U.S. Fish & Wildlife Service

Great Lakes RESTORATION

Great Lakes Avian Radar Technical Report

Lake Ontario Shoreline:

Jefferson, Wayne and

Niagara Counties, New York

Fall 2016

Biological Technical Publication

BTP-R3017-2018

U.S. Fish & Wildlife Service, Region 3

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Funding for this study was provided by the Great Lakes Restoration Initiative

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

Recommended citation:

Heist, K.W., N.A. Rathbun, M.T. Wells, E. Olson, and J. C. Gosse. 2018. Great Lakes Avian Radar Technical Report Lake Ontario Shoreline, Jefferson County, Niagara County, and Wayne County, New York, Fall 2016. U.S. Department of Interior, Fish and Wildlife Service, Biological Technical Publication FWS/BTP-BTP-R3017-2018

ISSN-978-1-938956-10-2
Biological Technical Publications online:
http://digitalmedia.fws.gov/cdm/search/collection/document/searchterm/Biological%20Technical%20Publications/field/collec/mode/exact/conn/and/order/nosort

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Acknowledgements

This project would not have been possible without the funding provided through the Great Lakes Restoration Initiative for which we are very appreciative. We are grateful for the advice, technical assistance, and contributions of our collaborators Doug Johnson (U.S. Geological Service), and Anna Peterson (University of Minnesota). Jake Ferguson's (University of Florida) statistical and programming expertise provided our model of the geometric shape of the radar beam. We also thank the landowners that provided space for our radar units; Robert De Badts, William Haller, and others. We also want to thank other programs for their assistance during this season including the New York Department of Environmental Conservation, U.S. Army at Fort Drum, and the USFWS New York Field Office. This manuscript benefited from external reviews and we thank those that contributed, which included: Tim Sullivan, Fish and Wildlife Biologist at the USFWS New York Field Office; and Jeff Bolsinger, Migratory Bird Biologist at Fort Drum, NY.

Executive Summary

Every spring and fall, millions of birds and bats migrate through the Great Lakes region where shorelines provide important stopover habitat. Shorelines are thought to concentrate migrants as they offer the last refuge near a geographic obstacle and are likely used for navigation. Shorelines also offer areas attractive for the development of wind energy facilities, which may impact birds and bats through direct collision or barotrauma fatalities, avoidance or attraction of birds or bats in flight, or displacement of roosting, nesting, or rafting birds. With this potential for conflicting interests more information is needed on the aeroecology of the Great Lakes shorelines. We used two avian radar systems to identify activity patterns, timing, direction, and duration of migration that occurred along shorelines of the Great Lakes.

We placed avian radar systems at two sites on the south shore of Lake Ontario and one site northeast of Lake Ontario, where the automated systems tracked and recorded target (bird and bat) movements continuously from early August to late October, 2016. We calculated direction of movement, target passage rates, and altitude profiles for targets moving through the air space above our study sites. We also used a model of our vertical sample volume that allowed us to correct for sample volume bias and report an estimate of target density by altitude band.

Migration along Lake Ontario's southern and eastern coasts appeared strong at all three study sites. Mean nocturnal passage rates were greater than mean passage rates for dawn, day, and dusk combined at all three locations. Nocturnal movement was typically oriented in a southerly direction, but we also recorded other behaviors associated with migrants such as dawn ascent and dramatic changes in flight intensity and orientation shortly after sunset. After correcting for differing sample volumes among altitude bands, we found that peak density occurred between 100 – 400 m above ground level. However, density may have been underestimated at higher and lower altitudes. We documented migration activity in the air space above our study areas which indicates that the density of targets at low altitudes may present conservation concerns. The data we collected showed the ebb and flow of migration across the sampling period and documented that large nocturnal movements continued through late October. Given the amount of time that migration occurred in the sampled sites, it seems that curtailing wind energy operations to minimize bird and bat mortality during nocturnal pulses could result in limited operational time along 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 often relied upon to perform surveys for pre-construction risk analysis.

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

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

Given the rapid growth of the wind energy sector, our most effective conservation effort might be our ability to identify and avoid development in locations where migrants concentrate. Our use of commercial-grade avian radar to document migration is a broad-scale effort toward that end. To our knowledge, the Great Lakes radar monitoring project represents the first of its kind by the U.S. Fish and Wildlife Service. The results of our research highlight the potential role of radar in implementing the U.S. Fish and Wildlife Service's Land-Based Wind Energy Guidelines and help to identify areas where impacts to wildlife could be minimized.

Introduction

The Great Lakes are one of the largest freshwater systems on the planet and collectively represent a surface area of nearly 245,000 km^2 with over 17,500 km of shoreline. Global wind patterns help to move millions of migrating birds 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 likely represent a geographic obstacle that migrants choose to cross, or not, based on environmental and physiological conditions at the time of encounter (Faaborg et al. 2010, Schmaljohann et al. 2011). For migrants that rely on powered flight it is more efficient to make several short flights than a long flight due to the cost of carrying high fuel loads (Alerstam 1990). This is perhaps one reason why migrants partially circumnavigate the Great Lakes, though they have the physiological capability of crossing (Alerstam 1990, 2001, Ruth 2007). The decision to cross likely represents a trade-off between minimizing costs (e.g., energy and time) and exposure to risk factors (e.g., predation and fatigue) that are associated with migration (McGuire et al. 2012a). In this trade-off, shorelines offer refuge when conditions do not favor flights over water.

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

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

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

Lakes are subject to pressures from urban and energy development, land conversion, and environmental contamination that may limit habitat availability and/or reduce habitat quality (France et al. 2012).

Of further concern, White-nose Syndrome is devastating hibernating bat populations and has increased the need to identify and protect high-use areas to bolster survival and recovery of cave bats, as several of these species face the risk of extirpation in the Great Lakes region (Turner et al. 2011). Adding further devastation to bat populations is the increase of wind energy installation within the U.S., which has resulted in high numbers of fatalities, most frequently impacting long-distance migratory tree bats (Kunz et al. 2007a, Cryan 2011, Arnett and Bearwald 2013, Hayes 2013, Smallwood 2013, Frick et al. 2017). In response to factors such as these, substantial efforts are being made to identify and protect stopover habitat along the Great Lakes shorelines (Buler and Dawson 2012, Ewert et al. 2012, France et al. 2012, Johnson 2013). With climate change, considerations calling for both an increase in renewable energy development and conservation of migratory species, careful planning is needed to balance these demands.

There is a national movement towards wind power supplying 20% of end-use electricity to the US market by 2030 (US DOE 2008, 2015) and 35% by 2050 (US DOE 2015). If achieved, this would represent nearly a five-fold increase in wind energy capacity during the next 13 years (Loss et al. 2013). Coinciding with this national effort, wind energy developments are increasing within the Great Lakes region where windy 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, Arnett and Bearwald 2013, Hayes 2013, Smallwood 2013). Three species of long-distance migratory bats that are impacted by wind energy facilities account for approximately 75% of all bat mortalities (Cryan 2011, Kunz et al. 2007a, Arnett and Baerwald 2013). These migrants, the hoary bat (*Lasiurus cinereus*), eastern red bat (*Lasiurus borealis*), and silver-haired bat (*Lasionycteris noctivagans*) typically make up the majority of bat fatalities at wind facilities in the Upper Midwest and elsewhere (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 high numbers of little brown and big brown bat fatalities at those sites. Low reproductive rates inhibit the ability of bats to rebound from population decline (Racey and Entwistle 2000) and these declines have already begun for several species (Kunz et al. 2007a, Cryan 2011). Cumulative impacts to bird and bat 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. Some promising conservation measures have been proposed to reduce mortality levels, 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 both renewable energy development and wildlife conservation, we established this project to identify activity patterns, timing, and magnitude of migration that occurs along shorelines of the Great Lakes. This project has been collecting radar data on migration for six consecutive years (Bowden et al. 2015, Horton et al. 2016, Rathbun et al. 2016a, Rathbun et al. 2016b, Rathbun et al. 2016c). Because bats and many bird species migrate during the nighttime hours throughout the spring and fall seasons, documenting bird and bat migration is challenging due to the difficulty of observing nocturnal movements that occur sporadically over the course of a season. To address this we used two avian radar units that operated 24 hours per day and simultaneously scanned horizontal and vertical planes. Our objectives for the portion of the study we are reporting on include:

Objectives

- Monitor locations along the Lake Ontario shoreline 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.
- Estimate the duration of the migration season.
- Identify areas of concentrated migratory activity.
- Document changes in behavior of migrants during different parts of the season.

Methods

Study Area and Site Selection

During the fall 2016 season, we selected three sites in New York State, along southern and eastern Lake Ontario for radar placement; one site was on the western side of the south lakeshore in Niagara County, another site was located on the eastern side of the south lakeshore in Wayne County, and a third was inland from the St. Lawrence River outflow northeast of the lake in Jefferson County (Figure 1). We located the two southern shoreline sites within 1.5 km of Lake Ontario to monitor airspace above inland, shoreline, and lake areas. The Jefferson County site was approximately 25 km from Lake Ontario and 10 km from the St. Lawrence River.

In Jefferson County, the radar unit was located at 44.1746° N, -75.9850° W, in an open field within an area where agricultural fields and patches of deciduous forest were the predominant landscape features within range of the radar unit, according to our analysis using Esri ArcGIS software and the 2006 National Land Cover Database (Fry et al. 2011; Table 1, Figure 2, Appendix 2). A small limestone quarry is located approximately 1 km north of the Jefferson County radar's location. The other two sites in Niagara County (43.3401° N, -78.6591° W) and Wayne County (43.2755°N, -77.0919° W) were both located in apple orchards, with surrounding landscape that included a mix of agriculture (hay and fruit fields) and forested patches. Both southern sites also included substantial segments of coastlines as well as large areas of open water within the horizontal extent of radar coverage (Table 1, Figure 2, Appendix 2). The site in Niagara County was used in a previous season of our project (spring 2013), and the Wayne County Site was located within 1.6 km of our site used during that same season (Rathbun et al. 2016a).

One radar unit, "Batman" collected data at the Jefferson County site for entire study period (August 4 – October 28). The other radar unit, "Robin" began collecting data at the Wayne County site and was moved to the Niagara County site on September 10, in accordance with our study plan. This monitoring regime enabled consistency and comparability without limiting the study to two locations. It allowed us to examine activity at two different locations near the coast, while monitoring throughout the season at an inland site to control for purely temporal variation.

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

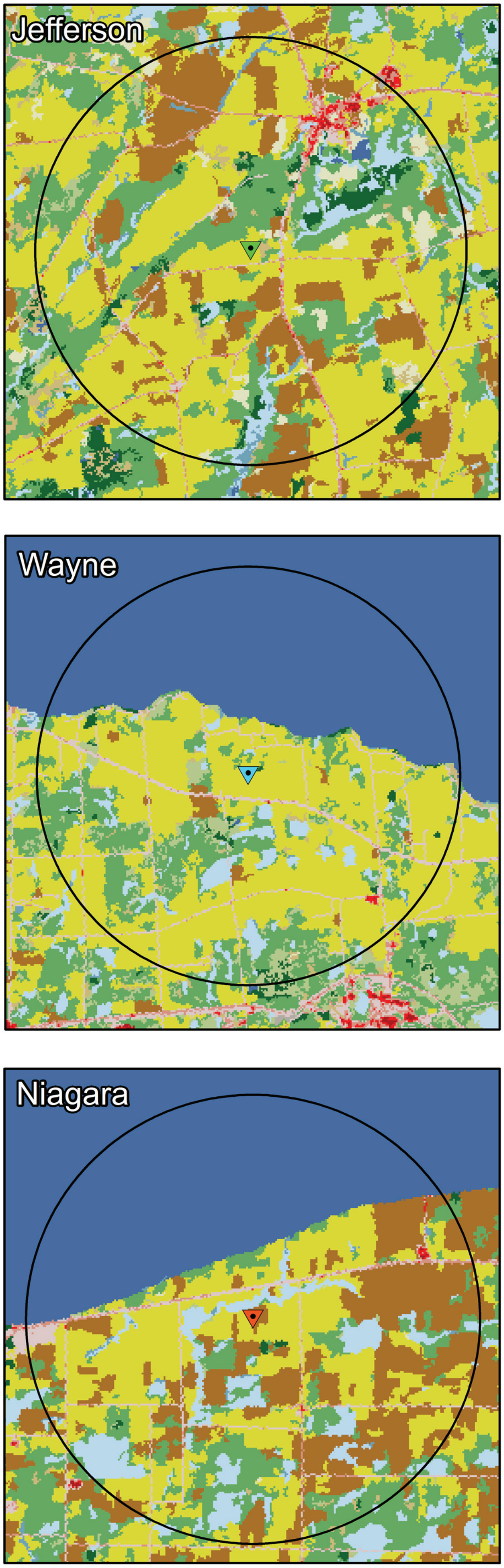
Biologists were dispatched to areas of interest to do a more thorough assessment of potential sites identified by the modeling effort. This assessment included evaluating the land use, visual obstructions, and accessibility for placement of radar units. Additional locations not identified through the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

Figure 1. Fall 2016 radar locations in Jefferson, Wayne, and Niagara Counties, New York. The map image is the intellectual property of Esri and is used herein under license. Copyright © 2016 Esri and its licensors. All rights reserved.

Table 1. Predominant land cover types found within a 3.7 km radius of the radar locations located in New York during fall 2016.

National Land Cover Class	**Jefferson**	**Wayne**	**Niagara**
Cultivated Crops, Hay/Pasture	60.14%	46.69%	39.23%
Developed[1]	4.84%	2.99%	3.84%
Forest[2]	24.29%	10.59%	17.72%
Open Water	0.27%	31.68%	34.70%
Other[3]	10.46%	8.05%	4.51%

[1] Includes low, medium and high intensity development and developed open space.
[2] Includes Deciduous, Evergreen and Mixed Forests.
[3] Includes barren land, grassland/herbaceous, shrub/scrub and woody and emergent herbaceous wetlands.



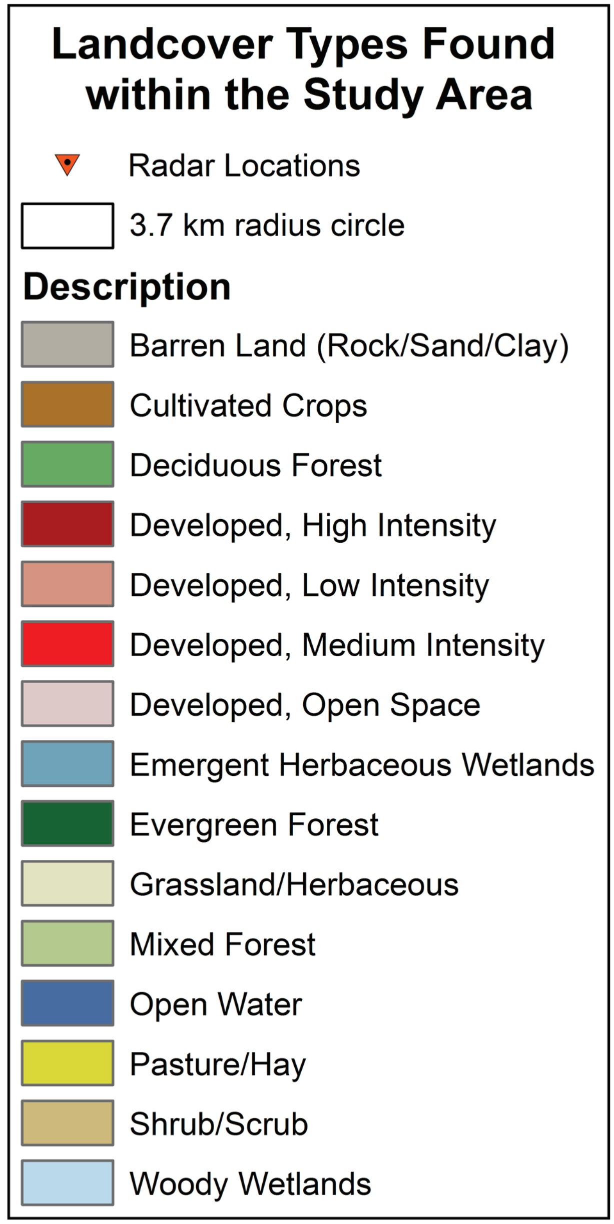


Figure 2. Land cover within approximate horizontal radar range. National Landcover Dataset land cover types within a circle of radius 3.7 km, approximating the horizontal coverage of radar units located in New York during fall 2016. Map image is the intellectual property of Esri and is used herein under license.

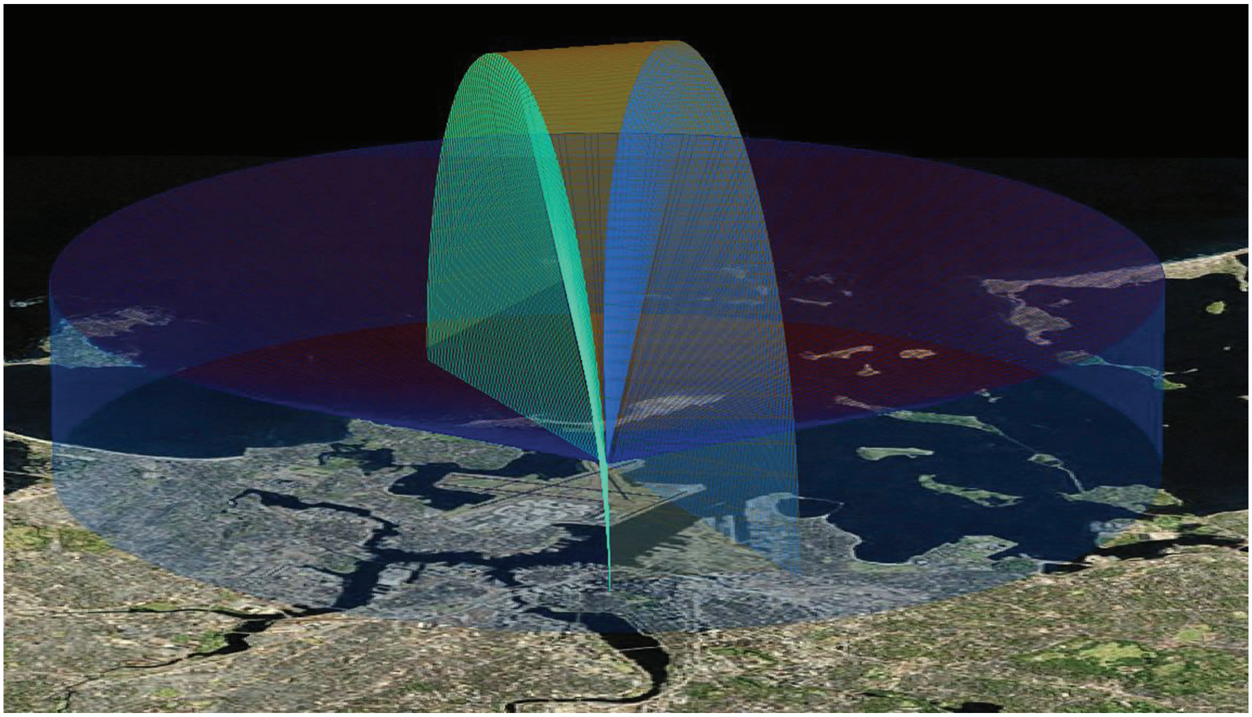


Figure 3. Graphic of volume scanned by horizontal and vertical radars. Blue represents the horizontal radar (HSR) and green represents the vertical radar (VSR). Graphic provided by DeTect, Inc.

Equipment

We used two model SS200DE MERLIN Avian Radar Systems (DeTect Inc., Panama City, FL) to document migration movements. This systems was selected because it is a self-contained mobile unit specifically designed to detect, track, and count bird and bat targets. The tracking capabilities of the MERLIN system have been independently evaluated (Gerringer et al. 2015, May et al. 2017). Each system employed two marine radar antennae 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, storage, and review. The units were configured with a wireless router to allow remote access to the computers and automated status updates.

Description of radars. Solid state marine radar antennas (Kelvin Hughes, London, UK) employed by our systems were 3.9 m in length, with 170 W peak power, S-band (10 cm) wavelength, 2.92 – 3.08 GHz frequency range, and were configured to operate with both short and medium pulse (0.1 and 5 microseconds, respectively). The horizontal radar was also equipped with Doppler to help filter stationary targets. The radars emanated a fan-shaped beam which had an approximate 1° horizontal and 25° vertical span when operated in the horizontal plane. S-band radar (approximately 10 cm wavelength) was selected because the longer wavelength is less sensitive to insect and weather contamination than X-band radar (approximately 3 cm wavelength; Bruderer 1997). It is also less sensitive to signal attenuation from ground clutter such as vegetation and structures (DeTect Inc., unpublished data, 2009). The radars spin perpendicular to each other at a rate of 20 revolutions per minute and were synchronized so as not to emit over one another. The horizontal scanning radar (HSR) was affixed to a telescoping base that was raised to approximately 7 m above ground for operation. This radar rotated in the x-y plane with a 7° tilt to reduce the amount of ground clutter included within its view. While the radar had the capability to scan longer distances, we selected a 3.7 km range setting for data collection in order to have higher resolution and identify smaller targets such as passerines and bats. The HSR was primarily used to provide information on target direction. The vertical scanning radar (VSR) rotated in the x-z plane and scanned a 1° x 25° span of the atmosphere. We selected a 2.8 km range setting for this radar for increased resolution and used the VSR to provide information on the number and height of targets.

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

Radar Set Up and Data Collection

The two radar systems were deployed during the first week of August at the Jefferson and Wayne County sites. In the second week of September, the radar unit in Wayne County was relocated to the study site in Niagara County, while the Jefferson County radar remained in its location. Both radar systems were operational into the last week of October to capture the anticipated end dates of the migration season.

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 fall and oriented the beam of the vertical radars to an angle that was slightly off of perpendicular to anticipated direction of traffic. This orientation was a compromise between a perpendicular angle that would intercept the greatest number of targets (birds or bats) and a parallel angle that would maximize the amount of travel time within the radar beam. The orientation was also influenced by micro-site selection. Micro-site selection is important in that positioning the radar can affect the amount of interference from ground clutter or other sources of radar interference. If large areas were obstructed from the radar view or if substantial amounts of clutter impeded data collection, systems were rotated incrementally to improve the radar's view and/or reduce interference.

The radar's view of sample airspace can be obscured by two main sources of interference, both of which can be seen on the clutter maps (Figure 4). 1) Ground clutter is produced by static returns from ground-based objects such as trees, buildings, towers, and topographical features. Ground clutter is more prevalent on the horizontal antenna due to its low beam angle, and creates "blind spots" in which target detection is partially or totally blocked. 2) Side lobes are more prevalent on the vertical antenna, and take the form of low-elevation patches or arcs, indicating return energy from airspace that is actually empty. Side lobes result from irregular and unpredictable refractions of the radar beam off the surrounding landscape or atmosphere. Side lobes can be reduced by making small adjustments to the radar's orientation, but can rarely be eliminated.

To improve radar tracking performance, tracking software analyzed the site's airspace prior to data collection to "map" areas of clutter that would be removed from target tracking. Clutter maps (Figure 4) were generated using 60-scan composite images, taken at time periods with low biological activity in order to identify areas with constant returns (white) associated with ground clutter or side lobes. These areas were assigned a reflectivity threshold that precluded the constant returns from being included in the data used for target tracking, and as a result, also reduced our ability to detect targets in these areas.

Whereas the vertical scan at Wayne was relatively clean, the Jefferson site had some interference at low altitudes near the radar, and Niagara had several side lobe arcs at various distances from the radar. Clutter on the horizontal antenna was worst at the Jefferson site, and relatively clean at Wayne and Niagara. However, the Wayne site had an obstruction to the south that created a blind spot to the south and southwest of the radar unit. Clutter on the horizontal antenna is more likely to prevent target detection, and is one reason horizontal data include numerous broken tracks in which a single animal is counted multiple times. Data from the vertical antenna are more reliable for counts. The vertical sample volume is cleaner overall, and especially at high altitudes. Side lobes on the vertical antenna can reduce detection rates in certain areas, but do not completely block detection except in very high-return areas near the ground (bright white), and do not prevent detection of targets behind the obscured area, as ground clutter does. Variation in detection rates among sites can have an effect on results, but we currently have no means of correcting for these effects.

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).

Following initial set up, MERLIN software was fitted to site conditions. The MERLIN software provides real-time processing of raw radar data to locate and track targets while excluding non-targets and rain events. However, parameters used by the tracking software require adjustments to account for site specific conditions. DeTect personnel trained our biologists in establishing these settings during previous seasons of this project with the goal of minimizing inclusion of non-targets while maximizing cohesive tracks of targets.

Processed data from each day were stored in Access databases, which were regularly transferred into a cumulative SQL database containing data for the

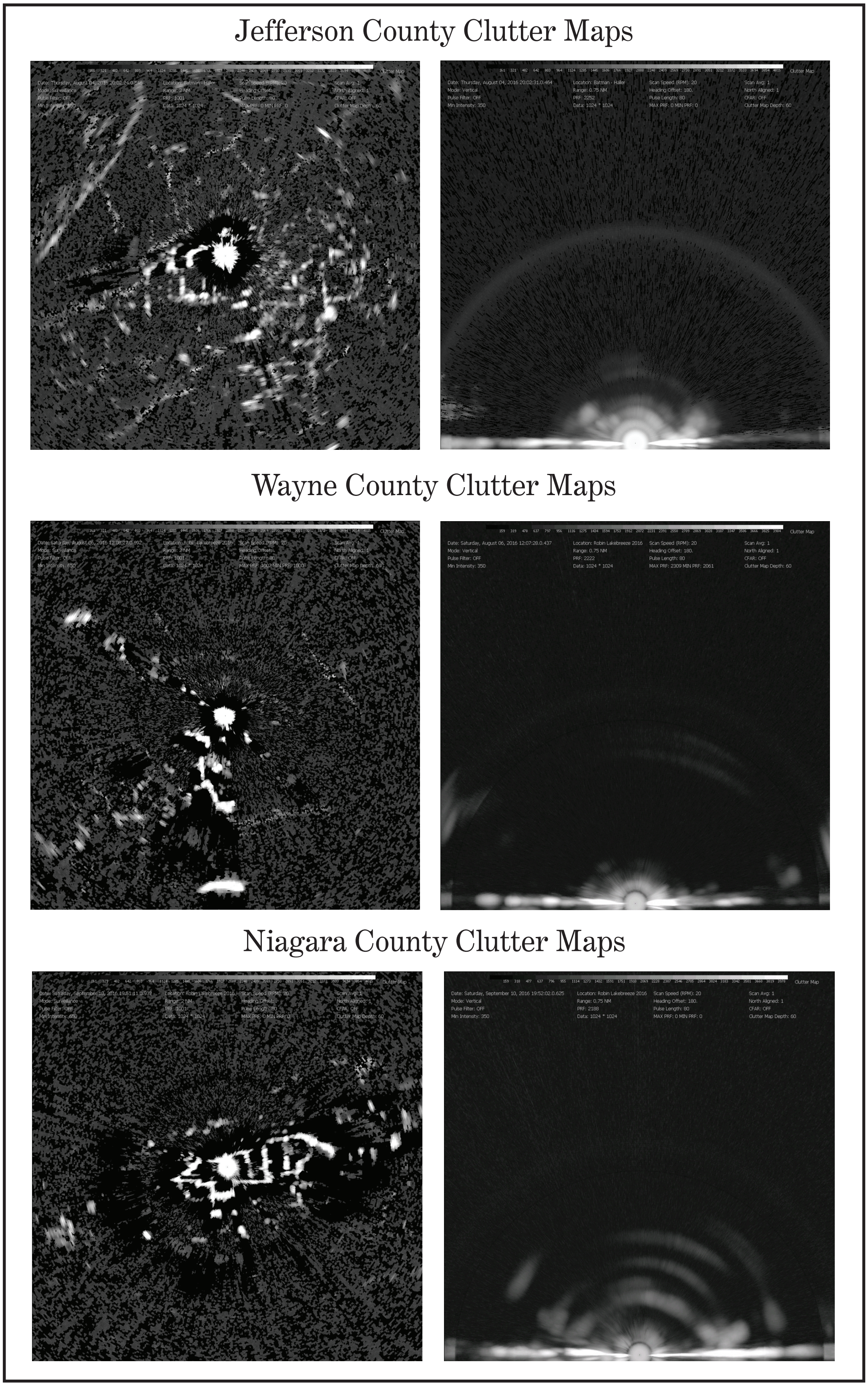


Figure 4. Clutter maps for horizontal antenna (left, radar at center) and vertical antenna (right, radar at bottom middle). Brighter areas represent static returns from stationary objects such as tree lines and fencerows. Detection of targets may be lost in these areas due to obstruction from these objects.

entire season. SQL databases were later queried for data analysis. In addition to processed data, we maintained all raw radar image data for potential reprocessing until the end of the migration season. Raw radar data were temporarily stored in the field on external hard drives and regularly transported back to the USFWS Regional Office (Region 3) on external drives.

