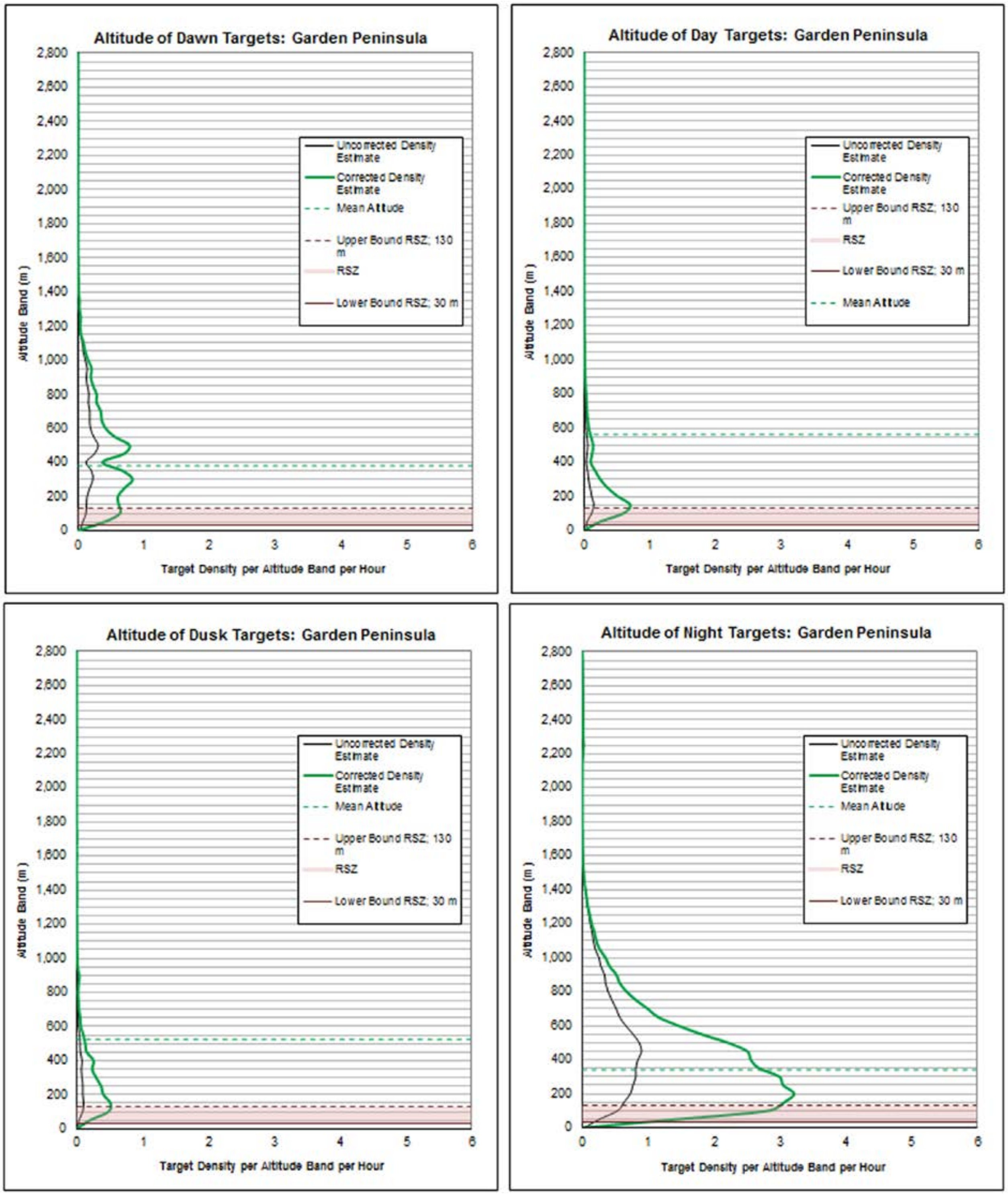


Figure 21. Altitude profile of targets at our site in Garden Peninsula. Corrected lines depict target density (targets/1,000,000 m^3) per 50-m per hour altitude band after adjusting for the structure of the sample volume. Uncorrected lines depict target density per 50-m altitude band per hour with an assumed uniform volume distribution (volume of each band is equal to the total volume divided by the number of bands). The red band represents the rotor swept zone (RSZ) between 30 – 130 m and the y-axis labels represent the top of the altitude band.

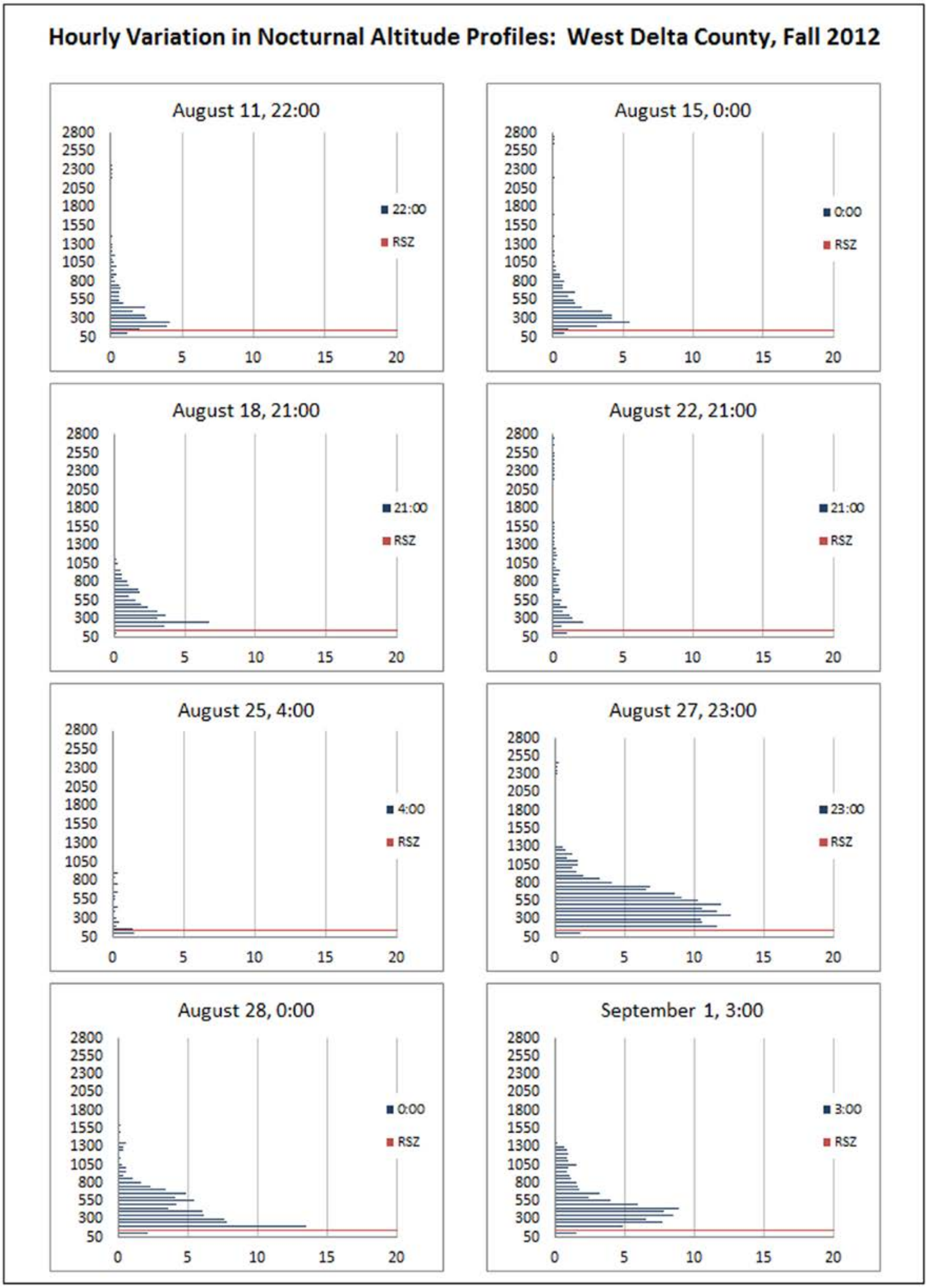


Figure 22. A sample of hourly nocturnal altitude profiles corrected for the shape of the sample volume at our site in West Delta County, during fall 2012. Hours were selected to portray the variability in density per altitude band of passing targets. The x-axis represents target density. The red line represents the top of the rotor swept zone at 130 m.

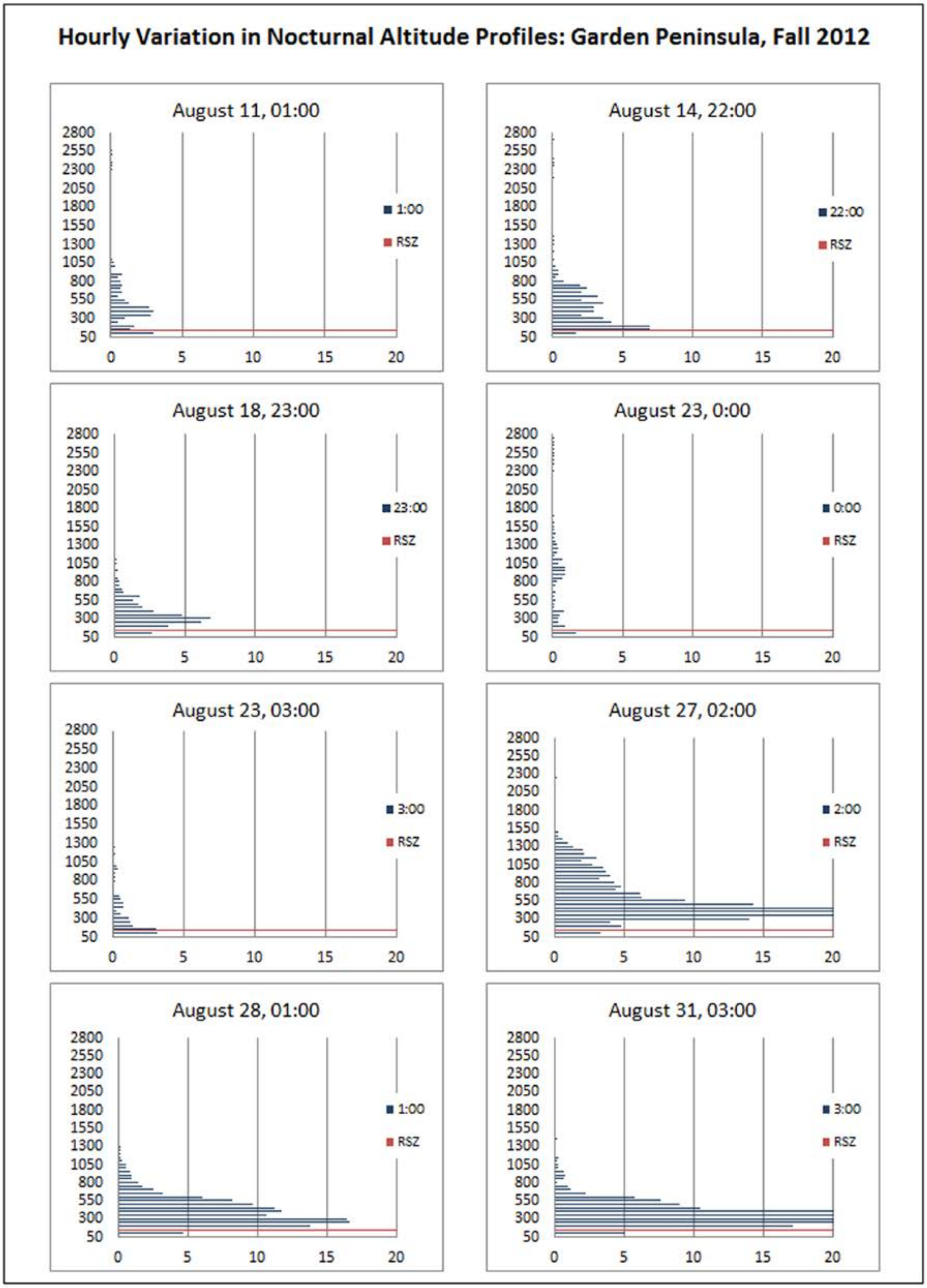


Figure 23. A sample of hourly nocturnal altitude profiles corrected for the shape of the sample volume at our site in Garden Peninsula during fall 2012. Hours were selected to portray the variability in density per altitude band of passing targets. The x-axis represents target density. The red line represents the top of the rotor swept zone at 130 m.

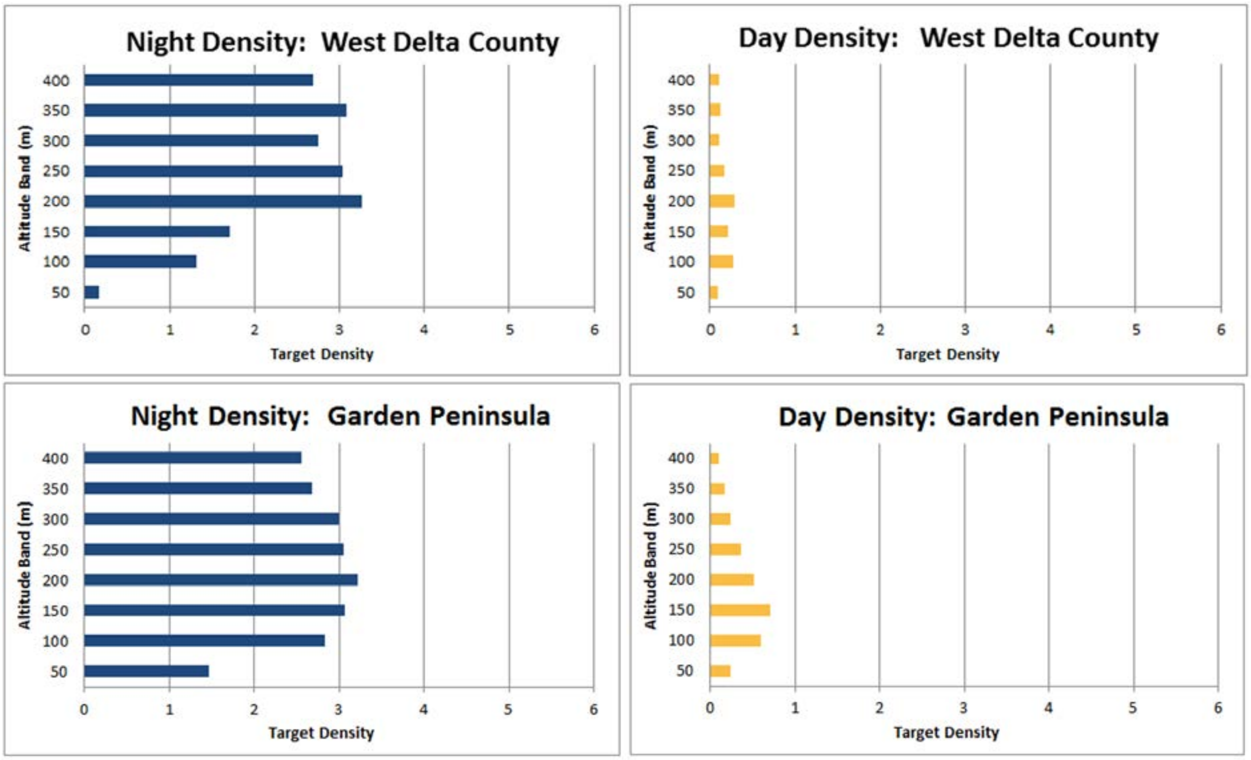


Figure 24. Altitude profile of target density below 400 meters in West Delta County and Garden Peninsula. The x-axis represents target density (targets/1,000,000 m^3) per 50-m altitude band. The y-axis represents altitude bands in meters.

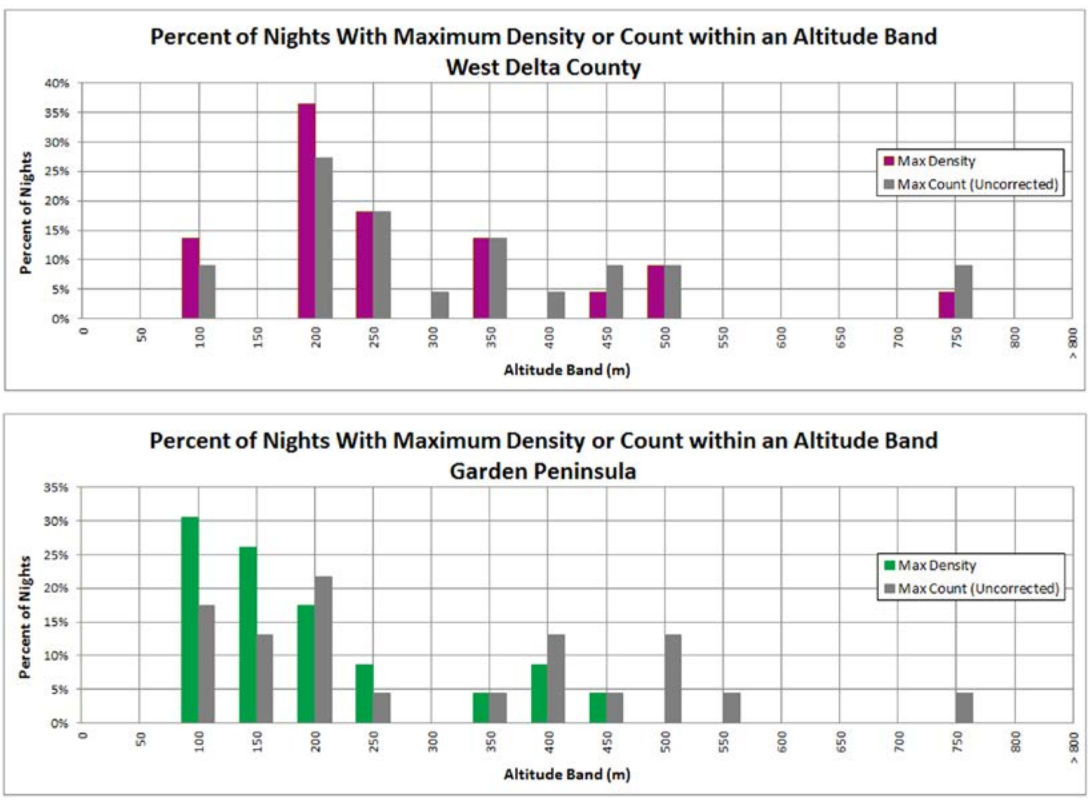


Figure 25. Percent of nights when the maximum density (targets/1,000,000 m^3/ altitude band) or count (targets/altitude band) occurred within 50-m altitude bands in West Delta County and Garden Peninsula, during fall 2012.

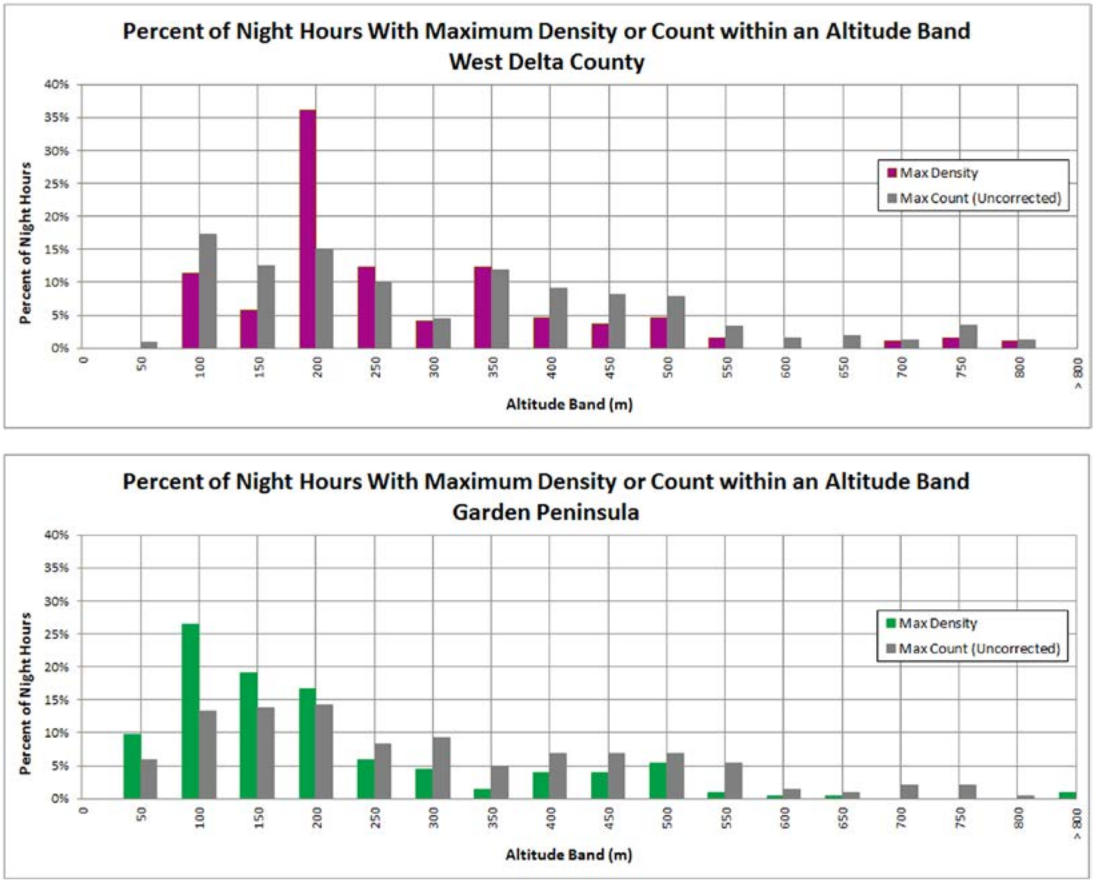


Figure 26. Percent of night hours (20:00 – 04:00) when the maximum density (targets/1,000,000 m^3/ altitude band) or count (targets/altitude band) occurred within 50-m altitude bands in West Delta County and Garden Peninsula, during fall 2012.

