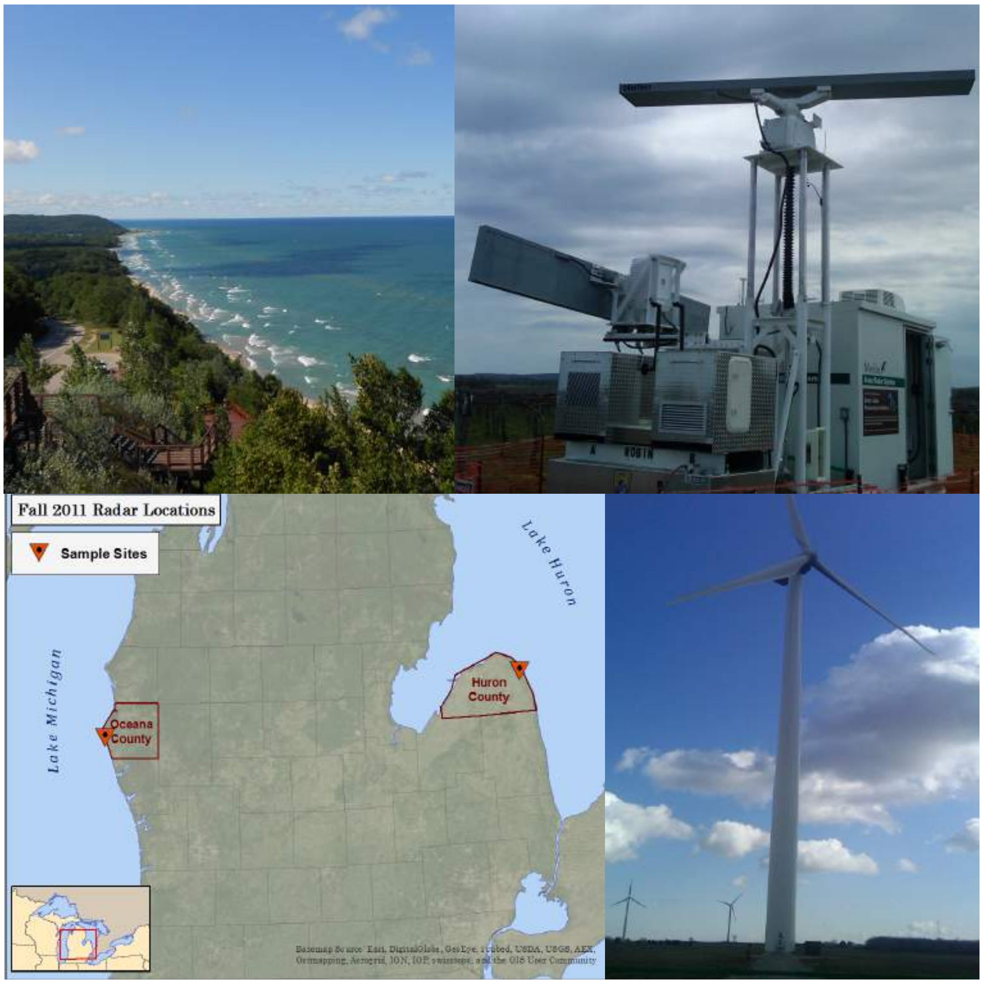
U.S. Fish & Wildlife Service

Great Lakes Avian Radar Technical Report Huron and Oceana Counties, MI

Biological Technical Publication

BTP-R3011-2015



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Funded by Great Lakes Restoration Initiative

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Great Lakes RESTORATION

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Executive Summary

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

We placed avian radar systems on shorelines on opposite sides of Michigan, where the automated systems tracked and recorded target (bird and bat) movements continuously from mid-August to mid-November, 2011. We calculated the direction of movement, target passage rates, and altitude profiles for the air space above our study areas. We also developed a model of our vertical sample volume that allowed us to report an estimate of target density by altitude band.

Migration appeared strong along the studied shorelines in Michigan. Mean nocturnal passage rates were greater than mean passage rates for dawn, day, and dusk combined at both of our locations. Nocturnal movement was typically oriented in a southerly direction, but we also recorded other behaviors associated with migrants such as reverse migration, dawn ascent, and migrants over water returning to land at dawn. Peak density occurred between 100 – 150 m above radar height; however, density may have been underestimated at higher altitudes.

The results of our research highlight the potential role of radar in implementing the Land-Based Wind Energy Guidelines and in identifying areas where impacts to wildlife would be minimized. We documented migration activity in the air space above our study areas and think the density of targets at low altitudes may present conservation concerns. The data we collected demonstrated the ebb and flow of migration across the sampling period and showed that nocturnal peaks continued into November. Given the time periods during which migration occurred at the sampled sites, it appears 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 interpretation of standardized radar studies.

Avian radar is increasingly relied upon to perform surveys for pre-construction risk analysis. While an important tool, few regulatory agencies have experience in implementing avian radar or recognizing the strengths and limitations of the technology. This report highlights several considerations about avian radar and reviews a number of potentially confusing metrics. We also introduce new metrics for reporting radar data. However, our analysis continues to evolve, and changes will be incorporated into our final report. 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 provide methods that identify components of migration, such as:

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

Given the rapid growth of the wind energy sector, the most effective conservation efforts might be based on our ability to identify and avoid development in locations where migrants concentrate. Our use of commercial-grade avian radar to document migration and, in subsequent reports, to identify concentrations of activity is a broad-scale effort toward that end. To our knowledge, this effort represents the first of its type by the US Fish and Wildlife Service.

Introduction

The Great Lakes support one of the largest bodies of freshwater on the planet and collectively represent a surface area of nearly 245,000 km2, with 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 lake shorelines feature widely recognized Important Bird Areas (Audubon 2013). Migrants passing through the region concentrate near shorelines (Ewert et al. 2011, Peterson and Niemi 2011, Buler and Dawson 2012, France et al. 2012), which provide important stopover habitats – en route areas used temporarily for refueling, rest, and protection. These shorelines offer increased foraging opportunities relative to inland areas (Smith et al. 2004, 2007, Bonter et al. 2007, 2009) and may be used as a visual cue for navigation or for refuge prior to or after crossing open water (Buler and Moore 2011).

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

igrants challenged by a barrier may temporarily reverse or deviate from seasonally appropriate flight directions or return to land to delay or recover from a crossing (Bruderer and Liechti 1998, Akesson 1999, Ewert et al. 2011). Schmaljohann and Naef-Daenzer (2011) found that birds with low fuel loads and/or facing unfavorable weather conditions returned to shoreline habitat rather than continuing across open water in a direction appropriate for migration. Migrating bats varied their choice to circumnavigate above shorelines or cross lakes, and certain long-distance migrants used torpor to postpone migration during periods of unfavorable conditions (McGuire et al. 2012b). These behavioral responses, as well as the necessity of using stopover habitat during migration, likely contribute to the increased use of shorelines and emphasize the importance of these areas for conservation.

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

Migrant populations may experience the greatest mortality pressure during migration (Newton 2006, 2007, Diehl et al. 2014), and the negative ramifications of compromised stopover habitat to migratory populations are becoming increasingly clear (Sillett and Holmes 2002, Mehlman et al. 2005, Faaborg et al. 2010). Shoreline habitats along the

Great Lakes are subject to pressures from urban and energy development, land conversion, and environmental contamination that may limit their availability and/or reduce habitat quality (France et al. 2012). Further, White-nose Syndrome is devastating bat populations and has increased the need to identify conservation areas, as several species face the risk of extirpation in the Great Lakes region (Kurta 1995, Turner et al. 2011). In response to factors such as these, substantial efforts are being made to identify and protect stopover habitat along the Great Lakes shorelines (Buler and Dawson 2012, France et al. 2012). With climate change considerations calling for both an increase in renewable energy development and conservation of migratory species, careful planning is needed to balance these demands.

There is a national movement towards a 20% wind energy sector in the US market by 2030 (U.S. Department of Energy 2008). If achieved, this would represent nearly a fivefold increase in wind energy capacity during the next 15 years (Loss et al. 2013). Coinciding with this national effort, wind energy developments are increasing within the Great Lakes region, where shorelines offer areas attractive for turbine placement (Mageau et al. 2008, Great Lakes Commission 2011). Utility-grade wind facilities have been associated with mortality events for migrating vertebrates (Newton 2007, Arnett et al. 2008, Smallwood and Thelander 2008), and chronic fatalities across the US, particularly for bats, are a concern (Timm 1989, Johnson 2005). For example, three species of long-distance migratory bats that are impacted by wind energy facilities represent approximately 75% of bat mortalities (Kunz et al. 2007a, Cryan 2011, Arnett and Baerwald 2013). These migrants, the hoary bat (Lasiurus cinereus), eastern red bat (Lasiurus borealis), and silver-haired bat (Lasionycteris noctivagans), typically constitute the majority of bat fatalities at wind facilities in the Upper Midwest (Arnett et al. 2008). Three Wisconsin studies found high fatality rates for these same migrant species but also found that little brown bat (Myotis lucifugus) and big brown bat (Eptesicus fuscus) fatalities were substantial (Gruver et al. 2009, BHE Environmental 2010, Grodsky et al. 2012). The presence of major hibernacula in the vicinity of these latter three studies may have contributed to the difference in ratios. Low reproductive rates inhibit the ability of bats to rebound from population declines (Racey and Entwistle 2000), and these declines have already begun for several species (Kunz et al. 2007a, Cryan 2011). Cumulative impacts to migrant species are a concern, and this concern will increase with the growth of wind energy if methods to avoid or minimize mortality events are not established. Several promising conservation measures have been proposed to reduce mortality events; however, 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 renewable energy development and wildlife conservation, we established the current project to identify activity patterns, timing, and magnitude of migration along shorelines of the Great Lakes. Documenting bird and bat migration is challenged by the difficulty of observing nocturnal movements and because migration activity occurs sporadically over the course of a season. We used a combination of techniques to address this challenge. As the primary means of data collection, we used two avian radar units that operated 24 hrs per day and simultaneously scanned horizontal and vertical planes. We used over 30 automated ultrasonic/acoustic monitors to record bird and bat calls. We also collected incidental bird observations in areas near monitoring equipment. Our objectives for the portion of the study presented in this report were to:

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

The focus of this report is on the radar data collected during the fall 2011 migration season. Subsequent reports will address the ultrasonic/acoustic monitoring data, incidental field observations, gradient transects, and patterns associated with the multiple seasons of this project.

Methods

Study Area and Site Selection

During the fall 2011 season, we selected two sites in Michigan for radar placement (Figure 1). We placed radar units approximately 1.5 km from the shoreline to monitor airspace above inland, shoreline, and lake areas. One site was located on the east side of Lake Michigan in Oceana County. This radar unit was located at 43.614095° N, -86.520783° W, and 226 m above mean sea level. It was placed along the edge of an agricultural field in an area where deciduous forest and cultivated crops were the predominant land cover types within the range of the radar unit, according to our analysis using ESRI ArcGIS software and the 2006 National Land Cover Database (Fry et al. 2011) (Table 1, Figure 2, Appendix 2). The second site was located on the west side of Lake Huron in Huron County. This radar unit was located at 43.952649° N, -82.735476° W, and 183 m above mean sea level. It was placed in a large open agricultural field, which was the primary land cover type within range of the radar unit (Table 1, Figure 2, Appendix 2).

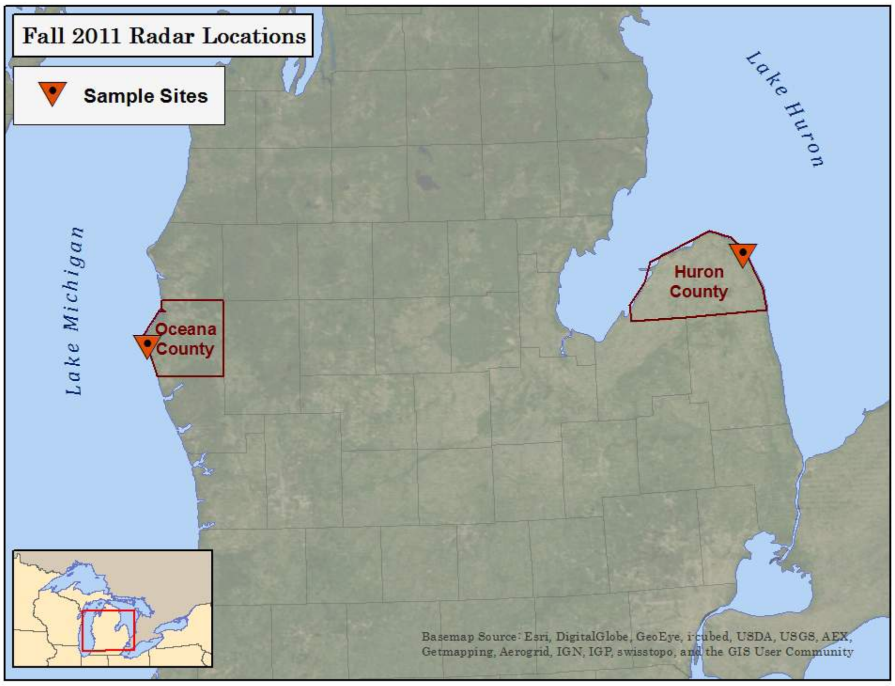


Figure 1. Locations where MERLIN Avian Radar Systems were deployed during the fall 2011 migration season.

Table 1. Predominant land cover types found within a 3.7-km radius of the radar locations in Michigan during fall 2011.

National Land Cover Class	Oceana County % Land Cover	Huron County % Land Cover
Cultivated Crops/Pasture	19.3%	53.5%
Deciduous Forest	32.1%	7.2%
Open water	29.3%	23.7%
Developed*	5.0%	6.7%
Other**	14.3%	8.9%

* Includes low, medium, and high intensity development and developed open space.
** Includes barren land, evergreen forest, herbaceous, mixed forest, shrub/scrub, and woody or emergent herbaceous wetlands.

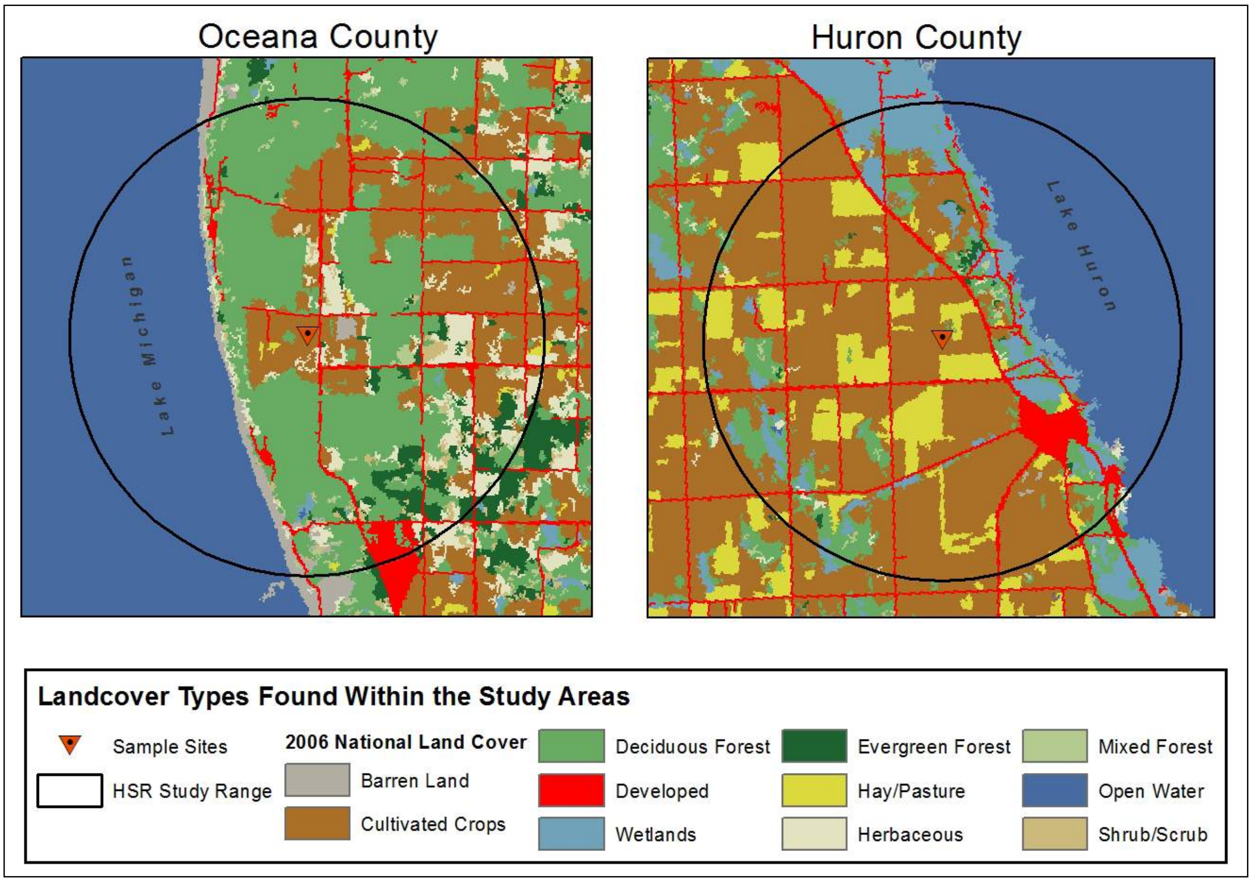


Figure 2. Land cover types found within a 3.7-km radius of the radar locations in Michigan during fall 2011.