Biologists visited each site periodically during the data collection period to ensure continuous function, monitor raw (unprocessed analog radar returns) and processed radar outputs, provide routine maintenance (such as re-fueling and oil changes), and manage data storage.

Radar System Outputs

The MERLIN software generates more than 30 measurements to describe the size, shape, location, speed, and direction of movement of each target detected. 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. As well, an automated filter was used to remove sectors of the sample volume that were dominated by rain.

In addition to storing target attribute data, DeTect software outputs included a two-dimensional digital display of targets being tracked in real-time and static images of tracked targets over a specified period of time (Trackplots) for both vertical and horizontal radars. During each site check, we viewed the real-time digital display to ensure it agreed with the raw radar display. We later viewed 15-minute and 1-hour Trackplots to assess target direction and height during the previous day's activity.

Data Processing and Quality Control

Prior to data analysis, data processed by MERLIN software was further evaluated for potential contamination by non-targets. While an automated rain filter was used, during some time periods it did not remove all rain from the recorded outputs. In addition, insects and various forms of transient clutter may be recorded during data collection. We relied on visual inspection of track patterns to discern contamination events. Rain and insect events form diagnostic patterns (Detect Inc., personal communication, 2011) and time periods with these types of track patterns can be removed when present. Biologists reviewed all data in 15-minute time increments and removed time periods that were dominated by rain; data were also reviewed for time periods dominated by insects or other clutter, but there were no time periods where these types of non-desirable targets needed to be removed from the dataset. Unknown contamination that mimicked patterns of desired targets was not removed from the database and, to the extent that this occurred, contributed to error associated with indices. In addition to visual review, we evaluated initial counts by generating a time series to show the number of targets per hour across the season for both HSR and VSR radars. In general, the HSR and VSR hourly counts are positively correlated, with the HSR having higher counts. In situations where the VSR resulted in higher counts than the HSR or where peak counts appeared to be outliers, the data was further investigated for evidence of contamination or potential issues with radar performance. On rare occasions when time periods with anomalies appeared to represent artifacts not related to target movement (e.g., rain events, insects or data processing errors) they were removed from further analysis.

Once contaminated time periods were removed we summarized data using SQL queries provided with the MERLIN radar system. Data from the HSR were used to calculate hourly counts and target direction. All targets within 3.7 km of the radar unit were included in the analysis. Data from the VSR were used to calculate hourly counts and height estimates and these data were truncated to a 1-km front or "standard front". We adopted this sampling technique as it is the method used by the manufacturer of the MERLIN units and this metric is also reported by other researchers (Lowery 1951, Liechti et al. 1995, Kunz et al. 2007b). The standard front was defined by a volume of space that extended 500 m to either side of the radar and continued up to 2800 m, the maximum height of data collection (Figure 5).

Biological Time Periods. For each site location, sunrise and sunset times were calculated and target counts were further segregated into four biological time periods: dawn, day, dusk, and night. "Dawn" was defined as 30 minutes before sunrise to 30 minutes after sunrise, "day" as 30 minutes after sunrise to 30 minutes before sunset, "dusk" as 30 minutes before to sunset to 30 minutes after sunset, and "night" as 30 minutes after sunset to 30 minutes before sunrise.

Data Summary and Trends Analysis

We used the processed data to assess activity patterns that are associated with migration. Horizontal Trackplots were viewed to identify changes in activity and to investigate migrant behaviors such as reverse migration (Akesson 1999) and migrants moving toward shore at dawn; Vertical Trackplots were viewed to investigate changes in activity such as dawn ascent (Myres 1964, Diehl et al. 2003). 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 methodology for circular statistics (Zar 1999) provided within DeTect SQL queries. The angular concentration value is 1 when all angles are the same and 0 when all angles cancel each other (e.g., if 50% of the vectors are 180° and 50% are 360°, then there is not a predominate direction because there were as many targets heading south as there were heading north, thus the angular concentration is 0). We anticipated a generally southward direction of movement from nocturnal targets during the fall migration season and report the mean direction of nocturnal targets and the percent of nights targets

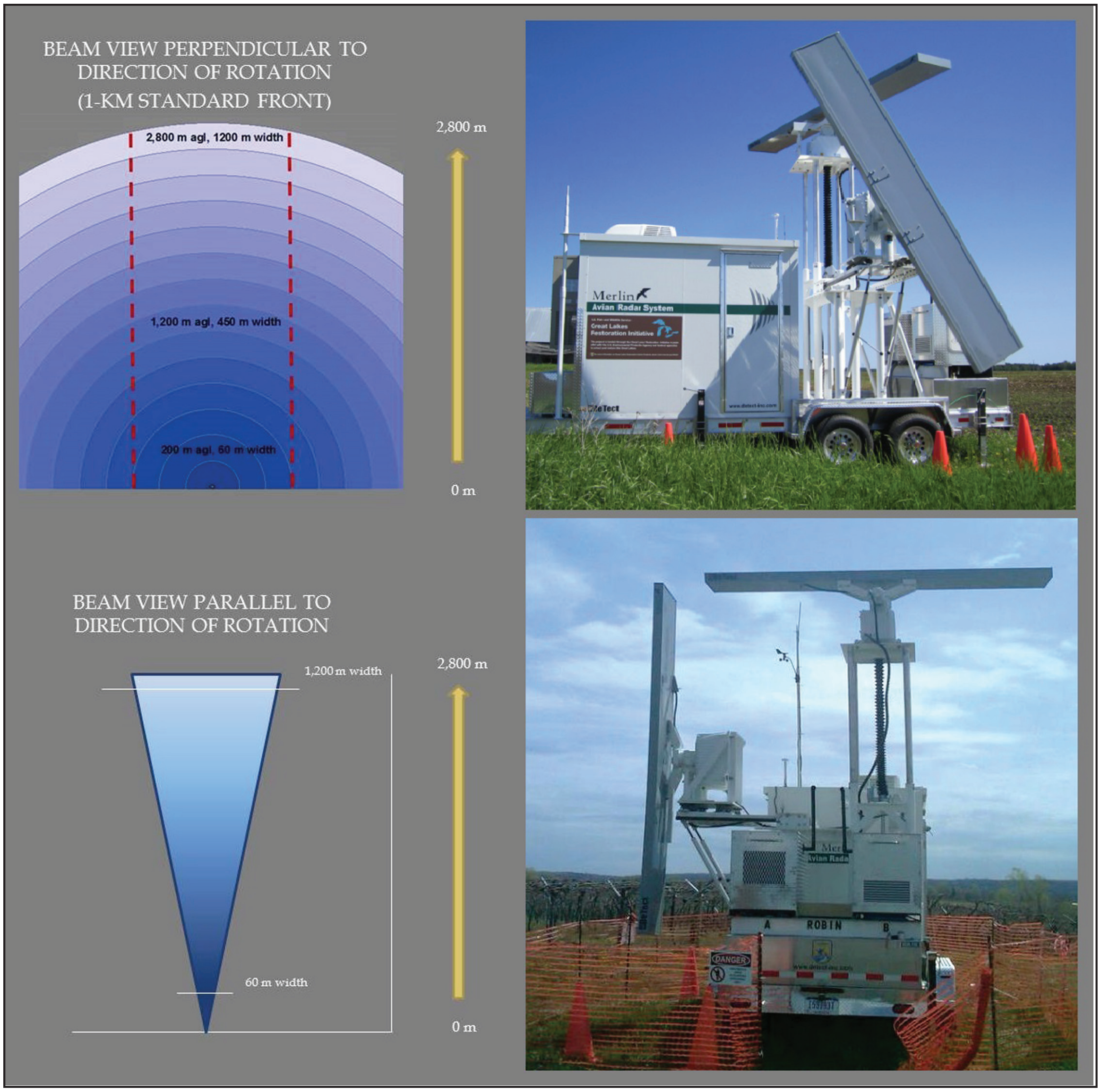


Figure 5. Schematic of vertical scanning radar beam. Graphical representations (left) pair with photos (right) of the radar unit aligned perpendicular (top) and parallel (bottom) to rotational plane. The standard front used for data analysis is marked on the top left image. The standard front extends to 500 m on either side of the radar and up to a height of 2800 m. In this graphic the radar is situated at the bottom center and the red dashed lines represent the lateral limits of the standard front. In the bottom graphic the radar rotation is suspended so that the beam emits directly upward; this view is an approximation of the beam dispersion as it travels away from the radar unit (schematic not drawn to scale).

traveled in a direction between east-southeast and west-southwest (112.5° – 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 the four biological time periods dawn, day, dusk, and night.

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

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

Altitudinal Trends. DeTect SQL queries calculated height estimates from the VSR data of targets tracked within the standard front. Height estimates were calculated based on the range and bearing of the target location with the largest radar echo and reported as the height above ground level as measured at the radar unit; this measurement does not take into account changes in topography as you move across the landscape. We used these estimates to calculate mean altitude of targets above ground level by biological time period and hour and report mean and median altitudes for the season.

Density per Altitude Band. In order to provide information on the density of targets per 50-m altitude band per hour within the standard front, we first estimated the volume of the radar beam's approximate geometric shape. The width of the radar beam expands as it travels from the radar resulting in increased survey volume with distance from origin. The shape of the survey volume contains the space in which targets have the potential of being detected and represents one of several considerations that define the realized or actual survey volume (Bruderer 1997, Schmaljohann et al. 2008). We calculated the volume contained by the shape of the radar beam and report density of targets (targets per 1,000,000 m3) per 50-m altitude band per hour for each biological period. This was calculated by dividing the number of targets per volume of an altitude band by the number of minutes with clean data during the biological time period of interest and multiplied by 60.

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

We used R software (R Core Team 2012) to describe a box of known volume that was large enough to enclose the radar beam and saturated this space with 10 million random points. For the radar beam, we determined two simple rules that defined whether a point was in the survey volume. The first rule was that the distance of the randomly drawn point from the origin was less than 2.8 km, the second rule was that the angle between a randomly drawn point and the vertical plane (the x-z axis in Figure 6) was less than 12.5° (i.e., half the angle of beam width). The volume of a full sweep of the radar beam as estimated via Monte Carlo integration was within 5% of the analytical solution using spherical coordinates, thus, the number of random points that we used provided a reasonable approximation of the volume. With the volume of a full sweep of the radar beam described we were able to further constrain the Monte Carlo integration to describe the structural volume of the radar beam within a standard front (Figure 6) and within altitude bands (Figure 7).

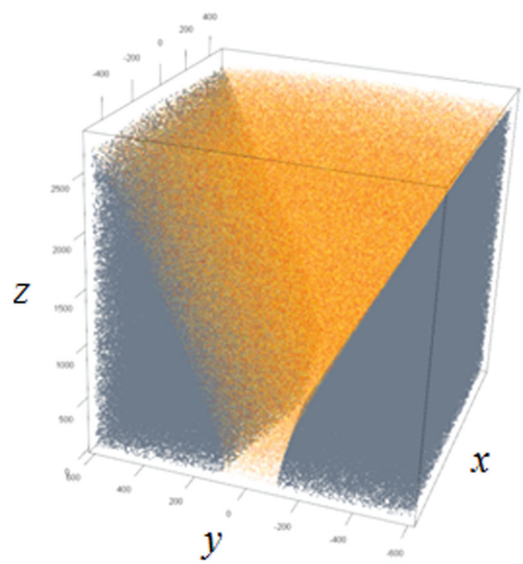


Figure 6. Sample volume estimation for the vertical scanning radar within the standard front. In this graphic the radar unit is located at the origin and the radar beam extends to 500 m on either side of the radar unit (x-axis) and up to a maximum height of 2800 m (z-axis). The y-axis represents the spread of the radar beam as it extends away from the origin. The orange semi-transparent points represent the volume contained by the structure of the radar beam. Dark gray points represent the volume that is within the box but are not included in the volume of the radar beam.

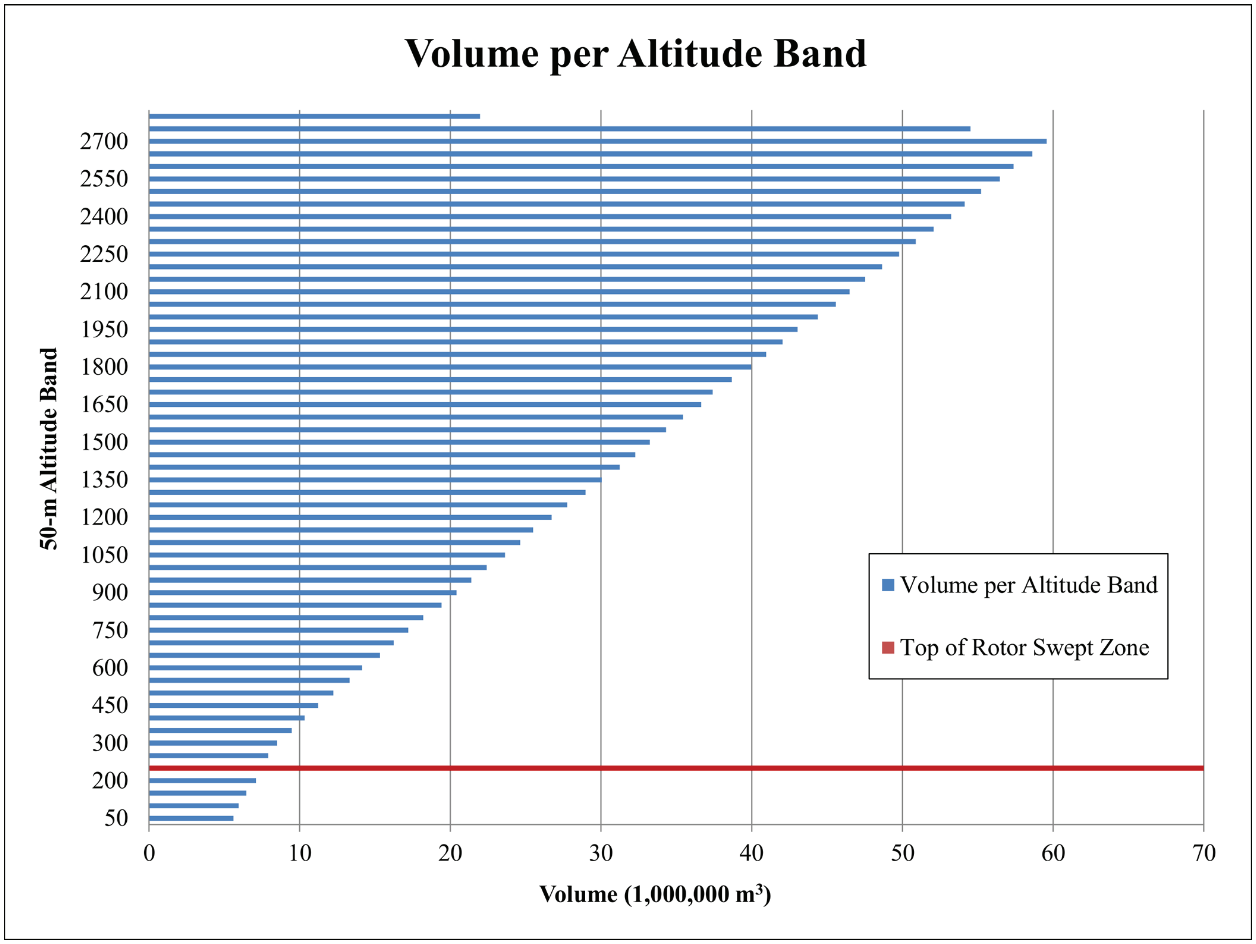


Figure 7. Volume of 50 m altitude bands within the standard front. Volumes were estimated with Monte Carlo integration. Altitude band intervals represent the upper band limit. Target counts provided by the vertical scanning radar are limited to the structure of the standard front. The red line represents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

The number of targets per altitude band is often reported by other researchers; however, these numbers are commonly reported without 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 compare our density estimate to a density estimate based on the number of targets per 50-m altitude band per hour while assuming that there is an equal amount of volume within each altitude band (the volume of each altitude band is equal to the total volume divided by the number of altitude bands). An assumption implicit to reporting the number of targets per altitude band is that comparisons among bands can be made directly (i.e., that altitude bands are equal). For our comparison metric we made this implicit assumption explicit (see Appendix 4).

Results

During the fall 2016 season we began data collection on August 3 and 4 at the Wayne and Jefferson County sites, respectively. Data collection at Wayne ended on September 9, 2016, at which point this radar unit was relocated to Niagara County. Data collection at the Niagara site began on September 10. The radars remained operational until October 27, resulting in a survey period of 2042 hours at the Jefferson site, 924 hours at the Wayne site, and 1177 hours at the Niagara site (Table 2). Data were recorded continuously while the radar units were operational. Gaps in analyzed data occurred mostly during rain events. Limited radar downtime occurred when the radar units were not operational due to computer hardware or software malfunction, and/or maintenance. Minor data gaps occurred at Jefferson County on August 22 (HSR only), September 2, and October 21 (VSR only); Wayne County on August 4; and Niagara County on September 24 (HSR only) and October 20 (VSR only).

When correcting for radar downtime and removal of periods with rain, the radars collected useable data 86% and 94% of the season in Jefferson County, 88% and 93% in Wayne County, and 87% and 93% in Niagara County, with the vertical and horizontal radars, respectively.

Table 2. Survey effort (hours) by vertical and horizontal scanning radars during fall 2016 at our radar sites in Jefferson, Wayne, and Niagara Counties in New York. Vertical and horizontal radars are not equally impacted by rain events or downtime.

Site	Radar	Survey Period	Radar Downtime	Data Collected	Data w/Rain	Usable Data	% Data Collected	% Usable Data
Jefferson	VSR	2,042	67	1,975	214	1,761	97%	86%
Jefferson	HSR	2,042	91	1,951	22	1,929	96%	94%
Wayne	VSR	924	45	879	69	809	95%	88%
Wayne	HSR	924	52	872	9	863	94%	93%
Niagara	VSR	1,177	35	1,142	124	1,018	97%	87%
Niagara	HSR	1,177	77	1,100	5	1,095	93%	93%

Qualitative Assessments

Plots of tracked targets showed nocturnal migration events at all three locations (Figures 8, 9, and 10). Examples of a single night from each site are included on the following pages. Each page displays eight one-hour periods of target tracking that display the increase and decrease of flight activity over the course of a day: noon, 18:00, 20:00, 23:00; and 1:00, 4:00, 5:00, and noon the following day are included. Times are in Eastern Standard Time (UTC – 5:00), not adjusted for daylight saving time.

On September 1 at the Jefferson County site, we can see light traffic at noon, with little concentration of direction (scattered flights of various colors) and mostly low elevations. These tracks may represent short-distance daily movements. At 18:00, flight activity is still light, but some southward concentration is beginning to occur, which may indicate that some early departures for migratory flights are starting. Sunset on September 1 at this site was at 18:39 (EST). By 20:00, the horizontal radar image shows mass migration in the south and southeast directions (red and yellow respectively). The vertical image shows the most intense movement at about 750 m above the radar, with most activity occurring below 2000 m.

Heavy migration continues through the 23:00 hour at the Jefferson County site, with flight directions still concentrated to the south, but a shift to more southwesterly (orange) routes. Altitudes appear more concentrated at this hour as well, with the most intense activity around 600 m and 1300 m. Low-elevation flights have become relatively sparse. Activity decreases slightly by the 1:00 hour, with flights still predominantly towards the southwest. High-elevation

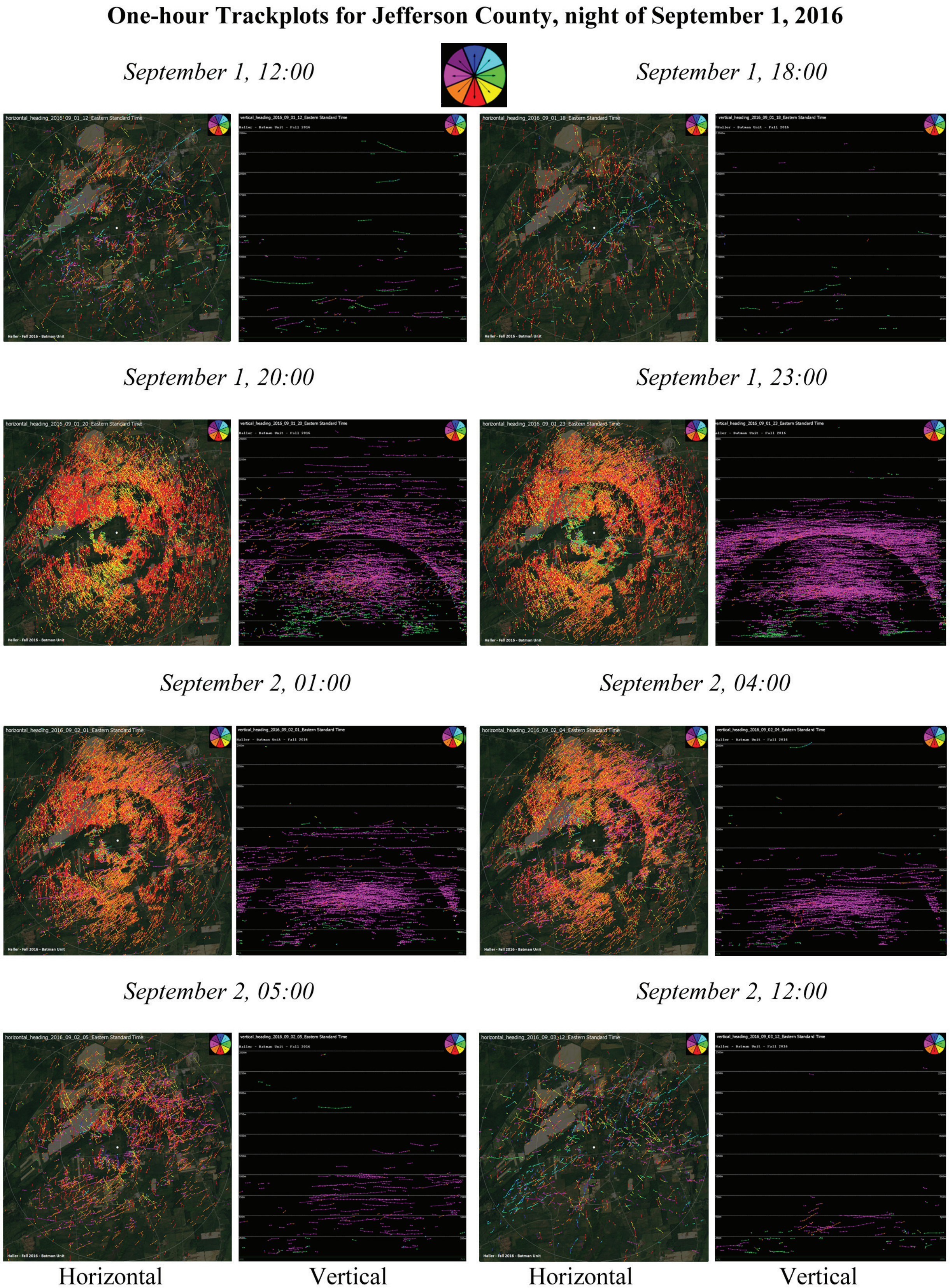


Figure 8. Sample Trackplots at Jefferson County. Flight tracks during 1 hour increments recorded by horizontal (first and third columns) and vertical (second and fourth columns) radars during a migration event at the study site in Jefferson County. Colors on the horizontal radar images show direction of flights as indicated on the color wheel (dark blue indicates a direction of travel to the north and red travel to the south). Vertical radar images show target heights (colors do not indicate direction).

One-hour Trackplots for Wayne County, night of August 28, 2016

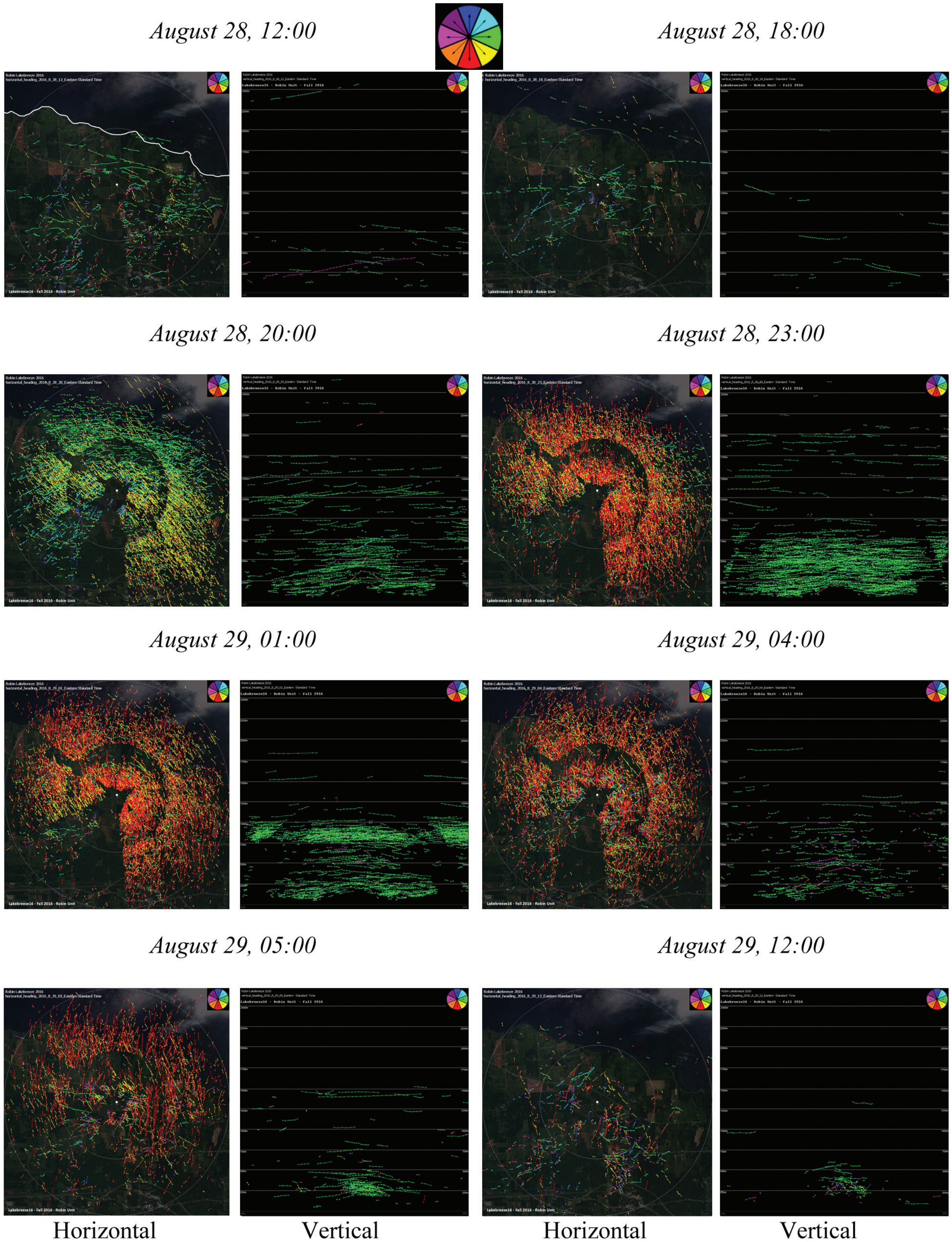


Figure 9. Sample Trackplots at WayneCounty. Flight tracks during 1 hour increments recorded by horizontal (first and third columns) and vertical (second and fourth columns) radars during a migration event at the study site in Wayne County. Colors on the horizontal radar images show direction of flights as indicated on the color wheel (dark blue indicates a direction of travel to the north and red travel to the south). Vertical radar images show target heights (colors do not indicate direction). The coastline is highlighted in white on the first horizontal image.