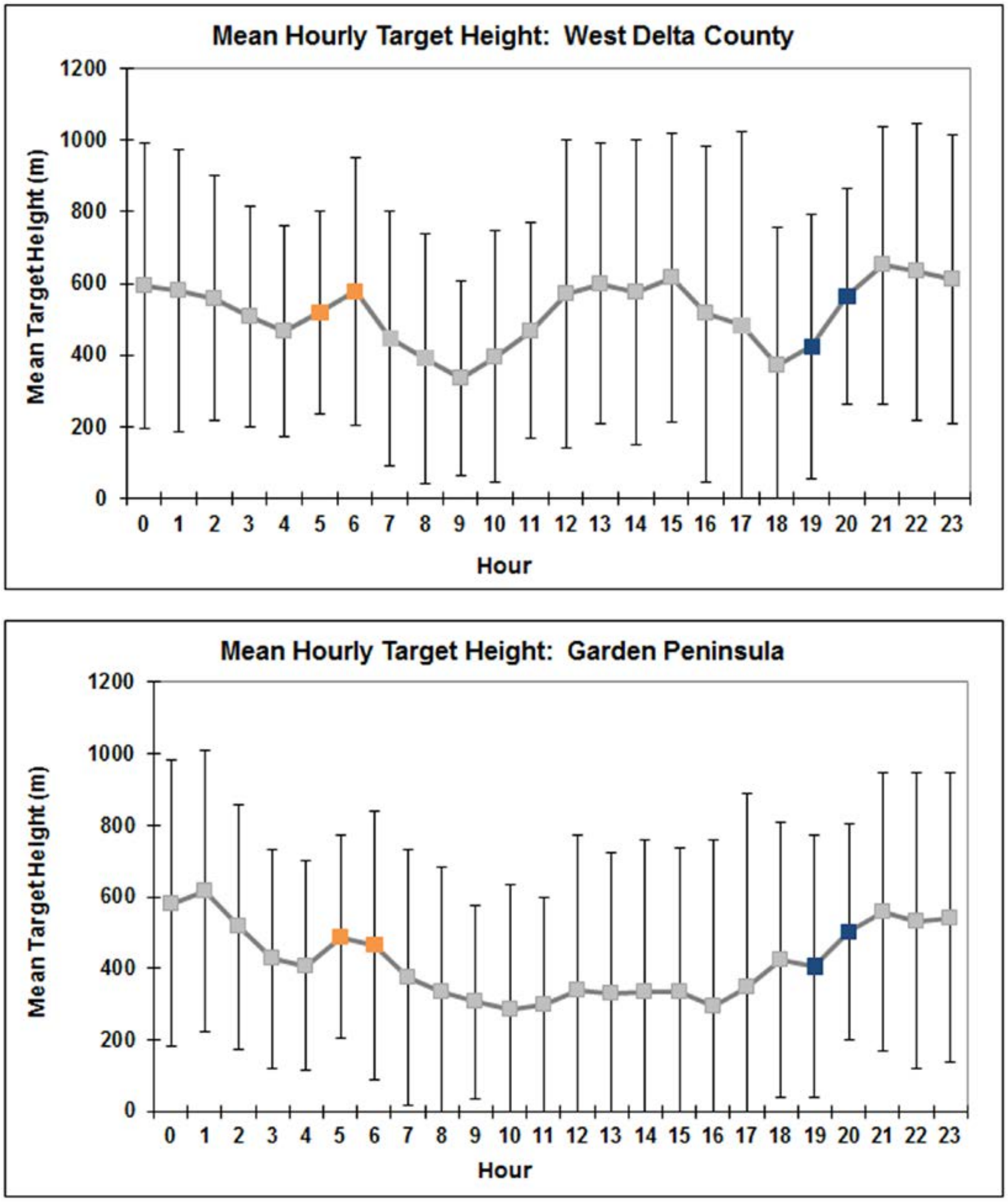


Figure 27. Mean hourly target height (m) during fall 2012 at our West Delta County (top) and Garden Peninsula (bottom) sites. Orange and blue markers indicate the hours in which sunrise and sunset occurred during the season, respectively. Error bars represent one standard deviation.

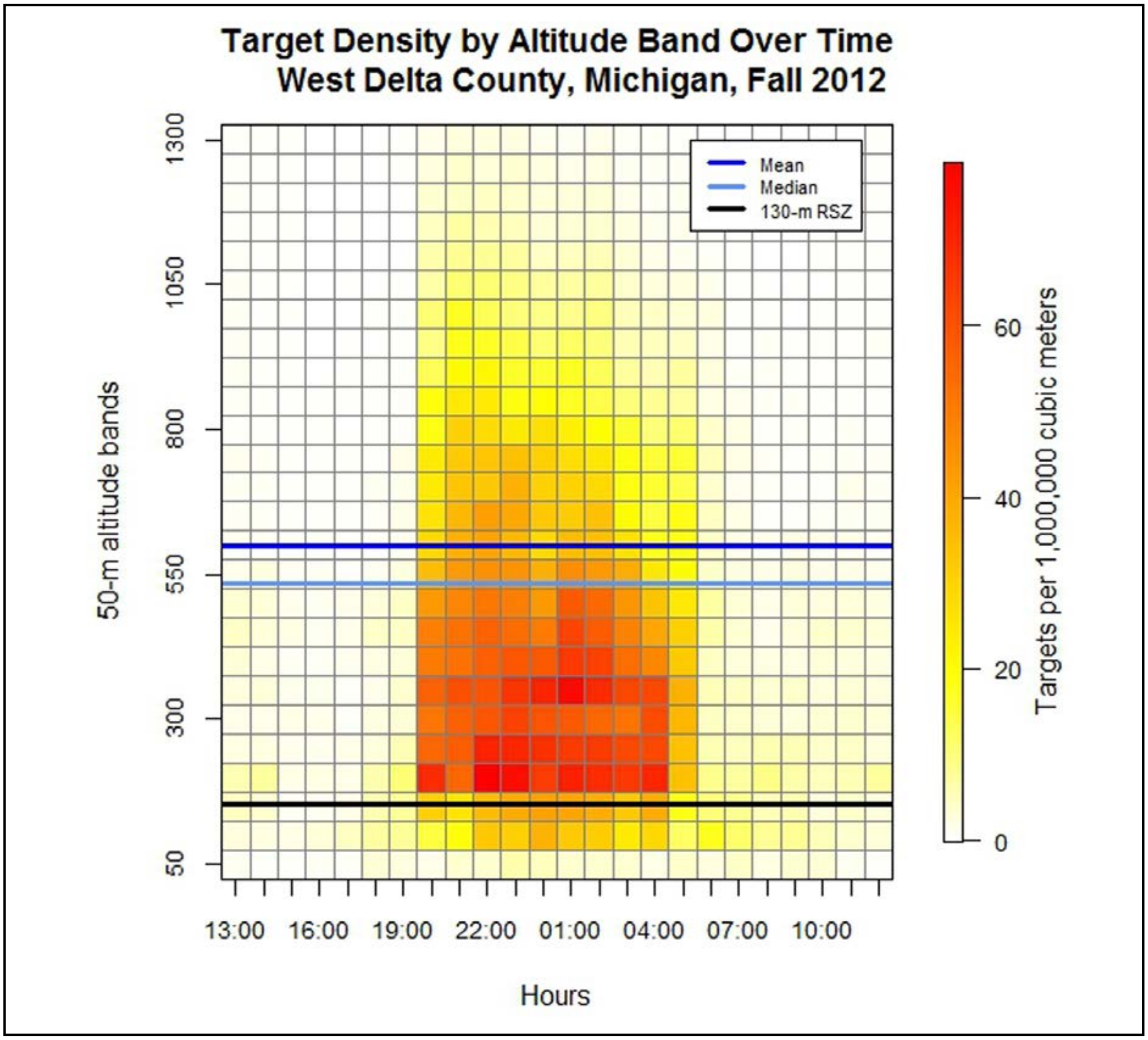


Figure 28. Variation in flight altitudes based on target density (targets/1,000,000 m^3) at our West Delta County site throughout the study period. Altitude bands are in meters, and labels represent the max value of each altitude band. Colors shown in each rectangle indicate the relative density observed 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 line at 130 m represents the max height of a turbine with a RSZ of 30 – 130 m. Note the difference in density scale used in other figures.

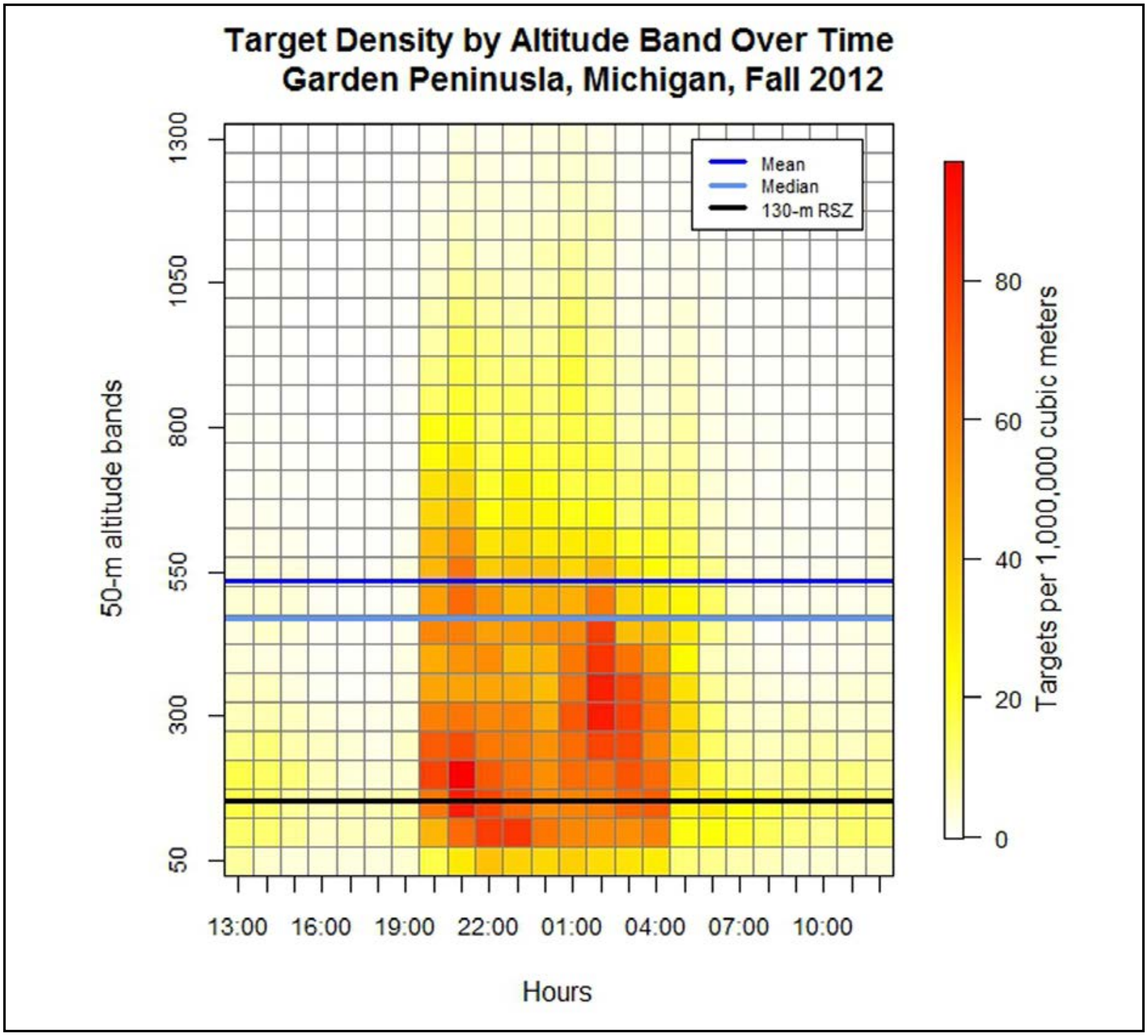


Figure 29. Variation in flight altitudes based on target density (targets/1,000,000 m^3) at our Garden Peninsula, Michigan site throughout the study period. Altitude bands are in meters, and labels represent the max value of each altitude band. Colors shown in each rectangle indicate the relative density 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 line at 130 m represents the max height of a turbine with a RSZ of 30 – 130 m. Note the difference in density scale used in other figures.

Lower Peninsula of Michigan – Saginaw Bay, Lake Huron

We began data collection September 2 and 6, 2012 at the West Huron County and Iosco County sites, respectively. Data were recorded continuously while the radar units were operational, although gaps in the data collection occurred during rain events and when the radar units were not operational due to maintenance or malfunction (radar downtime).

When correcting for radar downtime and removing the periods with rain, the vertical and horizontal radars collected usable data for 89% and 99% of the study period at the Iosco County site, and for 88% and 99% of the season at the Garden Peninsula site, respectively (Table 6).

Table 6. Survey effort (hours) by vertical and horizontal scanning radars during fall 2012 at our Iosco County (IC) and West Huron County (WHC) radar sites.

Site	Radar	Survey Period	Radar Downtime	Time Radar Collected Data	Radar Data w/Rain	Useable Radar Data	% Survey Period w/ Collected Data	% Survey Period w/ Useable Data
IC	VSR[1]	1513	16	1497	150	1347	99%	89%
IC	HSR	1513	11	1502	0	1502	99%	99%
WHC	VSR	1609	23	1586	168	1418	99%	88%
WHC	HSR	1609	19	1590	2	1588	99%	99%

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

Qualitative Assessments

Plots of tracked targets showed images of nocturnal migration events at both locations (Figures 30 and 31). For example, on October 26 at the Iosco County site the horizontal radar recorded scattered activity, and the vertical radar recorded a low number of targets from 12:00 – 15:00 (Eastern Standard Time). During the 17:00 hour, directional movement occurred with targets heading southward, and both horizontal and vertical target counts increased. Detection on both radars continued to increase as the night progressed, and the vertical radar detected more targets at higher altitudes around 22:00. By 06:00, target counts decreased on both horizontal and vertical scanning radars, and westward movement towards shore occurred. By 12:00, diurnal activity appeared similar to the preceding day at 12:00 (Figure 30). This pattern of target movement and changes in altitude were indicative of a pulse of migratory activity.

A similar pattern of low target activity and flight heights during the day and increased directional activity and higher flight heights at night was also seen at the West Huron County site. Figure 31 shows targets moving southeast and south throughout the night. By 06:00, target movement shifted to the east, and the normal non-directional diurnal movement returned by 12:00.

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 5), resulting in reduced detection in the air space that was within the range of data collection (e.g., north and northeast of the radar at Iosco County and in the center and southwestern areas of the West Huron County radar site, as seen in the horizontal Trackplots (Figures 30 and 31)). Rings of decreased detection near the radar unit and where the radar switched from short to medium pulse are also evident in both the vertical (October 26, 22:00 at Iosco County) and horizontal (October 21, 06:00 at West Huron County) Trackplots (observed at a range of approximately 1,400 – 2,000 m).

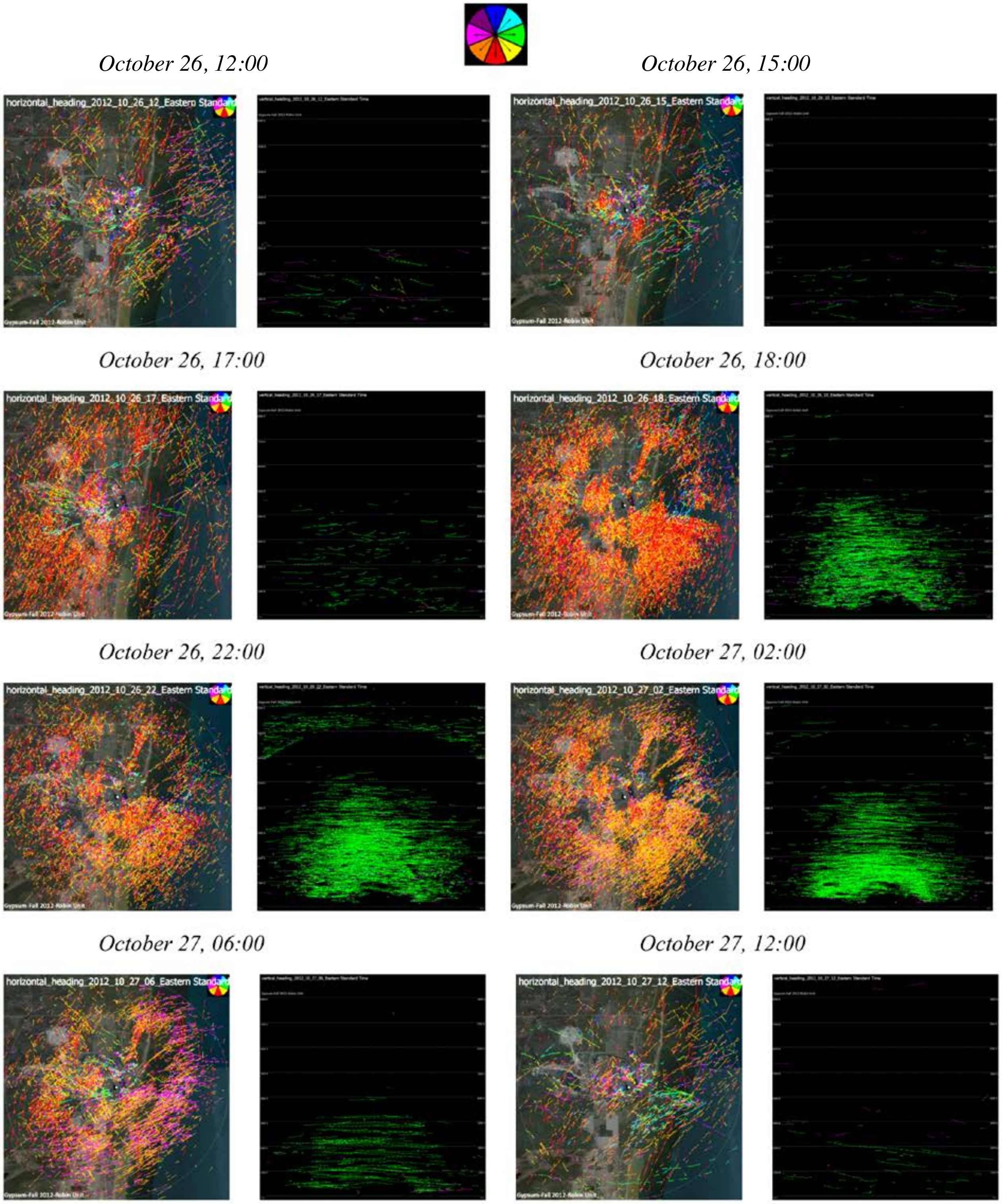


Figure 30. Images of tracks during one hour increments recorded by horizontal and vertical scanning radars during a migration event at our radar site in Iosco County. Horizontal radar images (columns 1 and 3) show direction of targets as indicated by the color wheel (dark blue indicates travel to the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

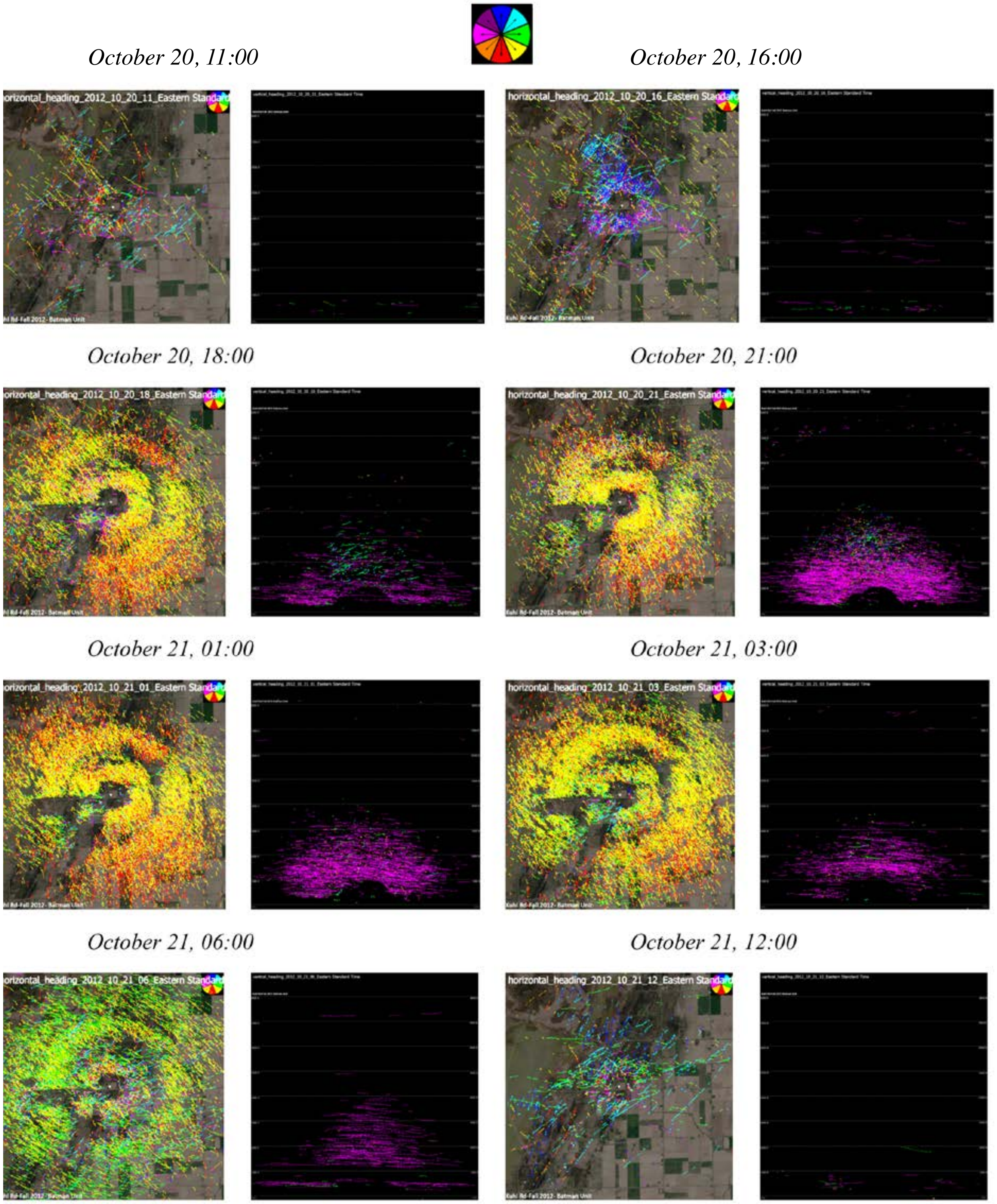


Figure 31. Images of tracks during one hour increments recorded by horizontal and vertical scanning radars during a migration event at our West Huron County radar site. Horizontal radar images (columns 1 and 3) show direction of targets as indicated by the color wheel (dark blue indicates travel to the north and red indicates travel to the south). Vertical radar images (columns 2 and 4) show target show target heights.

Directional Trends

During the fall 2012 season, nocturnal target direction was generally south/southwest at Iosco County and south/southeast at the West Huron County site (Table 7, Figure 32). At our Iosco County site, mean nocturnal direction was 191° (r = 0.48, n = 4,818,790 targets), and during 75% of nights mean target direction was between southeast and southwest (113.5° – 247.5°). Direction at the West Huron County site had a mean nocturnal direction of 168° (r = 0.43, n = 4,232,783), with 60% of nights having a mean direction between southeast and southwest. Movement towards shore at dawn was observed at both sites (Figure 32).

