Great Lakes Avian Radar Technical Report

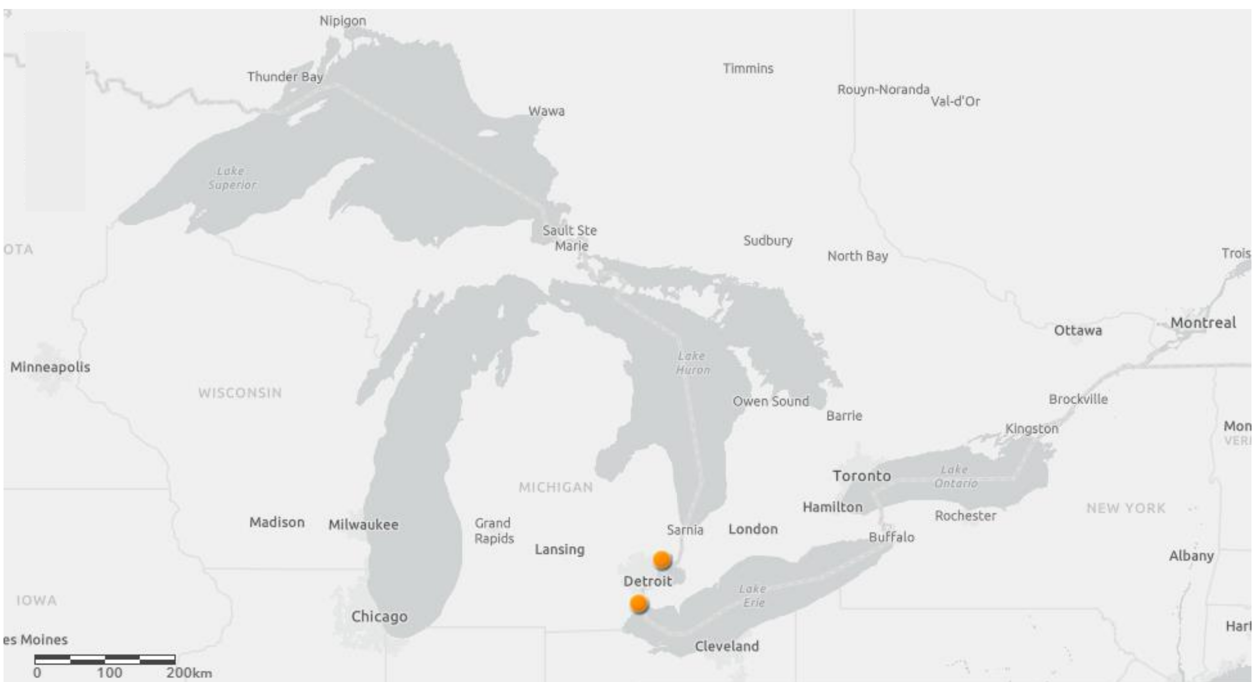
Lake Erie Lakeshore:

Macomb and Wayne County, MI

Fall 2018

U.S. Fish and Wildlife Service, Region 3

Funding Provided by Great Lakes Restoration Initiative



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INTRODUCTION

The Great Lakes support one of the largest bodies of freshwater on the planet and collectively represent a surface area of nearly 245,000 km^2 with over 17,500 km of shoreline. Global wind patterns help to move millions of migrating birds and bats through the Great Lakes region (Rich 2004, Liechti 2006, France et al. 2012) and lake lakeshores feature widely recognized Important Bird Areas (Audubon 2013). Migrants passing through the region concentrate near lakeshores (Ewert et al. 2011, Ewert et al. 2012, Peterson and Niemi 2011, Buler and Dawson 2012, France et al. 2012), which provide important stopover habitats – *en route* areas used temporarily for refueling, rest, and protection. These lakeshores offer increased foraging opportunities relative to inland areas (Smith et al. 2004, 2007; Bonter et al. 2007, 2009) and may be used as a visual cue for navigation or for refuge prior to or after crossing open water (Buler and Moore 2011).

Given their location and size, the Great Lakes likely represent a geographic obstacle that migrants choose to cross, or not, based on environmental and physiological conditions at the time of encounter (Faaborg et al. 2010, Schmaljohann et al. 2011). For migrants that rely on powered flight it is more efficient to make several short flights than a long flight due to the cost of carrying high fuel loads (Alerstam 1990). This may cause a migrant to avoid crossing a large body of water even though they have the physiological ability to do so (Alerstam 1990, 2001, Ruth 2007). The decision to cross likely represents a trade-off between minimizing costs (e.g., energy and time) and exposure to risk factors (e.g., predation and fatigue) that are associated with migration (McGuire et al. 2012a). In this trade-off, lakeshores offer refuge when conditions do not favor flights over water.

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

Migrants concentrated along lakeshores 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 lakeshores (Wiedner et al. 1992). These flights typically occur within 2 hours of sunrise and are thought to represent reorientation along a geographic obstacle or movements among stopover habitats (Able 1977, Moore et al. 1990, Wiedner et al. 1992). Flights of this nature often occur above tree line (Bingman 1980) but lower than heights associated with nocturnal migration (Harmata et al. 2000, Mabee and Cooper 2004, Newton 2008). Migrants have also been observed initiating nightly exploratory flights at stopover sites (Schmaljohann et al. 2011). These flights are thought to represent normal activity of migrants as they calibrate their internal compass and test wind speed and direction aloft. In addition to these activities while in stopover, migration flights follow north-south oriented lakeshores *en route* to their destination (Buler and Dawson 2012) while east-west oriented lakeshores may be used to circumnavigate open water or find narrow points for crossing (Alerstam 2001, Diehl et al. 2003, France et al. 2012). Cumulatively, these types of activities define a use area near lake shores that include a variety of movements and altitudes for landscape level, exploratory, and migratory flights. These movements in proximity to lake shores may increase vulnerability to collision risk with a variety of structures, including low-rise buildings which pose collision risk during the day time (Gelb and Delacretaz 2009), and tall structures such as high-rise buildings, communication towers or wind turbines which pose collision risk during nocturnal migration (Longcore et al. 2013).

Migrant populations may experience the greatest mortality pressure during migration (Newton 2006, 2007, Sillett and Holmes 2002, Diehl et al. 2014) and the negative ramifications of compromised stopover habitat to migratory populations are becoming increasingly clear (Sillett and Holmes 2002, Mehlman et al. 2005, Faaborg et al. 2010). Shoreline habitats along the Great Lakes are subject to pressures from urbanization, energy development, land conversion, and environmental contamination that may limit habitat availability and/or reduce habitat quality (France et al. 2012).

We established this project to identify activity patterns, timing, and magnitude of migration along Great Lakes lakeshores to understand and help meet the needs of wildlife conservation. Documenting bird and bat migration is challenging because bats and many bird species migrate at night. In addition, nocturnal movements occur sporadically over the course of a season. To study nocturnal migration we used two avian radar units that operated 24 hours per day and simultaneously scanned horizontal and vertical planes.

METHODS

Study Area

During the fall 2018 season, we deployed radar units at two sites along Lake Erie. One unit was located at the Selfridge Air National Guard Base (hereafter SANG), Macomb Co., MI, on the shore of St. Clair (Table 1, Fig. 1). The second unit was located at the Lake Erie Metropark Detroit (hereafter DETS), Wayne Co., MI on the western shore of Lake Erie (Table 1, Fig. 1). Land cover types within a 3.7-km radius of the radar are presented (Fig. 1).

Equipment

We used two model SS200DE MERLIN Avian Radar Systems (DeTect Inc., Panama City, FL) to document migration movements, for more details see (Wells et al. 2018). These systems were selected because they are self-contained mobile units specifically designed to detect, track, and count bird and bat targets. Each system employed two marine radars that operated simultaneously, one that scanned the horizontal plane (horizontal scanning radar, HSR) while the other scanned vertically (vertical scanning radar, VSR; Fig. 2). Additionally, each unit contained four computers for real-time automated data processing and a SQL server for processed data storage and review. The units were configured with a wireless router to allow remote access to the computers and automated status updates.

