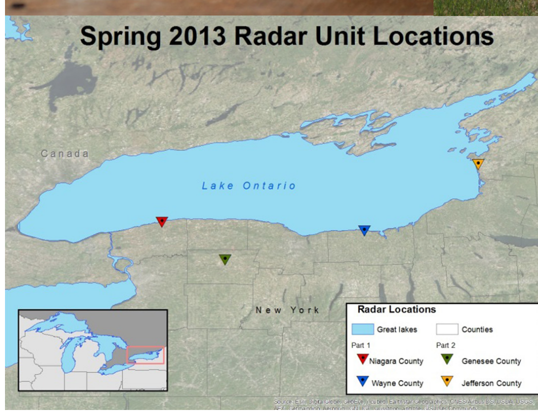
U.S. Fish & Wildlife Service

Great Lakes Avian Radar Technical Report Niagara, Genesee, Wayne and Jefferson Counties, New York

Spring 2013 Season



U.S. Fish & Wildlife Service, Region 3

Funding Provided by the Great Lakes Restoration Initiative

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Great Lakes RESTORATION

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Executive Summary

Global wind patterns assist the migration of millions of birds and bats through the Great Lakes region, where shorelines provide important stopover habitat. Shorelines are thought to concentrate migrants because they offer the last refuge adjacent to a geographic obstacle and are likely used for navigation. Shorelines are also attractive for wind energy development. Because of this potential for conflict of interest, more information is needed on the aeroecology of the Great Lakes shorelines. We used two avian radar systems to simultaneously identify the activity patterns, timing, and duration of migration along the shorelines of the Great Lakes. We placed avian radar systems near Lake Ontario in New York, where the automated systems continuously tracked and recorded target (bird and bat) movements from late March to early June, 2013. We calculated the direction of movement, target passage rates, and altitude profiles for the air space above our study areas. We also modeled the vertical sample volume to estimate target density by altitude band.

Heavy migration was observed along the studied shorelines in New York and at a site surveyed inland of the lake shore. The mean nocturnal passage rates were greater than the mean passage rates for dawn, day, and dusk combined at all but one of the four studied locations. Nocturnal movement was typically oriented in a northeasterly direction, but we also recorded other behaviors associated with migrants, such as a slight dawn ascent and migrants returning from over water to land at dawn. Peak density occurred between 100 and 250 m above ground level at 3 of the 4 sites. At the fourth site, the peak density occurred at 400–450 m, although clutter likely interfered with detection at lower altitudes. At all of the sites, density may have been underestimated at higher altitudes due to loss of detection at longer ranges. Underestimation of target density may also have occurred at lower altitudes due to clutter.

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

Avian radar has been relied upon to perform surveys for pre-construction risk analysis but has been used rarely in New York in recent years. The consistent methodology and reliable data analysis techniques that we present in this report may promote the future use of avian radar. Although it is an important tool, few regulatory agencies possess experience implementing avian radar or recognize both the strengths and limitations of the technology.

This report highlights some considerations regarding avian radar and reviews potentially confusing metrics. We also introduce 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 reviews of avian radar studies and provide methods that identify components of migration such as the following:

- 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 efforts may require the identification of locations where migrants concentrate to avoid development in these areas. Our use of commercial-grade avian radar to document migration and, in subsequent reports, to identify concentrations of activity is a broad-scale effort toward this goal.

Introduction

The Great Lakes are one of the largest bodies of freshwater on the planet and collectively occupy a surface area of nearly 245,000 km2, with more than 17,500 km of shoreline. Global wind patterns facilitate the migration of millions of birds and bats through the Great Lakes region (Rich 2004, Liechti 2006, France et al. 2012), and lake shorelines feature widely recognized Important Bird Areas (Audubon 2013). Migrants passing through the region concentrate along shorelines (Ewert et al. 2011, Peterson and Niemi 2011, Buler and Dawson 2012, France et al. 2012), which provide important stopover habitat—areas used temporarily for rest, refueling, and protection. These shorelines offer increased foraging opportunities relative to inland areas (Smith et al. 2004, 2007; Bonter et al. 2007, 2009) and may be used as visual cues for navigation or for refuge prior to or after crossing open water (Buler and Moore 2011).

Given their location and size, the Great Lakes likely represent a geographic obstacle (Diehl et al. 2003) that migrants choose to cross or not based on environmental and physiological conditions at the time of encounter (Faaborg et al. 2010, Schmaljohann et al. 2011). For migrants that rely on powered flight, it is more efficient to make several short flights than a long flight due to the cost of carrying large fuel loads (Alerstam 1990). This efficiency may explain why migrants partially circumnavigate the Great Lakes, which they are physiologically capable of crossing (Alerstam 1990, Alerstam 2001, Ruth 2007). The decision to cross likely represents a trade-off between minimizing costs (e.g., energy and time) and exposure to risk factors (e.g., predation and fatigue) associated with migration (McGuire et al. 2012a). In this trade-off, shorelines offer refuge when the 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) observed that birds with low fuel loads and/or facing unfavorable weather conditions return to shoreline habitat rather than continue across open water in a direction appropriate for migration. Migrant bats vary their decision to circumnavigate above shorelines or cross lakes, and some long-distance migrants use torpor to postpone migration during periods of unfavorable conditions (McGuire et al. 2012b). These behavioral responses and the necessity of using stopover habitats during migration likely contribute to the heavy 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 migrants regularly engage in morning flights along shorelines (Wiedner et al. 1992). These flights typically occur within 2 hours of sunrise and are thought to represent reorientation along a geographic obstacle or movements among stopover habitats (Able 1977, Moore 1990, Wiedner et al. 1992). Flights of this nature often occur above the tree line (Bingman 1980) but at heights lower than those associated with nocturnal migration (Harmata et al. 2000, Mabee and Cooper 2004, Newton 2008). Migrants also initiate nightly exploratory flights at stopover sites (Schmaljohann et al. 2011). These flights are thought to represent the normal activity of migrants as they calibrate their internal compasses and test wind speed and direction aloft. In addition to these activities, during stopover, migration flights follow north-south oriented shorelines en route to their destination (Buler and Dawson 2012), whereas east-west oriented shorelines may be used to circumnavigate open water or identify narrow points for crossing (Alerstam 2001, Diehl et al. 2003, France et al. 2012). Cumulatively, these activities define a use area near lake shores that include a variety of movements and altitudes for landscape level, exploratory, and migrational flights. These activities may increase the vulnerability to collision with tall structures such as communication towers or wind turbines.

The risk of mortality among migrant populations may be greatest during migration (Newton 2006, 2007; Diehl et al. 2014), and the negative ramifications of compromised stopover habitat for migratory populations are increasingly clear (Sillett and Holmes 2002, Mehlman et al. 2005, Faaborg et al. 2010). Shoreline habitats along the Great Lakes are subject to impacts from urban and energy development, land conversion, and environmental contamination that may limit habitat availability and/or reduce habitat quality (France et al. 2012). Furthermore, White-nose Syndrome is devastating populations of hibernating bats and has increased the need to identify conservation areas because several hibernating bat species face extirpation in the Great Lakes region (Turner et al. 2011). In response to such factors, substantial efforts are focused on identifying and protecting stopover habitat along the Great Lakes shorelines (Buler and Dawson 2012, Ewert et al. 2012, France et al. 2012). Careful planning is needed to balance the demands of increased renewable energy development to combat climate change with increased conservation of migratory species.

There is a national movement toward a 20% wind energy sector in the US market by 2030 (DOE 2008). Through 2012, wind energy installation was on target for achieving this goal (AWEA 2015), which if achieved, would represent nearly a five-fold increase in wind energy capacity over the next 15 years (Loss et al. 2013). Coinciding with this national effort, wind energy developments within the Great Lakes region, where windy shorelines offer areas attractive for turbine placement, are increasing (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 Baerwald 2013, Hayes 2013, Smallwood 2013). Three species of long-distance migratory bats impacted by wind energy facilities account for approximately 75% of all bat mortalities (Kunz et al. 2007a, Cryan 2011, Arnett and Baerwald 2013). These migrants, the hoary bat (*Lasiurus cinereus*), the eastern red bat (*Lasiurus borealis*), and the silver-haired bat (*Lasionycteris noctivagans*) typically make up the majority of bat fatalities at wind facilities in the Upper Midwest (Arnett et al. 2008). Three Wisconsin studies observed high fatality rates for these same migrant species as well as substantial fatalities for the little brown bat (*Myotis lucifugus*) and big brown bat (*Eptesicus fuscus*) (Gruver et al. 2009, BHE Environmental 2010, Grodsky et al. 2012). The proximity of major hibernacula in the latter three studies may have contributed to the difference in ratios. Low reproductive rates inhibit the ability of bats to rebound from population declines (Racey and Entwistle 2000), and these declines have already begun for several species (Kunz et al. 2007a, Cryan 2011). Concerns about the cumulative impacts on migrant bird and bat species will increase as wind energy expands if methods to avoid or minimize mortality events are not established. Promising conservation measures to reduce mortality levels have been proposed, but the greatest opportunity for migrant conservation may lie in our ability to identify and avoid future growth in locations at which migrants concentrate.

To help meet the needs of both renewable energy development and wildlife conservation, we established this project to identify the activity patterns, timing, and magnitude of migration along shorelines of the Great Lakes. Since bats and many bird species migrate during the nighttime hours throughout the spring and fall, documenting the migration of these animals is challenging due to the difficulty of observing nocturnal movements that occur sporadically throughout the season. We used a combination of techniques to address this challenge. As the primary means of data collection, we used two avian radar units operating 24 hours per day; each unit simultaneously scanned the horizontal and vertical planes. Our objectives for the avian radar portion of the study were as follows:

- Monitor shorelines and inland locations along Lake Ontario using a consistent methodology.
- Maintain an archive of continuously recorded radar data during the spring migration season.
- Identify activity patterns captured by avian radar that are diagnostic of migration on an east-west oriented lakeshore in the spring.
- Estimate the duration of the migration season.
- Document changes in the behavior of migrants under varying conditions and during different parts of the season.

Methods

Study Area

During spring 2013, we selected four sites in New York for radar placement (Figure 1). During the first part of the season, two sites were located along the southern shore of Lake Ontario in Niagara and Wayne counties. In the second half of the season, one radar unit was placed along the eastern shore of Lake Ontario in Jefferson County, and the other unit was placed inland approximately 35 km from the southern shore of Lake Ontario in Genesee County. We initially placed radar units approximately 1 km from the shoreline to monitor the airspace above the inland, shoreline, and lake areas. In Niagara County, the radar unit was located at 43.340106° N, -78.659148° W and 91 m above mean sea level. The unit was placed in an open field within a large commercial orchard where cultivated crops/pasture and open water were the predominant landcover types within range of the radar unit, according to our analysis using Esri ArcGIS software and the 2011 National Land Cover Database (Jin et al. 2013; Table 1, Figure 2, Appendix 2). In Wayne County, the radar unit was located at 43.275550° N and -77.091850° W and 97 m above mean sea level. The unit was placed within a commercial orchard where cultivated crops/pasture and open water were the predominant landcover types within range of the radar unit (Table 1, Figure 2, Appendix 2).

The radar units were moved mid-season to different sites. In Genesee County, the radar unit was located at 43.050520° N, -78.169800° W and 247 m above mean sea level. The unit was placed within an agricultural field where cultivated crops/pasture was the predominant landcover type within range of the radar unit (Table 1, Figure 2, Appendix 2). This radar unit was located inland, and consequently, no open water was within radar range. By contrast, open water accounted for approximately 30% of the landcover at the other sites. Iroquois National Wildlife Refuge is located approximately 10 miles (16 km) ENE of the Genesee County site. In Jefferson County, the radar unit was located at 43.785000° N and -76.208920° W and 83 m above mean sea level. The unit was placed within a fallow field where open water, cultivated crops/pasture, and wetlands were the predominant landcover types within range of the radar unit (Table 1, Figure 2, Appendix 2). This radar site was also adjacent to (<0.5 miles, <1 km) the Black Pond Wildlife Management Area, an area that includes large patches of marsh and forested woodlands.

One radar unit was located at the two eastern locations: the Wayne County site for the first part of the season and the Jefferson County location for the second part of the season. The second radar unit started the season at the Niagara County site and was moved to the Genesee County site for the second part of the season. The two radar units were the same model and have subsequently performed similarly when compared with each other.

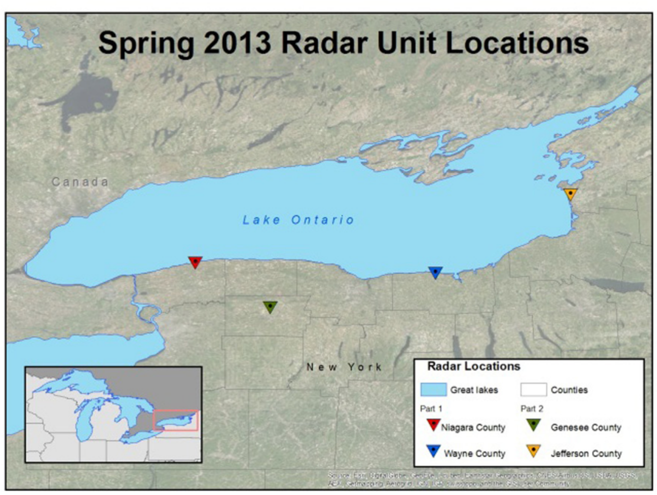


Figure 1. Locations at which MERLIN Avian Radar Systems were deployed during the spring 2013 migration season. The map image is the intellectual property of Esri and is used herein under license. Copyright © 2014 Esri and its licensors. All rights reserved.

Table 1. Predominant landcover types within a 3.7-km radius of the radar locations in New York in spring 2013.

National Landcover Class	Niagara County % Land Cover	Wayne County % Land Cover	Genesee County % Land Cover	Jefferson County % Land Cover
Cultivated Crops/Pasture	46.8%	39.3%	77.1%	26.6%
Deciduous Forest	10.6%	13.6%	4.8%	8.3%
Open Water	31.1%	34.6%	0.0%	33.2%
Developed*	3.0%	3.8%	9.1%	3.0%
Other**	8.5%	8.7%	9.0%	28.8%***

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

** Includes barren land, evergreen forest, herbaceous, mixed forest, shrub/scrub, and woody or emergent herbaceous wetlands.

*** Wetlands and Shrub/Scrub made up 12.2% and 9.3% of the Other landcover class for Jefferson County, respectively (Appendix 2).

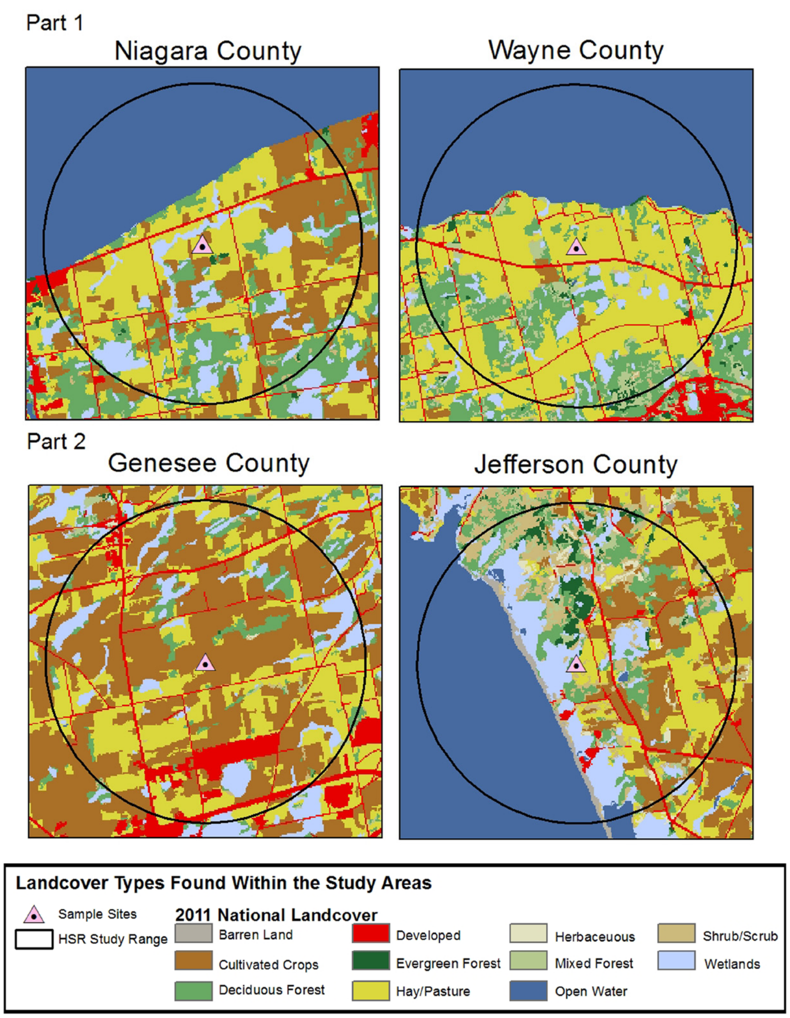


Figure 2. Landcover types (Jin et al. 2013) within a 3.7-km radius of the radar locations in New York during spring 2013.

Site Selection

The radar monitoring sites were selected via a combination of geographic modeling and on-site assessment to locate areas near shorelines with unimpeded views. First, large sections of the Great Lakes shoreline were identified as areas of interest for the placement of radar units during the migration season. Esri ArcGIS software was used to model the areas of interest to identify potentially suitable locations for radar siting. This suitability modeling incorporated datasets describing the elevation, land cover, and shoreline of the Great Lakes. Additional landscape characteristics were derived from these datasets (elevation below local maximum elevation, percent forest, 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 from the GIS modeling process were targeted for on-site assessment.

Biologists were dispatched to areas of interest to perform a thorough assessment of potential sites identified by modeling. This assessment included evaluating the land use, line of sight to shorelines, and accessibility for placement of radar units. Additional locations not identified by modeling were frequently discovered during on-site assessments and were also evaluated. When a location was determined by field biologists to be highly suitable compared to other locations visited, contact was initiated with property owners to obtain permission to set up the radar units.

Equipment

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

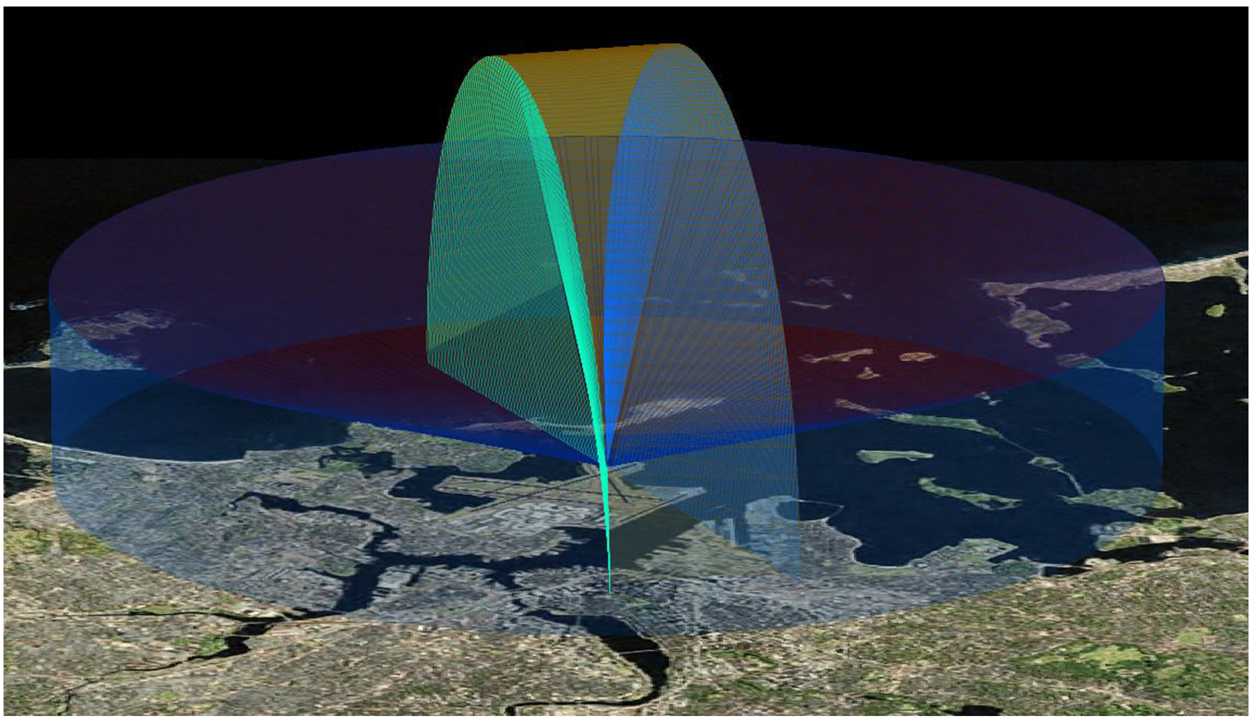


Figure 3. Computer representation of the potential survey volume scanned by the horizontal and vertical radars used in New York during spring 2013. Graphic provided by DeTect, Inc.

Description of radar. The solid-state marine radar antennas (Kelvin Hughes, London, UK) employed by our systems were 3.9 m in length, with a peak power of 170 W, S-band (10 cm) wavelength, and a frequency range of 2.92–3.08 GHz and were configured to operate with both short and medium pulses (0.1 and 5 microseconds, respectively). The horizontal radar was also equipped with Doppler to filter out stationary targets. The radar emitted a fan-shaped beam with a span of approximately 1° horizontal and 25° vertical when operated in the horizontal plane. The S-band radar was selected because the longer wavelength is less sensitive to insect and weather contamination than X-band (3 cm wavelength) antennas (Bruderer 1997). S-band radar is also less sensitive to signal attenuation from ground clutter such as vegetation and structures (DeTect Inc., unpublished data, 2009). The radars spun perpendicular to each other at a rate of 20 revolutions per minute and were synchronized to avoid emitting over one another. The horizontal scanning radar (HSR) was affixed to a telescoping base that was raised to approximately 7 m above ground for operation. This radar rotated in the x-y plane with a 7° tilt to reduce the amount of ground clutter included within its view. Although the radar had the capability to scan large distances, we selected a 3.7-km range setting for data collection to obtain 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° segment of the atmosphere. We selected a 2.8-km range setting for this radar to increase resolution and used the VSR to provide information on the number and height of targets.

Extended-range horizontal antenna. An extended-range horizontal radar accompanied by two additional computers were installed on one of the radar units prior to this field season. These accessories allowed us to survey out to 11.1 km with this antenna while continuing our survey efforts at the 3.7-km range. The settings for this antenna were developed independently of the normal range horizontal radar, and all data were analyzed separately for the two different ranges.

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

Radar Set Up and Data Collection

The radar systems were deployed at their respective sites during the last week of March and were maintained into the second week of June to capture the anticipated end date of the migration season. The radar units were moved to different locations on May 8th and 9th, between the first and second parts of the migration season. The move allowed additional areas along Lake Ontario and an inland location that was not along the lakeshore to be sampled.

Establishing the radar systems at a selected site involved several activities, including orientating the VSR, selecting the micro-site, and adjusting the radar to ensure that adequate information was captured. For the sites located on the southern shore, we anticipated a primarily northbound migration crossing over Lake Ontario as well as an eastbound migration moving along the shoreline. For the Jefferson County site, we anticipated a northbound migration movement following the shoreline. In Niagara County, our vertical radar antenna was oriented at 283° relative to true north to capture the anticipated northward and eastward movement. At the radar site in Wayne County, the vertical antenna was oriented at 325°. At the site along the eastern side of Lake Ontario in Jefferson County, the vertical antenna was oriented at 277°. For the inland site in Genesee County, the vertical antenna was oriented at 286° to maintain an orientation similar to the shoreline site at Niagara County. These orientations were a compromise between a perpendicular angle that would intercept the greatest number of targets (birds or bats) and a parallel angle that would maximize the amount of travel time within the radar beam. The orientations were also influenced by micro-site selection. Micro-site selection is important because the positioning and orientation of the radar can affect the amount of interference from ground clutter or other sources of noise. If large areas were obstructed from the radar view or if substantial amounts of clutter impeded data collection, systems were rotated incrementally to improve the radar's view and/or reduce interference.

Once a position was established, clear-air thresholds and the radar's built-in sensitivity time control (STC) filters were employed to reduce small non-target returns and improve the tracking of distant targets. These settings were required because an object reflects more energy at close range than it does when it is further from the radar. For example, an object will return approximately 16 times more energy at 50 m than at 100 m (Bruderer 1997, Schmaljohann et al. 2008). To further improve data collection, clutter maps were generated using 60-scan composite images (Figures 4-5) during time periods with low biological activity to identify areas with constant returns (areas in white) that were not biological targets, such as treelines, fencerows, and buildings. In addition, side lobes (areas of high radar returns from clear air) on the VSR were included in the clutter maps. These areas were all assigned a reflectivity threshold that excluded the constant returns from the data, consequently reducing our ability to detect targets in these areas.

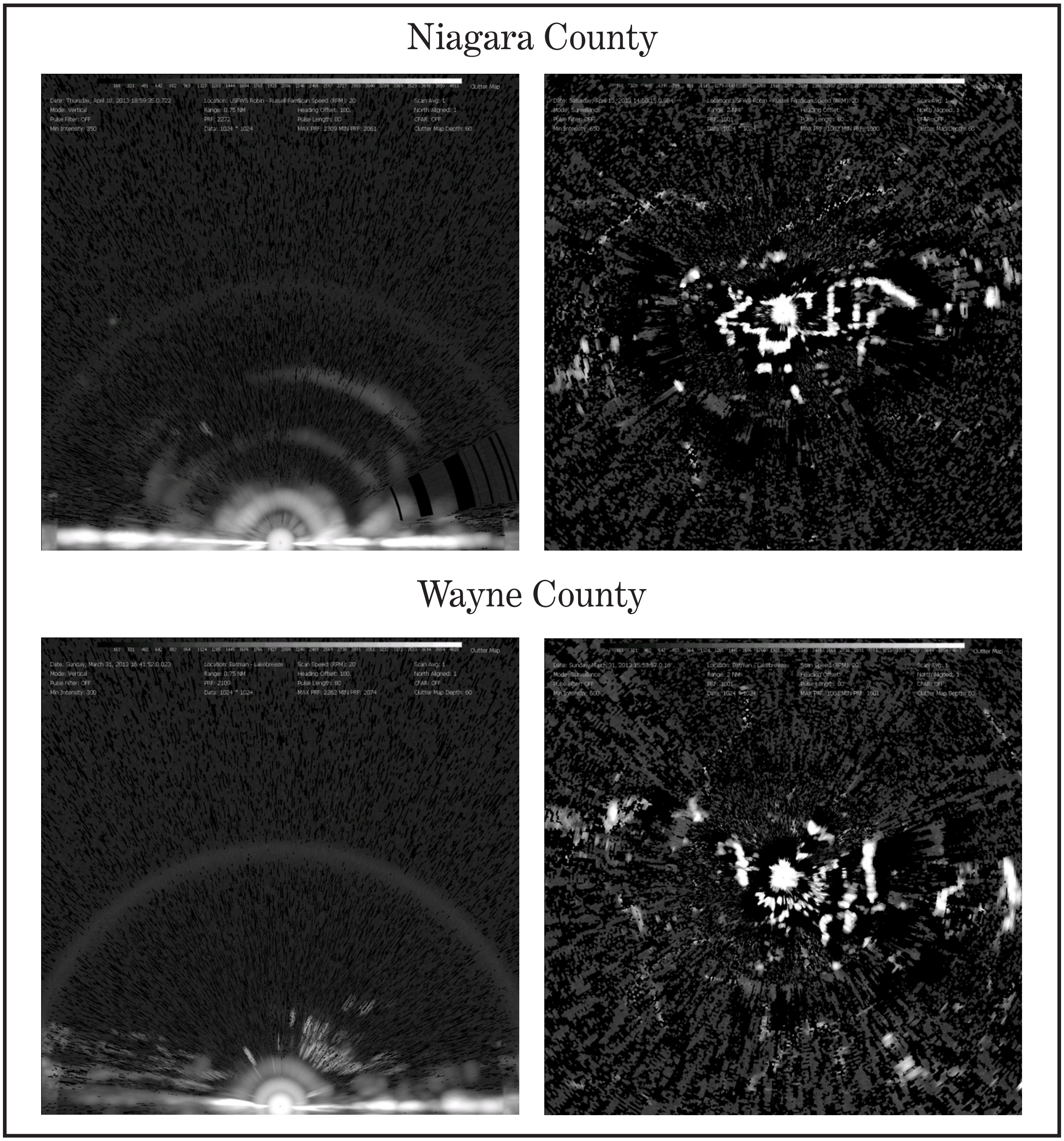


Figure 4. Vertical (left) and horizontal (right) clutter maps from Niagara (top) and Wayne (bottom) counties, New York. Examples of side lobes are the rings of white on the vertical radar, some are partial rings while others connect fully. The side lobes can vary in intensity (how bright they are) as well as how thick the band is.