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

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

Equipment

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

Description of radars – solid state marine radar antennas (Kelvin Hughes, London, UK) used by our systems were 3.9 m in length, with 170 W peak power, S-band (10 cm) wavelength, 2.92 – 3.08 GHz frequency range, and operated 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, which had an approximate 1° horizontal and 25° vertical span when operated in the horizontal plane. The S-band radar was selected because the longer wavelength is less sensitive to insects and weather contamination than X-band (3 cm wavelength) antenna (Bruderer 1997). It is also less sensitive to signal attenuation from ground clutter, such as vegetation and structures (DeTect Inc., unpublished data, 2009). The radars spin perpendicularly to each other at a rate of 20 revolutions per minute and were synchronized to not 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. Although the radar had the capability to scan large distances, we selected a 3.7-km range setting for data collection to allow higher resolution and identify smaller targets, such as passerines and bats. The HSR was primarily used to provide information on target direction. The vertical scanning radar (VSR) rotated in the x-z plane and scanned a 1° x 25° span of the atmosphere. We selected a 2.8-km range setting for this radar for increased resolution and used the VSR to provide information on the number and height of targets.

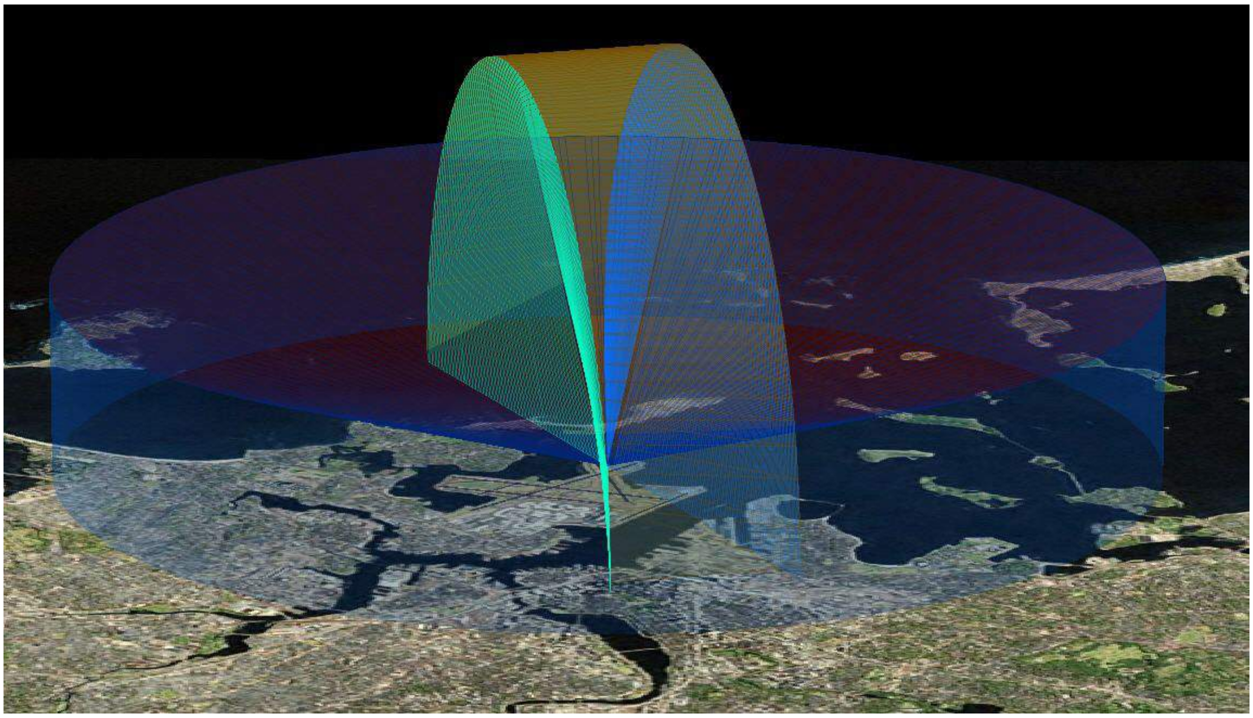


Figure 3. Computer representation of the potential survey volume scanned by horizontal and vertical radars used in Michigan during fall 2011. Graphic provided by DeTect, Inc**.**

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

Radar Setup and Data Collection

Radar systems were deployed during the first week of August at their respective sites and were maintained into the second week of November to capture the anticipated start and end dates of the migration season.

Establishing radar systems at a selected site involved several activities, including orientation of the VSR, micro-site selection, and adjustments to ensure that adequate information was captured. We anticipated a primarily southbound direction of migration along the shorelines of Michigan during autumn and oriented vertical scanning radars at an angle that was slightly less than 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 because the positioning of the radar can affect the amount of interference from ground clutter or other sources of noise. If large areas were obstructed from the radar view or if substantial amounts of clutter impeded data collection, systems were rotated incrementally to improve the radar's view and/or reduce interference.

Once a position was established, clear-air thresholds and the radar's built-in sensitivity time control (STC) filters were employed to reduce small non-target returns and improve the tracking of distant targets. These settings are needed because objects reflect more energy at close ranges than when they are farther from the radar. For example, an object at a 50-m range will return approximately 16 times more energy than when it is at a 100-m range (Bruderer 1997, Schmaljohann et al. 2008). To further improve data collection, clutter maps were generated using 60-scan composite images (Figure 4). These images were used to identify areas with constant returns that were not biological targets. These areas were assigned a reflectivity threshold that excluded the constant returns from the data and, as a result, also reduced our ability to detect targets in these areas.

Following this initial set up, MERLIN software was fitted to site conditions. The MERLIN software provides real-time processing of raw radar data to identify and track targets while excluding non-targets and rain events. However, parameters used by the tracking software require adjustments to reflect site-specific conditions. DeTect personnel trained our biologists in the establishment of these settings, with the goal of minimizing inclusion of non-targets while maximizing cohesive tracks of targets. Once established, simultaneous visual observations of birds in flight and tracked targets were used to confirm the settings of the tracking algorithm. 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 support remote operation for extended periods of time, biologists remained on site during the data collection period to ensure continuous function, monitor raw 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 on ruggedized external drives back to a Regional Office, where data were transferred to long-term tape storage.

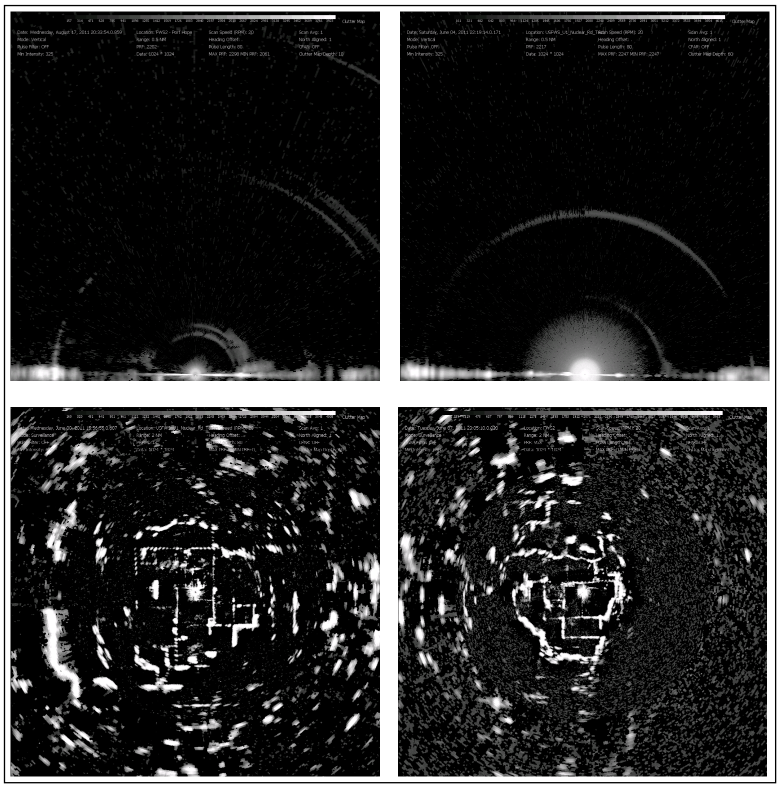


Figure 4. Vertical (top row) and horizontal (bottom row) clutter maps from Oceana and Huron Counties, Michigan.

Radar System Outputs

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

In addition to storing target attribute data, DeTect software outputs included a two-dimensional digital display of targets being tracked in real-time and static images of tracked targets over a specified period of time (Trackplots) for both vertical and horizontal radars. These graphics were generated to assess target attributes such as reflectivity, direction, height, and size class. We viewed 15-min and 1-hr Trackplots with direction attributes daily to monitor the previous night's activity and used the real-time digital display to ensure that it agreed with the raw radar display.

Data Processing and Quality Control

Prior to data analysis, data processed by MERLIN software was further evaluated for potential contamination by non-targets. Biologists reviewed all data in 15-min time increments and removed time periods that were dominated by rain or other forms of transient clutter. We relied on the visual inspection of track patterns to discern contamination events. Rain events form diagnostic patterns (Detect Inc., personal communication, 2011) that were readily omitted when present. Contamination that mimicked track patterns of targets was not removed from the database and, to the extent that such contamination occurred, contributed to the error associated with the indices. In addition, we evaluated initial counts by generating a time series to show the variation in the number of targets per hr across the season for both HSR and VSR radars. In general, the HSR and VSR hourly counts were positively correlated with the HSR having higher counts. In situations in which the VSR resulted in higher counts than the HSR or peak counts appeared to be outliers, the data were further investigated for evidence of contamination or potential issues with radar performance. On rare occasions when time periods with anomalies appeared to represent artifacts not related to target movement (e.g., rain events or data processing errors), they were excluded from further analysis.

During the fall 2011 season, our vertical radar pulse heading was oriented to 0 degrees instead of the intended 180 degrees. This error had the potential to result in double counting or undercounting in certain situations. We re-processed a sample of our data with the correct pulse heading and found a difference in counts that was less than 1% for all targets and less than 10% for targets below 200 m. For this reason, the data used for analysis were not reprocessed.

After contaminated time periods had been removed, we summarized data using SQL queries provided with the MERLIN radar system. Data from the HSR were used to calculate hourly counts and target direction. All targets within 3.7 km of the radar unit were included in the analysis. Data from the VSR were used to calculate hourly counts and heights, and these data were truncated to a 1-km front or "standard front." We adopted this sampling technique because it is the method used by the manufacturer of the MERLIN units and because it is 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 5). Counts were further segregated into four biological time periods: Dawn, 30 min prior to sunrise to 30 min post sunrise; Day, 30 min post sunrise to 30 min prior to sunset; Dusk, 30 min prior to sunset to 30 min post sunset; and Night, 30 min post sunset to 30 min prior to sunrise.

Data Summary and Analysis of Trends

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

Directional trends – mean angle and concentration (r) of target directions were analyzed following the methodology for circular statistics (Zar 1999) provided within DeTect SQL queries. The angular concentration value has a value of 1 when all angles are the same and a value of 0 when all angles cancel each other (e.g., 50% of the vectors are 180° and 50% are 360°), indicating that there is no predominant direction of travel. We reported the mean direction of nocturnal targets and the percentage of nights that targets traveled in a southerly direction, which ranged from 112.5° to 247.5°. We used radial graphs to plot the number of targets per 8-cardinal directions (i.e., eight groups centered on N, NE, E, SE, S, SW, W, NW) during four biological time periods (i.e., dawn, day, dusk, night).

Temporal trends – we plotted counts of targets per hr processed by MERLIN software for both HSR and VSR antennas as a time series to identify pulses of nocturnal activity, season duration, and changes in patterns of activity over time. We plotted both indices together, as the radars have different strengths that complement one another. The HSR index tracks low-flying targets in a 360° span

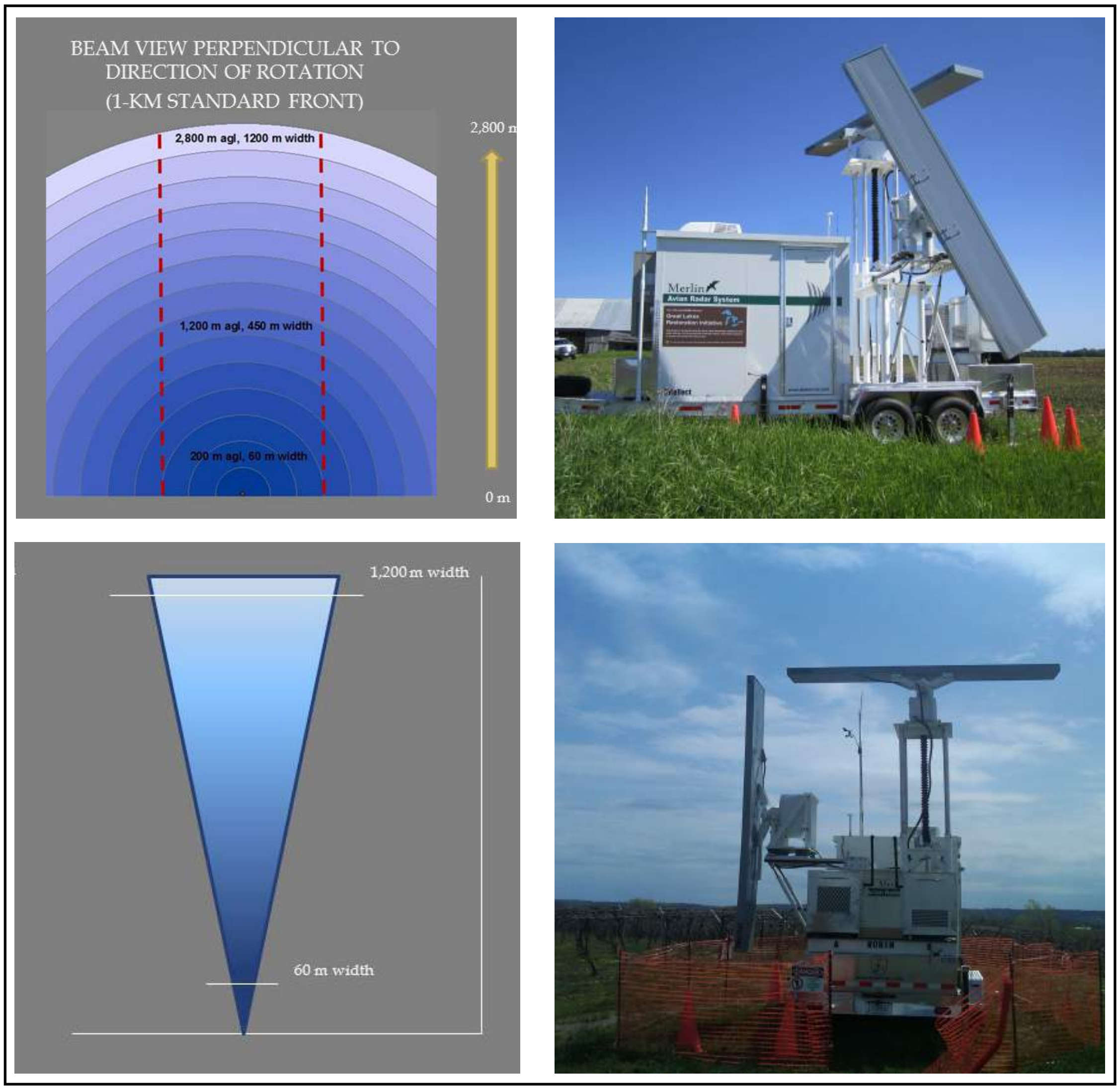


Figure 5. This schematic depicts the vertical scanning radar beam from two different views as well as pictures of the radar unit from those views. The top left graphic identifies the standard front used for data analysis. The standard front extends to 500 m on either side of the radar and up to a height of 2800 m, as depicted in the top left graphic. In this graphic, the radar is situated at the bottom center, and the red dashed lines represent the lateral limits of the standard front. In the bottom graphic, the radar rotation is suspended so that the beam emits directly upward, and we view an approximation of the beam dispersion as it travels away from the radar unit (schematic not drawn to scale).

around the radar unit, and detection is not affected by the target's direction of travel as it is with the VSR. However, this index is much more affected by ground clutter than the VSR, which affects target detection and tracking. Errors caused by ground clutter lead to both under and overcounting. As a result, HSR counts are more influenced by site conditions than VSR counts. However, the HSR index better captures targets under certain conditions, such as cases in which targets are primarily at low elevation and/or traveling parallel to the VSR. The HSR is also much more susceptible than the VSR to beam bending from dynamic atmospheric conditions; beam refraction in the VSR is minimal, primarily due to its orientation. The VSR index was used to track targets captured within the standard front, and it provides more consistent detection than the HSR because it tracks primarily against clear air except in the lowest altitude bands. Its detection is affected by target direction and distance from the radar (Bruderer 1997, Schmaljohann et al. 2008). Plotting these indices together provided a more comprehensive understanding of changes in target activity over time.