One-hour Trackplots for Niagara County, night of October 22, 2016

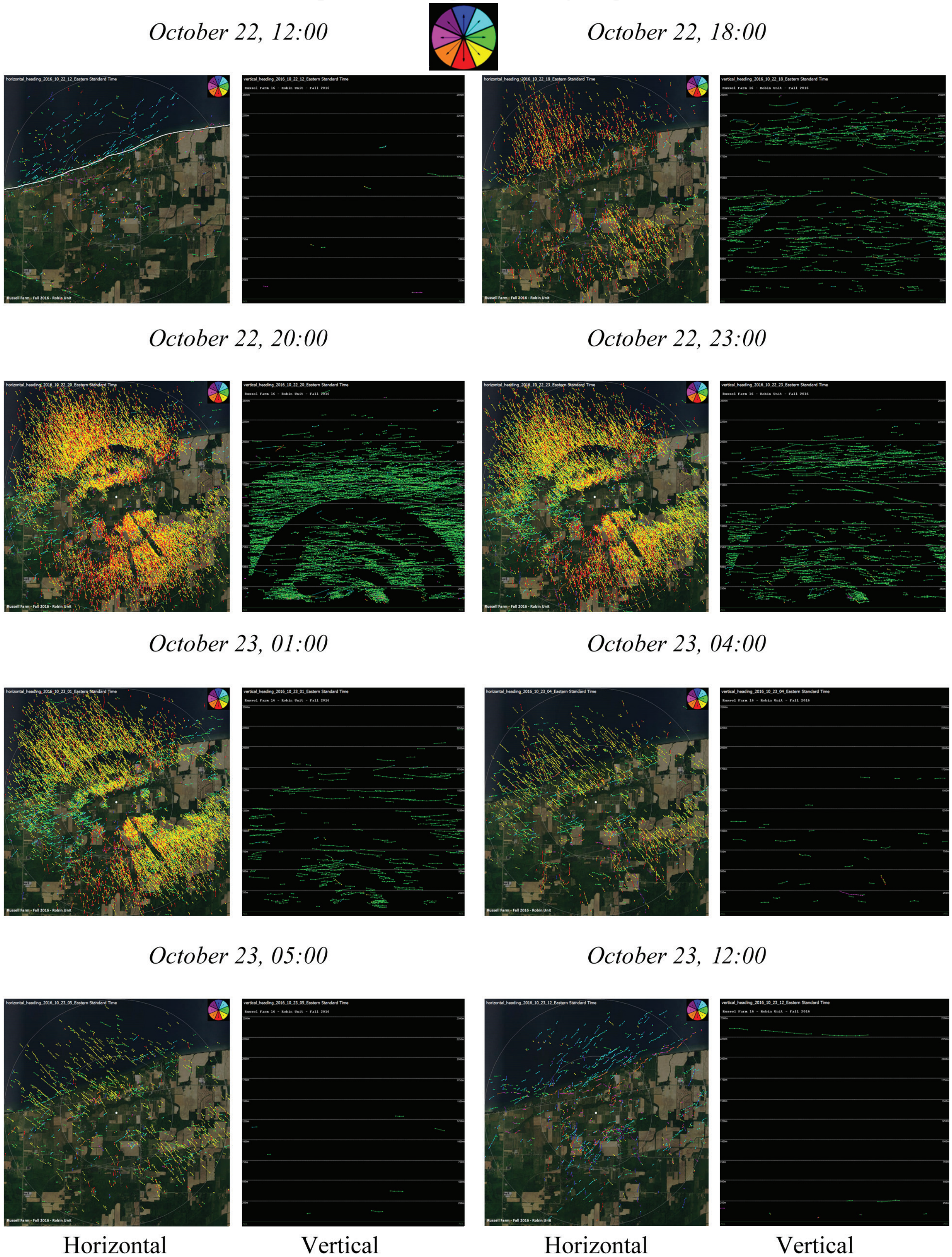


Figure 10. Sample Trackplots at Niagara County. Flight tracks during 1 hour increments recorded by horizontal (first and third columns) and vertical (second and fourth columns) radars during a migration event at the study site in Niagara County. Colors on the horizontal radar images show direction of flights as indicated on the color wheel (dark blue indicates a direction of travel to the north and red travel to the south). Vertical radar images show target heights (colors do not indicate direction). The coastline is highlighted in white on the first horizontal image.

flights have mostly stopped, and flights appear clustered between 500 m and 750 m. A similar pattern is apparent at 4:00, with moderate southwestern flight activity concentrated around 600 m. At 5:00, activity has significantly dropped, directions are more mixed, and there is little altitudinal concentration. Sunrise was at 05:29 (EST) at this site on September 2. By noon, flight activity is sparse and directionally scattered, similar to the same time period the day before.

At the Wayne County site on August 28-29, another typical migration event was captured. The pattern is somewhat similar to the sequence from September 1-2 in Jefferson County, however here the effect of the coastline can be seen. In daytime flights (12:00), several birds fly parallel to the coast in an east-west direction. The coastline runs approximately WNW to ESE, with the Lake in the top 1/3 of the image. At 18:00, traffic is still light, but most flights are to the east and southeast. At 20:00, activity increases dramatically, with targets near the coast flying east and targets south of the coast flying southeast. A directional shift is apparent at 23:00, with most targets flying south or southeast. Flight heights are generally low throughout this night, with concentration below 750 m. Southerly flights continue at 1:00, but targets are now concentrated between 750 and 1000 m above the radar. Activity decreased during the 4:00 and 5:00 hours, but still strongly directional to the south; the altitudinal concentration has dispersed. By noon, activity is again sparse and scattered.

The trackplot sequence for the Niagara County study site on October 22-23 shows another episode of nocturnal migration. Flight activity increases dramatically after nightfall (sunset at 17:19), then decreases through the early morning and returns to low levels by midday. Directionality of flights at the Niagara site was more heavily concentrated to the southeast on this night, which is approximately perpendicular to the coastline at this site. Some concentration of flights near the coastline in the NE-SW direction can be seen on the daytime images.

Images from high-activity time periods during the night also illustrate the patterns of high and low detection on both horizontal and vertical radars. These patterns result from three different phenomena. First, both antennae have a blind spot immediately around the radar, out to a distance of about 300 m. This initial "main bang" is an area of high energy return that occurs close to the radar antenna, and is common to all radars. To prevent constant overwhelming returns from this region, it is masked (excluded from target tracking) on both HSR and VSR using site-specific clutter maps discussed earlier in this report (Figure 4). Second, topographical features, vegetation, and other structures can also prevent target detection by blocking the radar signal along the line-of-sight between the radar and target. Because this ground clutter is typically stationary, it will prevent target detection in the same area on successive radar scans, resulting in distinct blind spots or "shadows," which are particularly evident during times of high activity. These shadows can be seen as white areas on the clutter maps, for example forested hills to the west and south-southeast of the Jefferson radar, to the south of the Wayne radar, and to the east and west of the Niagara radar. Third, this particular radar system uses two different radio frequencies to detect targets at different distances. Maximum detection of birds and bats occurs at different distances from the radar depending on the specific frequency used. To increase target detection over a larger area, Merlin uses two different frequencies, one with maximum detection at about 500 m, the other with maximum detection at about 1000 m or more. To enable the use of both frequencies in the same scan, the radar receiver switches between listening for short-distance signal returns and long-distances signal returns in quick succession. This produces a circle (on HSR) or arc (on VSR) where the detection rate shifts from low to high, at about 1600 m and 1300 m from the HSR and VSR antennae, respectively.

Directional Trends

During the fall 2016 season, nocturnal target flight directions were mixed during the dawn, day, and dusk periods, but were predominantly oriented in a southern (southwest, south, or southeast) direction during nocturnal activity at all three sampled locations (Figures 11-13, Table 3). Night was the biological time period with the most flight activity, with target numbers (n, Table 3) substantially exceeding those of dawn, day and dusk combined. Mean direction of nocturnal flights was close to south (180°) for all three locations: 188°, 189°, and 193° for Jefferson, Wayne, and Niagara respectively. Angular concentration (r), which is close to one if targets are flying in the same direction and close to zero if they are flying in different directions, was highest at night for all three sites as well. In addition, most targets were flying in a similar direction ($r \geq 0.5$) during about 75% of the night, whereas times of common directional movements were much more infrequent during other biological time periods. The common directionality and southward orientation of flight is strong evidence that much of the nocturnal activity observed is associated with long-distance migratory flights.

Jefferson County

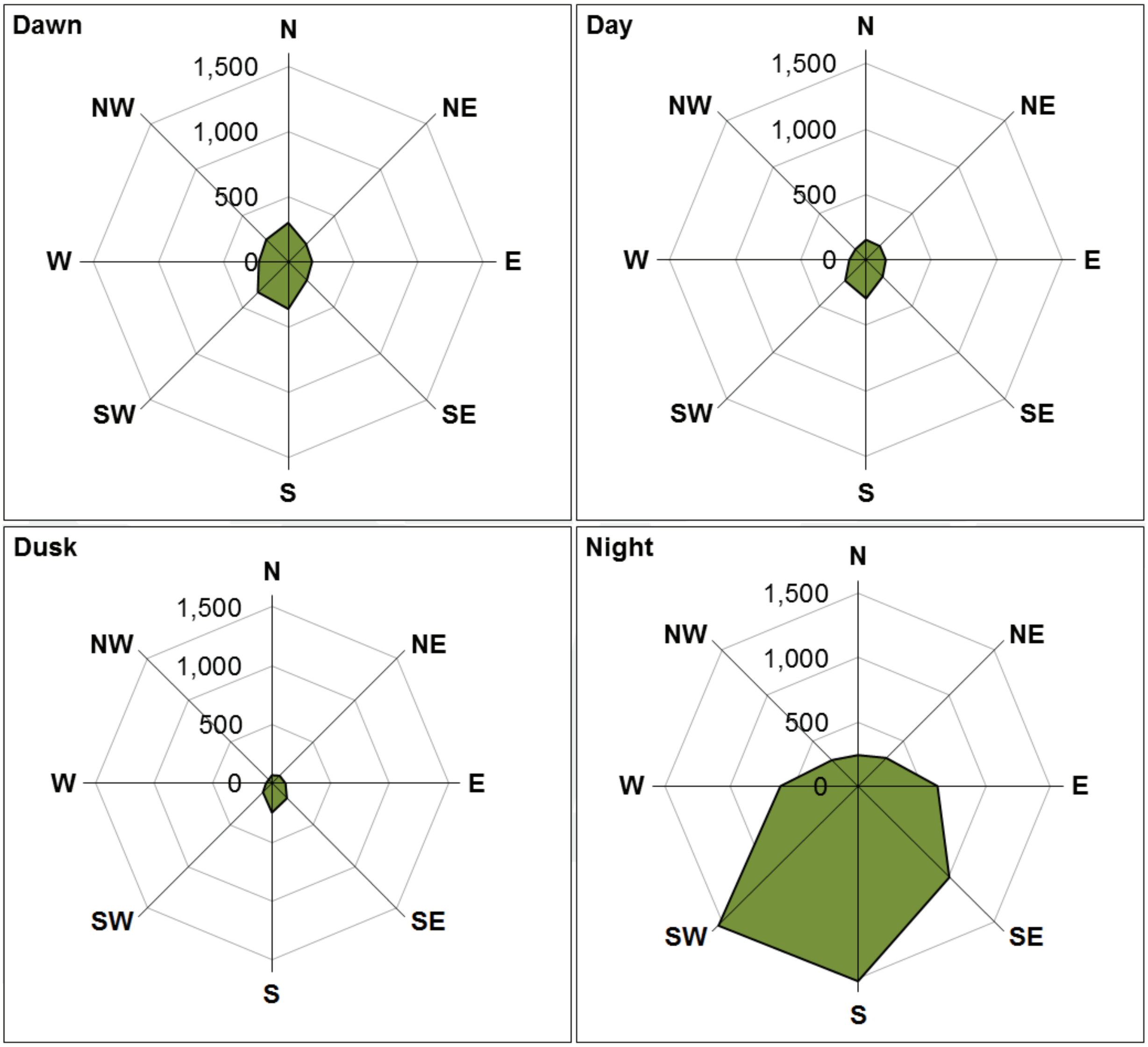


Figure 11. Direction of targets during Dawn, Day, Dusk, and Night at the Jefferson County site. Each point on the perimeter of the rose graph indicates the average number of targets per hour moving in each of the eight directions. Axis scale is fixed, so the area of polygons also represents the relative amount of target activity during that period.

Wayne County

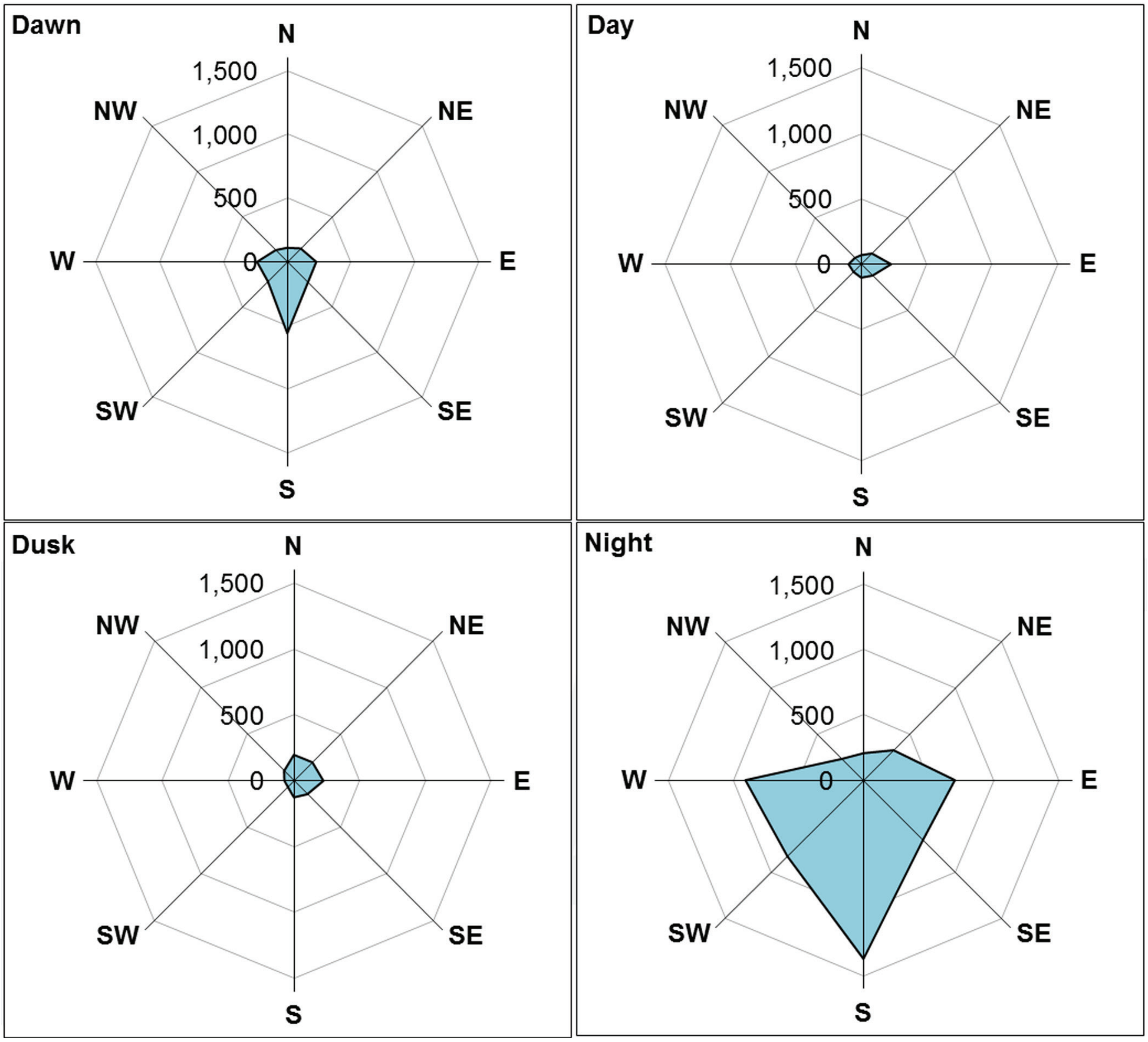


Figure 12. Direction of targets during Dawn, Day, Dusk, and Night at the Wayne County site. Each point on the perimeter of the rose graph indicates the average number of targets per hour moving in each of the eight directions. Axis scale is fixed, so the area of polygons also represents the relative amount of target activity during that period.

Niagara County

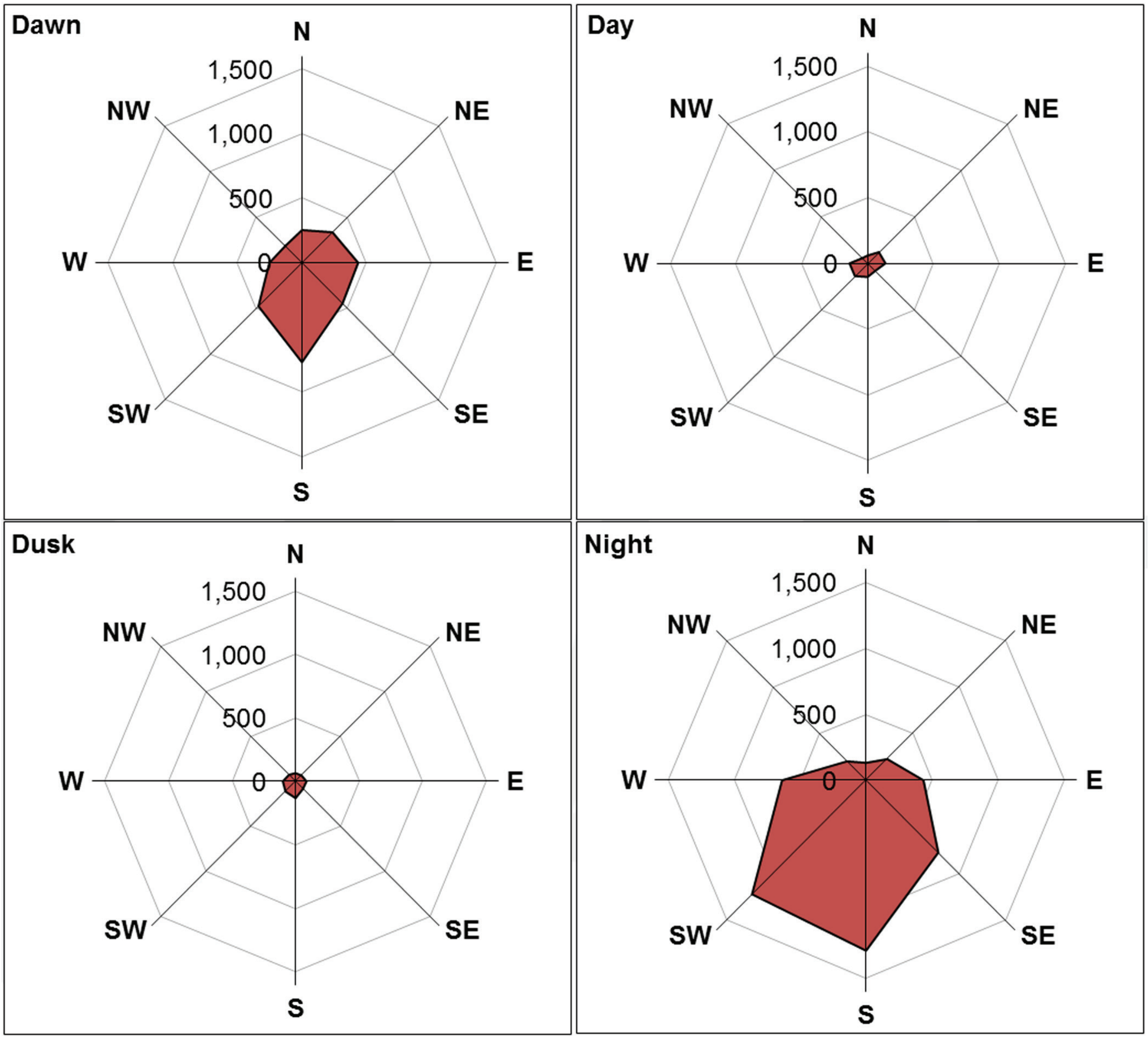


Figure 13. Direction of targets during Dawn, Day, Dusk, and Night at the Niagara County site. Each point on the perimeter of the rose graph indicates the average number of targets per hour moving in each of the eight directions. Axis scale is fixed, so the area of polygons also represents the relative amount of target activity during that period.

Table 3. Mean direction, angular concentration (r), and percent of biological time periods with strong directionality (r ≥ 0.5) of targets during biological time periods at our sites in New York.

	Jefferson				Wayne			
Biological Period	Mean Direction (degrees)	r	% of Time r ≥ 0.5	n	Mean Direction (degrees)	r	% of Time r ≥ 0.5	n
Dawn	232	0.11	29.1%	163,652	179	0.31	48.4%	68,388
Day	178	0.17	8.9%	1,261,025	105	0.23	10.0%	401,731
Dusk	153	0.37	48.1%	73,602	64	0.28	48.4%	41,655
Night	188	0.45	74.4%	5,297,392	189	0.36	74.2%	1,763,623

	Niagara			
Biological Period	Mean Direction (degrees)	r	% of Time r ≥ 0.5	n
Dawn	162	0.28	45.7%	147,870
Day	177	0.09	4.4%	396,842
Dusk	203	0.16	37.8%	32,335
Night	193	0.48	73.3%	2,597,193

To visualize the direction and magnitude of migration movements each night, we plotted mean orientation angle and target count as lines on a map of the region (Figures 14-16). These lines approximate the origin of migrant targets, assuming that targets maintain a relatively constant heading throughout nighttime flights. Mean flight directions were highly variable at the Jefferson County site (Figure 14), but typically indicated origination from the northeast, north, or west. Heavy movement during late August and early September was observed both from the direction of the St. Lawrence River to the northeast, as well as from the north shore of Lake Ontario to the west. Several nights of "reverse migration" early in the season were observed at the Jefferson County site as well. Flights directly from the north were most frequent during the latest nights in mid to late October. At the Wayne County site (Figure 15), many of the flight directions throughout the first half of the season indicate flights over Lake Ontario, originating to the north or northwest of the radar location. A few large flights from the east and southwest were observed, and very little activity moving north from the Finger Lakes region was seen. At the Niagara County site (Figure 16), flight directions from many nights, especially late in the season, indicate flight over Lake Ontario. Several of the largest flights had average origination from the southeast or southwest.

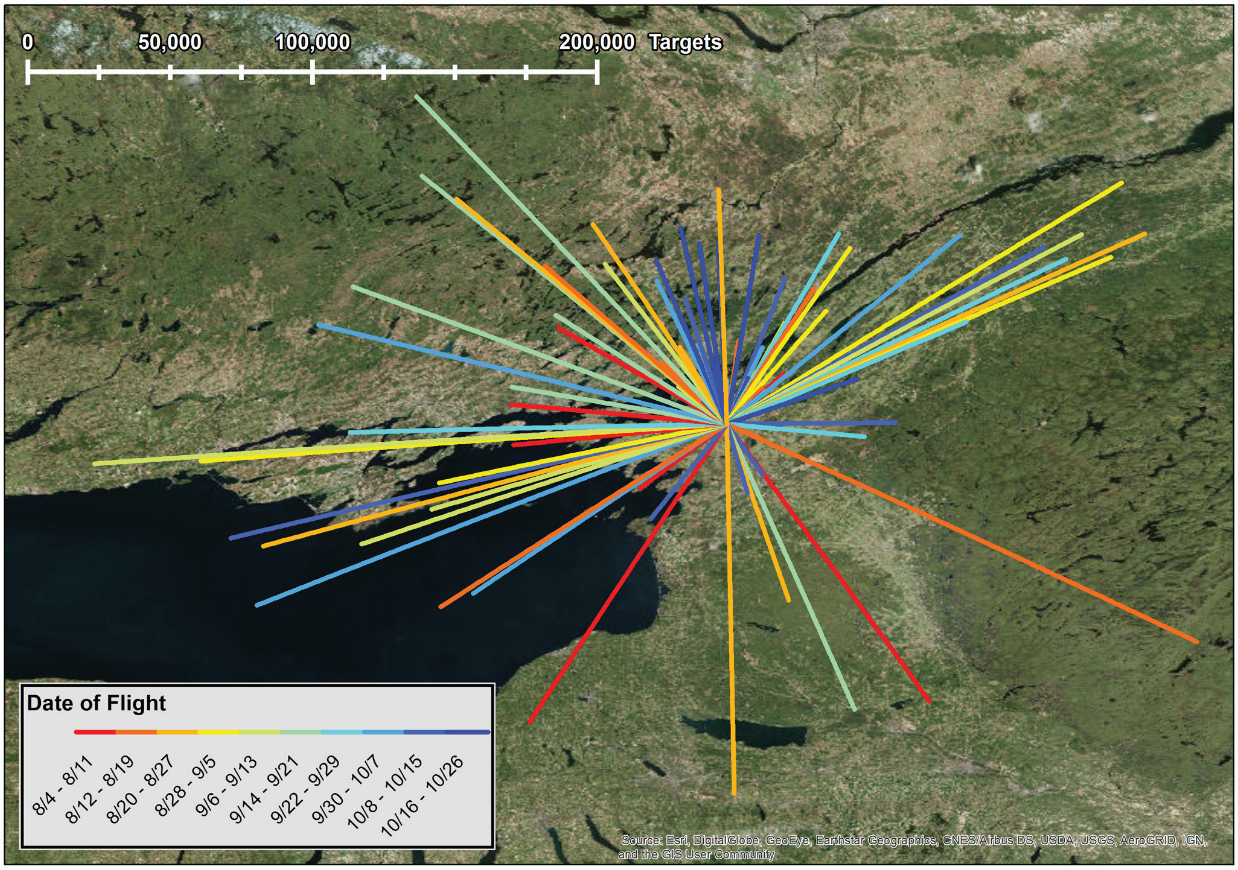


Figure 14. Average direction of target origin, Jefferson County. The angle of each line represents the mean orientation of targets each night, approximating the direction of flight origination. The length of each line indicates the target count for one night, and the color of line indicates the date.

Temporal Trends

Time Series. Hourly target counts provided by horizontal and vertical radars showed nightly pulses of elevated activity with peaks occurring a few hours before midnight at our study sites (Figures 17 – 19). Across our sampling period these events would often occur over a series of 2 to 3 nights at the beginning and end of the season (August and October), and more consistently, for periods of five consecutive days or more, during the middle of the season (September). At Jefferson and Wayne County sites, consistent nightly migration activity began in late August. In Jefferson County, the magnitude of pulses decreased in the second half of October, but at the Niagara County site, strong pulses continued to be observed into the end of October (data collection ended October 28).

Nightly pulses in target counts on the vertical radar typically corresponded to pulses on the horizontal radar, although the vertical radar records far fewer targets overall, due to sample volume and detection differences discussed earlier. Even though the vertical and horizontal antennae are two parts of the same machine, their measurements are somewhat independent in that they observe mostly non-overlapping volumes of air, especially when limiting the vertical scan to a standard front. To some extent, horizontal and vertical radars can each be used to support the other's general observations regarding the amount of bird-sized targets moving at bird-like speeds through the airspace in the vicinity of the radar.

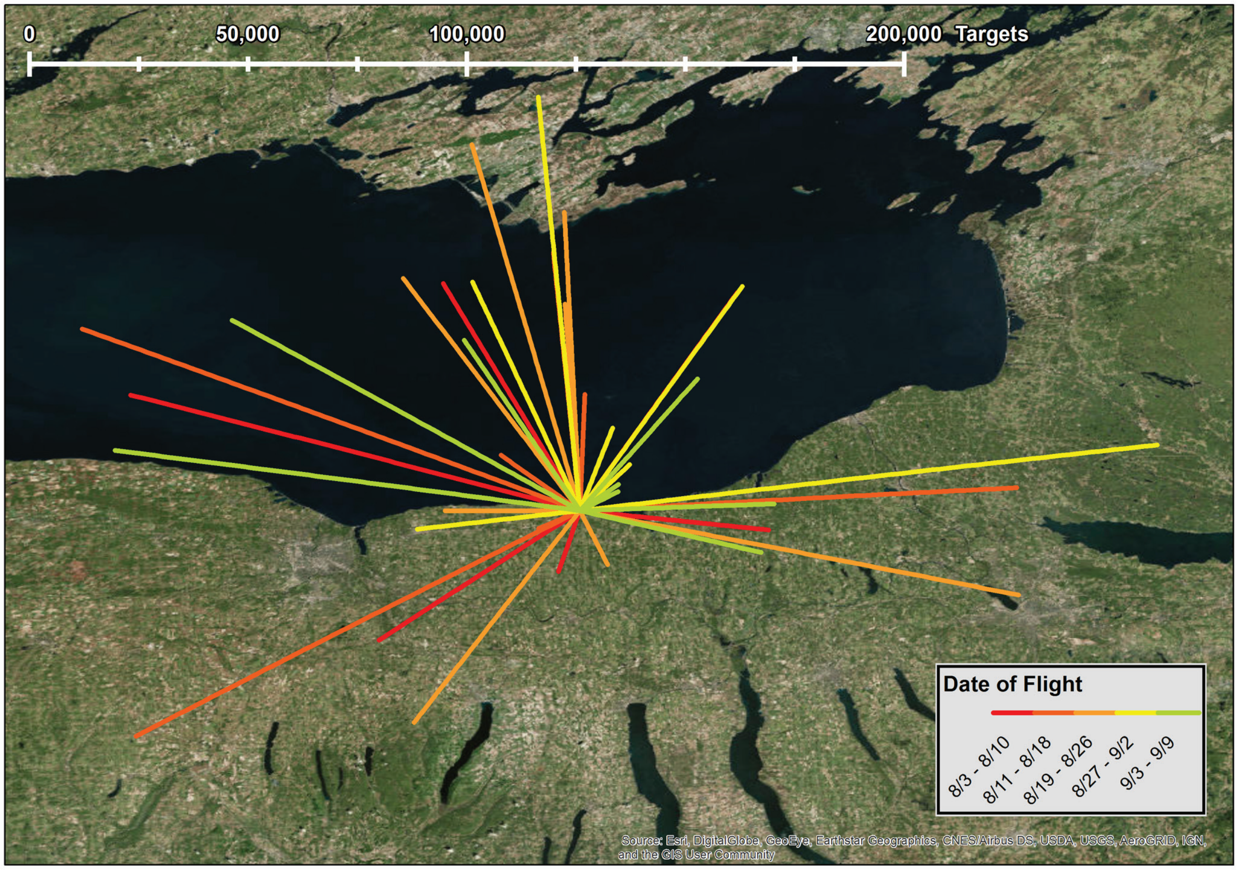


Figure 15. Average direction of target origin, Wayne County. The angle of each line represents the mean orientation of targets each night, approximating the direction of flight origination. The length of each line indicates the target count for one night, and the color of line indicates the date.