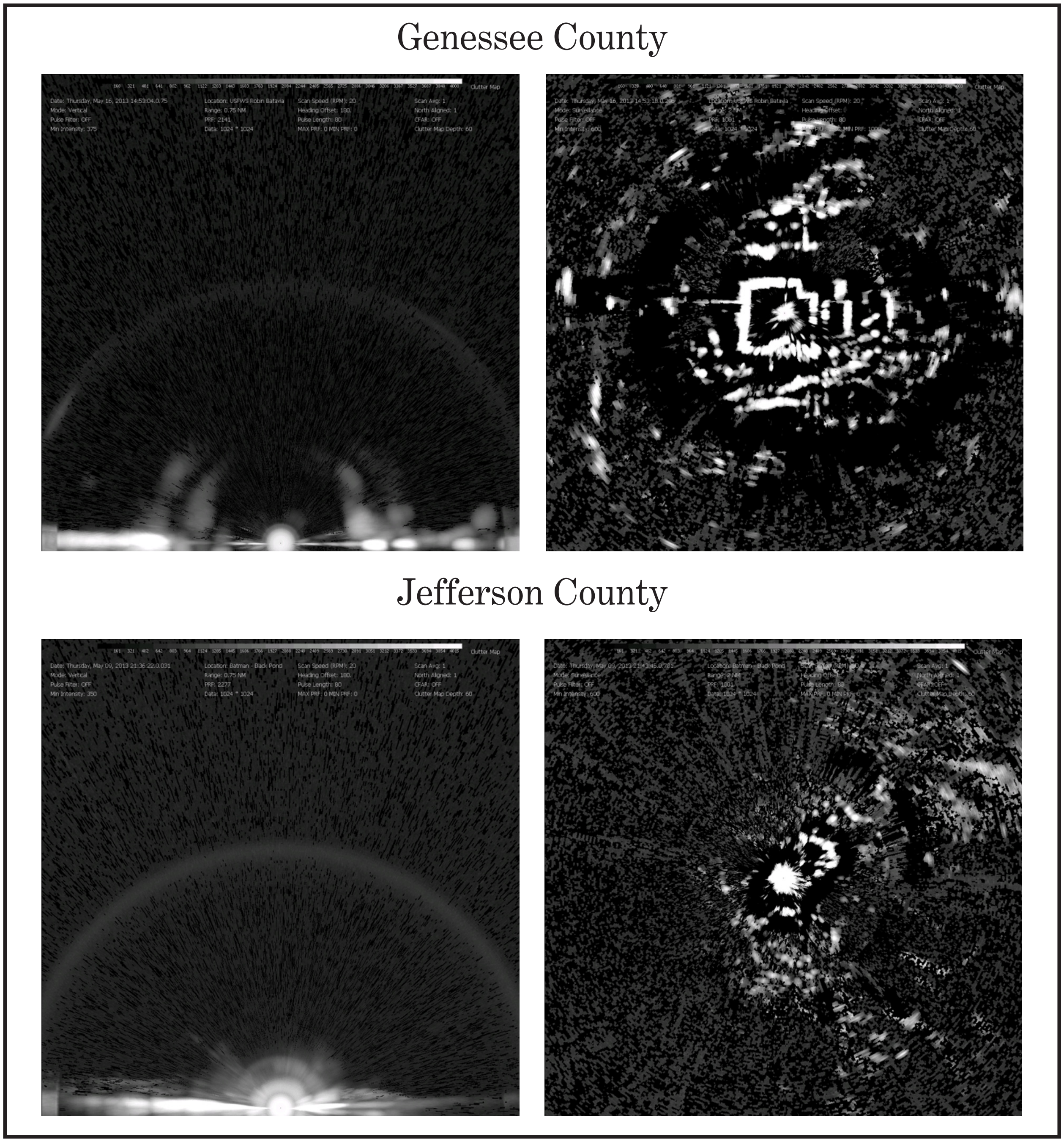


Figure 5. Vertical (left) and horizontal (right) clutter maps from Genesee (top) and Jefferson (bottom) counties, New York. Examples of side lobes are the rings of white on the vertical radar, some are partial rings while others connect fully. The side lobes can vary in intensity (how bright they are) as well as how thick the band is.

Following this initial set up, MERLIN software was adjusted to the site conditions. The MERLIN software provides real-time processing of raw radar data to identify and track targets while excluding non-targets and rain events. However, the parameters used by the tracking software require adjustments to account for site-specific conditions. DeTect personnel trained our biologists in establishing these settings with the goal of minimizing the inclusion of non-targets while maximizing cohesive tracking of targets. These settings were established by varying the settings for a small sample of data early in the season and re-running the same data repeatedly to determine the optimal settings. The processed data were stored in a Microsoft Access database and transferred daily to a SQL database, where they were stored and later queried for data analysis.

Despite the ability to operate the radar systems remotely for extended periods of time, biologists remained on site during the data collection period to ensure continuous function, monitor raw and processed radar outputs, provide routine maintenance (such as generator refueling and oil changes), and manage data storage. The vertical and horizontal radars were not equally affected by maintenance downtime or data loss due to rain. In addition to processed data, we maintained all raw radar data for potential reprocessing. Raw radar data were temporarily stored in the field on 2-TB external hard drives and regularly transported back to the Regional Office on ruggedized external drives, where the data were transferred to long-term tape storage.

Radar System Outputs

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

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

Data Processing and Quality Control

Prior to data analysis, data processed by the MERLIN software were further evaluated for potential contamination by non-targets. Biologists reviewed all data in 15-min time increments and removed time periods that were dominated by rain, insects, or other forms of clutter that were not filtered out by the MERLIN software. We relied on visual inspection of track patterns to discern contamination events. Rain and insect events produce diagnostic patterns (Detect Inc., personal communication, 2011) that were readily identified and omitted when present. Contamination that mimicked the track patterns of desired targets was not removed from the database and, to the extent that this occurred, contributed to error associated with the indices. At many of the sites, the levels of biological activity on the vertical radar were very high even when rain was detected and/or clouds were present. This situation occurred only on a few nights during the season and appeared to be less common at the inland site. After reviewing the data, these time periods were included in our analysis when most of the targets recorded appeared to be biological in nature rather than rain or clouds. If the number of rain targets constituted a sufficient proportion of the overall targets that the reviewer thought that valid conclusions about that time period could not be made, that time period was excluded from our analysis. In addition, we evaluated initial counts by generating a time series to illustrate the variation in the number of targets per hour across the season for both the HSR and VSR. In general, the HSR and VSR hourly counts were positively correlated, and the HSR had higher counts. In situations in which the VSR resulted in higher counts than the HSR or peak counts appeared to be outliers, the data were further investigated for evidence of contamination or potential issues with radar performance. On the rare occasions when anomalies appeared to represent artifacts not related to target movement (e.g., rain events or data processing errors), the corresponding time periods were removed from further analysis.

After removing contaminated time periods, we summarized the data using SQL queries provided with the MERLIN radar system. Data from the HSR were used to calculate hourly counts and target direction. All targets within 3.7 km of the radar unit were included in the analysis. Data from the VSR were used to calculate hourly counts and height estimates, and these data were truncated to a 1-km front or "standard front". The standard front was defined as a volume of space that extended horizontally 500 m to either side of the radar and vertically up to the maximum height of data collection (2,800 m) (Figure 6). We adopted this sampling technique because it is the method used by the manufacturer of the MERLIN units as well as other researchers (Lowery 1951, Liechti et al. 1995, Kunz et al. 2007b). 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 extended from 30 min prior to sunrise to 30 min post sunrise; day extended from 30 minutes post sunrise to 30 min prior to sunset; dusk extended from 30 min prior to sunset to 30 min post sunset; and night extended from 30 min post sunset to 30 min prior to sunrise of the next day.

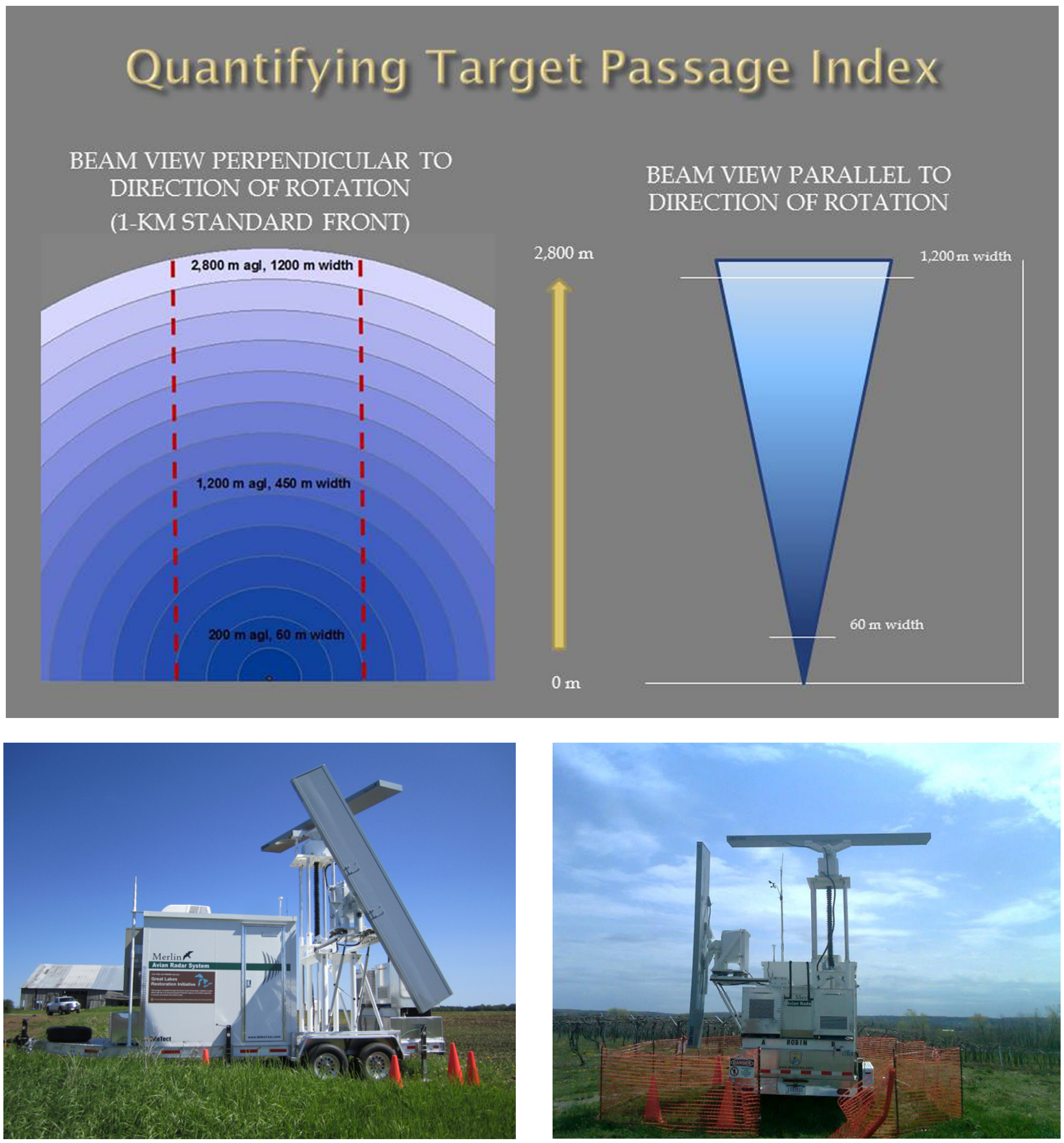


Figure 6. Depiction of the vertical scanning radar beam from two different views as well as pictures of the radar unit from those views. The top left graphic defines the standard front used for data analysis. The standard front extended 500 m on either side of the radar unit and up to a height of 2,800 m as depicted. In this graphic, the radar unit 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).

Data Summary and Trends Analysis

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

Directional Trends. The mean angle and concentration (r) of target directions were analyzed using the methodology for circular statistics (Zar 1999) provided within the DeTect SQL queries. The angular concentration has a value of 1 when all angles are the same and a value of 0 when all angles cancel each other (e.g., 50% of the vectors are 180° and 50% are 360°), indicating that there is no predominant direction of travel. We reported the mean direction of nocturnal targets and the percent of nights that targets traveled in a direction between north and east, i.e., from 337.5-112.5°. These directions were chosen because they represented the anticipated direction of movement as well as the mean direction of movement at night. We used radial graphs to plot the number of targets for each of the 8 cardinal directions (i.e., eight groups centered on N, NE, E, SE, S, SW, W, NW) during four biological time periods (i.e., dawn, day, dusk, night).

Temporal Trends. We plotted the hourly count indices of targets processed by the 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 for each site. We plotted both indices simultaneously because the HSR and VSR have different strengths that complement one another. 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 index is much more affected by ground clutter than the VSR, which affects target detection and tracking on the HSR. Errors caused by ground clutter can lead to both under and over counting. Consequently, site conditions may have a greater influence on HSR counts than on VSR counts. However, the HSR index better captures targets under certain conditions, such as when targets are primarily at low altitude and/or are traveling parallel to the VSR. The HSR is also much more susceptible to beam bending from dynamic atmospheric conditions than the VSR; beam refraction in the VSR is minimal primarily due to its orientation. The VSR index tracks target activity captured within the standard front and enables more consistent detection than the HSR because VSR primarily tracks against clear air, except in the lowest altitude bands. VSR detection is affected by target movement direction relative to the vertical scanning plane and distance from the radar (Bruderer 1997, Schmaljohann et al. 2008). Plotting these indices together provided a more comprehensive understanding of changes in target activity over time.

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

Altitudinal Trends. SQL queries provided by DeTect, Inc., were used to calculate height estimates from the VSR data for 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 (usually the closest to the center of the radar beam) and were reported as the height above ground level at the radar unit. We used these estimates to calculate the mean altitude of targets above ground level per biological time period and hour and report mean and median altitudes for the season. These height estimates were also used to assign each target to a 50-m altitude band. Using these 50-m bands, we present graphics showing the altitudes with the highest frequency of use, a measure which we believe better represents risk than mean or median values.

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

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

We used R software (R Core Team 2012) to describe a box of known volume sufficient 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 within the survey volume. The first rule was that the distance of the randomly drawn point from the origin was less than 2.8 km; the second rule was that the angle between a randomly drawn point and the vertical plane (the x-z axis in Figure 7) was less than 12.5° (i.e., half the angle of the beam width). The volume of a full sweep of the radar beam as estimated via Monte Carlo integration was within 5% of the analytical solution using spherical coordinates; thus, the number of random points 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 7) and within altitude bands (Figure 8).

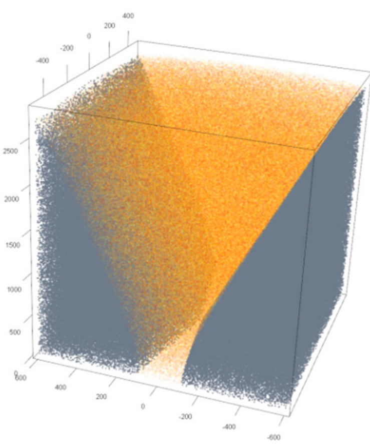


Figure 7. Graphical representation of the structural volume of the vertical scanning radar within the standard front. In this graphic, the radar unit is located at the origin, and the radar beam extends to 500 m on either side of the radar unit (x-axis) and up to a maximum height of 2,800 m (z-axis).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

The number of targets per altitude band is often reported by other researchers; however, a volume correction is not often reported. We wanted to compare our corrected method to the uncorrected method, but the scales of count and volume data differ. Consequently, we compared our density estimate to a density estimate based on the number of targets per 50-m altitude band per hour, assuming that the volumes within each altitude band are equal (i.e., the volume of each altitude band is equal to the total volume divided by the number of altitude bands). An assumption implicit in reporting the number of targets per altitude band is that comparisons among bands can be made directly (i.e., that altitude bands are equal). For our comparison metric, we made this implicit assumption explicit (see Appendix 4). Our correction method does not account for differences in clutter between these 50-m bands or for reductions in detection ability due to distance from the radar.

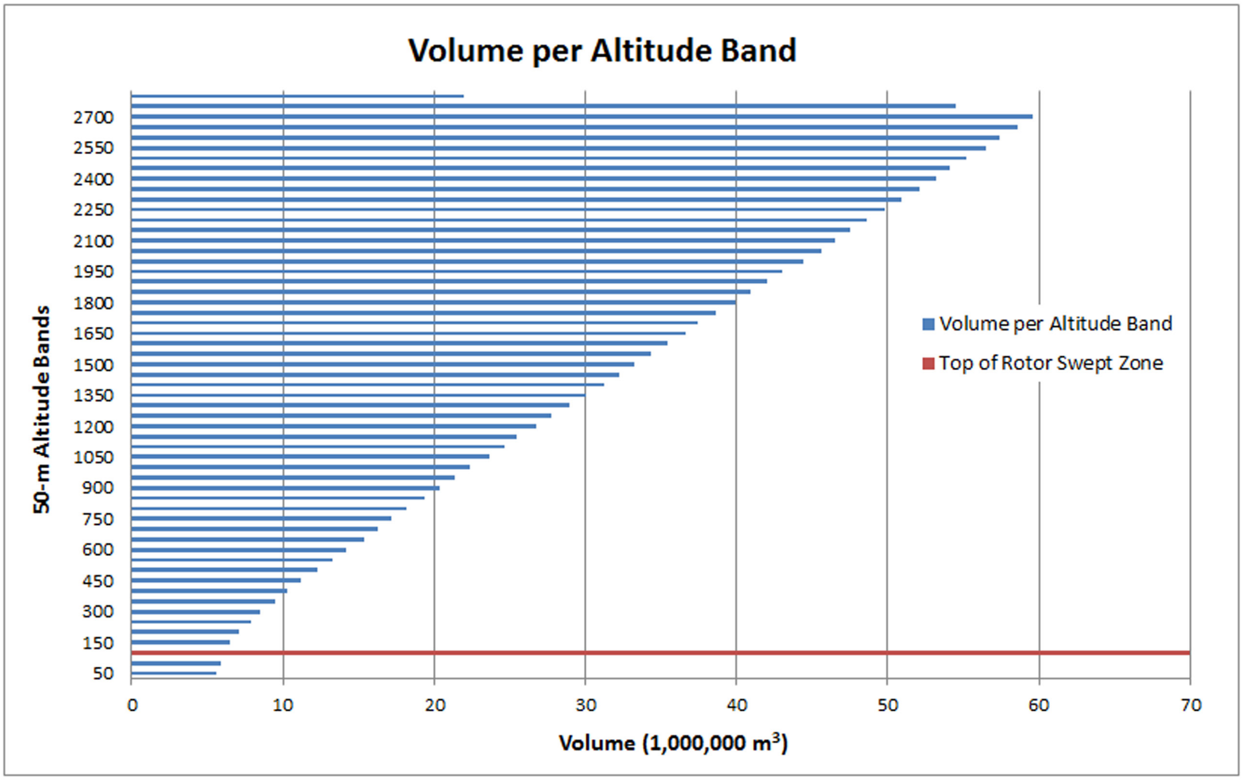


Figure 8. Volume of 50-m altitude bands within the standard front as estimated by Monte Carlo integration. The target counts provided by the vertical scanning radar are limited to the structure of the standard front. The altitude band labels represent the top of each 50-m altitude band.

Results

During the spring 2013 season, we began data collection on March 26 and 27 at the Niagara and Wayne county sites, respectively. We moved the radar units to the Genesee and Jefferson county sites for the second part of the season on May 8 and 9, respectively. We ended data collection on June 10, 2013, at both sites. Thus, the radar units were in place for 1,055 and 1,078 hours at the first set of sites and for 792 and 793 hours at the second set of sites (Table 2). We recorded data continuously during the survey periods when the radar units were operational. Radar downtime occurred when the radar units were non-operational due to maintenance or malfunction. Data that contained contamination (such as rain) were removed prior to analysis; consequently, not all of the collected data were useable. Gaps in analyzed data occurred when contaminated data were removed or data were not collected during radar downtime.

Table 2. Survey effort (hours) by the vertical and horizontal scanning radars in spring 2013 in Niagara, Wayne, Genesee and Jefferson counties, New York.

Site	Radar	Survey Period (hrs)	Radar Downtime (hrs)	Radar Collected Data (hrs)	Radar Data with Rain* (hrs)	Useable Radar Data (hrs)	% Survey Period with Collected Data	% Survey Period with Useable Data
Niagara	VSR	1055	93	962	133	829	91%	79%
Niagara	HSR	1055	53	1002	8	994	95%	94%
Wayne	VSR	1078	60	1018	171	847	94%	79%
Wayne	HSR	1078	88	990	8	982	92%	91%
Genesee	VSR	792	18	774	130	644	98%	81%
Genesee	HSR	792	18	774	32	742	98%	94%
Jefferson	VSR	793	40	753	98	655	95%	83%
Jefferson	HSR	793	70	723	42	681	91%	86%

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

Qualitative Assessments

Hourly plots of the tracked targets produced images of diurnal and nocturnal movement at all four locations (Figures 9-12). For example, over a 24-hr period on May 4 at the Niagara County site, the horizontal radar recorded scattered activity, and the vertical radar recorded few targets from 12:00 to 18:00. During the 20:00 hour, directional movement heading north to northwest began, and the vertical radar activity increased, with more targets at higher altitudes. At 23:00, both the horizontal and vertical radars recorded very large numbers of targets, and the direction of movement had shifted primarily to the north, with targets moving out over the lake. During the 01:00 hour on May 5, high numbers of targets on both antennas continued, with the direction of movement shifting slightly toward the east and northeast. During the 04:00 and 05:00 hours, the number of targets on the vertical radar began to decrease, and the direction of movement on the horizontal radar shifted to the east, with targets moving along the lakeshore. Targets over the water during the dawn hour of 05:00 also began to move inland (south). By 12:00, diurnal activity had returned to the same low numbers that we observed the preceding day. This pattern of target movement and changes in altitude were indicative of a pulse of migratory activity.

A similar pattern was observed at the other radar sites with lower activity during the day, with increasing activity on both antennas near dusk with a peak close to midnight, a sharp decrease close to dawn with targets moving to the shoreline from over the water and along the shoreline, and a return to lower diurnal activity the next day. Target movement directions also often changed early in the night and close to dawn, indicating that the migrants changed their behavior depending on the time of night that they encountered the obstacle of the lake. Weather conditions and wind speed and direction may also have contributed to the shift in movement direction.

The Trackplots showed rings of decreased detection near the radar unit from the 'main bang' (the area closest to the radar unit with very high reflectance) to where the radar switched between short and medium pulses. Portions of the area sampled by the radar had reduced detection (e.g., the northeast corner of the Jefferson County site) due to beam blockage from ground clutter (topography, vegetation, buildings, etc.) (Figures 4-5). In addition, artifacts of the radar unit setup can be observed in the Trackplots. Examples of these include rings of decreased detection immediately adjacent to the radar unit (cone of silence) and the ring on the radar at which the radar unit switched pulses (See examples in: Vertical: May 5, 01:00, Niagara County, Figure 9; Horizontal: May 22, 04:00, Jefferson County, Figure 12).

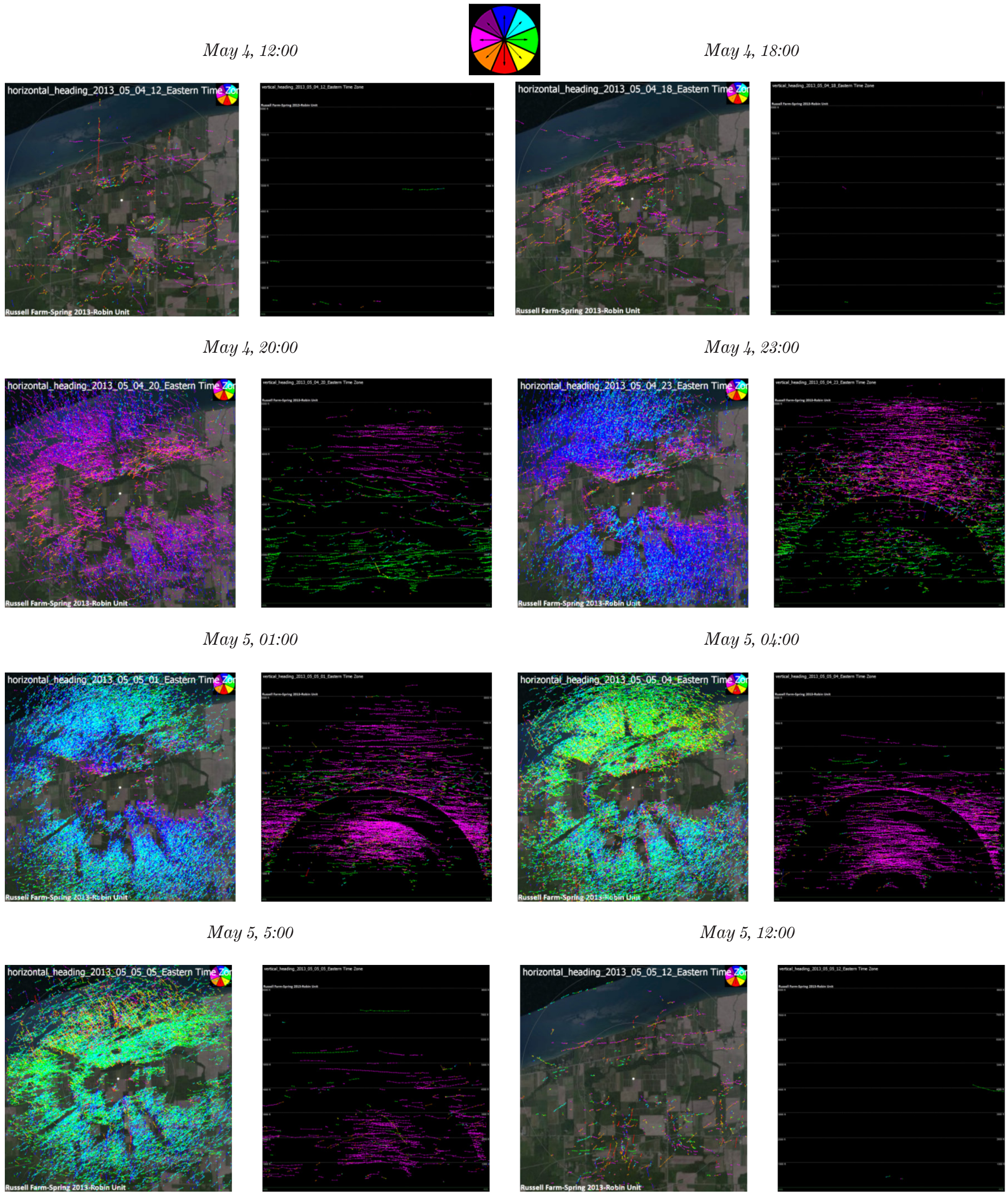


Figure 9. Images of tracks in 1-hour increments recorded by the horizontal and vertical scanning radars during a migration event in Niagara County, New York. The horizontal radar images (columns 1 and 3) show the direction of targets as indicated by the color wheel at the top. The vertical radar images (columns 2 and 4) show the target heights.