Table 1. Site names and study locations for two marine radar units deployed during fall 2018 in Michigan (MI).

Site	Nearby Town	Latitude	Longitude
SANG	Mount Clemens, MI	-82.8196	42.6166
DETS	Detroit, MI	-83.2030	42.0689

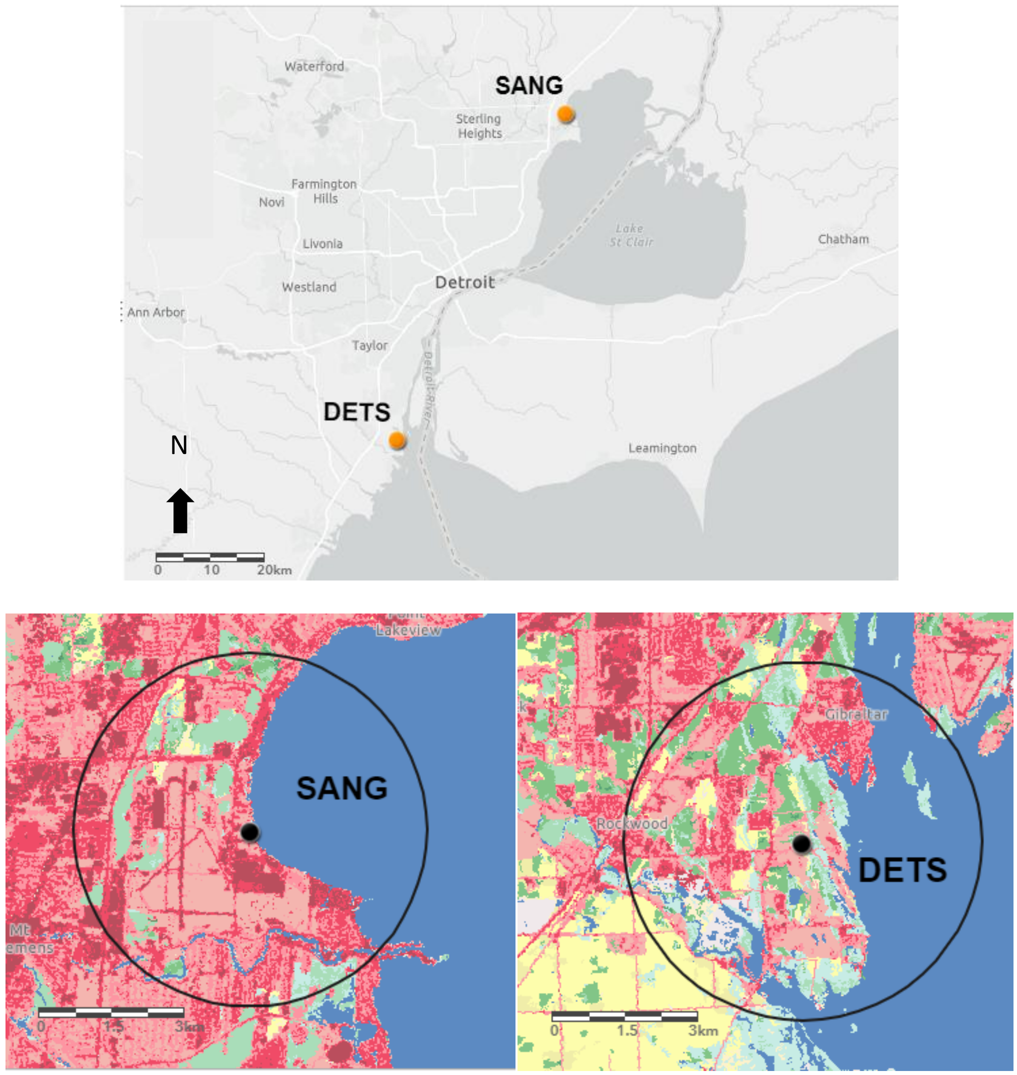

Figure 1. Radar System locations in Macomb (SANG) and Wayne (DETS) Counties, MI. Land cover is indicated with color coding; light pink=developed open space, dark pink=high intensity development; green= deciduous forest, light green=woody wetlands, blue=open water, light blue=emergent herbaceous wetlands, yellow=cultivated crops (Homer et al. 2012). The black circle indicates 3.7 km radius around each radar location.

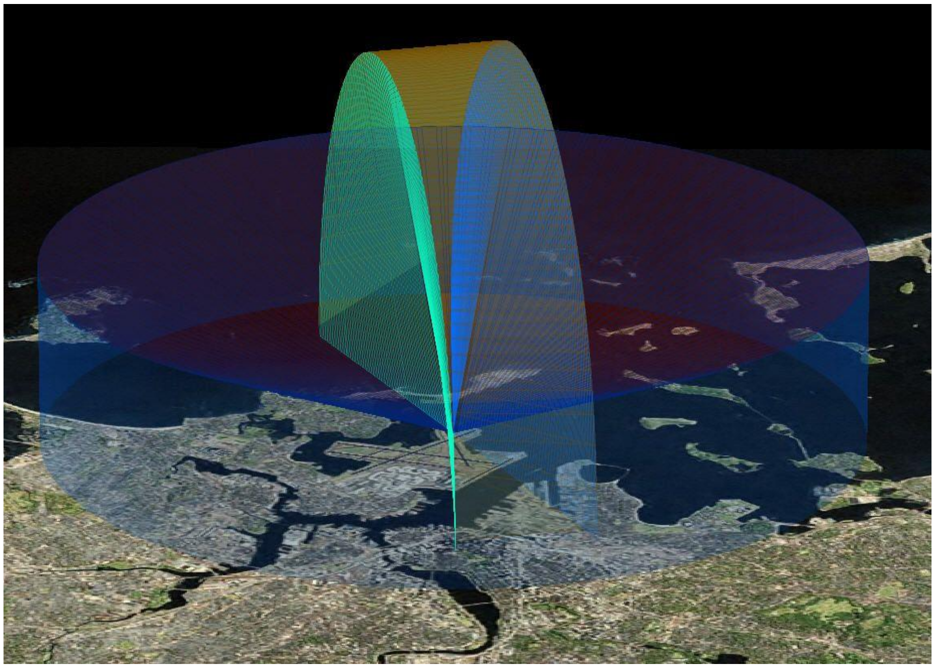

Figure 2. Computer representation of the potential survey volume scanned by horizontal (blue) and vertical (green) radars used by the U.S. Fish and Wildlife Service during fall 2018. Graphic provided by DeTect, Inc.

<u>Radar Set Up and Data Collection</u>
Radar systems were deployed during the first week of August at their respective sites. Each radar system was maintained into the second week of November to capture the anticipated end dates of the migration season. Establishing the radar system at the selected site involved micro-site selection, orienting the VSR, and making adjustments to ensure adequate information was captured and interference from the surrounding landscape was minimized. We anticipated a primarily northbound direction of migration during spring and oriented the VSR to an angle that was slightly off perpendicular to anticipated direction of traffic. This orientation was a compromise between a perpendicular angle that would intercept the greatest number of targets (birds or bats) and a parallel angle that would maximize the amount of travel time within the vertical radar beam.

To improve data collection, clutter maps were generated using 60-scan composite images (Figs. 3 & 4) at time periods with low biological activity. These maps identify areas with static returns (areas that are white). These objects reduced our ability to detect targets in certain regions of the sample volume, and as a result those regions were assigned a reflectivity threshold that prevented the static returns from being included in the data.

Following this initial set up, the MERLIN software from DeTect Inc. was calibrated to site conditions. The MERLIN software provides real-time processing of raw radar data to locate and track targets while excluding non-targets and precipitation. However, parameters used by the tracking software require adjustments to account for site-specific conditions. We established these settings to minimizing inclusion of non-targets while maximizing cohesive tracks of bird and bat targets. We checked these settings periodically during the data collection period to ensure continuous function. We monitored raw (unprocessed analog radar returns) and processed radar outputs and managed data storage. In addition to storing all the processed data, we maintained samples of raw radar data for potential reprocessing.