The orientation of the vertical antenna affects the relationship between vertical radar target counts and horizontal radar target counts, especially during periods when flights directions are concentrated ($r > 0$). If the plane of the vertical radar aligns with the predominant direction of flight, targets flying to either side will be missed, but if the plane is perpendicular to the predominant direction of flight, most flights will intersect the sample volume. Horizontal radar detection rates are the same for all flight directions. When flight directions run parallel to the vertical radar, it is possible that the HSR will detect proportionately more targets than would be expected given activity observed on the VSR. For an example of this, see August 28, 18:00 at Wayne County (Figure 9). The vertical radar is oriented east-west, parallel to shore and orthogonal to the expected direction of migratory flights. Many of the HSR tracks run west-east, and only a few tracks show up on VSR.

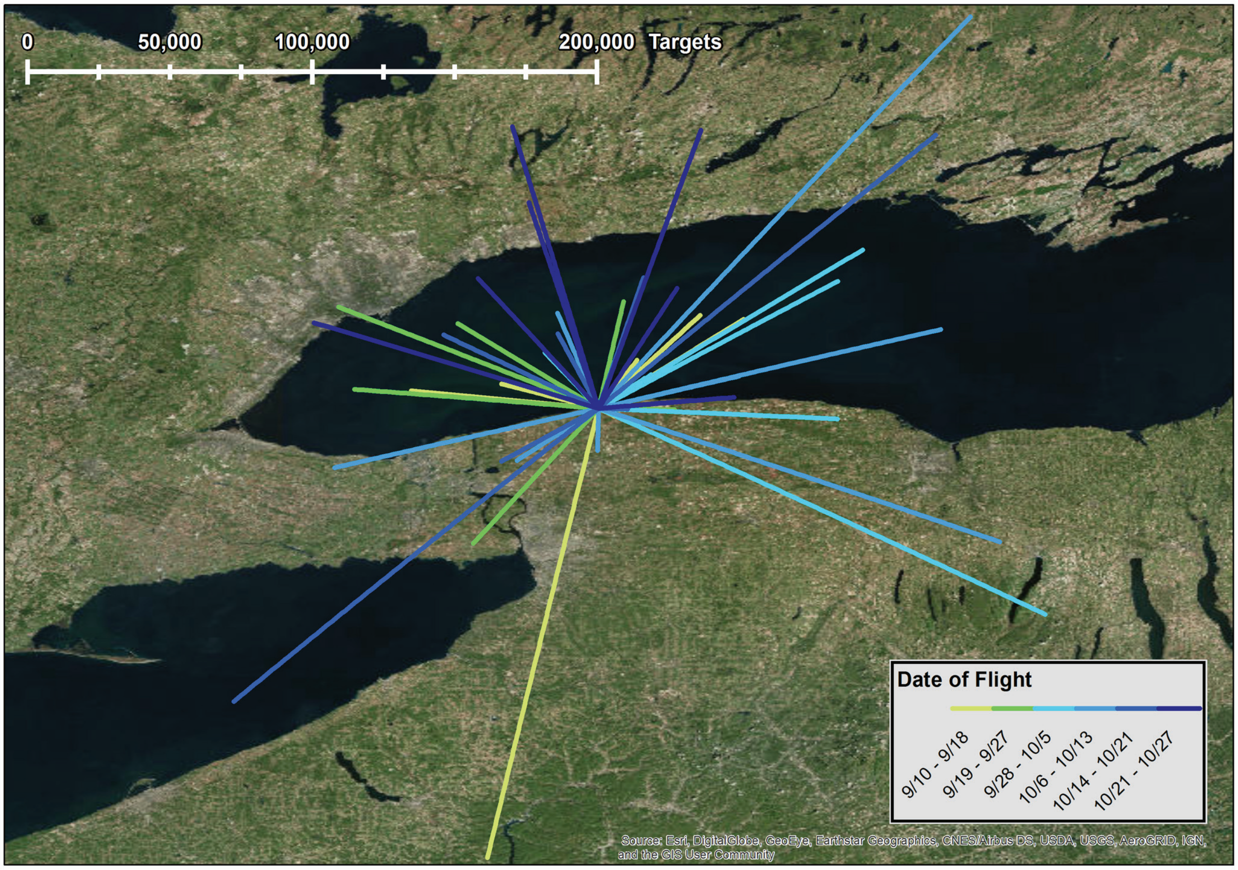


Figure 16. Average direction of target origin, Niagara County. The angle of each line represents the mean orientation of targets each night, approximating the direction of flight origination. The length of each line indicates the target count for one night, and the color of line indicates the date.

Hourly Counts by Horizontal and Vertical Radars in Jefferson County

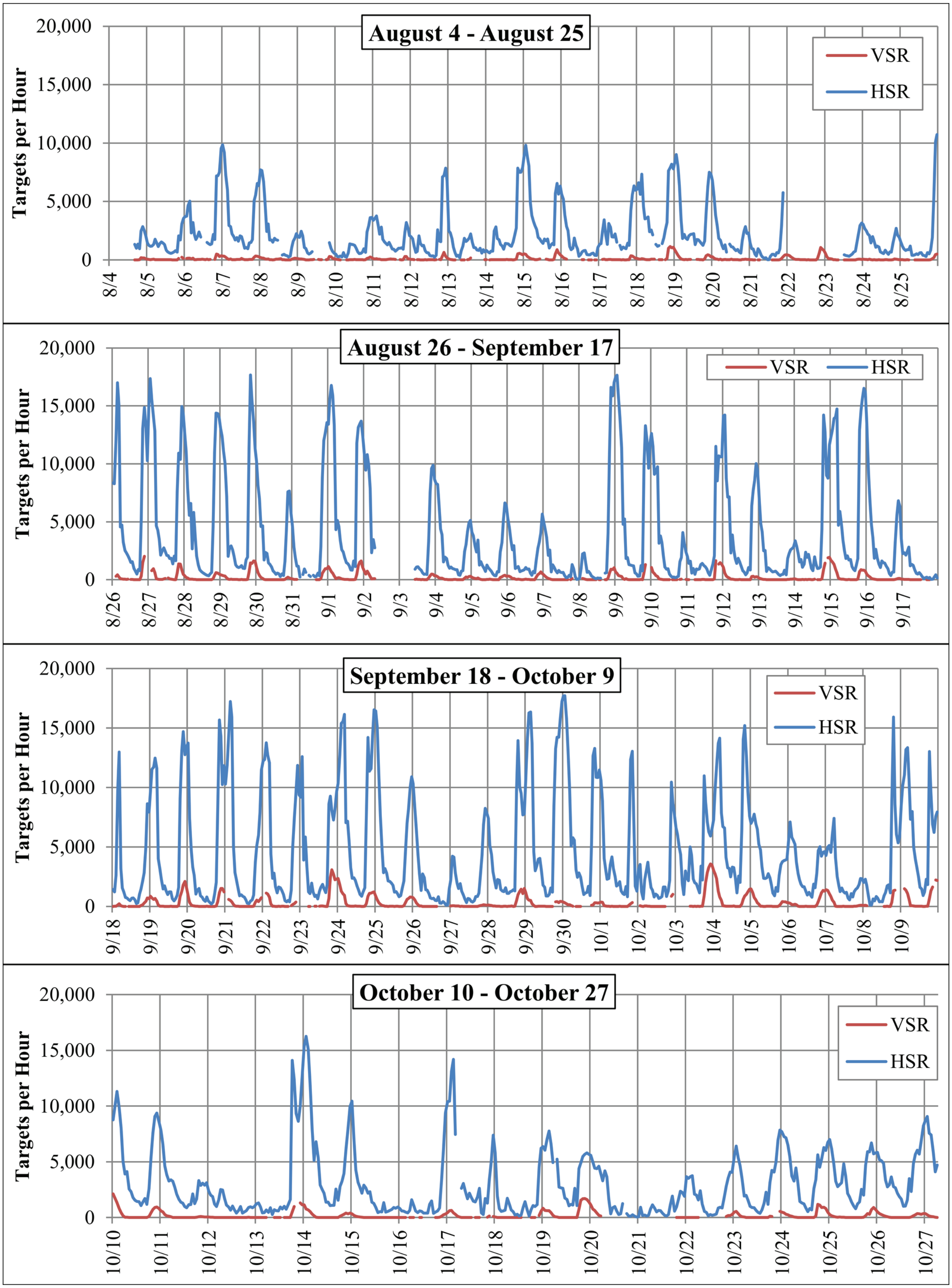


Figure 17. Hourly target counts in Jefferson County by horizontal and vertical radars from August 4 – October 27, 2016 Jefferson County. Vertical lines represent midnight.

Hourly Counts by Horizontal and Vertical Radars in Wayne County

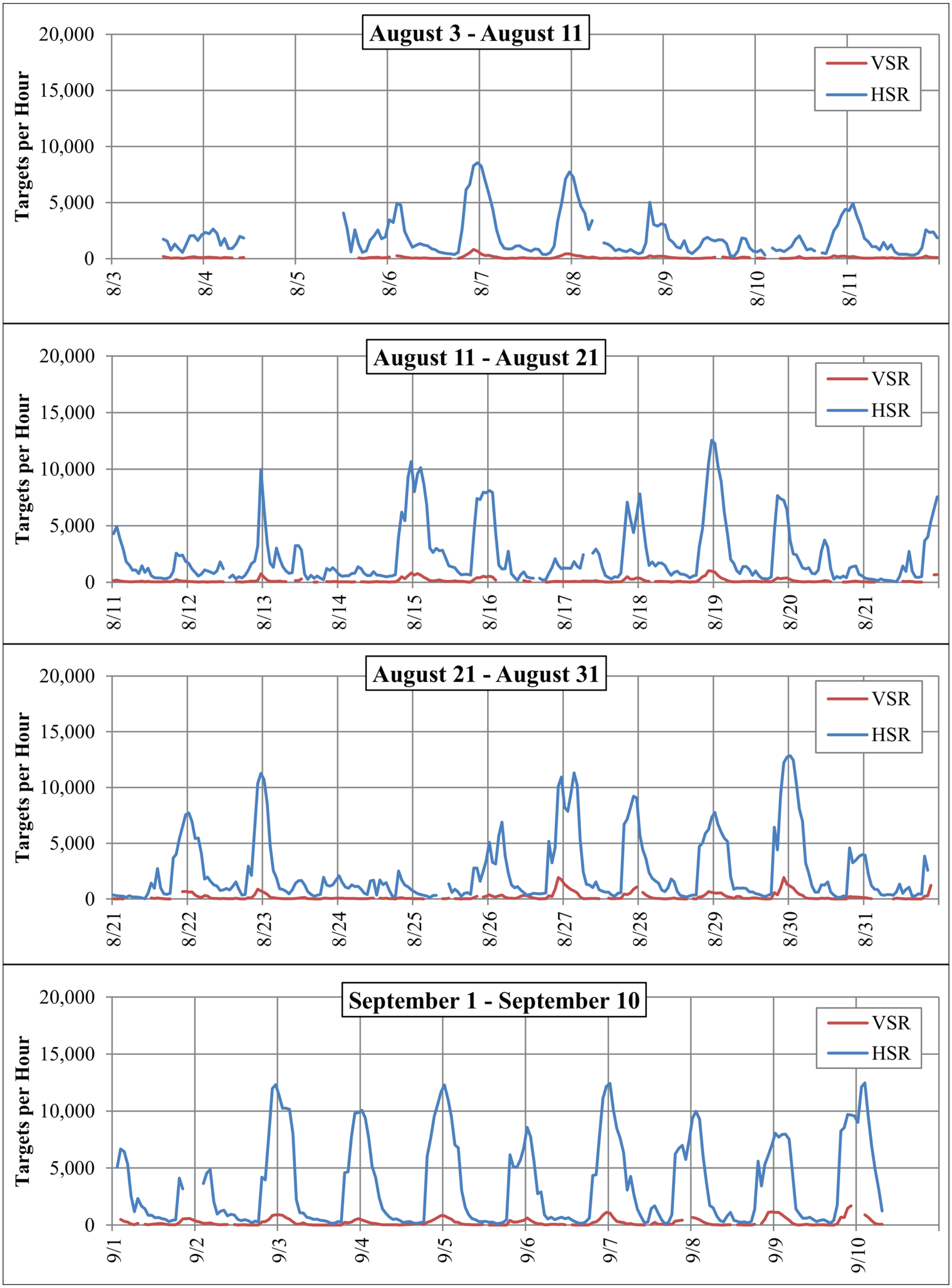


Figure 18. Hourly target counts in Wayne County by horizontal and vertical radars from August 3 – September 10, 2016 in Wayne County. Vertical lines represent midnight.

Hourly Counts by Horizontal and Vertical Radars in Niagara County

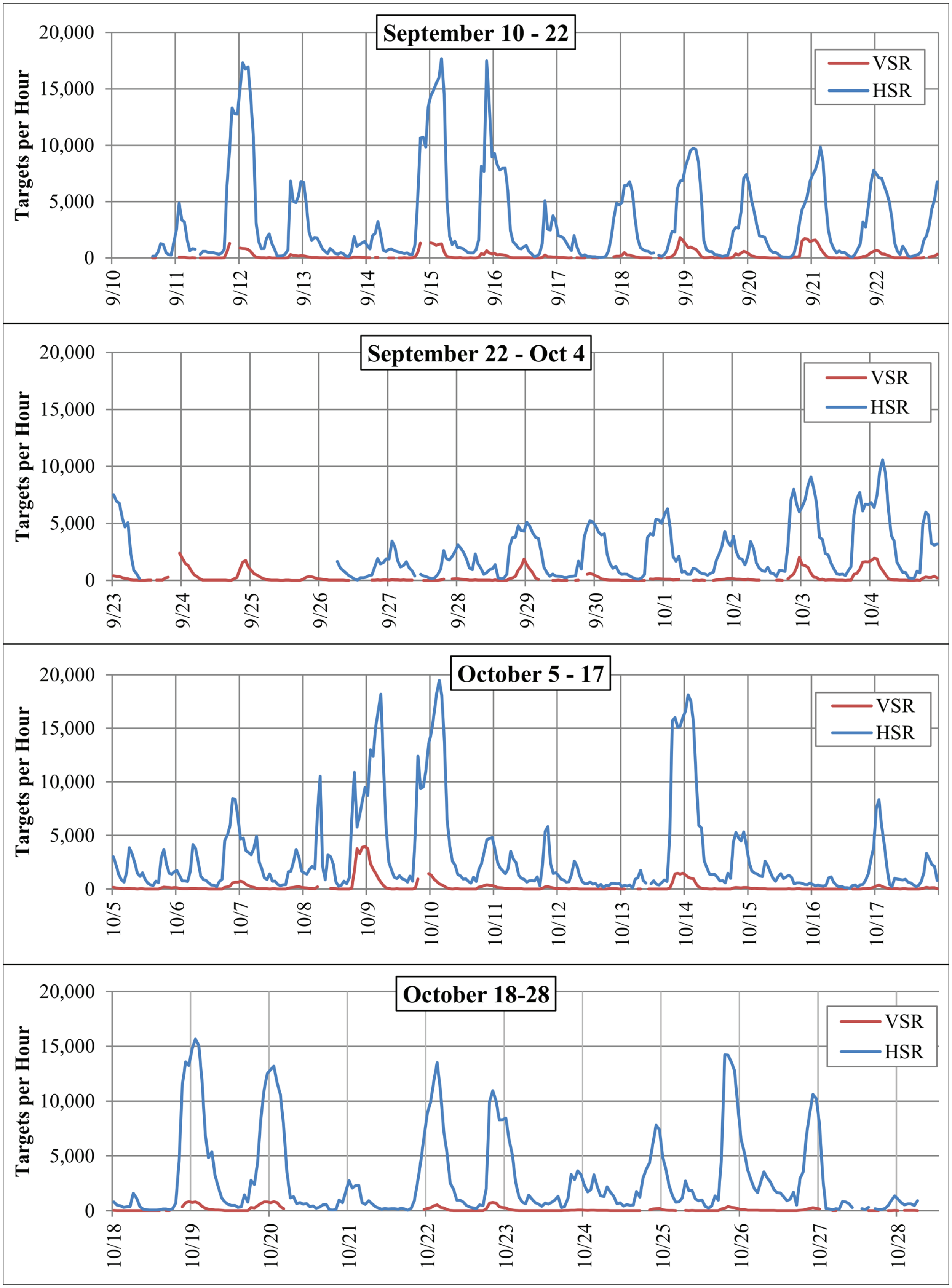


Figure 19. Hourly target counts in Niagara County by horizontal and vertical radars from September 10 – October 28, 2016 in Niagara County. Vertical lines represent midnight.

Target Passage Rate. The pattern of mean TPR during the four biological time periods was similar among the three study sites (Figure 20). Mean TPR at night was greater than the combined means of the other three biological time periods (Table 4). Mean nocturnal TPR in Jefferson County was 427± 439 SD (n = 80 nights), 338 ± 263 SD (n= 39 nights) in Wayne County, and 412 ± 476 SD (n= 46 nights) at the Niagara County site. Mean TPR varied by hour with peak numbers reached during the 21:00, 22:00 and 23:00 hours at Jefferson, Wayne, and Niagara sites, respectively. At all three locations, mean TPR decreased almost linearly after midnight, until leveling out at a low activity level around 6:00, which roughly corresponds with dawn (Figure 21). Variation between day and night TPR was greatest at Jefferson and Niagara sites, where peak TPR was higher than that of Wayne County and dropped to near zero during the day. Activity peaked earlier and faded earlier at Jefferson County than at Niagara, where the peak came later in the night and remained higher in the early morning. TPR at the Wayne site still showed a large difference between day and night, but the change was more moderate than the other two sites, with lower nightly peaks and substantial activity during the day.

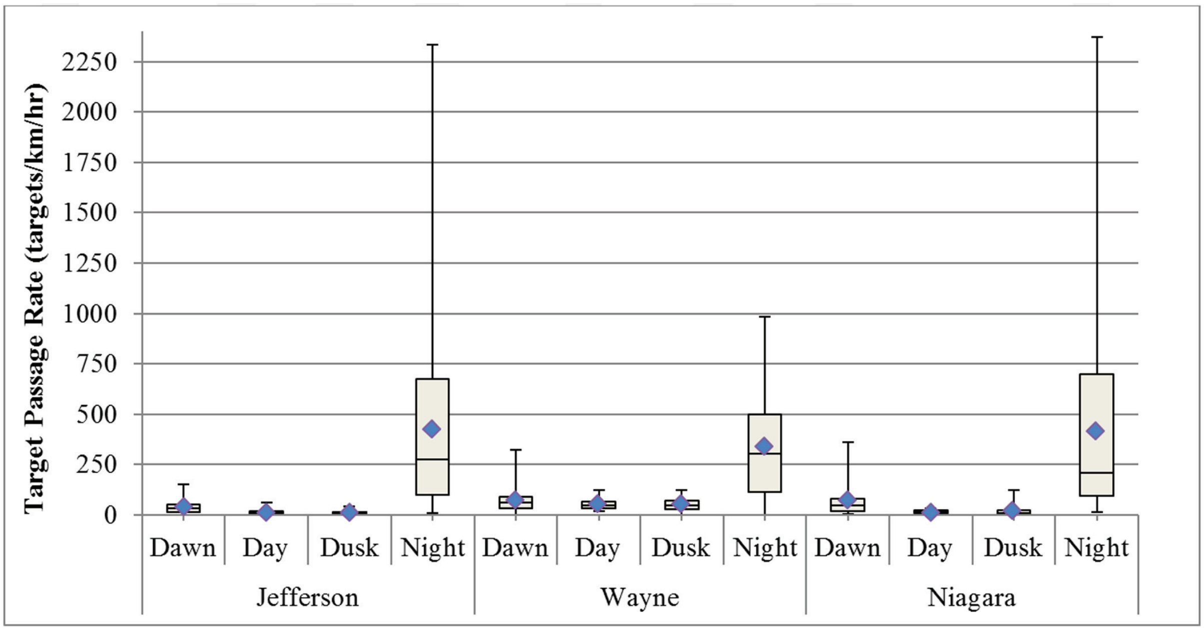


Figure 20. Box plots of target passage rates (TPR) showing variability during four biological periods for fall 2016 in Jefferson, Wayne, and Niagara Counties, New York. Whiskers extend to the minimum and maximum TPR. Boxes span from the 1st quartile to the 3rd quartile, with a line at the median. Blue diamonds are the seasonal mean for the biological period.

Table 4. Mean target passage rate (TPR) with standard deviations during four biological periods in New York during fall 2016.

	Mean Target Passage Rate		
Biological Period	Jefferson	Wayne	Niagara
Dawn	36 ± 30	70 ± 63	67 ± 74
Day	14 ± 12	50 ± 24	14 ± 7
Dusk	10 ± 10	52 ± 31	18 ± 23
Night	427 ± 439	338 ± 263	413 ± 476

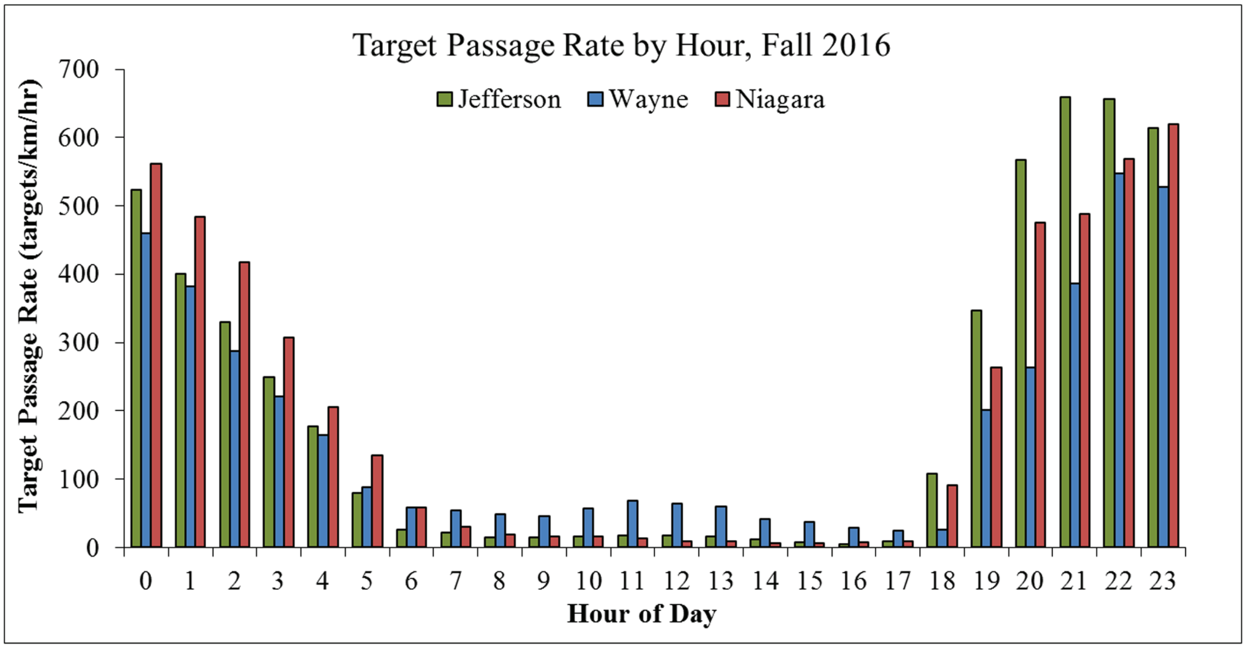


Figure 21. Mean hourly target passage rate (TPR) during fall 2016 at sites in Jefferson, Wayne, and Niagara Counties, New York.

Weekly Mean of Target Passage Rates. At all three sites weekly means of nocturnal target passage rates were about 10 to 20 times higher than diurnal rates. Over the course of the season, weekly passage rates rose into October then declined in the second half of October (Figure 22). The lower TPR during the last week of October is likely due to a change in weather conditions, with lower temperatures and a mix of sleet and snow.

Seven Day Moving Average. A seven-day moving average was used to smooth out daily variation, eliminate minor data gaps, and examine broader patterns in activity over the course of the season. After smoothing, patterns in nocturnal TPR are strikingly similar between Jefferson and the other two sites (Figure 23, top). Using seven-day average of nocturnal TPR, the temporal correlation between Jefferson and Wayne during the first half of the season was 0.91, and the correlation between Jefferson and Niagara during the second half of the season was 0.87 (versus the correlation of non-smoothed nightly TPR 0.87 and 0.76 between Jefferson and Wayne, and Jefferson and Niagara, respectively). The overall seasonal rise and fall, as well as shorter-term peaks and dips in nocturnal activity are consistent between sites. TPR at Wayne and Jefferson match closely. Niagara's numbers are generally lower than Jefferson, but nearly every increase and decrease is echoed, even though these sites are over 200 km apart. Diurnal patterns are less closely associated, although some increases and decreases are echoed between sites. Correlation between seven-day average TPR at Jefferson and Wayne was 0.04, and was 0.55 between Jefferson and Niagara (correlation of non-smoothed daily TPR 0.31 and 0.49 between Jefferson and Wayne, and Jefferson and Niagara, respectively).

Nocturnal patterns at each site track much more closely with their counterpart radar site than with diurnal patterns at the site itself (Figures 23, 24). For example, nocturnal activity at Jefferson and Wayne Counties covary closely, but neither corresponds closely with its own diurnal activity rates. Niagara's nocturnal rates reflect the general pattern in diurnal rates over the season, but individual peaks and lulls are more closely linked to nocturnal rates at Jefferson. To facilitate comparisons of daytime and nighttime passage rates given the large difference in activity levels (e.g., Figure 20), proportional passage rates, equaling each day's target count as a proportion of the total target count for the season, within the biological period, were used. Correlation between daytime and nighttime proportional TPR was -0.24, -.031, and 0.82 for Jefferson, Wayne, and Niagara, respectively.

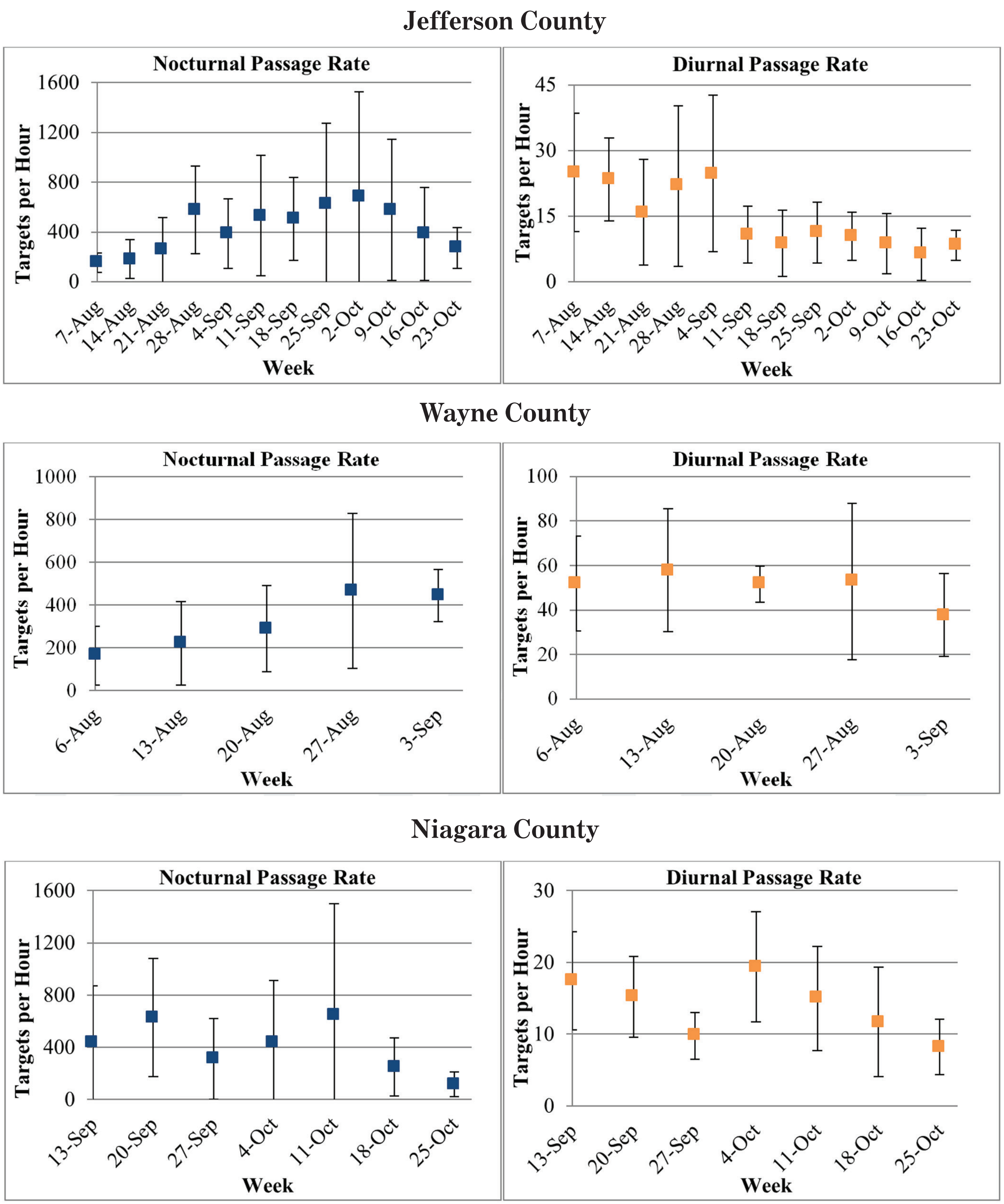


Figure 22. Weekly mean of nocturnal and diurnal target passage rates (targets/km/hr) in Jefferson (top row), Wayne (middle row) and Niagara (bottom row) counties from August to October, 2016. Error bars represent one standard deviation. Note different scales on nocturnal and diurnal plots.