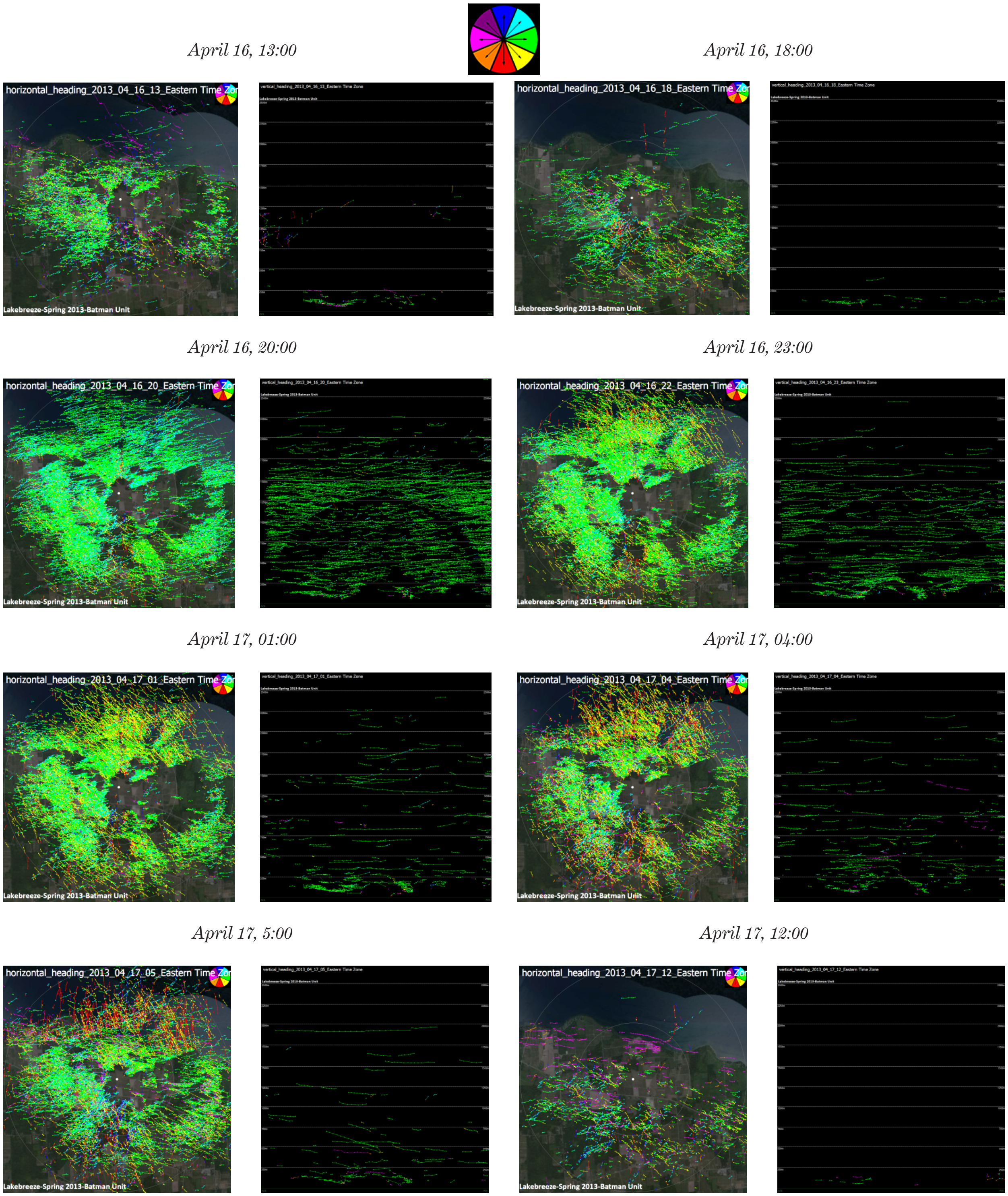


Figure 10. Images of tracks in 1-hour increments recorded by the horizontal and vertical scanning radars during a migration event in Wayne County, New York. The horizontal radar images (columns 1 and 3) show the direction of targets as indicated by the color wheel. The vertical radar images (columns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

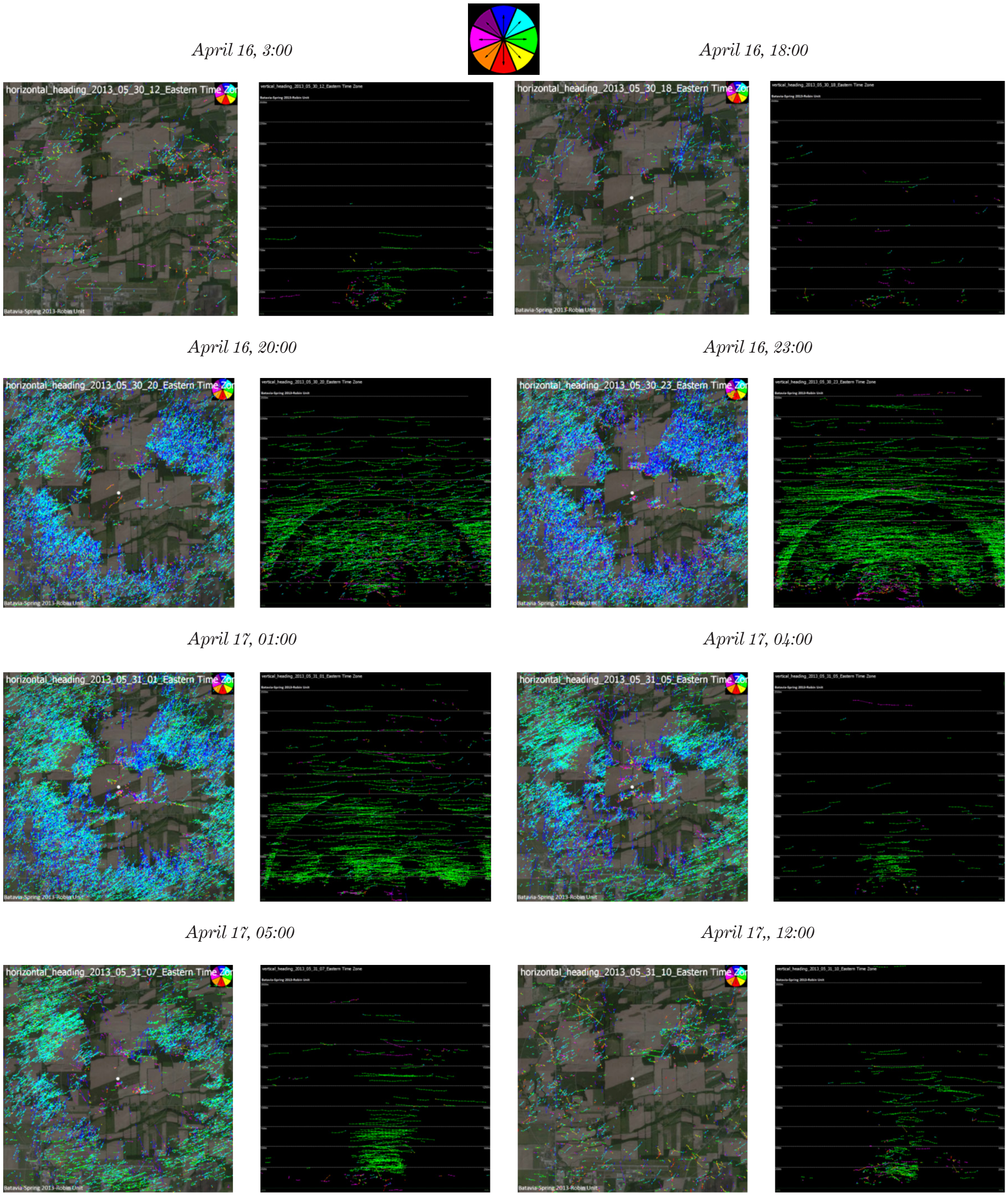


Figure 11. Images of tracks in 1-hour increments recorded by the horizontal and vertical scanning radars during a migration event in Genesee County, New York. The horizontal radar images (columns 1 and 3) show the direction of targets as indicated by the color wheel. The vertical radar images (columns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

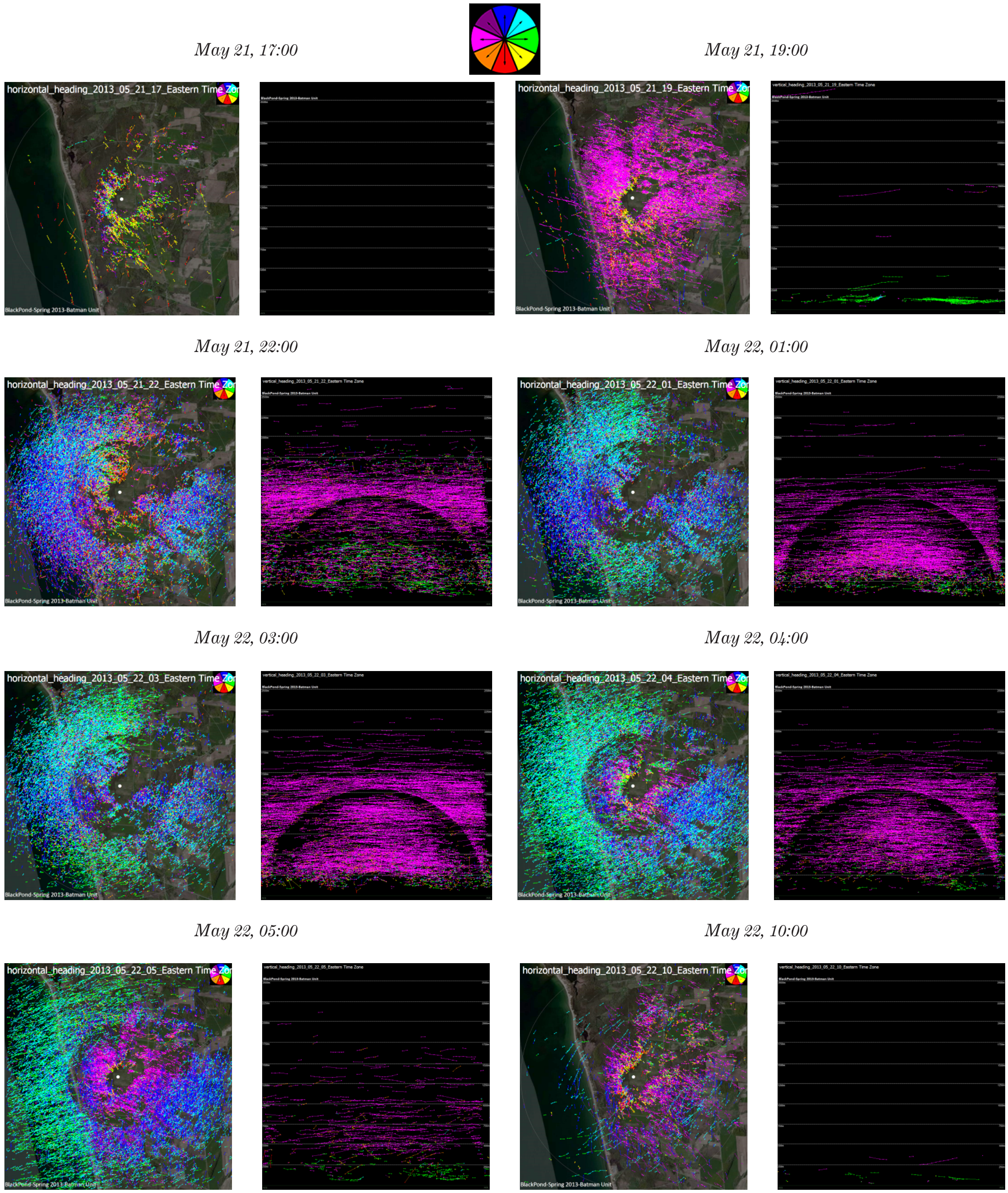


Figure 12. Images of tracks in 1-hour increments recorded by the horizontal and vertical scanning radars during a migration event in Jefferson County, New York. The horizontal radar images (columns 1 and 3) show the direction of targets as indicated by the color wheel. The vertical radar images (columns 2 and 4) show the target heights.

Directional Trends

During the spring 2013 season, the nocturnal target direction was generally between north and east (337.5-112.5°) at all sampled locations (Figures 13-14, Tables 3-4). At the Niagara County site, the mean nocturnal direction was 38°, and the angular concentration (r) was 0.53 (n=2,622,830 targets). During 77% of nights, the mean target direction was between north and east. The direction at the Wayne County site was slightly more variable during each biological time period than at the Niagara County site. The mean nocturnal direction was 25° (r=0.47, n = 3,369,396), and 83% of nights had a mean direction between north and east. The Genesee County site had a mean nocturnal direction of 44° (r=0.54, n=2,217,143), and 85% of nights had a mean direction between north and east. The Jefferson County site had a mean nocturnal direction of 32° (r=0.55, n=1,596,789), and 88% of nights had a mean direction between north and east. The lower number of targets at the Jefferson County site was likely due to the large amount of clutter on the HSR at this site. There was some evidence for onshore movement at dawn at the 3 shoreline sites (Niagara, Wayne, and Jefferson counties). Dawn movement at the inland site (Genesee County) did not appear to differ from nocturnal activity.

The day biological period often had high numbers of targets but a low percentage of time with $r>0.5$, indicating that the targets were active but did not often move in one specific direction. This observation would be consistent with the local movement of targets moving back and forth across the landscape searching for areas to feed. Higher directional concentrations may indicate use of the area by diurnal migrants, although low percentages do not necessarily exclude this possibility. However, one reason for the large differences in target numbers between time periods is that the day and night time periods were much longer than the dawn and dusk time periods.

Overall, the general directional trends observed with the extended-range (11.1 km) horizontal radar matched the observations from the standard-range (3.7 km) horizontal radar. The total counts on the extended-range radar were higher due to the increased area surveyed, but the temporal pattern of high and low numbers as well as the general direction of movement were similar between the standard- and extended-range radars. We do not present the extended-range data in this report due to their similarity to the data from the standard-range horizontal radar.

Table 3. Mean direction, angular concentration (r), and percent of biological time periods with strong directionality (r≥0.5) of targets during the biological time periods in Niagara and Wayne counties, New York. This table provides information about the direction of target movement and not overall counts because the amount of time sampled differed for each biological period.

Biological Period	Niagara				Wayne			
	Mean Direction (degrees)	r	% Time Periods r≥0.5	n	Mean Direction (degrees)	r	% Time Periods r≥0.5	n
Dawn	69	0.31	43.9%	263,578	60	0.28	32.6%	389,344
Day	76	0.43	41.5%	1,374,537	45	0.24	19.5%	1,575,349
Dusk	44	0.40	37.5%	78,181	21	0.33	54.8%	106,191
Night	38	0.53	87.5%	2,622,830	25	0.47	67.4%	3,369,396

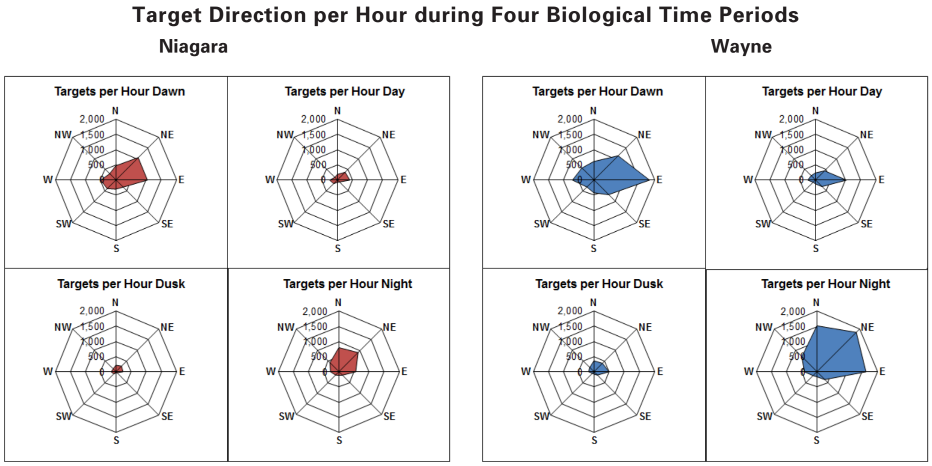


Figure 13. Target direction per hour during four biological periods during spring 2013 in Niagara (left) and Wayne (right) counties, New York.

Table 4. Mean direction, angular concentration (r), and percent of biological time periods with strong directionality (r ≥ 0.5) of targets during the biological time periods in Genesee and Jefferson counties, New York. This table provides information about the direction of target movement and not overall counts because the amount of time sampled differed for each biological period.

Biological Period	Genesee				Jefferson			
	Mean Direction (degrees)	r	% Time Periods r≥0.5	n	Mean Direction (degrees)	r	% Time Periods r≥0.5	n
Dawn	33	0.62	64.5%	120,666	47	0.40	57.1%	233,784
Day	43	0.44	40.6%	660,427	328	0.15	10.3%	2,434,111
Dusk	71	0.36	43.3%	28,507	284	0.51	64.5%	136,960
Night	44	0.54	73.3%	2,217,143	32	0.55	76.0%	1,596,789

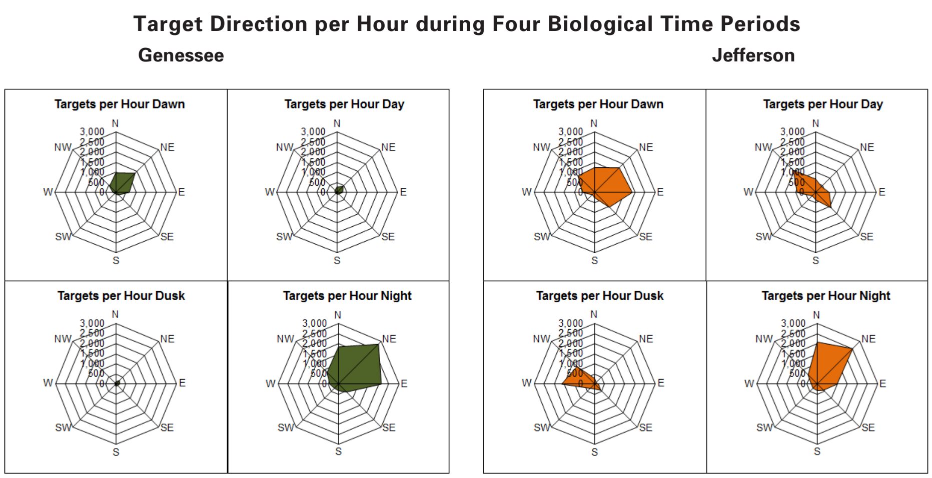


Figure 14. Target direction per hour during the four biological periods in spring 2013 in Genesee (left) and Jefferson (right) counties, New York.

Temporal Trends

Time Series Plots. The hourly target counts obtained from the horizontal and vertical radars showed pulses of elevated nocturnal activity with peaks near or slightly after midnight at the four study sites. Across the sampling period, these events were often clustered into groups of several sequential nights; these repeated groups of peaks were first observed on April 14 at both sites during the first part of the season, with some individual nights showing migration prior to this date (Figures 15-16). These clusters of peaks of activity occurred regularly at these sites until the radar units were moved to the second pair of sites (Genesee and Jefferson county sites) on May 8 and 9. Although there were peaks during the first week at the new sites, the strongest peaks occurred during the second week of sampling (Figures 17-18). The occurrence and magnitude of nocturnal pulses decreased substantially after June 1, although one peak was observed as late as June 8 at the Genesee County site.

On approximately May 24, a large storm passed through the Lake Ontario region and was likely responsible for the low numbers observed over the next few days at the Genesee and Jefferson county sites. Some of the highest peaks on the vertical radar occurred in the few days immediately preceding this large storm, suggesting that birds may have been using the winds preceding the storm to migrate, or that they sensed the storm was coming and may have accelerated their movement to get ahead of the storm. This observation indicates that storms and weather can accelerate or delay the movement of migrants by at least a week, which should be considered when determining the starting, ending, and peak activity dates for the season.

Different patterns of activity were observed at the study sites as the season progressed. For example, beginning in late March, activity patterns became dominated by nocturnal pulses that were observed on both the horizontal and vertical radars at both sites. This pattern continued until the radar units were moved to new sites (May 8 and 9) and ended at the new sites around June 1 (Figures 17-18). After this date, a decrease in overall activity was observed at the Genesee County site, whereas at the Jefferson County site, activity shifted toward more diurnal activity, with peaks near dawn and dusk. Ground observations by radar team biologists indicated that much of this diurnal activity at the end of the season was associated with gulls moving between nesting and feeding grounds.

Hourly Counts by Horizontal and Vertical Radars: Niagara County, New York

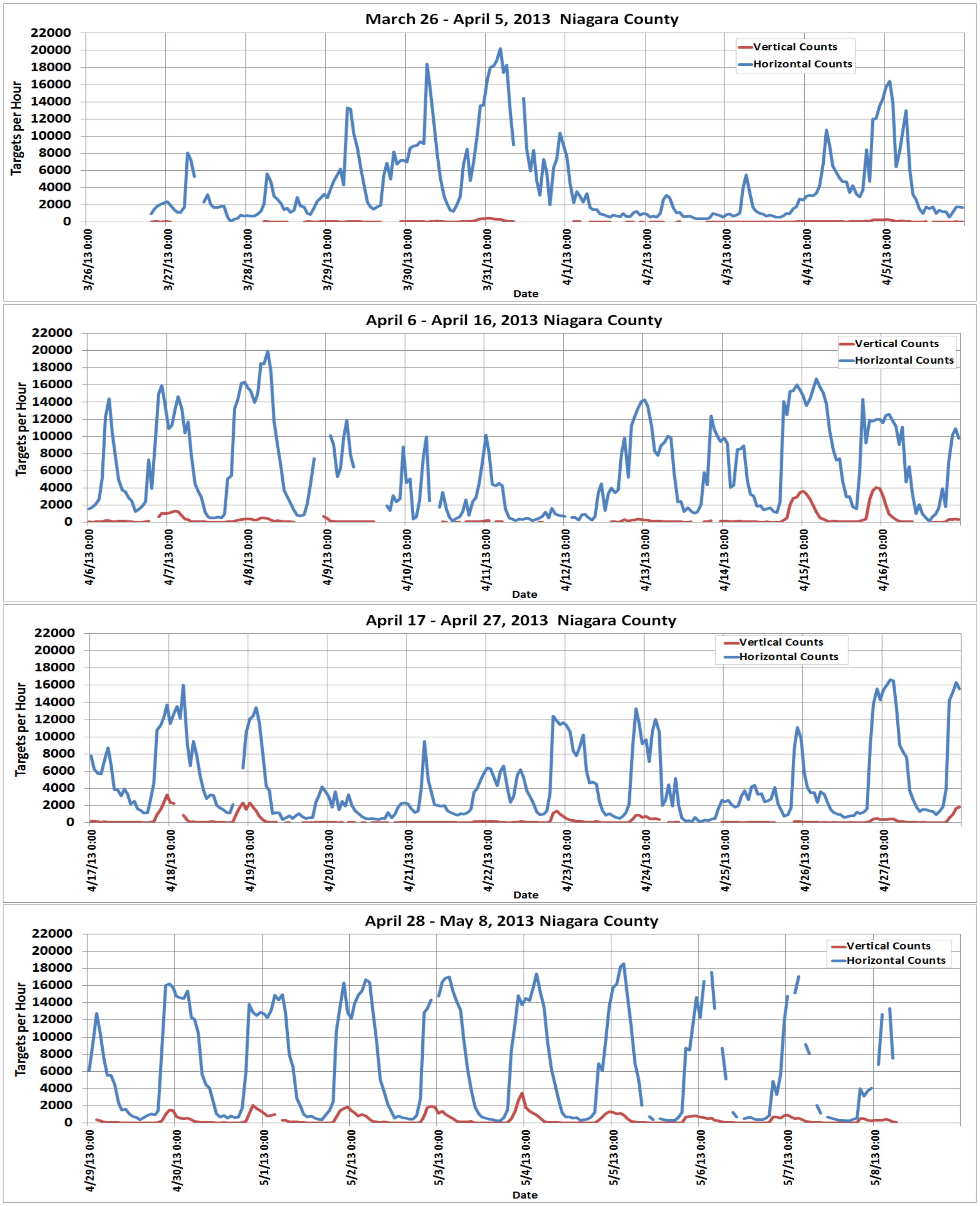


Figure 15. Hourly counts by the horizontal radar and vertical radars standard front from March 26 to May 8, 2013, in Niagara County, New York. The light gray vertical lines represent midnight.

Hourly Counts by Horizontal and Vertical Radars: Wayne County, New York

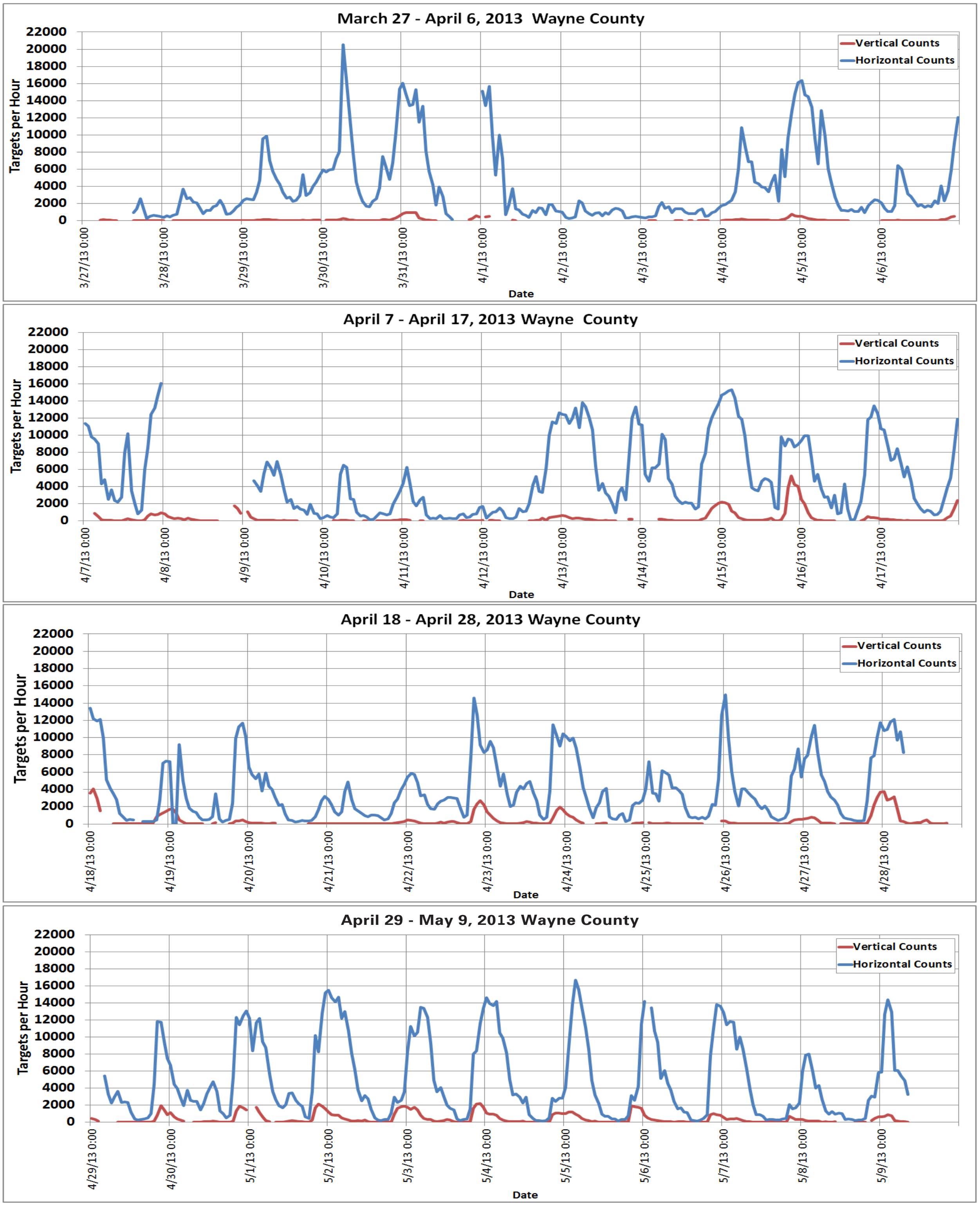


Figure 16. Hourly counts by the horizontal radar and vertical radars standard front from March 27 to May 9, 2013, in Wayne County, New York. The light gray vertical lines represent midnight.

Hourly Counts by Horizontal and Vertical Radars: Genesee County, New York

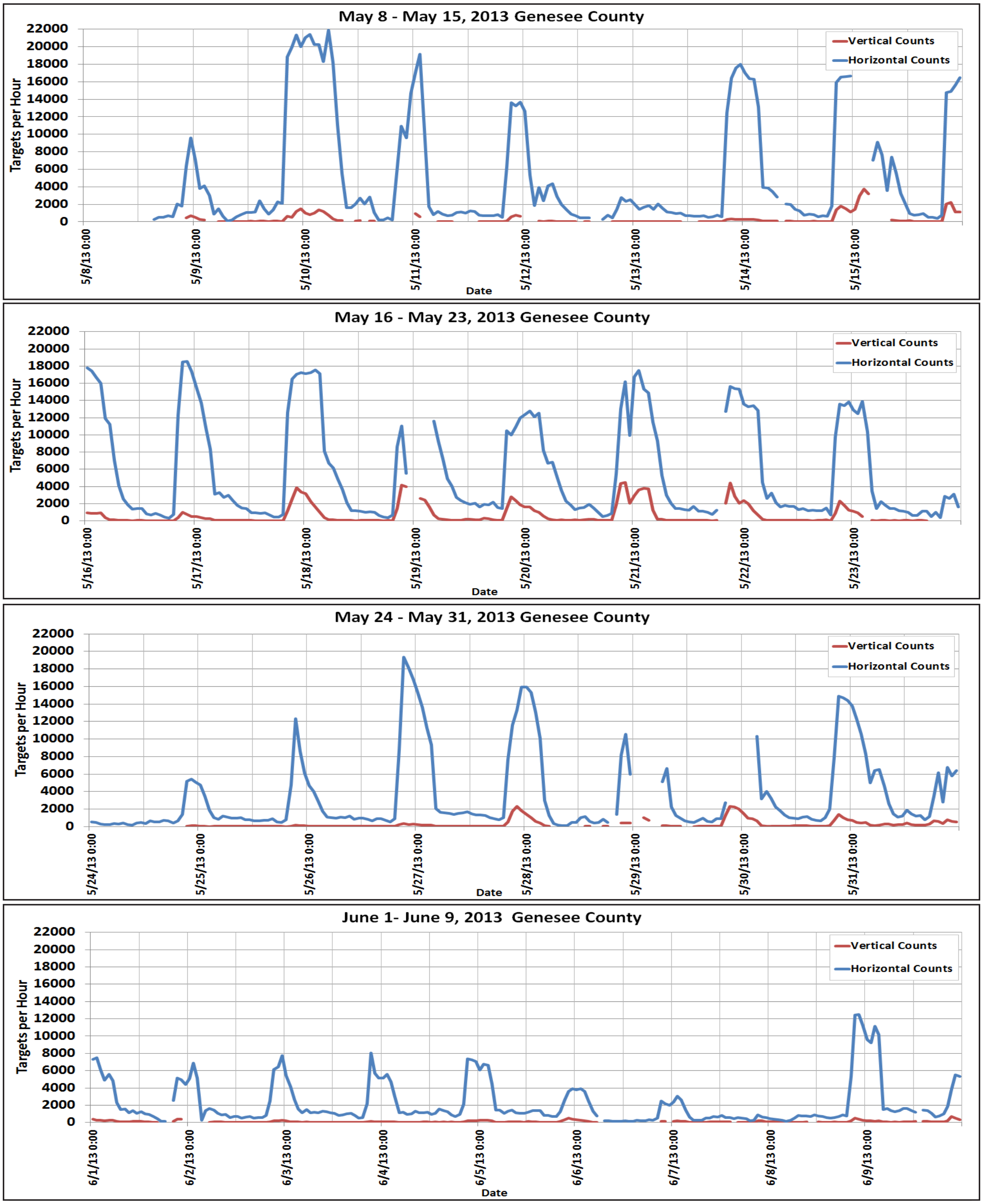


Figure 17. Hourly counts by the horizontal radar and vertical radars standard front from May 8 to June 9, 2013, in Genesee County, New York. The light gray vertical lines represent midnight.