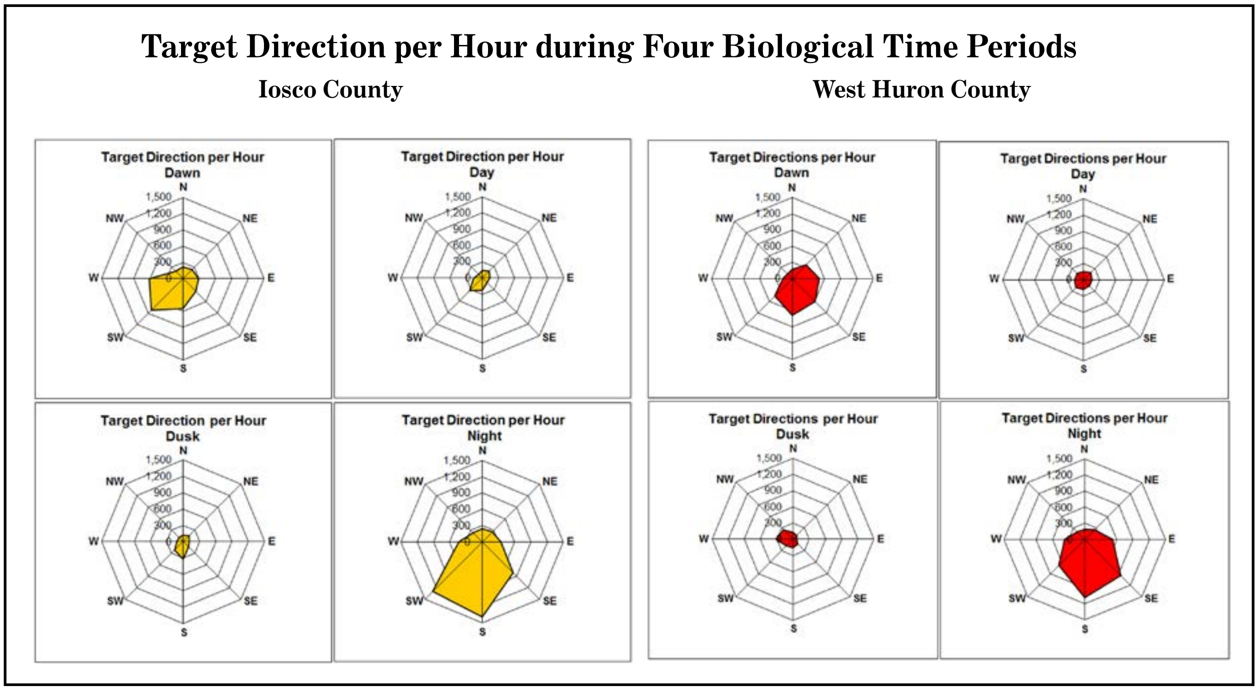


Figure 32. Target direction per hour during four biological periods during fall 2012 at our Iosco County (left) and West Huron County (right) radar sites.

Table 7. Mean direction, angular concentration (r), and percentage of biological time periods with strong directionality (r ≥ 0.5) of targets during biological time periods at our Iosco County and West Huron County sites during fall 2012.

	Iosco County				West Huron County			
Biological Period	Mean Direction (degrees)	r	% Time r ≥ 0.5	n	Mean Direction (degrees)	r	% Time r ≥ 0.5	n
Dawn	217	0.34	36.5%	205,654	147	0.37	36.4%	272,882
Day	209	0.18	9.5%	903,062	218	0.03	1.5%	1,294,053
Dusk	187	0.21	20.6%	81,662	272	0.3	49.3%	117,913
Night	191	0.48	54.8%	4,818,790	168	0.43	65.2%	4,232,783

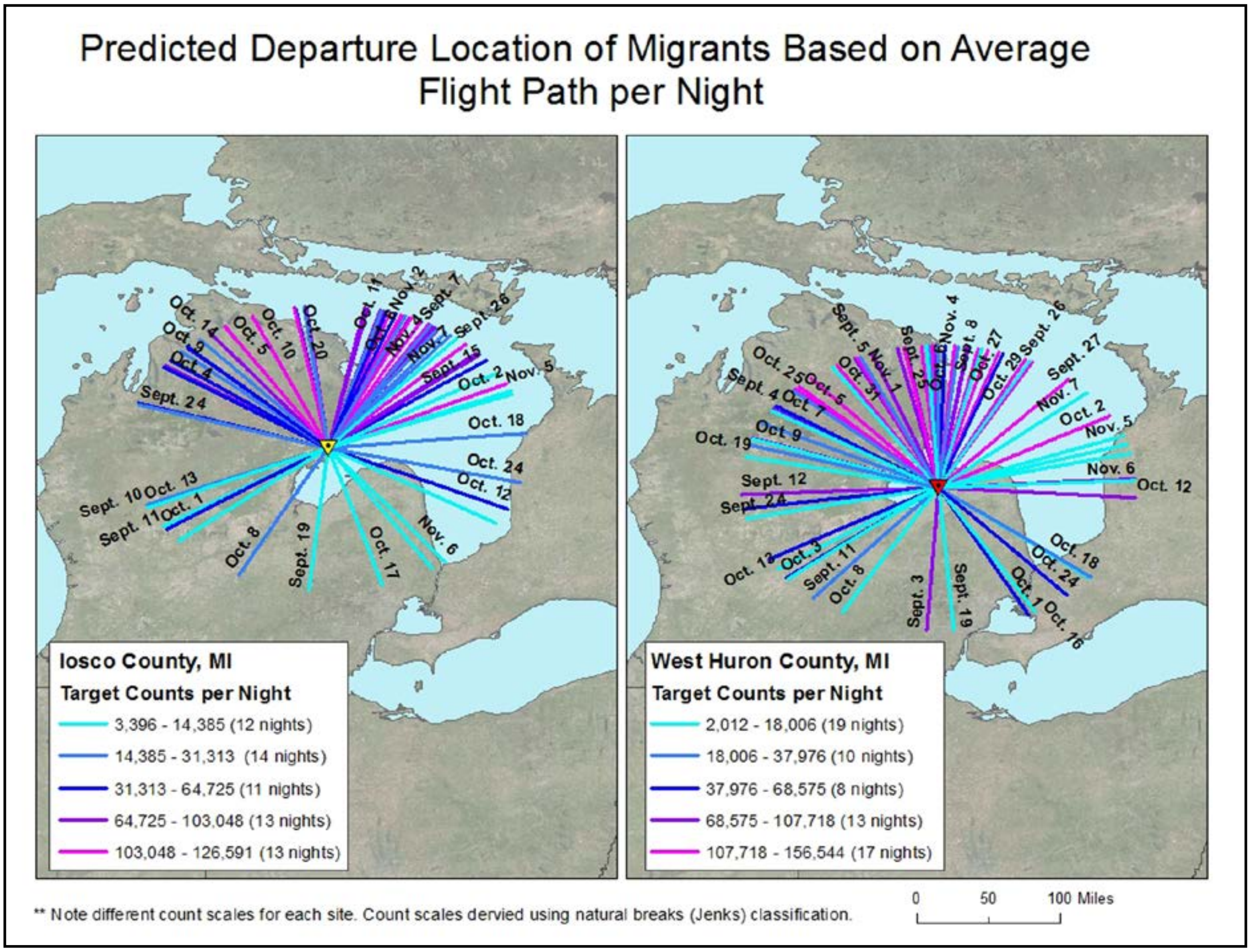


Figure 33. Movement direction of targets for each night over the second part of the season. Each line represents the average movement direction targets were coming from for one night during the season. These directions assume that migrants move in a straight line, which was not the case, but it helped to show where the general direction of movement that migrants were coming from was located. The color of the lines indicates the magnitude of migration on that night. By focusing on the dark blue and pink lines (high migration nights), a pattern emerged at each site. In Iosco County, the migrants were mostly following the shoreline but had more than a few nights where they crossed over Saginaw Bay. In West Huron County, the majority of targets were arriving from across Saginaw Bay. These directions provide evidence that migrants are flying across the open water of the Great Lakes, as well as following along the shorelines. Count categories are derived using natural breaks (Jenks) classification. Date labels are missing for some lines that were too closely clumped together.

Temporal Trends

Time Series Plots – Hourly target counts provided by horizontal and vertical radars showed different activity patterns throughout the season, including pulses of elevated nocturnal activity. Across our sampling period, these pulses were often clustered into groups of several nights and were first observed on September 6 at both sites; September 6 was the first night of the survey period at Iosco County. Nocturnal peaks occurred a few hours before to a few hours after midnight. At both sites the occurrence and magnitude of nocturnal pulses decreased substantially by the end of October (Figures 34 and 35).

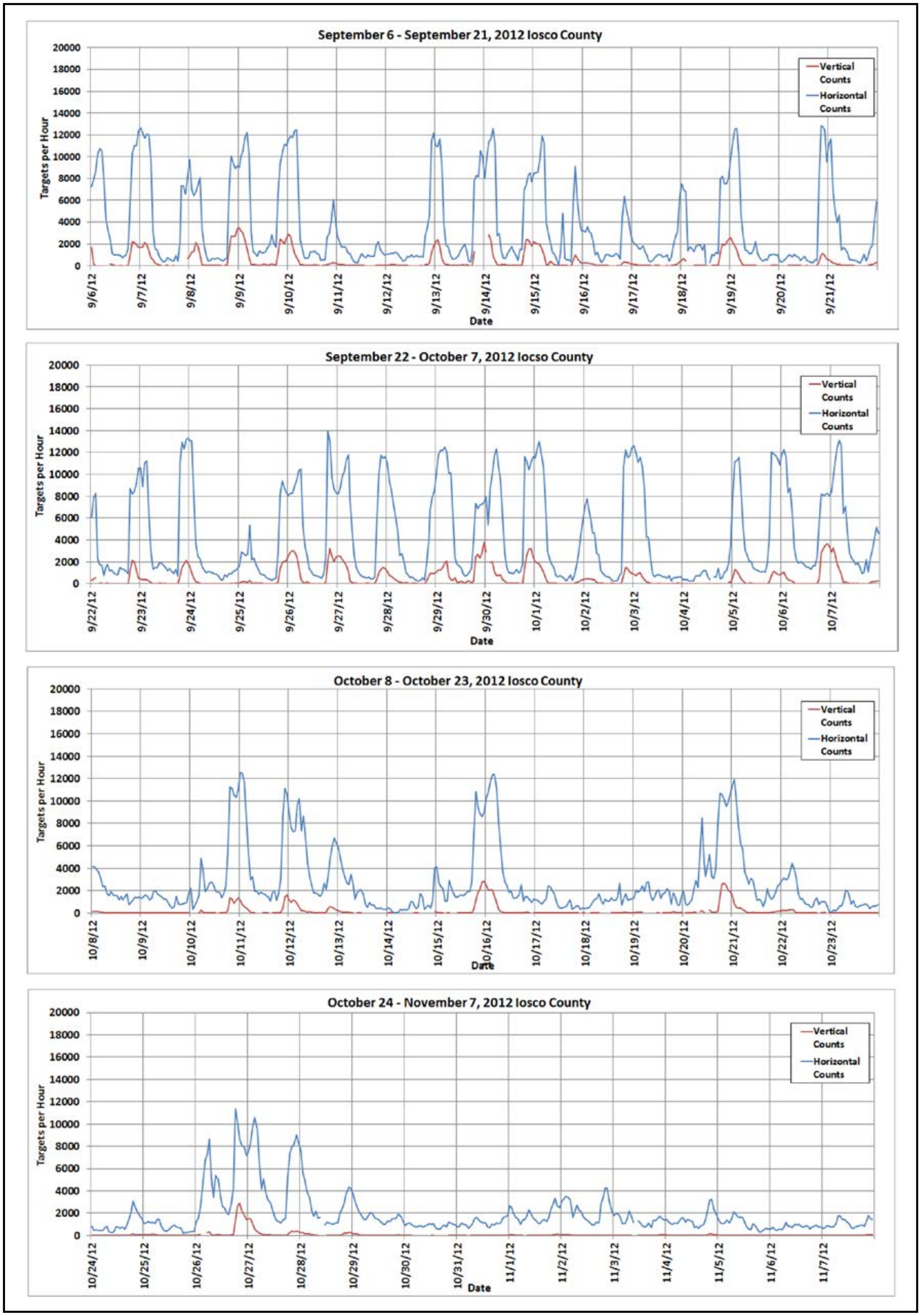


Figure 34. Hourly counts by horizontal and vertical scanning radars from September 6 – November 7, 2012 Iosco County, Michigan. Light gray vertical lines represent midnight.

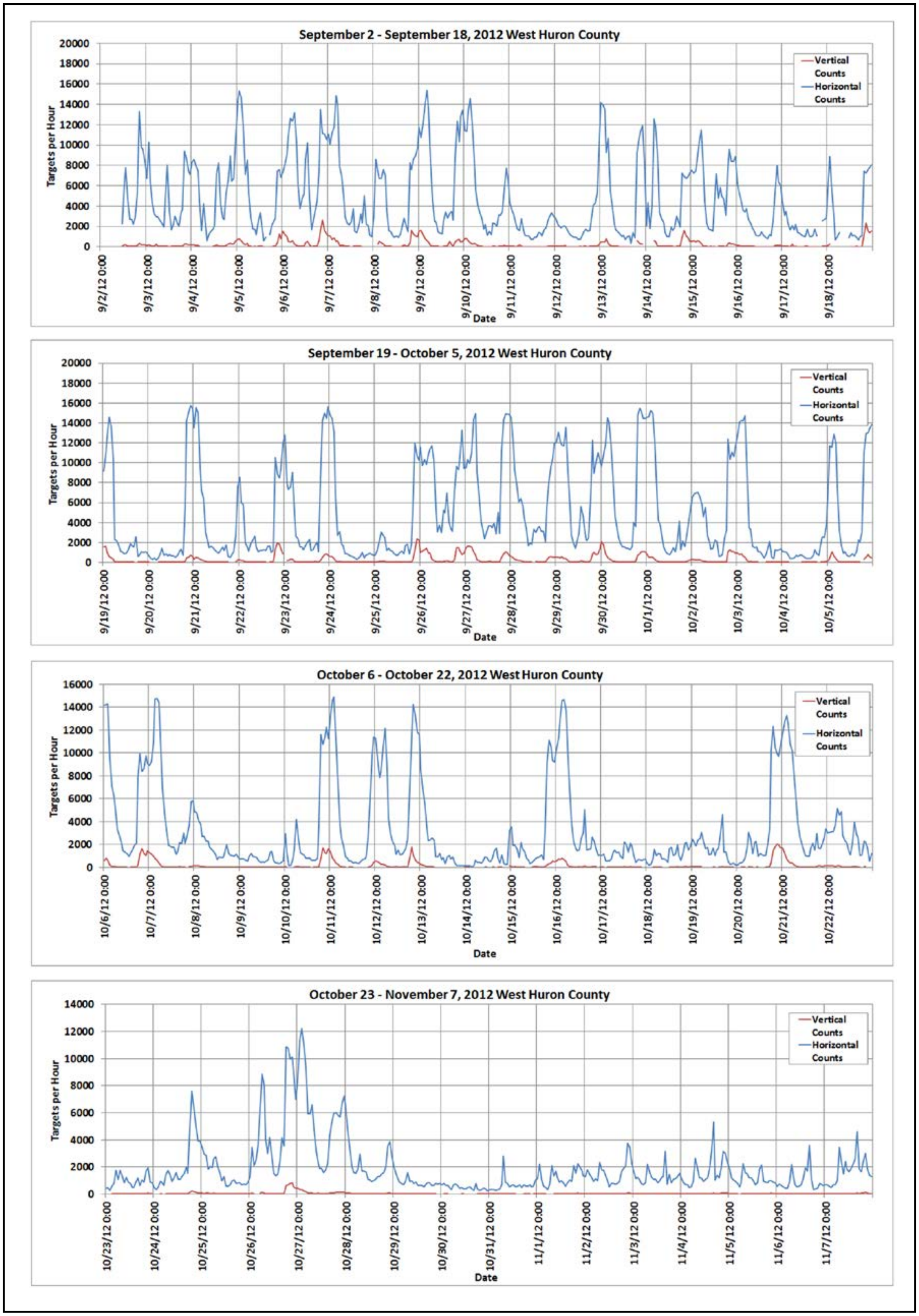


Figure 35. Hourly counts by horizontal and vertical scanning radars from September 2 – November 7, 2012 in Huron County, Michigan. Light gray vertical lines represent midnight.

Target Passage Rate – The pattern of mean TPR among the four biological time periods was similar between the two study sites (Figure 36) with mean TPR at night being greater than the combined means of the other three biological time periods (Table 8). Mean nocturnal TPR was 664 ± 793 SD (n = 60 nights) and 344 ± 395 SD (n=62 nights) at the Iosco County and West Huron County sites, respectively. Mean TPR for the season varied by hour with peak numbers reached during the 22:00 hour at Iosco County and at 20:00 at West Huron County. At both locations, mean TPR gradually decreased as the night progressed, with the most drastic decline occurring between 05:00 and 06:00 (Figure 37).

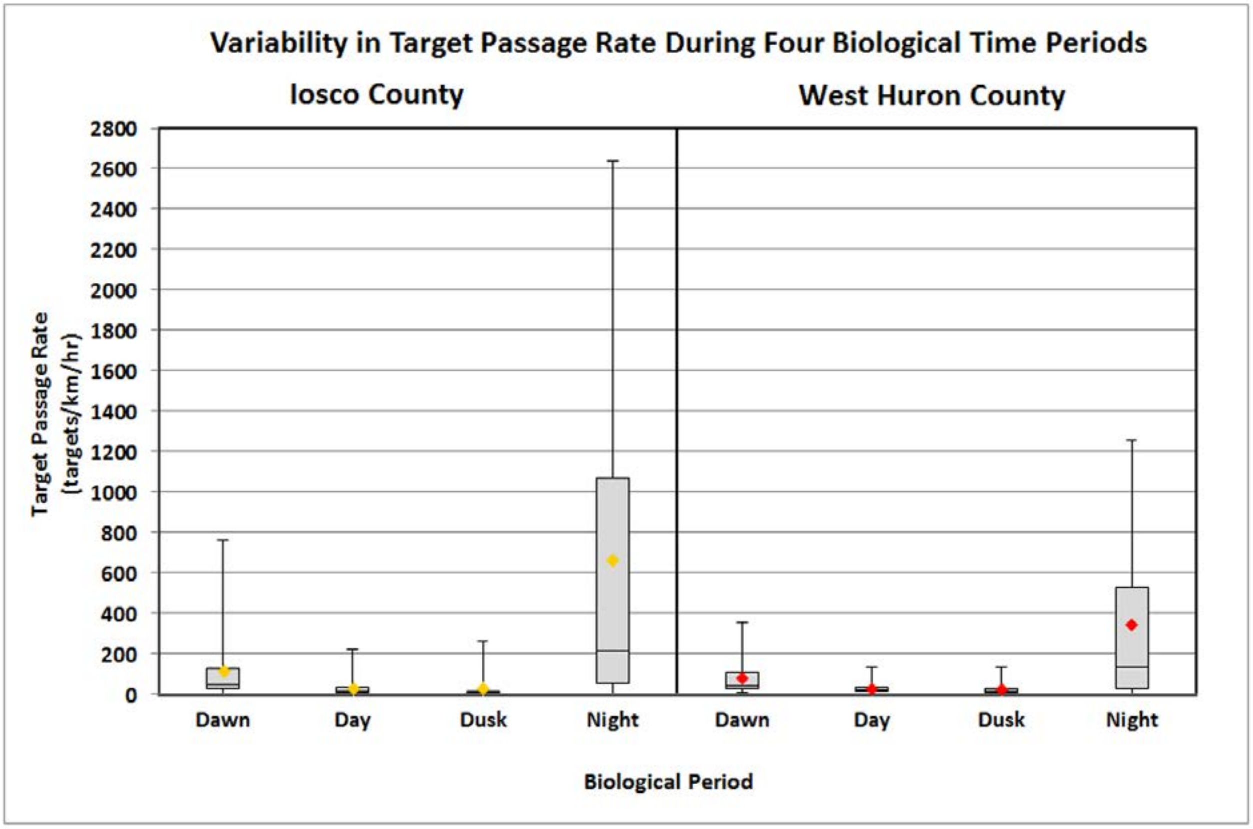


Figure 36. Box plots showing variability in target passage rate (targets/km/hr) during four biological periods for fall 2012 in Iosco and West Huron Counties. Whiskers represent the 1st and 4th quartiles; boxes represent the 2nd and 3rd quartiles (with the line between indicating the median); the colored diamonds represent seasonal mean for the biological time period.

Table 8. Mean target passage rate (TPR) with standard deviations during four biological periods at our Iosco County and West Huron County sites during fall 2012.

Biological Period	Iosco County Mean TPR	West Huron County Mean TPR
Dawn	116 ± 164	81 ± 86
Day	30 ± 39	27 ± 24
Dusk	28 ± 57	25 ± 28
Night	664 ± 793	344 ± 395

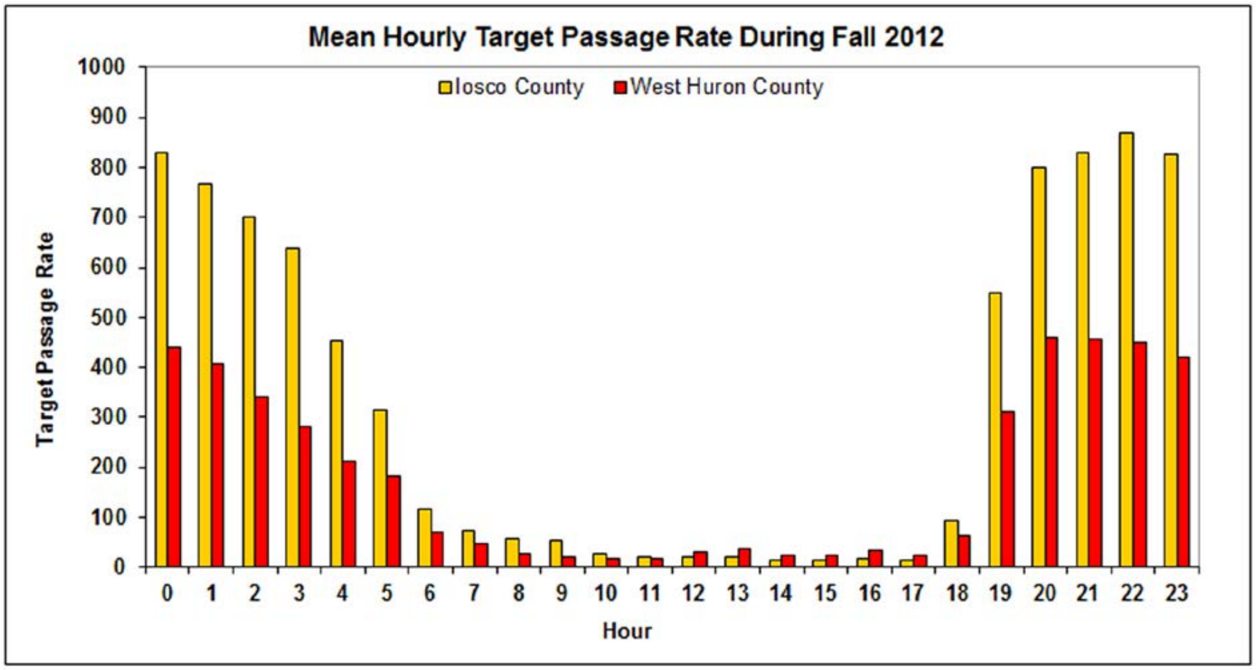


Figure 37. Mean hourly target passage rate during fall 2012 at our Iosco County and West Huron County radar sites.