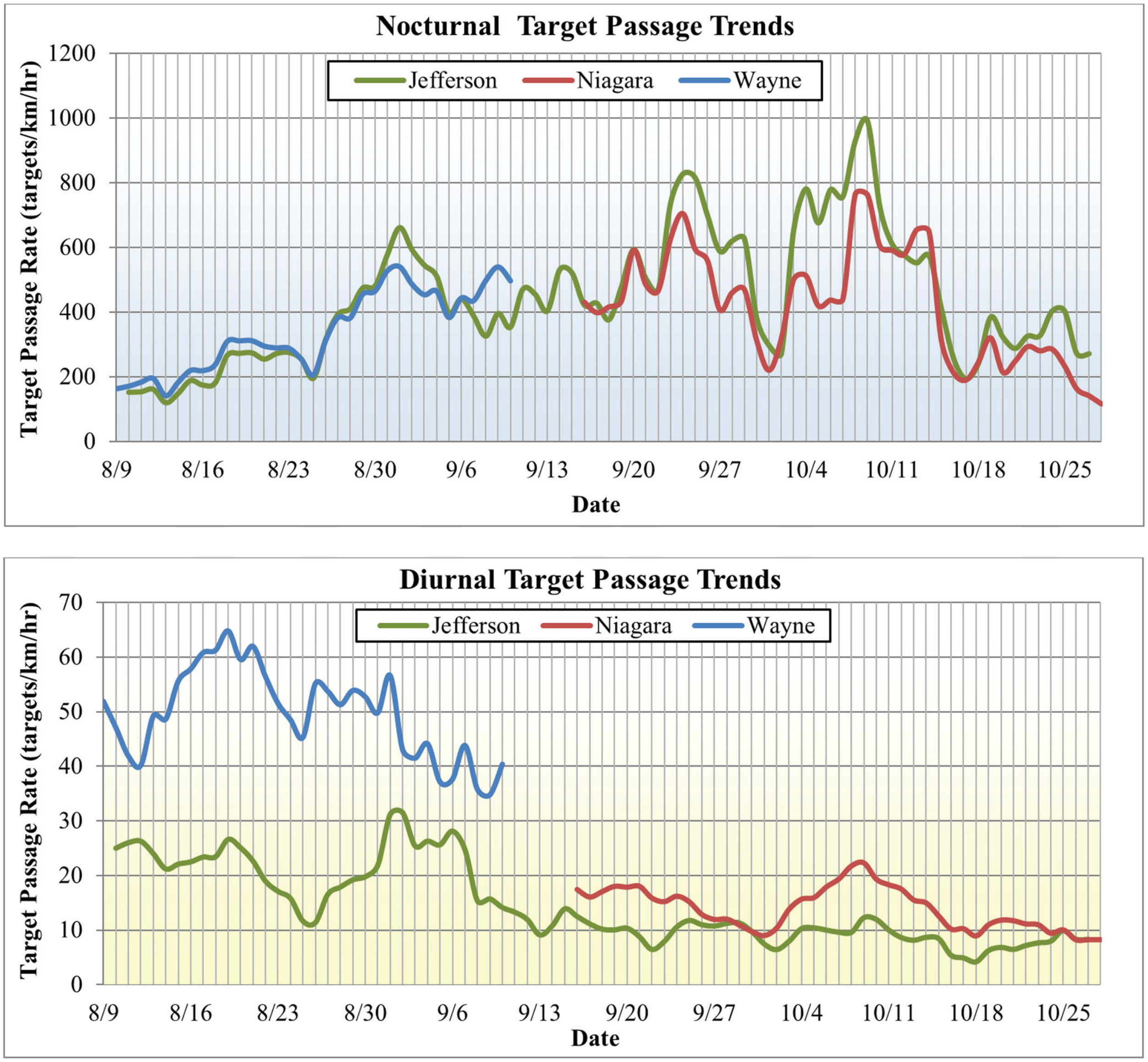


Figure 23. Seven-day moving mean TPR for nocturnal (top) and diurnal (bottom) target passage trends during fall 2016 in Jefferson, Wayne, and Niagara County radar sites.

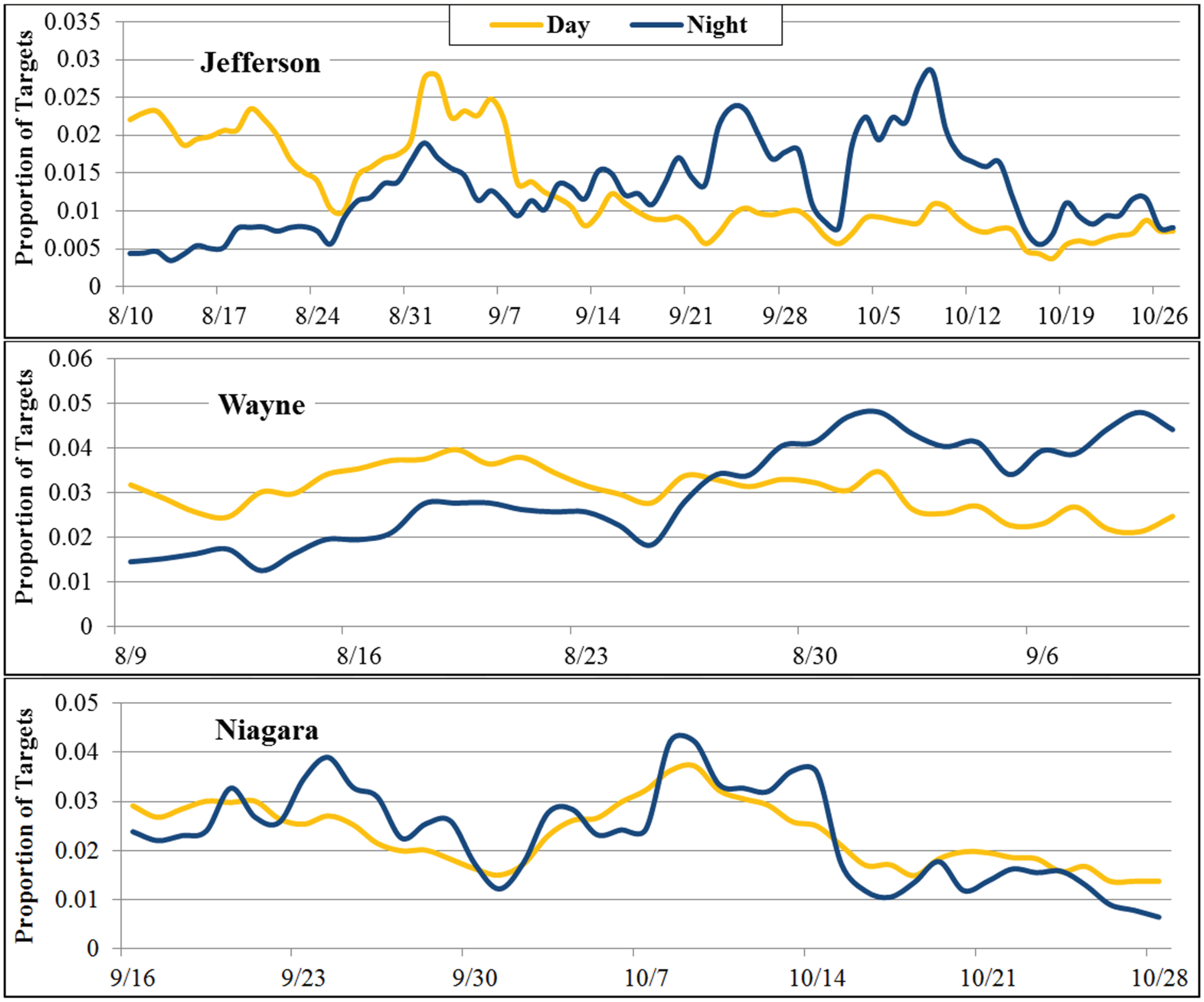


Figure 24. Proportional diurnal and nocturnal seven-day moving means at Jefferson (top), Wayne (middle), and Niagara (bottom) sites, New York during fall 2016. Proportions (single day or night target count divided by the sum of day or night target counts for the entire season) are used rather than TPR to account for the large difference between nocturnal and diurnal flight intensity, allowing comparisons between daytime and nighttime relative activity levels over the course of the season.

Altitudinal Trends

At all three sites, targets were observed within the entire range of altitude bands sampled. Mean altitude of nocturnal targets was 779 m ± 481 m SD at Jefferson County, 521 m ± 437 m SD at Wayne County, and 675 m ± 520 m SD at Niagara County. Median altitude at night was 644 m, 385 m, and 508 m above ground level at the Jefferson, Wayne, and Niagara sites, respectively. All three sites had their highest median flight heights during night and dawn, and lowest flight heights during the day or dusk.

Activity at the Jefferson site was low during dawn, day, and dusk, but flight heights during these periods were bimodal, with highest concentrations at about 100 m and 400 m for all three periods (Figure 25). Flight heights during the highly active night period also showed high concentrations at 100 m and 400 m, but there was also substantial activity at much higher elevations, including above 2000 m. This is reflected in the higher mean and median flight heights at this site (Table 5). Relatively high target detection rates during non-night periods at the Wayne County site are reflected in the altitude profiles as well (Figure 26). Unlike Jefferson and Niagara, the flight height profiles at Wayne are relatively consistent among biological periods, with little increase in heights during the night, and median heights for all periods under 400 m. Flight heights at Niagara are similar to those of Jefferson in that the high-activity night period had a higher-elevation distribution of flights (Figure 27).

Mean altitude per hour during the season showed a similar pattern at all three locations (Figure

37). Mean altitude was lowest during the daytime, increased during the dusk hour (blue boxes are hours that contained dusk during the season) until reaching a maximum 1-3 hours before midnight, and decreased following midnight. A temporary increase in mean altitude occurred during the dawn hours of 05:00 – 06:00 (orange boxes) at all three sites.

Whereas many radar reports include estimates of mean and median altitude of targets, we found that these estimates were poor indicators of maximum density (Table 5) due to the difference in volume of sampled air space at various altitude bands. The altitude profile graphs in Figures 25–27 display the limitations of both mean and median in representing typical flight heights, especially with uncorrected density estimates. To provide more realistic estimates of activity at various heights, we corrected VSR data for volume sample bias resulting from large differences in the volume of sampled airspace at different altitudes. Targets were classified by 50-meter altitude band according to observed height above ground level. Each band is a horizontal slice of the scanned airspaces that has a unique volume, as the 3-dimensional shape of the radar beam changes with height. We estimated the volume of each band via Monte Carlo simulation (see Figures 6 and 7) and calculated a volume-corrected density estimate that accounted for the geometric shape of the sample volume. This correction resulted in a substantially different density estimate than one assuming an equal amount of sample volume per altitude band (e.g., Figures 25-27). The altitude band with the highest density during each biological period is reported as Max Density Band in Table 5. The Max Density Band was consistently lower than mean and median flight heights, indicating concentration of activity at lower altitudes than would otherwise be apparent from summary statistics, and was often at altitudes near or within the rotor-swept zone.

Table 5. Altitude summary statistics. Comparison of mean altitude (m) with standard deviations, median altitude, and 50 m altitude band that contained the maximum target density during four biological periods at our sites in Jefferson, Wayne, and Niagara Counties during fall 2016. Max band density values represent the top of the altitude band.

	Jefferson			Wayne		
Biological Period	Mean ± SD	Median	Max Density Band	Mean ± SD	Median	Max Density Band
Dawn	637 ± 429	522	400	535 ± 460	376	300
Day	501 ± 410	388	100	386 ± 371	288	250
Dusk	675 ± 540	440	400	349 ± 373	241	200
Night	779 ± 481	644	350	521 ± 437	385	200

	Niagara		
Biological Period	Mean ± SD	Median	Max Density Band
Dawn	630 ± 524	494	100
Day	373 ± 481	188	100
Dusk	365 ± 407	258	100
Night	675 ± 520	508	150

Altitude Profile, Jefferson

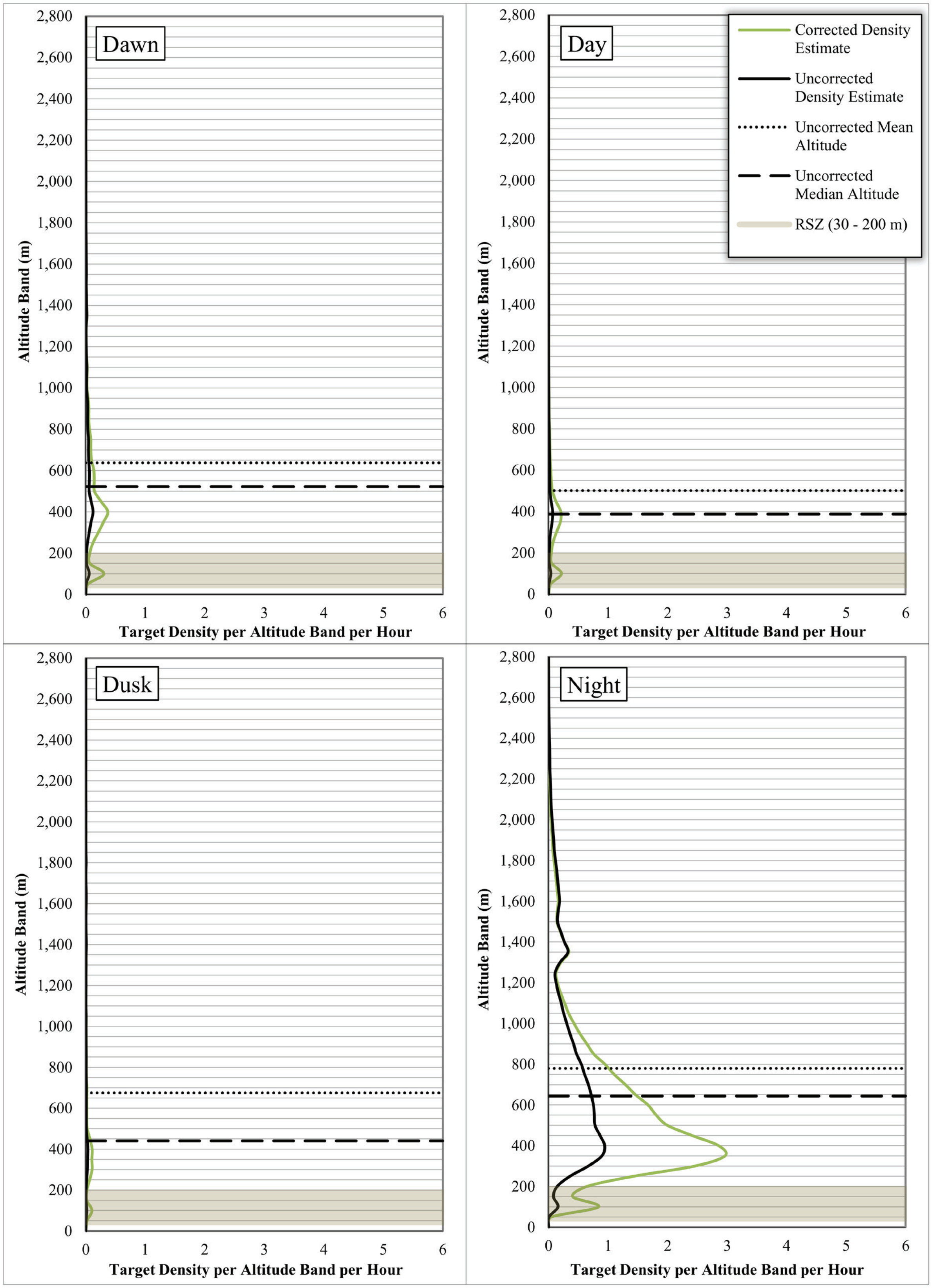


Figure 25. Altitude profile of targets at Jefferson County. Corrected lines depict target density (targets/1,000,000 m^3) within each 50-m altitude band per hour after adjusting for the sample volume within the band. Uncorrected lines depict target density per 50-m altitude band per hour without adjusting for volume (i.e., under the assumption that each band's volume is equal to the total volume divided by the number of bands). Shaded area represents the rotor swept zone (RSZ) between 30 - 200 m. Y-axis labels represent the top of the altitude band.

Altitude Profile, Wayne

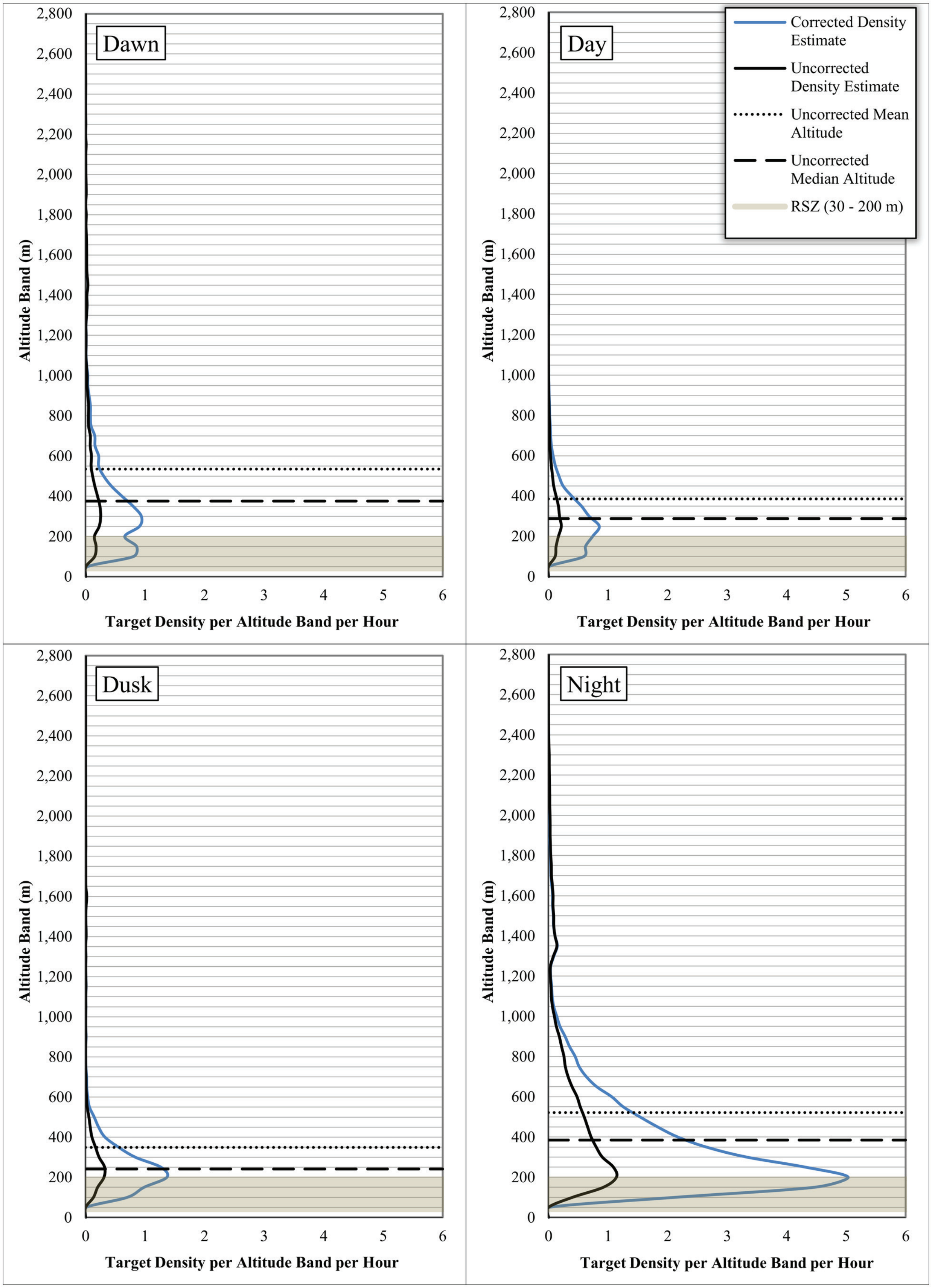


Figure 26. Altitude profile of targets at Wayne County. Corrected lines depict target density (targets/1,000,000 m^3) within each 50-m altitude band per hour after adjusting for the sample volume within the band. Uncorrected lines depict target density per 50-m altitude band per hour without adjusting for volume (i.e., under the assumption that each band's volume is equal to the total volume divided by the number of bands). Shaded area represents the rotor swept zone (RSZ) between 30 - 200 m. Y-axis labels represent the top of the altitude band.

Altitude Profile, Niagara

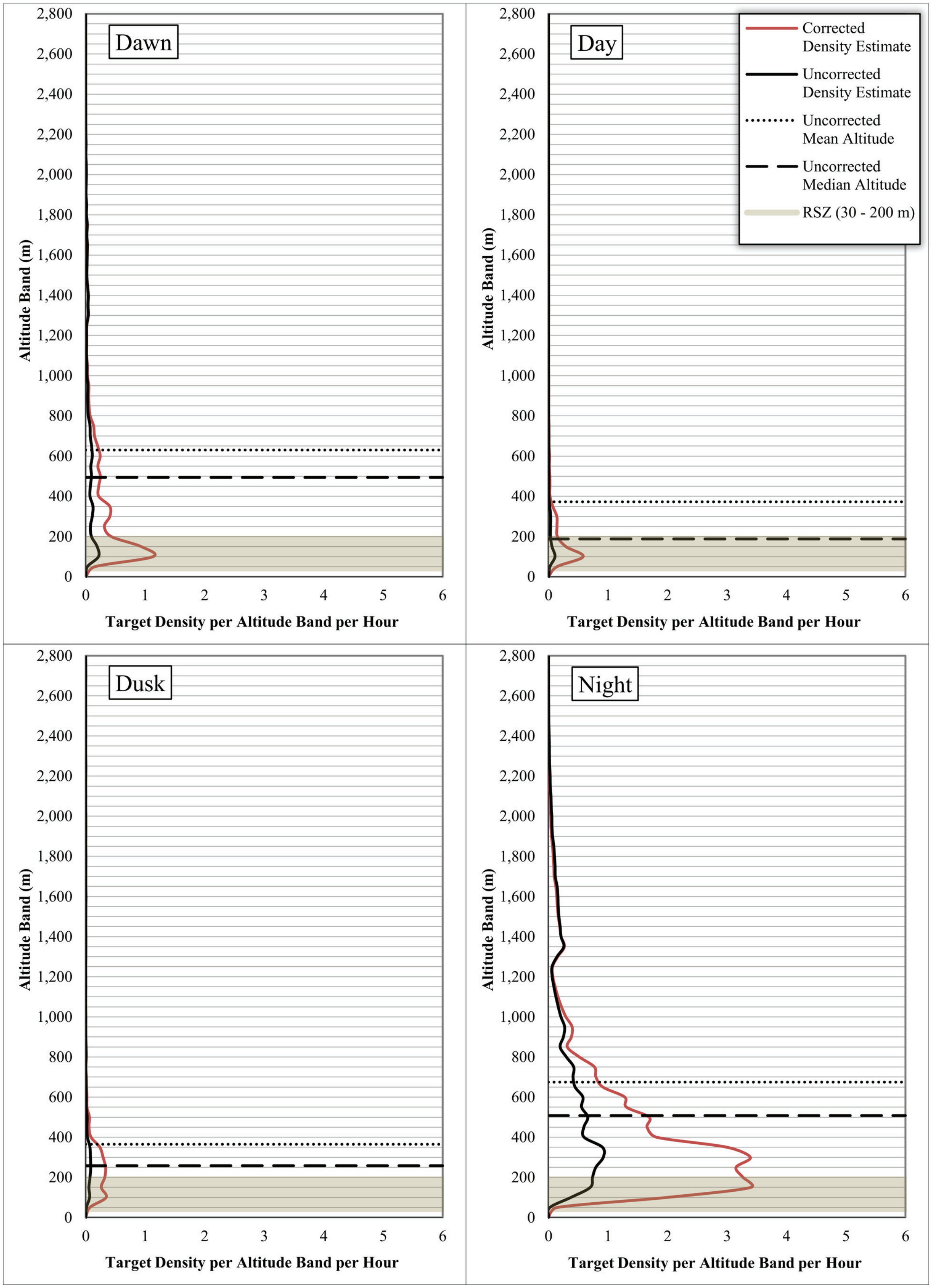


Figure 27. Altitude profile of targets at Niagara County. Corrected lines depict target density (targets/1,000,000 m^3) within each 50-m altitude band per hour after adjusting for the sample volume within the band. Uncorrected lines depict target density per 50-m altitude band per hour without adjusting for volume (i.e., under the assumption that each band's volume is equal to the total volume divided by the number of bands). Shaded area represents the rotor swept zone (RSZ) between 30 - 200 m. Y-axis labels represent the top of the altitude band.

Hourly Variation in Altitude Profiles October 3-4, 2016, Jefferson County

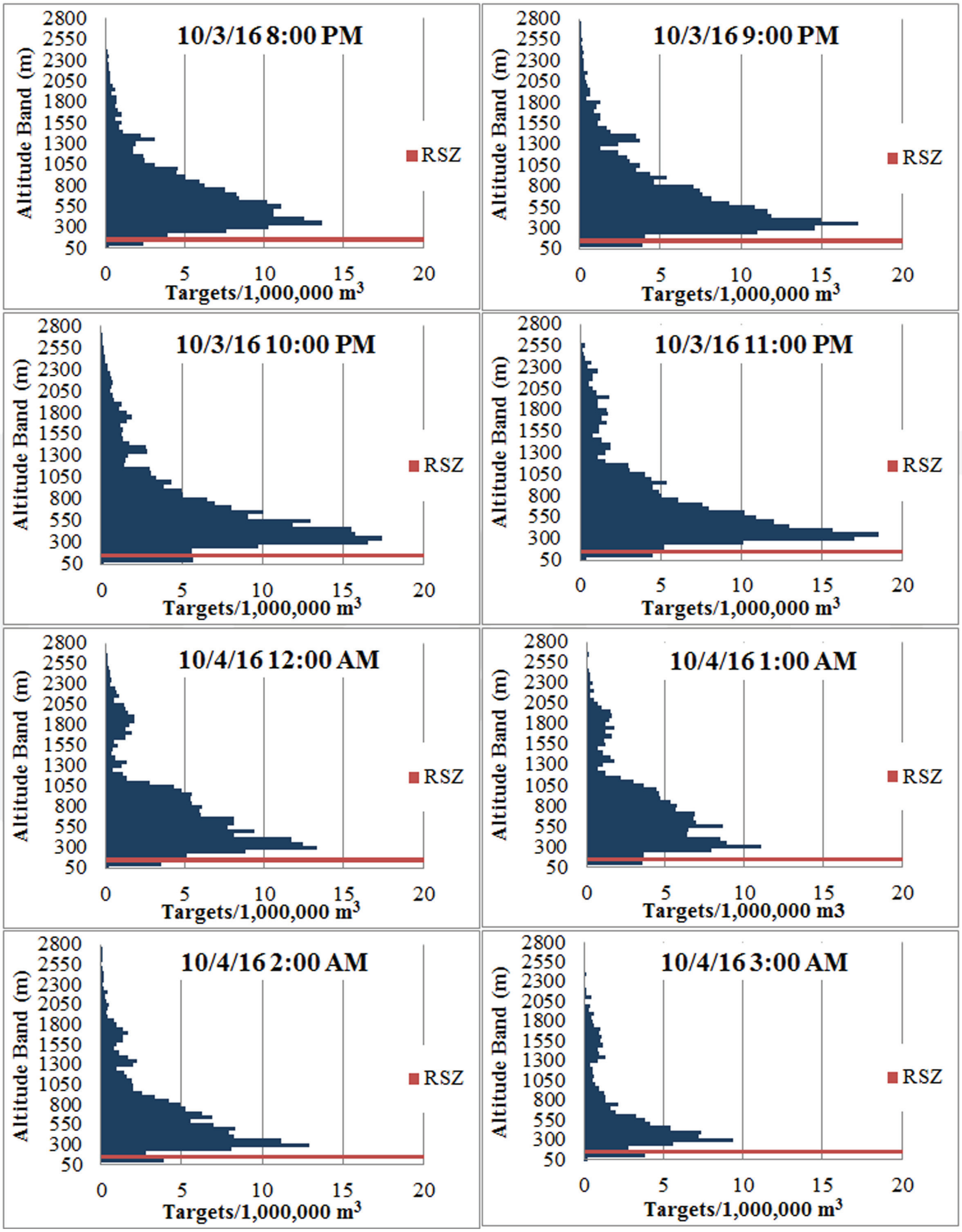


Figure 28. A sample of hourly altitude profiles in Jefferson County, corrected for the shape of the sample volume from October 3 – 4, 2016. The x-axis represents target density. The red line represents the top of the rotor swept zone from 150 m to 200 m. Y-axis labels represent the top of the altitude band.