Hourly Counts by Horizontal and Vertical Radars: Jefferson County, New York

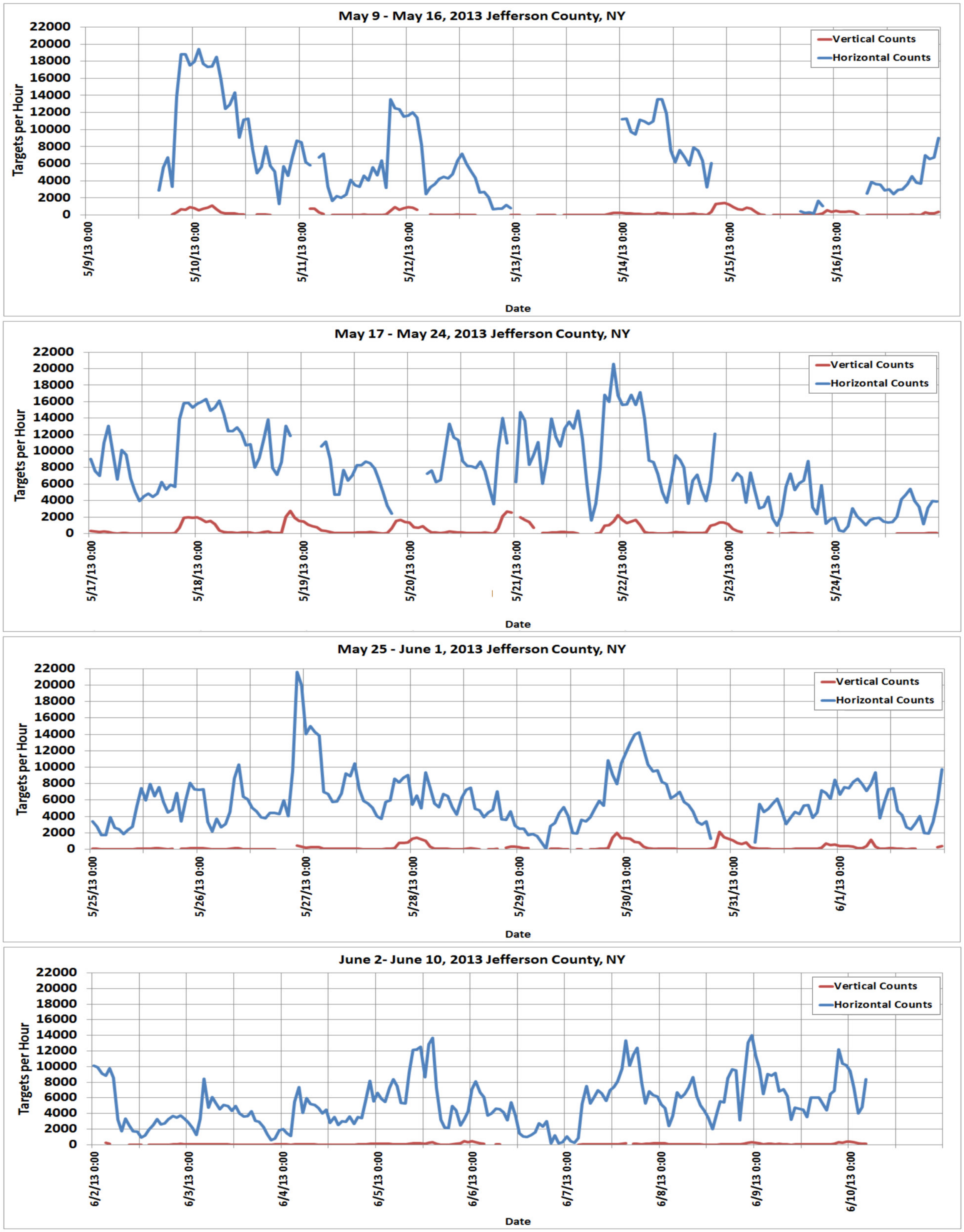
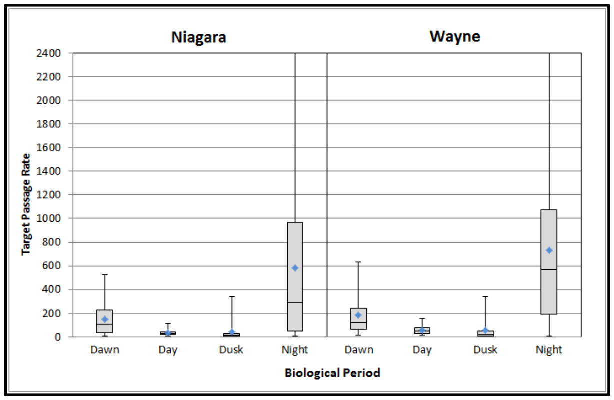


Figure 18. Hourly counts by the horizontal radar and vertical radars standard front from May 9 to June 10, 2013, in Jefferson County, New York. The light gray vertical lines represent midnight.

Target Passage Rate. The pattern of mean TPR among the four biological time periods was similar among the four study sites (Figure 19). The mean TPR was greatest at night (Table 5). The TPR for the dawn biological period exhibited the greatest difference between the two parts of the season, with a low TPR and less variability at the first two sites (Niagara and Wayne counties) and a higher TPR and greater variability at the second two sites (Genesee and Jefferson counties).

The mean nocturnal TPR was 582±663 SD (n=38 nights) and 732±690 targets/km/hr (n=38 nights) in Niagara and Wayne counties, respectively; the mean nocturnal TPR in Genesee and Jefferson counties was 818±850 (n=29 nights) and 555±492 (n=25 nights), respectively. The mean TPR varied hourly, with peak numbers documented just prior to midnight in Niagara, Wayne, and Jefferson counties, which were located along the shoreline, and within 1–2 hours of sunset in Genesee County. At all four locations, the mean hourly TPR began to decrease after midnight (Figure 20).



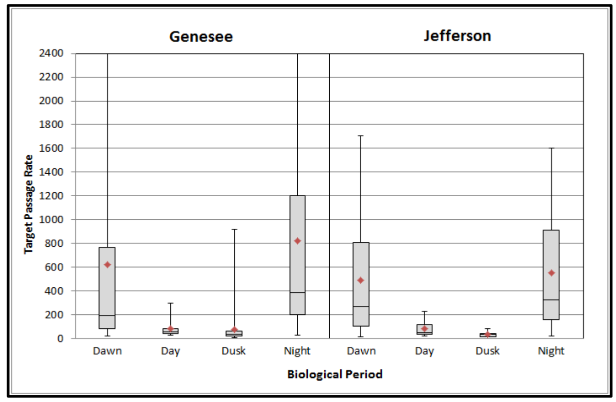


Figure 19. Box plots of the variability in the target passage rate (targets/km/hr) during the four biological periods in spring 2013 in four New York counties: Niagara and Wayne counties (left) and Genesee and Jefferson counties (right). The whiskers represent the 1st and 4th quartiles, the boxes represent the 2nd and 3rd quartiles (with the line between indicating the median), and the blue and red diamonds represent the seasonal means for the time period at that site.

Table 5. Mean target passage rate (targets/km/hr) and standard deviation during the four biological periods in Niagara, Wayne, Genesee and Jefferson counties, New York, in spring 2013.

Biological Period	Niagara Mean TPR	Wayne Mean TPR	Genesee Mean TPR	Jefferson Mean TPR
Dawn	149±142	184±165	618±920	492±496
Day	33±26	57±38	78±65	78±63
Dusk	39±74	53±81	76±177	31±22
Night	582±663	732±690	818±850	555±492

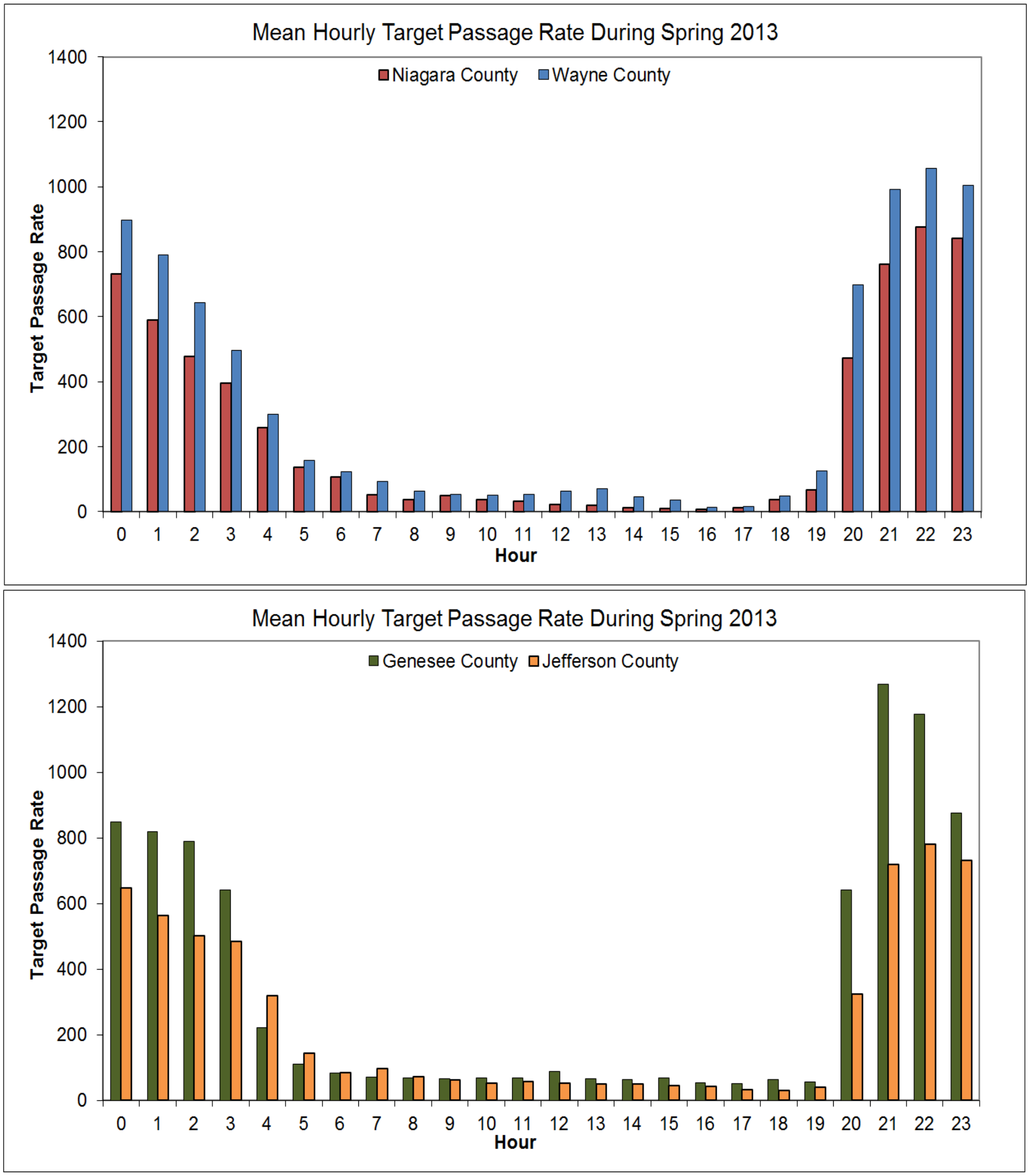


Figure 20. Mean hourly target passage rate (targets/km/hr) in spring 2013 in Niagara and Wayne counties (earlier in season, top) and Genesee and Jefferson counties (later in season, bottom), New York.

Weekly Mean of Target Passage Rates. The weekly means of the nocturnal TPR were relatively high until the last week or two of the sampling period, when a reduction was observed at both the Genesee and Jefferson county locations (Figure 21). The weekly means of the nocturnal TPR were consistently higher than the weekly means of the diurnal TPR (Figure 21). However, as the recorded migration season subsided, the difference between the nocturnal and diurnal TPRs decreased (Figures 21-23).

The overall patterns of the nocturnal TPR (7-day moving means) and diurnal TPR were similar among three of the sites (Wayne, Genesee, and Jefferson counties), with pulses in nocturnal activity patterns matching pulses in diurnal activity. By contrast, at the Niagara County site, there was an early peak of diurnal activity that was not matched by nocturnal movement, and subsequent peaks in nocturnal activity did not match increases in diurnal activity (Figures 22-23).

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

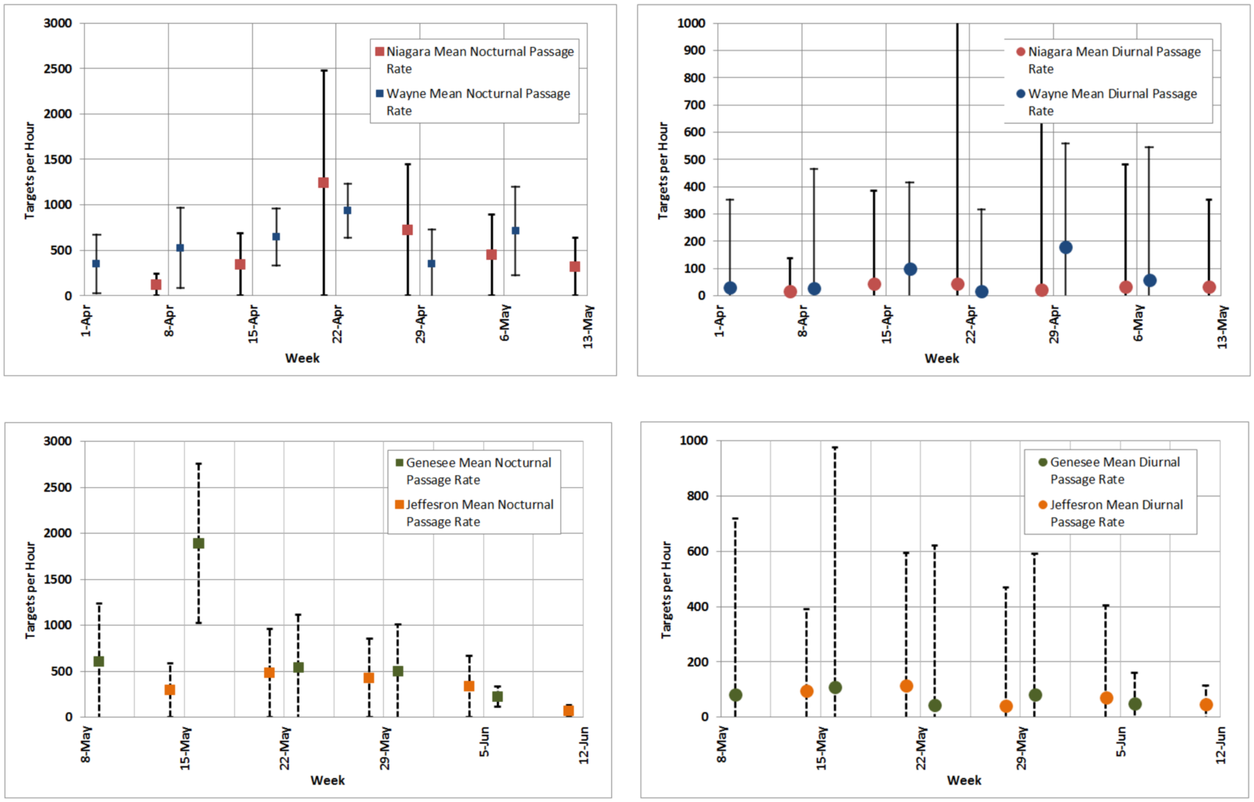


Figure 21. Weekly means of the nocturnal (left column) and diurnal (right column) target passage rates (targets/km/hr) during the first part of season (top row, Niagara and Wayne counties) and the second part of season (bottom row, Genesee and Jefferson counties) from March 26 to May 9, 2013 (top row), and May 8 to June 10, 2013 (bottom row). The error bars represent one standard deviation. Note the different scales of the nocturnal and diurnal plots.

Moving 7-Day Mean of the Target Passage Rate at the Study Sites

Nocturnal Passage Rates

Diurnal Passage Rates

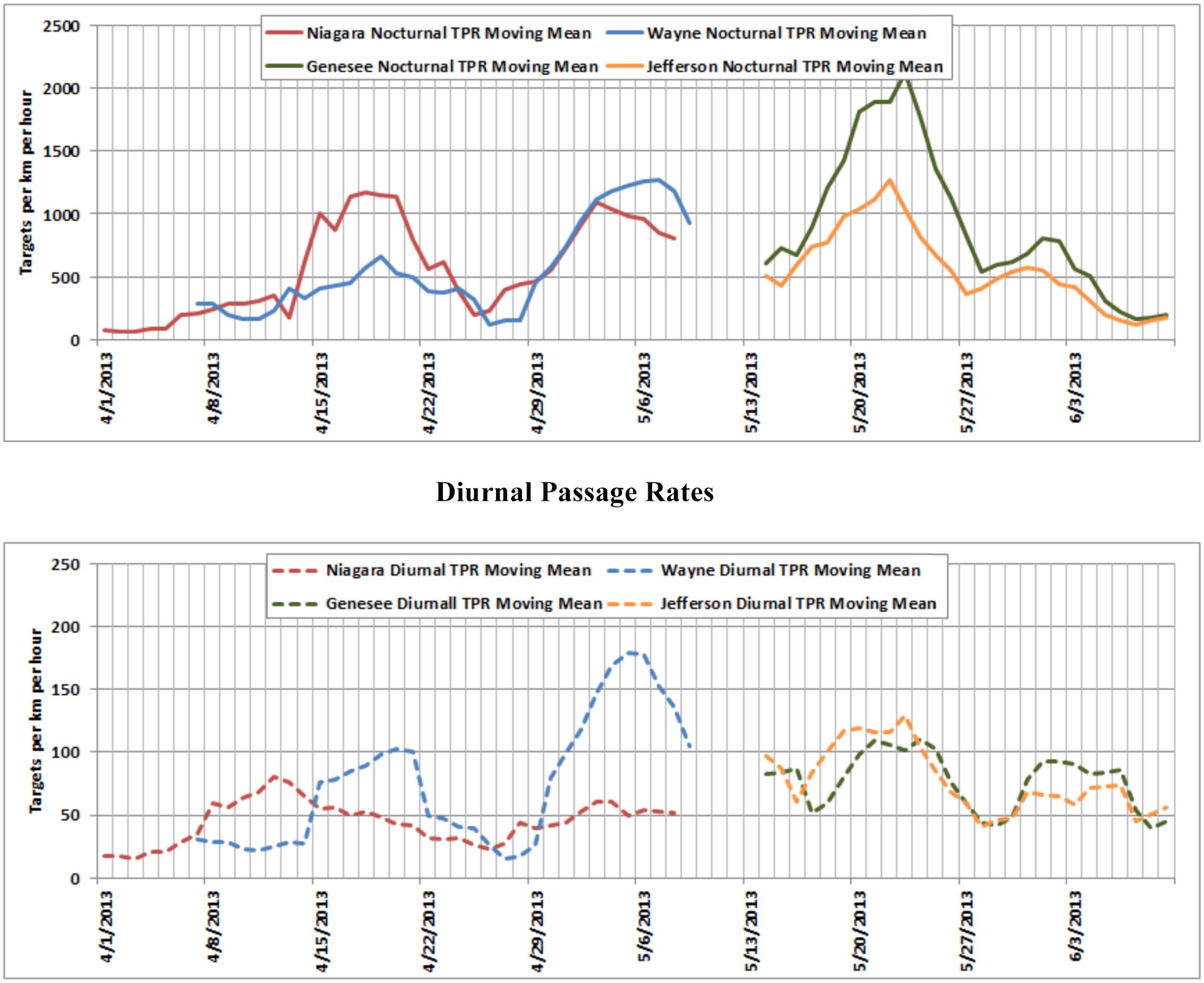
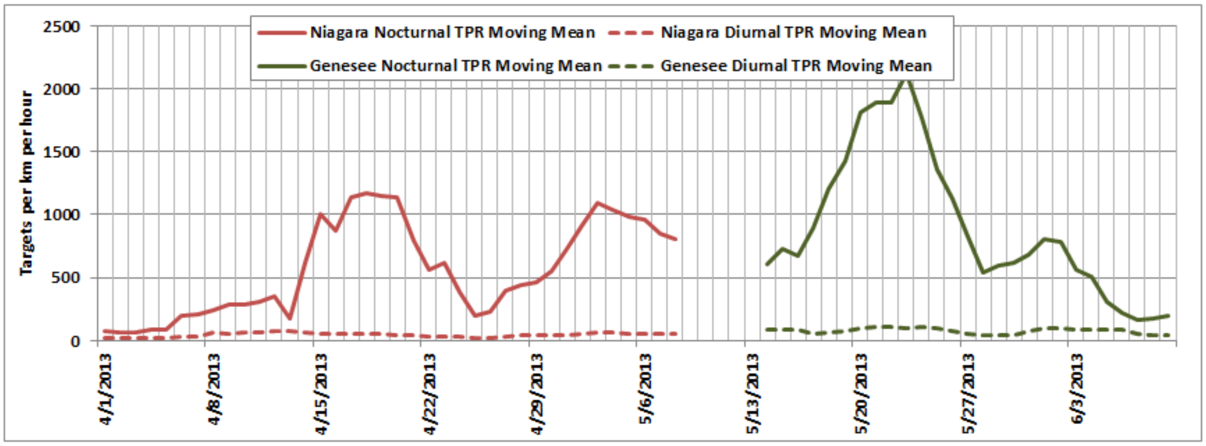


Figure 22. Among-site comparison (based on a moving 7-day mean) of nocturnal (top graph) and diurnal (bottom graph) target passage rate trends (targets/km/hr) during spring 2013 in Niagara, Genesee, Wayne, and Jefferson counties, New York. Data prior to 14 May at the second set of sites were excluded due to the recent move to those sites.

Moving 7-day Mean of Target Passage Rates within Sites

Western Lake Ontario Sites



Eastern Lake Ontario Sites

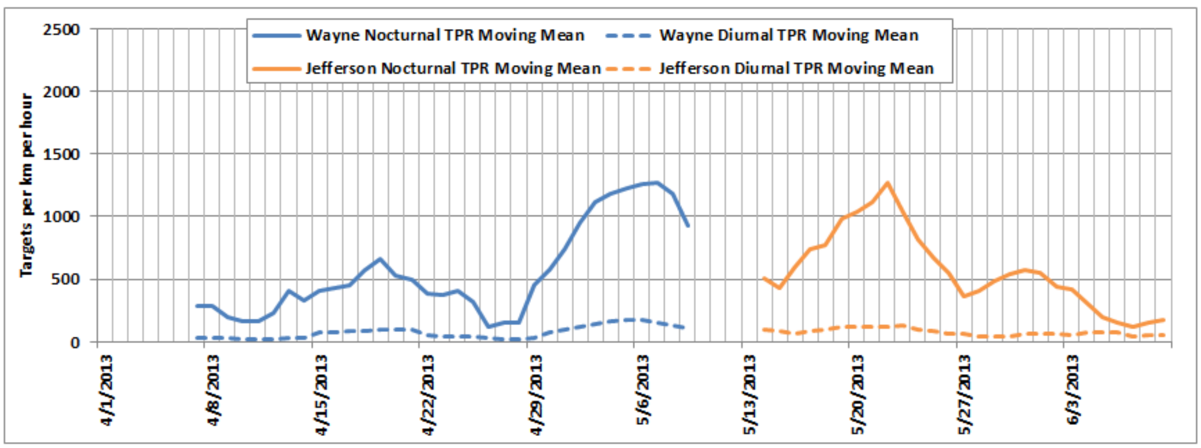


Figure 23. Within-site comparison (based on a moving 7-day mean) of nocturnal (solid lines) and diurnal (dashed lines) target passage rate trends (targets/km/hr) in spring 2013 in Niagara and Genesee counties (top graph) and Wayne and Jefferson counties (bottom graph), New York. Data prior to14 May at the second set of sites was excluded due to the recent move to those sites.

Altitudinal Trends

Our density estimate accounting for the geometric shape of the sampled space resulted in a significantly different density estimate and a higher estimate of risk to migrants compared with the estimate that assumed an equal sample volume per altitude band. The approximate rotor-swept zone is 40–120 m above ground for a 1.5-MW turbine and 50–150 m above ground for a 2.5-MW turbine. The rotor-swept zone is the area through which the rotor blades spin as the turbine turns. The altitude profiles for the dawn biological time period differed between the two parts of the season, with an increase in targets at higher altitudes during the dawn hour for the second half of the season (Figures 24-27). The dusk altitude profile differed at the Niagara County site compared to the other locations and exhibited a reduction in density estimates at the lower altitude bands that could be due to increased clutter at low altitudes for this site.

The hourly altitude profiles at night revealed considerable variation in the use of altitude bands (Figures 28-31); however, over the course of the season, the lower altitude bands (50-200 m) were the most heavily used bands at 3 of the 4 sites (Figure 32). Niagara County was the only site that did not follow this pattern; the most heavily used band for the entire season at this site was the 350-400 m band (Figure 32), again likely due to the increased clutter at lower altitudes (Figure 4). In Wayne County, the 50-100 m altitude band was the most heavily used (Figure 32), with a total of 1.21 targets/1,000,000 m^3/night-hour. In Genesee County, the 100-150 m altitude band was the most heavily used, with 5.91 targets/1,000,000 m^3/night-hour. In Jefferson County, the 150-200 m altitude band was the most heavily used, with 3.80 targets/1,000,000 m3/night-hour. Likely due to clutter reducing detection ability at lower altitudes, Niagara County had 2.19 targets/1,000,000 m^3/night-hour in the 350-400 m band. The density in the 100-150 m band for Niagara County was 1.47 targets/1,000,000 m^3/night-hour.

The maximum density of volume-corrected target estimates occurred below 150 m on 26.8% and 58.7% of the nights at the Niagara and Wayne county sites, respectively, during the first part of the season. For the second part of the season at the Genesee and Jefferson county sites, the maximum density of corrected target estimates occurred below 150 m on 50.0% and 21.9% of the nights, respectively (Figure 33). A similar but more variable pattern occurred when the hours from 20:00 to 04:00 were considered individually; the maximum density of targets occurred below 150 m on 17.7% and 51.1% of the night hours during the first part of the season at Niagara and Wayne counties, respectively. The maximum density for individual night hours occurred below 150 m during 46.3% and 29.5% of the night hours during the second part of the season at Genesee and Jefferson counties, respectively (Figure 34). The maximum density may have occurred at higher altitudes on some nights due to lower overall migration, particularly favorable winds at higher altitudes, or a combination of factors.

At all four sites, targets were observed across the entire range of altitude bands sampled. The mean altitude of nocturnal targets was 694±518 m and 600±484 m above ground level at the Niagara and Wayne county sites, respectively, with a median target altitude at night of 861 m and 842 m, respectively. During the second part of the season at the Genesee and Jefferson county sites, the mean altitude of nocturnal targets was 774±566 m and 816±556 m above ground level, respectively, with a median nocturnal altitude of 605 m and 650 m, respectively. The median altitude was highest during the night biological time period, followed by the dawn period at all four sites.

Mean or median altitudes are often presented to indicate the altitude at which most targets are migrating. However, the estimates of mean and median altitude from radar data were poor indicators of the altitude band with the maximum density, and we believe that there are better metrics to represent the distribution of targets, such as volume-corrected measures and 50-m band analysis (Table 6). Using mean or median estimates for altitude tends to underestimate the risk to migrants. This under-representation would have occurred at all of the sites during all of the time periods sampled. By examining the density of each altitude band across the 24-hour cycle, we can see that there are particular times where the highest densities are within or near the rotor-swept zone for each of the sites (Figure 35). Figure 35 shows that night hours at all four sites had the highest density of flight activity and that the range of flight altitudes increased during the night hours. The graphics also show that many targets flew well within the rotor-swept zone and that the mean and median altitudes do not reflect peak density altitudes, demonstrating how the mean and median altitudes can misrepresent flight risk.

We present mean and median altitudes here to provide a common reference point for comparison with previous studies to examine why the mean and median altitudes are poor indicators of the distribution of migrants and to provide a comparison to metrics that we feel are better indicators of the distribution of targets (Table 6). The mean altitude per hour during the season exhibited a similar pattern at the four locations (Figure 36). The mean altitude increased after dusk, tapered off toward midnight, and decreased after midnight. The mean altitudes were always lower in daytime than at nighttime. There was a spike in mean altitude near noon at both the Niagara and Wayne county sites, which may be the result of daytime migrants such as hawks. This daytime spike was not observed at either the Genesee or Jefferson county sites, which were surveyed during the second part of the season, and therefore the absence of daytime peaks could also be due to the sampling dates. A spike in mean altitude occurred during the 06:00 hour in Niagara County and during the 04:00 hour in Wayne, Genesee, and Jefferson counties, representing a slight dawn ascent at all of our surveyed sites.