We used the VSR index to calculate target passage rate (TPR). We calculated TPR as the number of targets per standard front per hr using DeTect SQL queries. Hours with fewer than 30 min of recording time were omitted from this calculation. For example, after removing all hours with less than 30 min of clean data, the nocturnal TPR for a given night (biological time period) was calculated by dividing the target count by the number of nighttime minutes and multiplying by 60 to provide

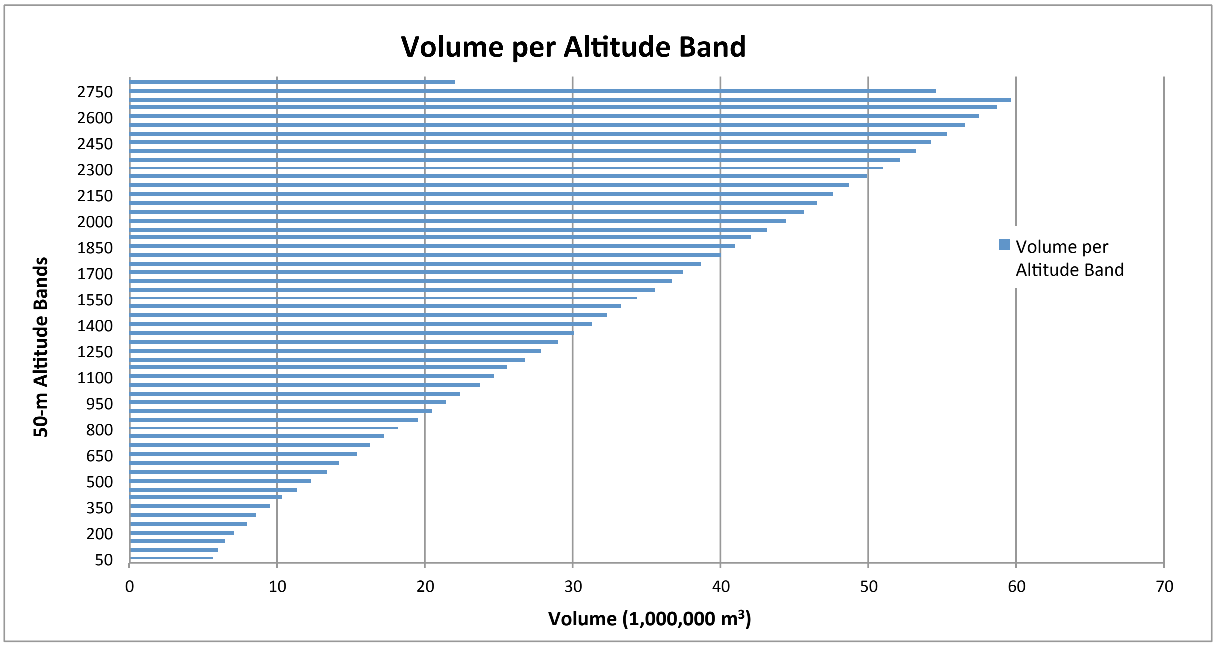


Figure 7. Volume of 50-m altitude bands within the standard front as estimated with Monte Carlo integration. Target counts provided by the vertical scanning radar are limited to the structure of the standard front.

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 on different scales. For this reason, we compared our density estimate with a density estimate based on the number of targets per 50-m altitude band per hr 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 in 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

We began data collection on 14 and 18 August during the fall 2011 season at the Oceana and Huron sites, respectively. Data were recorded continuously while the radar units were operational. Gaps in analyzed data occurred during rain events and when the radar units were non-operational due to maintenance or malfunction. We ended data collection on Nov 13, 2011. In all, the radars were in place for 2234 and 2138 hrs at the Oceana and Huron sites, respectively (Table 2).

Table 2. Survey effort (hrs) by vertical and horizontal scanning radars during fall 2011 in Oceana and Huron Counties, Michigan.

Site	Radar	Collected Data	Radar Downtime	Radar Data with Rain	Usable Radar Data	% Season with Usable Data
Oceana	Vertical*	2172	62	39	2133	96%
Oceana	Horizontal	2140	94	24	2116	95%
Huron	Vertical	2101	37	211	1890	88%
Huron	Horizontal	2111	27	86	2024	95%

* 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 8 and 9). For example, on 8 September at the Oceana site, the horizontal radar recorded scattered activity, and the vertical radar recorded few targets from 12:00 – 18:00. During the 19:00 hr, directional movement heading south to southwest began, and the vertical radar detections increased, with more targets at higher altitude. This pattern grew stronger until approximately 02:00, when the target heights began to decrease. By 05:00, there was a partial direction shift to the southeast, and the vertical radar indicated a further decrease in target height. During the 06:00 hr, target direction shifted strongly to the east (toward land) in a direction not well recorded by the vertical radar, and by 12:00 on 9 September, diurnal activity appeared similar to the preceding day at noon (Figure 8). This pattern of target movement and the changes in altitude were indicative of a pulse of migratory activity. Rings of decreased detection near the radar unit and where the radar switched between short and medium pulses are also apparent on the Trackplots.

A similar pattern can be observed at the Huron site, with targets moving to the shoreline at dusk, building to peak levels of movement in a southerly direction at night, and moving inland at dawn. The Huron site was affected to a greater degree than the Oceana site by ground clutter, and this resulted in reduced detection in the air space that was within the range of data collection (e.g., south and west of the radar unit).

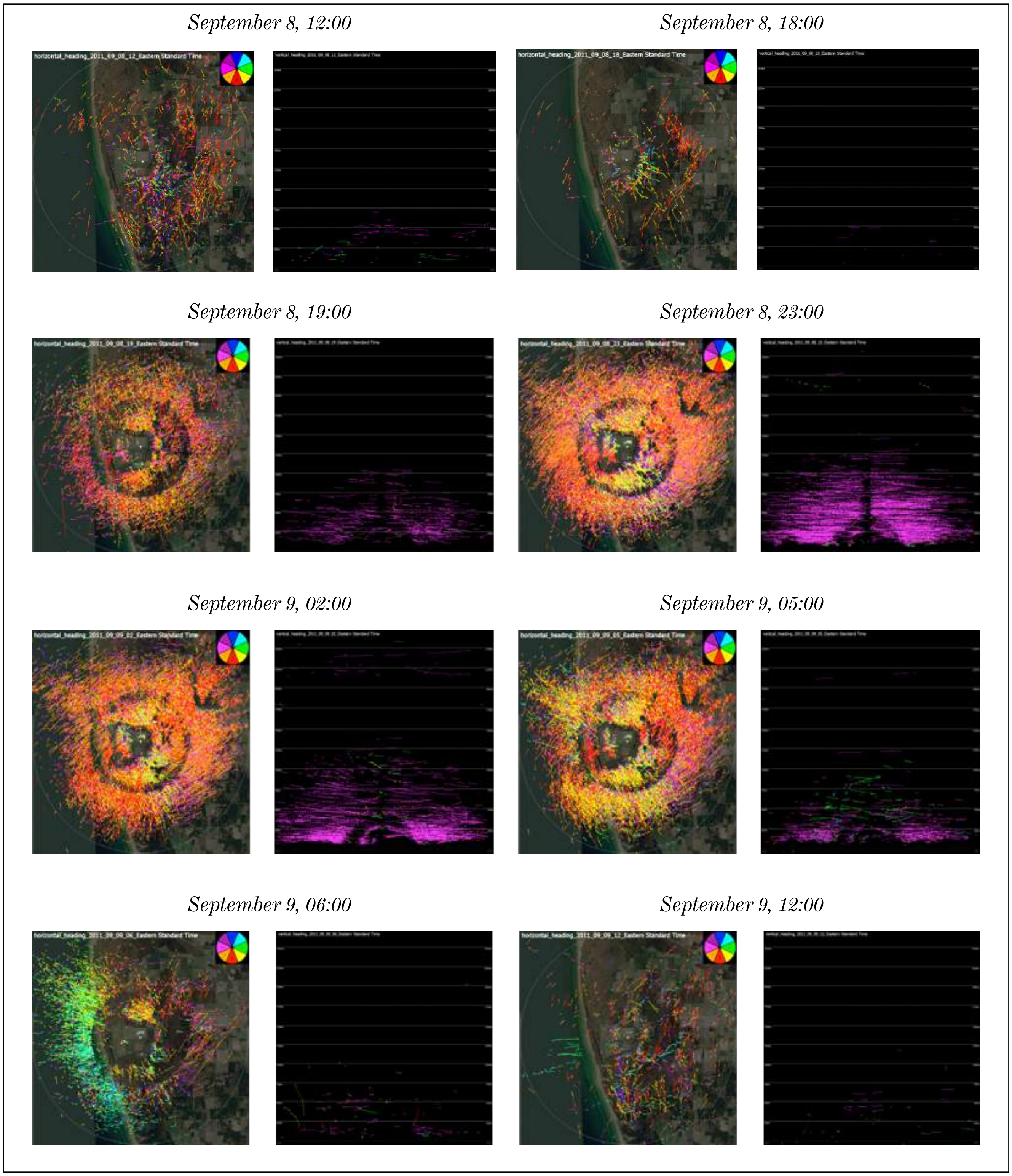


Figure 8. Images of tracks during 1-hr increments recorded by horizontal and vertical scanning radars during a migration event in Oceana County, Michigan. Horizontal radar images (columns 1 and 3) show the direction of the targets as indicated by the color wheel. Vertical radar images (columns 2 and 4) show the target heights with the labels representing 250 m increments.

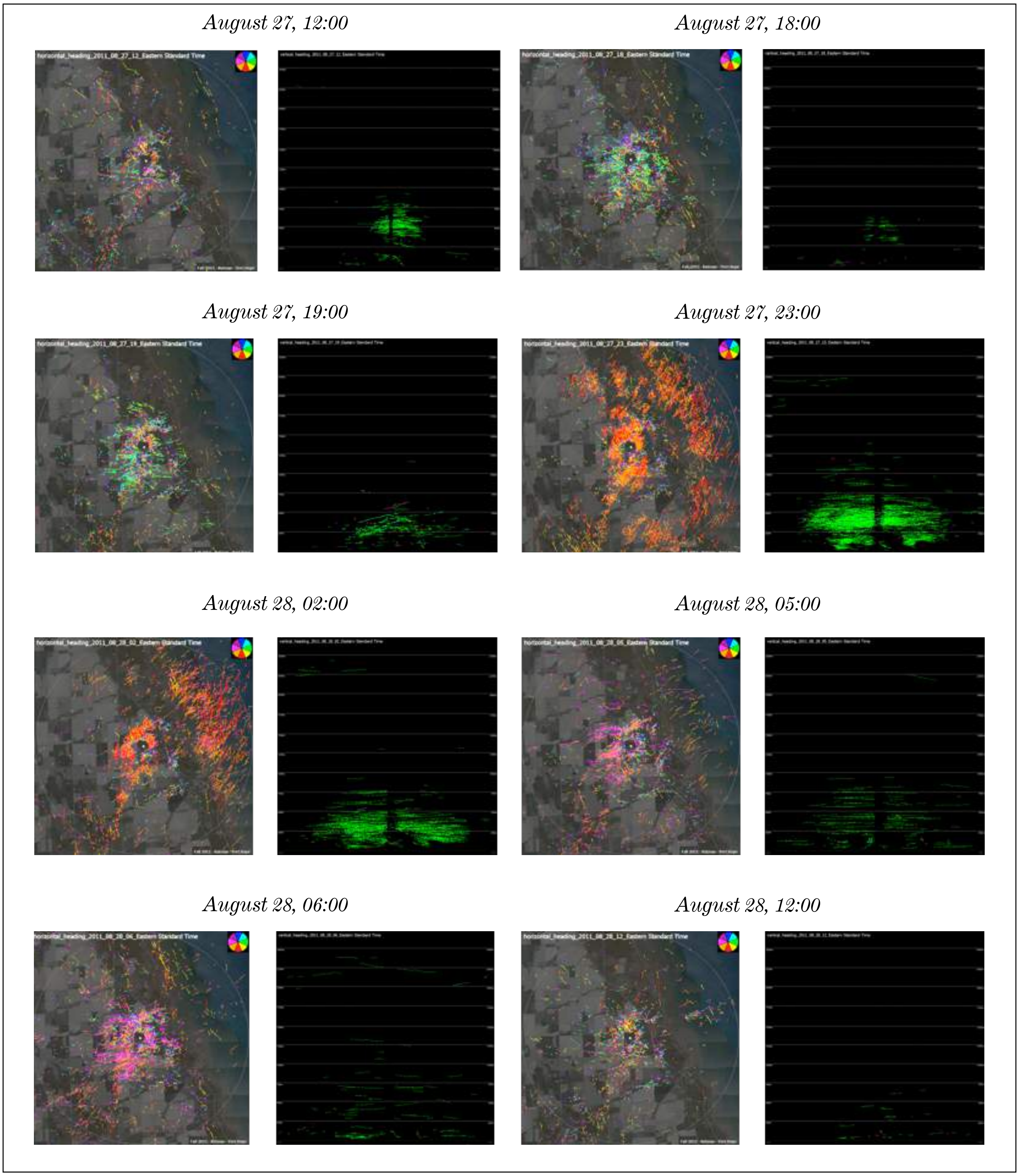


Figure 9. Images of tracks during 1-hr increments recorded by horizontal and vertical scanning radars during a migration event in Huron County, Michigan. Horizontal radar images (columns 1 and 3) show the direction of the targets as indicated by the color wheel. Vertical radar images (columns 2 and 4) show the target heights with the labels representing 250 m increments.

Directional Trends

During the fall 2011 season, nocturnal target direction was generally southerly at both sampled locations (Figure 10). At the Oceana site, mean nocturnal direction was 179° (r = 0.44, n = 4,064,319 targets), and during 68% of the nights, the mean target direction was between southeast and southwest (112.5° – 247.5°). Directions at the Huron site were more variable and had a mean nocturnal direction of 203° (r = 0.24, n = 1,818,939), with 49% of nights having a mean direction between southeast and southwest. Onshore movement (east – southeast at Oceana, west – south at Huron) at dawn was visible at both locations (Figure 10). Uniform directionality at night was stronger in Oceana than Huron (Table 3).

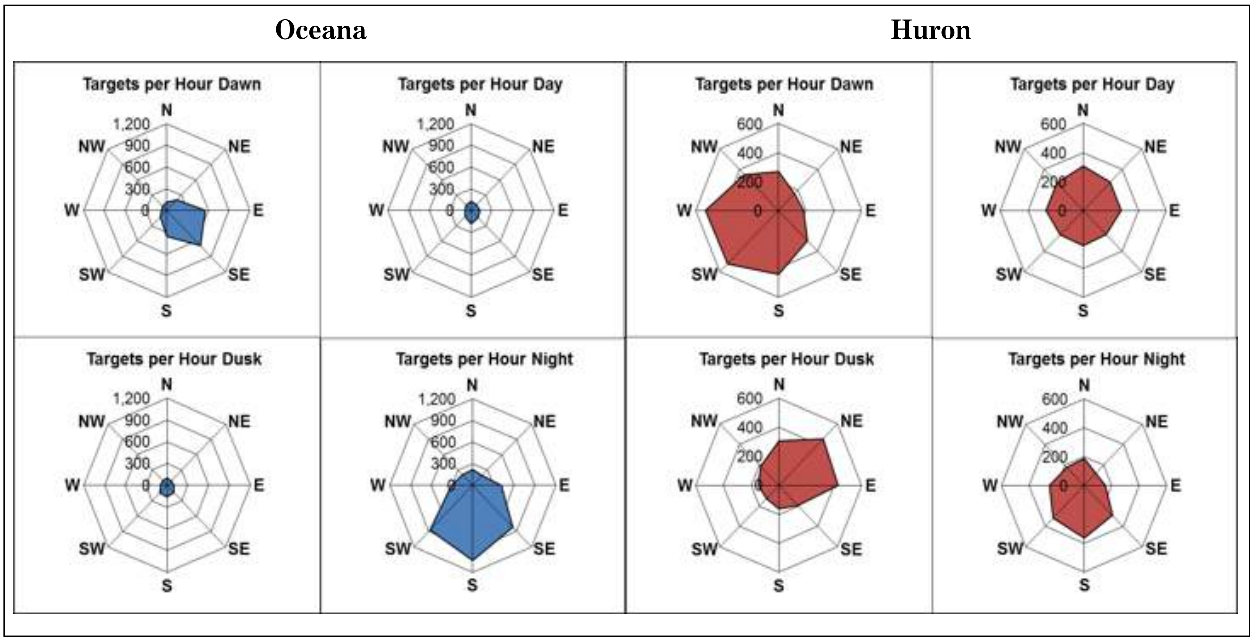


Figure 10. Target direction per hr during four biological periods during the fall of 2011 at Oceana (left) and Huron (right) Counties, Michigan. Note the different scales on the plots for Oceana and Huron Counties.

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 in Oceana and Huron Counties, Michigan.