Data Processing and Quality Control

Prior to data analysis, data processed by MERLIN software was further evaluated for potential contamination by non-targets. We visually reviewed all data in 15-minute time increments and removed time periods that were dominated by rain; data also were reviewed for other forms of transient clutter. Once contaminated time periods were removed, we summarized data for further analysis using database queries provided with the radar system by DeTect Inc.

Data Summary and Trends Analysis

Qualitative Analysis – We used the processed data to assess activity patterns that are associated with migration. Horizontal Trackplots were viewed to identify changes in activity and to investigate migrant behaviors associated with direction of flight, such as reverse migration (Åkesson 1999) and migrants moving toward shore at dawn. Vertical Trackplots were viewed to investigate changes in activity associated with altitudinal distributions, such as dawn ascent (Myres 1964, Diehl et al. 2003). Target counts from the VSR represented an index of abundance and we used these indices to identify temporal trends and overall patterns in migration intensity.

Target Counts & Ground Clutter –The HSR and VSR radars have different strengths that complement one another. For example, the HSR tracks low flying targets in a 360˚span around the radar unit and detection is not affected by the target's direction of travel. However, the HSR is much more affected by ground clutter (obstacles that block the radar beam) which affects target detection and tracking. Ground clutter is due to topography, vegetation, buildings, and other obstacles. We mapped static clutter for SANG and DETS (Figs. 3 & 4, respectively). Errors caused by ground clutter lead to both under- and over-counting; targets blocked by ground clutter may not get counted, and targets that fly in and out of areas with ground clutter may get counted multiple times. This leads to HSR counts that are more influenced by site conditions than VSR counts. However, the HSR better captures targets under certain conditions, such as when targets are primarily at low elevation (Bruderer 1997, Schmaljohann et al. 2008). The HSR also is much more susceptible than the VSR to beam bending (anomalous propagation) from dynamic atmospheric conditions; beam refraction in the VSR is minimal primarily due to its orientation. The VSR was used to track targets captured within the 1-km standard front (defined by a volume of space that extended 500 m to either side of the radar and continued up to the maximum height of data collection (2800 m). The VSR has more consistent detection than HSR as it mostly tracks against clear air, except in the lowest altitude bands. At low altitude bands the VSR is impacted by ground clutter (Figs. 3 & 4). Another strength of the VSR is that it provides

SANG Clutter Maps

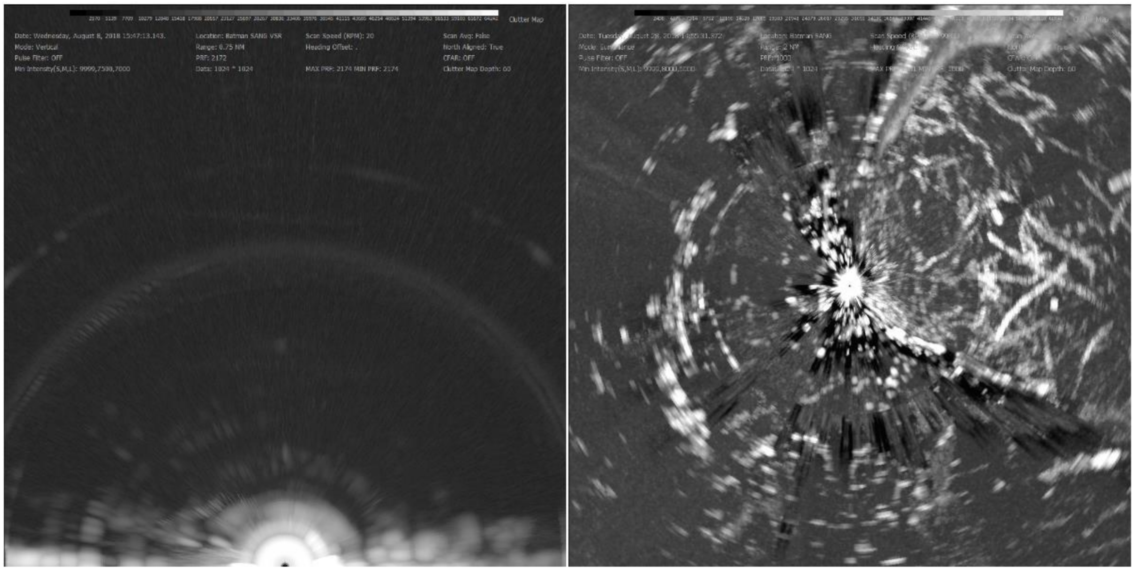

Figure 3. Clutter maps from VSR (left) and HSR (right) during the fall 2018 migration season. Brighter areas represent static returns from stationary objects such as tree lines and buildings or arcs from irregular radar returns. Detection of targets may be reduced or lost in these areas due to obstruction from these objects.

DETS Clutter Maps

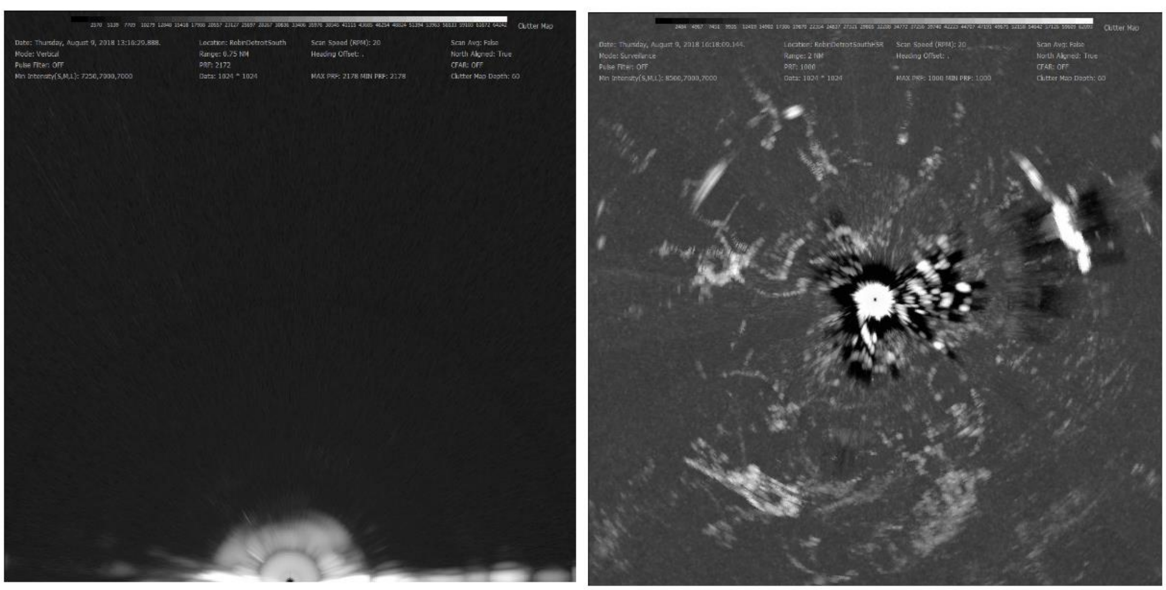

Figure 4. Clutter maps from VSR (left) and HSR (right) during the fall 2018 migration season. Brighter areas represent static returns from stationary objects such as tree lines and buildings or arcs from irregular radar returns. Detection of targets may be reduced or lost in these areas due to obstruction from these objects.

altitudinal distribution of the targets. The VSR detection ability is affected by target direction and distance from the radar (Bruderer 1997, Schmaljohann et al. 2008). Plotting these indices together provided a more comprehensive view of changes in target activity over time.

Temporal Trends - We used the VSR index to calculate target passage rate (TPR). We calculated TPR as the number of targets detected in the standard front per hour using DeTect SQL queries. Hours with less than 30 minutes of recording time were omitted from this calculation. For example, after removing all hours with less than 30 minutes of clean data, nocturnal TPR for a given night (biological time period) was calculated by dividing the target count by the number of nighttime minutes and multiplying by 60 to provide the number of targets per hour during that night. We extended this metric to the season and calculated mean TPR for biological time periods and hourly TPR. Mean nocturnal TPR for the season is the sum of nightly TPRs divided by the number of nights sampled. Similarly, mean hourly TPR for the season is the sum of TPRs for an hour period divided by the number times that hour of the day was sampled.