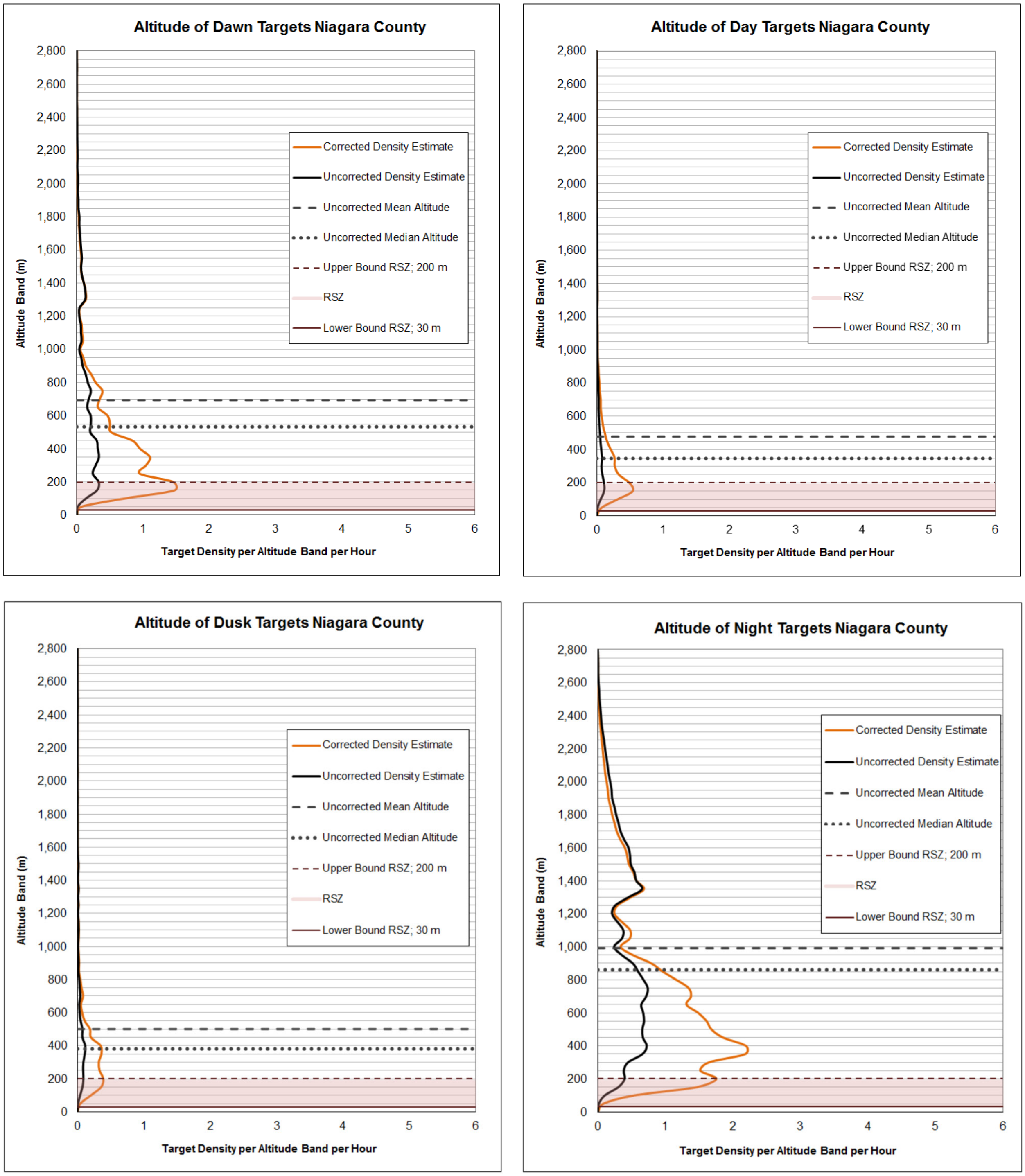


Figure 24. Altitude profiles of targets in Niagara County, New York. The corrected lines (orange) depict the target density (targets/1,000,000 m^3) per 50-m altitude band per hour after adjusting for the structure of the sample volume. The uncorrected lines (black) depict the target density per 50-m altitude band per hour assuming a uniform volume distribution (i.e., the volume of each band is equal to the total volume divided by the number of bands). The red band represents the rotor-swept zone (RSZ) from 30 to 200 m. The x-axis represents the target density (targets/1,000,000 m^3) per 50-m altitude band. The y-axis labels represent the top of each altitude band in meters.

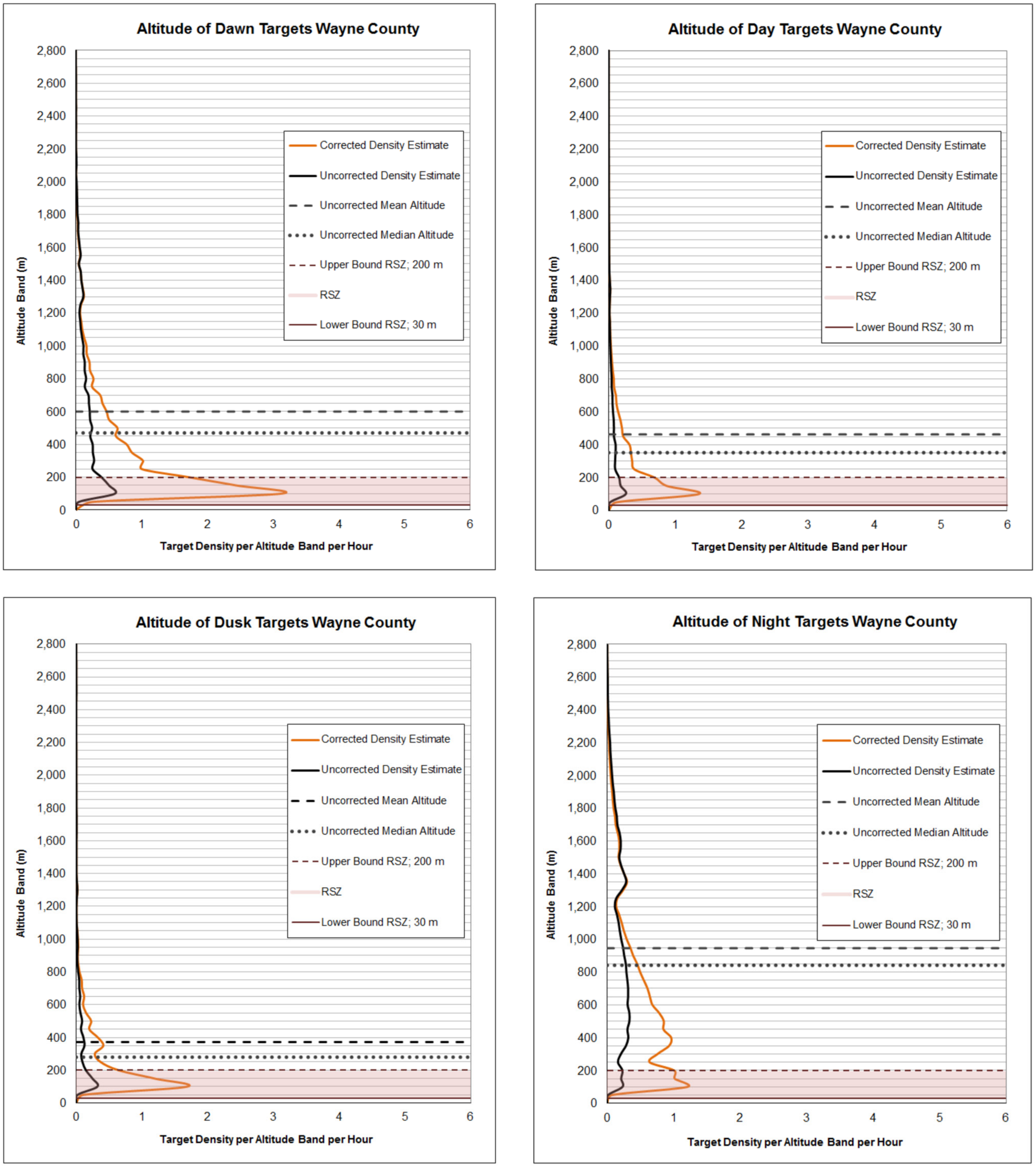


Figure 25. Altitude profiles of targets in Wayne County, New York. The corrected lines (orange) depict the target density (targets/1,000,000 m³) per 50-m altitude band per hour after adjusting for the structure of the sample volume. The uncorrected lines (black) depict the target density per 50-m altitude band per hour assuming a uniform volume distribution (i.e., the volume of each band is equal to the total volume divided by the number of bands). The red band represents the rotor-swept zone (RSZ) from 30 to 200 m. The x-axis represents the target density (targets/1,000,000 m³) per 50-m altitude band. The y-axis labels represent the top of each attitude band in meters.

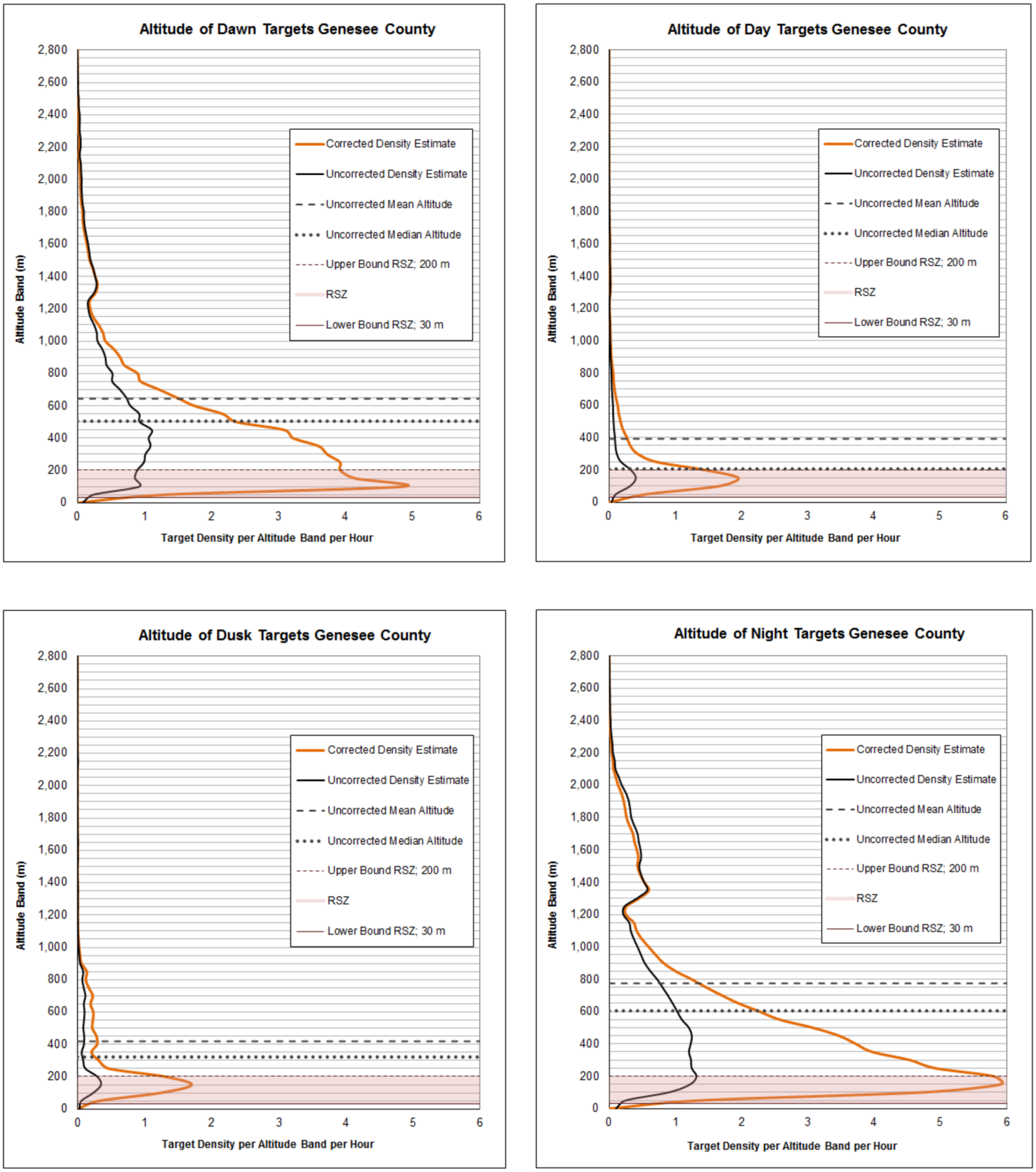


Figure 26. Altitude profiles of targets in Genesee County, New York. The corrected lines (orange) depict the target density (targets/1,000,000 m^3) per 50-m altitude band per hour after adjusting for the structure of the sample volume. The uncorrected lines (black) depict the target density per 50-m altitude band per hour assuming a uniform volume distribution (i.e., the volume of each band is equal to the total volume divided by the number of bands). The red band represents the rotor-swept zone (RSZ) from 30 to 200 m. The x-axis represents the target density (targets/1,000,000 m^3) per 50-m altitude band. The y-axis labels represent the top of each altitude band in meters.

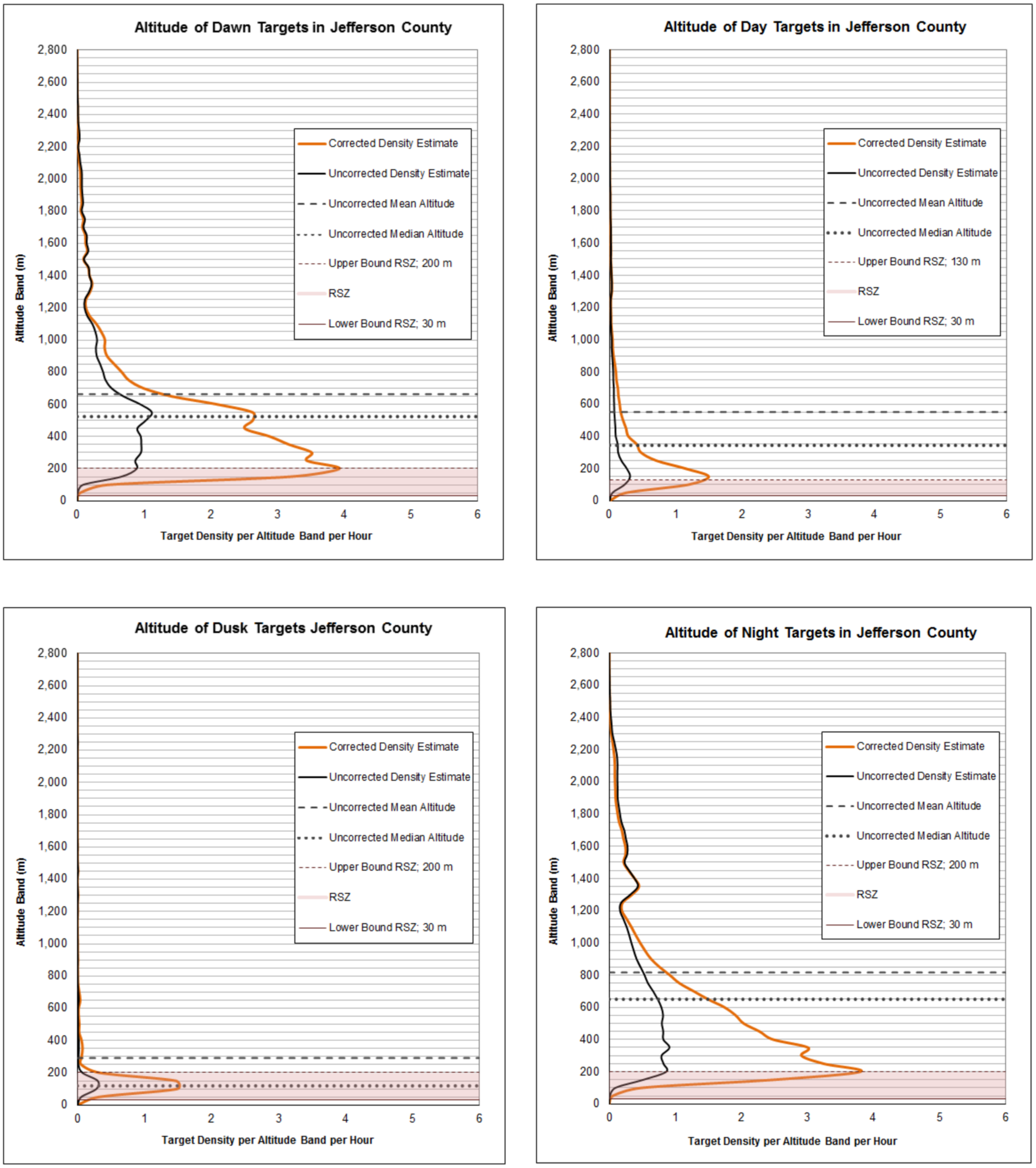


Figure 27. Altitude profiles of targets in Jefferson County, New York. The corrected lines (orange) depict the target density (targets/1,000,000 m³) per 50-m altitude band per hour after adjusting for the structure of the sample volume. The uncorrected lines (black) depict the target density per 50-m altitude band per hour assuming a uniform volume distribution (i.e., the volume of each band is equal to the total volume divided by the number of bands). The red band represents the rotor-swept zone (RSZ) from 30 to 200 m. The x-axis represents the target density (targets/1,000,000 m³) per 50-m altitude band. The y-axis labels represent the top of each altitude band in meters.

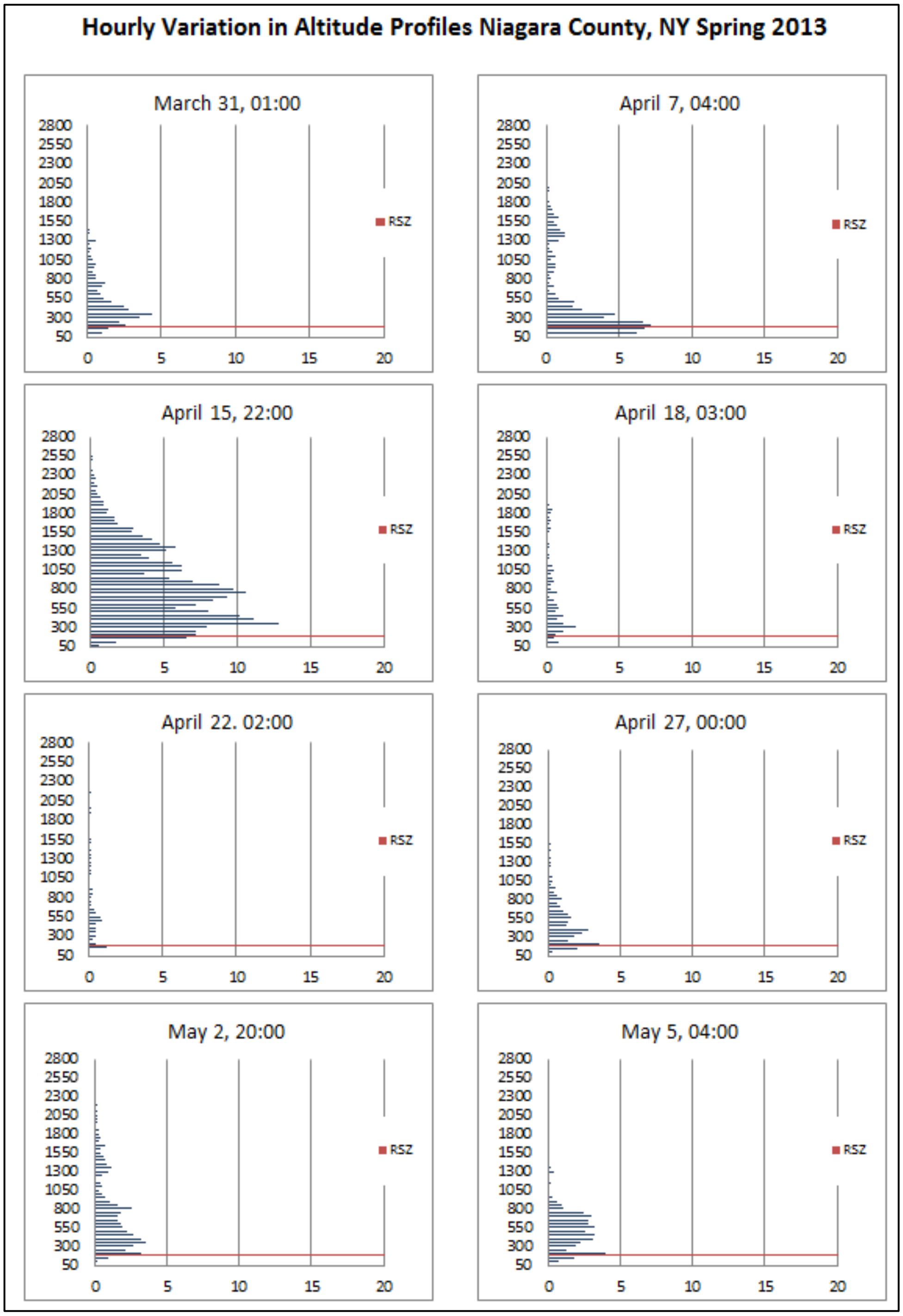


Figure 28. A sample of nocturnal hourly altitude profiles corrected for the shape of the sample volume in Niagara County, New York, in spring 2013. Hours were selected to portray the variability in density per altitude band of passing targets during the night and early morning hours. The x-axis represents the uncorrected target density (targets/1,000,000 m^3) per 50-m altitude band. The y-axis labels represent the top of each altitude band in meters. The red line represents the top of the rotor-swept zone at 200 m.

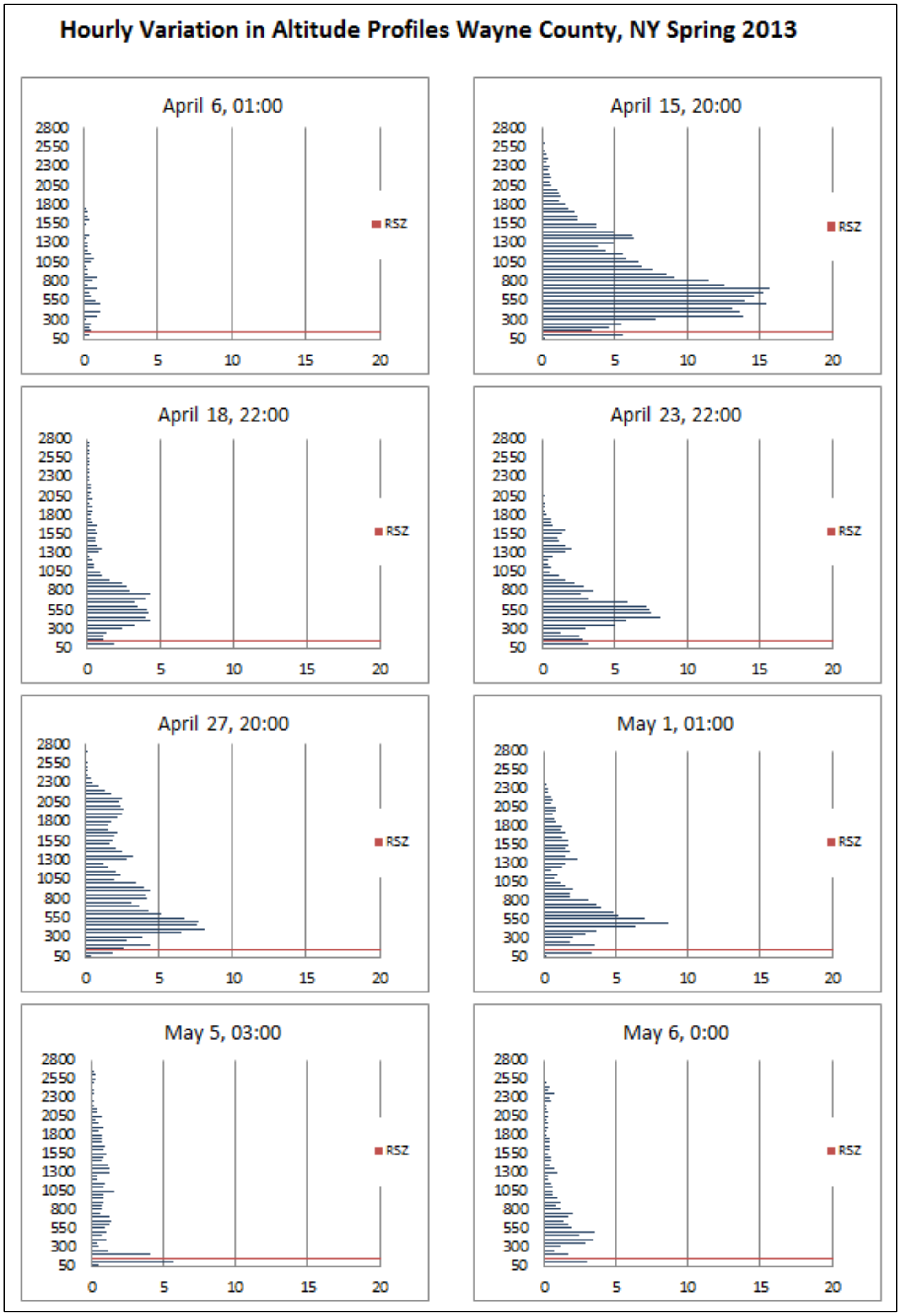


Figure 29. A sample of nocturnal hourly altitude profiles corrected for the shape of the sample volume in Wayne County, New York, in spring 2013. Hours were selected to portray the variability in density per altitude band of passing targets during the night and early morning hours. The x-axis represents the uncorrected target density (targets/1,000,000 m^3) per 50-m altitude band. The y-axis labels represent the top of each altitude band in meters. The red line represents the top of the rotor-swept zone at 200 m.

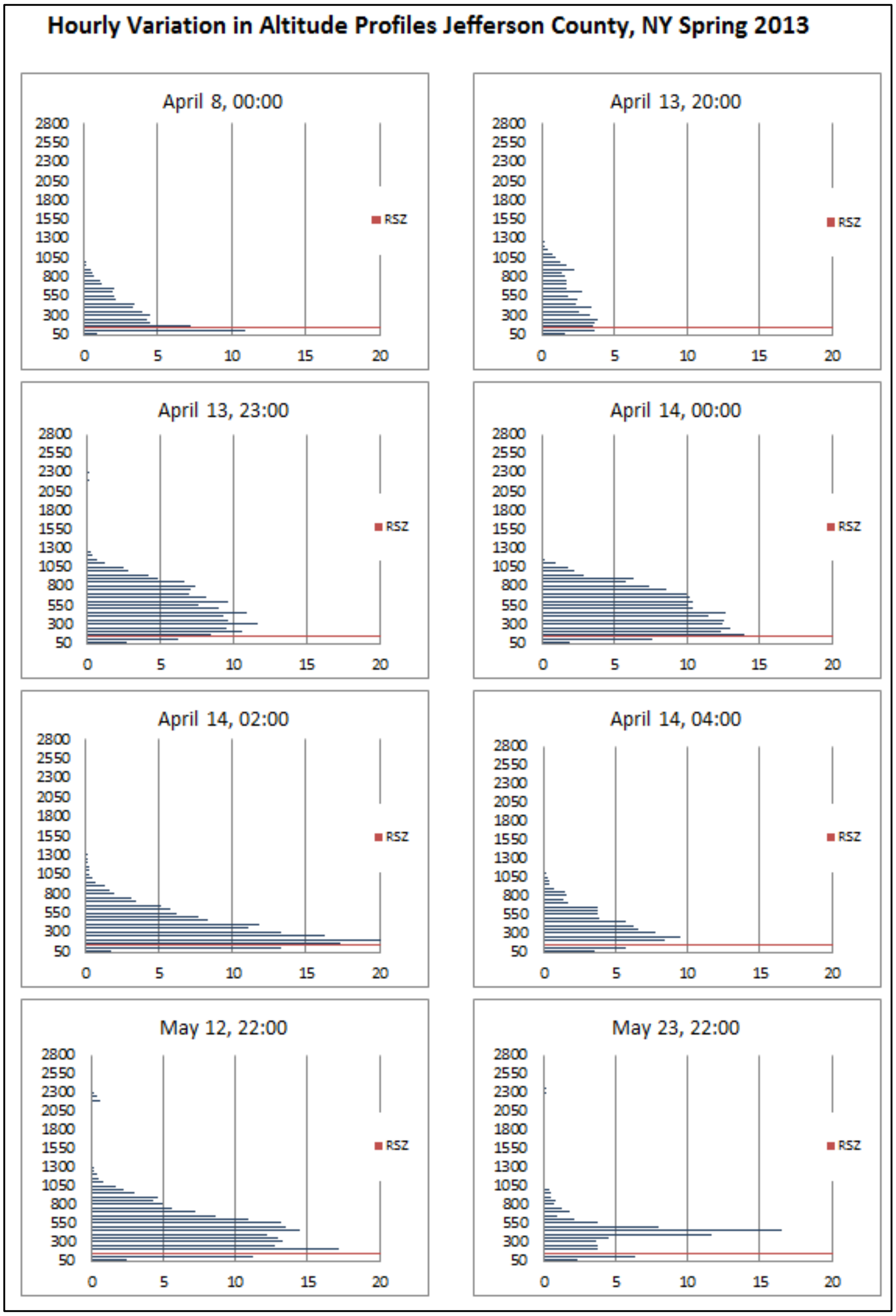


Figure 30. A sample of nocturnal hourly altitude profiles corrected for the shape of the sample volume in Genesee County, New York, during spring 2013. Hours were selected to portray the variability in density per altitude band of passing targets during the night and early morning hours. The x-axis represents the uncorrected target density (targets/1,000,000 m^3) per 50-m altitude band. The y-axis labels represent the top of each altitude band in meters. The red line represents the top of the rotor-swept zone at 200 m.