	Oceana				Huron			
Biological Period	**Mean Direction (degrees)**	**r**	**% Time r ≥ 0.5**	**n**	**Mean Direction (degrees)**	**r**	**% Time r ≥ 0.5**	**n**
Dawn	123	0.53	57.3%	196,856	239	0.28	1.2%	237,064
Day	147	0.11	23.6%	945,052	4	0.06	0.0%	1,851,502
Dusk	180	0.15	44.4%	82,694	55	0.32	6.9%	172,808
Night	179	0.44	69.2%	4,064,314	203	0.24	21.6%	1,818,939

Temporal Trends

Time series plots – hourly target counts provided by horizontal and vertical radars showed pulses of elevated nocturnal activity, with peaks near midnight at our study sites. Across our sampling period, these events were often clustered into groups of several nights and were first observed on 15 and 26 August at Oceana and Huron Counties, respectively. At both sites, the occurrence and magnitude of nocturnal pulses decreased substantially after 1 November (Figures 11 and 12). Different patterns of activity were apparent as the season progressed at our study sites. For example, beginning in late August, activity patterns become dominated by nocturnal pulses that were observed on both horizontal and vertical radars. This pattern continued until about mid-October, when activity patterns began to shift. At the Oceana site, there was a decrease in activity overall, whereas the Huron site shifted to a more pronounced diurnal pattern. By November at Huron, a pattern of peaks near dawn and dusk was established on the horizontal index (visual observations indicated that these peaks were caused by low-flying Canada geese and several gull species moving between foraging and roosting locations).

Differences in detection capability of the VSR and HSR radars were also apparent. At the Huron site in late September, particularly on the 26th, nocturnal targets traveled at low elevation and in a direction that was parallel to the VSR (Figure 12). These targets were better represented by the horizontal index. On 11 and 22 October, many nocturnal targets passed at a high elevation above the HSR range of detection. 2 October provided a case in which targets passed above the study area in a direction and with an altitude distribution that allowed detection by both radars.

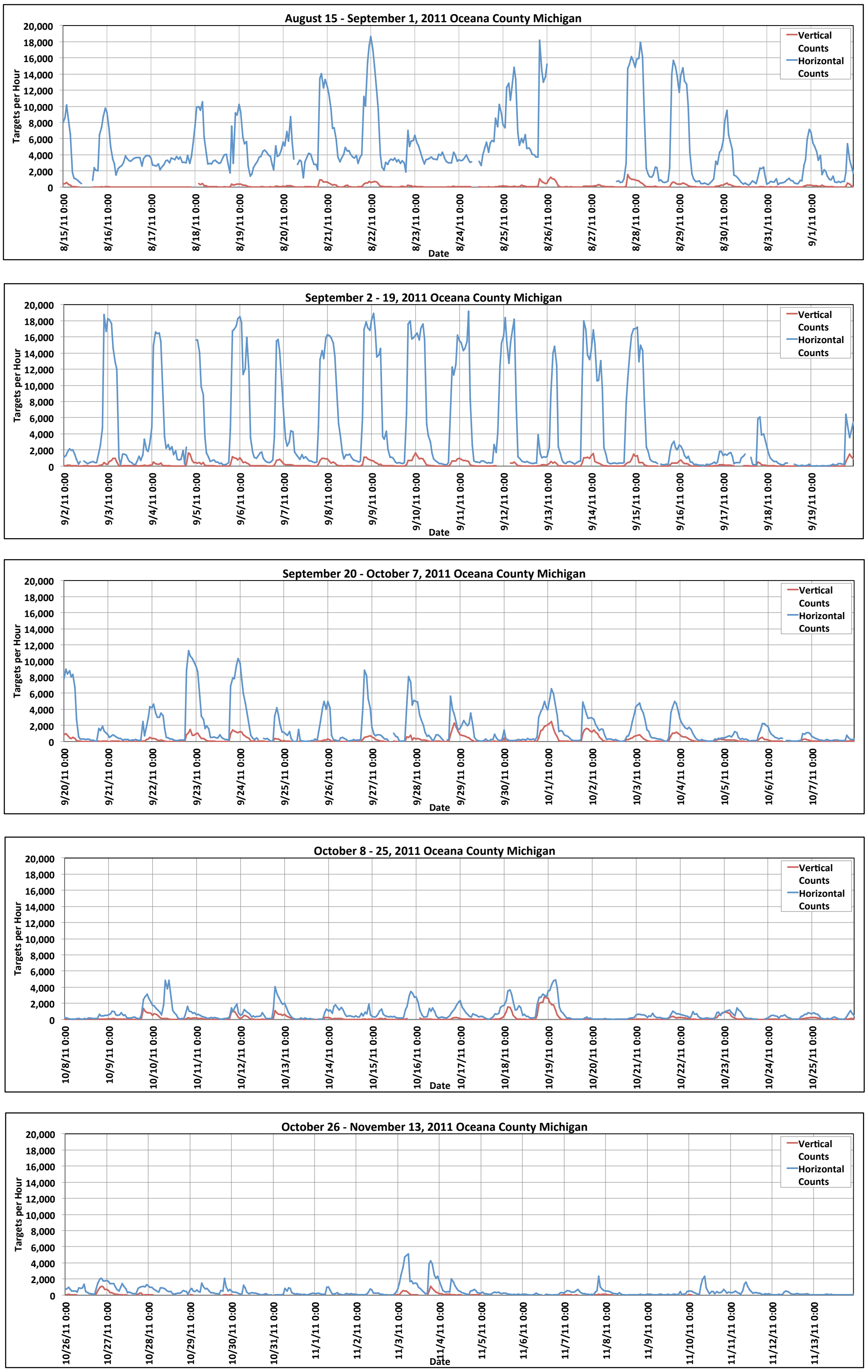


Figure 11. Hourly counts by horizontal and vertical radars from 15 August – 13 November 2011 in Oceana County, Michigan. Light gray vertical lines represent midnight.

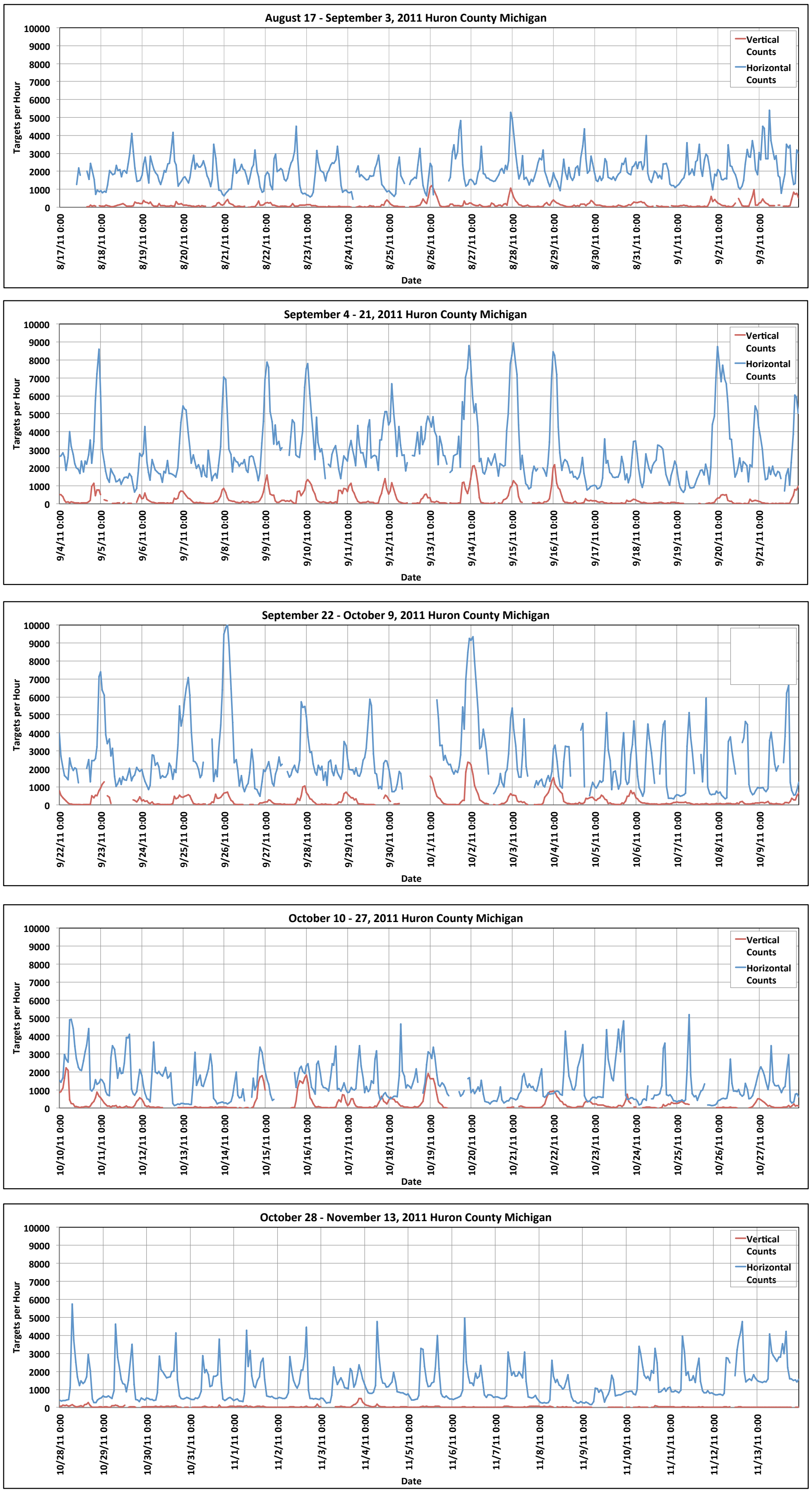


Figure 12. Hourly counts by horizontal and vertical radars from 18 August – 13 November 2011 in Huron County, Michigan. Light gray vertical lines represent midnight.

Target passage rate – the pattern of mean TPR among the four biological time periods was similar for the two study sites (Figure 13), with mean TPR at night greater than mean TPR during the combined means of the other three biological time periods (Table 4). Mean nocturnal TPR was 442 ± 475 SD (n = 82 nights) and 340 ± 328 SD targets per km per hr (n = 86 nights) in Oceana and Huron Counties, respectively. Mean TPR varied by hour, with peak numbers achieved within 1-2 hrs after sunset in Oceana and near midnight in Huron. At both locations, mean hourly TPR began to decrease by 02:00 hrs (Figure 14).

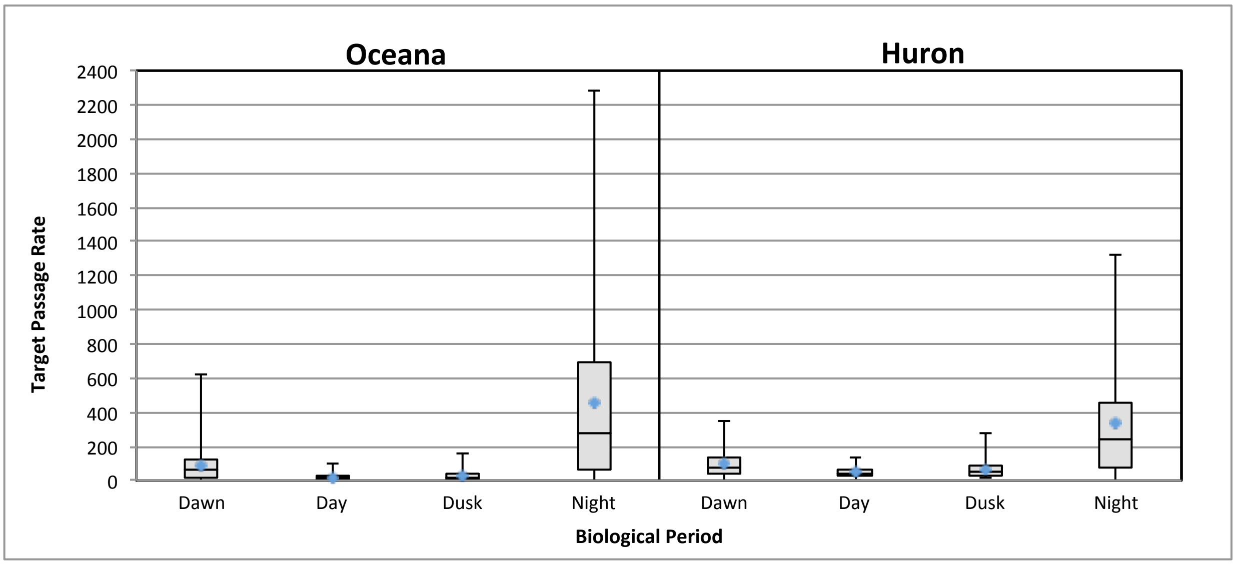


Figure 13. Box plots showing variability in the target passage rate (targets per km per hr) during four biological periods for fall 2011 in Oceana and Huron Counties, Michigan. Whiskers represent the 1st and 4th quartiles, boxes represent the 2nd and 3rd quartiles (with the line between indicating the median), and blue diamonds represent the seasonal mean for the time period.

Table 4. Mean target passage rate (Targets per kilometer per hour) with standard deviations during four biological periods in Oceana and Huron Counties, Michigan during fall 2011.

Biological Period	Oceana Mean TPR	Huron Mean TPR
Dawn	84 ± 98	103 ± 77
Day	17 ± 15	49 ± 26
Dusk	33 ± 41	60 ± 46
Night	442 ± 475	340 ± 328

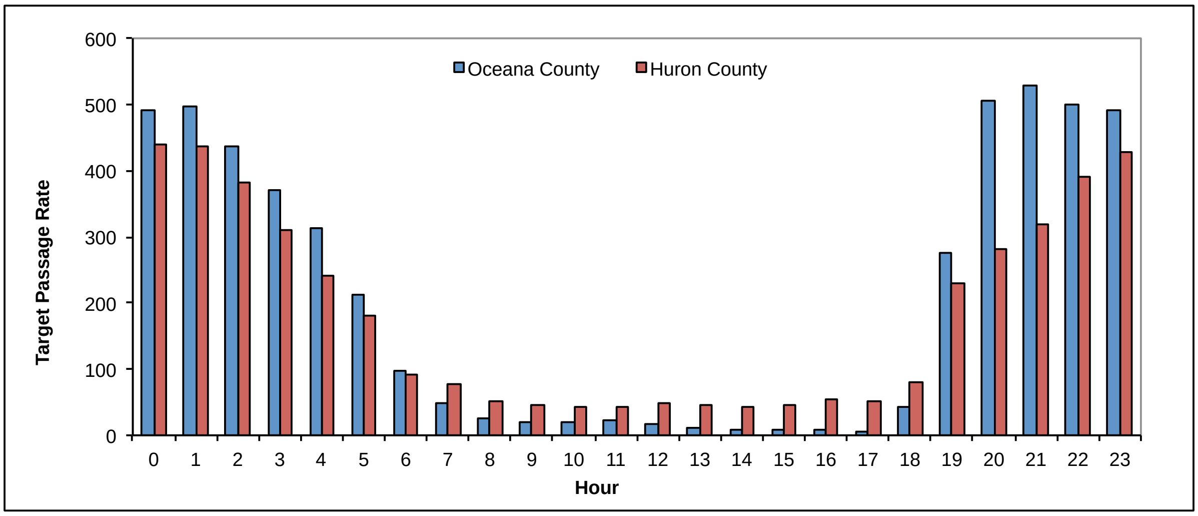


Figure 14. Mean hourly target passage rate (targets per km per hour) during fall 2011 in Oceana and Huron Counties, Michigan.

Weekly mean of target passage rates – weekly means of TPRs at night were relatively high until the last two weeks of our sampling period, when a decrease was observed at both locations (Figure 15). The weekly means of nocturnal TPRs were consistently higher than weekly means of diurnal TPRs (Figure 15). As the recorded migration season subsided, however, the difference between these passage rates decreased (Figures 15 and 16). Trends in nocturnal TPRs (7-day moving means) were similar at our sites, but trends in diurnal TPRs differed (Figure 17).

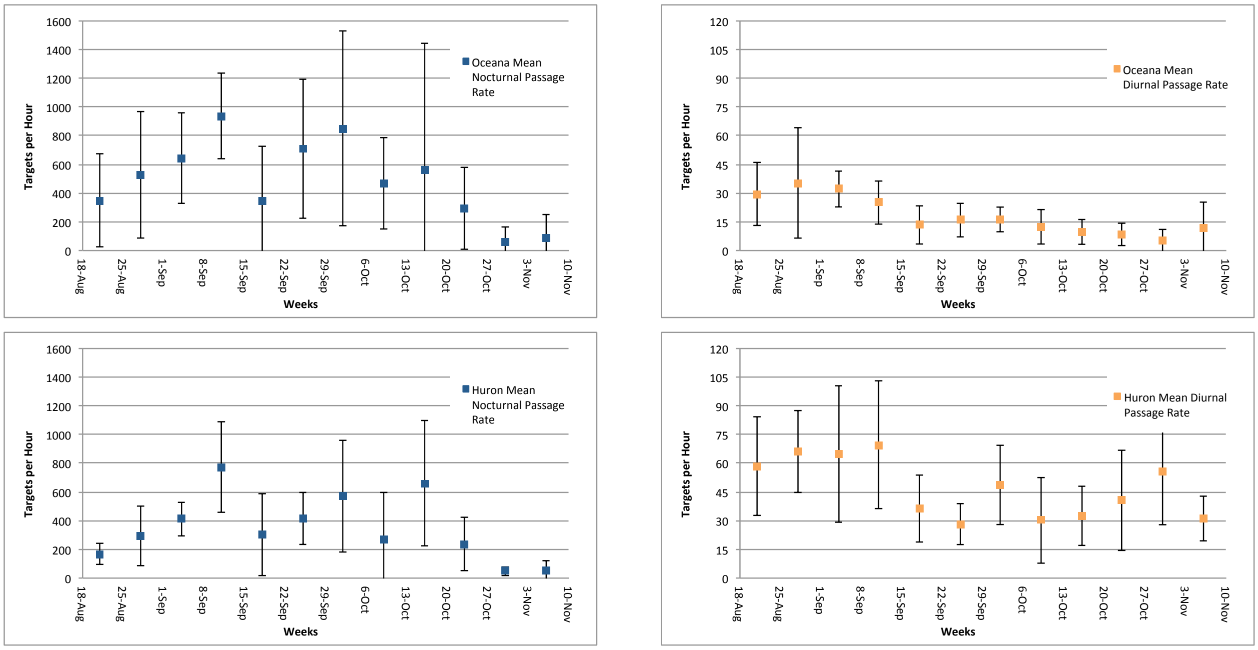


Figure 15. Weekly mean of nocturnal and diurnal target passage rates (targets per km per hr) in Oceana (top row) and Huron (bottom row) Counties from 18 August – 10 November 2011. Error bars represent one standard deviation. Note the different scales on the nocturnal and diurnal plots.