Weekly Mean of Target Passage Rates – The weekly means of nocturnal target passage rates were relatively high (compared to diurnal TPRs) at both sites, and both sites showed generally increasing means throughout the season, until late October, when the nocturnal mean TPRs began to decrease (Figure 38). The weekly means of nocturnal TPR were consistently higher than weekly means of diurnal TPR. As the recorded migration season subsided, there was less difference between the nocturnal and diurnal target passage rates (Figures 39 and 40). Trends in both nocturnal and diurnal TPRs (7 day moving means) were similar at both sites.

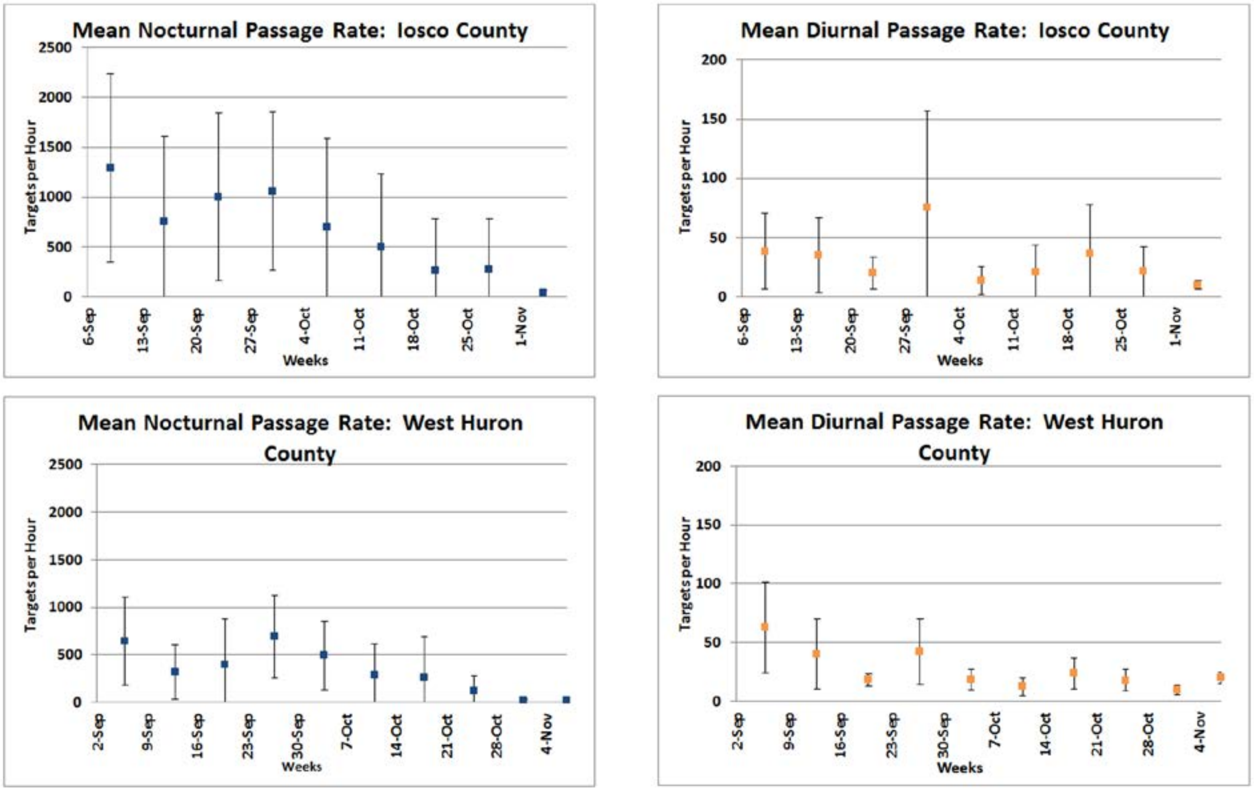
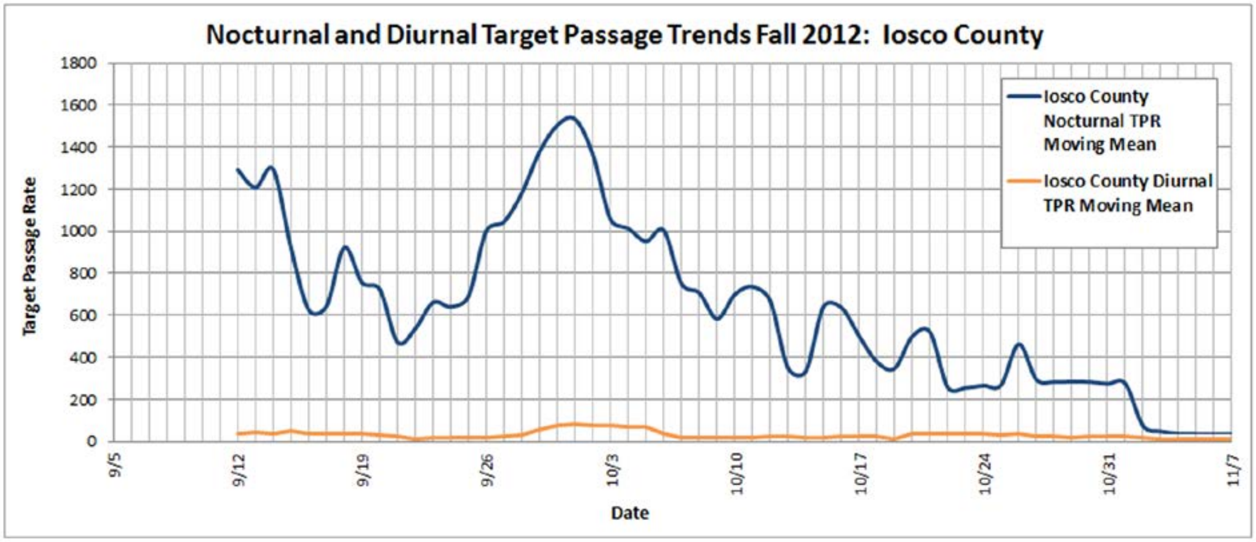


Figure 38. Weekly mean of nocturnal and diurnal target passage rates (targets/km/hr) at our Iosco County (top row) and West Huron County (bottom row) radar sites during fall 2012. Error bars represent one standard deviation. Note different scales on nocturnal and diurnal plots.



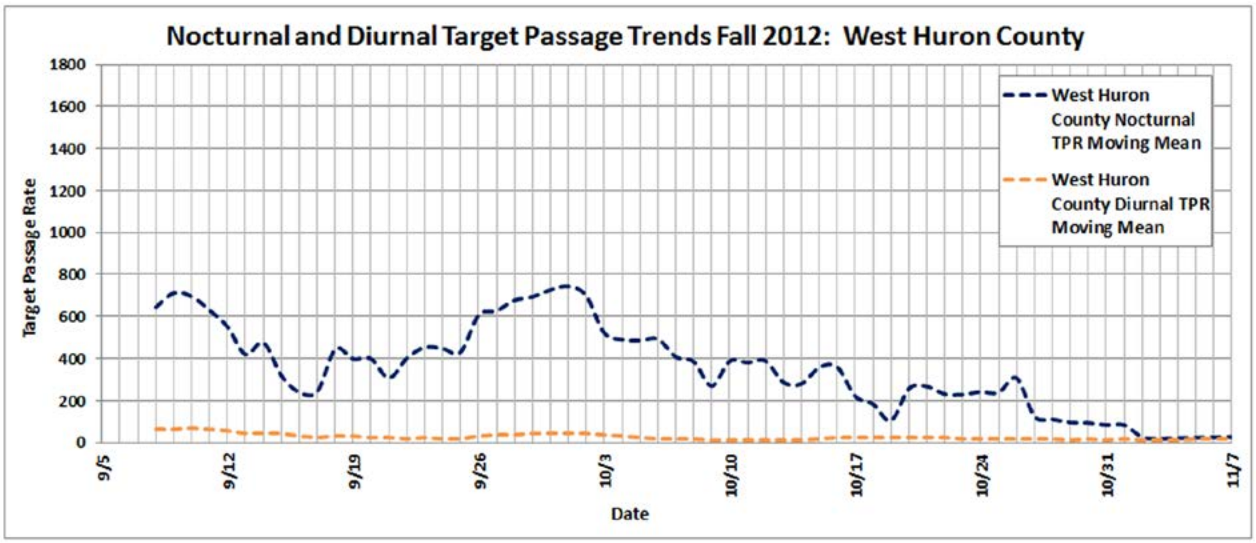


Figure 39. Comparison of nocturnal and diurnal target passage trends (based on a moving 7-day mean) during fall 2012 at our Iosco County and West Huron County sites.

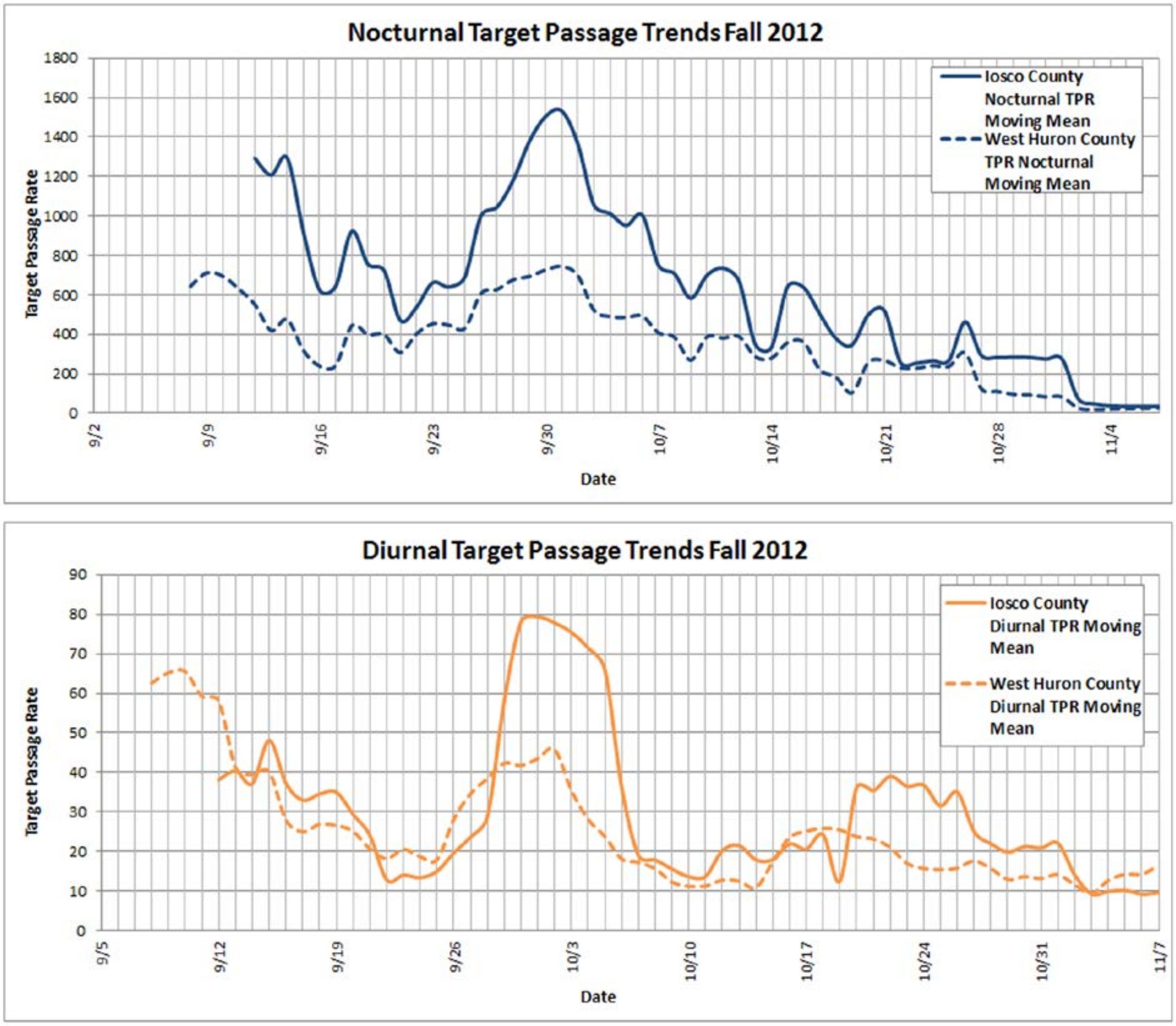


Figure 40. Comparison of nocturnal (top row) and diurnal (bottom row) target passage trends (based on a moving 7-day mean) during fall 2012 at our Iosco County (top row) and West Huron County sites (bottom row).

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 (Figures 41 and 42). Altitude profiles for all time periods differed between our two locations. Hourly altitude profiles at night revealed considerable variation in use of altitude bands (Figures 43 and 44); however over the course of the season, the 150 - 200 m altitude band and the 300 – 350 m altitude band were the most densely populated at the Iosco County and West Huron County sites (Figure 45), with a total of 6.03 targets/1,000,000 m^3/night-hour and 3.08 targets/1,000,000 m^3/night-hour, respectively. The maximum density of targets was below 150 m during 57.8% and 36.4% of the nights at the Iosco County and West Huron County sites, respectively (Figure 46). A similar pattern occurred when considering nocturnal hours individually with the maximum density of targets being below 150 m during 50.3% and 33.4% of night hours (Figure 47).

At both sites, targets were observed within the entire range of altitude bands sampled. Mean altitude of nocturnal targets was 522 m ± 327 m SD and 505 m ± 296 m SD above radar elevation at the Iosco County and West Huron County sites, respectively (Table 9). The median altitude at night was 466 m and 460 m above radar elevation at the Iosco and West Huron County sites, respectively. The median altitude was greatest during the night and dawn biological time periods. The mean altitude per hour during the season showed a similar pattern at the two locations (Figure 48). The mean altitude increased around dusk and tapered an hour or two afterwards. The mean target heights gradually decreased throughout the night, with a spike in mean altitude occurring around dawn.

Although many radar reports include estimates of the mean and median target altitudes, we found that these estimates were poor indicators of maximum density because of differences in the volume of air space sampled at various altitude bands. Figures 49 and 50 are based on target density and show the variation in flight altitudes used by targets that were counted by our vertical scanning radars throughout our survey period (Sept 6 – November 7, 2012 at the Iosco County site and September 2 – November 7, 2012 at the West Huron County site). These graphics show the altitude bands of 0 – 1,300 m where most targets were counted (targets were counted up to 2,750 m, which is the extent of our sampling range). These graphics show that night hours at both sites had the highest density of flight activity and that the range of flight altitudes increased during the night hours. The graphics also show that many targets flew within, or just outside of a 30 – 130 m RSZ, and that the mean and median altitudes do not reflect peak density altitudes, demonstrating how these values can misrepresent flight risk.

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 Michigan during fall 2012.

	Iosco County			West Huron County		
Biological Period	Mean	Median	Max Band Density	Mean	Median	Max Band Density
Dawn	500 ± 366	432	100	471 ± 337	405	100
Day	386 ± 278	345	100	319 ± 314	210	100
Dusk	483 ± 338	388	100	309 ± 343	200	150
Night	522 ± 327	466	200	505 ± 296	460	350

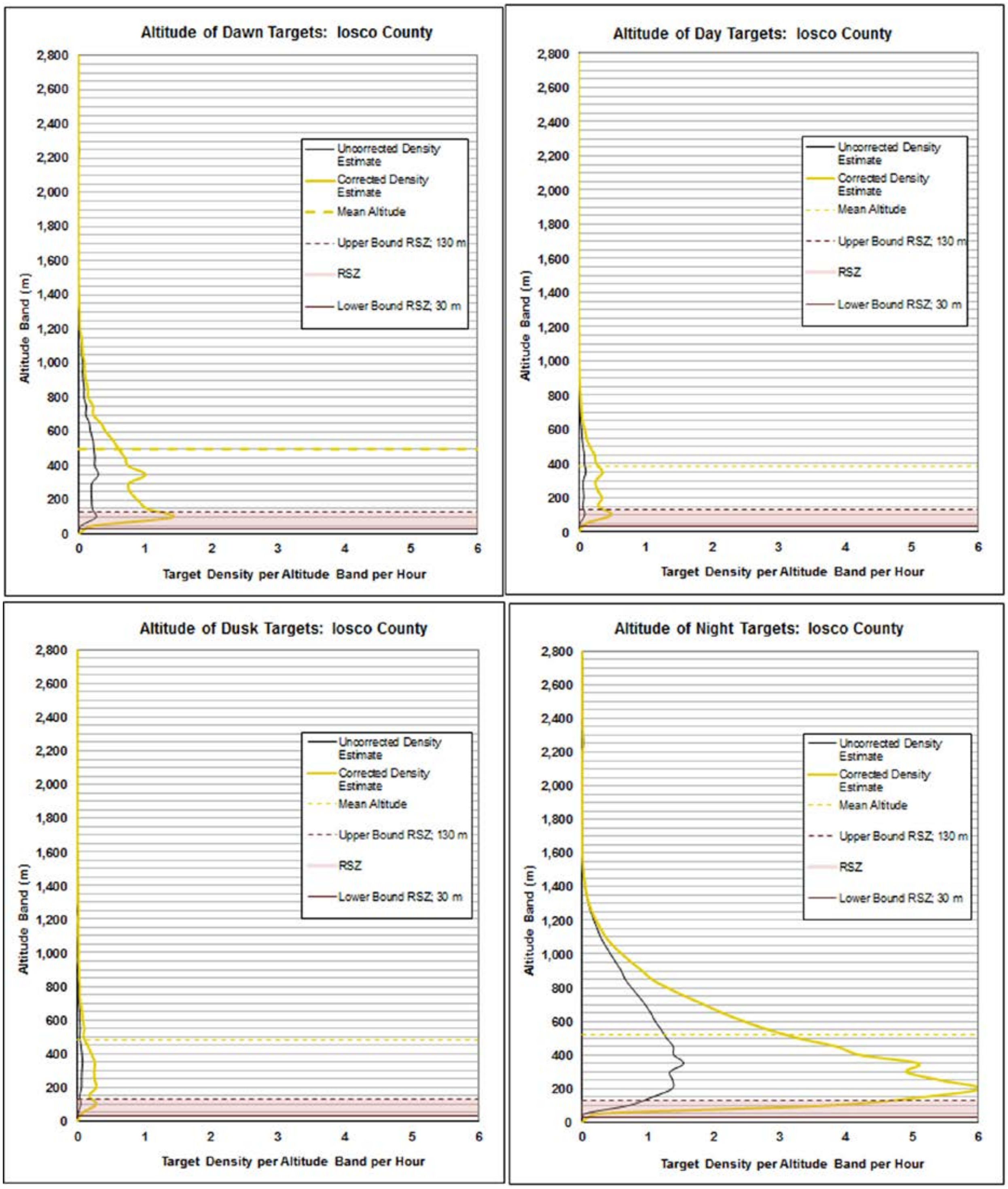


Figure 41. Altitude profile of targets at our Iosco County site. Corrected lines depict target density (targets/1,000,000 m^3) per 50-m altitude band per hour after adjusting for the structure of the sample volume. Uncorrected lines depict target density per 50-m altitude band per hour with an assumed uniform volume distribution (volume of each band is equal to the total volume divided by the number of bands). The red band represents the rotor swept zone (RSZ) between 30 – 130 m, and the y-axis labels represent the top of the altitude band.

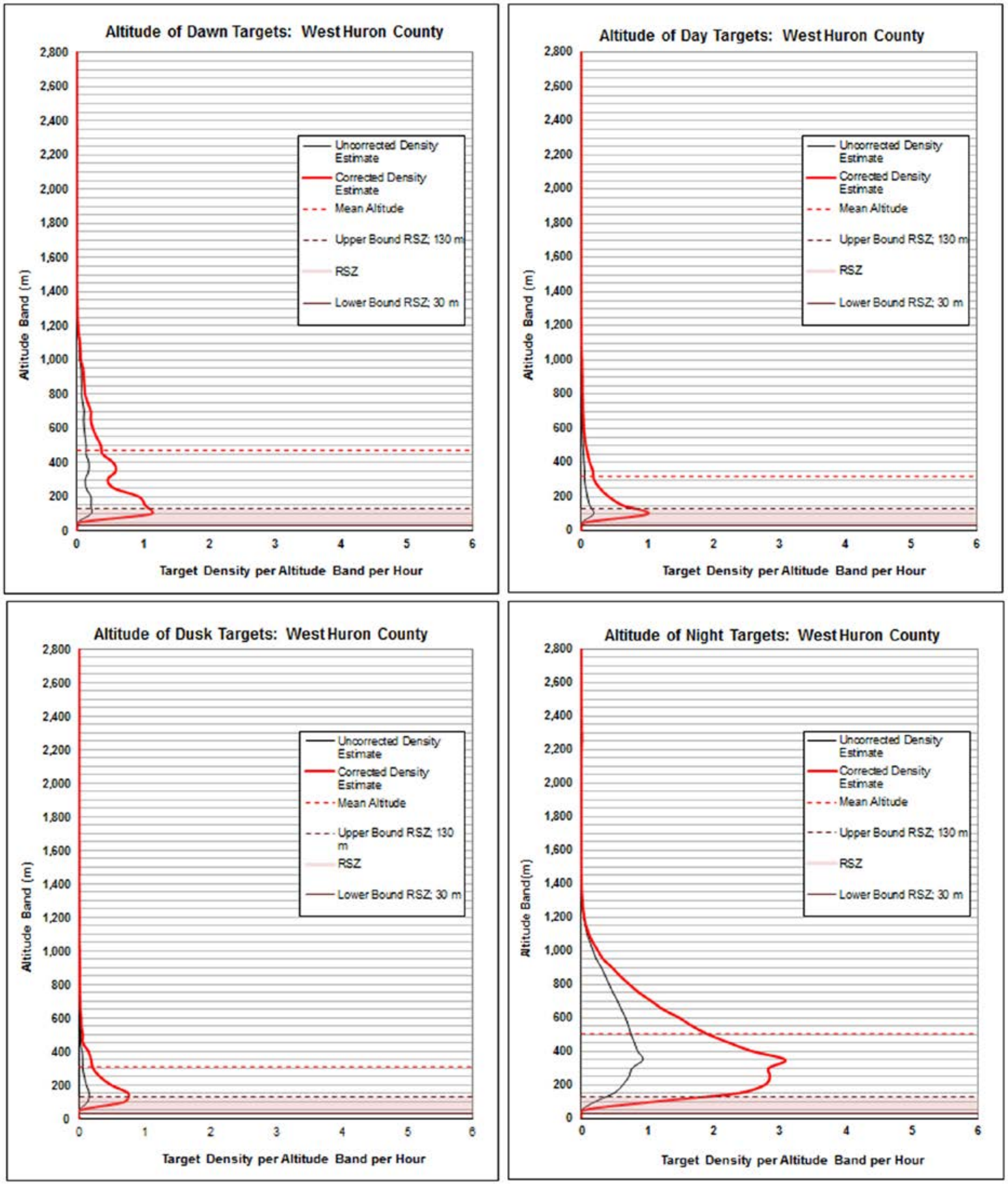


Figure 42. Altitude profile of targets at our West Huron County site. Corrected lines depict target density (targets/1,000,000 m³) per 50-m per hour altitude band after adjusting for the structure of the sample volume. Uncorrected lines depict target density per 50-m altitude band per hour with an assumed uniform volume distribution (volume of each band is equal to the total volume divided by the number of bands). The red band represents the rotor swept zone (RSZ) between 30 – 130 m, and the y-axis labels represent the top of the altitude band.