Directional Trends – Mean angle and concentration (r) of target directions were analyzed following methodology for circular statistics (Zar 1999) provided within DeTect SQL queries. The angular concentration has a value of 1 when all angles are the same (perfect alignment with all targets flying in the same direction) and a value of 0 when there is no alignment. For example, a circular uniform distribution (targets flying in all directions equally) or equal-sized groups flying in opposite directions. We anticipated a generally southward direction of movement from nocturnal targets during fall migration. We used radial graphs to plot the number of targets per 8-cardinal directions (i.e., eight groups centered on N, NE, E, SE, S, SW, W, NW) during four biological time periods (i.e., dawn, day, dusk, night).

In addition, we used the circular mean direction of targets each night to examine potential origins of migrants, plotting the estimated direction of origin as a line with length representing the number of migrants. This measure does not indicate variance of directionality, which can be large, but does provide a visualization of the likely origin direction of many migrants.

Altitudinal Trends – DeTect SQL queries calculated height estimates from the VSR data of targets tracked within the standard front. However, the size and shape of the radar beam changes with altitude, producing a smaller sample volume at low altitudes and a larger sample volume at high altitudes (Fig. 5). To address this we calculated the volume of the radar beam within each 50-m altitude band by Monte Carlo integration (Press et al. 2007). Height estimates were calculated based on the range and bearing of the target location and reported as the height above ground level at the radar unit; this measurement does not take into account changes in topography. We used these estimates to calculate mean altitude of targets above ground level by biological time period and hour and report mean and median altitudes for the season.

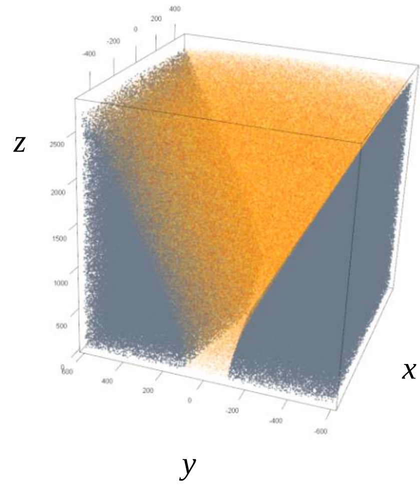

Figure 5. A representation of the structural volume of the vertical scanning radar (VSR) within the standard front. In this graphic the radar unit is located at the origin and the radar beam extends to 500 m on either side of the radar unit (x-axis) and up to a maximum height of 2800 m (z-axis). The y-axis represents the spread of the radar beam as it extends away from the origin. The orange semi-transparent points represent the volume contained by the structure of the radar beam. Dark gray points represent the volume that is within the box but are not included in the volume of the radar beam.

RESULTS

During the fall 2018 season data were collected from August 8th to November 14th at SANG, Macomb Co. MI and from August 8th to November 12th at DETS, Wayne Co. MI (Table 1, Fig. 1). VSR radar units collected data for 2,360 hours at SANG and 2,318 hours at DETS. Data were recorded continuously while the radar units were operational. Gaps in analyzed data occurred during rain events (150 and 270 hours at SANG and DETS respectively) and when the radar units were not operational due to maintenance or malfunction (radar downtime, 19 and 36 hours at SANG and DETS respectively). When correcting for radar downtime and removal of periods with rain, the vertical and horizontal radars collected useable data 93% and 100% respectively at SANG and 87% and 99% respectively at DETS.

<u>Qualitative Assessments</u>
Plots of tracked targets show nocturnal migration events at both locations (Figs. 6 & 7). Also apparent on the Trackplots from both sites are areas not well recorded by the radar due to beam blockage from ground clutter (Figs. 4 & 5) resulting in reduced detection in the air space that was within the range of data collection. Rings of decreased detection near the radar unit and where the radar switched from short to medium pulse are also evident in both the horizontal and vertical (e.g., Sept. 28, 11:30 pm, Fig. 7) Trackplots (seen at a range of about 1,400 – 2,000 m).

Temporal Trends

We plotted counts of targets per hour processed by MERLIN software for both HSR and VSR antennas as a time series to identify pulses of nocturnal activity, season duration, and changes in patterns of activity over time (Figs 8 & 9). Hourly target counts provided by horizontal and vertical radars showed nightly pulses of elevated activity with peaks occurring a few hours before midnight at our study sites (Figs 8 & 9). Across our sampling period these events would often occur over a series of 2 to 3 nights at the beginning and end of the season (August and November), and more consistently, for periods of five consecutive days or more, during the middle of the season (September-October). Peak nighttime pulses occurred at both sites during mid-September through October. Nightly pulses in target counts on the vertical radar typically corresponded to pulses on the horizontal radar, though the vertical radar records fewer targets overall.

The pattern of mean and median target passage rate among biological time periods was similar among the two sites with greater target passage at night followed by dawn time periods (Table 2). The mean nighttime TPR also was similar between these two sites (Table 2). The mean and median TPR was higher from dawn to dusk at DETS than at SANG (Table 2).

Table 2. Seasonal target passage rate at SANG and DETS Michigan (MI), fall 2018.

	SANG		**DETS**	
Biological Period	Mean ± SD	Median	Mean ± SD	Median
Dawn	252 ± 233	163	438 ± 371	346
Day	135 ± 127	93	304 ± 182	272
Dusk	82 ± 78	51	249 ± 170	196
Night	911 ± 846	565	965 ± 918	718

Directional Trends

During the fall 2018 season, nocturnal target direction was generally southwest/south at both sampled locations (Figs. 10 & 11, Table 3). At SANG migrant movements at dawn were in the westerly/northwesterly direction, typical of dawn reorientation as migrants turn towards land concluding nighttime migration (Fig. 10). These were the most concentrated movements at this site. Daytime movements were in a north/south direction suggesting daytime movements along the shore (Fig. 10); these movements tended slightly toward the south though the concentration of direction was low (Table 3). Movements at dusk were primarily to the east/southeast as birds began nighttime migration.

At DETS migrant movements at dawn were primarily westerly and daytime movements were primarily westerly/southwesterly but had a low concentration of direction (Fig. 11, Table 3). Movements at dusk were primarily to the south as birds began nighttime migration. Nighttime migration had the strongest directional concentration at this site (Table 3).

Table 3. Mean direction (compass degrees with north at 0 degrees, increasing clockwise) and angular concentration (r) of targets during different time periods at SANG and DETS, fall 2018.

	SANG		**DETS**	
Biological Period	Mean Direction (°)	r	Mean Direction (°)	r
Dawn	285	0.30	277	0.23
Day	209	0.05	232	0.14
Dusk	93	0.16	176	0.24
Night	222	0.23	209	0.35

In addition to studying the flight direction of migrants, we also studied their direction of origin. The mean nightly direction of origin for SANG spanned primarily from the northwest to the east/northeast (Fig. 12a); although, there was one night with a high magnitude of migration from a west/southwesterly direction. Flight origin for SANG indicated that a large proportion of targets flew over Lake St. Clair to reach this point. Target origin for DETS also ranged from northwest to east/northeast (Fig. 12b).

Altitudinal Trends

At both SANG and DETS targets were observed across all sampled altitude bands (Figs. 13 & 14). The highest mean altitude for migrants occurred during the Night (631 ± 452 m) and Dawn (516 ± 464 m) time periods at SANG. Day and Dusk mean altitudes at this site were 424 ± 364 m and 438 ± 451 m respectively. DETS also had its highest mean altitude for migrants during the Night and Dawn time periods (646 ± 500 m and 497 ± 518 m, respectively). Day and Dusk mean altitudes were 388 ± 420 m and 304 ± 303 m, respectively at DETS.