Hourly Variation in Altitude Profiles August 27-28, 2016, Wayne County

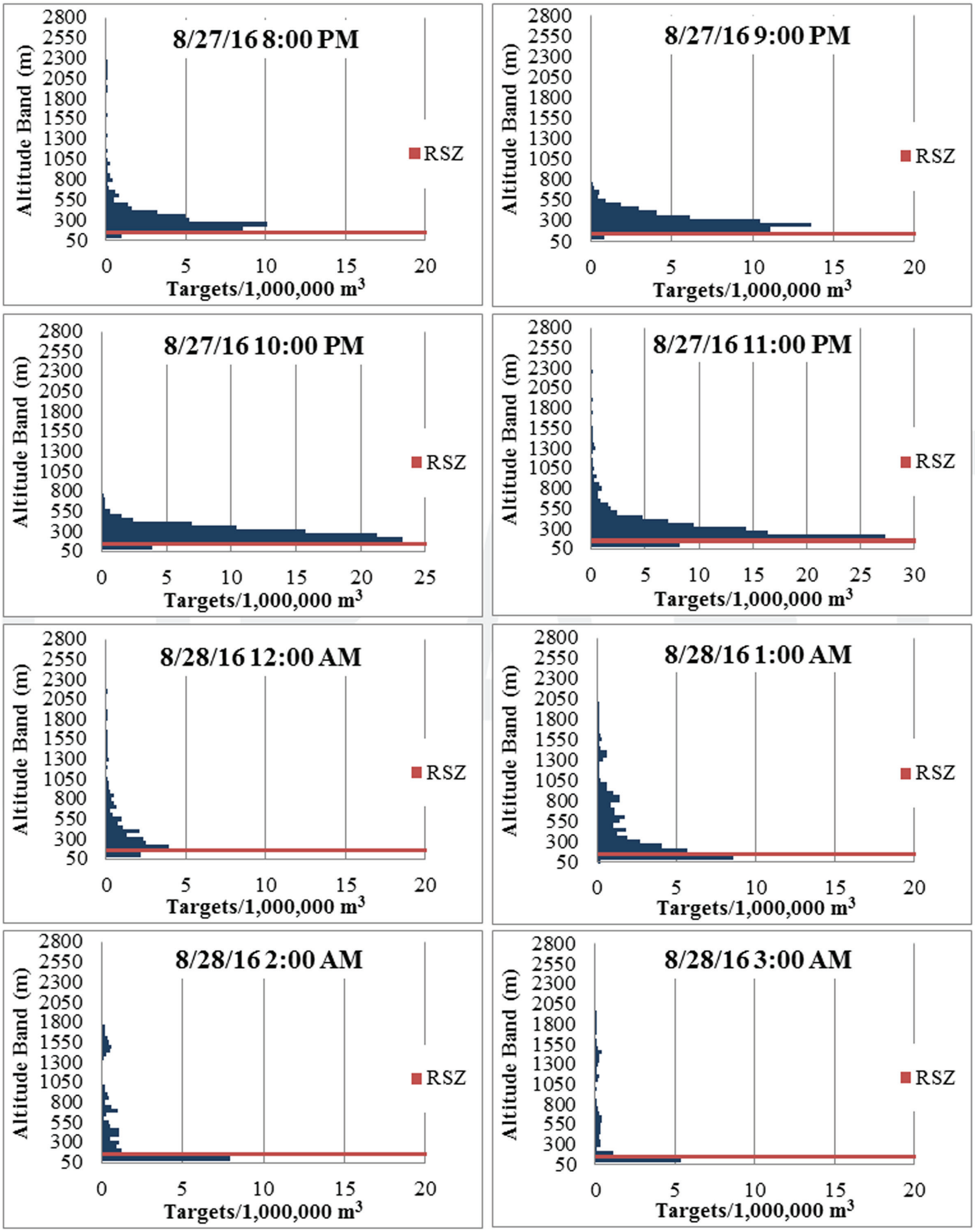


Figure 29. A sample of hourly altitude profiles in Wayne County, corrected for the shape of the sample volume From August 27 – 28, 2016. The x-axis represents target density. The red line represents the top of the rotor swept zone from 150 m to 200 m. Y-axis labels represent the top of the altitude band.

Hourly Variation in Altitude Profiles October 8-9, 2016, Niagara County

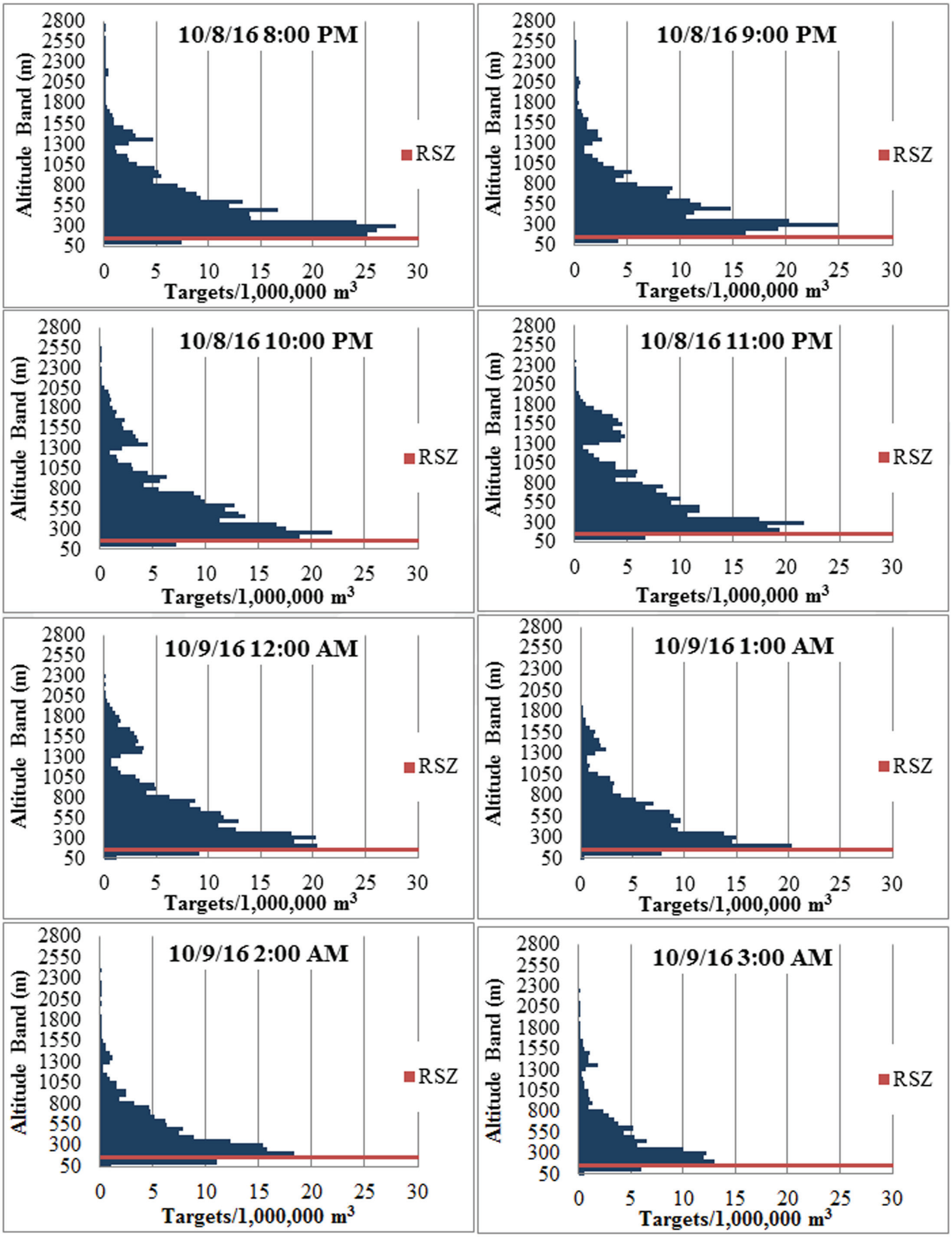


Figure 30. A sample of hourly altitude profiles in Niagara County, corrected for the shape of the sample volume on October 8 – 9, 2016. The x-axis represents target density. The red line represents the top of the rotor swept zone from 150 m to 200 m. Y-axis labels represent the top of the altitude band.

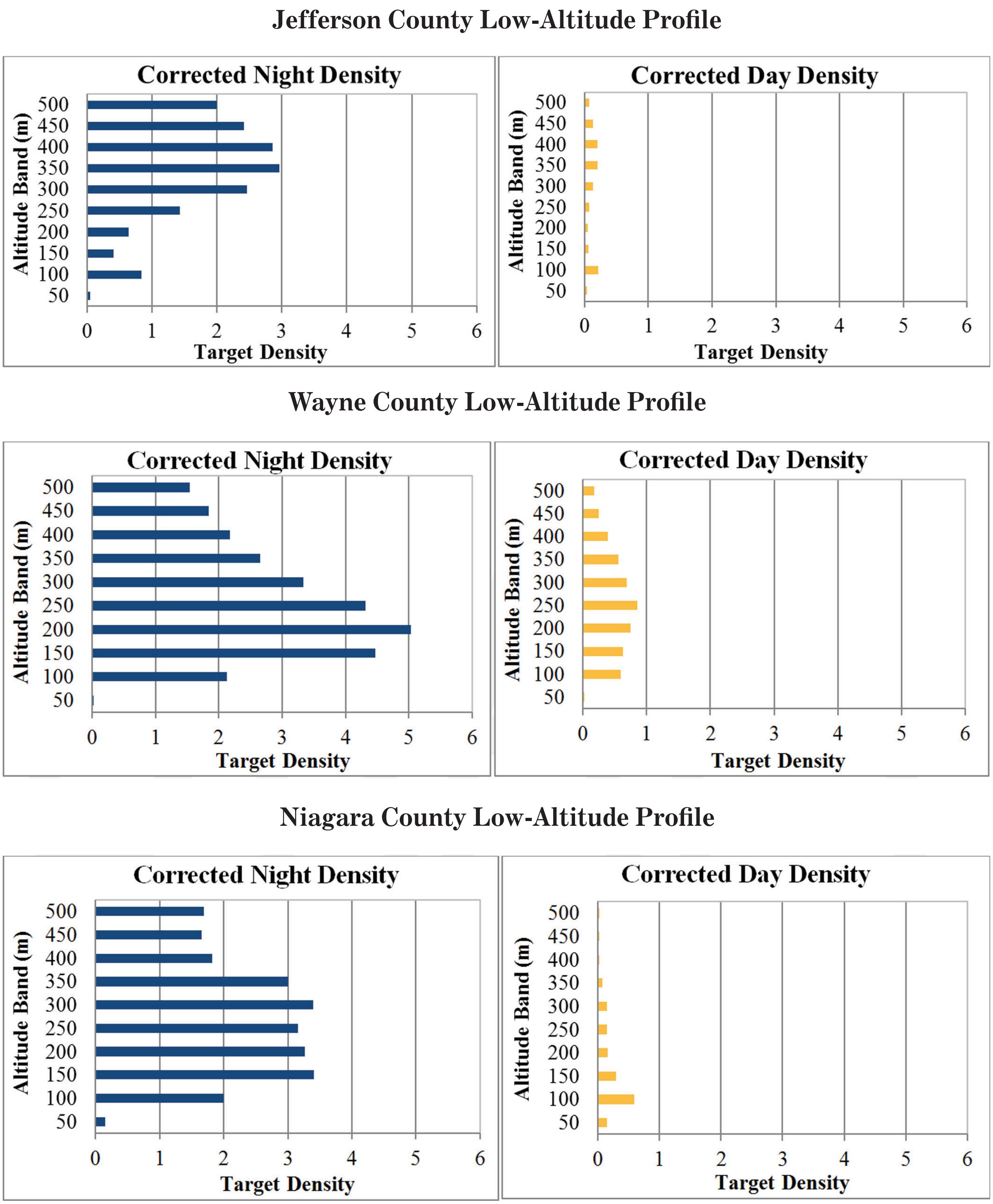


Figure 31. Altitude profile of corrected target density below 500 m in Jefferson, Wayne, and Niagara Counties, New York. The x-axis represents target density (targets/1,000,000 m^3) per 50-m altitude band. Y-axis labels represent the top of the altitude band.

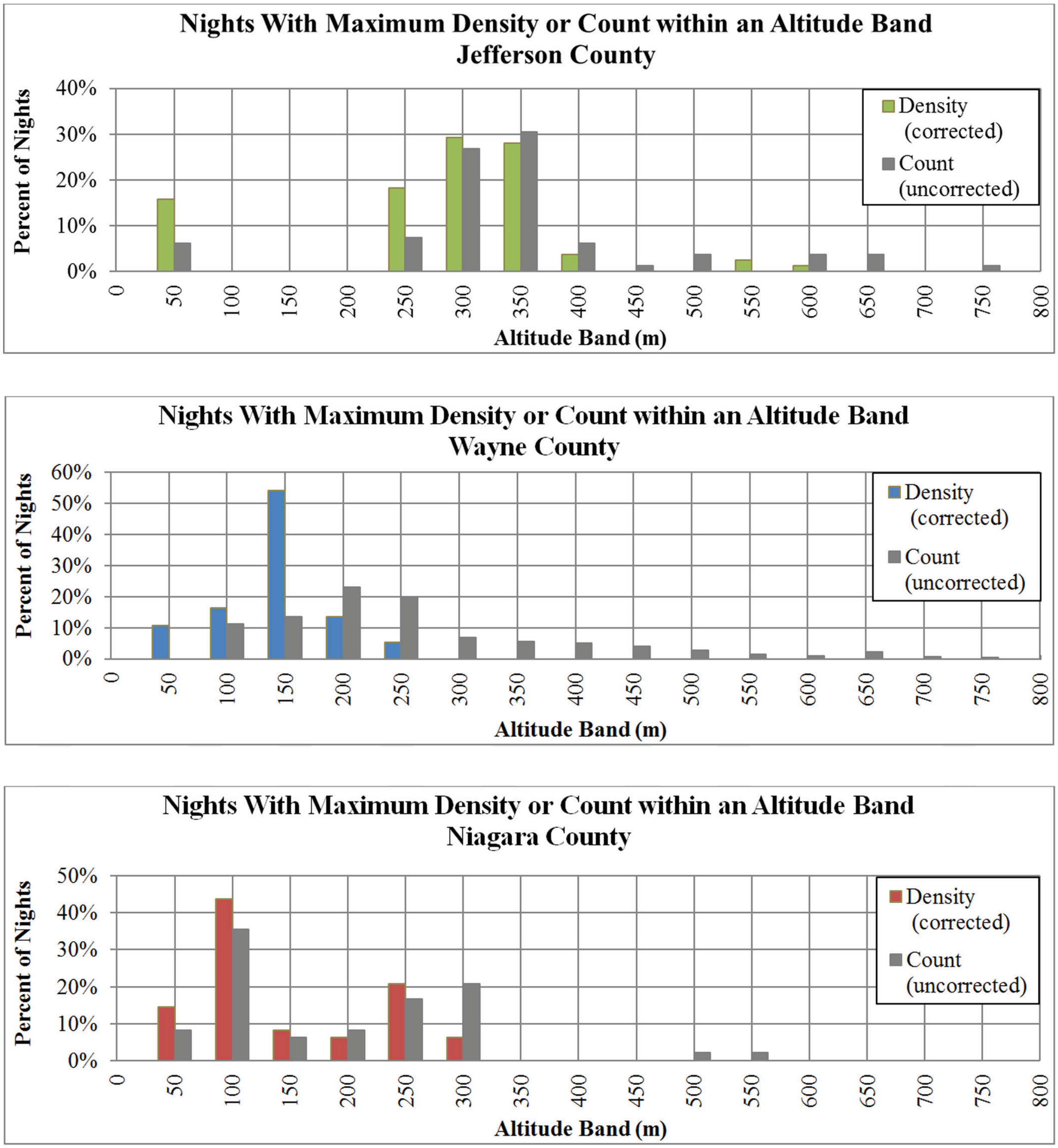


Figure 32. Maximum density by night. Percent of nights when the maximum density (targets/1,000,000 m^3/altitude band) or count (targets/altitude band) occurred within 50-m altitude bands in Jefferson, Wayne, and Niagara County study sites during fall 2016. X-axis labels represent the top of the altitude band.

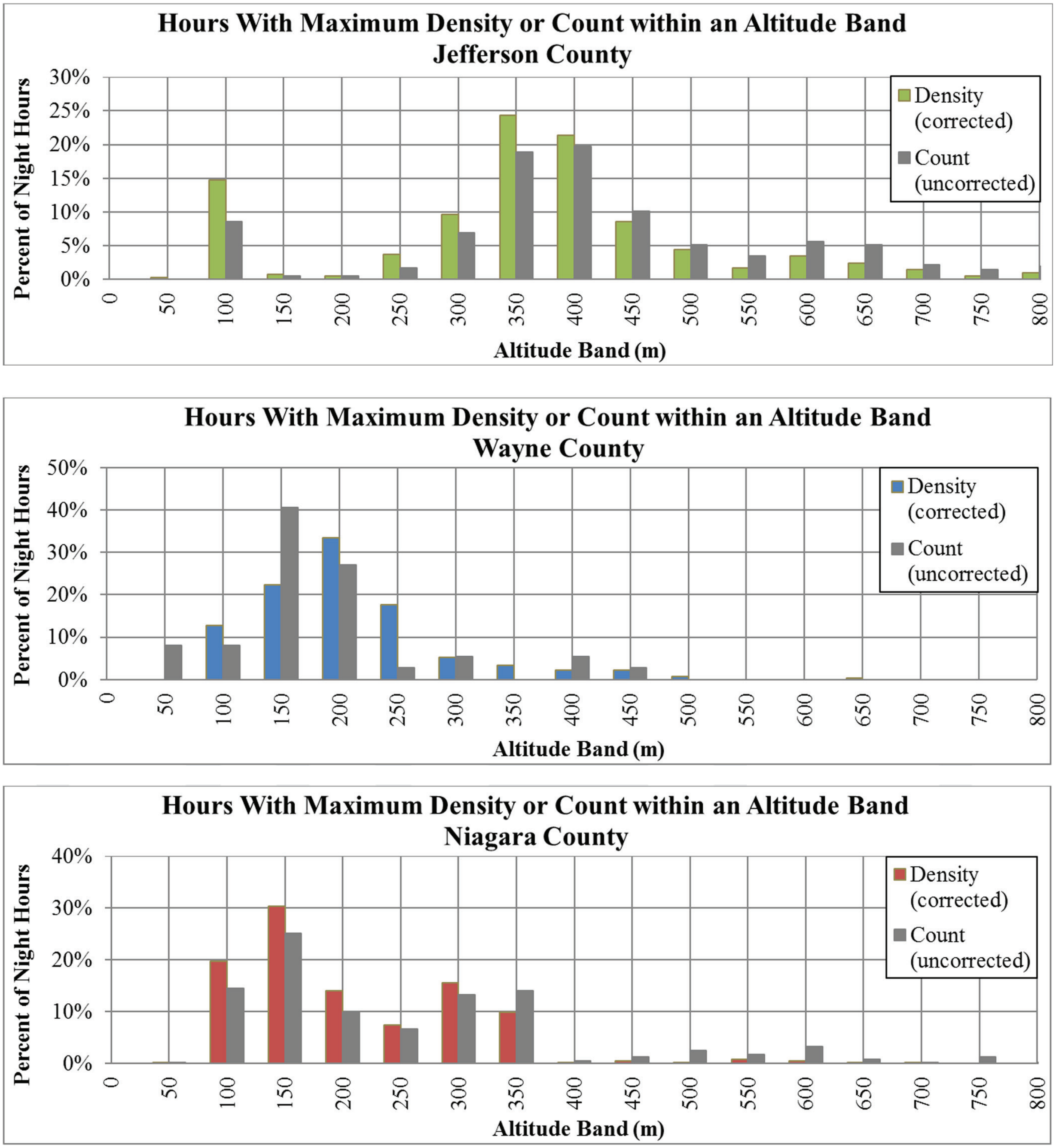


Figure 33. Maximum density by night hour. Percent of night hours (20:00 – 04:00) when the maximum density (targets/1,000,000 m^3/ altitude band) or count (targets/altitude band) occurred within 50-m altitude bands in Jefferson, Wayne, and Niagara Counties during fall 2016. X-axis labels represent the top of the altitude band.

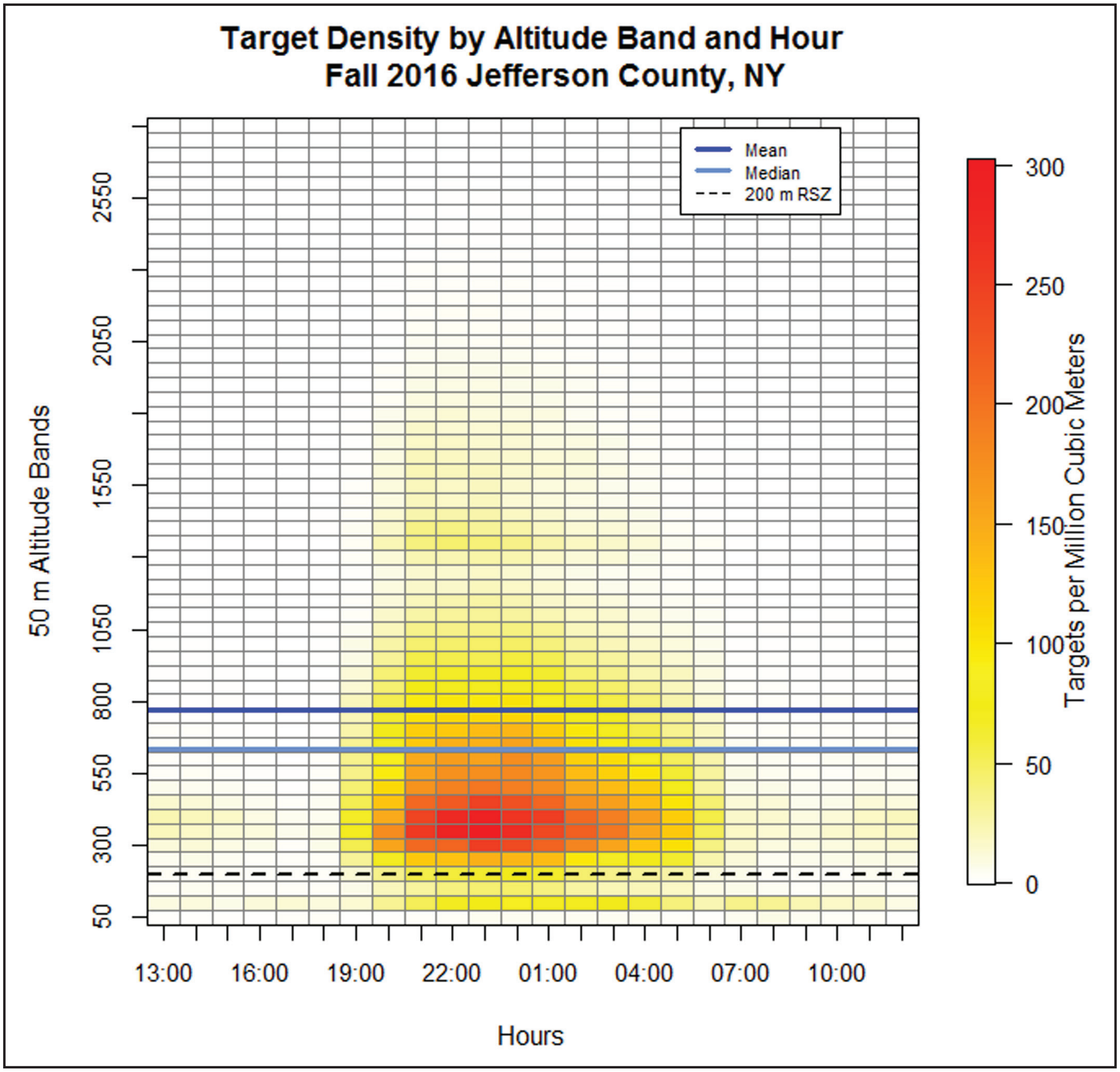


Figure 34. Heatmap for Jefferson County, representing variation in flight altitudes based on target density (targets per million cubic m). Altitude bands are in meters and labels represent the max value of each altitude band. Density of targets is in targets per million cubic meters. Colors shown in each rectangle indicate the relative density observed for that altitude (key shown on the right) and time. The dark blue and light blue lines represent the nocturnal mean and median target heights, respectively. The black line at 200 m represents the max height of a turbine with a RSZ of 30 – 200 m. Note the difference in density scale used in Figures 35 and 36. Some of the lack of low-altitude activity at this site may be attributable to relatively high clutter on the vertical antenna, which can be seen as white areas on the clutter map in Figure 4.

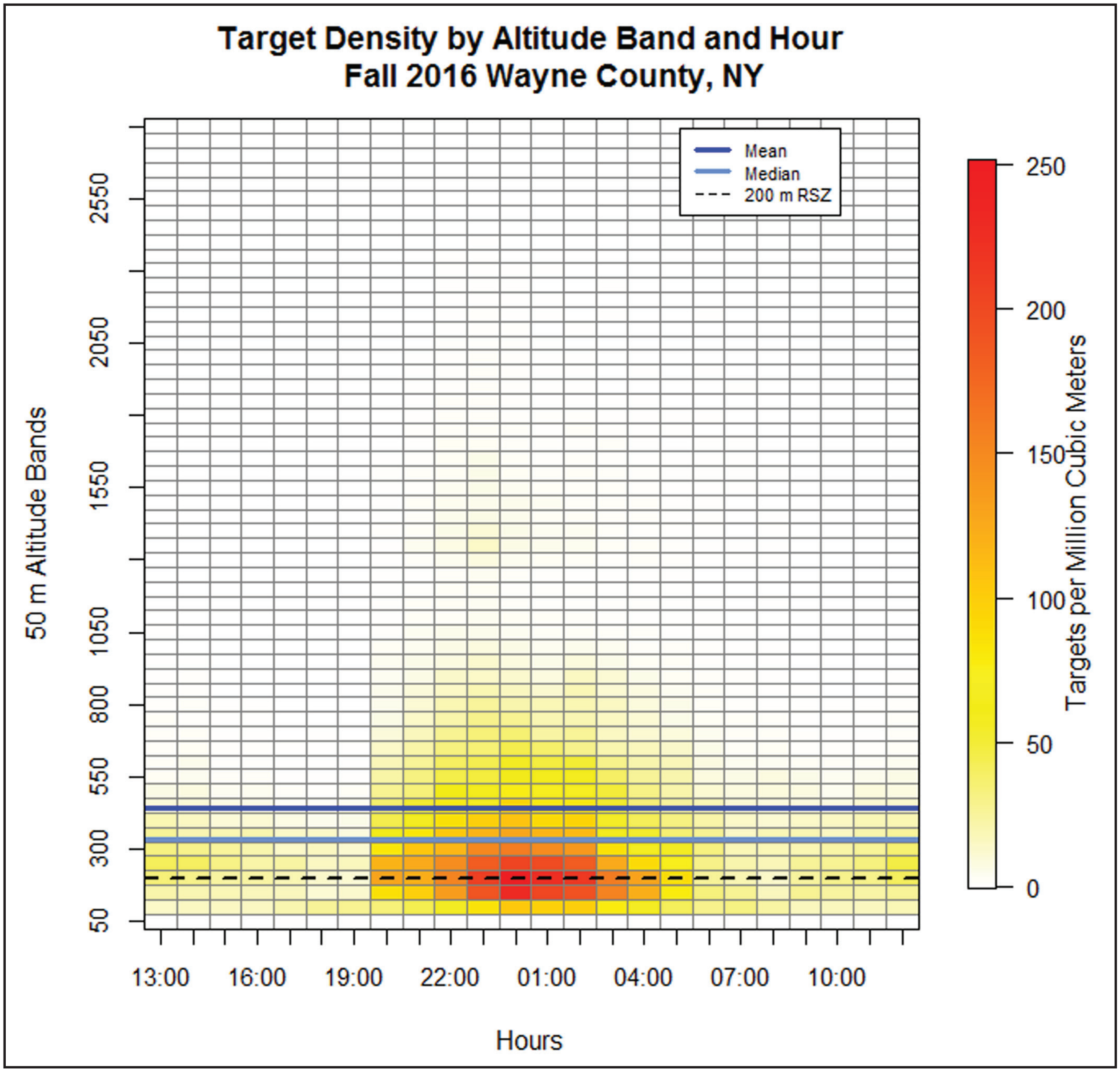


Figure 35. Heatmap for Wanye County, representing variation in flight altitudes based on target density (targets per million cubic m). Altitude bands are in meters and labels represent the max value of each altitude band. Density of targets is in targets per million cubic meters. Colors shown in each rectangle indicate the relative density observed for that altitude (key shown on the right) and time. The dark blue and light blue lines represent the nocturnal mean and median target heights, respectively. The black line at 200 m represents the max height of a turbine with a RSZ of 30 – 200 m. Note the difference in density scale used in Figures 34 and 36.