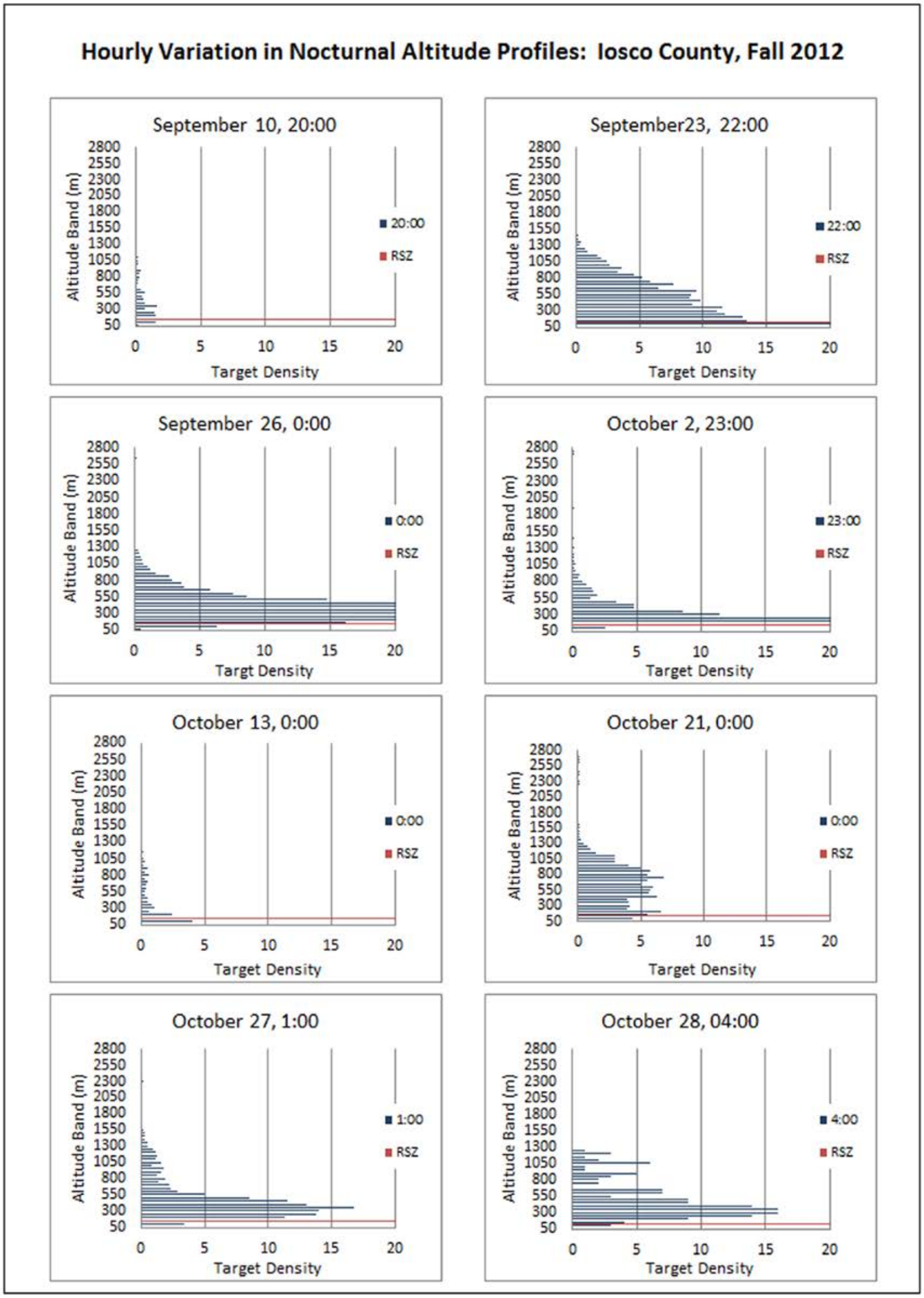


Figure 43. A sample of hourly nocturnal altitude profiles corrected for the shape of the sample volume at our site in Iosco County, during fall 2012. Hours were selected to portray the variability in density per altitude band of passing targets. The x-axis represents target density (targets/1,000,000 m^3) per 50-m altitude band. The y-axis represents altitude bands in meters. The red line represents the top of the rotor swept zone at 130 m.

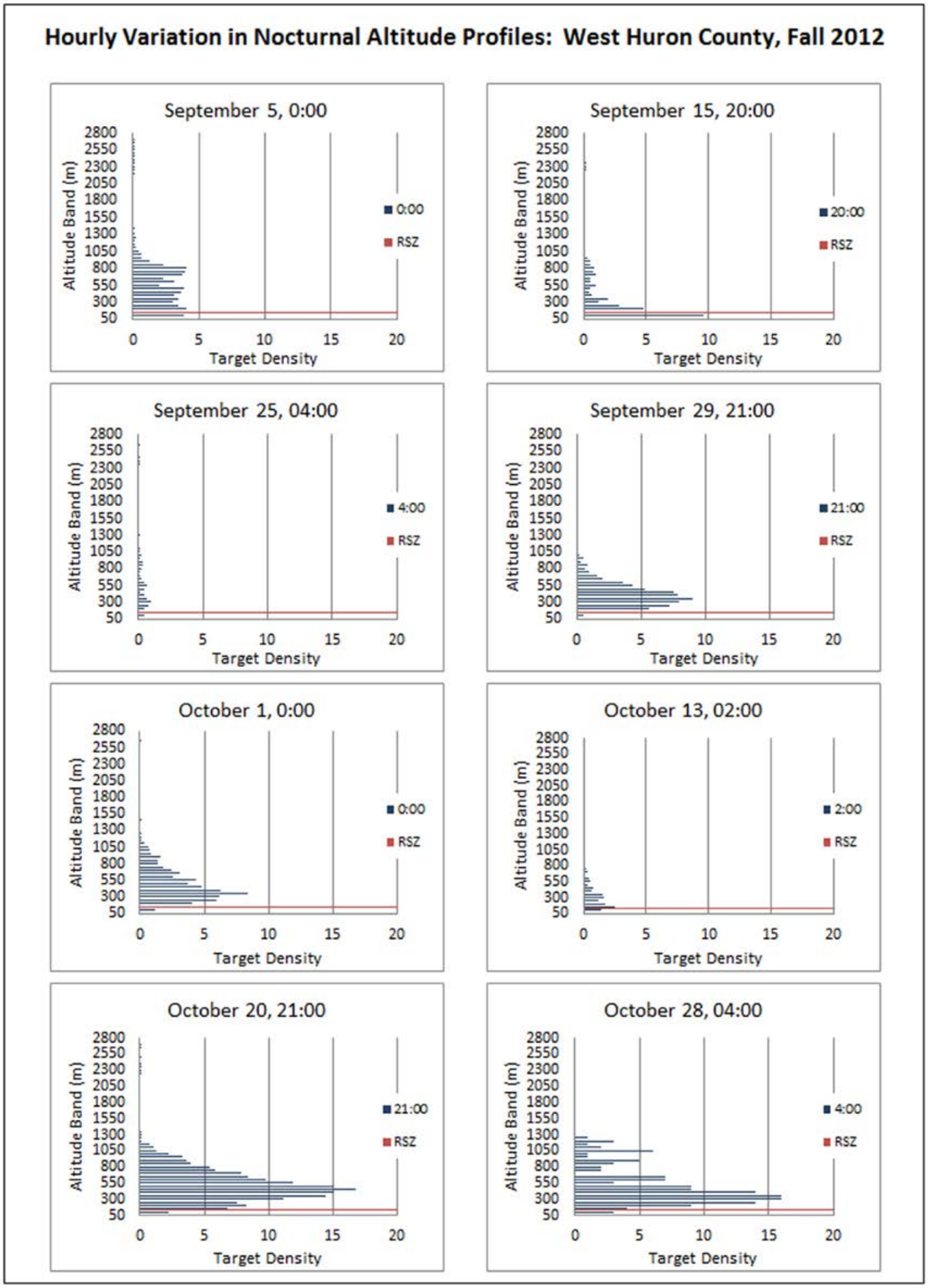


Figure 44. A sample of hourly nocturnal altitude profiles corrected for the shape of the sample volume at our West Huron County site during fall 2012. Hours were selected to portray the variability in density per altitude band of passing targets. The x-axis represents target density (targets/1,000,000 m^3) per 50-m altitude band. The y-axis represents altitude bands in meters. The red line represents the top of the rotor swept zone at 130 m.

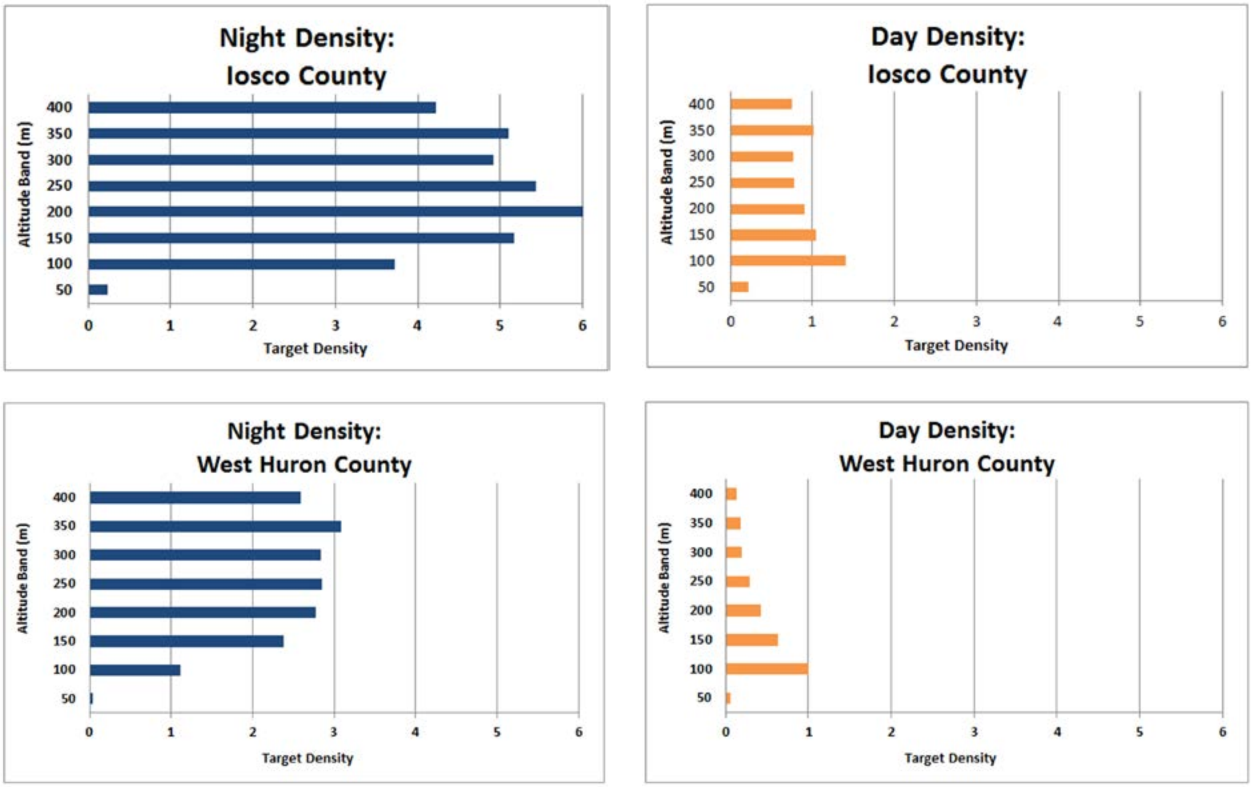
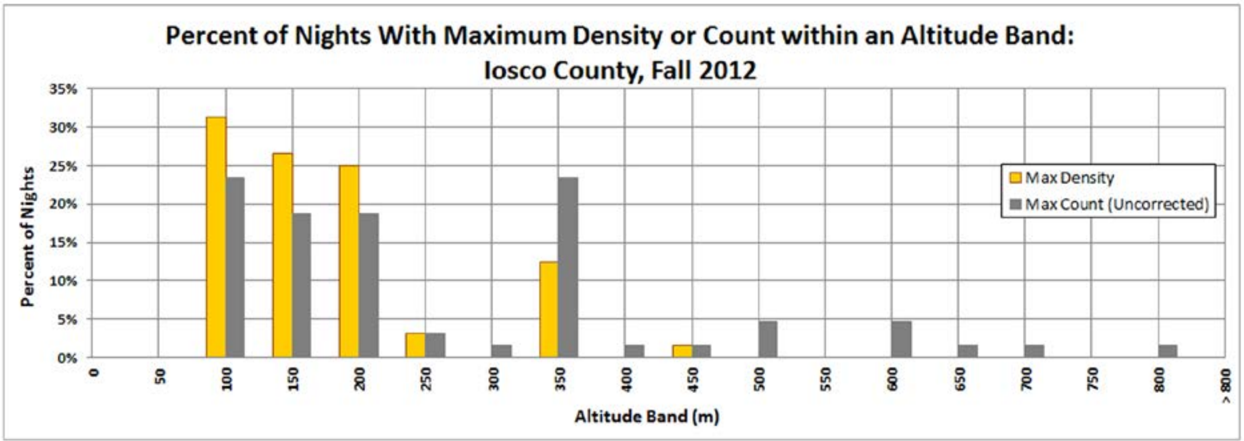


Figure 45. Altitude profile of target density below 400 meters in at our sites in Iosco County and West Huron County during fall 2012. The x-axis represents target density (targets/1,000,000 m^3) per 50-m altitude band.



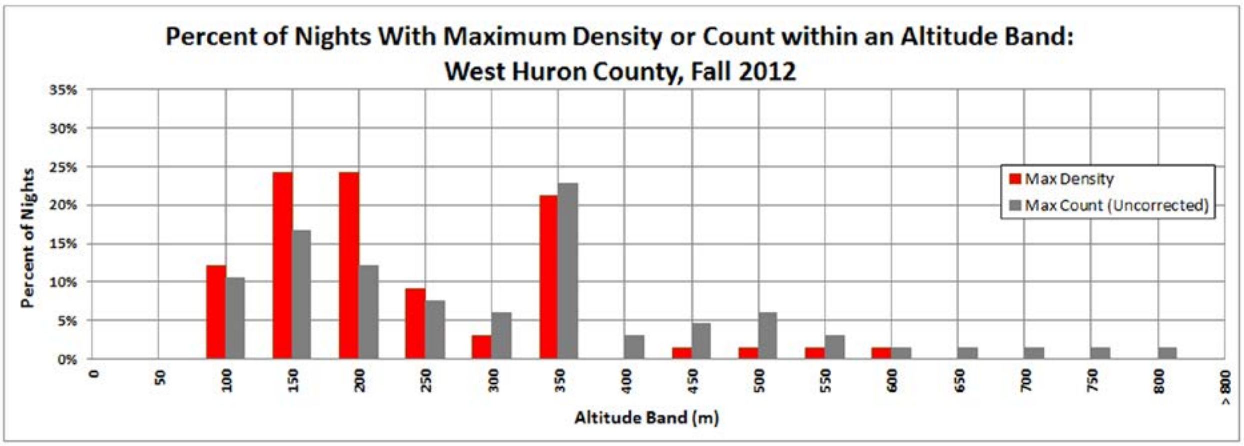


Figure 46. Percent of nights when the maximum density (targets/1,000,000 m^3/ altitude band) or count (targets/altitude band) occurred within 50-m altitude bands at our Iosco County and West Huron County study sites, during fall 2012.

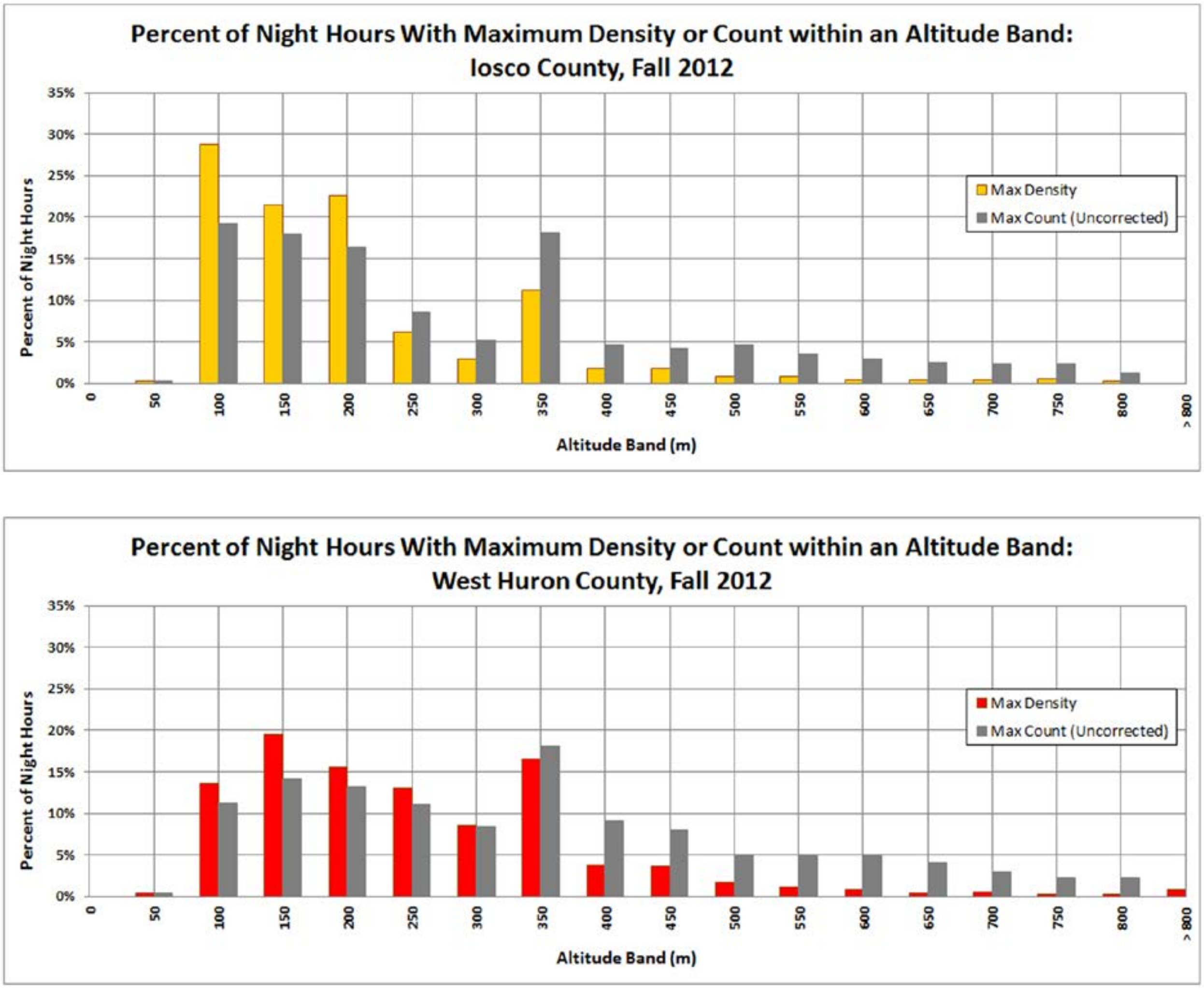
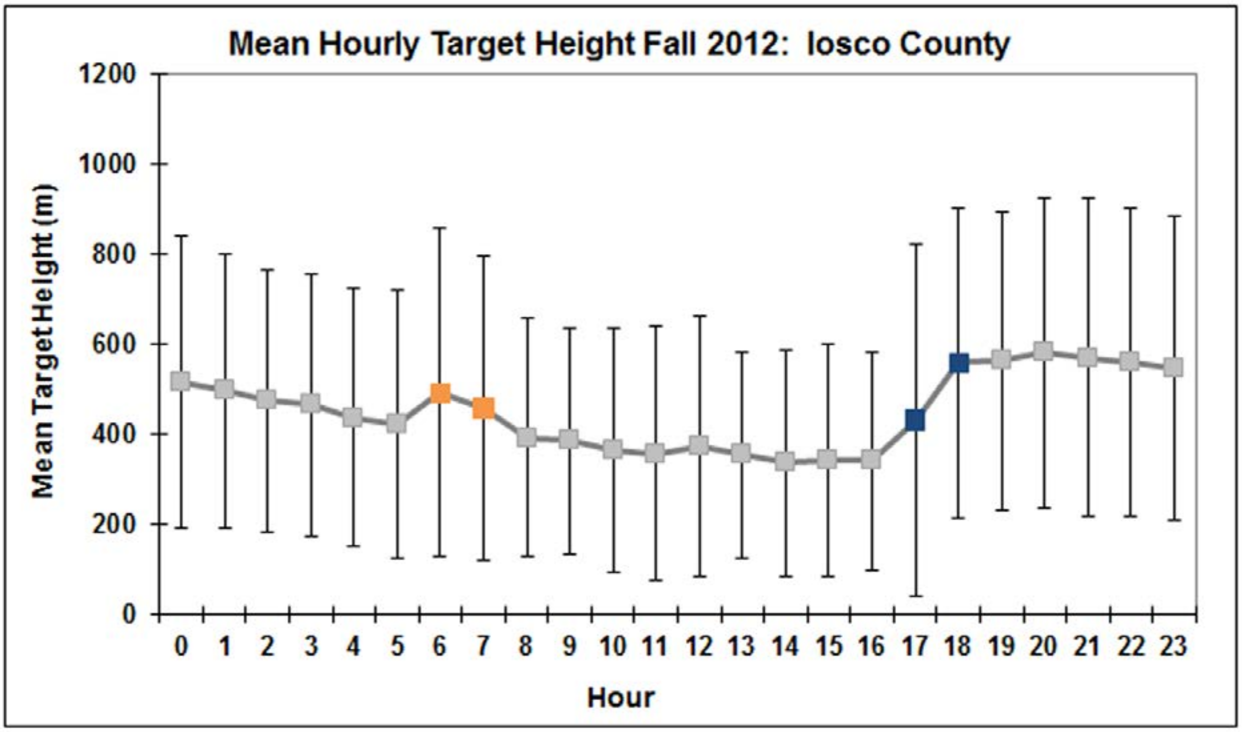


Figure 47. These graphics show the percent of night hours (20:00 – 04:00) when the maximum density (targets/1,000,000 m^3/ altitude band) or count (targets/altitude band) occurred within 50-m altitude bands our Iosco County and West Huron County study sites, during fall 2012.