The corrected density estimates for both SANG and DETS show a much higher density of birds within the Rotor-swept Zone (the area through which wind turbine blades sweep, 30-200 m) compared to the uncorrected density estimates (Figs. 13 & 14). The altitude profiles differed between these two sites, SANG having generally lower densities than DETS, particularly during dawn, day, and dusk time periods. Nighttime for each site had higher densities than the other periods, reflected in the x-axis (Figs. 13 & 14), this was particularly true for SANG (Fig. 13).

The density of migrants at different altitudes by hour throughout the day is presented in Figures 15 & 16, note that the heat scale varies slightly between the two figures. The greatest density of migrants occurred during nocturnal hours, and migrants generally were most dense at less than 550 m altitude at both sites, suggesting heavy use of the lower airspace (Figs. 15 & 16). At SANG there was a low density of targets during the daytime (7 am to 7 pm) observed at low altitude (e.g. below 200 m altitude, Fig. 15). Migrant density at SANG increased as migrants rose in altitude with the onset of nighttime migration (8 pm, Fig. 15). Migrants remained at higher altitudes from 9-11 pm before lowering slightly (12-3 am) and then descending at 4 am (Fig. 15). At DETS, there was a moderate density of targets during the daytime compared to SANG (e.g. at lower altitudes from 7 am to 7 pm, Fig. 16). These daytime targets may have been waterbirds, for example gulls, which are known to use urban environments where they supplement diet with anthropogenic food sources (Laurich et al. 2019) or find nesting sites (Dwyer et al. 1996). At

DETS targets began to increase altitude at 8 pm and had their highest altitudes from 9 pm to 1 am, after which nighttime migration altitude was lower until the end of migration at 6 am (Fig. 16).

DISCUSSION

This study was undertaken to document migration in the Great Lakes basin. Our findings for the western end of Lake Erie indicate that this area is important for fall migration. Our research contributes to a growing body of literature that documents various aspects of migration and identifies Great Lakes lakeshores as areas important for conservation of migratory species. Our data provide unique observations about the magnitude and timing of nocturnal migration that could not be observed without the aid of radar.

Migration Patterns

Patterns of movement recorded at these sites were consistent with other observations of migration (Newton 2008) and indicated that nocturnal migratory flights occurred regularly at both locations during fall 2018. Target passage rate was greatest during the nocturnal biological time period at both locations (Figs. 13 & 14). Nocturnal activity was typically oriented in a south/southwest direction (Figs. 10 & 11) and occurred in pulses across the season (Figs. 8 & 9). Both sites had peaks in migration on September 19th and 27th, October 5th, SANG had another peak on October 15th and DETS had one on October 25th (Figs. 8 & 9). Fluctuations in migrant numbers may be related to broad scale weather fronts, variation in timing among guilds of migrants, or a combination of these and other factors (Newton 2009).

Though nocturnal migration was primarily in the expected direction of migration (i.e. south/southwesterly) movements during other biological time periods varied (Figs. 10 & 11). This may be related to daytime movements along the shore, foraging or other movements. It also may be related to movements of resident birds (e.g. American Crow), or short-distance migrants on their breeding grounds (e.g. Ring-billed Gull). Changes in flight direction can be observed in the Trackplots; for example, with migrants over water returning to shore at dawn (Fig. 6), or on different nights of migration (e.g. top row of Trackplots, Fig. 7).

Flight Altitude

Altitude profiles indicated that most nocturnal targets passed below 600-700 m with peak density in the 100-400 m altitude bands (Figs. 15 & 16). We corrected for the approximate shape of the survey volume and included this correction in our density estimates. This correction is based on the manufacturer's estimate of beam geometry, which may not be precise, and beam propagation is not consistent over time. Beam propagation is affected by side lobes, target size and distance, and atmospheric conditions. Nonetheless, we think the correction was an improvement over altitude profiles that ignore beam geometry and sampling effort. We were not able to correct for the loss of detection with distance from the radar (Schmaljohan et al. 2008); in addition, our vertical scanning radars lost detection at a range of about 1,400 – 2,000 m where the radar transitioned from the short to medium pulse. For these reasons, our estimates likely under-represent density as altitude increases. However, densities per altitude band were already decreasing before the 1,400 m band (Figs. 15 & 16), so any undercount is unlikely to change the overall picture that migrants are primarily using lower altitude bands for migration.

Migrants adjust flight altitude with wind direction and speed, visibility, time, and landscape below flight trajectory (Alerstam 1990, Hueppop et al. 2006, Liechti 2006). For example, head winds aloft have resulted in migrants moving *en masse* to lower altitudes where wind speeds were reduced (Gauthreaux 1991). Changes in flight altitude can occur at various times over the course of the night and also are associated with targets ascending from and descending to stopover sites. Depending on location, these altitude changes may place migrants at risk of collision with wind turbines and other tall human-made structures.

Radar Study and Management Considerations

Whereas radar may be the best tool available for gathering large amounts of data on nocturnal migration, the interpretation of radar data can be challenging. Marine radar is the most common type used to track bird and bat movements (Larkin 2005) and its use to assess risk will likely increase with wind energy development. Despite this growing trend, standardized equipment and methodology for establishing radar settings, ground truthing biological targets, and data processing have not been adopted. These considerations can substantially affect the quality of data. This presents a challenge that is not easily solved. Without standards, comparisons among studies may be more reflective of differences in equipment, methodology, and site conditions rather than in differences in migration activity among sites.

Additionally, metrics reported in radar surveys can be misleading to someone unfamiliar with avian radar. For example, mean altitude of target passage is often reported to be above the rotor-swept zone and has been interpreted as indication of low risk. However, the mean altitude can be well above the rotor-swept zone even when there is a high rate of target passage within the rotor-swept zone. This is due to the long range at which radars collect altitude data, up to 3 km above ground level in our study, where high flying targets inflate the mean altitude. This bias is apparent in our data and can be seen by comparing the mean altitude of nocturnal targets to the most densely populated altitude band (Figs. 13, 14, 15 & 16). It also is misleading to compare the percent of targets below and above the height of the rotor-swept zone without addressing the inherent difference in radar sampling effort at various altitude bands. Within our sampling framework, there are four 50-m altitude bands below 200 m (an estimate for the height of the rotor-swept zone) and 52 altitude bands above 200 m. Based on our model, we estimated that about 1 percent of the potential survey volume is below 200 m. Given that information, we would expect a small percentage of targets to be recorded at or below the rotor-swept zone but this does not necessarily indicate low risk.

When examining general migration patterns, high nighttime migrant activity was documented at both Lake Erie radar sites. This is evident from the Trackplots (Figs. 6 & 7), time series plots (Figs. 8 & 9), and high target passage rates (Figs. 13 & 14). Density of targets within a 30 – 200 m rotor-swept zone also were high when compared to the dawn, day and dusk time periods (Figs. 13, 14, 15 & 16). Throughout the migration season, nighttime targets were recorded flying both across the lake and along the lakeshores (Figs. 6 & 7). The combination of these behaviors indicates that high numbers of night migrants may be at risk of collision with a wind facility, communication tower or other tall structures placed within the lakeshores of Lake Erie. These collisions can have detrimental effects on populations; for example, for 13 bird species of conservation concern, communication tower collisions caused mortality of 1-9% of these populations annually (Longcore et al. 2013). Likewise, population models show that wind turbine mortality can drastically reduce migratory bat populations, leading to extinction (Frick et al. 2017).

While target passage rate and target density are lower during the dawn, day, and dusk time periods (Figs. 13, 14, 15, & 16), migrants are still active and at risk of collision (Gelb and Delacretaz 2009, Kahle et al. 2016). Targets were recorded flying along the Lake Erie shoreline during all time periods, indicating the lakeshore provides important migratory pathways and stopover habitat during all times of the day. Therefore, conservation of the entire migration airspace along these lakeshores will be important. This is particularly true at DETS where target density was moderately high from dawn to dusk. Given the high density of targets within the DETS metropolitan area it will be important to continue identifying and mitigating mortality risks for birds and bats in addition to enhancing stopover habitat. Programs such as Safe Passage Great Lakes and the Detroit Urban Bird Treaty are important conservation tools in making built infrastructure and the urban landscape safer for birds.