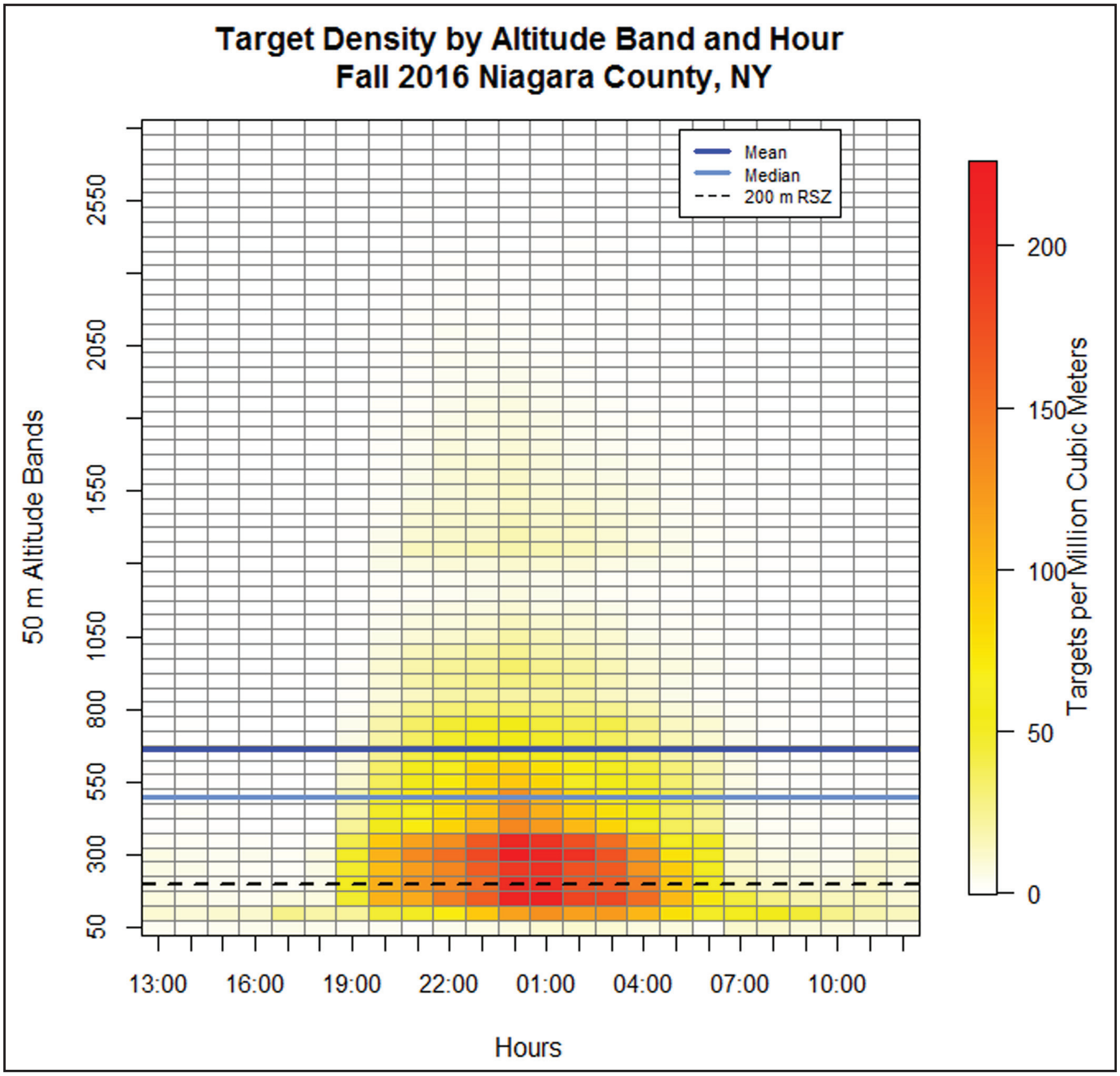


Figure 36. Heatmap for Niagara County, representing variation in flight altitudes based on target density (targets per million cubic m). Altitude bands are in meters and labels represent the max value of each altitude band. Density of targets is in targets per million cubic meters. Colors shown in each rectangle indicate the relative density observed for that altitude (key shown on the right) and time. The dark blue and light blue lines represent the nocturnal mean and median target heights, respectively. The black line at 200 m represents the max height of a turbine with a RSZ of 30 – 200 m. Note the difference in density scale used in Figures 34 and 35.

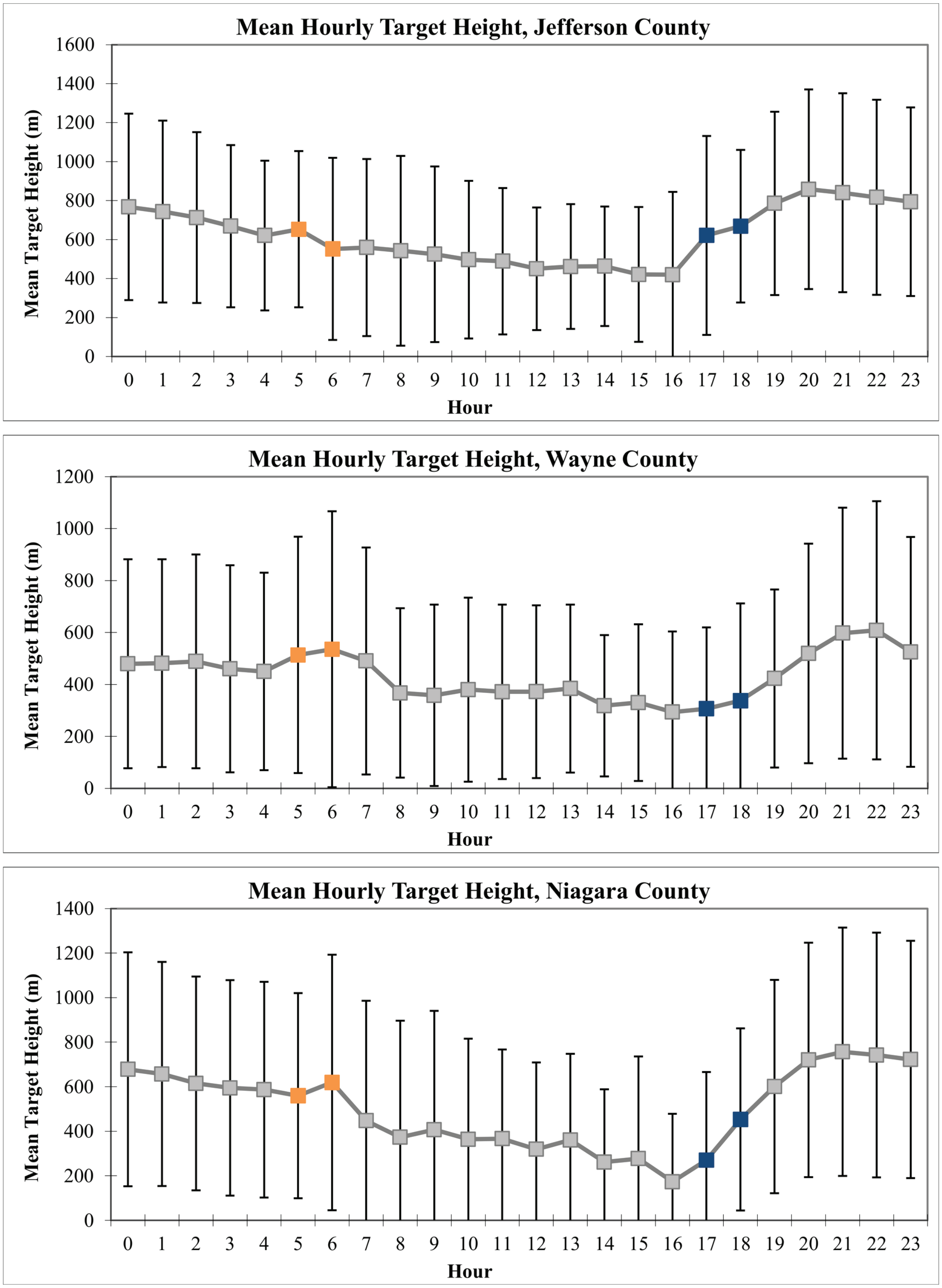


Figure 37. Mean hourly target height (m) during fall 2016 in Jefferson, Wayne, and Niagara Counties New York. Orange and blue markers indicate the hours in which sunrise and sunset occurred during the season, respectively. Error bars represent one standard deviation.

Discussion

We undertook this study to document migration along the shorelines of the Great Lakes. What we found indicates migration movements were common along the southern and eastern shorelines of Lake Ontario where we established our study sites. We believe that some aspects of data collected at these three sites are representative of migration along the rest of the Lake Ontario shorelines. Our research contributes to a growing body of literature that documents various aspects of migration and identifies Great Lake shorelines as areas important for conservation of migratory species. Our data provide unique observations about the magnitude, timing, and altitude 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 an intermittent systematic (e.g., once per week) or random sampling scheme, which may result in missing pulses of activity (Figure 38). Monitoring during both day and night is important as well. We used diurnal radar observations to provide a baseline for comparing nocturnal activity and including this time period in the sampling scheme helped to determine the relative magnitude of nocturnal migration events (Figures 17-19). Our sampling regime was also useful in showing when major migration pulses began in early August, but ending data collection in late October may have been too early to capture all the migratory pulses at the end of the 2016 migration. 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, calibration, filtering of clutter and non-biological 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 indices of target passage relative to specific sites, we are cautious about making comparisons among sites or studies. Rather than relying solely on the magnitude of target passage as an indication of migration, we assess the patterns of activity among sites to compare the relative strength of migration. For example, a site with a nocturnal passage rate having peaks multiple times larger than lulls for the majority of the sampling period would be considered to have more migration activity 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.

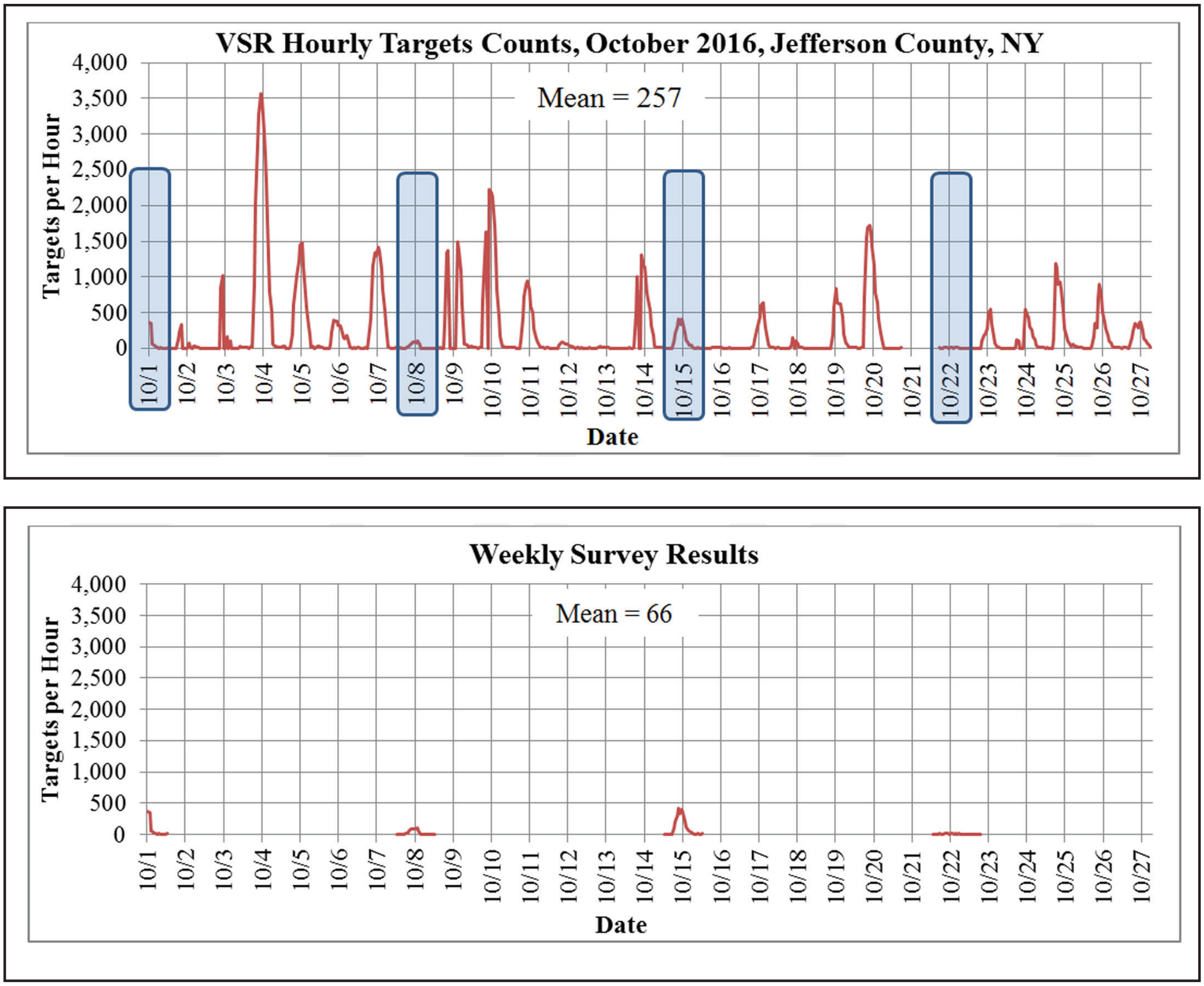


Figure 38. Results of hypothetical non-continuous sampling schedule where data were collected on a continuous sampling schedule (top graphic) versus a weekly sampling schedule (bottom graphic). Red lines represent the number of targets counted per hour by the vertical scanning radar in October 2016 in Jefferson County, New York.

Migration Patterns

Patterns of movement we recorded were consistent with other observations of migration (Newton 2008, Bowden et al. 2015, Horton et al. 2016, Rathbun et al. 2016a, Rathbun et al. 2016b, Rathbun et al. 2016c) and indicated that nocturnal migratory flights occurred regularly during fall 2016 at all three of our surveyed locations. The nocturnal activity we observed was typically oriented in a southern direction (Figures 11-13) and occurred in nightly pulses across the season that were captured by horizontal and vertical radars (Figures 8 - 10). We observed targets in the vicinity of the shoreline flying parallel to shore during daylight, and then shifting to southbound flight after dark (e.g., Figure 9, Wayne County, August 28th). Target passage rates were about 10 times higher during night (between 30 minutes after sunset and 30 minutes before sunrise) than during dawn, dusk, or day at all three locations (Table 4, Figure 20). Mean hourly heights showed a pattern previously associated with migration (Harmata et al. 2000, Mabee and Cooper 2004) in which heights increase near dusk, peak a few hours before midnight, and begin to decrease prior to dawn (Figure 37). The slight increase in mean height near dawn at the three sites 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.

Large migratory flights occurred regularly on successive nights during peak migration in September and early October. At these times, migration pulses occurred most nights, with occasional lulls in activity, and lulls tended to occur at the same times at both radar sites (Jefferson coinciding with Wayne in the first half of the season, and Jefferson coinciding with Niagara during the second half of the season). Migratory pulses outside of peak migration were more sporadic, but also generally occurred on the same nights at Jefferson and the corresponding site, both early and late in the season (at Wayne and Niagara respectively). Migratory flight intensity, as measured by mean target passage rate, was highly correlated among nights (correlation of 0.87 between Jefferson and Wayne, and 0.76 between Jefferson and Niagara), but not as much among days (correlations of 0.31 and 0.49 respectively). Additionally, nocturnal migration was much more closely related to night time flight intensity at the other site than to daytime flight intensity at the same site. As seen in Figure 23, broader trends were also similar between Jefferson and the other site during the night and less so during the day.

Contemporaneous rapid increases in flight activity after sunset may suggest broad front migration events in response to regional environmental factors such as the movement of weather fronts, or variation in timing among guilds of migrants, or a combination of these and other factors (Newton 2008). The close relationship between migration patterns at distant locations could indicate that further investigation into their cause would allow prediction of high migration events.

Flight Altitude

Altitude profiles indicated that there was activity well above 1 km, particularly during the night; however, most targets passed below 1 km with peak density typically below 600 m (Figures 25-27). Maximum target densities occurred more frequently at the lower elevations, with most common peak densities falling between 100 m and 400 m among night and nocturnal hours (Figures 32 and 33). We corrected for the approximate shape of the survey volume and included this correction in our density estimates. This correction is based on the manufacturer's estimate of beam geometry, which may not be precise, and beam propagation is not consistent over time. Beam propagation is affected by side lobes (arc-shaped static return patterns resulting from unpredictable reflections off the surrounding landscape), target size and distance, and atmospheric conditions. Nonetheless, we think the correction was an improvement over altitude profiles that ignore beam geometry and sampling effort. We were not able to correct for variation in detection rates with distance from the radar (Schmaljohann et al. 2008); in addition, detection on our vertical scanning radars decreased significantly at a range of about 1,600 m where the radar transitioned from short to medium pulse. For these reasons, our estimates likely under-represent density as altitude increases. However, we observed densities decreasing well before the 1,600 m band (Figures 25- 27), so this undercounting is unlikely to change the overall picture.

Altitude profiles varied considerably among nocturnal hours at our sites in Jefferson, Wayne, and Niagara Counties (Figures 28-30). 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). Also, migrants ascend and descend between land and migration flight heights during each flight, and changes in flight altitude can occur at various times within each leg of a migratory flight. Depending on location, these altitude changes may place migrants at risk of collision with wind turbines and other tall anthropogenic structures multiple times every night.

Radar Study and Management Considerations

Whereas 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. Unlike larger-scale systems such as NEXRAD weather radar, the sample volume of mobile marine radar units overlap wind turbine rotor-swept zones (30 to 200 m above ground) across much of their detection range. Despite the trend of increasing use of marine radar for impact assessment, standardized equipment and methodology for establishing radar settings, and collecting and processing radar data have not been adopted. These considerations can substantially affect the quality of data. This presents a challenge that is not easily solved. However, without standards, comparisons among studies may be more reflective of changes in equipment, methodology, and site conditions rather than in differences in migration activity among sites.

Additionally, metrics reported in radar surveys can be misleading to someone unfamiliar with avian radar. For example, mean altitude of target passage is often reported to be above the rotor swept zone and has been interpreted as indication of low risk. However, 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 is due to the long range at which radars collect altitude data, up to 3 km above ground level in our study, where high flying targets inflate the mean altitude. This skew is apparent in our data and can be seen by comparing the mean altitude of nocturnal targets to the most densely populated altitude band (Table 5, Figures 34 - 36). 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 are three 50-m altitude bands below 200 m (an estimate for the height of the rotor swept zone) and 53 altitude bands above 200 m. Based on our model, we estimated that about 2 percent of the survey volume is below 200 m. Given that information, we would expect a small percentage of targets to be recorded at or below the rotor swept zone. This indicates only low detection, not low risk.

When examining general migration patterns, high nighttime migrant activity was documented at our three Lake Ontario radar sites. This is evident from our Trackplots (Figures 8-10), the time series plots from each site (Figures 17-19) and high target passage rates (Figures 20– 22 and Table 4). Densities of nighttime targets within a 30 – 200 m rotor swept zone were also high, when compared to the dawn, day and dusk time periods (Figures 25-27). Throughout the migration season, nocturnal targets were recorded flying both across the lake and along the shorelines (Figures 14-16). The combination of these behaviors indicates that high numbers of night time migrants may be at risk of collision with wind turbines, communication towers or other tall structures placed along the shorelines of Lake Ontario.

While target passage rate and target density is lower during the dawn, day, and dusk time periods, migrants may be at risk of collision during these time periods as well. Targets were recorded flying along the lakeshore, flying out over the lake from shore, and returning to shore from over the lake during these time periods, indicating the Lake Ontario shoreline is used by migrants during all times of the day and the migration season, providing 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 single site indicates the level of migration activity and this is a better indicator than comparing the magnitude of counts among studies. Careful attention should be given to how these indices fluctuate over fine temporal scales, such as hourly, as opposed to monthly or seasonal summaries. 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 provide a concept for 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 migrating birds and bats.

The results of our research highlight the potential role of radar in implementing recommendations from the wind energy guidelines (USFWS 2012) to identify areas where impacts to wildlife would be minimized. We documented clear examples of migrant activity around Lake Ontario at our study sites in Jefferson, Wayne, and Niagara Counties, and the density of targets at lower altitudes is a concern. An additional concern is that turbine height and blade length continues to grow, with that the rotor swept zone is growing as well, creating larger areas of flight risk for birds and bats passing through an area. The data we collected may be of interest to public and private entities that are involved with wind energy development and potential placement of turbines in the Great Lakes region. Coupling avian radar systems with other forms of research or using radar in conjunction with post construction fatality searches may broaden the utility of its use in making risk assessments and assessing wind energy developments.

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Appendices

Appendix 1

Fall 2016 Report Summary

- Migration occurred on the southern shoreline, and on the eastern end of Lake Ontario during fall 2016
  - Migration is identified by general direction of movement (southwards) at night, high target passage rate, and nighttime peaks
  - Patterns and timing of migration were similar between the sites
    - Consistent waves of migration with high concentrations of migrants in late August, throughout September, and during the first half of October occurred at both radar units (one unit switched sites on September 10)
    - Waves of migration also occurred early August and late October, at Jefferson and Wayne, and Jefferson and Niagara, respectively; however, nightly pulses were less consistent and of lesser magnitude than those in the middle of the season.
- General date range of pulses that occurred during the migration season
  - Jefferson County, New York (field season August 4 – October 27)
    - August 26 - September 2
    - September 9 - 26
    - September 29 - October 5
  - Wayne County, New York (field season August 3 – September 10)
    - August 27 - 30
    - September 3 - 10
  - Niagara County, New York (field season September 10 – October 28)
    - August 15 - 16
    - October 9 - 10
    - October 19 - 20
- Patterns of activity were different between Dawn, Day, Dusk, and Night time periods
  - Nocturnal movement south:
    - Flight directions were oriented south, southeast, or southwest more frequently than random (37.5% expected with no directionality).
      - 64% of nights surveyed the mean direction of travel was generally southerly at Jefferson County, New York
      - 52% of nights surveyed the mean direction of travel was generally southerly at Wayne County, New York
      - 56% of nights surveyed the mean direction of travel was generally southerly at Niagara County, New York

- Flights influenced by shoreline
  - Longshore flights observed at near-coast study sites (Wayne and Niagara)
  - Heavy concentration of nocturnal flights to the south at all three sites, with strong southwest component at Jefferson and Wayne
  - At dawn, flights at shoreline sites (Wayne and Niagara) remained oriented to the south while flights at inland site (Jefferson) were more uniform (non-directional)
- Movement concentrated at night
  - Target passage rates increased dramatically at night, compared to day, dawn, and dusk periods
- Dawn ascent
  - Increase in height around dawn hours observed at all three sites

■ Peak density of targets in volume-corrected counts

- Max density below 400 m 92% of nights and 54% of night hours at Jefferson County, New York
- Max density below 300 m 100% of nights and 86% of night hours at Wayne County, New York
- Max density below 300 m 94% of nights and 72% of night hours at Niagara County, New York

■ 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) in addition to 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 (for example, due to wind, weather, topography, and time of day) and that targets flying well above the rotor swept zone may still be at risk.

Appendix 2

Percent Land Cover Associated with Study Sites from the 2011 National Land Cover Database

Percent land cover found within 3.7 km of radar locations in Jefferson, Wayne, and Niagara Counties, New York.

National Land Cover Class	Jefferson % of Land Cover	Wayne % of Land Cover	Niagara % of Land Cover
Barren Land	0.13%	0.00%	0.00%
Cultivated Crops	16.61%	20.67%	0.93%
Deciduous Forest	21.20%	10.26%	13.60%
Developed*	4.84%	2.99%	3.84%
Evergreen Forest	2.39%	0.15%	0.74%
Hay/Pasture	43.53%	26.02%	38.31%
Herbaceous	3.46%	0.04%	0.02%
Mixed Forest	0.71%	0.18%	3.38%
Open Water	0.27%	31.68%	34.70%
Shrub/Scrub	1.49%	0.12%	0.52%
Wetlands**	5.37%	7.88%	3.97%

* Includes low, medium and high intensity development and developed open space.

** Includes woody and emergent herbaceous wetlands.

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 density of targets by altitude band during spring biological time periods (dawn, day, dusk, night) in New York (targets/1,000,000 m³/hour).

Jefferson				
Altitude Band	**Dawn**	**Day**	**Dusk**	**Night**
50	0.0	0.0	0.0	0.0
100	0.3	0.2	0.1	0.8
150	0.1	0.1	0.0	0.4
200	0.1	0.0	0.0	0.6
250	0.1	0.1	0.1	1.4
300	0.2	0.1	0.1	2.5
350	0.3	0.2	0.1	3.0
400	0.4	0.2	0.1	2.9
450	0.3	0.1	0.1	2.4
500	0.1	0.1	0.0	2.0
550	0.1	0.0	0.0	1.8
600	0.1	0.0	0.0	1.7
650	0.1	0.0	0.0	1.5
700	0.1	0.0	0.0	1.3
750	0.1	0.0	0.0	1.1
800	0.1	0.0	0.0	0.9
850	0.1	0.0	0.0	0.8
900	0.1	0.0	0.0	0.6
950	0.0	0.0	0.0	0.5
1000	0.0	0.0	0.0	0.4

Estimated density of targets by altitude band during spring biological time periods (dawn, day, dusk, night) in New York (targets/1,000,000 m³/hour).

Wayne				
Altitude Band	**Dawn**	**Day**	**Dusk**	**Night**
50	0.0	0.0	0.0	0.0
100	0.8	0.6	0.7	2.1
150	0.9	0.6	1.0	4.5
200	0.7	0.7	1.4	5.0
250	0.9	0.9	1.3	4.3
300	0.9	0.7	0.8	3.3
350	0.8	0.6	0.6	2.7
400	0.6	0.4	0.3	2.2
450	0.4	0.2	0.2	1.8
500	0.3	0.2	0.1	1.5
550	0.2	0.1	0.1	1.3
600	0.2	0.1	0.0	1.1
650	0.2	0.0	0.0	0.8
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	0.4
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

Estimated density of targets by altitude band during spring biological time periods (dawn, day, dusk, night) in New York (targets/1,000,000 m^3/hour).

	Niagara			
Altitude Band	**Dawn**	**Day**	**Dusk**	**Night**
50	0.2	0.1	0.1	0.1
100	1.1	0.6	0.3	2.0
150	0.9	0.3	0.3	3.4
200	0.4	0.2	0.3	3.3
250	0.3	0.1	0.3	3.2
300	0.4	0.1	0.3	3.4
350	0.4	0.1	0.2	3.0
400	0.2	0.0	0.1	1.8
450	0.2	0.0	0.1	1.7
500	0.2	0.0	0.1	1.7
550	0.2	0.0	0.0	1.3
600	0.2	0.0	0.0	1.3
650	0.2	0.0	0.0	0.9
700	0.1	0.0	0.0	0.8
750	0.1	0.0	0.0	0.8
800	0.1	0.0	0.0	0.5
850	0.1	0.0	0.0	0.3
900	0.0	0.0	0.0	0.4
950	0.1	0.0	0.0	0.4
1000	0.0	0.0	0.0	0.3

Appendix 4

Comparison of Static and Corrected Density Estimates

Comparison of methods to estimate target density by altitude band during the *dawn* biological period in Jefferson County, NY, fall 2016.