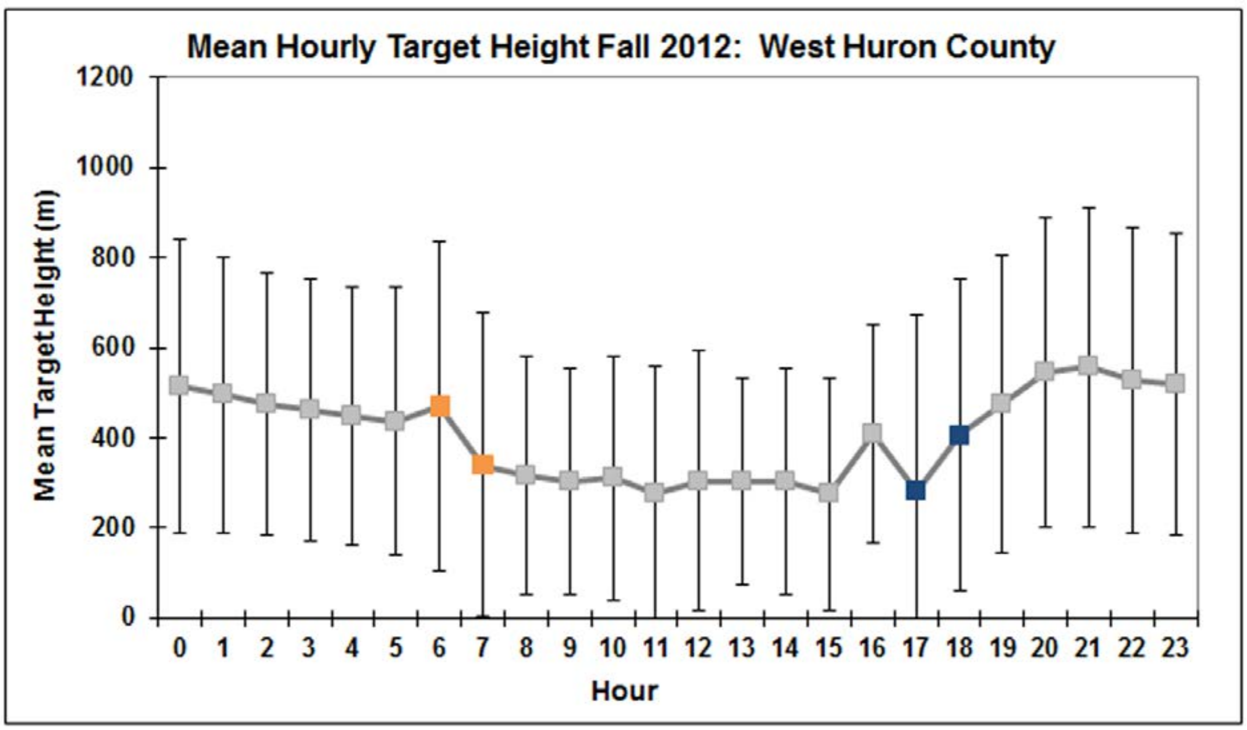


Figure 48. Mean hourly target height (m) during fall 2012 at our Iosco County (top) and West Huron County (bottom) sites. Orange and blue markers indicate the hours in which sunrise and sunset occurred during the season, respectively. Error bars represent one standard deviation.

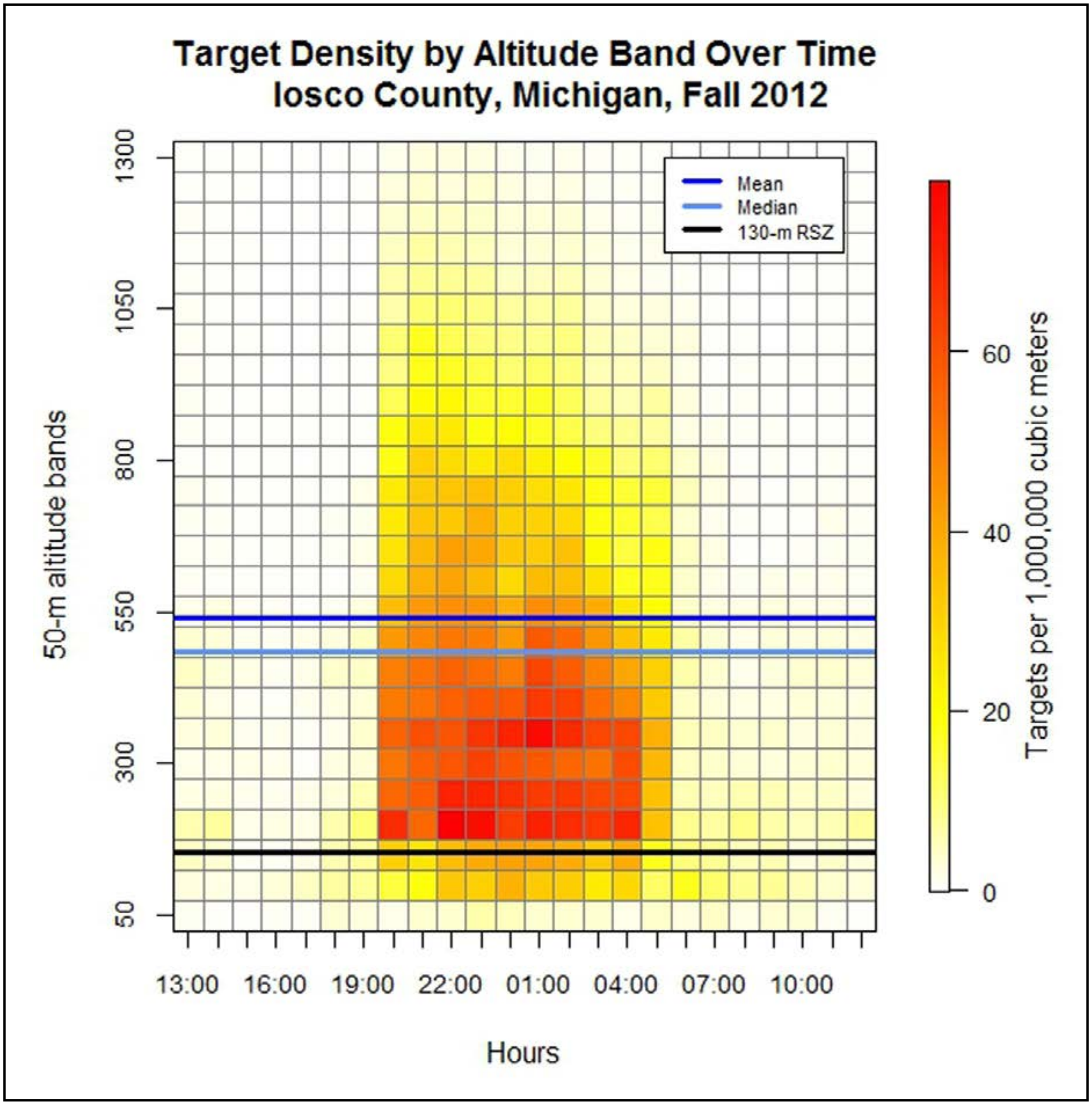


Figure 49. Variation in flight altitudes based on target density (targets per million cubic m) at our Iosco County, Michigan site throughout the fall 2012 study period. Altitude bands are in meters, and labels represent the max value of each altitude band. Colors shown in each rectangle indicate the 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 line at 130 m represents the max height of a turbine with a RSZ of 30 – 130 m. Note the difference in density scale used in other figures.

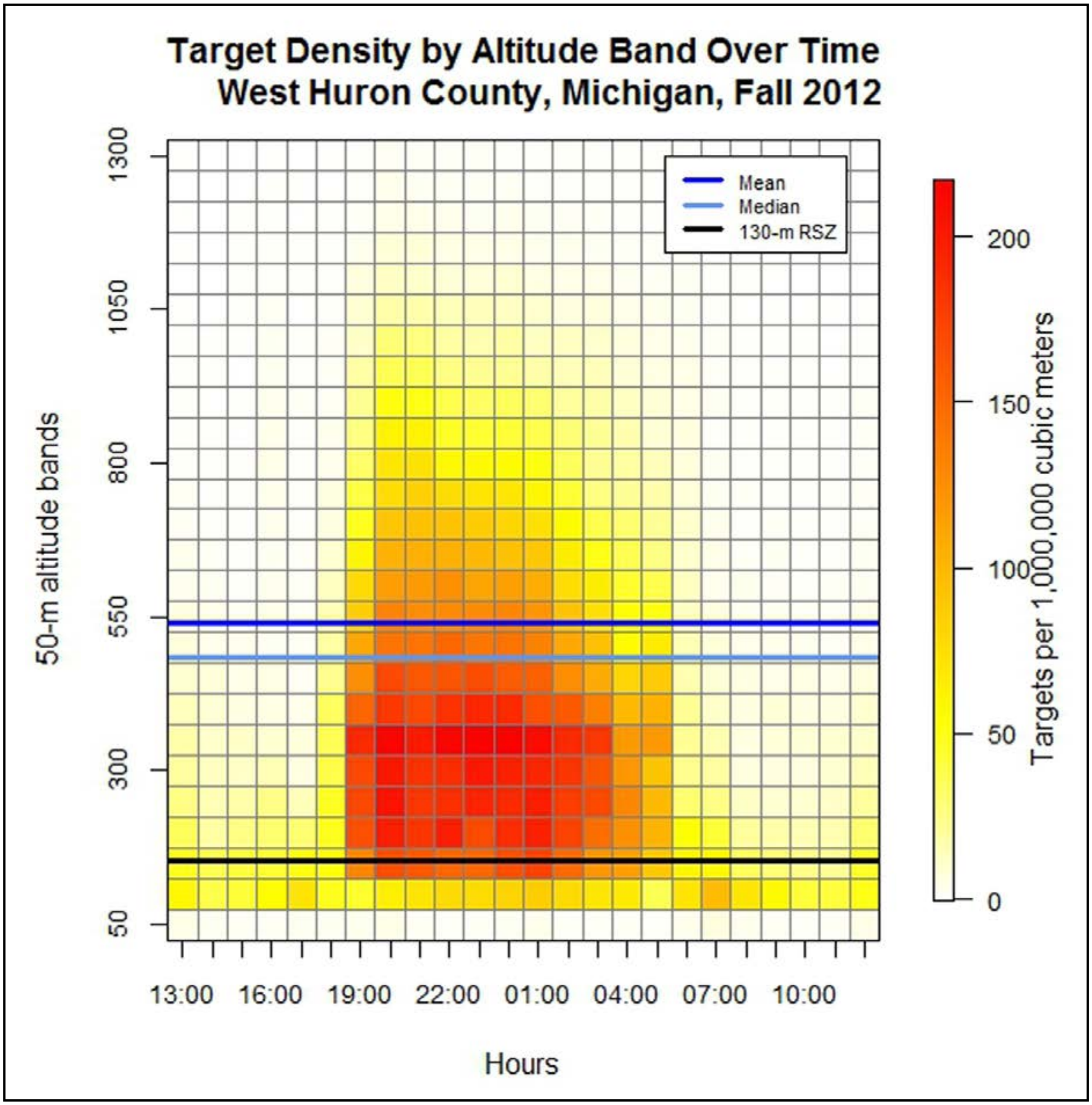


Figure 50. Variation in flight altitudes based on target density (targets per million cubic m) at our West Huron County, Michigan site throughout the fall 2012 study period. Altitude bands are in meters, and labels represent the max value of each altitude band. Colors shown in each rectangle indicate 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 line at 130 m represents the max height of a turbine with a RSZ of 30 – 130 m. Note the difference in density scales used in other figures.

Discussion

We undertook this study to document migration along the shorelines of the Great Lakes. We found that migration movements were common along the shorelines of northern Lake Michigan and western Lake Huron (where we established our study sites), and we believe that the data collected at these four sites are generally representative of migration along these shorelines, even if our time on northern Lake Michigan was for a short part of the season. Our research contributes to a growing body of literature that documents various aspects of migration and identifies the Great Lakes shorelines as areas important for 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 technology. Additionally, the gathered data may be useful outside of its application to wind energy development. Areas viewed as concentration areas may be higher prioritized for habitat conservation or enhancement. While specific habitat patches may be hard to evaluate using marine radar data, general trends of where migrants are traveling to can be found and further investigated with on the ground surveys.

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). Our continuous sampling scheme captured the timing of migration events and provided a more complete picture of the migratory season than a systematic or random sampling scheme, which may have missed pulses of activity (Figure 51). Even with splitting the season and our short amount of time in the Upper Peninsula, we were able to see patterns in migration using our continuous sampling scheme. We used diurnal radar observations to provide a baseline for comparing nocturnal activity, and including this time period helped to distinguish the magnitude of migration events (Figures 15 and 36). Our sampling regime was also useful in showing when the migration season for passerines and bats declined in late October. Although by moving from the Upper Peninsula sites to the Lower Peninsula sites in early September, we missed documenting the full migration for each site. As more data are collected, we will be able to better describe the migration season and how it varies with location and year. This information will help conservation efforts to be tailored to appropriate time frames.

Site Comparison Considerations

Target counts provided by radar are influenced by radar type and calibration, filtering of non-intended targets, count algorithms, frequency band, antenna orientation, sampling scheme, and how researchers account for variation in detection probability and sample volume (Bruderer 1997, Harmata et al. 1999, Schmaljohann et al. 2008). Even when the same equipment and methodology are used among sites or studies, comparisons should be made cautiously if the probability of detection and sampling volume are ignored (Schmaljohan et al. 2008). Recognizing that our counts represent an index of target passage that is relative to a site, we are cautious in making comparisons among sites or studies. Rather than relying solely on the magnitude of the target passage as an indication of migration, we assess the patterns of activity among sites to compare the relative strength of migration. For example, a site with a nocturnal passage rate that shows peaks that are many times larger than nocturnal lulls for the majority of the sampling period would likely be considered to have more migration than a site with less of a discrepancy between nocturnal peaks and lulls or a site that had a nocturnal passage rate that only occasionally spiked above a baseline of nocturnal passage rates.

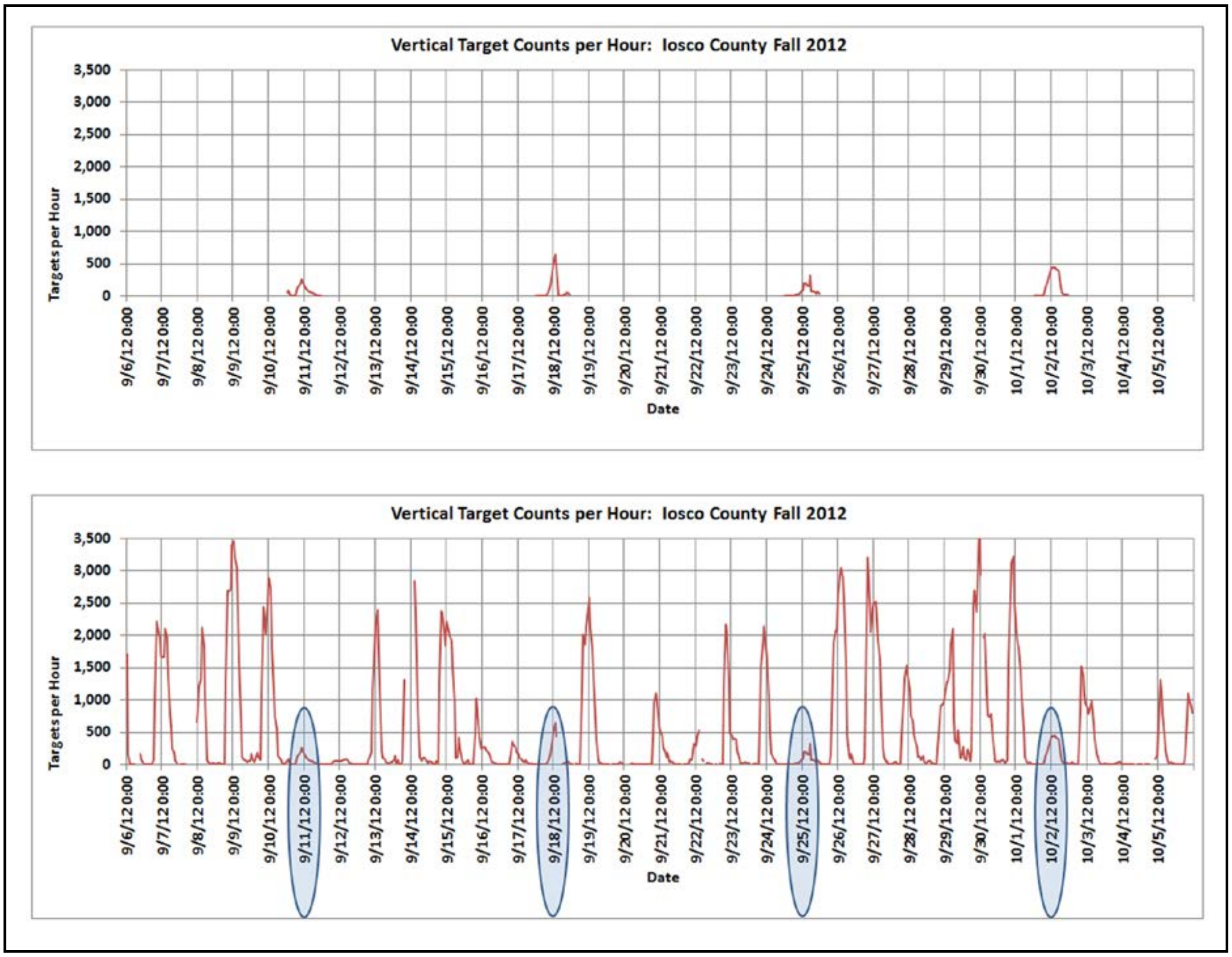


Figure 51. Example of a hypothetical sampling schedule where data were collected once per week (top graphic) versus the actual continuous sampling schedule (bottom graphic). Red lines represent the number of targets counted per hour by the vertical scanning radar from September 6 – October 5, 2012 at our Iosco County site.

Migration Patterns

The patterns of movement we recorded were consistent with other observations of migration (Newton 2008) and they indicated that nocturnal migratory flights occurred regularly in fall 2012 at our surveyed locations. The nocturnal activity we observed was typically oriented in a southerly direction (Figures 11-12 and 32-33) and occurred in pulses across the season that were captured by horizontal and vertical radars (Figures 13, 14, 34, and 35). During the night, targets often traveled perpendicular to the shorelines, heading out over the water to cross to the other side, while at dawn we observed targets that were flying over water return to shorelines. Movement towards shore at dawn may be due to migrants drifting with the wind as they migrate and needing to adjust their position at dawn to find suitable stopover habitat to rest and refuel (Horton et al. 2016b). While these patterns were common, they were not observed every night. Occasionally we observed migration in the opposite direction, indicating that reverse migration occurred at all sites, although this was more common earlier in the season. Target passage rate (mean for the season) was greatest during the nocturnal biological time period at all locations (Tables 4 and 8, Figures 15 and 36). Mean hourly heights showed a pattern previously associated with migration (Harmata et al. 2000, Mabee and Cooper 2004) with heights that increased near dusk, peaked at night, and began to decrease prior to dawn. The slight increase in mean height near dawn at our sites (Figure 27 and 48) is consistent with a migratory behavior described as dawn ascent (Myres 1964, Diehl et al. 2003). This behavior is attributed to migrants increasing altitude to gain a broader view of the surrounding landscape before selecting stopover habitat or returning to the shoreline if they were flying over water. Taken together, we attribute these nocturnal observations to migrants and suggest that the shorelines we studied are important for their conservation.

While comparing direct numbers between sites is problematic, overall trends can be more easily compared. In general, we observed similar behaviors at similar times when looking at different sites. Nocturnal migration started at generally the same time and often moved in generally the same direction when comparing West Delta County with Garden Peninsula or Iosco County with West Huron County. General magnitude was also similar between sites on a given night, and there were rarely times when one of the sites had large numbers and the other site did not. These pattern comparisons provide evidence for broad scale movements of migrants across the landscape and that these movements may be due to broad scale influences such as weather front movements.

At our four sample locations, nocturnal targets appeared to move across the landscape in waves with peaks starting on August 27 at both of our sites located near Lake Michigan (Figures 13 and 14). Due to our longer sampling period at our Iosco and West Huron County sites, located near Lake Huron, we were able to capture a series of peaks that occurred beginning in early September and extending through late October (Figures 34 and 35). These fluctuations may be related to broad scale weather fronts, variation in timing among guilds of migrants, or a combination of these and other factors (Newton 2008). The pattern of these trends at our study locations suggests broad-scale influences and could indicate that further investigation into their cause would allow prediction of high migration events.

The weekly mean nocturnal TPR estimates were consistently higher than weekly mean diurnal TPR estimates throughout the data collection period (Figures 18 and 39), with peaks between late August and late October. The difference between peaks was diminished in early August, late October, and early November. This shift from time periods with significantly higher nocturnal activity to time periods with diminished nocturnal activity indicates that migration substantially contributed to the aeroecology above our study areas.

Flight Altitude

Altitude profiles indicated that most nocturnal targets passed below 800 m, with peak density between the 100 and 350 m altitude bands (Figures 20, 21, 24, 41, 42 and 45). We corrected for the approximate shape of the survey volume and included this correction in our density estimates, although this correction is based on the manufacturer's estimate of beam geometry, which may not be precise. Furthermore, beam propagation was not consistent over time because it was affected by side lobes, target size and distance, and atmospheric conditions. Nevertheless, we believe that the correction was an improvement over the altitude profiles that ignored beam geometry and sampling effort. We were not able to correct for the loss of detection with distance from the radar (Schmaljohann et al. 2008), and our vertical scanning radars lost detection at a range of approximately 1,400 – 2,000 m, which was where the radar transitioned from the short to medium pulse. For these reasons, our estimates likely under-represented the density as altitude increases. However, the densities per altitude band were already decreasing (Figure 20-21 and 41-42) before the 1,400 m band, and any undercount would be unlikely to change the overall picture.

The reported altitude profiles varied considerably among nocturnal hours at our four study sites (Figures 22, 23, 43 and 44). Migrants likely adjusted flight altitude with wind direction and speed, visibility, time, and landscape below flight trajectory (Alerstam 1990, Hueppop et al. 2006, Liechti 2006). For example, head winds aloft have resulted in migrants moving en masse to lower altitudes that present lower wind speeds (Gauthreaux 1991). In addition, migrants are typically on land at least twice during every 24-hour period. Changes in flight altitude can occur at various times over the course of the night and are associated with targets ascending from and descending to stopover sites. Depending on location, these altitude changes may place migrants at risk of collision with wind turbines.

Radar Study Considerations

Although radar may be the best tool available for gathering large amounts of data on nocturnal migration, the interpretation of radar data can be challenging. Marine radar is the most common type of radar used to track the movements of birds and bats (Larkin 2005), and its use in risk assessments will likely increase with the expected increase in wind energy development. Despite this growing trend, standardized equipment and methodologies for establishing radar settings, ground-truthing biological targets, and data processing have not been adopted, although such considerations would substantially improve the quality of the data and the conclusions drawn from them. Standardization presents an enormous challenge; however, without it, comparisons among studies may be more reflective of changes in equipment, methodology, and site conditions rather than differences in migratory activity among sites.