Conclusion

Overall, we found that radar provided valuable information on movements throughout the day and insight into nocturnal migration that would otherwise be unattainable. We believe continued development and careful interpretation of radar data will result in valuable contributions to the management and conservation of migrating birds and bats.

This study highlights the potential role of radar in implementing recommendations from wind energy guidelines (USFWS 2012) to identify areas where impacts to wildlife would be minimized. We documented clear examples of migrant activity along the western lakeshores of Lake St. Clair and Lake Erie at our study sites in Michigan, and the density of targets at lower altitudes is a concern. An additional concern is that turbine height and blade length continues to grow, increasing the area of the rotor-swept zone. This increases the altitude range of flight risk for birds and bats migrating through an area. The data we collected may be of interest to public and private entities that are involved with wind energy development or other construction and potential placement of turbines, towers or other structures in the Great Lakes region. Coupling avian radar systems with other forms of research or using radar in conjunction with post-construction fatality searches may broaden the utility of its use in making risk assessments and assessing wind energy development or other projects.

SANG Migration Trackplots

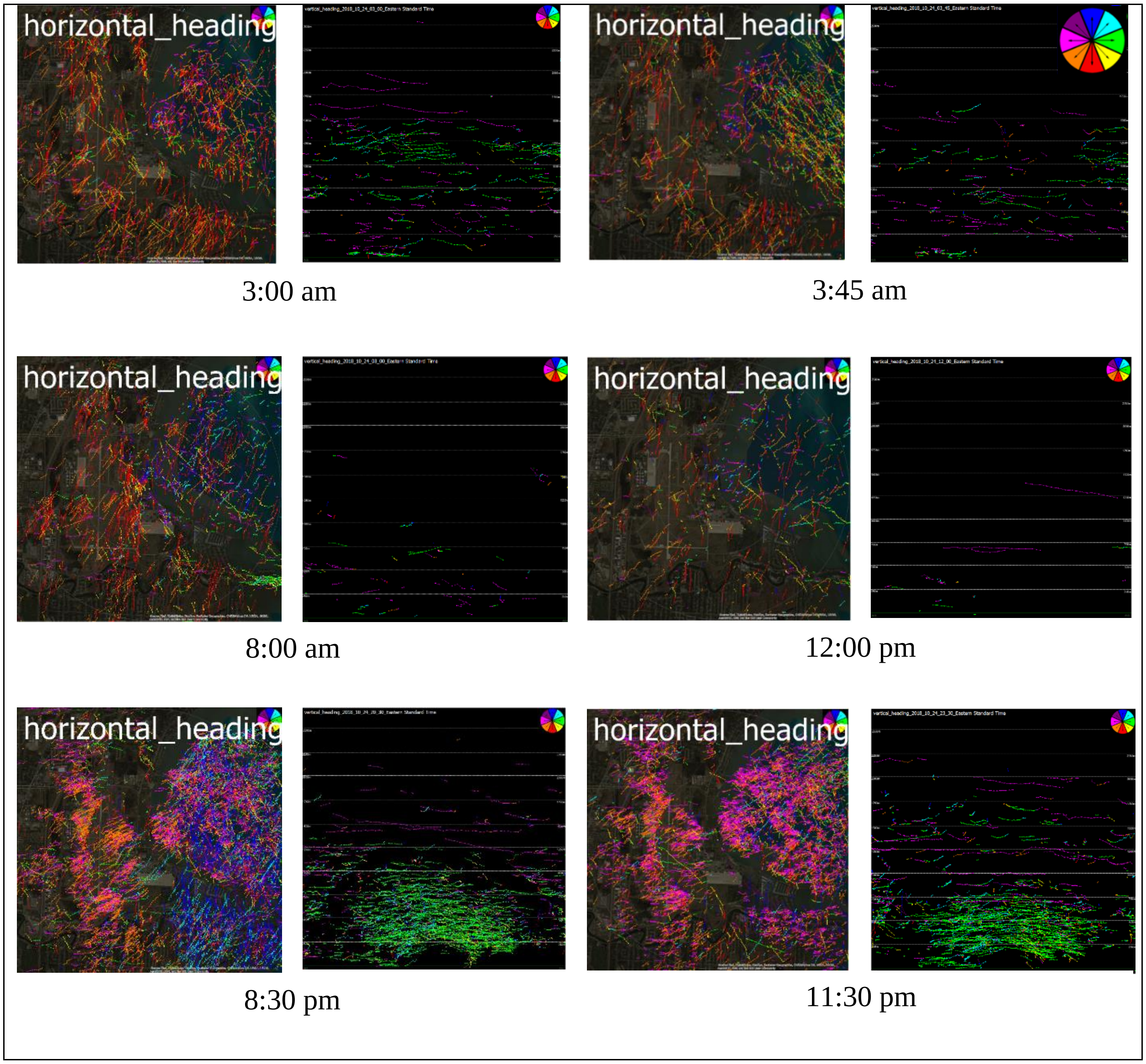

Figure 6. Horizontal (HSR) and vertical (VSR) migration Trackplots, Macomb Co, MI, October 24, 2018. Horizontal radar images show the direction of the targets as indicated by the color wheel. Early morning migration in a southerly direction (3:00 am), targets flying southeast over water toward shore (3:45 am), targets flying south at low elevation along the lakeshore (8:00 am) and few movements during midday (12:00 pm). West/southwesterly movements and northward movements from the shore to Lake St. Clair as migration commences (8:30 pm). Nighttime migration in a predominately westerly and southwesterly direction (11:30 pm). Vertical radar images show target heights during different time periods. The range of horizontal and vertical radar are 3.7 km and 2.8 km, respectively.