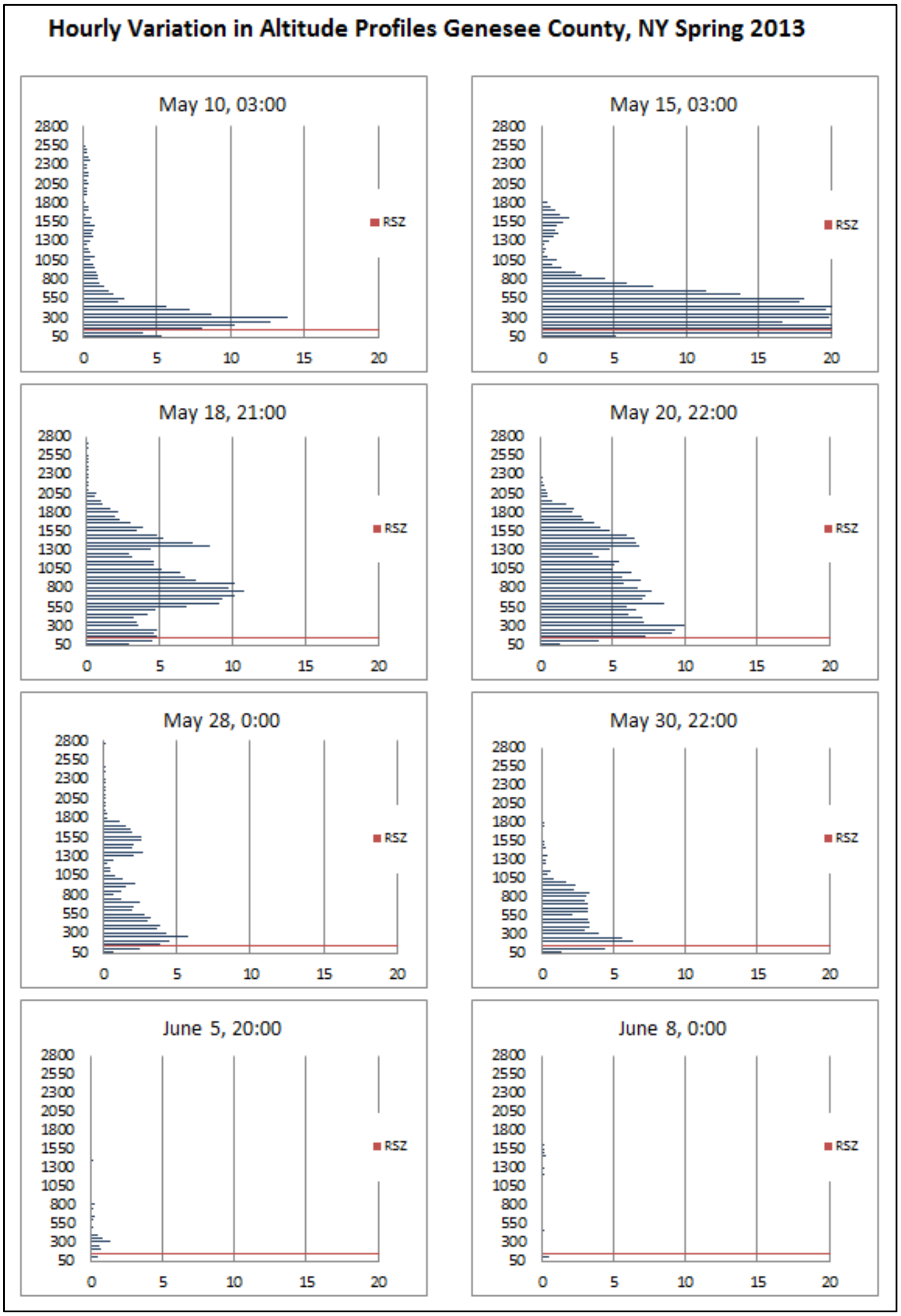


Figure 31. A sample of nocturnal hourly altitude profiles corrected for the shape of the sample volume in Jefferson County, New York, in spring 2013. Hours were selected to portray the variability in density per altitude band of passing targets during the night and early morning hours. The x-axis represents the uncorrected target density (targets/1,000,000 m^3) per 50-m altitude band. The y-axis labels represent the top of each altitude band in meters. The red line represents the top of the rotor-swept zone at 200 m.

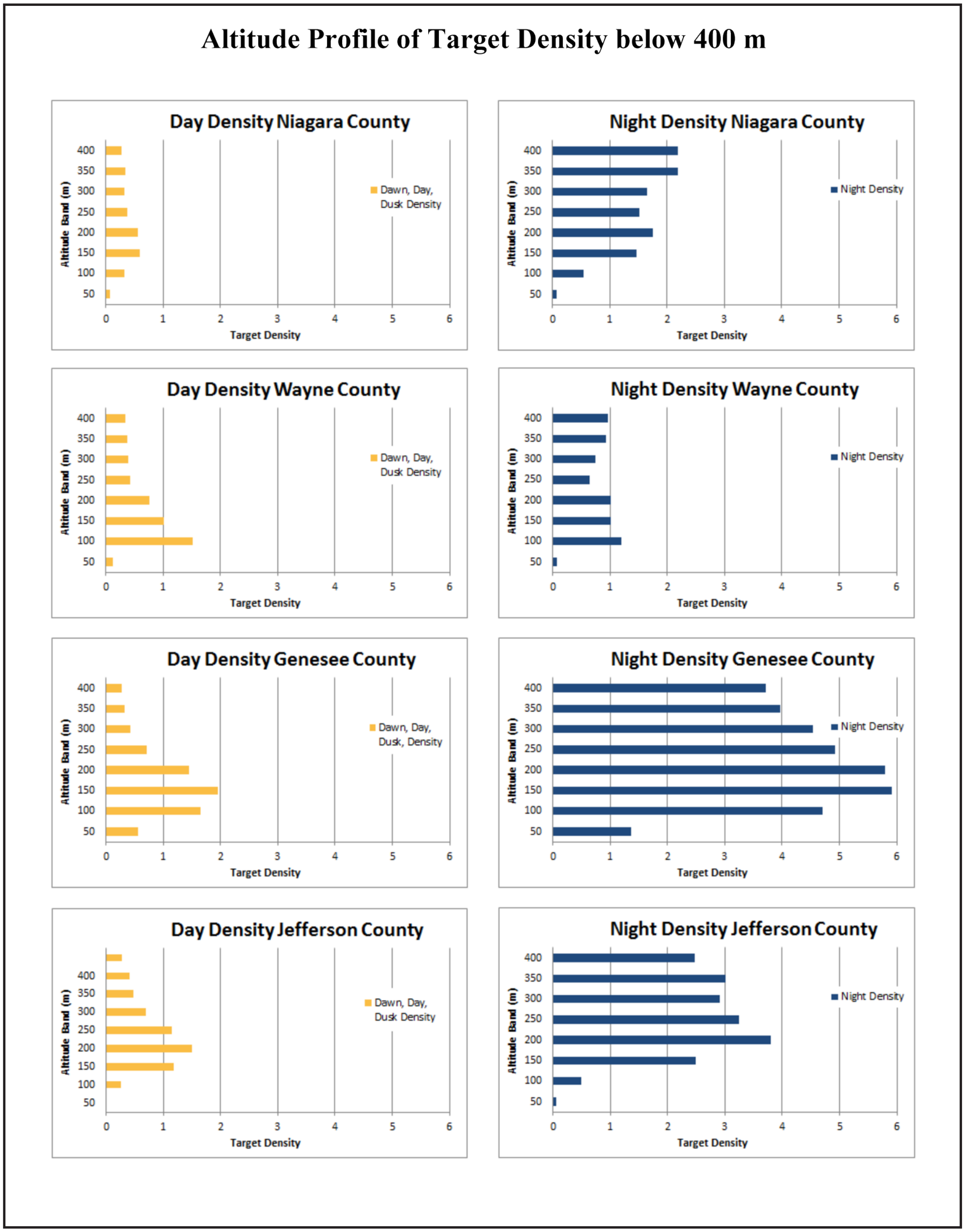


Figure 32. Altitude profile of target density below 400 meters in Niagara, Wayne, Genesee, and Jefferson counties, New York. These graphs present the altitude bands where the maximum density occurred during spring 2013. The x-axis represents the corrected target density (targets/1,000,000 m^3) per 50-m altitude band. The y-axis labels represent the top of each altitude bands in meters.

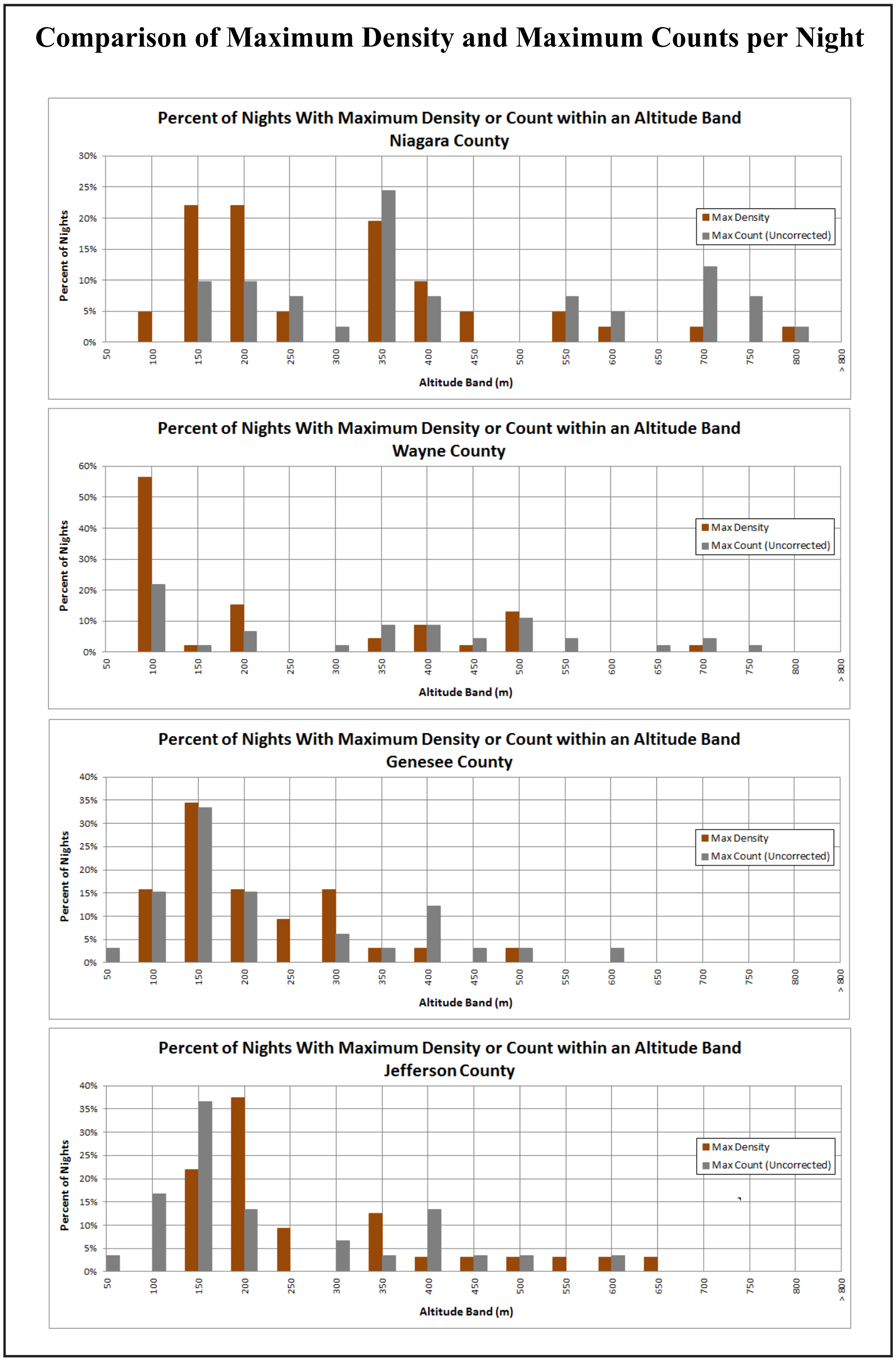


Figure 33. These graphs present the proportion of nights when the maximum density (targets/1,000,000 m^3/altitude band) or count (targets/altitude band) occurred within each 50-m altitude band in Niagara, Wayne, Genesee, and Jefferson counties, New York, in spring 2013. The x-axis labels represent the top of each altitude band.

Comparison of Maximum Density and Maximum Counts per Hour

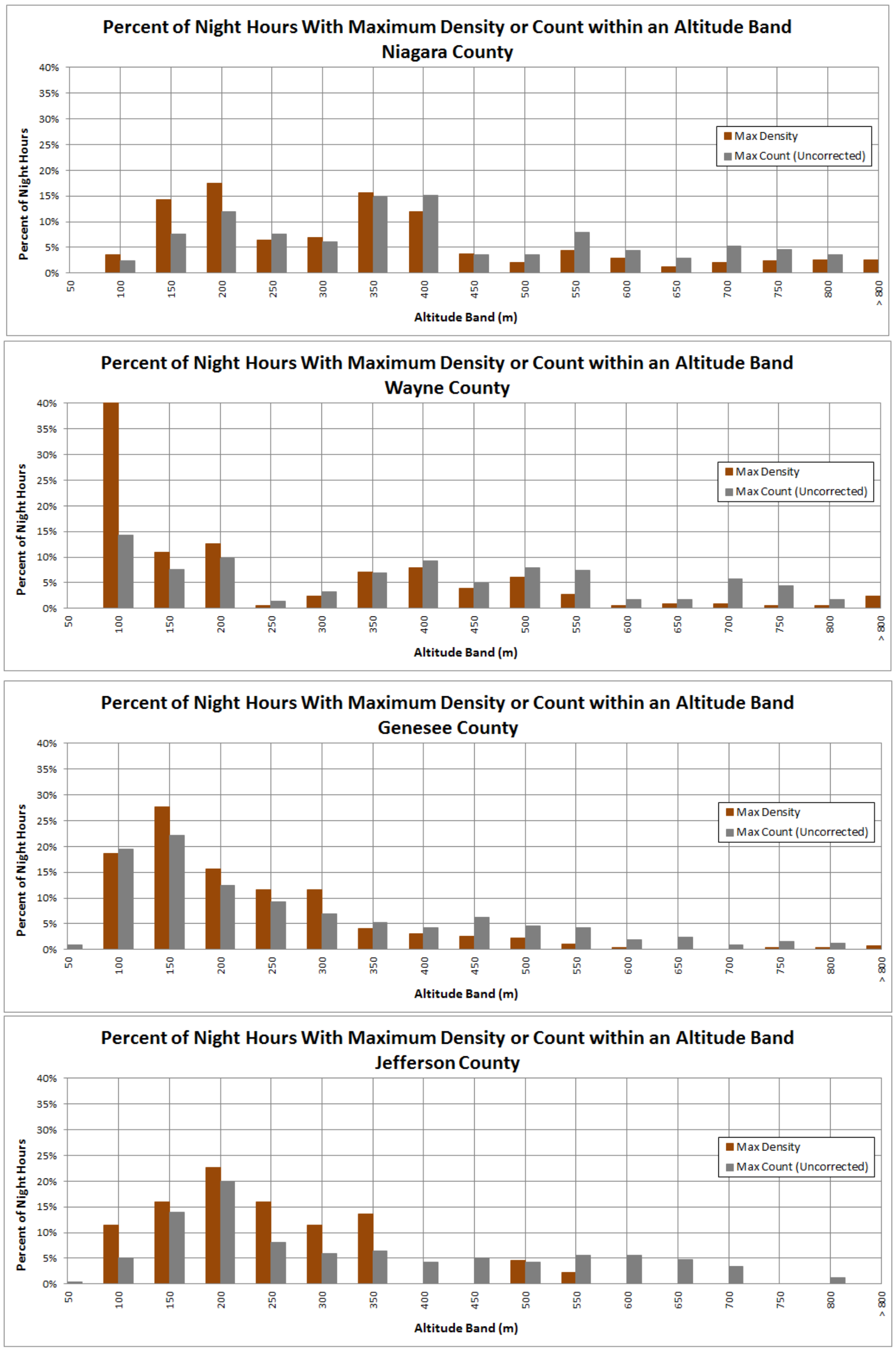


Figure 34. These graphs present the proportion of night hours (20:00 – 04:00) when the maximum density (targets/1,000,000 m³/ altitude band) or count (targets/altitude band) occurred within each 50-m altitude band in Niagara, Wayne, Genesee, and Jefferson counties, New York, in spring 2013. The x-axis labels represent the top of each altitude band.

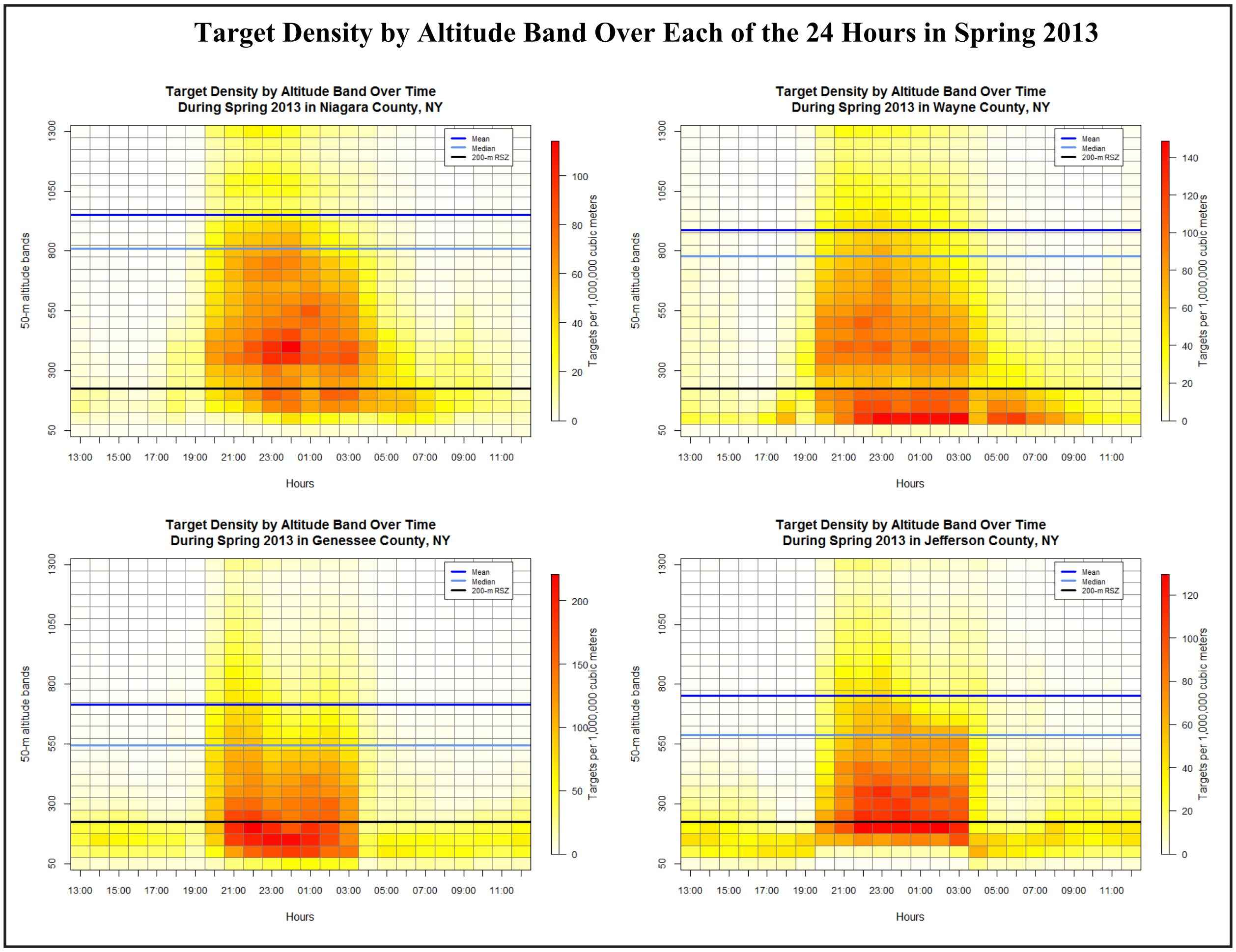


Figure 35. These graphs present the density of targets that occurred within each 50-m altitude band in Niagara, Wayne, Genesee, and Jefferson counties, New York, in spring 2013 over each of the 24 hours in a day. Please note the different scales for each of the heat maps. Deep red areas on one graph may be equivalent in density to yellow areas on another heat map. This is at least partially due to differences in detection ability due to clutter and target movement direction which make comparisons between sites difficult. Dark blue lines represent the mean altitude and light blue lines represent the median altitude across all hours. The black lines represent the top of the 200-m rotor-swept zone. The graphs only extend up to 1300 m and not to the full height of the radar scan to better show detail of the lower altitude bands.

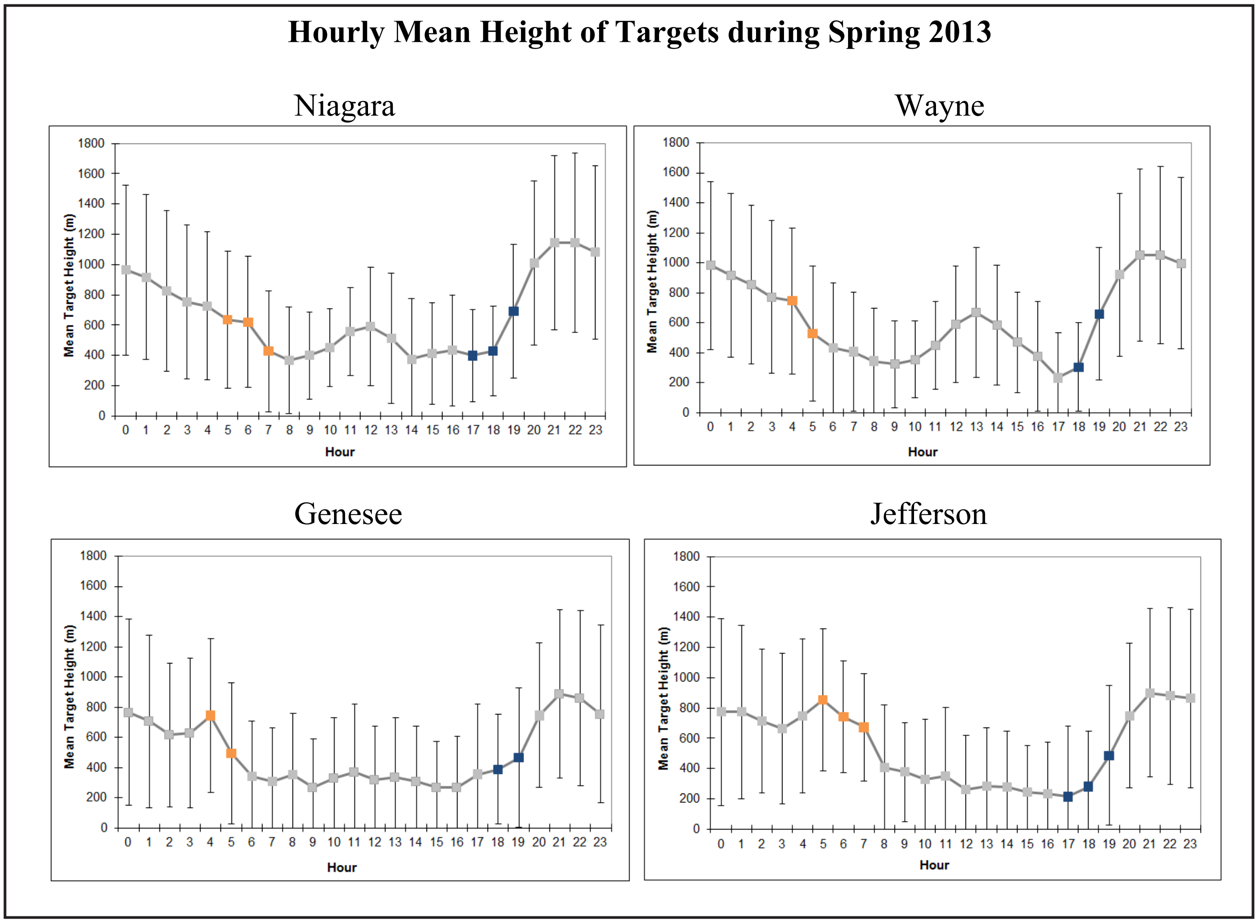


Figure 36. Hourly mean target height (m) during spring 2013 in Niagara, Wayne, Genesee, and Jefferson counties, New York. The orange and blue markers indicate the hours of sunrise and sunset, respectively. Due to differences in the survey locations and times, the hours of sunrise and sunset were not identical for all sites across the season. The error bars represent one standard deviation.

Table 6. Comparison of mean altitude (m, ± standard deviation), median altitude (m), and altitude bands (50-m bands) containing the maximum target density during the four biological periods in Niagara, Wayne, Genesee and Jefferson counties, New York, in spring 2013. The maximum density is the top of the 50-m altitude band.

	Biological Period	Mean	Median	Max Density		Mean	Median	Max Density
Niagara	Dawn	694 ± 518	533	150	Wayne	600 ± 484	470	100
	Day	478 ± 420	347	150		463 ± 397	352	100
	Dusk	501 ± 386	381	200		372 ± 340	280	100
	Night	992 ± 568	861	400		946 ± 564	842	100
Genesee	Dawn	644 ± 497	505	100	Jefferson	663 ± 476	524	200
	Day	393 ± 434	207	150		551 ± 520	344	150
	Dusk	419 ± 367	322	150		291 ± 440	119	100
	Night	774 ± 566	605	150		816 ± 556	650	200

Discussion

We performed this seasonal study to document migration along the shorelines of the Great Lakes as part of a series of seasonal studies; this report focuses on Lake Ontario. Our findings indicate that migrational movements were common along the shoreline of Lake Ontario in New York where we established study sites and at an inland site in Genesee County. We believe that our data can be extrapolated to represent much of the remaining shoreline of Lake Ontario because our sites are representative of the entire lakeshore. Our research contributes to a growing body of literature that documents various aspects of migration and identifies Great Lakes shorelines as areas important for the conservation of migratory species of birds and bats. Our data provide unique observations on the magnitude and timing of nocturnal migration that could not be documented without the aid of radar technology.

Spring 2013 was the first season that we stationed one of the radar units at a location away from the lake shore. The inland site in Genesee County was approximately 40 km south of the Lake Ontario shoreline and 60 km east of the tip of Lake Erie. Our inland radar site was approximately 20 km from the Iroquois National Wildlife Refuge, which is also in Genesee County. This refuge has large patches of different habitats that attract migrants needing to stop and refuel. The proximity of the refuge combined with the time periods sampled and a possible migratory pathway from the eastern end of Lake Erie to the shore of Lake Ontario could explain why our sole inland site appeared to have higher activity than our shoreline sites. Many other site-specific factors, including differences in ground clutter interference and side lobes, make comparisons between sites potentially misleading.

When examining patterns of activity, however, our inland site did not feature the change in movement direction at dawn observed at all of the shoreline sites. The dawn movement activity at the Genesee County site was similar to nighttime activity, whereas at the other locations, a shift in direction was observed between the night and dawn periods, with targets moving back to the shore from out over the lake. Our inland site at Genesee County did show a pattern of dawn ascent, to an even larger degree than some of our shoreline sites. This could indicate that migrants were moving to higher altitudes to look for stopover habitat at our inland site as well, suggesting that dawn ascent may not occur only as a response to obstacles during migration. Comparing these general activity patterns among sites may be more valid than comparing raw numbers; because the general activity patterns may be less affected by site-specific factors.

There were more nights with low or no nocturnal migration in the first part of the season (Niagara and Wayne counties) than in the second part of the season (Genesee and Jefferson counties) due to our early start date which arose from our goal to estimate when the nocturnal migration season began for passerines and bats. Due to the inclusion of these early non-migration nights and the different time periods sampled, our aggregate summary statistics may underrepresent the true heavy migration activity at these early-sampled sites. In addition, each of these sites was affected to varying degrees by clutter on the horizontal and vertical radars, further emphasizing the need for caution when making numerical comparisons between sites, parts of the season, or shoreline and inland locations.

The Jefferson County site exhibited different patterns that may have been due to the habitat in the area. Over time, the horizontal peaks are not as pronounced as those observed at the other sites, and there appears to be a great deal of daytime activity (Figure 18). Some of this daytime activity was determined by biologists to be gulls and geese. Waterfowl and other birds that were active during the day were also likely attracted to the nearby Black Pond Wildlife Management Area. The local movement of these birds may have inflated the hourly daytime horizontal counts on the timeline. At the Jefferson County site, there were also issues with clutter and detection that caused more of the horizontal data to be excluded than at other sites, potentially affecting the nighttime counts. Daytime target detection in this area appeared to be less affected by clutter, possibly due to the larger target size, different flight altitude, or other factors.