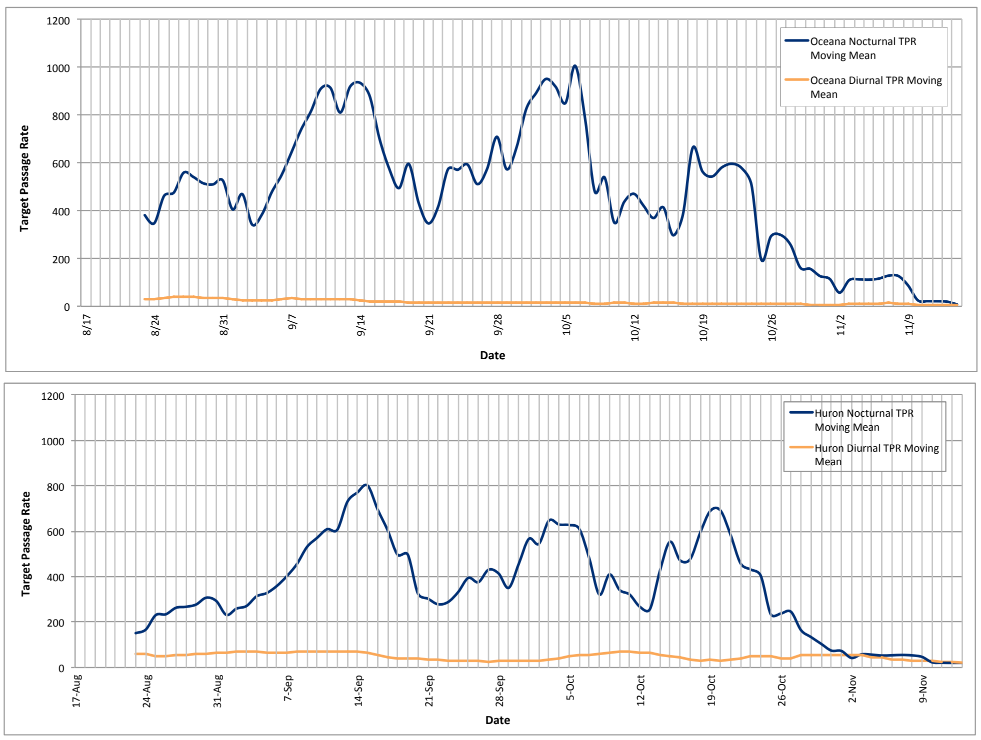


Figure 16. Within site comparison of nocturnal and diurnal trends (based on a moving 7-day mean) in target passage rate (targets per km per hour) during fall 2011 in Oceana and Huron Counties, Michigan.

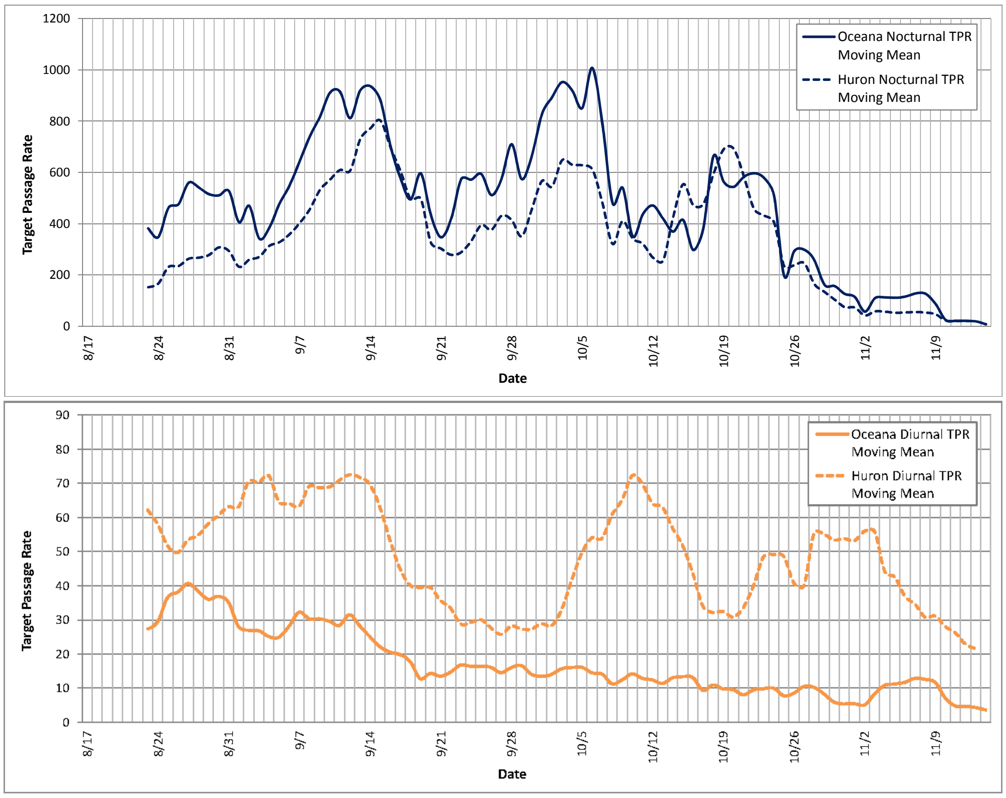


Figure 17. Between site comparison of nocturnal and diurnal trends (based on a moving 7-day mean) in target passage rate (targets per km per hour) during fall 2011 in Oceana and Huron Counties, Michigan.

Altitudinal Trends

The density estimate that incorporated the geometric shape of the sampled space resulted in a substantially different density value than the estimate that assumed an equal amount of sample volume per altitude band (Figure 18 and 19). The altitude profiles for dawn and dusk differed between our locations, with a greater density at low elevation at Huron (Figures 18 and 19). The hourly altitude profiles at night revealed considerable variations in the use of altitude bands (Figure 20 and 21); however, the 100 – 150 m altitude band was the most densely populated over the course of the season (Figure 22), with a total of 5.05 targets per 1,000,000 m^3 per night-hr and 5.81 targets per 1,000,000 m^3 per night-hr at the Oceana and Huron sites, respectively. The maximum density of targets occurred at less than 150 m during 43.3% and 92% of the nights at Oceana and Huron Counties, respectively (Figure 23). A similar pattern, although with more variation, occurred if the hours from 20:00 – 04:00 were considered individually, with the maximum density of targets occurring at less than 150 m during 41% and 71.5% of these night hours at Oceana and Huron Counties, respectively (Figure 24).

At both sites, targets were observed within the entire range of altitude bands sampled. The mean altitude of the nocturnal targets was 500 m ± 398 m SD and 380 m ± 328 m SD above radar elevation at the Oceana and Huron sites, respectively. The median altitude at night was 416 m and 305 m above radar elevation at the Oceana and Huron sites, respectively. The median altitude was greatest during the night biological time period, with the dawn period the next highest. Estimates of mean and median altitude were poor indicators of density (Table 5).

Mean altitude per hr during the season showed a similar pattern at the two locations (Figure 25). Mean altitude increased following dusk, tapered toward midnight, and decreased following midnight. A spike in mean altitude occurred during the 07:00 hr in Oceana and during the 06:00 hr in Huron.

Table 5. Comparison of mean altitude with standard deviations, median altitude, and altitude band (50 m bands) that contained the maximum target density during four biological periods in Oceana and Huron Counties, Michigan during fall 2011.

	Oceana			Huron		
Biological Period	Mean	Median	Max Density	Mean	Median	Density
Dawn	492 ± 461	390	100	375 ± 408	252	100
Day	434 ± 460	351	100	213 ± 290	118	100
Dusk	309 ± 323	242	200	179 ± 197	125	100
Night	500 ± 398	416	150	380 ± 328	304	150

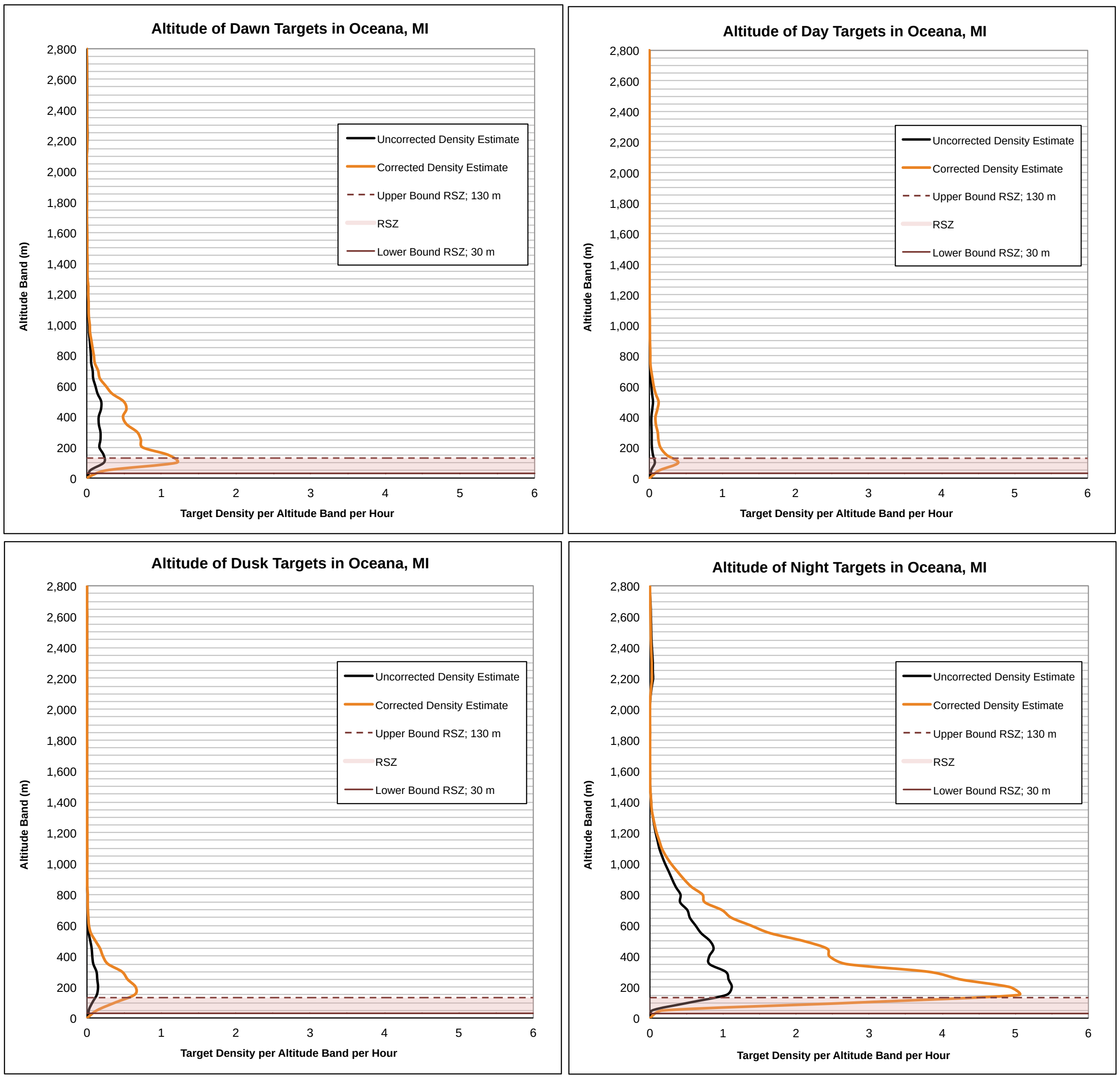


Figure 18. Altitude profile of targets in Oceana County, MI. Corrected lines depict target density (targets per 1,000,000 m^3) per 50-m altitude band per hr after adjusting for the structure of the sample volume. Uncorrected lines depict target density per 50-m altitude band per hr with an assumed uniform volume distribution (the 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. Y-axis labels represent the top of the altitude band.

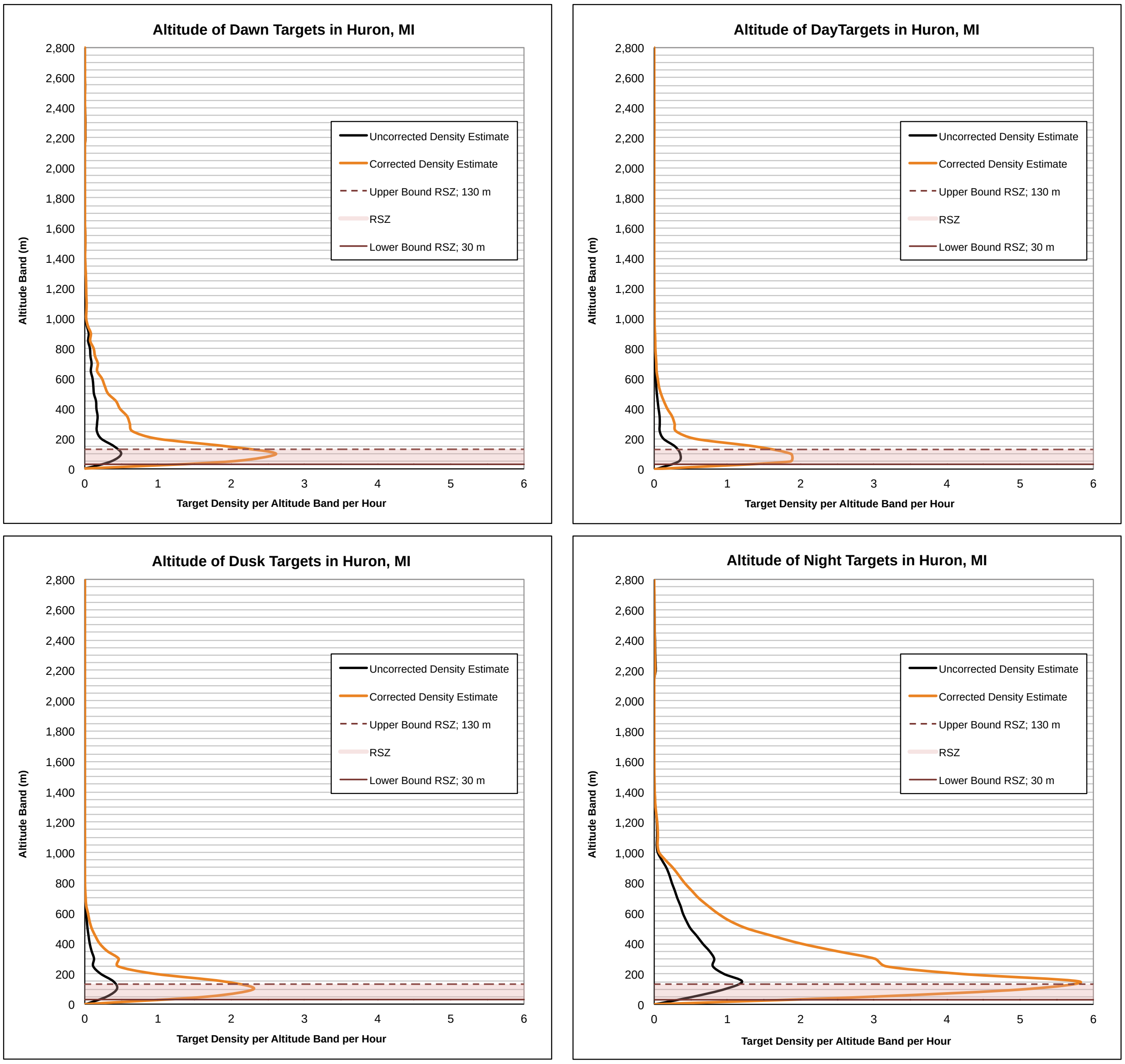


Figure 19. Altitude profile of targets in Huron County, MI. Corrected lines depict target density (targets per 1,000,000 m^3) per 50-m per hr altitude band after adjusting for the structure of the sample volume. Uncorrected lines depict target density per 50-m altitude band per hr with an assumed uniform volume distribution (the 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. Y-axis labels represent the top of the altitude band.