DETS Migration Trackplots

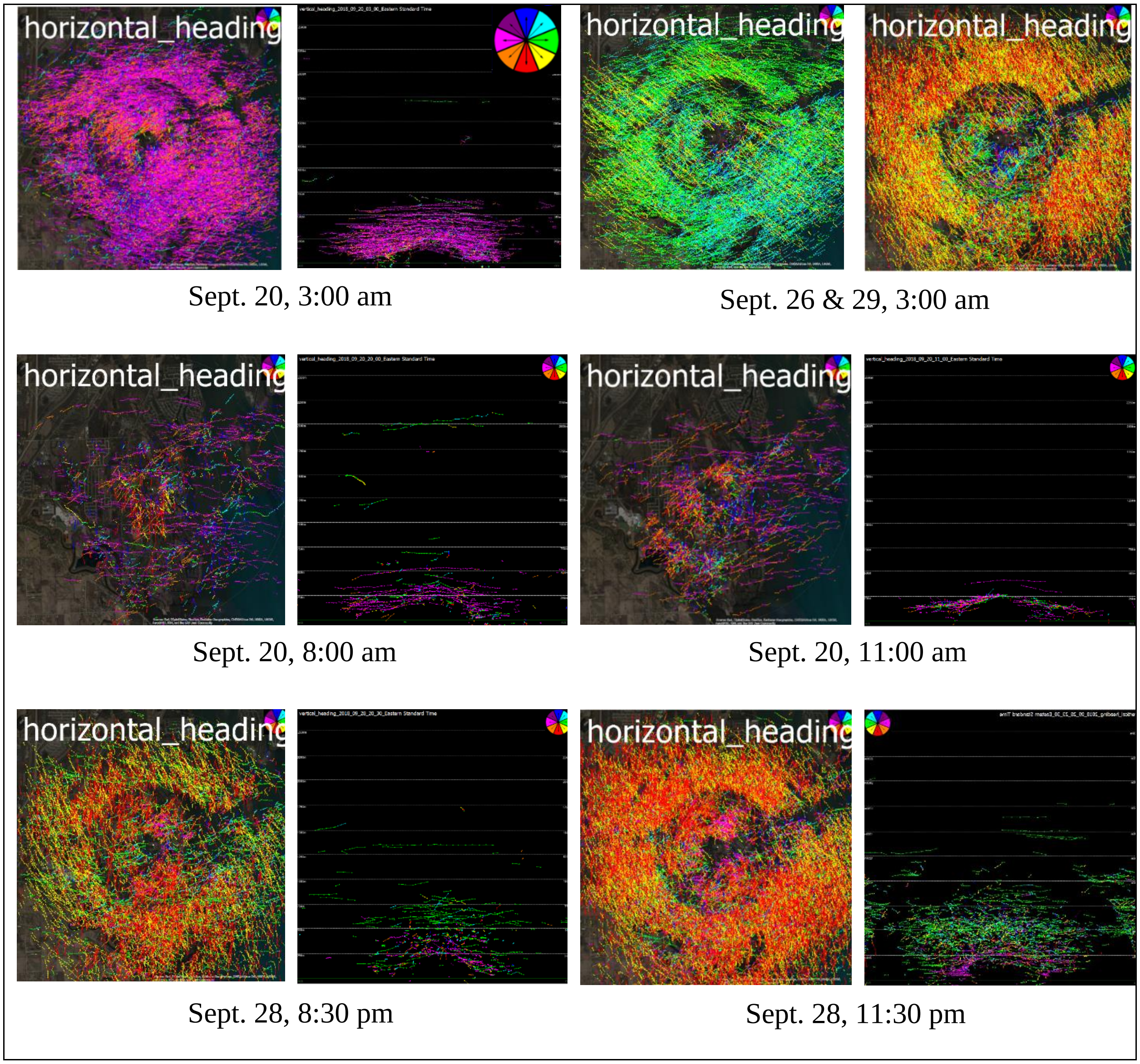

Figure 7. Horizontal (HSR) and vertical (VSR) migration Trackplots, Wayne Co. MI, fall 2018. Horizontal radar images show the direction of the targets as indicated by the color wheel. Early morning migration in a westerly direction (September 20, HSR and VSR, 3:00 am) and variation in migratory direction on different nights. (HSR Sept 26 & 29, 3:00 am). Daytime movements (8:00, 11:00 am). Southeastern/southerly movements at the commencement of migration and southerly nighttime movements (September 28, 8:30 pm and 11:30 pm, respectively). Vertical radar images show target heights during different time periods. The range of horizontal and vertical radar are 3.7 km and 2.8 km, respectively.

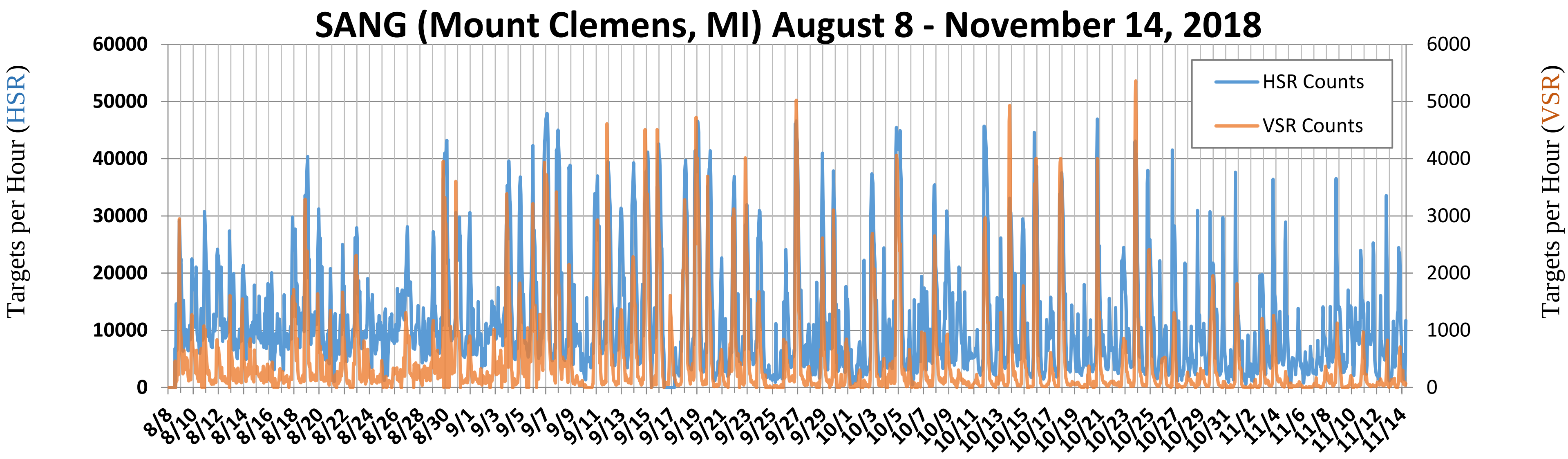

Figure 8. Time series of horizontal (blue) and vertical (red) scanning radar counts for SANG, Macomb Co. MI, fall 2018. Note the differing scale between the HSR and VSR counts.

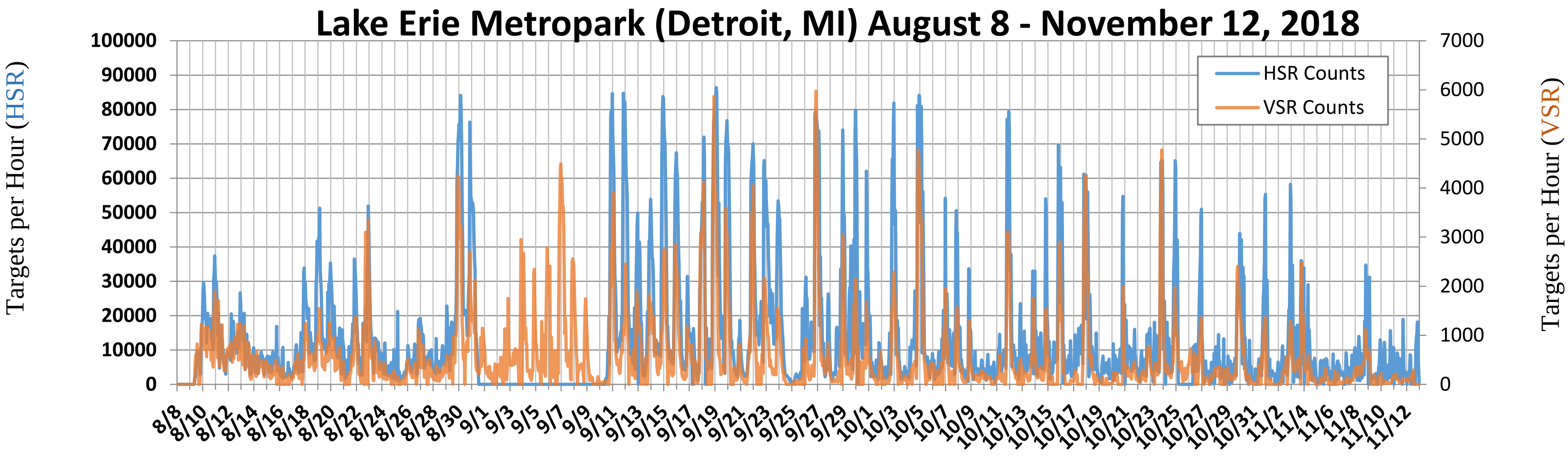

Figure 9. Time series of horizontal (blue) and vertical (red) scanning radar counts for DETS, Wayne Co. MI, fall 2018. Note the differing scale between the HSR and VSR counts.

Target Direction per Hour during Four Biological Time Periods at SANG

Figure 10. Movement direction of targets during four biological periods, SANG, Macomb Co. MI, fall 2018. Measures are number of targets per hour, note the difference in targets by time period and marked increase in nighttime and dawn targets.