Additionally, the metrics reported in radar surveys can be misleading to anyone unfamiliar with avian radar. For example, the mean altitude of target passage is often reported to be above the rotor-swept zone and has been interpreted to indicate low risk. However, the mean altitude can be well above the rotor-swept zone, even when there is a high rate of target passage within the zone because of the long range over which radars collect altitude data, which was up to 3 km above the ground in our study; thus, high flying targets can inflate the mean altitude. This bias was apparent in our data and can be observed by comparing the mean altitude of nocturnal targets to the most densely populated altitude band (Figures 24-26, 28-29, 45-47, 49-50, and Tables 5 and 9). It is also misleading to compare the percent of targets below and above the height of the rotor-swept zone without addressing the inherent difference in radar sampling effort at various altitude bands. Within our sampling framework, there were three 50-m altitude bands below 150 m (an estimate for the height of the rotor-swept zone) and 53 altitude bands above 150 m. Based on our model, we estimated that approximately 1% of the potential survey volume was below 150 m. Therefore, we would expect a small percentage of targets to be recorded at or below the rotor-swept zone, although this does not necessarily indicate low risk. Additionally, sampling in areas in the lower altitude bands is often poor due to the effects of ground clutter (Figure 4 and 5).

When examining general migration patterns, high nighttime migrant activity was documented at our Lake Michigan and Lake Huron radar sites as demonstrated by our Trackplots (Figures 9, 10, 30, 31), the time series plots from each site (Figures 13, 14, 34, and 35), and high target passage rates (Figures 15, 16, 36, and 37 and Tables 4 and 8). Percent of targets within a 30 – 130 m rotor-swept zone were high during all biological time periods, with target density being highest at night (Figures 15-21 and 36-42). Throughout the migration season, nighttime targets were recorded flying along the shorelines and across the lake (Figures 9, 10, 12, 30, 31 and 33). As dawn approaches nighttime migrants need a place for refuge, rest, and foraging, thus migrants flying over water have been recorded returning towards shore around dawn. The combination of these behaviors indicates that high numbers of nighttime migrants may be at risk of collision with wind facilities, communication towers, or other tall structures located along the shorelines of Lakes Michigan and Huron.

Although the target passage rate and target density were lower during the dawn, day, and dusk periods, the migrants may still be at risk of collision during these time periods. Targets were recorded flying along the lakeshore, indicating that the Lakes Michigan and Huron shorelines are used by migrants during all times of the day in the migration season for both migratory flightpaths and stopover habitat.

Conclusions

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

The results of our research highlight the potential role of radar in implementing recommendations from the Land-based Wind Energy Guidelines (USFWS 2012) for the identification of areas where impacts to wildlife should be minimized. We documented examples of migrant activity along the northern shorelines of Lake Michigan and the western shorelines of Lake Huron at our study sites, and the density of targets at lower altitudes is a potential concern. Additionally, increases in turbine heights and blade lengths increase the size of the rotor-swept zone, thus creating larger areas of flight risk for birds and bats. The collected data may be of interest to public and private entities involved with wind energy development and the potential placement of turbines in the Great Lakes region as well as decision makers evaluating land conservation and stopover habitat use. Coupling avian radar systems with other forms of research or using radar in conjunction with post-construction fatality searches may broaden the utility of their use in risk assessments of wind energy developments.

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Appendices

Appendix 1

Fall 2012 Report Summary

- Migration occurred at our four fall study sites
  - Migration occurred on the western and northern shoreline of Lake Michigan on both sides of Green Bay during fall 2012 (West Delta County and Garden Peninsula sites)
  - Migration occurred on the western shoreline of Lake Huron on both sides of Saginaw Bay during fall 2012 (Iosco County and West Huron County sites)
  - Migration is identified by uniformity of movement of direction (south) at night, high target passage rate, and peaking of numbers a couple of hours before to a couple of hours after midnight
  - Patterns and timing of migration were similar between the paired sites
    - Lake Michigan sites:
      - A wave of migration occurred at our West Delta County and Garden Peninsula sites beginning on August 27
    - Lake Huron sites:
      - Waves of migration occurred at our Iosco County and West Huron County sites early September through mid/late October
        - Highest concentrations occurred the first and last week of September
- Date range of pulses that occurred during the fall 2012 survey period
  - August 27 through September 1 at our Lake Michigan sites (September 1 was the last day of the survey period)
  - September 6 through mid/late October at our Lake Huron sites (survey period started on September 2 and 6 at these sites)
- Patterns of activity were different between Dawn, Day, Dusk, and Night time periods
  - Movement south during the night: Lake Michigan sites
    - 52% of nights surveyed the mean direction of travel was generally southerly at our West Delta County site
    - 62% of nights surveyed the mean direction of travel was generally southerly at our Garden Peninsula site
  - Movement south during the night: Lake Huron sites
    - 75% of nights surveyed the mean direction of travel was generally southerly at our Iosco County site
    - 60% of nights surveyed the mean direction of travel was generally southerly at our West Huron County site
  - Movement in towards shore at dawn
    - Observed all sites
  - Highest target passage rate at night
  - Dawn ascent
    - Increase in height around dawn hours observed at all sites

- Peak density of targets in volume corrected counts
  - Lake Michigan sites:
    - Max density below 150 m 14% of nights and 17% of night hours our West Delta County site
    - Max density below 150 m 56% of nights and 55% of night hours at our Garden Peninsula site
  - Lake Huron sites:
    - Max density below 150 m 58% of nights and 50% of night hours our Iosco County site
    - Max density below 150 m 36% of nights and 33% of night hours at our West Huron County site
- Standards for radar studies need to be established, and recommendations are included in this report
  - Using radar counts as an index of activity and not a population estimate
  - Surveying continuously over the whole migration season
  - Examining smaller time periods (Dawn/Day/Dusk/Night or Hourly) rather than seasonal metrics
  - Using volume corrected counts on the vertical radar to better estimate use of low altitudes and the rotor swept zone
  - Using 50-m altitude bands to represent height distributions rather than mean or median heights
  - Examining the most densely populated altitude bands rather than comparing numbers or percentages of targets below, within, and above the rotor swept zone
  - Recognizing that migrants change altitude for various reasons over time and that targets flying several altitude bands above the rotor swept zone may still be at risk.

Appendix 2

Percent Land Cover Associated with Study Sites and the 2011 National Land Cover Database Classification

Percent land cover found within 3.7 km of radar locations at our West Delta County, Garden Peninsula, Iosco County, and West Huron County sites.

Land Cover Class	Percent Land Cover: West Delta County	Garden Peninsula	Iosco County	West Huron County
Cultivated crops/Hay pasture	3%	21%	5%	61%
Deciduous forest	6%	10%	10%	6%
Deveoloped[1]	4%	4%	8%	6%
Emergent herbaceous wetlands	2%	1%	7%	6%
Evergreen Forest	7%	18%	4%	0%
Mixed Forest	8%	10%	2%	0%
Open water	24%	7%	35%	10%
Other[2]	7%	8%	10%	1%
Woody wetlands	39%	22%	19%	9%

[1] Includes low, medium and high intensity development and developed open space.

[2] Includes barren land, herbaceous and shrub/scrub.

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

Classification Description
Water
Open Water - areas of open water, generally with less than 25% cover of vegetation or soil.
Perennial Ice/Snow - area 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 total cover. These areas most commonly include single-family housing units.
Developed, High Intesity - 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.

(Appendix 2 continued)

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 target density by altitude band during fall 2012 biological time periods in West Delta County.

Altitude Band (m)	Dawn	Day	Dusk	Night
50	0.1	0.1	0.1	0.2
100	0.5	0.3	0.4	1.3
150	0.3	0.2	0.3	1.7
200	0.4	0.3	0.7	3.3
250	0.3	0.2	0.6	3.0
300	0.4	0.1	0.4	2.8
350	0.4	0.1	0.5	3.1
400	0.3	0.1	0.4	2.7
450	0.5	0.1	0.3	2.5
500	0.5	0.1	0.3	2.2
550	0.4	0.1	0.2	1.9
600	0.4	0.0	0.1	1.5
650	0.5	0.0	0.1	1.5
700	0.4	0.0	0.1	1.3
750	0.5	0.0	0.1	1.3
800	0.4	0.0	0.0	1.0
850	0.2	0.0	0.0	0.8
900	0.3	0.0	0.0	0.7
950	0.2	0.0	0.0	0.5
1000	0.2	0.0	0.0	0.5

Estimated target density by altitude band during fall 2012 biological time periods in Garden Peninsula.

Altitude Band (m)	Dawn	Day	Dusk	Night
50	0.4	0.2	0.2	1.5
100	0.6	0.6	0.5	2.8
150	0.6	0.7	0.5	3.1
200	0.6	0.5	0.4	3.2
250	0.7	0.4	0.4	3.0
300	0.8	0.2	0.3	3.0
350	0.7	0.2	0.2	2.7
400	0.4	0.1	0.3	2.6
450	0.7	0.1	0.2	2.5
500	0.8	0.1	0.1	2.2
550	0.6	0.1	0.1	1.8
600	0.4	0.1	0.1	1.5
650	0.4	0.1	0.1	1.2
700	0.3	0.0	0.0	1.0
750	0.3	0.0	0.0	0.8
800	0.3	0.0	0.0	0.7
850	0.2	0.0	0.0	0.6
900	0.2	0.0	0.0	0.5
950	0.2	0.0	0.0	0.4
1000	0.2	0.0	0.0	0.4

Estimated target density by altitude band during fall 2012 biological time periods in Iosco County.

Altitude Band (m)	Dawn	Day	Dusk	Night
50	0.2	0.1	0.1	0.2
100	1.4	0.5	0.3	3.7
150	1.0	0.3	0.2	5.2
200	0.9	0.3	0.3	6.0
250	0.8	0.3	0.3	5.4
300	0.8	0.3	0.3	4.9
350	1.0	0.4	0.3	5.1
400	0.8	0.3	0.2	4.2
450	0.7	0.2	0.2	3.9
500	0.6	0.2	0.1	3.3
550	0.5	0.1	0.1	2.8
600	0.4	0.1	0.1	2.5
650	0.3	0.1	0.1	2.1
700	0.2	0.0	0.1	1.8
750	0.2	0.0	0.0	1.6
800	0.2	0.0	0.0	1.3
850	0.1	0.0	0.0	1.1
900	0.1	0.0	0.0	0.9
950	0.1	0.0	0.0	0.8
1000	0.1	0.0	0.0	0.6

Estimated target density by altitude band during fall 2012 biological time periods in West Huron County.

Altitude Band (m)	Dawn	Day	Dusk	Night
50	0.0	0.1	0.0	0.0
100	1.1	1.0	0.7	1.1
150	1.0	0.6	0.8	2.4
200	0.9	0.4	0.5	2.8
250	0.6	0.3	0.3	2.9
300	0.5	0.2	0.2	2.8
350	0.6	0.2	0.2	3.1
400	0.6	0.1	0.1	2.6
450	0.4	0.1	0.1	2.2
500	0.4	0.1	0.1	1.9
550	0.3	0.1	0.0	1.7
600	0.2	0.0	0.0	1.5
650	0.2	0.0	0.0	1.2
700	0.2	0.0	0.0	1.1
750	0.2	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	0.3
1000	0.1	0.0	0.0	0.3

Appendix 4

Comparison of Static and Corrected Density Estimates

Comparison of methods to estimated target density by altitude band during the *dawn* biological period in West Delta County, fall 2012.

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	16	16	31.3	5.6	0.0	0.1	0.7%	0.7%	1.8%
100	65	81	31.3	5.9	0.1	0.5	3.0%	3.0%	6.8%
150	38	119	31.3	6.5	0.1	0.3	1.8%	1.8%	3.6%
200	66	185	31.3	7.1	0.1	0.4	3.0%	3.0%	5.7%
250	58	243	31.3	7.9	0.1	0.3	2.7%	2.7%	4.5%
300	71	314	31.3	8.5	0.1	0.4	3.3%	3.3%	5.2%
350	82	396	31.3	9.5	0.1	0.4	3.8%	3.8%	5.4%
400	76	472	31.3	10.3	0.1	0.3	3.5%	3.5%	4.5%
450	113	585	31.3	11.2	0.2	0.5	5.2%	5.2%	6.2%
500	138	723	31.3	12.2	0.2	0.5	6.4%	6.4%	7.0%
550	121	844	31.3	13.3	0.2	0.4	5.6%	5.6%	5.6%
600	116	960	31.3	14.1	0.2	0.4	5.4%	5.4%	5.1%
650	152	1,112	31.3	15.3	0.2	0.5	7.0%	7.0%	6.1%
700	124	1,236	31.3	16.2	0.2	0.4	5.7%	5.7%	4.7%
750	201	1,437	31.3	17.2	0.3	0.5	9.3%	9.3%	7.2%
800	151	1,588	31.3	18.2	0.2	0.4	7.0%	7.0%	5.1%
850	96	1,684	31.3	19.4	0.1	0.2	4.4%	4.4%	3.1%
900	112	1,796	31.3	20.4	0.2	0.3	5.2%	5.2%	3.4%
950	70	1,866	31.3	21.4	0.1	0.2	3.2%	3.2%	2.0%
1,000	74	1,940	31.3	22.4	0.1	0.2	3.4%	3.4%	2.0%

[1] Total target counts recorded up to the 2,800 m band during the dawn time period was 2,168.

[2] Total density of targets per hour recorded up to the 2,800 m band during the dawn time period was 7.55.

Comparison of methods to estimated target density by altitude band during the *day* biological period in West Delta County, fall 2012.

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	122	122	31.3	5.6	0.0	0.1	2.3%	2.3%	1.1%
100	421	543	31.3	5.9	0.1	0.3	8.0%	8.0%	3.7%
150	351	894	31.3	6.5	0.0	0.2	6.6%	6.6%	2.8%
200	516	1,410	31.3	7.1	0.1	0.3	9.8%	9.8%	3.8%
250	328	1,738	31.3	7.9	0.0	0.2	6.2%	6.2%	2.2%
300	246	1,984	31.3	8.5	0.0	0.1	4.7%	4.7%	1.5%
350	303	2,287	31.3	9.5	0.0	0.1	5.7%	5.7%	1.7%
400	261	2,548	31.3	10.3	0.0	0.1	4.9%	4.9%	1.3%
450	396	2,944	31.3	11.2	0.0	0.1	7.5%	7.5%	1.8%
500	376	3,320	31.3	12.2	0.0	0.1	7.1%	7.1%	1.6%
550	243	3,563	31.3	13.3	0.0	0.1	4.6%	4.6%	1.0%
600	151	3,714	31.3	14.1	0.0	0.0	2.9%	2.9%	0.6%
650	152	3,866	31.3	15.3	0.0	0.0	2.9%	2.9%	0.5%
700	154	4,020	31.3	16.2	0.0	0.0	2.9%	2.9%	0.5%
750	167	4,187	31.3	17.2	0.0	0.0	3.2%	3.2%	0.5%
800	124	4,311	31.3	18.2	0.0	0.0	2.3%	2.3%	0.4%
850	103	4,414	31.3	19.4	0.0	0.0	2.0%	2.0%	0.3%
900	105	4,519	31.3	20.4	0.0	0.0	2.0%	2.0%	0.3%
950	86	4,605	31.3	21.4	0.0	0.0	1.6%	1.6%	0.2%
1,000	82	4,687	31.3	22.4	0.0	0.0	1.6%	1.6%	0.2%

[1] Total target counts recorded up to the 2,800 m band during the day time period was 5,280.

[2] Total density of targets per hour recorded up to the 2,800 m band during the day time period was 2.02.

Comparison of methods to estimated target density by altitude band during the *dusk* biological period in West Delta County, fall 2012.

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	12	12	31.3	5.6	0.0	0.1	1.3%	1.3%	2.3%
100	50	62	31.3	5.9	0.1	0.4	5.4%	5.4%	8.9%
150	38	100	31.3	6.5	0.1	0.3	4.1%	4.1%	6.2%
200	98	198	31.3	7.1	0.2	0.7	10.6%	10.6%	14.6%
250	91	289	31.3	7.9	0.1	0.6	9.8%	9.8%	12.1%
300	75	364	31.3	8.5	0.1	0.4	8.1%	8.1%	9.3%
350	93	457	31.3	9.5	0.1	0.5	10.0%	10.0%	10.4%
400	79	536	31.3	10.3	0.1	0.4	8.5%	8.5%	8.1%
450	74	610	31.3	11.2	0.1	0.3	8.0%	8.0%	7.0%
500	79	689	31.3	12.2	0.1	0.3	8.5%	8.5%	6.8%
550	51	740	31.3	13.3	0.1	0.2	5.5%	5.5%	4.0%
600	31	771	31.3	14.1	0.0	0.1	3.3%	3.3%	2.3%
650	35	806	31.3	15.3	0.1	0.1	3.8%	3.8%	2.4%
700	23	829	31.3	16.2	0.0	0.1	2.5%	2.5%	1.5%
750	24	853	31.3	17.2	0.0	0.1	2.6%	2.6%	1.5%
800	5	858	31.3	18.2	0.0	0.0	0.5%	0.5%	0.3%
850	3	861	31.3	19.4	0.0	0.0	0.3%	0.3%	0.2%
900	11	872	31.3	20.4	0.0	0.0	1.2%	1.2%	0.6%
950	5	877	31.3	21.4	0.0	0.0	0.5%	0.5%	0.2%
1,000	5	882	31.3	22.4	0.0	0.0	0.5%	0.5%	0.0%

[1] Total target counts recorded up to the 2,800 m band during the dusk time period was 926.
[2] Total density of targets per hour recorded up to the 2,800 m band during the dusk time period was 4.57.

Comparison of methods to estimated target density by altitude band during the *night* biological period in West Delta County, fall 2012.

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	192	192	31.3	5.6	0.0	0.2	0.2%	0.2%	0.5%
100	1,534	1,726	31.3	5.9	0.2	1.3	1.8%	1.8%	3.7%
150	2,182	3,908	31.3	6.5	0.4	1.7	2.6%	2.6%	4.9%
200	4,554	8,462	31.3	7.1	0.7	3.3	5.5%	5.5%	9.3%
250	4,730	13,192	31.3	7.9	0.8	3.0	5.7%	5.7%	8.7%
300	4,607	17,799	31.3	8.5	0.7	2.8	5.5%	5.5%	7.9%
350	5,755	23,554	31.3	9.5	0.9	3.1	6.9%	6.9%	8.8%
400	5,469	29,023	31.3	10.3	0.9	2.7	6.6%	6.6%	7.7%
450	5,537	34,560	31.3	11.2	0.9	2.5	6.6%	6.6%	7.1%
500	5,410	39,970	31.3	12.2	0.9	2.2	6.5%	6.5%	6.4%
550	4,944	44,914	31.3	13.3	0.8	1.9	5.9%	5.9%	5.4%
600	4,175	49,089	31.3	14.1	0.7	1.5	5.0%	5.0%	4.3%
650	4,421	53,510	31.3	15.3	0.7	1.5	5.3%	5.3%	4.2%
700	4,226	57,736	31.3	16.2	0.7	1.3	5.1%	5.1%	3.8%
750	4,279	62,015	31.3	17.2	0.7	1.3	5.1%	5.1%	3.6%
800	3,698	65,713	31.3	18.2	0.6	1.0	4.4%	4.4%	2.9%
850	3,092	68,805	31.3	19.4	0.5	0.8	3.7%	3.7%	2.3%
900	2,706	71,511	31.3	20.4	0.4	0.7	3.2%	3.2%	1.9%
950	2,194	73,705	31.3	21.4	0.4	0.5	2.6%	2.6%	1.5%
1,000	2,010	75,715	31.3	22.4	0.3	0.5	2.4%	2.4%	1.3%

[1] Total target counts recorded up to the 2,800 m band during the night time period was 83,384.

[2] Total density of targets per hour recorded up to the 2,800 m band during the night time period was 35.02.

(Appendix 4 continued)

Comparison of methods to estimated target density by altitude band during the *dawn* biological period in Garden Peninsula, fall 2012.

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	51	51	31.3	5.6	0.1	0.4	1.9%	1.9%	4.1%
100	86	137	31.3	5.9	0.1	0.6	3.3%	3.3%	6.5%
150	91	228	31.3	6.5	0.1	0.6	3.5%	3.5%	6.4%
200	98	326	31.3	7.1	0.1	0.6	3.7%	3.7%	6.2%
250	127	453	31.3	7.9	0.2	0.7	4.8%	4.8%	7.3%
300	160	613	31.3	8.5	0.2	0.8	6.1%	6.1%	8.5%
350	146	759	31.3	9.5	0.2	0.7	5.6%	5.6%	7.0%
400	87	846	31.3	10.3	0.1	0.4	3.3%	3.3%	3.8%
450	178	1,024	31.3	11.2	0.3	0.7	6.8%	6.8%	7.2%
500	217	1,241	31.3	12.2	0.3	0.8	8.3%	8.3%	8.0%
550	169	1,410	31.3	13.3	0.2	0.6	6.4%	6.4%	5.7%
600	134	1,544	31.3	14.1	0.2	0.4	5.1%	5.1%	4.3%
650	125	1,669	31.3	15.3	0.2	0.4	4.8%	4.8%	3.7%
700	127	1,796	31.3	16.2	0.2	0.3	4.8%	4.8%	3.5%
750	111	1,907	31.3	17.2	0.2	0.3	4.2%	4.2%	2.9%
800	117	2,024	31.3	18.2	0.2	0.3	4.5%	4.5%	2.9%
850	100	2,124	31.3	19.4	0.1	0.2	3.8%	3.8%	2.3%
900	90	2,214	31.3	20.4	0.1	0.2	3.4%	3.4%	2.0%
950	100	2,314	31.3	21.4	0.1	0.2	3.8%	3.8%	2.1%
1,000	77	2,391	31.3	22.4	0.1	0.2	2.9%	2.9%	1.6%

[1] Total target counts recorded up to the 2,800 m band during the dawn time period was 2,626.

[2] Total density of targets per hour recorded up to the 2,800 m band during the dawn time period was 9.74.

Comparison of methods to estimated target density by altitude band during the *day* biological period in Garden Peninsula, fall 2012.