Sampling Regime

The sampling regime is an important consideration for migration studies. Migratory movements are guided in part by environmental conditions and occur in pulses across the migratory season (Alerstam 1990). Our continuous sampling scheme, although split into two different sites for each radar unit, captured the timing of migration events and provided a more complete picture of a portion of the migratory season than a systematic or random sampling scheme, which might have missed pulses of activity even when sampling as frequently as every three days (Figure 37). The top portion of this figure could be interpreted to mean that there is only one week-long period of migration, when in fact the migration period was much longer and had much higher peaks than when observed with a non-continuous sampling regime. We used diurnal radar observations to provide a baseline for comparing nocturnal activity, and including the diurnal time period in the sampling scheme helped to distinguish the magnitude of migration events (Figure 19). Our sampling regime was also useful for determining when the nocturnal migration season for passerines and bats began in April and declined into June. These determinations were based on our vertical radar TPR counts, but there was some directional movement on the horizontal radars even prior to April, as well as continuing later into June. Some early season diurnal peaks on the horizontal radar could have been due to the migration of hawks or waterfowl. There were also many peaks that occurred near midnight, which could have been nocturnal migrating waterfowl, owls, or early moving passerines. Another explanation for the mismatch of peaks on the horizontal radar and vertical radar early in the season could be that the targets observed on the horizontal radar were flying at a low altitude, preventing their effective detection by the vertical radar. Consequently, the risk to migrants during these early season periods may be greater than we show in our results, highlighting the importance of sampling early in the season.

Although we changed sites in the middle of the season to cover more area, we believe that our radar unit locations were sufficiently similar to represent the approximate start and end dates for the entire Lake Ontario area. As more data are collected, our description of the migration season and how it varies with location and year will improve. This information will help tailor conservation efforts, such as turbine curtailment, to time frames during which they will be most effective.

Site Comparison Considerations

The target counts provided by radar are influenced by radar type and calibration, filtering of non-intended targets, count algorithms, frequency band, antenna orientation, sampling scheme, and how researchers account for variation in detection probability and sample volume (Bruderer 1997, Harmata et al. 1999, Schmaljohann et al. 2008). Even when identical equipment and methodology are used among sites or studies, comparisons of numbers should be made cautiously if the probability of detection and sampling volume are ignored (Schmaljohann et al. 2008).

Recognizing that our counts represent an index of target passage that is relative to a site, and not a true population count, we are cautious in making comparisons among sites or studies. Rather than relying solely on the magnitude of target passage as an indication of airspace usage, we assessed the general patterns of activity among sites to compare the relative strength of migration. For example, a site at which the nocturnal passage rate exhibits peaks many times larger than nocturnal lulls for the majority of the sampling period during the migration season would be considered to have more migration than a site with less of a difference between nocturnal peaks and nocturnal lulls or a site that had a nocturnal passage rate that only occasionally spiked above a baseline nocturnal passage rate.

High baseline activity may also indicate areas that could be at risk from renewable energy development. The presence of behaviors such as dawn movement to or along the shoreline, changes in movement direction during the course of the night, and other indications of an obstacle to migration may indicate the level of risk that migrants in a particular area face, in addition to more quantitative measurements such as the density of targets in the rotor-swept zone. By examining both behavioral patterns and quantitative data from a site, we can gain insight into how much risk development of a site might pose to migrants.

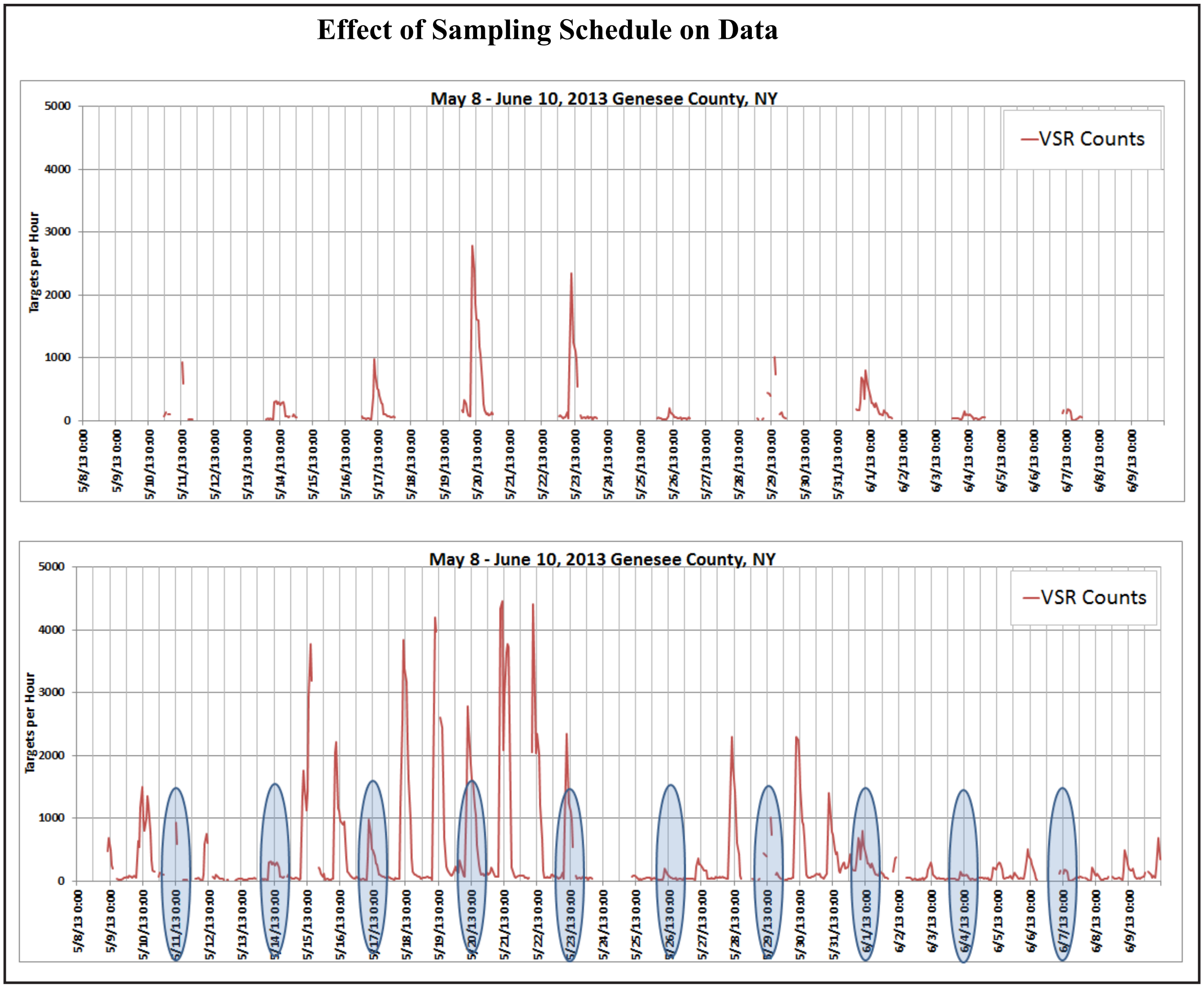


Figure 37. Example of a hypothetical sampling schedule in which data are collected once every three days (top graph) versus the actual continuous sampling schedule (bottom graph). The red lines represent the number of targets counted per km per hour by the vertical scanning radar for the entire sampling season (May 8-June 10) in Genesee County, New York. The blue circles on the bottom graph represent the times that would have been sampled if using the sampling schedule in the top graph; many of the larger migration peaks would be missed.

Migration Patterns

The patterns of movement we recorded were consistent with other observations of migration (Newton 2008) and indicated that nocturnal migratory flights occurred regularly during spring 2013 at all four of our surveyed locations, including our inland site. The nocturnal activity we observed was typically oriented between north and east (Figures 13-14) and occurred in pulses across the season that were captured by the horizontal and vertical radars (Figures 15-18). We also observed that targets flying over water returned to shorelines near dawn (Figure 9-12). The behavior of returning to shore at dawn has occurred at every site we have sampled in the Great Lakes so far (Bowden et al. 2015). Migrants may move across the landscape in a broad front but then concentrate along the shorelines due to this movement back to shore at dawn as well as the concentration of stopover habitat along the shoreline. The TPR (season mean) was highest during the nocturnal biological period at all locations, followed closely by the dawn biological period (Table 5, Figure 19). The pattern of hourly mean heights was identical to that previously associated with migration (Harmata et al. 2000, Mabee and Cooper 2004); heights increased near dusk, peaked toward midnight, and began to decrease prior to dawn. The slight increase in mean height near dawn (Figure 36) is consistent with the migratory behavior described as dawn ascent, although we expected to see a greater effect at the Niagara and Wayne county sites (Myres 1964, Diehl et al. 2003). This behavior is attributed to migrants increasing their altitude to gain a broader view of the surrounding landscape before selecting stopover habitat or returning to the shoreline if flying over water. The differences in dawn ascent observed between the sites during the first part of the season (Niagara and Wayne counties) and the second part of the season (Genesee and Jefferson counties) may be due to the time period sampled, but it is also possible that targets behave differently when approaching an east/west lakeshore (Niagara and Wayne) than at inland sites (Genesee) or when approaching a north/south lakeshore (Jefferson).

Overall, we attribute these nocturnal observations to migrants and suggest that the areas we studied are important for their conservation. Interestingly, in contrast to the behavior at the shoreline sites, targets did not change their direction of movement significantly from the nocturnal direction of movement at the inland site but still exhibited an increase in altitude at dawn. The dawn ascent at the inland site may indicate that the migrants were also looking for stopover habitat near the inland site. During the second part of the season, our radar also indicated a more dramatic increase in mean altitude near dawn than that observed at our sites during the first part of the season. This increase may be due to the sample period, the specific locations surveyed, or the species migrating through the area at that time. At all four of our sample locations, nocturnal targets appeared to move across the landscape in four waves, with peaks near April 20, May 5, May 24, and June 1 (Figures 22-23). These fluctuations could be related to broad-scale weather fronts, variations in timing among guilds of migrants, or a combination of these and other factors (Newton 2009). The similarity in the pattern of these waves when compared among sites, even at the opposite ends of Lake Ontario, suggests broad-scale influences, and further investigation into their causes might allow the prediction of high migration events and allow wind turbine operations to be adjusted accordingly, although this is not likely in the near future.

The weekly mean estimates of the nocturnal TPR were consistently higher than the weekly mean diurnal TPR across all weeks of data collection (Figures 21-23). Although the nocturnal TPR was always greater, the difference between the nocturnal and diurnal time periods was smallest at the beginning and end of the migration season. The shift in time periods with orders of magnitude more nocturnal activity than diurnal activity to time periods with similar levels of nocturnal and diurnal activity indicates that migration contributed significantly to the aeroecology of our study areas, although this specific measure may not be appropriate for all areas.

Flight Altitude

The altitude profiles indicated that most nocturnal targets passed below 800 m, with peak density in the 50–200 m altitude bands for most of the sites that we surveyed during this season (Figures 32-34). The analysis of altitude bands with the highest densities is a better indicator of where the most migratory movement is occurring than uncorrected mean or median flight altitudes. We corrected for the approximate shape of the survey volume and included this correction in our density estimates. This correction is based on the manufacturer's estimate of beam geometry, which may not be precise, and may be affected by the inconsistency of beam propagation. Beam propagation (how the radar waves travel through the air and are reflected back from a target) is affected by side lobes, target size and distance, and atmospheric conditions (Bruderer 1997). However, we believe that the correction is an improvement over altitude profiles that ignore beam geometry and sampling effort. We were not able to correct for the loss of detection with distance from the radar (Schmaljohann et al. 2008), and our vertical scanning radars lost detection in the region where the radar transitioned from a short to medium pulse, at a range of approximately 1,000–1,200 m. For these reasons, our estimates likely under-represent density as altitude increases.

The altitude profiles that we report varied considerably among nocturnal hours at our sites (Figures 23-26). Migrants adjust flight altitude with wind direction and speed, visibility, time, and landscape below the flight trajectory (Alerstam 1990, Hueppop et al. 2006, Liechti 2006). For example, head winds aloft can result in migrants moving en masse to lower altitudes, where wind speeds are lower (Gauthreaux 1991). Changes in flight altitude can occur at various times over the course of the night and are associated with targets ascending from and descending to stopover sites. Depending on the location, these altitude changes may place migrants at risk of collision with wind turbines and other tall human-made structures.

Radar Study Considerations

Although radar may be the best tool available for gathering large quantities 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 application to risk assessment will likely increase as wind energy development increases. Despite this accelerating trend, standardized methodologies for establishing radar settings, ground-truthing biological targets, and processing data have not been adopted. These considerations can substantially affect the quality of data and its interpretation and present a challenge that is not easily solved. However, without standards, comparisons among studies may be more representative of changes in methodology and site conditions than differences in migration activity. In addition, the metrics reported in these types of surveys can be misleading to someone unfamiliar with avian radar.

For example, the mean altitude of target passage is often reported to be above the rotor-swept zone, which is consequently interpreted as an indication of low risk. However, the mean altitude can be well above the rotor-swept zone even when there is a high rate of targets passing within the rotor-swept zone. This is due to the long range at which radar collects altitude data, up to 3 km above ground level in our study, where high-flying targets skew the mean altitude. This bias is apparent in our data when comparing the mean altitude of nocturnal targets to the most densely populated altitude band (Table 6 and Figures 32-35). It is also misleading to compare the percentage of targets below, within, and above the height of the rotor-swept zone without addressing the difference in sampling effort. Within our sampling framework, there were three 50-m altitude bands below 150 m (an estimate for the height of the rotor-swept zone) and 53 altitude bands above 150 m. Based on our model, we estimated that approximately 1 percent of the potential survey volume was below 150 m. Accordingly, we would expect a small percentage of targets to be recorded at or below the rotor-swept zone, but this does not necessarily indicate low risk. If targets were spread evenly throughout the survey volume, we would thus expect to have a minimal percentage of targets within the rotor-swept zone. Uncorrected numbers such as 5-10% of targets in the rotor-swept zone are frequently reported and classified as “low risk”, even though this means that the area is many times more concentrated with targets than we would expect from a random distribution of targets throughout the survey volume. When using estimates of target counts that are corrected for volume, we often see a much higher concentration in the rotor-swept zone than if the numbers do not take sampling volume into account (Figures 24-27).

In this report, we provide examples of methodologies and analyses that we have found helpful in interpreting radar data and have used in other seasons. We suggest that the patterns of activity and the relative changes in counts at a site indicate the level of migration activity and that these parameters are better indicators of migration activity than comparing the magnitude of counts among studies. Careful attention should be given to how these indices fluctuate over fine temporal scales, e.g., hourly, as opposed to monthly or seasonal summaries (Figure 35). These fine temporal scale measures may reveal more times when the collision risk to migrants could be high. The clutter maps we have included provide information about our ability to detect targets at various altitudes, and it is important, particularly for risk assessment, that radar operators address their ability to detect targets at low altitude. We provide a concept for a method to account for the structure of the sample volume that, although not without limitations (Schmaljohann et al. 2008), provides a partial solution rather than ignoring the biases associated with sampling effort. Overall, we observed that radar provided insight into nocturnal migration that would otherwise be unattainable, and its continued development and careful interpretation will result in valuable contributions to the management and conservation of migrants.

Management Considerations

Each piece of data that we present fits together to provide a larger picture of migration that we must step back and assess. Our radars were primarily located along the shoreline, and this is the area in which we can gain the best picture of migrant behavior. The general patterns along the shorelines of Lake Ontario reveal that these areas are used heavily by nocturnal migrants during the spring migration. This pattern of migration is evident from our sample Trackplots as well as the timelines from each of the sites. Beginning on approximately April 15, migration occurs on many if not most nights. Birds and bats, including diurnal migrants that we did not focus on, likely began migrating prior to this date, but our vertical radar started to detect them in higher numbers on this date. In the early part of migration nights, many of the birds and bats were leaving the shoreline area and crossing over Lake Ontario if the conditions were favorable. Later in the night, and on nights when conditions were not favorable to crossing, we often saw migrants moving parallel to the lakeshore as others arrived from inland areas to join them. This behavior indicated that migrants are active while they are waiting for the right times and conditions to cross or circumnavigate an obstacle such as the Great Lakes. The movement of migrants along the shoreline implies that a wind energy facility or communication tower constructed in these areas would be encountered by both birds actively migrating across the lake or along the lakeshore and those moving between stopover habitats.

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

At the survey locations this season, our risk analysis revealed that during a large proportion of nocturnal hours or nights overall, the numbers and densities of birds and bats flying in or near the rotor-swept zone were high. The only exception was a site (Niagara County) where low-flying targets were likely undercounted due to clutter (Figure 4), and there was still an indication of times with higher risk (Figures 33-34). Making comparisons between sites must take into account differences in detection ability between the sites (Figures 4-5).

Migrants will also change altitudes depending on environmental conditions, and thus targets in altitude bands that are just above the rotor-swept zone may also be at risk of collision with turbines. In addition, our analysis only shows the rotor-swept zone for turbines that were in planning stages at the time of the study. Wind turbines are being constructed to higher altitudes (Eller 2015), with larger rotor-swept zones extending into the altitude bands just above where turbine blades currently reach, which may impact more migrants (Figure 35).

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

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

The results of our research highlight the potential role of radar in following these recommendations and may be of interest to public and private entities that are involved in wind energy development and its potential placement in the Lake Ontario area as well as the entire Great Lakes region. Coupling avian radar studies with other methods of studying migration may broaden the utility of risk assessments and the assessment of wind energy developments.

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Appendices

Appendix 1: **Spring 2013 Report Summary**

Appendix 2: **Percent Land Cover Associated with Study Sites and the 2011 National Land Cover Database Classification**

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

Appendix 4: **Comparison of Static and Corrected Density Estimates**

Appendix 1

Spring 2013 Report Summary

- Migration occurred on both the south and east the shoreline of Lake Ontario during spring 2013.
    - Migration was identified by uniformity of movement of direction (north/east) at night, high target passage rate, and typically a peaking of numbers near midnight
    - Patterns and timing of migration were similar between the sites sampled during the same period
        - 4 main waves of migration with highest concentrations near April 20, May 4, May 23, and May 31.
- Date range of pulses that occurred during the migration season
    - Began on Mar 30 in Niagara and Wayne counties, NY
    - Ended on May 30 in Genesee and Jefferson counties, NY
- Patterns of activity were different between Dawn, Day, Dusk, and Night time periods
    - Movement north, northeast, and east during the night at all locations
        - 77% of nights surveyed the mean direction of travel was between N and E in Niagara County, NY
        - 83% of nights surveyed the mean direction of travel was between N and E in Wayne County, NY
        - 85% of nights surveyed the mean direction of travel was between N and E in Genesee County, NY
        - 88% of nights surveyed the mean direction of travel was between N and E in Jefferson County, NY
    - Movement in towards and/or along the shore at dawn
        - Observed at all four sites
    - Highest target passage rate at night
    - Dawn ascent
        - Slight increase in height around dawn hours observed at all four sites
- Peak density of targets in volume corrected counts
    - Max density below 150 m 26.8% of nights and 17.7% of night hours at Niagara County, NY
    - Max density below 150 m 58.7% of nights and 51.1% of night hours at Wayne County, NY
    - Max density below 150 m 50% of nights and 46.3% of night hours at Genesee County, NY
    - Max density below 150 m 21.9% of nights and 29.5% of night hours at Jefferson County, NY
- Standards for radar studies need to be established and recommendations are included in this report
    - Using radar counts as an index of activity and not a population estimate
    - Surveying continuously over the whole migration season
    - Examining smaller time periods (Dawn/Day/Dusk/Night or Hourly) rather than seasonal metrics
    - Using volume corrected counts on the vertical radar to better estimate use of low altitudes and the rotor swept zone
    - Using 50-m altitude band graphics to represent height distributions rather than mean or median heights
    - Examining the most densely populated altitude bands rather than comparing numbers or percentages of targets below, within, and above the rotor swept zone
    - Recognizing that migrants change altitude for various reasons over time and that targets flying several altitude bands above the rotor swept zone may still be at risk.

Appendix 2

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

Percent landcover found within 3.7 km of radar locations in New York during spring 2013.

National Landcover Class	Niagara County %	Wayne County %	Genesee County %	Jefferson County %
Barren Land	0%	0%	0%	2%
Cultivated Crops	21%	1%	50%	15%
Deciduous Forest	11%	14%	5%	8%
Developed*	3%	4%	9%	3%
Evergreen Forest	0%	1%	0%	3%
Hay/Pasture	26%	38%	28%	12%
Herbaceous	0%	0%	0%	1%
Mixed Forest	0%	3%	0%	2%
Open Water	31%	35%	0%	33%
Shrub/Scrub	0%	1%	0%	9%
Wetlands**	8%	4%	8%	12%

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

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

Appendix 3

Corrected Density per Hour by Biological Period

Estimated density of targets by altitude band during fall biological periods in Niagara County, New York (targets/1,000,000 m^3/time period).

Niagara County

Altitude Band	Dawn	Day	Dusk	Night
50	0.1	0.1	0.0	0.1
100	0.7	0.3	0.2	0.5
150	1.5	0.5	0.4	1.5
200	1.5	0.5	0.4	1.8
250	1.0	0.3	0.3	1.5
300	1.0	0.3	0.3	1.6
350	1.1	0.3	0.4	2.2
400	1.0	0.2	0.3	2.2
450	0.8	0.2	0.2	1.9
500	0.5	0.1	0.2	1.7
550	0.5	0.1	0.1	1.6
600	0.5	0.1	0.1	1.5
650	0.3	0.1	0.1	1.3
700	0.3	0.1	0.1	1.4
750	0.4	0.0	0.1	1.3
800	0.3	0.0	0.0	1.2
850	0.2	0.0	0.0	1.0
900	0.1	0.0	0.0	0.8
950	0.1	0.0	0.0	0.5
1000	0.1	0.0	0.0	0.3

Estimated density of targets by altitude band during fall biological periods in Wayne County, New York (targets/1,000,000 m^3/time period).

Wayne County

Altitude Band	Dawn	Day	Dusk	Night
50	0.3	0.1	0.1	0.1
100	3.1	1.4	1.7	1.2
150	2.4	0.9	1.2	1.0
200	1.7	0.7	0.6	1.0
250	1.0	0.4	0.4	0.6
300	1.0	0.4	0.3	0.8
350	0.9	0.3	0.4	0.9
400	0.8	0.3	0.3	1.0
450	0.6	0.2	0.2	0.8
500	0.6	0.2	0.2	0.9
550	0.5	0.2	0.1	0.8
600	0.5	0.1	0.1	0.7
650	0.4	0.1	0.1	0.6
700	0.4	0.1	0.1	0.6
750	0.2	0.1	0.1	0.6
800	0.3	0.1	0.0	0.5
850	0.2	0.1	0.0	0.5
900	0.2	0.0	0.0	0.4
950	0.2	0.0	0.0	0.3
1000	0.2	0.0	0.0	0.3

Estimated density of targets by altitude band during fall biological periods in Genesee County, New York (targets/1,000,000 m³/time period).

Genesee County

Altitude Band	Dawn	Day	Dusk	Night
50	1.3	0.6	0.3	1.4
100	4.9	1.7	1.2	4.7
150	4.2	2.0	1.7	5.9
200	3.9	1.5	1.3	5.8
250	3.9	0.7	0.5	4.9
300	3.7	0.4	0.3	4.5
350	3.6	0.3	0.2	4.0
400	3.2	0.3	0.3	3.7
450	3.1	0.2	0.3	3.5
500	2.4	0.2	0.2	3.1
550	2.2	0.1	0.2	2.6
600	1.7	0.1	0.2	2.3
650	1.5	0.1	0.2	2.0
700	1.2	0.1	0.2	1.7
750	0.9	0.1	0.2	1.5
800	0.9	0.1	0.1	1.2
850	0.7	0.0	0.1	1.0
900	0.6	0.0	0.1	0.8
950	0.5	0.0	0.0	0.7
1000	0.4	0.0	0.0	0.6

Estimated density of targets by altitude band during fall biological periods in Jefferson County, New York (targets/1,000,000 m³/time period).

Jefferson County

Altitude Band	Dawn	Day	Dusk	Night
50	0.0	0.3	0.3	0.1
100	0.5	1.2	1.5	0.5
150	3.2	1.5	1.5	2.5
200	3.9	1.1	0.3	3.8
250	3.4	0.7	0.1	3.2
300	3.5	0.5	0.1	2.9
350	3.2	0.4	0.1	3.0
400	2.9	0.3	0.1	2.5
450	2.5	0.2	0.0	2.3
500	2.6	0.2	0.0	2.0
550	2.6	0.2	0.0	1.9
600	2.1	0.2	0.0	1.7
650	1.4	0.1	0.0	1.5
700	1.0	0.1	0.0	1.3
750	0.8	0.1	0.0	1.1
800	0.7	0.1	0.0	0.9
850	0.6	0.1	0.0	0.8
900	0.4	0.1	0.0	0.6
950	0.4	0.0	0.0	0.5
1000	0.4	0.0	0.0	0.5

Appendix 4

Comparison of Static and Corrected Density Estimates

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

Altitude Band (m)	Target Count	Running Total Target Count[1]	Static Volume	Corrected Volume	Static Target Density per Hour	Corrected Target Density per Hour[2]	% Total Targets	% Static Density	% Corrected Density
50	13	13	31.3	5.6	0.0	0.1	0.2%	0.2%	0.5%
100	151	164	31.3	5.9	0.1	0.7	2.6%	2.6%	5.4%
150	341	505	31.3	6.5	0.3	1.5	5.8%	5.8%	11.2%
200	370	875	31.3	7.1	0.3	1.5	6.3%	6.3%	11.1%
250	269	1,144	31.3	7.9	0.2	1.0	4.6%	4.6%	7.2%
300	317	1,461	31.3	8.5	0.3	1.0	5.4%	5.4%	7.9%
350	374	1,835	31.3	9.5	0.3	1.1	6.4%	6.4%	8.4%
400	353	2,188	31.3	10.3	0.3	1.0	6.1%	6.1%	7.2%
450	337	2,525	31.3	11.2	0.3	0.8	5.8%	5.8%	6.4%
500	227	2,752	31.3	12.2	0.2	0.5	3.9%	3.9%	3.9%
550	238	2,990	31.3	13.3	0.2	0.5	4.1%	4.1%	3.8%
600	235	3,225	31.3	14.1	0.2	0.5	4.0%	4.0%	3.5%
650	175	3,400	31.3	15.3	0.2	0.3	3.0%	3.0%	2.4%
700	201	3,601	31.3	16.2	0.2	0.3	3.4%	3.4%	2.6%
750	238	3,839	31.3	17.2	0.2	0.4	4.1%	4.1%	2.9%
800	185	4,024	31.3	18.2	0.2	0.3	3.2%	3.2%	2.2%
850	151	4,175	31.3	19.4	0.1	0.2	2.6%	2.6%	1.6%
900	99	4,274	31.3	20.4	0.1	0.1	1.7%	1.7%	1.0%
950	76	4,350	31.3	21.4	0.1	0.1	1.3%	1.3%	0.8%
1,000	42	4,392	31.3	22.4	0.0	0.1	0.7%	0.7%	0.4%

1 Total target counts recorded up to the 2,800 m band during the dawn time period was 5,834.

2 Total density of targets per hour recorded up to the 2,800 m band during the dawn time period was 13.18.

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

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	173	173	31.3	5.6	0.0	0.1	1.2%	1.2%	0.6%
100	782	955	31.3	5.9	0.1	0.3	5.6%	5.6%	2.4%
150	1,485	2,440	31.3	6.5	0.1	0.5	10.6%	10.6%	4.1%
200	1,479	3,919	31.3	7.1	0.1	0.5	10.5%	10.5%	3.7%
250	1,114	5,033	31.3	7.9	0.1	0.3	7.9%	7.9%	2.5%
300	984	6,017	31.3	8.5	0.1	0.3	7.0%	7.0%	2.1%
350	1,088	7,105	31.3	9.5	0.1	0.3	7.7%	7.7%	2.1%
400	932	8,037	31.3	10.3	0.1	0.2	6.6%	6.6%	1.6%
450	741	8,778	31.3	11.2	0.1	0.2	5.3%	5.3%	1.2%
500	633	9,411	31.3	12.2	0.0	0.1	4.5%	4.5%	0.9%
550	518	9,929	31.3	13.3	0.0	0.1	3.7%	3.7%	0.7%
600	459	10,388	31.3	14.1	0.0	0.1	3.3%	3.3%	0.6%
650	396	10,784	31.3	15.3	0.0	0.1	2.8%	2.8%	0.5%
700	417	11,201	31.3	16.2	0.0	0.1	3.0%	3.0%	0.5%
750	335	11,536	31.3	17.2	0.0	0.0	2.4%	2.4%	0.3%
800	340	11,876	31.3	18.2	0.0	0.0	2.4%	2.4%	0.3%
850	257	12,133	31.3	19.4	0.0	0.0	1.8%	1.8%	0.2%
900	225	12,358	31.3	20.4	0.0	0.0	1.6%	1.6%	0.2%
950	140	12,498	31.3	21.4	0.0	0.0	1.0%	1.0%	0.1%
1,000	120	12,618	31.3	22.4	0.0	0.0	0.9%	0.9%	0.1%