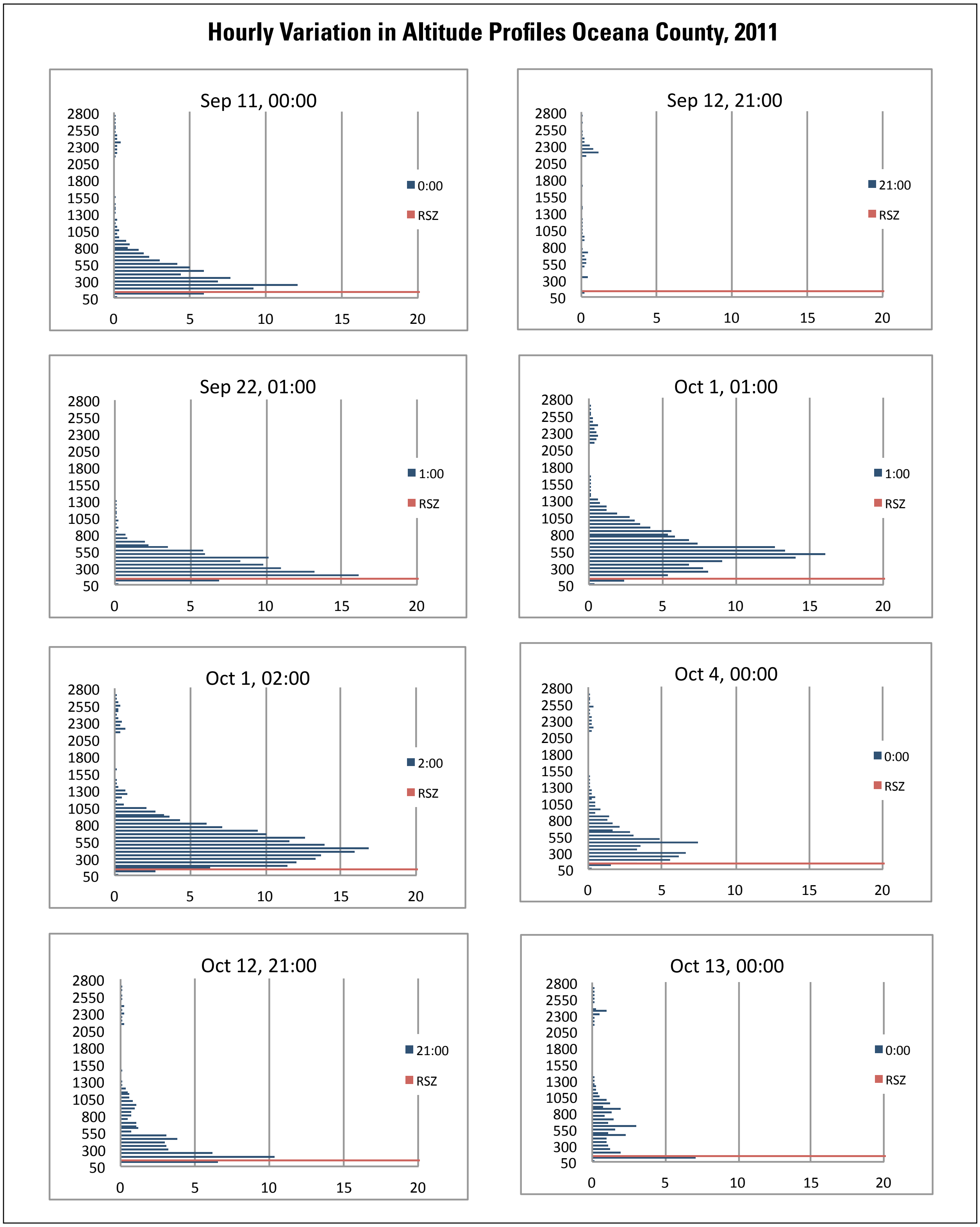


Figure 20. A sample of hourly altitude profiles corrected for the shape of the sample volume in Oceana County, Michigan during fall 2011. Hours were selected to portray the variability in density per altitude band of passing targets. The x-axis represents target density (targets per 1,000,000 m^3) per 50-m altitude band. The y-axis labels represent the top of altitude bands in meters. The red line represents the top of the rotor swept zone at 130 m.

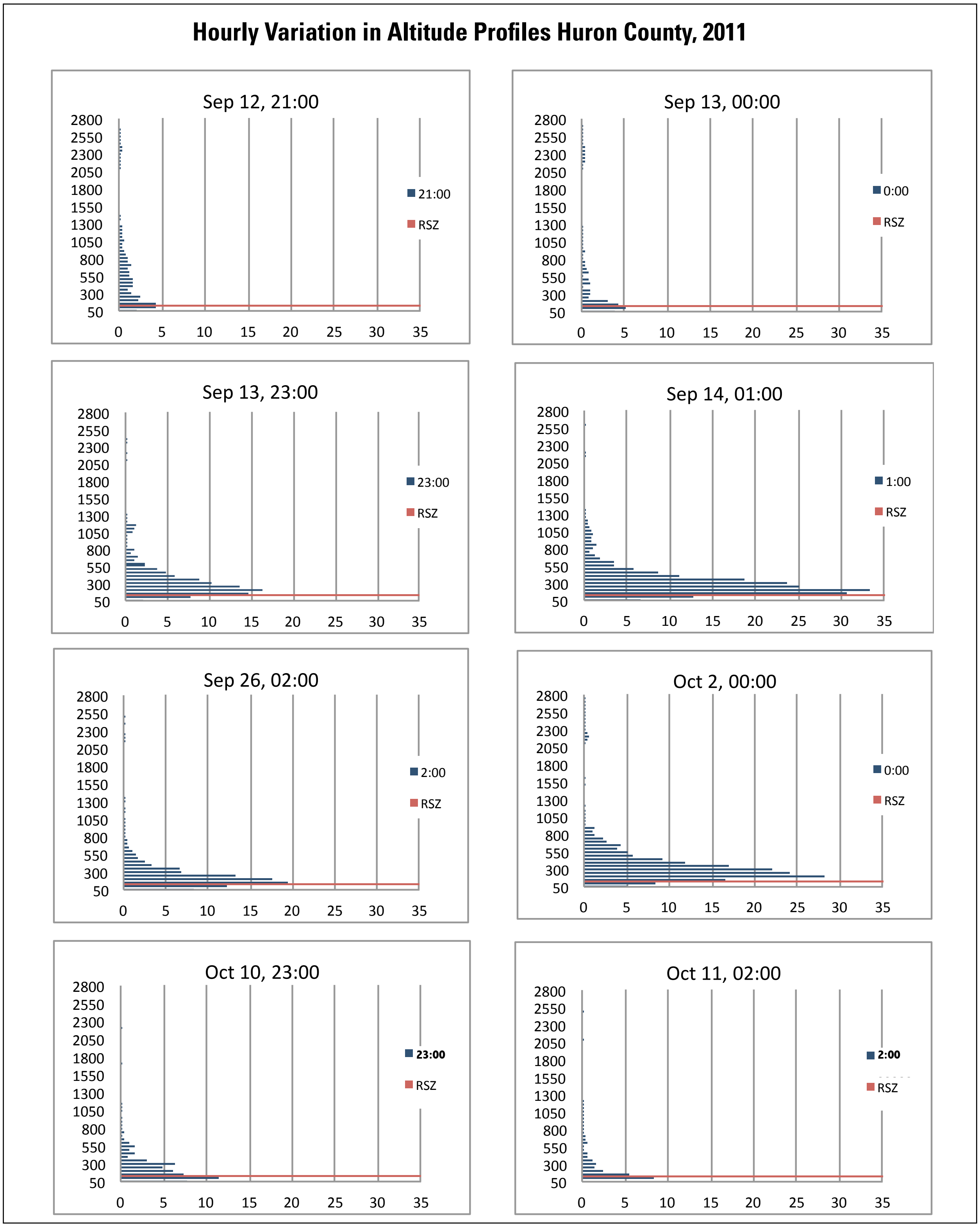


Figure 21. A sample of hourly altitude profiles corrected for the shape of the sample volume in Huron County, Michigan during fall 2011. Hours were selected to portray the variability in density per altitude band of passing targets. The x-axis represents target density (targets per 1,000,000 m^3) per 50-m altitude band. The y-axis labels represent the top of altitude bands in meters. The red line represents the top of the rotor swept zone at 130 m.

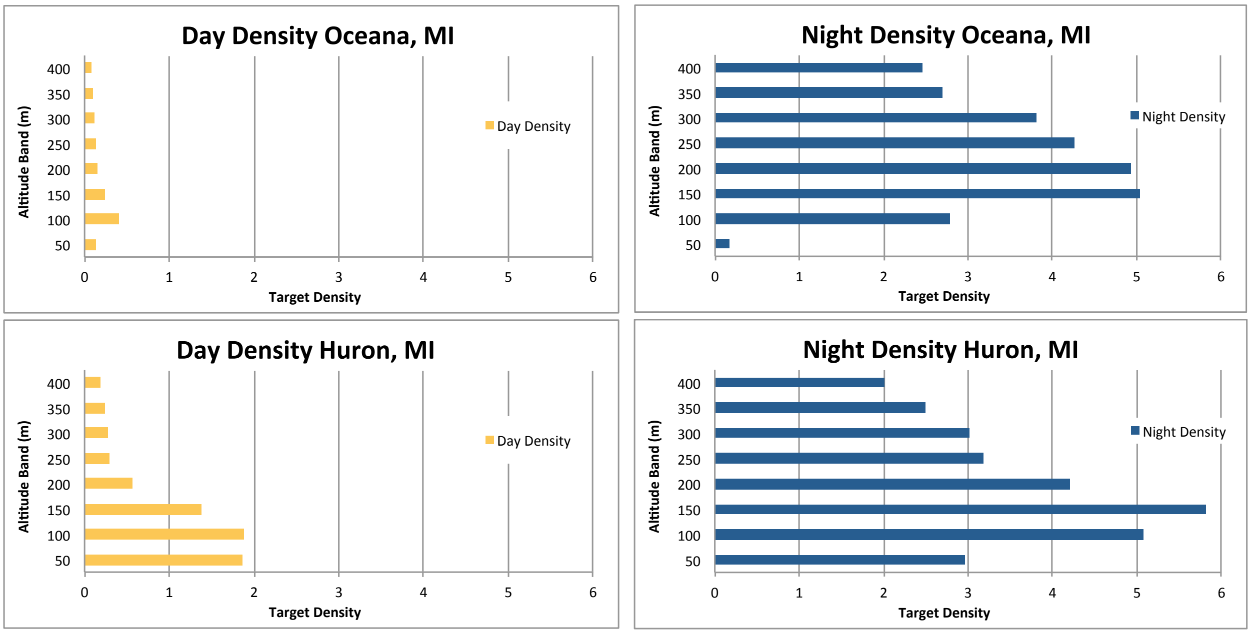


Figure 22. Altitude profile of target density below 400 meters in Oceana and Huron Counties, Michigan. These graphics show the altitude band in which the maximum density occurred during fall 2011. The x-axis represents target density (targets per 1,000,000 m³) per 50-m altitude band. The y-axis labels represent the top of the altitude bands in meters.

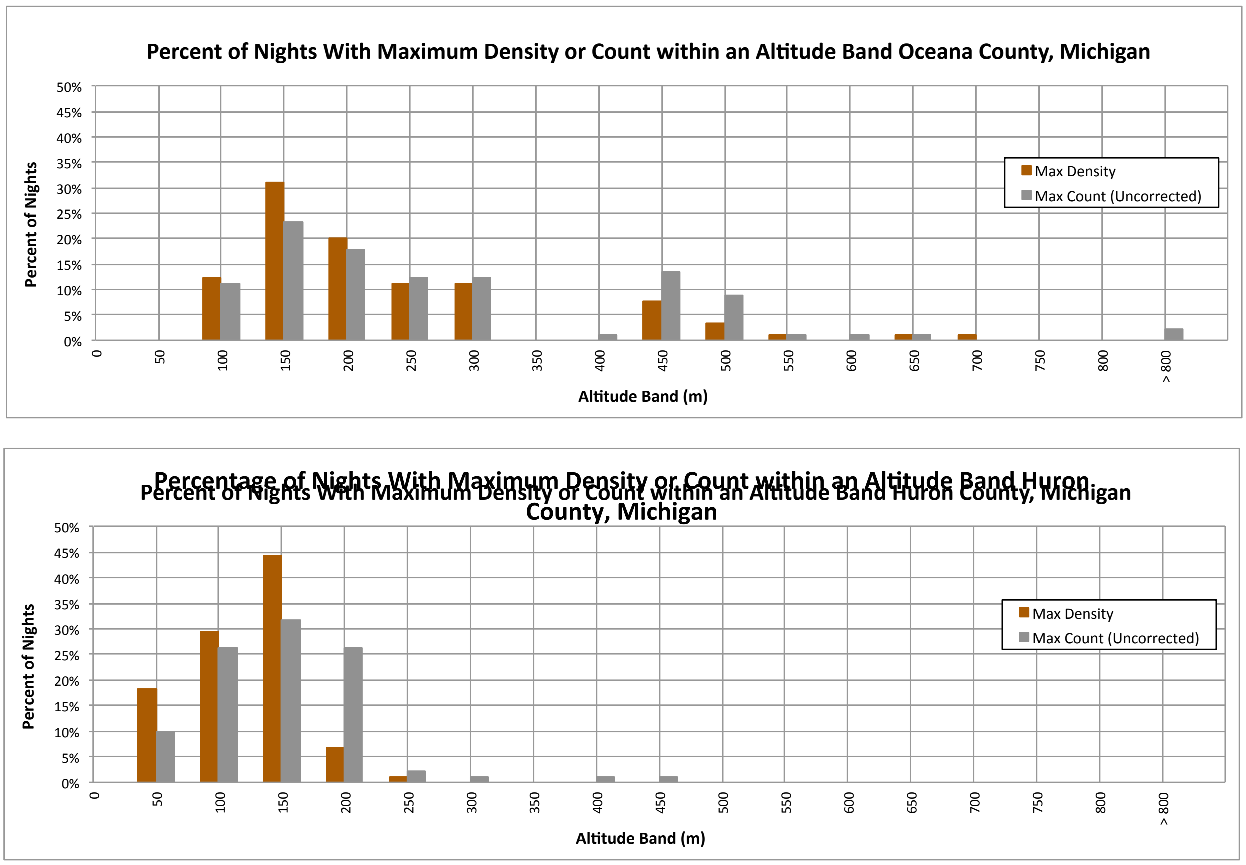


Figure 23. Percent of nights when the maximum density (targets per 1,000,000 m³ per altitude band) or count (targets per altitude band) occurred within 50-m altitude bands in Oceana and Huron Counties, Michigan, during fall 2011.

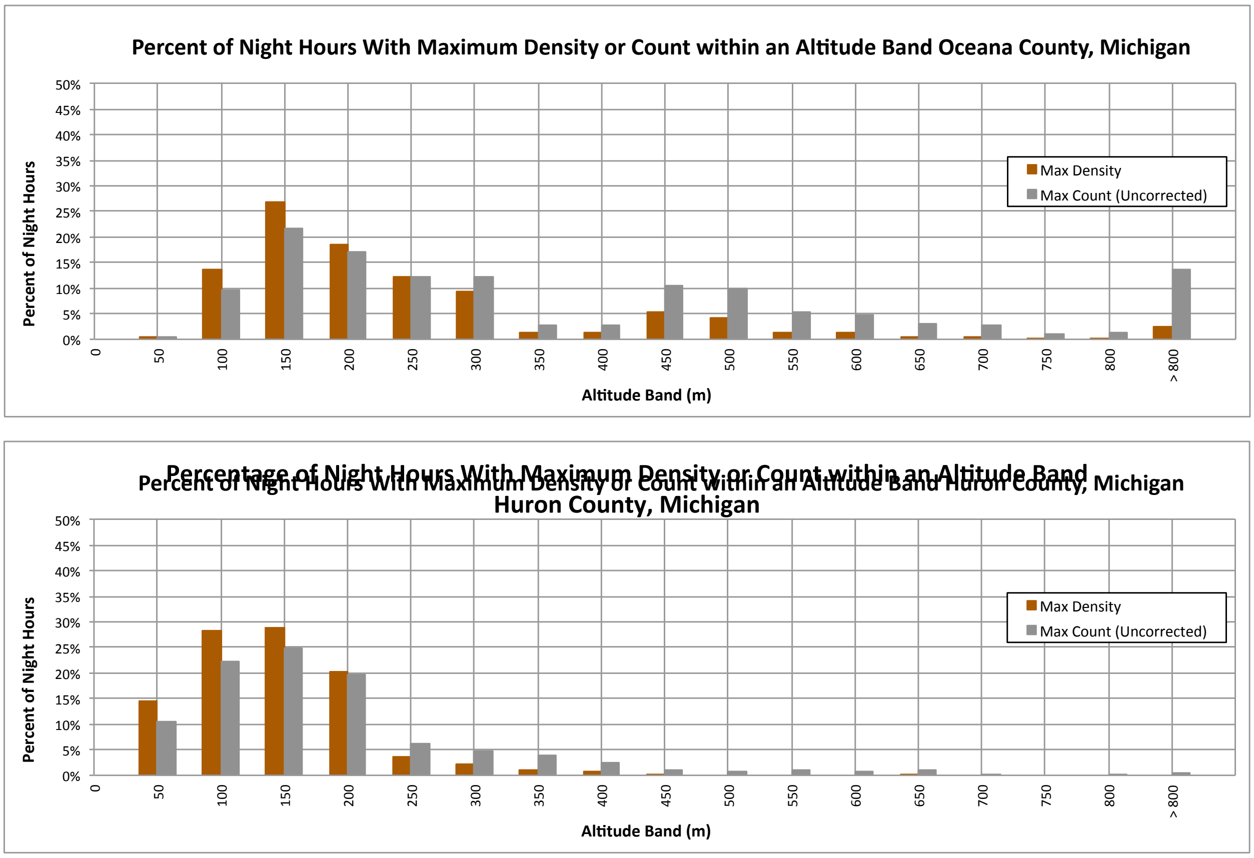


Figure 24. Percent of night hours (20:00 – 04:00) when the maximum density (targets per 1,000,000 m^3 per altitude band) or count (targets per altitude band) occurred within 50-m altitude bands in Oceana and Huron Counties, Michigan, during fall 2011.