Altitude Band (m)	Target Count	Running Total Target Count[1]	Static Volume	Corrected Volume	Static Target Density per Hour	Corrected Target Density per Hour[2]	% Total Targets	% Static Density	% Corrected Density
50	17	17	31.3	5.6	0.0	0.0	0.6%	0.6%	1.4%
100	138	155	31.3	5.9	0.1	0.3	5.1%	5.1%	10.7%
150	34	189	31.3	6.5	0.0	0.1	1.3%	1.3%	2.4%
200	37	226	31.3	7.1	0.0	0.1	1.4%	1.4%	2.4%
250	74	300	31.3	7.9	0.0	0.1	2.7%	2.7%	4.3%
300	137	437	31.3	8.5	0.1	0.2	5.0%	5.0%	7.4%
350	214	651	31.3	9.5	0.1	0.3	7.9%	7.9%	10.4%
400	291	942	31.3	10.3	0.1	0.4	10.7%	10.7%	12.9%
450	220	1,162	31.3	11.2	0.1	0.3	8.1%	8.1%	9.0%
500	137	1,299	31.3	12.2	0.1	0.1	5.0%	5.0%	5.1%
550	145	1,444	31.3	13.3	0.1	0.1	5.3%	5.3%	5.0%
600	147	1,591	31.3	14.1	0.1	0.1	5.4%	5.4%	4.8%
650	116	1,707	31.3	15.3	0.0	0.1	4.3%	4.3%	3.5%
700	107	1,814	31.3	16.2	0.0	0.1	3.9%	3.9%	3.0%
750	110	1,924	31.3	17.2	0.0	0.1	4.0%	4.0%	2.9%
800	87	2,011	31.3	18.2	0.0	0.1	3.2%	3.2%	2.2%
850	75	2,086	31.3	19.4	0.0	0.1	2.8%	2.8%	1.8%
900	80	2,166	31.3	20.4	0.0	0.1	2.9%	2.9%	1.8%
950	68	2,234	31.3	21.4	0.0	0.0	2.5%	2.5%	1.5%
1000	38	2,272	31.3	22.4	0.0	0.0	1.4%	1.4%	0.8%

1 Total target counts recorded up to 2,800m band during the dawn time period was 2719.

2 Total density of targets per hour recorded up to the 2,800 m band during the dawn time period was 2.8671

(Appendix 4 continued)

Comparison of methods to estimate target density by altitude band during the *day* biological period in Jefferson County, NY, fall 2016.

Altitude Band (m)	Target Count	Running Total Target Count[1]	Static Volume	Corrected Volume	Static Target Density per Hour	Corrected Target Density per Hour[2]	% Total Targets	% Static Density	% Corrected Density
50	17	17	31.3	5.6	0.0	0.0	0.1%	1.5%	2.7%
100	138	155	31.3	5.9	0.0	0.2	1.1%	8.6%	15.3%
150	34	189	31.3	6.5	0.0	0.1	0.3%	2.3%	3.8%
200	37	226	31.3	7.1	0.0	0.0	0.3%	2.3%	3.4%
250	74	300	31.3	7.9	0.0	0.1	0.6%	4.0%	5.3%
300	137	437	31.3	8.5	0.0	0.1	1.1%	7.6%	9.4%
350	214	651	31.3	9.5	0.1	0.2	1.7%	12.6%	14.0%
400	291	942	31.3	10.3	0.1	0.2	2.3%	14.2%	14.5%
450	220	1,162	31.3	11.2	0.0	0.1	1.8%	9.3%	8.7%
500	137	1,299	31.3	12.2	0.0	0.1	1.1%	5.4%	4.7%
550	145	1,444	31.3	13.3	0.0	0.0	1.2%	4.3%	3.4%
600	147	1,591	31.3	14.1	0.0	0.0	1.2%	3.7%	2.8%
650	116	1,707	31.3	15.3	0.0	0.0	0.9%	3.2%	2.2%
700	107	1,814	31.3	16.2	0.0	0.0	0.9%	2.8%	1.8%
750	110	1,924	31.3	17.2	0.0	0.0	0.9%	2.4%	1.5%
800	87	2,011	31.3	18.2	0.0	0.0	0.7%	2.0%	1.2%
850	75	2,086	31.3	19.4	0.0	0.0	0.6%	1.4%	0.8%
900	80	2,166	31.3	20.4	0.0	0.0	0.6%	1.2%	0.6%
950	68	2,234	31.3	21.4	0.0	0.0	0.5%	1.2%	0.6%
1000	38	2,272	31.3	22.4	0.0	0.0	0.3%	1.0%	0.4%

1 Total target counts recorded up to 2,800m band during the day time period was 12443.

2 Total density of targets per hour recorded up to the 2,800 m band during the day time period was 1.425.

Comparison of methods to estimate target density by altitude band during the *dusk* biological period in Jefferson County, NY, fall 2016.

Altitude Band (m)	Target Count	Running Total Target Count[1]	Static Volume	Corrected Volume	Static Target Density per Hour	Corrected Target Density per Hour[2]	% Total Targets	% Static Density	% Corrected Density
50	10	10	31.3	5.6	0.0	0.0	1.3%	1.3%	2.8%
100	47	57	31.3	5.9	0.0	0.1	6.1%	6.1%	12.3%
150	9	66	31.3	6.5	0.0	0.0	1.2%	1.2%	2.2%
200	12	78	31.3	7.1	0.0	0.0	1.6%	1.6%	2.6%
250	39	117	31.3	7.9	0.0	0.1	5.0%	5.0%	7.7%
300	69	186	31.3	8.5	0.0	0.1	8.9%	8.9%	12.6%
350	74	260	31.3	9.5	0.0	0.1	9.6%	9.6%	12.1%
400	85	345	31.3	10.3	0.0	0.1	11.0%	11.0%	12.8%
450	60	405	31.3	11.2	0.0	0.1	7.8%	7.8%	8.3%
500	24	429	31.3	12.2	0.0	0.0	3.1%	3.1%	3.0%
550	19	448	31.3	13.3	0.0	0.0	2.5%	2.5%	2.2%
600	20	468	31.3	14.1	0.0	0.0	2.6%	2.6%	2.2%
650	21	489	31.3	15.3	0.0	0.0	2.7%	2.7%	2.1%
700	25	514	31.3	16.2	0.0	0.0	3.2%	3.2%	2.4%
750	16	530	31.3	17.2	0.0	0.0	2.1%	2.1%	1.4%
800	13	543	31.3	18.2	0.0	0.0	1.7%	1.7%	1.1%
850	15	558	31.3	19.4	0.0	0.0	1.9%	1.9%	1.2%
900	12	570	31.3	20.4	0.0	0.0	1.6%	1.6%	0.9%
950	10	580	31.3	21.4	0.0	0.0	1.3%	1.3%	0.7%
1000	9	589	31.3	22.4	0.0	0.0	1.2%	1.2%	0.6%

1 Total target counts recorded up to 2,800m band during the dusk time period was 774.

2 Total density of targets per hour recorded up to the 2,800 m band during the dusk time period was 0.8558.

Comparison of methods to estimate target density by altitude band during the *night* biological period in Jefferson County, NY, fall 2016.

Altitude Band (m)	Target Count	Running Total Target Count[1]	Static Volume	Corrected Volume	Static Target Density per Hour	Corrected Target Density per Hour[2]	% Total Targets	% Static Density	% Corrected Density
50	216	216	31.3	5.6	0.0	0.0	0.1%	0.1%	0.2%
100	3,916	4,132	31.3	5.9	0.2	0.8	1.1%	1.1%	2.8%
150	2,051	6,183	31.3	6.5	0.1	0.4	0.6%	0.6%	1.3%
200	3,584	9,767	31.3	7.1	0.1	0.6	1.0%	1.0%	2.1%
250	8,838	18,605	31.3	7.9	0.4	1.4	2.6%	2.6%	4.7%
300	16,346	34,951	31.3	8.5	0.7	2.5	4.7%	4.7%	8.1%
350	21,958	56,909	31.3	9.5	0.9	3.0	6.4%	6.4%	9.8%
400	23,103	80,012	31.3	10.3	0.9	2.9	6.7%	6.7%	9.5%
450	21,204	101,216	31.3	11.2	0.9	2.4	6.1%	6.1%	8.0%
500	19,122	120,338	31.3	12.2	0.8	2.0	5.5%	5.5%	6.6%
550	18,838	139,176	31.3	13.3	0.8	1.8	5.5%	5.5%	6.0%
600	18,487	157,663	31.3	14.1	0.8	1.7	5.4%	5.4%	5.5%
650	17,540	175,203	31.3	15.3	0.7	1.5	5.1%	5.1%	4.8%
700	16,406	191,609	31.3	16.2	0.7	1.3	4.8%	4.8%	4.3%
750	14,857	206,466	31.3	17.2	0.6	1.1	4.3%	4.3%	3.7%
800	13,499	219,965	31.3	18.2	0.6	0.9	3.9%	3.9%	3.1%
850	11,556	231,521	31.3	19.4	0.5	0.8	3.3%	3.3%	2.5%
900	10,300	241,821	31.3	20.4	0.4	0.6	3.0%	3.0%	2.1%
950	8,824	250,645	31.3	21.4	0.4	0.5	2.6%	2.6%	1.7%
1000	7,531	258,176	31.3	22.4	0.3	0.4	2.2%	2.2%	1.4%

1 Total target counts recorded up to 2,800m band during the night time period was 345,226.

2 Total density of targets per hour recorded up to the 2,800 m band during the night time period was 30.192.

Comparison of methods to estimate target density by altitude band during the *dawn* biological period in Wayne County, NY, fall 2016.

Altitude Band (m)	Target Count	Running Total Target Count[1]	Static Volume	Corrected Volume	Static Target Density per Hour	Corrected Target Density per Hour[2]	% Total Targets	% Static Density	% Corrected Density
50	6	6	31.3	5.6	0.0	0.0	0.2%	0.2%	0.4%
100	153	159	31.3	5.9	0.2	0.8	5.8%	5.8%	10.3%
150	178	337	31.3	6.5	0.2	0.9	6.8%	6.8%	11.0%
200	150	487	31.3	7.1	0.1	0.7	5.7%	5.7%	8.4%
250	230	717	31.3	7.9	0.2	0.9	8.7%	8.7%	11.6%
300	256	973	31.3	8.5	0.3	0.9	9.7%	9.7%	12.0%
350	243	1,216	31.3	9.5	0.2	0.8	9.2%	9.2%	10.2%
400	203	1,419	31.3	10.3	0.2	0.6	7.7%	7.7%	7.8%
450	157	1,576	31.3	11.2	0.2	0.4	6.0%	6.0%	5.6%
500	120	1,696	31.3	12.2	0.1	0.3	4.6%	4.6%	3.9%
550	94	1,790	31.3	13.3	0.1	0.2	3.6%	3.6%	2.8%
600	100	1,890	31.3	14.1	0.1	0.2	3.8%	3.8%	2.8%
650	79	1,969	31.3	15.3	0.1	0.2	3.0%	3.0%	2.1%
700	81	2,050	31.3	16.2	0.1	0.2	3.1%	3.1%	2.0%
750	51	2,101	31.3	17.2	0.1	0.1	1.9%	1.9%	1.2%
800	48	2,149	31.3	18.2	0.0	0.1	1.8%	1.8%	1.1%
850	51	2,200	31.3	19.4	0.1	0.1	1.9%	1.9%	1.0%
900	39	2,239	31.3	20.4	0.0	0.1	1.5%	1.5%	0.8%
950	26	2,265	31.3	21.4	0.0	0.0	1.0%	1.0%	0.5%
1000	27	2,292	31.3	22.4	0.0	0.0	1.0%	1.0%	0.5%

1 Total target counts recorded up to 2,800m band during the dawn time period was 2637.

2 Total density of targets per hour recorded up to the 2,800 m band during the dawn time period was 7.82116.

Comparison of methods to estimate target density by altitude band during the *day* biological period in Wayne County, NY, fall 2016.

Altitude Band (m)	Target Count	Running Total Target Count[1]	Static Volume	Corrected Volume	Static Target Density per Hour	Corrected Target Density per Hour[2]	% Total Targets	% Static Density	% Corrected Density
50	19	19	31.3	5.6	0.0	0.0	0.1%	0.1%	0.2%
100	1,471	1,490	31.3	5.9	0.1	0.6	7.3%	7.3%	11.2%
150	1,673	3,163	31.3	6.5	0.1	0.6	8.3%	8.3%	11.7%
200	2,193	5,356	31.3	7.1	0.2	0.7	10.9%	10.9%	13.9%
250	2,812	8,168	31.3	7.9	0.2	0.9	14.0%	14.0%	16.0%
300	2,418	10,586	31.3	8.5	0.2	0.7	12.0%	12.0%	12.8%
350	2,188	12,774	31.3	9.5	0.2	0.6	10.9%	10.9%	10.4%
400	1,679	14,453	31.3	10.3	0.1	0.4	8.4%	8.4%	7.3%
450	1,153	15,606	31.3	11.2	0.1	0.2	5.7%	5.7%	4.6%
500	897	16,503	31.3	12.2	0.1	0.2	4.5%	4.5%	3.3%
550	647	17,150	31.3	13.3	0.0	0.1	3.2%	3.2%	2.2%
600	463	17,613	31.3	14.1	0.0	0.1	2.3%	2.3%	1.5%
650	316	17,929	31.3	15.3	0.0	0.0	1.6%	1.6%	0.9%
700	253	18,182	31.3	16.2	0.0	0.0	1.3%	1.3%	0.7%
750	222	18,404	31.3	17.2	0.0	0.0	1.1%	1.1%	0.6%
800	161	18,565	31.3	18.2	0.0	0.0	0.8%	0.8%	0.4%
850	134	18,699	31.3	19.4	0.0	0.0	0.7%	0.7%	0.3%
900	100	18,799	31.3	20.4	0.0	0.0	0.5%	0.5%	0.2%
950	82	18,881	31.3	21.4	0.0	0.0	0.4%	0.4%	0.2%
1000	55	18,936	31.3	22.4	0.0	0.0	0.3%	0.3%	0.1%

1 Total target counts recorded up to 2,800m band during the day time period was 20,068.

2 Total density of targets per hour recorded up to the 2,800 m band during the day time period was 5.3306.

Comparison of methods to estimate target density by altitude band during the *dusk* biological period in Wayne County, NY, fall 2016.

Altitude Band (m)	Target Count	Running Total Target Count[1]	Static Volume	Corrected Volume	Static Target Density per Hour	Corrected Target Density per Hour[2]	% Total Targets	% Static Density	% Corrected Density
50	2	2	31.3	5.6	0.0	0.0	0.1%	0.1%	0.2%
100	147	149	31.3	5.9	0.1	0.7	7.3%	7.3%	10.5%
150	224	373	31.3	6.5	0.2	1.0	11.2%	11.2%	14.7%
200	342	715	31.3	7.1	0.3	1.4	17.0%	17.0%	20.4%
250	354	1,069	31.3	7.9	0.3	1.3	17.6%	17.6%	18.9%
300	251	1,320	31.3	8.5	0.2	0.8	12.5%	12.5%	12.5%
350	185	1,505	31.3	9.5	0.2	0.6	9.2%	9.2%	8.3%
400	119	1,624	31.3	10.3	0.1	0.3	5.9%	5.9%	4.9%
450	87	1,711	31.3	11.2	0.1	0.2	4.3%	4.3%	3.3%
500	63	1,774	31.3	12.2	0.1	0.1	3.1%	3.1%	2.2%
550	31	1,805	31.3	13.3	0.0	0.1	1.5%	1.5%	1.0%
600	18	1,823	31.3	14.1	0.0	0.0	0.9%	0.9%	0.5%
650	11	1,834	31.3	15.3	0.0	0.0	0.5%	0.5%	0.3%
700	10	1,844	31.3	16.2	0.0	0.0	0.5%	0.5%	0.3%
750	4	1,848	31.3	17.2	0.0	0.0	0.2%	0.2%	0.1%
800	2	1,850	31.3	18.2	0.0	0.0	0.1%	0.1%	0.0%
850	2	1,852	31.3	19.4	0.0	0.0	0.1%	0.1%	0.0%
900	7	1,859	31.3	20.4	0.0	0.0	0.3%	0.3%	0.1%
950	3	1,862	31.3	21.4	0.0	0.0	0.1%	0.1%	0.1%
1000	3	1,865	31.3	22.4	0.0	0.0	0.1%	0.1%	0.1%

1 Total target counts recorded up to 2,800m band during the dusk time period was 2006.

2 Total density of targets per hour recorded up to the 2,800 m band during the dusk time period was 6.70436

Comparison of methods to estimate target density by altitude band during the *night* biological period in Wayne County, NY, fall 2016.

Altitude Band (m)	Target Count	Running Total Target Count[1]	Static Volume	Corrected Volume	Static Target Density per Hour	Corrected Target Density per Hour[2]	% Total Targets	% Static Density	% Corrected Density
50	11	11	31.3	5.6	0.0	0.0	0.0%	0.0%	0.0%
100	4,136	4,147	31.3	5.9	0.4	2.1	3.5%	3.5%	6.2%
150	9,432	13,579	31.3	6.5	0.9	4.5	8.0%	8.0%	13.0%
200	11,663	25,242	31.3	7.1	1.1	5.0	9.9%	9.9%	14.6%
250	11,144	36,386	31.3	7.9	1.1	4.3	9.5%	9.5%	12.5%
300	9,241	45,627	31.3	8.5	0.9	3.3	7.9%	7.9%	9.7%
350	8,192	53,819	31.3	9.5	0.8	2.7	7.0%	7.0%	7.7%
400	7,322	61,141	31.3	10.3	0.7	2.2	6.2%	6.2%	6.3%
450	6,725	67,866	31.3	11.2	0.7	1.8	5.7%	5.7%	5.3%
500	6,137	74,003	31.3	12.2	0.6	1.5	5.2%	5.2%	4.5%
550	5,459	79,462	31.3	13.3	0.5	1.3	4.6%	4.6%	3.6%
600	4,907	84,369	31.3	14.1	0.5	1.1	4.2%	4.2%	3.1%
650	4,055	88,424	31.3	15.3	0.4	0.8	3.4%	3.4%	2.4%
700	3,374	91,798	31.3	16.2	0.3	0.6	2.9%	2.9%	1.8%
750	2,895	94,693	31.3	17.2	0.3	0.5	2.5%	2.5%	1.5%
800	2,669	97,362	31.3	18.2	0.3	0.4	2.3%	2.3%	1.3%
850	2,246	99,608	31.3	19.4	0.2	0.4	1.9%	1.9%	1.0%
900	1,866	101,474	31.3	20.4	0.2	0.3	1.6%	1.6%	0.8%
950	1,355	102,829	31.3	21.4	0.1	0.2	1.2%	1.2%	0.6%
1000	1,021	103,850	31.3	22.4	0.1	0.1	0.9%	0.9%	0.4%

1 Total target counts recorded up to 2,800m band during the night time period was 117,691.

2 Total density of targets per hour recorded up to the 2,800 m band during the night time period was 34.4771

Comparison of methods to estimate target density by altitude band during the *dawn* biological period in Niagara County, NY, fall 2016.

Altitude Band (m)	Target Count	Running Total Target Count[1]	Static Volume	Corrected Volume	Static Target Density per Hour	Corrected Target Density per Hour[2]	% Total Targets	% Static Density	% Corrected Density
50	36	36	31.3	5.6	0.0	0.2	1.3%	1.3%	2.5%
100	279	315	31.3	5.9	0.2	1.1	9.9%	9.9%	18.6%
150	250	565	31.3	6.5	0.2	0.9	8.9%	8.9%	15.3%
200	126	691	31.3	7.1	0.1	0.4	4.5%	4.5%	7.0%
250	103	794	31.3	7.9	0.1	0.3	3.7%	3.7%	5.2%
300	143	937	31.3	8.5	0.1	0.4	5.1%	5.1%	6.7%
350	159	1,096	31.3	9.5	0.1	0.4	5.7%	5.7%	6.6%
400	94	1,190	31.3	10.3	0.1	0.2	3.3%	3.3%	3.6%
450	102	1,292	31.3	11.2	0.1	0.2	3.6%	3.6%	3.6%
500	125	1,417	31.3	12.2	0.1	0.2	4.4%	4.4%	4.0%
550	113	1,530	31.3	13.3	0.1	0.2	4.0%	4.0%	3.4%
600	143	1,673	31.3	14.1	0.1	0.2	5.1%	5.1%	4.0%
650	128	1,801	31.3	15.3	0.1	0.2	4.6%	4.6%	3.3%
700	100	1,901	31.3	16.2	0.1	0.1	3.6%	3.6%	2.4%
750	95	1,996	31.3	17.2	0.1	0.1	3.4%	3.4%	2.2%
800	57	2,053	31.3	18.2	0.0	0.1	2.0%	2.0%	1.2%
850	45	2,098	31.3	19.4	0.0	0.1	1.6%	1.6%	0.9%
900	41	2,139	31.3	20.4	0.0	0.0	1.5%	1.5%	0.8%
950	46	2,185	31.3	21.4	0.0	0.1	1.6%	1.6%	0.9%
1000	28	2,213	31.3	22.4	0.0	0.0	1.0%	1.0%	0.5%

1 Total target counts recorded up to 2,800m band during the dawn time period was 2813.

2 Total density of targets per hour recorded up to the 2,800 m band during the dawn time period was 6.0900.

Comparison of methods to estimate target density by altitude band during the *day* biological period in Niagara County, NY, fall 2016.

Altitude Band (m)	Target Count	Running Total Target Count[1]	Static Volume	Corrected Volume	Static Target Density per Hour	Corrected Target Density per Hour[2]	% Total Targets	% Static Density	% Corrected Density
50	356	356	31.3	5.6	0.0	0.1	5.7%	5.7%	8.3%
100	1,525	1,881	31.3	5.9	0.1	0.6	24.3%	24.3%	33.4%
150	834	2,715	31.3	6.5	0.1	0.3	13.3%	13.3%	16.8%
200	473	3,188	31.3	7.1	0.0	0.2	7.5%	7.5%	8.7%
250	502	3,690	31.3	7.9	0.0	0.1	8.0%	8.0%	8.3%
300	530	4,220	31.3	8.5	0.0	0.1	8.4%	8.4%	8.1%
350	306	4,526	31.3	9.5	0.0	0.1	4.9%	4.9%	4.2%
400	123	4,649	31.3	10.3	0.0	0.0	2.0%	2.0%	1.6%
450	126	4,775	31.3	11.2	0.0	0.0	2.0%	2.0%	1.5%
500	133	4,908	31.3	12.2	0.0	0.0	2.1%	2.1%	1.4%
550	95	5,003	31.3	13.3	0.0	0.0	1.5%	1.5%	0.9%
600	121	5,124	31.3	14.1	0.0	0.0	1.9%	1.9%	1.1%
650	80	5,204	31.3	15.3	0.0	0.0	1.3%	1.3%	0.7%
700	84	5,288	31.3	16.2	0.0	0.0	1.3%	1.3%	0.7%
750	75	5,363	31.3	17.2	0.0	0.0	1.2%	1.2%	0.6%
800	49	5,412	31.3	18.2	0.0	0.0	0.8%	0.8%	0.4%
850	39	5,451	31.3	19.4	0.0	0.0	0.6%	0.6%	0.3%
900	52	5,503	31.3	20.4	0.0	0.0	0.8%	0.8%	0.3%
950	46	5,549	31.3	21.4	0.0	0.0	0.7%	0.7%	0.3%
1000	43	5,592	31.3	22.4	0.0	0.0	0.7%	0.7%	0.3%

1 Total target counts recorded up to 2,800m band during the day time period was 6281.

2 Total density of targets per hour recorded up to the 2,800 m band during the day time period was 1.7477

Comparison of methods to estimate target density by altitude band during the *dusk* biological period in Niagara County, NY, fall 2016.

Altitude Band (m)	Target Count	Running Total Target Count[1]	Static Volume	Corrected Volume	Static Target Density per Hour	Corrected Target Density per Hour[2]	% Total Targets	% Static Density	% Corrected Density
50	17	17	31.3	5.6	0.0	0.1	2.1%	2.1%	3.2%
100	88	105	31.3	5.9	0.1	0.3	10.9%	10.9%	15.7%
150	73	178	31.3	6.5	0.1	0.3	9.0%	9.0%	12.0%
200	98	276	31.3	7.1	0.1	0.3	12.1%	12.1%	14.6%
250	114	390	31.3	7.9	0.1	0.3	14.1%	14.1%	15.3%
300	107	497	31.3	8.5	0.1	0.3	13.3%	13.3%	13.3%
350	97	594	31.3	9.5	0.1	0.2	12.0%	12.0%	10.9%
400	40	634	31.3	10.3	0.0	0.1	5.0%	5.0%	4.1%
450	27	661	31.3	11.2	0.0	0.1	3.3%	3.3%	2.5%
500	33	694	31.3	12.2	0.0	0.1	4.1%	4.1%	2.9%
550	12	706	31.3	13.3	0.0	0.0	1.5%	1.5%	1.0%
600	12	718	31.3	14.1	0.0	0.0	1.5%	1.5%	0.9%
650	9	727	31.3	15.3	0.0	0.0	1.1%	1.1%	0.6%
700	7	734	31.3	16.2	0.0	0.0	0.9%	0.9%	0.5%
750	2	736	31.3	17.2	0.0	0.0	0.2%	0.2%	0.1%
800	8	744	31.3	18.2	0.0	0.0	1.0%	1.0%	0.5%
850	6	750	31.3	19.4	0.0	0.0	0.7%	0.7%	0.3%
900	2	752	31.3	20.4	0.0	0.0	0.2%	0.2%	0.1%
950	1	753	31.3	21.4	0.0	0.0	0.1%	0.1%	0.0%
1000	2	755	31.3	22.4	0.0	0.0	0.2%	0.2%	0.1%

1 Total target counts recorded up to 2,800m band during the dusk time period was 807.

2 Total density of targets per hour recorded up to the 2,800 m band during the dusk time period was 2.1917.

Comparison of methods to estimate target density by altitude band during the *night* biological period in Niagara County, NY, fall 2016.

Altitude Band (m)	Target Count	Running Total Target Count[1]	Static Volume	Corrected Volume	Static Target Density per Hour	Corrected Target Density per Hour[2]	% Total Targets	% Static Density	% Corrected Density
50	414	414	31.3	5.6	0.0	0.1	0.2%	0.2%	0.4%
100	5,883	6,297	31.3	5.9	0.4	2.0	3.0%	3.0%	6.0%
150	10,893	17,190	31.3	6.5	0.7	3.4	5.5%	5.5%	10.2%
200	11,484	28,674	31.3	7.1	0.7	3.3	5.8%	5.8%	9.8%
250	12,348	41,022	31.3	7.9	0.8	3.2	6.2%	6.2%	9.5%
300	14,281	55,303	31.3	8.5	0.9	3.4	7.2%	7.2%	10.2%
350	14,062	69,365	31.3	9.5	0.9	3.0	7.1%	7.1%	9.0%
400	9,288	78,653	31.3	10.3	0.6	1.8	4.7%	4.7%	5.5%
450	9,224	87,877	31.3	11.2	0.6	1.7	4.6%	4.6%	5.0%
500	10,258	98,135	31.3	12.2	0.7	1.7	5.2%	5.2%	5.1%
550	8,639	106,774	31.3	13.3	0.6	1.3	4.3%	4.3%	3.9%
600	8,978	115,752	31.3	14.1	0.6	1.3	4.5%	4.5%	3.9%
650	6,946	122,698	31.3	15.3	0.4	0.9	3.5%	3.5%	2.8%
700	6,424	129,122	31.3	16.2	0.4	0.8	3.2%	3.2%	2.4%
750	6,587	135,709	31.3	17.2	0.4	0.8	3.3%	3.3%	2.3%
800	4,678	140,387	31.3	18.2	0.3	0.5	2.4%	2.4%	1.6%
850	3,057	143,444	31.3	19.4	0.2	0.3	1.5%	1.5%	1.0%
900	3,908	147,352	31.3	20.4	0.3	0.4	2.0%	2.0%	1.2%
950	4,225	151,577	31.3	21.4	0.3	0.4	2.1%	2.1%	1.2%
1000	3,262	154,839	31.3	22.4	0.2	0.3	1.6%	1.6%	0.9%

1 Total target counts recorded up to 2,800m band during the night time period was 198,703.

2 Total density of targets per hour recorded up to the 2,800 m band during the night time period was 33.2376.

Fall 2016