1 Total target counts recorded up to the 2,800 m band during the day time period was 14,068.

2 Total density of targets per hour recorded up to the 2,800 m band during the day time period was 3.36.

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

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	7	7	31.3	5.6	0.0	0.0	0.6%	0.6%	1.2%
100	37	44	31.3	5.9	0.0	0.2	3.4%	3.4%	6.0%
150	71	115	31.3	6.5	0.1	0.4	6.5%	6.5%	10.6%
200	85	200	31.3	7.1	0.1	0.4	7.8%	7.8%	11.6%
250	81	281	31.3	7.9	0.1	0.3	7.4%	7.4%	9.9%
300	84	365	31.3	8.5	0.1	0.3	7.7%	7.7%	9.5%
350	105	470	31.3	9.5	0.1	0.4	9.6%	9.6%	10.7%
400	111	581	31.3	10.3	0.1	0.3	10.2%	10.2%	10.4%
450	70	651	31.3	11.2	0.1	0.2	6.4%	6.4%	6.0%
500	71	722	31.3	12.2	0.1	0.2	6.5%	6.5%	5.6%
550	44	766	31.3	13.3	0.0	0.1	4.0%	4.0%	3.2%
600	30	796	31.3	14.1	0.0	0.1	2.8%	2.8%	2.0%
650	24	820	31.3	15.3	0.0	0.1	2.2%	2.2%	1.5%
700	41	861	31.3	16.2	0.0	0.1	3.8%	3.8%	2.4%
750	31	892	31.3	17.2	0.0	0.1	2.8%	2.8%	1.7%
800	24	916	31.3	18.2	0.0	0.0	2.2%	2.2%	1.3%
850	12	928	31.3	19.4	0.0	0.0	1.1%	1.1%	0.6%
900	15	943	31.3	20.4	0.0	0.0	1.4%	1.4%	0.7%
950	11	954	31.3	21.4	0.0	0.0	1.0%	1.0%	0.5%
1,000	7	961	31.3	22.4	0.0	0.0	0.6%	0.6%	0.0%

1 Total target counts recorded up to the 2,800 m band during the dusk time period was 1,089.

2 Total density of targets per hour recorded up to the 2,800 m band during the dusk time period was 3.35.

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

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	154	154	31.3	5.6	0.0	0.1	0.1%	0.1%	0.2%
100	1,099	1,253	31.3	5.9	0.1	0.5	0.6%	0.6%	1.6%
150	3,216	4,469	31.3	6.5	0.3	1.5	1.6%	1.6%	4.4%
200	4,222	8,691	31.3	7.1	0.4	1.8	2.2%	2.2%	5.2%
250	4,072	12,763	31.3	7.9	0.4	1.5	2.1%	2.1%	4.5%
300	4,739	17,502	31.3	8.5	0.4	1.6	2.4%	2.4%	4.9%
350	7,002	24,504	31.3	9.5	0.7	2.2	3.6%	3.6%	6.5%
400	7,682	32,186	31.3	10.3	0.7	2.2	3.9%	3.9%	6.5%
450	7,072	39,258	31.3	11.2	0.7	1.9	3.6%	3.6%	5.5%
500	6,977	46,235	31.3	12.2	0.7	1.7	3.6%	3.6%	5.0%
550	7,268	53,503	31.3	13.3	0.7	1.6	3.7%	3.7%	4.8%
600	7,121	60,624	31.3	14.1	0.7	1.5	3.7%	3.7%	4.4%
650	6,827	67,451	31.3	15.3	0.6	1.3	3.5%	3.5%	3.9%
700	7,596	75,047	31.3	16.2	0.7	1.4	3.9%	3.9%	4.1%
750	7,837	82,884	31.3	17.2	0.7	1.3	4.0%	4.0%	4.0%
800	7,169	90,053	31.3	18.2	0.7	1.2	3.7%	3.7%	3.5%
850	6,336	96,389	31.3	19.4	0.6	1.0	3.2%	3.2%	2.9%
900	5,490	101,879	31.3	20.4	0.5	0.8	2.8%	2.8%	2.4%
950	3,773	105,652	31.3	21.4	0.4	0.5	1.9%	1.9%	1.6%
1,000	2,569	108,221	31.3	22.4	0.2	0.3	1.3%	1.3%	1.0%

1 Total target counts recorded up to the 2,800 m band during the night time period was 195,063.

2 Total density of targets recorded up to the 2,800 m band during the night time period was 33.53.

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

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	57	57	31.3	5.6	0.0	0.3	0.8%	0.8%	1.5%
100	732	789	31.3	5.9	0.6	3.1	10.2%	10.2%	18.8%
150	623	1,412	31.3	6.5	0.5	2.4	8.7%	8.7%	14.7%
200	482	1,894	31.3	7.1	0.4	1.7	6.7%	6.7%	10.3%
250	313	2,207	31.3	7.9	0.3	1.0	4.4%	4.4%	6.0%
300	343	2,550	31.3	8.5	0.3	1.0	4.8%	4.8%	6.1%
350	319	2,869	31.3	9.5	0.3	0.9	4.4%	4.4%	5.1%
400	315	3,184	31.3	10.3	0.3	0.8	4.4%	4.4%	4.6%
450	270	3,454	31.3	11.2	0.2	0.6	3.8%	3.8%	3.7%
500	305	3,759	31.3	12.2	0.2	0.6	4.3%	4.3%	3.8%
550	266	4,025	31.3	13.3	0.2	0.5	3.7%	3.7%	3.0%
600	261	4,286	31.3	14.1	0.2	0.5	3.6%	3.6%	2.8%
650	245	4,531	31.3	15.3	0.2	0.4	3.4%	3.4%	2.4%
700	237	4,768	31.3	16.2	0.2	0.4	3.3%	3.3%	2.2%
750	168	4,936	31.3	17.2	0.1	0.2	2.3%	2.3%	1.5%
800	192	5,128	31.3	18.2	0.2	0.3	2.7%	2.7%	1.6%
850	165	5,293	31.3	19.4	0.1	0.2	2.3%	2.3%	1.3%
900	167	5,460	31.3	20.4	0.1	0.2	2.3%	2.3%	1.2%
950	140	5,600	31.3	21.4	0.1	0.2	2.0%	2.0%	1.0%
1,000	143	5,743	31.3	22.4	0.1	0.2	2.0%	2.0%	1.0%

1 Total target counts recorded up to the 2,800 m band during the dawn time period was 7,173.

2 Total density of targets per hour recorded up to the 2,800 m band during the dawn time period was 16.65.

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

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	285	285	31.3	5.6	0.0	0.1	1.1%	1.1%	0.7%
100	3,535	3,820	31.3	5.9	0.3	1.4	14.1%	14.1%	8.2%
150	2,465	6,285	31.3	6.5	0.2	0.9	9.8%	9.8%	5.2%
200	2,147	8,432	31.3	7.1	0.2	0.7	8.6%	8.6%	4.1%
250	1,345	9,777	31.3	7.9	0.1	0.4	5.4%	5.4%	2.3%
300	1,319	11,096	31.3	8.5	0.1	0.4	5.3%	5.3%	2.1%
350	1,391	12,487	31.3	9.5	0.1	0.3	5.6%	5.6%	2.0%
400	1,420	13,907	31.3	10.3	0.1	0.3	5.7%	5.7%	1.9%
450	1,078	14,985	31.3	11.2	0.1	0.2	4.3%	4.3%	1.3%
500	1,075	16,060	31.3	12.2	0.1	0.2	4.3%	4.3%	1.2%
550	1,032	17,092	31.3	13.3	0.1	0.2	4.1%	4.1%	1.1%
600	882	17,974	31.3	14.1	0.1	0.1	3.5%	3.5%	0.9%
650	779	18,753	31.3	15.3	0.1	0.1	3.1%	3.1%	0.7%
700	772	19,525	31.3	16.2	0.1	0.1	3.1%	3.1%	0.7%
750	606	20,131	31.3	17.2	0.0	0.1	2.4%	2.4%	0.5%
800	614	20,745	31.3	18.2	0.0	0.1	2.5%	2.5%	0.5%
850	517	21,262	31.3	19.4	0.0	0.1	2.1%	2.1%	0.4%
900	447	21,709	31.3	20.4	0.0	0.0	1.8%	1.8%	0.3%
950	388	22,097	31.3	21.4	0.0	0.0	1.5%	1.5%	0.2%
1,000	324	22,421	31.3	22.4	0.0	0.0	1.3%	1.3%	0.2%

1 Total target counts recorded up to the 2,800 m band during the day time period was 25,040.

2 Total density of targets per hour recorded up to the 2,800 m band during the day time period was 5.93.

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

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	21	21	31.3	5.6	0.0	0.1	1.1%	1.1%	1.7%
100	355	376	31.3	5.9	0.3	1.7	18.4%	18.4%	27.1%
150	271	647	31.3	6.5	0.2	1.2	14.1%	14.1%	19.0%
200	162	809	31.3	7.1	0.1	0.6	8.4%	8.4%	10.4%
250	104	913	31.3	7.9	0.1	0.4	5.4%	5.4%	6.0%
300	85	998	31.3	8.5	0.1	0.3	4.4%	4.4%	4.5%
350	138	1,136	31.3	9.5	0.1	0.4	7.2%	7.2%	6.6%
400	120	1,256	31.3	10.3	0.1	0.3	6.2%	6.2%	5.3%
450	79	1,335	31.3	11.2	0.1	0.2	4.1%	4.1%	3.2%
500	98	1,433	31.3	12.2	0.1	0.2	5.1%	5.1%	3.6%
550	70	1,503	31.3	13.3	0.1	0.1	3.6%	3.6%	2.4%
600	52	1,555	31.3	14.1	0.0	0.1	2.7%	2.7%	1.7%
650	65	1,620	31.3	15.3	0.1	0.1	3.4%	3.4%	1.9%
700	51	1,671	31.3	16.2	0.0	0.1	2.6%	2.6%	1.4%
750	50	1,721	31.3	17.2	0.0	0.1	2.6%	2.6%	1.3%
800	31	1,752	31.3	18.2	0.0	0.0	1.6%	1.6%	0.8%
850	19	1,771	31.3	19.4	0.0	0.0	1.0%	1.0%	0.4%
900	16	1,787	31.3	20.4	0.0	0.0	0.8%	0.8%	0.4%
950	23	1,810	31.3	21.4	0.0	0.0	1.2%	1.2%	0.5%
1,000	21	1,831	31.3	22.4	0.0	0.0	1.1%	1.1%	0.0%

1 Total target counts recorded up to the 2,800 m band during the dusk time period was 1,928.

2 Total density of targets per hour recorded up to the 2,800 m band during the dusk time period was 6.23.

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

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	339	339	31.3	5.6	0.0	0.1	0.1%	0.1%	0.4%
100	6,415	6,754	31.3	5.9	0.2	1.2	2.6%	2.6%	7.1%
150	5,874	12,628	31.3	6.5	0.2	1.0	2.4%	2.4%	6.0%
200	6,399	19,027	31.3	7.1	0.2	1.0	2.6%	2.6%	5.9%
250	4,517	23,544	31.3	7.9	0.2	0.6	1.8%	1.8%	3.8%
300	5,733	29,277	31.3	8.5	0.2	0.8	2.3%	2.3%	4.4%
350	7,868	37,145	31.3	9.5	0.3	0.9	3.2%	3.2%	5.5%
400	8,886	46,031	31.3	10.3	0.3	1.0	3.6%	3.6%	5.7%
450	8,500	54,531	31.3	11.2	0.3	0.8	3.5%	3.5%	5.0%
500	9,314	63,845	31.3	12.2	0.3	0.9	3.8%	3.8%	5.0%
550	9,317	73,162	31.3	13.3	0.3	0.8	3.8%	3.8%	4.6%
600	8,587	81,749	31.3	14.1	0.3	0.7	3.5%	3.5%	4.0%
650	8,794	90,543	31.3	15.3	0.3	0.6	3.6%	3.6%	3.8%
700	8,794	99,337	31.3	16.2	0.3	0.6	3.6%	3.6%	3.6%
750	8,465	107,802	31.3	17.2	0.3	0.6	3.5%	3.5%	3.2%
800	8,060	115,862	31.3	18.2	0.3	0.5	3.3%	3.3%	2.9%
850	7,835	123,697	31.3	19.4	0.3	0.5	3.2%	3.2%	2.7%
900	7,139	130,836	31.3	20.4	0.3	0.4	2.9%	2.9%	2.3%
950	6,650	137,486	31.3	21.4	0.2	0.3	2.7%	2.7%	2.0%
1,000	5,881	143,367	31.3	22.4	0.2	0.3	2.4%	2.4%	1.7%

1 Total target counts recorded up to the 2,800 m band during the night time period was 244,614.
2 Total density of targets recorded up to the 2,800 m band during the night time period was 16.97.

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

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	199	199	31.3	5.6	0.2	1.3	1.3%	1.3%	2.7%
100	769	968	31.3	5.9	0.9	4.9	5.0%	5.0%	10.0%
150	714	1,682	31.3	6.5	0.9	4.2	4.7%	4.7%	8.5%
200	741	2,423	31.3	7.1	0.9	3.9	4.8%	4.8%	8.1%
250	825	3,248	31.3	7.9	1.0	3.9	5.4%	5.4%	8.1%
300	843	4,091	31.3	8.5	1.0	3.7	5.5%	5.5%	7.7%
350	907	4,998	31.3	9.5	1.1	3.6	5.9%	5.9%	7.4%
400	884	5,882	31.3	10.3	1.1	3.2	5.8%	5.8%	6.6%
450	924	6,806	31.3	11.2	1.1	3.1	6.0%	6.0%	6.4%
500	773	7,579	31.3	12.2	0.9	2.4	5.0%	5.0%	4.9%
550	767	8,346	31.3	13.3	0.9	2.2	5.0%	5.0%	4.5%
600	656	9,002	31.3	14.1	0.8	1.7	4.3%	4.3%	3.6%
650	606	9,608	31.3	15.3	0.7	1.5	4.0%	4.0%	3.1%
700	527	10,135	31.3	16.2	0.6	1.2	3.4%	3.4%	2.5%
750	432	10,567	31.3	17.2	0.5	0.9	2.8%	2.8%	1.9%
800	434	11,001	31.3	18.2	0.5	0.9	2.8%	2.8%	1.8%
850	362	11,363	31.3	19.4	0.4	0.7	2.4%	2.4%	1.4%
900	346	11,709	31.3	20.4	0.4	0.6	2.3%	2.3%	1.3%
950	309	12,018	31.3	21.4	0.4	0.5	2.0%	2.0%	1.1%
1,000	248	12,266	31.3	22.4	0.3	0.4	1.6%	1.6%	0.9%

1 Total target counts recorded up to the 2,800 m band during the dawn time period was 15,340.

2 Total density of targets per hour recorded up to the 2,800 m band during the dawn time period was 48.60.

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

Altitude Band (m)	Target Count	Running Total Target Count[1]	Static Volume	Corrected Volume	Static Target Density per Hour	Corrected Target Density per Hour[2]	% Total Targets	% Static Density	% Corrected Density
50	1,178	1,178	31.3	5.6	0.1	0.6	4.2%	4.2%	1.2%
100	3,654	4,832	31.3	5.9	0.3	1.7	13.2%	13.2%	3.4%
150	4,684	9,516	31.3	6.5	0.4	2.0	16.9%	16.9%	4.0%
200	3,826	13,342	31.3	7.1	0.3	1.5	13.8%	13.8%	3.0%
250	2,097	15,439	31.3	7.9	0.2	0.7	7.6%	7.6%	1.5%
300	1,358	16,797	31.3	8.5	0.1	0.4	4.9%	4.9%	0.9%
350	1,128	17,925	31.3	9.5	0.1	0.3	4.1%	4.1%	0.7%
400	1,035	18,960	31.3	10.3	0.1	0.3	3.7%	3.7%	0.6%
450	873	19,833	31.3	11.2	0.1	0.2	3.1%	3.1%	0.4%
500	786	20,619	31.3	12.2	0.1	0.2	2.8%	2.8%	0.4%
550	720	21,339	31.3	13.3	0.1	0.1	2.6%	2.6%	0.3%
600	686	22,025	31.3	14.1	0.1	0.1	2.5%	2.5%	0.3%
650	583	22,608	31.3	15.3	0.1	0.1	2.1%	2.1%	0.2%
700	492	23,100	31.3	16.2	0.0	0.1	1.8%	1.8%	0.2%
750	445	23,545	31.3	17.2	0.0	0.1	1.6%	1.6%	0.1%
800	429	23,974	31.3	18.2	0.0	0.1	1.5%	1.5%	0.1%
850	331	24,305	31.3	19.4	0.0	0.0	1.2%	1.2%	0.1%
900	257	24,562	31.3	20.4	0.0	0.0	0.9%	0.9%	0.1%
950	235	24,797	31.3	21.4	0.0	0.0	0.8%	0.8%	0.1%
1,000	194	24,991	31.3	22.4	0.0	0.0	0.7%	0.7%	0.0%

1 Total target counts recorded up to the 2,800 m band during the day time period was 27,745.

2 Total density of targets per hour recorded up to the 2,800 m band during the day time period was 8.73.

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

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	45	45	31.3	5.6	0.1	0.3	2.4%	2.4%	4.0%
100	185	230	31.3	5.9	0.2	1.2	10.0%	10.0%	15.7%
150	276	506	31.3	6.5	0.4	1.7	14.9%	14.9%	21.5%
200	233	739	31.3	7.1	0.3	1.3	12.6%	12.6%	16.5%
250	93	832	31.3	7.9	0.1	0.5	5.0%	5.0%	5.9%
300	68	900	31.3	8.5	0.1	0.3	3.7%	3.7%	4.0%
350	50	950	31.3	9.5	0.1	0.2	2.7%	2.7%	2.7%
400	76	1,026	31.3	10.3	0.1	0.3	4.1%	4.1%	3.7%
450	80	1,106	31.3	11.2	0.1	0.3	4.3%	4.3%	3.6%
500	68	1,174	31.3	12.2	0.1	0.2	3.7%	3.7%	2.8%
550	77	1,251	31.3	13.3	0.1	0.2	4.2%	4.2%	2.9%
600	84	1,335	31.3	14.1	0.1	0.2	4.5%	4.5%	3.0%
650	75	1,410	31.3	15.3	0.1	0.2	4.0%	4.0%	2.5%
700	93	1,503	31.3	16.2	0.1	0.2	5.0%	5.0%	2.9%
750	73	1,576	31.3	17.2	0.1	0.2	3.9%	3.9%	2.1%
800	57	1,633	31.3	18.2	0.1	0.1	3.1%	3.1%	1.6%
850	68	1,701	31.3	19.4	0.1	0.1	3.7%	3.7%	1.8%
900	31	1,732	31.3	20.4	0.0	0.1	1.7%	1.7%	0.8%
950	21	1,753	31.3	21.4	0.0	0.0	1.1%	1.1%	0.5%
1,000	14	1,767	31.3	22.4	0.0	0.0	0.8%	0.8%	0.0%

1 Total target counts recorded up to the 2,800 m band during the dusk time period was 1,855.

2 Total density of targets per hour recorded up to the 2,800 m band during the dusk time period was 7.93.

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

Altitude Band (m)	Target Count	Running Total Target Count[1]	Static Volume	Corrected Volume	Static Target Density per Hour	Corrected Target Density per Hour[2]	% Total Targets	% Static Density	% Corrected Density
50	1,696	1,696	31.3	5.6	0.2	1.4	0.9%	0.9%	2.1%
100	6,218	7,914	31.3	5.9	0.9	4.7	3.4%	3.4%	7.4%
150	8,487	16,401	31.3	6.5	1.2	5.9	4.6%	4.6%	9.3%
200	9,142	25,543	31.3	7.1	1.3	5.8	4.9%	4.9%	9.2%
250	8,644	34,187	31.3	7.9	1.2	4.9	4.7%	4.7%	7.8%
300	8,571	42,758	31.3	8.5	1.2	4.5	4.6%	4.6%	7.2%
350	8,360	51,118	31.3	9.5	1.2	4.0	4.5%	4.5%	6.3%
400	8,540	59,658	31.3	10.3	1.2	3.7	4.6%	4.6%	5.9%
450	8,662	68,320	31.3	11.2	1.2	3.5	4.7%	4.7%	5.5%
500	8,355	76,675	31.3	12.2	1.2	3.1	4.5%	4.5%	4.9%
550	7,607	84,282	31.3	13.3	1.1	2.6	4.1%	4.1%	4.1%
600	7,128	91,410	31.3	14.1	1.0	2.3	3.9%	3.9%	3.6%
650	6,663	98,073	31.3	15.3	1.0	2.0	3.6%	3.6%	3.1%
700	6,139	104,212	31.3	16.2	0.9	1.7	3.3%	3.3%	2.7%
750	5,580	109,792	31.3	17.2	0.8	1.5	3.0%	3.0%	2.3%
800	5,014	114,806	31.3	18.2	0.7	1.2	2.7%	2.7%	2.0%
850	4,302	119,108	31.3	19.4	0.6	1.0	2.3%	2.3%	1.6%
900	3,717	122,825	31.3	20.4	0.5	0.8	2.0%	2.0%	1.3%
950	3,328	126,153	31.3	21.4	0.5	0.7	1.8%	1.8%	1.1%
1,000	2,959	129,112	31.3	22.4	0.4	0.6	1.6%	1.6%	0.9%

1 Total target counts recorded up to the 2,800 m band during the night time period was 184,728.

2 Total density of targets recorded up to the 2,800 m band during the night time period was 63.31.

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

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	7	7	31.3	5.6	0.0	0.0	0.1%	0.1%	0.1%
100	76	83	31.3	5.9	0.1	0.5	0.6%	0.6%	1.2%
150	572	655	31.3	6.5	0.7	3.2	4.2%	4.2%	8.1%
200	775	1,430	31.3	7.1	0.9	3.9	5.7%	5.7%	10.0%
250	757	2,187	31.3	7.9	0.9	3.4	5.6%	5.6%	8.8%
300	831	3,018	31.3	8.5	1.0	3.5	6.1%	6.1%	9.0%
350	836	3,854	31.3	9.5	1.0	3.2	6.1%	6.1%	8.1%
400	829	4,683	31.3	10.3	1.0	2.9	6.1%	6.1%	7.4%
450	784	5,467	31.3	11.2	0.9	2.5	5.8%	5.8%	6.4%
500	895	6,362	31.3	12.2	1.0	2.6	6.6%	6.6%	6.7%
550	973	7,335	31.3	13.3	1.1	2.6	7.1%	7.1%	6.7%
600	822	8,157	31.3	14.1	0.9	2.1	6.0%	6.0%	5.3%
650	602	8,759	31.3	15.3	0.7	1.4	4.4%	4.4%	3.6%
700	448	9,207	31.3	16.2	0.5	1.0	3.3%	3.3%	2.5%
750	370	9,577	31.3	17.2	0.4	0.8	2.7%	2.7%	2.0%
800	338	9,915	31.3	18.2	0.4	0.7	2.5%	2.5%	1.7%
850	299	10,214	31.3	19.4	0.3	0.6	2.2%	2.2%	1.4%
900	254	10,468	31.3	20.4	0.3	0.4	1.9%	1.9%	1.1%
950	244	10,712	31.3	21.4	0.3	0.4	1.8%	1.8%	1.0%
1,000	259	10,971	31.3	22.4	0.3	0.4	1.9%	1.9%	1.1%

1 Total target counts recorded up to the 2,800 m band during the dawn time period was 13,622.

2 Total density of targets per hour recorded up to the 2,800 m band during the dawn time period was 39.11.

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

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	537	537	31.3	5.6	0.0	0.3	1.8%	1.8%	0.6%
100	2,683	3,220	31.3	5.9	0.2	1.2	9.0%	9.0%	3.0%
150	3,677	6,897	31.3	6.5	0.3	1.5	12.3%	12.3%	3.8%
200	3,083	9,980	31.3	7.1	0.3	1.1	10.3%	10.3%	2.9%
250	2,108	12,088	31.3	7.9	0.2	0.7	7.1%	7.1%	1.8%
300	1,530	13,618	31.3	8.5	0.1	0.5	5.1%	5.1%	1.2%
350	1,478	15,096	31.3	9.5	0.1	0.4	4.9%	4.9%	1.1%
400	1,111	16,207	31.3	10.3	0.1	0.3	3.7%	3.7%	0.7%
450	1,060	17,267	31.3	11.2	0.1	0.2	3.5%	3.5%	0.6%
500	949	18,216	31.3	12.2	0.1	0.2	3.2%	3.2%	0.5%
550	852	19,068	31.3	13.3	0.1	0.2	2.9%	2.9%	0.4%
600	820	19,888	31.3	14.1	0.1	0.2	2.7%	2.7%	0.4%
650	782	20,670	31.3	15.3	0.1	0.1	2.6%	2.6%	0.3%
700	773	21,443	31.3	16.2	0.1	0.1	2.6%	2.6%	0.3%
750	677	22,120	31.3	17.2	0.1	0.1	2.3%	2.3%	0.3%
800	666	22,786	31.3	18.2	0.1	0.1	2.2%	2.2%	0.2%
850	587	23,373	31.3	19.4	0.0	0.1	2.0%	2.0%	0.2%
900	465	23,838	31.3	20.4	0.0	0.1	1.6%	1.6%	0.2%
950	387	24,225	31.3	21.4	0.0	0.0	1.3%	1.3%	0.1%
1,000	386	24,611	31.3	22.4	0.0	0.0	1.3%	1.3%	0.1%

1 Total target counts recorded up to the 2,800 m band during the dawn time period was 29,870.

2 Total density of targets per hour recorded up to the 2,800 m band during the dawn time period was 7.84.

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

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	50	50	31.3	5.6	0.1	0.3	6.0%	6.0%	7.8%
100	245	295	31.3	5.9	0.3	1.5	29.2%	29.2%	35.9%
150	263	558	31.3	6.5	0.3	1.5	31.4%	31.4%	35.5%
200	65	623	31.3	7.1	0.1	0.3	7.8%	7.8%	8.0%
250	13	636	31.3	7.9	0.0	0.1	1.6%	1.6%	1.4%
300	15	651	31.3	8.5	0.0	0.1	1.8%	1.8%	1.5%
350	20	671	31.3	9.5	0.0	0.1	2.4%	2.4%	1.8%
400	18	689	31.3	10.3	0.0	0.1	2.1%	2.1%	1.5%
450	8	697	31.3	11.2	0.0	0.0	1.0%	1.0%	0.6%
500	10	707	31.3	12.2	0.0	0.0	1.2%	1.2%	0.7%
550	7	714	31.3	13.3	0.0	0.0	0.8%	0.8%	0.5%
600	7	721	31.3	14.1	0.0	0.0	0.8%	0.8%	0.4%
650	18	739	31.3	15.3	0.0	0.0	2.1%	2.1%	1.0%
700	12	751	31.3	16.2	0.0	0.0	1.4%	1.4%	0.6%
750	5	756	31.3	17.2	0.0	0.0	0.6%	0.6%	0.3%
800	4	760	31.3	18.2	0.0	0.0	0.5%	0.5%	0.2%
850	3	763	31.3	19.4	0.0	0.0	0.4%	0.4%	0.1%
900	5	768	31.3	20.4	0.0	0.0	0.6%	0.6%	0.2%
950	3	771	31.3	21.4	0.0	0.0	0.4%	0.4%	0.1%
1,000	4	775	31.3	22.4	0.0	0.0	0.5%	0.5%	0.0%

1 Total target counts recorded up to the 2,800 m band during the dawn time period was 838.

2 Total density of targets per hour recorded up to the 2,800 m band during the dawn time period was 4.15.

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

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	66	66	31.3	5.6	0.0	0.1	0.1%	0.1%	0.1%
100	640	706	31.3	5.9	0.1	0.5	0.5%	0.5%	1.3%
150	3,532	4,238	31.3	6.5	0.5	2.5	2.9%	2.9%	6.4%
200	5,917	10,155	31.3	7.1	0.9	3.8	4.9%	4.9%	9.8%
250	5,634	15,789	31.3	7.9	0.8	3.2	4.7%	4.7%	8.4%
300	5,427	21,216	31.3	8.5	0.8	2.9	4.5%	4.5%	7.5%
350	6,249	27,465	31.3	9.5	0.9	3.0	5.2%	5.2%	7.8%
400	5,616	33,081	31.3	10.3	0.8	2.5	4.7%	4.7%	6.4%
450	5,604	38,685	31.3	11.2	0.8	2.3	4.7%	4.7%	5.9%
500	5,459	44,144	31.3	12.2	0.8	2.0	4.5%	4.5%	5.3%
550	5,589	49,733	31.3	13.3	0.8	1.9	4.6%	4.6%	4.9%
600	5,409	55,142	31.3	14.1	0.8	1.7	4.5%	4.5%	4.5%
650	5,025	60,167	31.3	15.3	0.7	1.5	4.2%	4.2%	3.9%
700	4,555	64,722	31.3	16.2	0.7	1.3	3.8%	3.8%	3.3%
750	4,006	68,728	31.3	17.2	0.6	1.1	3.3%	3.3%	2.7%
800	3,659	72,387	31.3	18.2	0.5	0.9	3.0%	3.0%	2.4%
850	3,239	75,626	31.3	19.4	0.5	0.8	2.7%	2.7%	2.0%
900	2,829	78,455	31.3	20.4	0.4	0.6	2.4%	2.4%	1.6%
950	2,553	81,008	31.3	21.4	0.4	0.5	2.1%	2.1%	1.4%
1,000	2,294	83,302	31.3	22.4	0.3	0.5	1.9%	1.9%	1.2%

1 Total target counts recorded up to the 2,800 m band during the dawn time period was 120,250.

2 Total density of targets per hour recorded up to the 2,800 m band during the dawn time period was 38.69.

Spring 2013