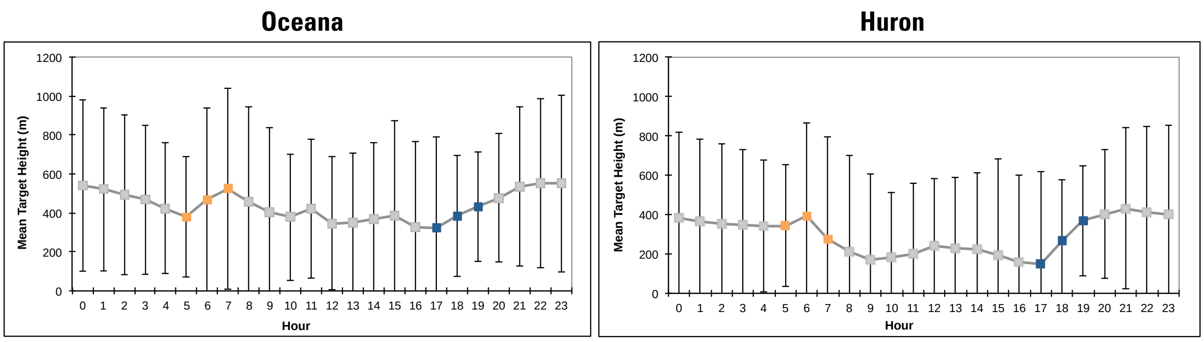


Figure 25. Mean hourly target height (m) during fall in Oceana and Huron Counties, Michigan. Yellow and blue markers indicate the hours in which sunrise and sunset occurred during the season, respectively. Error bars represent one standard deviation.

Discussion

We undertook this study to document migration along the shorelines of the Great Lakes. Our results indicate that migration movements were common along Michigan's east and west shorelines where we established study sites. Our research contributes to a growing body of literature that documents various aspects of migration and identifies Great Lakes shorelines as areas important for the conservation of migratory species. Our data provide unique observations about the magnitude and timing of nocturnal migration that could not be observed without the aid of radar.

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 might have missed pulses of activity (Figure 26). We used diurnal radar observations to provide a baseline for comparing nocturnal activity. Including this time period in the sampling scheme helped to distinguish the magnitude of the migration events (Figure 16). Our sampling regime was also useful in showing when the migration season declined in November, but our start date in August may not have included the onset of migration at our locations. 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 to tailor conservation efforts to appropriate time frames.

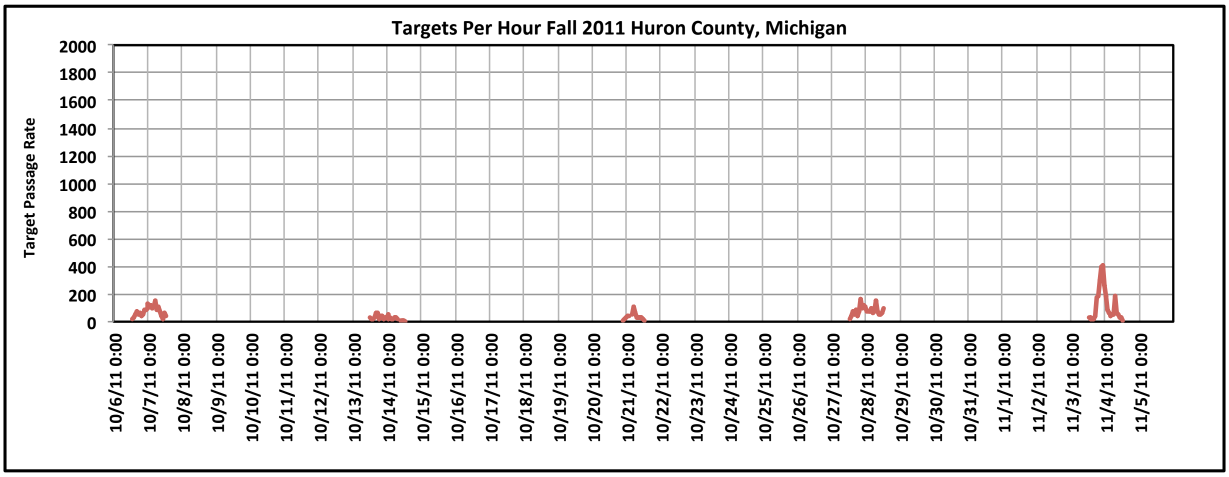
Target Counts

Target counts provided by radar are influenced by radar type and calibration, filtering of non-intended targets, count algorithms, frequency band, antenna orientation, sampling scheme, and the ways in which researchers incorporate variation in detection probability and sample volume (Bruderer 1997, Harmata et al. 1999, Schmaljohann et al. 2008). Even if 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 (Schmaljohann et al. 2008). Recognizing that our counts represent an index of target passage that is relative to a site, we are cautious about making comparisons among sites or studies. Rather than relying solely on the magnitude of target passage as an indication of airspace with or without a concentration 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 multiple times larger than lulls for the majority of the sampling period would 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.

Migration Patterns

The recorded patterns of movement were consistent with other observations of migration (Newton 2008) and indicated that nocturnal migratory flights occurred regularly during fall 2011 at both of our surveyed locations. The nocturnal activity we observed was typically oriented in a southward direction (Figure 10) and occurred in pulses across the season that were captured by horizontal and vertical radars (Figures 11 and 12). We also observed targets flying over water change course to return to shorelines near dawn. The TPR (mean for the season) was greatest during the nocturnal biological period at both locations (Table 4, Figure 13). The 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 toward midnight, and began to decrease prior to dawn. We also documented an abrupt increase in mean height near dawn (Figure 25) that represented a migratory behavior described as dawn ascent (Myres 1964, Diehl et al. 2003). This behavior is attributed to migrants that increase 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.

At both of our sample locations, nocturnal targets appeared to move across the landscape in four waves, with peaks near 30 August, 10 September, 2 October, and 18 October (Figure 17). These fluctuations may be related to broad-scale weather fronts, variations in the timing among guilds of migrants, or a combination of these and other factors (Newton 2008). The pattern of these trends at locations at similar latitudes but on opposite sides



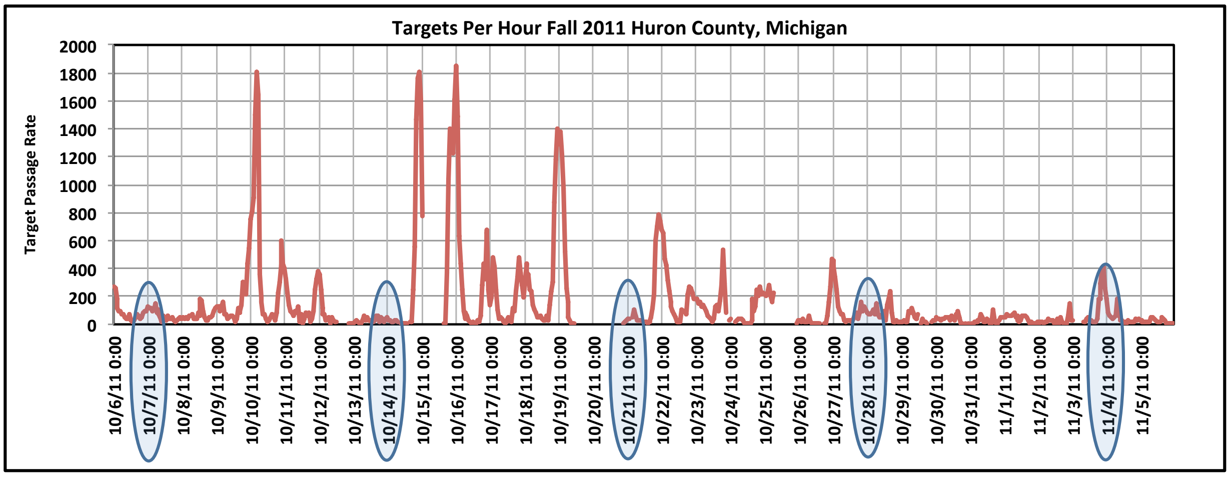


Figure 26. Example of a hypothetical sampling schedule where data were collected once per week (top graphic) versus the actual continuous sampling schedule (bottom graphic). Red lines represent the number of targets counted km per hr by the vertical scanning radar from 6 October – 5 November 2011 in Huron County, MI.

of Michigan reveals broad-scale influences and could indicate that further investigation into its cause would facilitate predictions of high-migration events.

Weekly mean estimates of nocturnal TPR were consistently higher than weekly mean diurnal TPR across all weeks of data collection until November (Figure 15). In November, this difference decreased substantially and, on occasion, diurnal trends were greater than nocturnal trends (Figure 16). This shift from time periods with orders of magnitude more nocturnal activity to time periods with comparable diurnal and nocturnal activity indicates that migration added substantially to the aeroecology above our study areas.

Flight Altitude

Altitude profiles indicated that most nocturnal targets passed below 800 m, with the peak density in the 100 – 150 m altitude band (Figure 18). We corrected for the approximate shape of the survey volume and included this correction in our density estimates. This correction is based on the manufacturer's estimate of beam geometry, which may not be precise, and does not account for the fact that beam propagation is not consistent over time. Beam propagation is affected by side lobes, target size and distance, and atmospheric conditions. Nevertheless, we think the correction was an improvement over altitude profiles that ignore beam geometry and sampling effort. We were not able to correct for the loss of detection with distance from the radar (Schmaljohann et al. 2008), and our vertical scanning radars lost detection in the region where the radar transitioned from the short to medium pulse, at a range of approximately 1400 – 2000 m. For these reasons, our estimates most likely under-represent density as altitude increases.

Altitude profiles varied considerably among nocturnal hours at our sites in Michigan (Figures 20 and 21). Migrants adjust flight altitude with wind direction and speed, visibility, time, and the landscape below flight trajectory (Alerstam 1990, Hueppop et al. 2006, Liechti 2006). For example, head winds aloft have resulted in migrants moving en masse to lower altitudes where wind speeds were reduced (Gauthreaux 1991). In addition, migrants are typically on land at least twice during every 24-hr 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 the location, these altitude changes may place migrants at risk of collision.

Management 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 used to track bird and bat movements (Larkin 2005), and its use to assess risk will likely increase with wind energy development. Despite this growing trend, standard methodologies for establishing radar settings, ground truthing biological targets, and processing data have not been adopted. These considerations can substantially affect the quality of data. This presents a challenge that is not easily solved. Yet, without standards, comparisons among studies may be more reflective of changes in methodology and site conditions than in differences in migration activity. Additionally, metrics reported in these types of surveys can be misleading to someone unfamiliar with avian radar.

For example, the mean altitude of targets is often reported to be above the rotor swept zone and can be interpreted as an indication of low risk. However, the mean altitude can be well above the rotor swept zone even when there is a high rate of target passage within the rotor swept zone. This difference is due to the long range at which radars collect altitude data, often up to 3 km above ground level, where high-flying targets inflate the mean altitude. This bias is apparent in our data and can be observed by comparing the mean altitude of nocturnal targets with the most densely populated altitude band (Table 5). It is also misleading to compare the percentage of targets below and above the height of the rotor swept zone without addressing the difference in sampling effort. Within our sampling framework, there are three 50-m altitude bands below 150 m (an estimate of the height of the rotor swept zone) and 53 altitude bands above 150 m. Based on our model of survey volume we estimate that approximately 1 percent of the potential survey volume is below 150 m. Given that calculation, we would expect a small percentage of targets to be recorded below the rotor swept zone, although this does not necessarily indicate low risk. In this report, we provide examples of a methodology and analyses that we find helpful in interpreting radar data. We suggest that the patterns of activity and relative change in counts at a site indicate migration and that this is a better indicator than comparing the magnitude of counts among studies. In addition, careful attention should be given to the way in which these indices fluctuate over fine temporal scales, e.g., hourly scales, as opposed to monthly or seasonal summaries. The clutter maps that we include provided information about our ability to detect targets at low altitude and show that within the 1-km front we had more clutter, and thus less detection, at low altitude in Oceana than we did at Huron. It is important, particularly for risk assessments, 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 was not without limitations but provided a first-order correction to a difficult problem. This represents an improvement over ignoring the biases associated with sampling effort. Overall, we found that radar provided insights 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 wind energy guidelines (U.S. Fish & Wildlife Service 2012) to identify areas where impacts to wildlife would be minimized. We documented clear examples of migrant activity along studied shorelines in Michigan, and the density of targets at lower altitudes is a potential concern. The data that we collected may be of interest to public and private entities that are involved with wind energy development and its potential placement in the Great Lakes region. Coupling avian radar systems with other forms of radar, such as NEXRAD, or using them in conjunction with post-construction fatality searches may broaden their utility in making risk assessments and serving wildlife-friendly wind energy developments.

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Appendices

Appendix 1

Fall 2011 Report Summary

- Migration occurred on the shoreline of both sides of Michigan during fall 2011.
    - Migration is identified by uniformity of movement of direction (south) at night, high target passage rate, and typically a peaking of numbers near midnight
    - Patterns and timing of migration were similar between the sites
        - 4 main waves of migration with highest concentrations near Aug 30, Sept 10, Oct 2, and Oct 18
- Date range of pulses that occurred during the migration season
    - Aug 15 – Nov 1 in Oceana County, MI
    - Aug 26 – Nov 1 in Huron County, MI
- Patterns of activity were different between Dawn, Day, Dusk, and Night time periods
    - Movement south during the night
        - 68% of nights surveyed the mean direction of travel was generally southerly at Oceana County, MI
        - 49% of nights surveyed the mean direction of travel was generally southerly at Huron County, MI
    - Movement in towards shore at dawn
        - Observed at both sites
    - Highest target passage rate at night
    - Dawn ascent
        - Increase in height around dawn hours observed at both sites
- Peak density of targets in volume corrected counts
    - Max density below 150m 54% of nights and 46% of night hours at Oceana County, MI
    - Max density below 150m 86% of nights and 76% of night hours at Huron County, MI
- Standards for radar studies need to be established and recommendations are included in this report
    - Using radar counts as an index of activity and not a population estimate
    - Surveying continuously over the whole migration season
    - Examining smaller time periods (Dawn/Day/Dusk/Night or Hourly) rather than seasonal metrics
    - Using volume corrected counts on the vertical radar to better estimate use of low altitudes and the rotor swept zone
    - Using 50-m altitude bands to represent height distributions rather than mean or median heights
    - Examining the most densely populated altitude bands rather than comparing numbers or percentages of targets below, within, and above the rotor swept zone
    - Recognizing that migrants change altitude for various reasons over time and that targets flying several altitude bands above the rotor swept zone may still be at risk.

Appendix 2

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

Percent landcover found within 3.7 km of radar locations in Michigan during fall 2011

National Landcover Class	Oceana County % Land Cover	Huron County % Land Cover
Barren Land	2.20%	0.12%
Cultivated Crops	18.87%	43.63%
Deciduous Forest	32.14%	7.17%
Developed*	5.02%	6.66%
Evergreen Forest	3.36%	0.37%
Hay/Pasture	0.43%	9.89%
Herbaceous	5.80%	0.29%
Mixed Forest	1.13%	0.38%
Open water	29.29%	23.66%
Shrub/Scrub	1.57%	0.03%
Wetlands**	0.20%	7.79%

* Includes low, medium and high intensity development and developed open space.
**Includes woody and emergent herbaceous wetlands.

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

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

(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% oftotal 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% oftotal 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 Hr by Biological Period

Estimated density of targets by altitude band during fall biological periods in Oceana County, Michigan.

Altitude Band	Dawn	Day	Dusk	Night
0	0.3	0.1	0.1	0.2
100	1.2	0.4	0.4	2.8
150	1.1	0.2	0.6	5.0
200	0.7	0.2	0.7	4.9
250	0.7	0.1	0.5	4.3
300	0.7	0.1	0.5	3.8
350	0.5	0.1	0.3	2.7
400	0.5	0.1	0.2	2.5
450	0.5	0.1	0.2	2.4
500	0.5	0.1	0.1	2.1
550	0.3	0.1	0.1	1.6
600	0.3	0.1	0.0	1.4
650	0.2	0.0	0.0	1.1
700	0.2	0.0	0.0	1.0
750	0.1	0.0	0.0	0.8
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	0.0	0.0	0.0	0.4
1000	0.0	0.0	0.0	0.3

Estimated density of targets by altitude band during fall biological periods in Huron County, Michigan.