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	341	341	31.3	5.6	0.0	0.2	4.3%	4.3%	2.4%
100	911	1,252	31.3	5.9	0.1	0.6	11.4%	11.4%	6.1%
150	1,174	2,426	31.3	6.5	0.1	0.7	14.7%	14.7%	7.2%
200	939	3,365	31.3	7.1	0.1	0.5	11.8%	11.8%	5.2%
250	731	4,096	31.3	7.9	0.1	0.4	9.2%	9.2%	3.7%
300	536	4,632	31.3	8.5	0.1	0.2	6.7%	6.7%	2.5%
350	409	5,041	31.3	9.5	0.1	0.2	5.1%	5.1%	1.7%
400	268	5,309	31.3	10.3	0.0	0.1	3.4%	3.4%	1.0%
450	354	5,663	31.3	11.2	0.0	0.1	4.4%	4.4%	1.2%
500	429	6,092	31.3	12.2	0.1	0.1	5.4%	5.4%	1.4%
550	353	6,445	31.3	13.3	0.0	0.1	4.4%	4.4%	1.1%
600	253	6,698	31.3	14.1	0.0	0.1	3.2%	3.2%	0.7%
650	212	6,910	31.3	15.3	0.0	0.1	2.7%	2.7%	0.5%
700	175	7,085	31.3	16.2	0.0	0.0	2.2%	2.2%	0.4%
750	169	7,254	31.3	17.2	0.0	0.0	2.1%	2.1%	0.4%
800	143	7,397	31.3	18.2	0.0	0.0	1.8%	1.8%	0.3%
850	93	7,490	31.3	19.4	0.0	0.0	1.2%	1.2%	0.2%
900	80	7,570	31.3	20.4	0.0	0.0	1.0%	1.0%	0.2%
950	66	7,636	31.3	21.4	0.0	0.0	0.8%	0.8%	0.1%
1,000	46	7,682	31.3	22.4	0.0	0.0	0.6%	0.6%	0.1%

[1] Total target counts recorded up to the 2,800 m band during the day time period was 7,988.

[2] Total density of targets per hour recorded up to the 2,800 m band during the day time period was 3.59.

Comparison of methods to estimated target density by altitude band during the *dusk* biological period in Garden Peninsula, fall 2012.

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	24	24	31.3	5.6	0.0	0.2	3.5%	3.5%	5.7%
100	61	85	31.3	5.9	0.1	0.5	9.0%	9.0%	13.7%
150	71	156	31.3	6.5	0.1	0.5	10.5%	10.5%	14.7%
200	62	218	31.3	7.1	0.1	0.4	9.1%	9.1%	11.7%
250	63	281	31.3	7.9	0.1	0.4	9.3%	9.3%	10.7%
300	54	335	31.3	8.5	0.1	0.3	8.0%	8.0%	8.5%
350	48	383	31.3	9.5	0.1	0.2	7.1%	7.1%	6.8%
400	57	440	31.3	10.3	0.1	0.3	8.4%	8.4%	7.4%
450	37	477	31.3	11.2	0.1	0.2	5.4%	5.4%	4.4%
500	34	511	31.3	12.2	0.1	0.1	5.0%	5.0%	3.7%
550	29	540	31.3	13.3	0.0	0.1	4.3%	4.3%	2.9%
600	19	559	31.3	14.1	0.0	0.1	2.8%	2.8%	1.8%
650	18	577	31.3	15.3	0.0	0.1	2.7%	2.7%	1.6%
700	12	589	31.3	16.2	0.0	0.0	1.8%	1.8%	1.0%
750	11	600	31.3	17.2	0.0	0.0	1.6%	1.6%	0.9%
800	8	608	31.3	18.2	0.0	0.0	1.2%	1.2%	0.6%
850	13	621	31.3	19.4	0.0	0.0	1.9%	1.9%	0.9%
900	18	639	31.3	20.4	0.0	0.0	2.7%	2.7%	1.2%
950	6	645	31.3	21.4	0.0	0.0	0.9%	0.9%	0.4%
1,000	6	651	31.3	22.4	0.0	0.0	0.9%	0.9%	0.0%

[1] Total target counts recorded up to the 2,800 m band during the dusk time period was 679.

[2] Total density of targets per hour recorded up to the 2,800 m band during the dusk time period was 3.5.

Comparison of methods to estimated target density by altitude band during the *night* biological period in Garden Peninsula, fall 2012.

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	1,690	1,690	31.3	5.6	0.3	1.5	2.0%	2.0%	4.0%
100	3,476	5,166	31.3	5.9	0.5	2.8	4.2%	4.2%	7.7%
150	4,086	9,252	31.3	6.5	0.6	3.1	4.9%	4.9%	8.4%
200	4,703	13,955	31.3	7.1	0.7	3.2	5.6%	5.6%	8.8%
250	4,970	18,925	31.3	7.9	0.8	3.0	6.0%	6.0%	8.3%
300	5,241	24,166	31.3	8.5	0.8	3.0	6.3%	6.3%	8.2%
350	5,239	29,405	31.3	9.5	0.8	2.7	6.3%	6.3%	7.3%
400	5,446	34,851	31.3	10.3	0.8	2.6	6.5%	6.5%	7.0%
450	5,800	40,651	31.3	11.2	0.9	2.5	7.0%	7.0%	6.8%
500	5,572	46,223	31.3	12.2	0.9	2.2	6.7%	6.7%	6.0%
550	4,970	51,193	31.3	13.3	0.8	1.8	6.0%	6.0%	4.9%
600	4,257	55,450	31.3	14.1	0.7	1.5	5.1%	5.1%	4.0%
650	3,651	59,101	31.3	15.3	0.6	1.2	4.4%	4.4%	3.2%
700	3,321	62,422	31.3	16.2	0.5	1.0	4.0%	4.0%	2.7%
750	2,899	65,321	31.3	17.2	0.4	0.8	3.5%	3.5%	2.2%
800	2,526	67,847	31.3	18.2	0.4	0.7	3.0%	3.0%	1.8%
850	2,276	70,123	31.3	19.4	0.4	0.6	2.7%	2.7%	1.6%
900	2,174	72,297	31.3	20.4	0.3	0.5	2.6%	2.6%	1.4%
950	1,821	74,118	31.3	21.4	0.3	0.4	2.2%	2.2%	1.1%
1,000	1,627	75,745	31.3	22.4	0.3	0.4	2.0%	2.0%	1.0%

[1] Total target counts recorded up to the 2,800 m band during the night time period was 83,259.

[2] Total density of targets per hour recorded up to the 2,800 m band during the night time period was 36.63.

Comparison of methods to estimated target density by altitude band during the *dawn* biological period in Iosco County, fall 2012.

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	70	70	31.3	5.6	0.0	0.2	1.1%	1.1%	2.0%
100	470	540	31.3	5.9	0.3	1.4	7.3%	7.3%	13.0%
150	376	916	31.3	6.5	0.2	1.0	5.8%	5.8%	9.5%
200	358	1,274	31.3	7.1	0.2	0.9	5.5%	5.5%	8.3%
250	346	1,620	31.3	7.9	0.2	0.8	5.3%	5.3%	7.2%
300	366	1,986	31.3	8.5	0.2	0.8	5.7%	5.7%	7.1%
350	537	2,523	31.3	9.5	0.3	1.0	8.3%	8.3%	9.3%
400	438	2,961	31.3	10.3	0.2	0.8	6.8%	6.8%	7.0%
450	443	3,404	31.3	11.2	0.3	0.7	6.8%	6.8%	6.5%
500	415	3,819	31.3	12.2	0.2	0.6	6.4%	6.4%	5.6%
550	394	4,213	31.3	13.3	0.2	0.5	6.1%	6.1%	4.9%
600	329	4,542	31.3	14.1	0.2	0.4	5.1%	5.1%	3.8%
650	295	4,837	31.3	15.3	0.2	0.3	4.6%	4.6%	3.2%
700	205	5,042	31.3	16.2	0.1	0.2	3.2%	3.2%	2.1%
750	218	5,260	31.3	17.2	0.1	0.2	3.4%	3.4%	2.1%
800	154	5,414	31.3	18.2	0.1	0.2	2.4%	2.4%	1.4%
850	159	5,573	31.3	19.4	0.1	0.1	2.5%	2.5%	1.3%
900	131	5,704	31.3	20.4	0.1	0.1	2.0%	2.0%	1.1%
950	117	5,821	31.3	21.4	0.1	0.1	1.8%	1.8%	0.9%
1,000	125	5,946	31.3	22.4	0.1	0.1	1.9%	1.9%	0.9%

[1] Total target counts recorded up to the 2,800 m band during the dawn time period was 6,470.
[2] Total density of targets per hour recorded up to the 2,800 m band during the dawn time period was 10.86.

Comparison of methods to estimated target density by altitude band during the *day* biological period in Iosco County, fall 2012.

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	355	355	31.3	5.6	0.0	0.1	2.0%	2.0%	1.0%
100	1,680	2,035	31.3	5.9	0.1	0.5	9.5%	9.5%	4.5%
150	1,118	3,153	31.3	6.5	0.1	0.3	6.3%	6.3%	2.8%
200	1,431	4,584	31.3	7.1	0.1	0.3	8.1%	8.1%	3.2%
250	1,263	5,847	31.3	7.9	0.1	0.3	7.1%	7.1%	2.5%
300	1,264	7,111	31.3	8.5	0.1	0.3	7.1%	7.1%	2.4%
350	1,961	9,072	31.3	9.5	0.1	0.4	11.0%	11.0%	3.3%
400	1,579	10,651	31.3	10.3	0.1	0.3	8.9%	8.9%	2.4%
450	1,556	12,207	31.3	11.2	0.1	0.2	8.8%	8.8%	2.2%
500	1,197	13,404	31.3	12.2	0.1	0.2	6.7%	6.7%	1.6%
550	890	14,294	31.3	13.3	0.0	0.1	5.0%	5.0%	1.1%
600	776	15,070	31.3	14.1	0.0	0.1	4.4%	4.4%	0.9%
650	504	15,574	31.3	15.3	0.0	0.1	2.8%	2.8%	0.5%
700	427	16,001	31.3	16.2	0.0	0.0	2.4%	2.4%	0.4%
750	345	16,346	31.3	17.2	0.0	0.0	1.9%	1.9%	0.3%
800	266	16,612	31.3	18.2	0.0	0.0	1.5%	1.5%	0.2%
850	204	16,816	31.3	19.4	0.0	0.0	1.1%	1.1%	0.2%
900	143	16,959	31.3	20.4	0.0	0.0	0.8%	0.8%	0.1%
950	107	17,066	31.3	21.4	0.0	0.0	0.6%	0.6%	0.1%
1,000	87	17,153	31.3	22.4	0.0	0.0	0.5%	0.5%	0.1%

[1] Total target counts recorded up to the 2,800 m band during the day time period was 17,754.

[2] Total density of targets per hour recorded up to the 2,800 m band during the day time period was 3.27.

Comparison of methods to estimated target density by altitude band during the *dusk* biological period in Iosco County, fall 2012.

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	27	27	31.3	5.6	0.0	0.1	1.7%	1.7%	3.2%
100	96	123	31.3	5.9	0.1	0.3	6.1%	6.1%	10.7%
150	66	189	31.3	6.5	0.0	0.2	4.2%	4.2%	6.7%
200	116	305	31.3	7.1	0.1	0.3	7.4%	7.4%	10.8%
250	117	422	31.3	7.9	0.1	0.3	7.4%	7.4%	9.8%
300	125	547	31.3	8.5	0.1	0.3	7.9%	7.9%	9.7%
350	143	690	31.3	9.5	0.1	0.3	9.1%	9.1%	10.0%
400	126	816	31.3	10.3	0.1	0.2	8.0%	8.0%	8.1%
450	100	916	31.3	11.2	0.1	0.2	6.3%	6.3%	5.9%
500	66	982	31.3	12.2	0.0	0.1	4.2%	4.2%	3.6%
550	81	1,063	31.3	13.3	0.0	0.1	5.1%	5.1%	4.0%
600	64	1,127	31.3	14.1	0.0	0.1	4.1%	4.1%	3.0%
650	64	1,191	31.3	15.3	0.0	0.1	4.1%	4.1%	2.8%
700	47	1,238	31.3	16.2	0.0	0.1	3.0%	3.0%	1.9%
750	33	1,271	31.3	17.2	0.0	0.0	2.1%	2.1%	1.3%
800	41	1,312	31.3	18.2	0.0	0.0	2.6%	2.6%	1.5%
850	28	1,340	31.3	19.4	0.0	0.0	1.8%	1.8%	1.0%
900	35	1,375	31.3	20.4	0.0	0.0	2.2%	2.2%	1.1%
950	20	1,395	31.3	21.4	0.0	0.0	1.3%	1.3%	0.6%
1,000	27	1,422	31.3	22.4	0.0	0.0	1.7%	1.7%	0.0%

[1] Total target counts recorded up to the 2,800 m band during the dusk time period was 1,577.
[2] Total density of targets per hour recorded up to the 2,800 m band during the dusk time period was 2.62.

Comparison of methods to estimated target density by altitude band during the *night* biological period in Iosco County, fall 2012.

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	869	869	31.3	5.6	0.0	0.2	0.2%	0.2%	0.4%
100	14,541	15,410	31.3	5.9	0.7	3.7	3.3%	3.3%	6.3%
150	21,969	37,379	31.3	6.5	1.1	5.2	5.0%	5.0%	8.7%
200	28,116	65,495	31.3	7.1	1.4	6.0	6.4%	6.4%	10.2%
250	28,268	93,763	31.3	7.9	1.4	5.4	6.5%	6.5%	9.2%
300	27,456	121,219	31.3	8.5	1.3	4.9	6.3%	6.3%	8.3%
350	31,728	152,947	31.3	9.5	1.5	5.1	7.3%	7.3%	8.6%
400	28,638	181,585	31.3	10.3	1.4	4.2	6.6%	6.6%	7.1%
450	28,503	210,088	31.3	11.2	1.4	3.9	6.5%	6.5%	6.5%
500	26,347	236,435	31.3	12.2	1.3	3.3	6.0%	6.0%	5.5%
550	24,736	261,171	31.3	13.3	1.2	2.8	5.7%	5.7%	4.8%
600	22,825	283,996	31.3	14.1	1.1	2.5	5.2%	5.2%	4.1%
650	21,435	305,431	31.3	15.3	1.0	2.1	4.9%	4.9%	3.6%
700	19,714	325,145	31.3	16.2	1.0	1.8	4.5%	4.5%	3.1%
750	17,637	342,782	31.3	17.2	0.9	1.6	4.0%	4.0%	2.6%
800	15,461	358,243	31.3	18.2	0.8	1.3	3.5%	3.5%	2.2%
850	13,464	371,707	31.3	19.4	0.7	1.1	3.1%	3.1%	1.8%
900	12,292	383,999	31.3	20.4	0.6	0.9	2.8%	2.8%	1.5%
950	10,554	394,553	31.3	21.4	0.5	0.8	2.4%	2.4%	1.3%
1,000	8,901	403,454	31.3	22.4	0.4	0.6	2.0%	2.0%	1.0%

[1] Total target counts recorded up to the 2,800 m band during the night time period was 436,554.

[2] Total density of targets per hour recorded up to the 2,800 m band during the night time period was 59.31.

Comparison of methods to estimated target density by altitude band during the *dawn* biological period in West Huron County, fall 2012.

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	15	15	31.3	5.6	0.0	0.0	0.3%	0.3%	0.6%
100	390	405	31.3	5.9	0.2	1.1	8.3%	8.3%	14.3%
150	388	793	31.3	6.5	0.2	1.0	8.3%	8.3%	13.1%
200	389	1,182	31.3	7.1	0.2	0.9	8.3%	8.3%	12.0%
250	259	1,441	31.3	7.9	0.1	0.6	5.5%	5.5%	7.1%
300	230	1,671	31.3	8.5	0.1	0.5	4.9%	4.9%	5.9%
350	324	1,995	31.3	9.5	0.2	0.6	6.9%	6.9%	7.5%
400	331	2,326	31.3	10.3	0.2	0.6	7.0%	7.0%	7.0%
450	254	2,580	31.3	11.2	0.1	0.4	5.4%	5.4%	4.9%
500	258	2,838	31.3	12.2	0.1	0.4	5.5%	5.5%	4.6%
550	230	3,068	31.3	13.3	0.1	0.3	4.9%	4.9%	3.8%
600	199	3,267	31.3	14.1	0.1	0.2	4.2%	4.2%	3.1%
650	187	3,454	31.3	15.3	0.1	0.2	4.0%	4.0%	2.7%
700	199	3,653	31.3	16.2	0.1	0.2	4.2%	4.2%	2.7%
750	165	3,818	31.3	17.2	0.1	0.2	3.5%	3.5%	2.1%
800	130	3,948	31.3	18.2	0.1	0.1	2.8%	2.8%	1.6%
850	130	4,078	31.3	19.4	0.1	0.1	2.8%	2.8%	1.5%
900	121	4,199	31.3	20.4	0.1	0.1	2.6%	2.6%	1.3%
950	116	4,315	31.3	21.4	0.1	0.1	2.5%	2.5%	1.2%
1,000	78	4,393	31.3	22.4	0.0	0.1	1.7%	1.7%	0.8%

[1] Total target counts recorded up to the 2,800 m band during the dawn time period was 4,696.

[2] Total density of targets per hour recorded up to the 2,800 m band during the dawn time period was 7.89.

Comparison of methods to estimated target density by altitude band during the *day* biological period in West Huron County, fall 2012.

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	196	196	31.3	5.6	0.0	0.1	1.1%	1.1%	0.7%
100	3,739	3,935	31.3	5.9	0.2	1.0	21.3%	21.3%	12.8%
150	2,569	6,504	31.3	6.5	0.1	0.6	14.7%	14.7%	8.1%
200	1,886	8,390	31.3	7.1	0.1	0.4	10.8%	10.8%	5.4%
250	1,423	9,813	31.3	7.9	0.1	0.3	8.1%	8.1%	3.7%
300	1,052	10,865	31.3	8.5	0.1	0.2	6.0%	6.0%	2.5%
350	1,069	11,934	31.3	9.5	0.1	0.2	6.1%	6.1%	2.3%
400	856	12,790	31.3	10.3	0.0	0.1	4.9%	4.9%	1.7%
450	717	13,507	31.3	11.2	0.0	0.1	4.1%	4.1%	1.3%
500	557	14,064	31.3	12.2	0.0	0.1	3.2%	3.2%	0.9%
550	476	14,540	31.3	13.3	0.0	0.1	2.7%	2.7%	0.7%
600	360	14,900	31.3	14.1	0.0	0.0	2.1%	2.1%	0.5%
650	344	15,244	31.3	15.3	0.0	0.0	2.0%	2.0%	0.5%
700	291	15,535	31.3	16.2	0.0	0.0	1.7%	1.7%	0.4%
750	278	15,813	31.3	17.2	0.0	0.0	1.6%	1.6%	0.3%
800	249	16,062	31.3	18.2	0.0	0.0	1.4%	1.4%	0.3%
850	222	16,284	31.3	19.4	0.0	0.0	1.3%	1.3%	0.2%
900	264	16,548	31.3	20.4	0.0	0.0	1.5%	1.5%	0.3%
950	213	16,761	31.3	21.4	0.0	0.0	1.2%	1.2%	0.2%
1,000	188	16,949	31.3	22.4	0.0	0.0	1.1%	1.1%	0.2%

[1] Total target counts recorded up to the 2,800 m band during the day time period was 17,529.
[2] Total density of targets per hour recorded up to the 2,800 m band during the day time period was 3.41.

Comparison of methods to estimated target density by altitude band during the *dusk* biological period in West Huron County, fall 2012.

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	0.3%	0.3%	0.4%
100	246	250	31.3	5.9	0.1	0.7	16.2%	16.2%	22.1%
150	292	542	31.3	6.5	0.2	0.8	19.3%	19.3%	24.1%
200	210	752	31.3	7.1	0.1	0.5	13.9%	13.9%	15.8%
250	152	904	31.3	7.9	0.1	0.3	10.0%	10.0%	10.2%
300	109	1,013	31.3	8.5	0.1	0.2	7.2%	7.2%	6.8%
350	105	1,118	31.3	9.5	0.1	0.2	6.9%	6.9%	5.9%
400	90	1,208	31.3	10.3	0.0	0.1	5.9%	5.9%	4.6%
450	40	1,248	31.3	11.2	0.0	0.1	2.6%	2.6%	1.9%
500	42	1,290	31.3	12.2	0.0	0.1	2.8%	2.8%	1.8%
550	30	1,320	31.3	13.3	0.0	0.0	2.0%	2.0%	1.2%
600	30	1,350	31.3	14.1	0.0	0.0	2.0%	2.0%	1.1%
650	19	1,369	31.3	15.3	0.0	0.0	1.3%	1.3%	0.7%
700	17	1,386	31.3	16.2	0.0	0.0	1.1%	1.1%	0.6%
750	14	1,400	31.3	17.2	0.0	0.0	0.9%	0.9%	0.4%
800	8	1,408	31.3	18.2	0.0	0.0	0.5%	0.5%	0.2%
850	13	1,421	31.3	19.4	0.0	0.0	0.9%	0.9%	0.4%
900	12	1,433	31.3	20.4	0.0	0.0	0.8%	0.8%	0.3%
950	8	1,441	31.3	21.4	0.0	0.0	0.5%	0.5%	0.2%
1,000	9	1,450	31.3	22.4	0.0	0.0	0.6%	0.6%	0.0%

[1] Total target counts recorded up to the 2,800 m band during the dusk time period was 1,514.
[2] Total density of targets per hour recorded up to the 2,800 m band during the dusk time period was 3.13.

Comparison of methods to estimated target density by altitude band during the *night* biological period in West Huron County, fall 2012.

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	157	157	31.3	5.6	0.0	0.0	0.1%	0.1%	0.1%
100	4,495	4,652	31.3	5.9	0.2	1.1	1.9%	1.9%	3.6%
150	10,383	15,035	31.3	6.5	0.5	2.4	4.4%	4.4%	7.7%
200	13,306	28,341	31.3	7.1	0.6	2.8	5.7%	5.7%	8.9%
250	15,242	43,583	31.3	7.9	0.7	2.9	6.5%	6.5%	9.2%
300	16,282	59,865	31.3	8.5	0.8	2.8	6.9%	6.9%	9.1%
350	19,719	79,584	31.3	9.5	0.9	3.1	8.4%	8.4%	9.9%
400	18,052	97,636	31.3	10.3	0.9	2.6	7.7%	7.7%	8.3%
450	17,015	114,651	31.3	11.2	0.8	2.2	7.2%	7.2%	7.2%
500	15,908	130,559	31.3	12.2	0.8	1.9	6.8%	6.8%	6.2%
550	15,102	145,661	31.3	13.3	0.7	1.7	6.4%	6.4%	5.4%
600	14,142	159,803	31.3	14.1	0.7	1.5	6.0%	6.0%	4.8%
650	12,805	172,608	31.3	15.3	0.6	1.2	5.4%	5.4%	4.0%
700	11,611	184,219	31.3	16.2	0.5	1.1	4.9%	4.9%	3.4%
750	10,128	194,347	31.3	17.2	0.5	0.9	4.3%	4.3%	2.8%
800	8,905	203,252	31.3	18.2	0.4	0.7	3.8%	3.8%	2.3%
850	7,660	210,912	31.3	19.4	0.4	0.6	3.3%	3.3%	1.9%
900	6,437	217,349	31.3	20.4	0.3	0.5	2.7%	2.7%	1.5%
950	4,772	222,121	31.3	21.4	0.2	0.3	2.0%	2.0%	1.1%
1,000	3,800	225,921	31.3	22.4	0.2	0.3	1.6%	1.6%	0.8%

[1] Total target counts recorded up to the 2,800 m band during the night time period was 235,486.
[2] Total density of targets per hour recorded up to the 2,800 m band during the night time period was 31.03.

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