Altitude Band	Dawn	Day		Night
0	2.0	1.9	1.7	3.0
100	2.6	1.9	2.3	5.1
150	1.9	1.4	1.9	5.8
200	1.0	0.6	1.0	4.2
250	0.7	0.3	0.5	3.2
300	0.6	0.3	0.5	3.0
350	0.6	0.2	0.3	2.5
400	0.5	0.2	0.2	2.0
450	0.4	0.1	0.1	1.6
500	0.3	0.1	0.1	1.3
550	0.3	0.1	0.1	1.0
600	0.2	0.0	0.0	0.9
650	0.2	0.0	0.0	0.7
700	0.2	0.0	0.0	0.6
750	0.1	0.0	0.0	0.5
800	0.1	0.0	0.0	0.4
850	0.1	0.0	0.0	0.3
900	0.1	0.0	0.0	0.3
950	0.0	0.0	0.0	0.2
1000	0.0	0.0	0.0	0.1

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 Oceana County, Michigan.

Altitude Band	Running Total	Count per Band	Static Volume	Corrected Volume	Static Density per Hr	Corrected Density per Hr	% Total per Band	% Static Density	% Corrected Density
50	131	131	31.3	5.6	0.0	0.3	1.8%	1.8%	3.2%
100	765	634	31.3	5.9	0.2	1.2	8.5%	8.5%	14.4%
150	1394	629	31.3	6.5	0.2	1.1	8.5%	8.5%	13.2%
200	1865	471	31.3	7.1	0.2	0.7	6.3%	6.3%	9.0%
250	2374	509	31.3	7.9	0.2	0.7	6.8%	6.8%	8.7%
300	2883	509	31.3	8.5	0.2	0.7	6.8%	6.8%	8.1%
350	3332	449	31.3	9.5	0.2	0.5	6.0%	6.0%	6.4%
400	3777	445	31.3	10.3	0.2	0.5	6.0%	6.0%	5.8%
450	4307	530	31.3	11.2	0.2	0.5	7.1%	7.1%	6.4%
500	4843	536	31.3	12.2	0.2	0.5	7.2%	7.2%	5.9%
550	5245	402	31.3	13.3	0.1	0.3	5.4%	5.4%	4.1%
600	5566	321	31.3	14.1	0.1	0.3	4.3%	4.3%	3.1%
650	5804	238	31.3	15.3	0.1	0.2	3.2%	3.2%	2.1%
700	6023	219	31.3	16.2	0.1	0.2	2.9%	2.9%	1.8%
750	6187	164	31.3	17.2	0.1	0.1	2.2%	2.2%	1.3%
800	6340	153	31.3	18.2	0.1	0.1	2.1%	2.1%	1.1%
850	6472	132	31.3	19.4	0.0	0.1	1.8%	1.8%	0.9%
900	6582	110	31.3	20.4	0.0	0.1	1.5%	1.5%	0.7%
950	6664	82	31.3	21.4	0.0	0.0	1.1%	1.1%	0.5%
1000	6743	79	31.3	22.4	0.0	0.0	1.1%	1.1%	0.5%

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

Altitude Band	Running Total	Count per Band	Static Volume	Corrected Volume	Static Density per Hr	Corrected Density per Hr	% Total per Band	% Static Density	% Corrected Density
50	719	719	31.3	5.6	0.0	0.1	4.3%	4.3%	7.1%
100	2961	2242	31.3	5.9	0.1	0.4	13.3%	13.3%	21.0%
150	4449	1488	31.3	6.5	0.0	0.2	8.8%	8.9%	12.8%
200	5484	1035	31.3	7.1	0.0	0.2	6.2%	6.2%	8.1%
250	6423	939	31.3	7.9	0.0	0.1	5.6%	5.6%	6.6%
300	7352	929	31.3	8.5	0.0	0.1	5.5%	5.5%	6.1%
350	8164	812	31.3	9.5	0.0	0.1	4.8%	4.8%	4.8%
400	8990	826	31.3	10.3	0.0	0.1	4.9%	4.9%	4.5%
450	10,168	1178	31.3	11.2	0.0	0.1	7.0%	7.0%	5.9%
500	11,644	1476	31.3	12.2	0.0	0.1	8.8%	8.8%	6.7%
550	12,762	1118	31.3	13.3	0.0	0.1	6.6%	6.7%	4.7%
600	13,573	811	31.3	14.1	0.0	0.1	4.8%	4.8%	3.2%
650	14,203	630	31.3	15.3	0.0	0.0	3.7%	3.7%	2.3%
700	14,605	402	31.3	16.2	0.0	0.0	2.4%	2.4%	1.4%
750	14,814	209	31.3	17.2	0.0	0.0	1.2%	1.2%	0.7%
800	15,033	219	31.3	18.2	0.0	0.0	1.3%	1.3%	0.7%
850	15,230	197	31.3	19.4	0.0	0.0	1.2%	1.2%	0.6%
900	15,377	147	31.3	20.4	0.0	0.0	0.9%	0.9%	0.4%
950	15,500	123	31.3	21.4	0.0	0.0	0.7%	0.7%	0.3%
1000	15,615	115	31.3	22.4	0.0	0.0	0.7%	0.7%	0.3%

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

Altitude Band	Running Total	Count per Band	Static Volume	Corrected Volume	Static Density per Hr	Corrected Density per Hr	% Total per Band	% Static Density	% Corrected Density
50	69	69	31.3	5.6	0.0	0.1	2.4%	2.4%	3.6%
100	272	203	31.3	5.9	0.1	0.4	7.2%	7.2%	10.1%
150	643	371	31.3	6.5	0.1	0.6	13.1%	13.1%	16.9%
200	1060	417	31.3	7.1	0.1	0.7	14.8%	14.8%	17.3%
250	1448	388	31.3	7.9	0.1	0.5	13.7%	13.7%	14.5%
300	1807	359	31.3	8.5	0.1	0.5	12.7%	12.7%	12.5%
350	2046	239	31.3	9.5	0.1	0.3	8.5%	8.5%	7.4%
400	2245	199	31.3	10.3	0.1	0.2	7.0%	7.0%	5.7%
450	2422	177	31.3	11.2	0.1	0.2	6.3%	6.3%	4.6%
500	2546	124	31.3	12.2	0.0	0.1	4.4%	4.4%	3.0%
550	2608	62	31.3	13.3	0.0	0.1	2.2%	2.2%	1.4%
600	2641	33	31.3	14.1	0.0	0.0	1.2%	1.2%	0.7%
650	2666	25	31.3	15.3	0.0	0.0	0.9%	0.9%	0.5%
700	2683	17	31.3	16.2	0.0	0.0	0.6%	0.6%	0.3%
750	2697	14	31.3	17.2	0.0	0.0	0.5%	0.5%	0.2%
800	2713	16	31.3	18.2	0.0	0.0	0.6%	0.6%	0.3%
850	2719	6	31.3	19.4	0.0	0.0	0.2%	0.2%	0.1%
900	2723	4	31.3	20.4	0.0	0.0	0.1%	0.1%	0.1%
950	2725	2	31.3	21.4	0.0	0.0	0.1%	0.1%	0.0%
1000	2729	4	31.3	22.4	0.0	0.0	0.1%	0.1%	0.1%

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

Altitude Band	Running Total	Count per Band	Static Volume	Corrected Volume	Static Density per Hr	Corrected Density per Hr	% Total per Band	% Static Density	% Corrected Density
50	971	971	31.3	5.6	0.0	0.2	0.2%	0.2%	0.4%
100	17,280	16,309	31.3	5.9	0.5	2.8	3.9%	3.9%	7.0%
150	49,414	32,134	31.3	6.5	1.0	5.0	7.8%	7.7%	12.6%
200	83,917	34,503	31.3	7.1	1.1	4.9	8.3%	8.3%	12.4%
250	117,097	33,180	31.3	7.9	1.1	4.3	8.0%	8.0%	10.7%
300	149,067	31,970	31.3	8.5	1.0	3.8	7.7%	7.7%	9.6%
350	174,190	25,123	31.3	9.5	0.8	2.7	6.1%	6.1%	6.7%
400	199,199	25,009	31.3	10.3	0.8	2.5	6.0%	6.0%	6.2%
450	226,033	26,834	31.3	11.2	0.9	2.4	6.5%	6.5%	6.1%
500	251,343	25,310	31.3	12.2	0.8	2.1	6.1%	6.1%	5.3%
550	272,954	21,611	31.3	13.3	0.7	1.6	5.2%	5.2%	4.1%
600	292,186	19,232	31.3	14.1	0.6	1.4	4.6%	4.6%	3.5%
650	309,036	16,850	31.3	15.3	0.5	1.1	4.1%	4.1%	2.8%
700	324,800	15,764	31.3	16.2	0.5	1.0	3.8%	3.8%	2.5%
750	337,540	12,740	31.3	17.2	0.4	0.8	3.1%	3.1%	1.9%
800	350,432	12,892	31.3	18.2	0.4	0.7	3.1%	3.1%	1.8%
850	361,321	10,889	31.3	19.4	0.4	0.6	2.6%	2.6%	1.4%
900	370,665	9344	31.3	20.4	0.3	0.5	2.3%	2.3%	1.2%
950	378,583	7918	31.3	21.4	0.3	0.4	1.9%	1.9%	0.9%
1000	384,965	6382	31.3	22.4	0.2	0.3	1.5%	1.5%	0.7%

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

Altitude Band	Running Total	Count per Band	Static Volume	Corrected Volume	Static Density per Hr	Corrected Density per Hr	% Total per Band	% Static Density	% Corrected Density
50	918	918	31.3	5.6	0.4	2.0	10.9%	10.9%	16.6%
100	2184	1266	31.3	5.9	0.5	2.6	15.1%	15.0%	21.6%
150	3204	1020	31.3	6.5	0.4	1.9	12.1%	12.1%	16.0%
200	3779	575	31.3	7.1	0.2	1.0	6.8%	6.8%	8.2%
250	4199	420	31.3	7.9	0.2	0.7	5.0%	5.0%	5.4%
300	4625	426	31.3	8.5	0.2	0.6	5.1%	5.1%	5.1%
350	5070	445	31.3	9.5	0.2	0.6	5.3%	5.3%	4.8%
400	5474	404	31.3	10.3	0.2	0.5	4.8%	4.8%	4.0%
450	5864	390	31.3	11.2	0.2	0.4	4.6%	4.6%	3.5%
500	6181	317	31.3	12.2	0.1	0.3	3.8%	3.8%	2.6%
550	6477	296	31.3	13.3	0.1	0.3	3.5%	3.5%	2.3%
600	6747	270	31.3	14.1	0.1	0.2	3.2%	3.2%	1.9%
650	6957	210	31.3	15.3	0.1	0.2	2.5%	2.5%	1.4%
700	7192	235	31.3	16.2	0.1	0.2	2.8%	2.8%	1.5%
750	7387	195	31.3	17.2	0.1	0.1	2.3%	2.3%	1.1%
800	7566	179	31.3	18.2	0.1	0.1	2.1%	2.1%	1.0%
850	7682	116	31.3	19.4	0.0	0.1	1.4%	1.4%	0.6%
900	7819	137	31.3	20.4	0.1	0.1	1.6%	1.6%	0.7%
950	7891	72	31.3	21.4	0.0	0.0	0.9%	0.9%	0.3%
1000	7925	34	31.3	22.4	0.0	0.0	0.4%	0.4%	0.2%

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

Altitude Band	Running Total	Count per Band	Static Volume	Corrected Volume	Static Density per Hr	Corrected Density per Hr	% Total per Band	% Static Density	% Corrected Density
50	8365	8365	31.3	5.6	0.3	1.9	20.5%	20.5%	25.8%
100	17,310	8945	31.3	5.9	0.4	1.9	21.9%	21.9%	26.1%
150	24,473	7163	31.3	6.5	0.3	1.4	17.5%	17.5%	19.2%
200	27,730	3257	31.3	7.1	0.1	0.6	8.0%	8.0%	8.0%
250	29,649	1919	31.3	7.9	0.1	0.3	4.7%	4.7%	4.2%
300	31,554	1905	31.3	8.5	0.1	0.3	4.7%	4.7%	3.9%
350	33,413	1859	31.3	9.5	0.1	0.2	4.6%	4.6%	3.4%
400	34,909	1496	31.3	10.3	0.1	0.2	3.7%	3.7%	2.5%
450	36,107	1198	31.3	11.2	0.0	0.1	2.9%	2.9%	1.8%
500	37,019	912	31.3	12.2	0.0	0.1	2.2%	2.2%	1.3%
550	37,698	679	31.3	13.3	0.0	0.1	1.7%	1.7%	0.9%
600	38,256	558	31.3	14.1	0.0	0.0	1.4%	1.4%	0.7%
650	38,654	398	31.3	15.3	0.0	0.0	1.0%	1.0%	0.5%
700	39,035	381	31.3	16.2	0.0	0.0	0.9%	0.9%	0.4%
750	39,343	308	31.3	17.2	0.0	0.0	0.8%	0.8%	0.3%
800	39,571	228	31.3	18.2	0.0	0.0	0.6%	0.6%	0.2%
850	39,792	221	31.3	19.4	0.0	0.0	0.5%	0.5%	0.2%
900	39,966	174	31.3	20.4	0.0	0.0	0.4%	0.4%	0.1%
950	40,059	93	31.3	21.4	0.0	0.0	0.2%	0.2%	0.1%
1000	40,136	77	31.3	22.4	0.0	0.0	0.2%	0.2%	0.1%

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

Altitude Band	Running Total	Count per Band	Static Volume	Corrected Volume	Static Density per Hr	Corrected Density per Hr	% Total per Band	% Static Density	% Corrected Density
50	719	719	31.3	5.6	0.3	1.7	15.8%	15.8%	19.5%
100	1763	1044	31.3	5.9	0.4	2.3	22.9%	22.9%	26.7%
150	2693	930	31.3	6.5	0.4	1.9	20.4%	20.4%	21.9%
200	3208	515	31.3	7.1	0.2	1.0	11.3%	11.3%	11.0%
250	3480	272	31.3	7.9	0.1	0.5	6.0%	6.0%	5.2%
300	3779	299	31.3	8.5	0.1	0.5	6.6%	6.6%	5.3%
350	3999	220	31.3	9.5	0.1	0.3	4.8%	4.8%	3.5%
400	4158	159	31.3	10.3	0.1	0.2	3.5%	3.5%	2.3%
450	4280	122	31.3	11.2	0.1	0.1	2.7%	2.7%	1.7%
500	4367	87	31.3	12.2	0.0	0.1	1.9%	1.9%	1.1%
550	4431	64	31.3	13.3	0.0	0.1	1.4%	1.4%	0.7%
600	4477	46	31.3	14.1	0.0	0.0	1.0%	1.0%	0.5%
650	4499	22	31.3	15.3	0.0	0.0	0.5%	0.5%	0.2%
700	4513	14	31.3	16.2	0.0	0.0	0.3%	0.3%	0.1%
750	4520	7	31.3	17.2	0.0	0.0	0.2%	0.2%	0.1%
800	4523	3	31.3	18.2	0.0	0.0	0.1%	0.1%	0.0%
850	4526	3	31.3	19.4	0.0	0.0	0.1%	0.1%	0.0%
900	4526	0	31.3	20.4	0.0	0.0	0.0%	0.0%	0.0%
950	4526	0	31.3	21.4	0.0	0.0	0.0%	0.0%	0.0%
1000	4529	3	31.3	22.4	0.0	0.0	0.1%	0.1%	0.0%

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

Altitude Band	Running Total	Count per Band	Static Volume	Corrected Volume	Static Density per Hr	Corrected Density per Hr	% Total per Band	% Static Density	% Corrected Density
50	14,857	14,857	31.3	5.6	0.5	3.0	5.0%	5.0%	8.0%
100	41,828	26,971	31.3	5.9	1.0	5.1	9.1%	9.1%	13.7%
150	75,414	33,586	31.3	6.5	1.2	5.8	11.3%	11.3%	15.7%
200	102,087	26,673	31.3	7.1	1.0	4.2	9.0%	9.0%	11.4%
250	124,523	22,436	31.3	7.9	0.8	3.2	7.5%	7.5%	8.6%
300	147,454	22,931	31.3	8.5	0.8	3.0	7.7%	7.7%	8.2%
350	168,591	21,137	31.3	9.5	0.8	2.5	7.1%	7.1%	6.8%
400	187,117	18,526	31.3	10.3	0.7	2.0	6.2%	6.2%	5.4%
450	203,415	16,298	31.3	11.2	0.6	1.6	5.5%	5.5%	4.4%
500	217,267	13,852	31.3	12.2	0.5	1.3	4.6%	4.6%	3.4%
550	229,537	12,270	31.3	13.3	0.4	1.0	4.1%	4.1%	2.8%
600	240,480	10,943	31.3	14.1	0.4	0.9	3.7%	3.7%	2.3%
650	250,506	10,026	31.3	15.3	0.4	0.7	3.4%	3.4%	2.0%
700	259,328	8822	31.3	16.2	0.3	0.6	3.0%	3.0%	1.6%
750	267,182	7854	31.3	17.2	0.3	0.5	2.6%	2.6%	1.4%
800	273,924	6742	31.3	18.2	0.2	0.4	2.3%	2.3%	1.1%
850	279,757	5833	31.3	19.4	0.2	0.3	2.0%	2.0%	0.9%
900	284,406	4649	31.3	20.4	0.2	0.3	1.6%	1.6%	0.7%
950	287,362	2956	31.3	21.4	0.1	0.2	1.0%	1.0%	0.4%
1000	288,726	1364	31.3	22.4	0.0	0.1	0.5%	0.5%	0.2%

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