Target Direction per Hour during Four Biological Time Periods at DETS

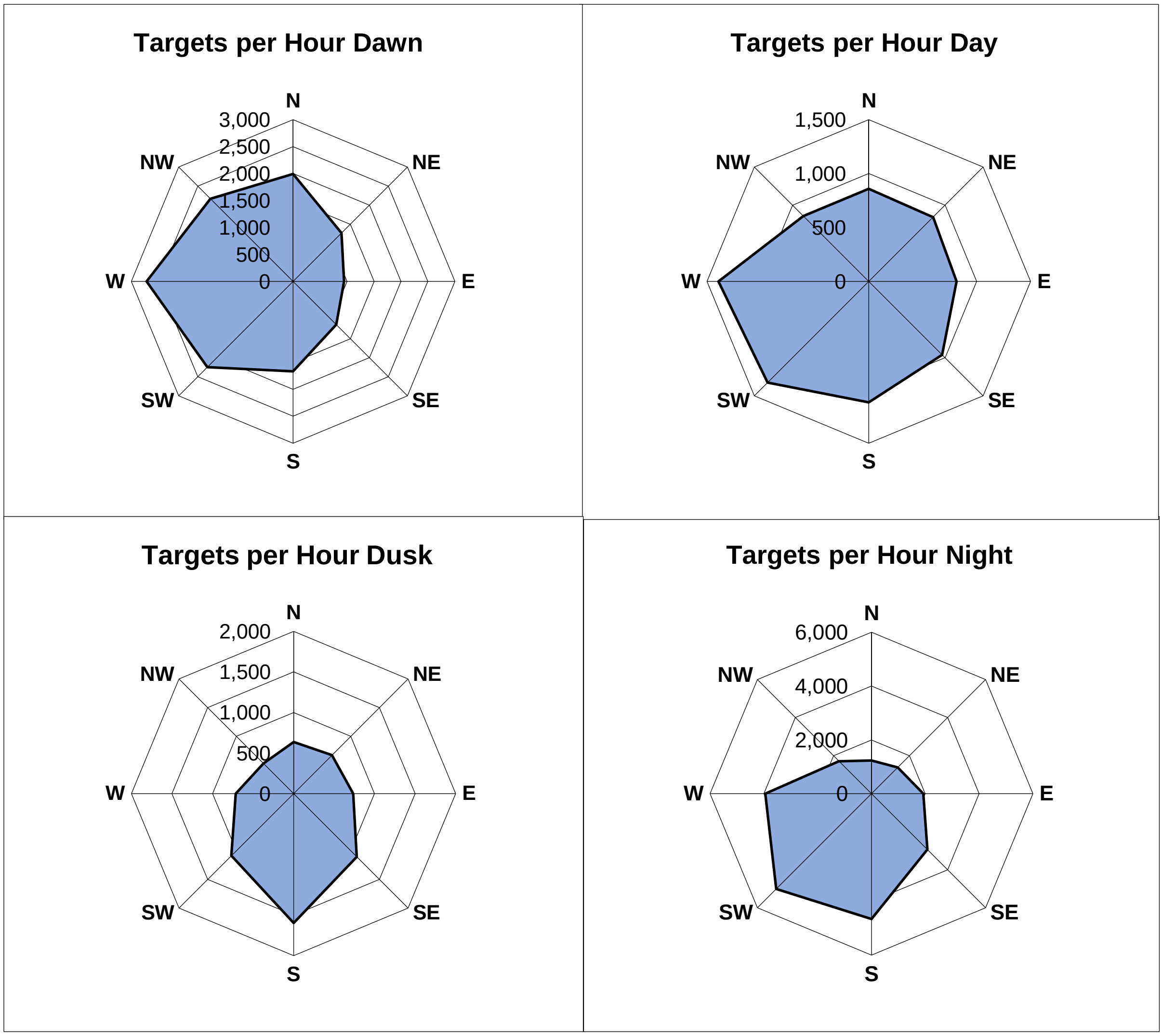

Figure 11. Movement direction of targets during four biological periods, DETS, Wayne Co. MI, fall 2018. Measures are number of targets per hour, note the difference in targets by time period and marked increase in nighttime targets.

A

B

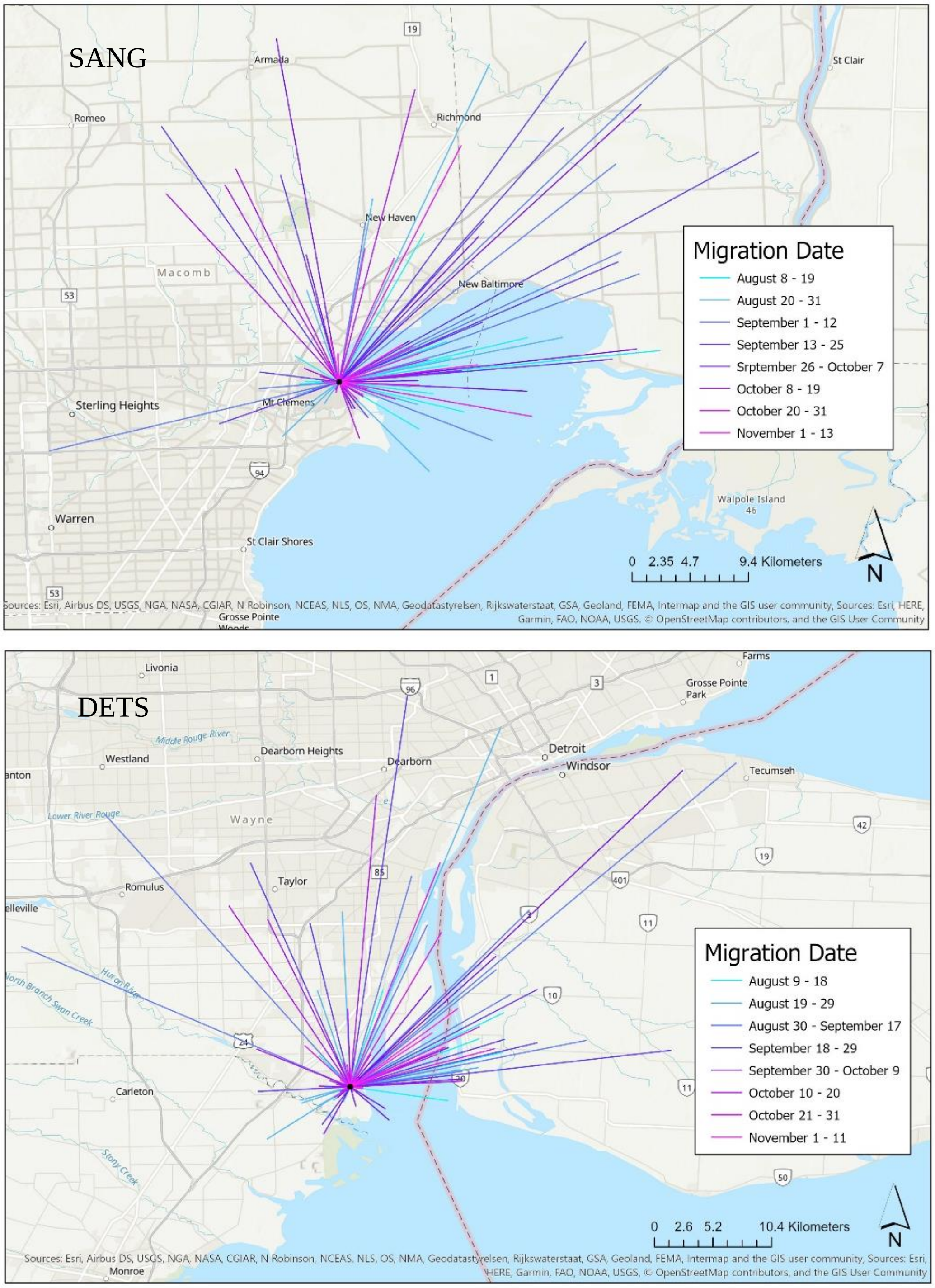

Figure 12. Estimated direction of origin, magnitude and timing of migration at each site, SANG (A) and DETS (B), during the fall 2018 season. The angle of each line is the circular mean of target headings, represented as movement toward the radar unit. Line length is proportional to the number of targets detected by HSR each night. Date is represented by color, with purple/pink later in the season and blues earlier in the season.

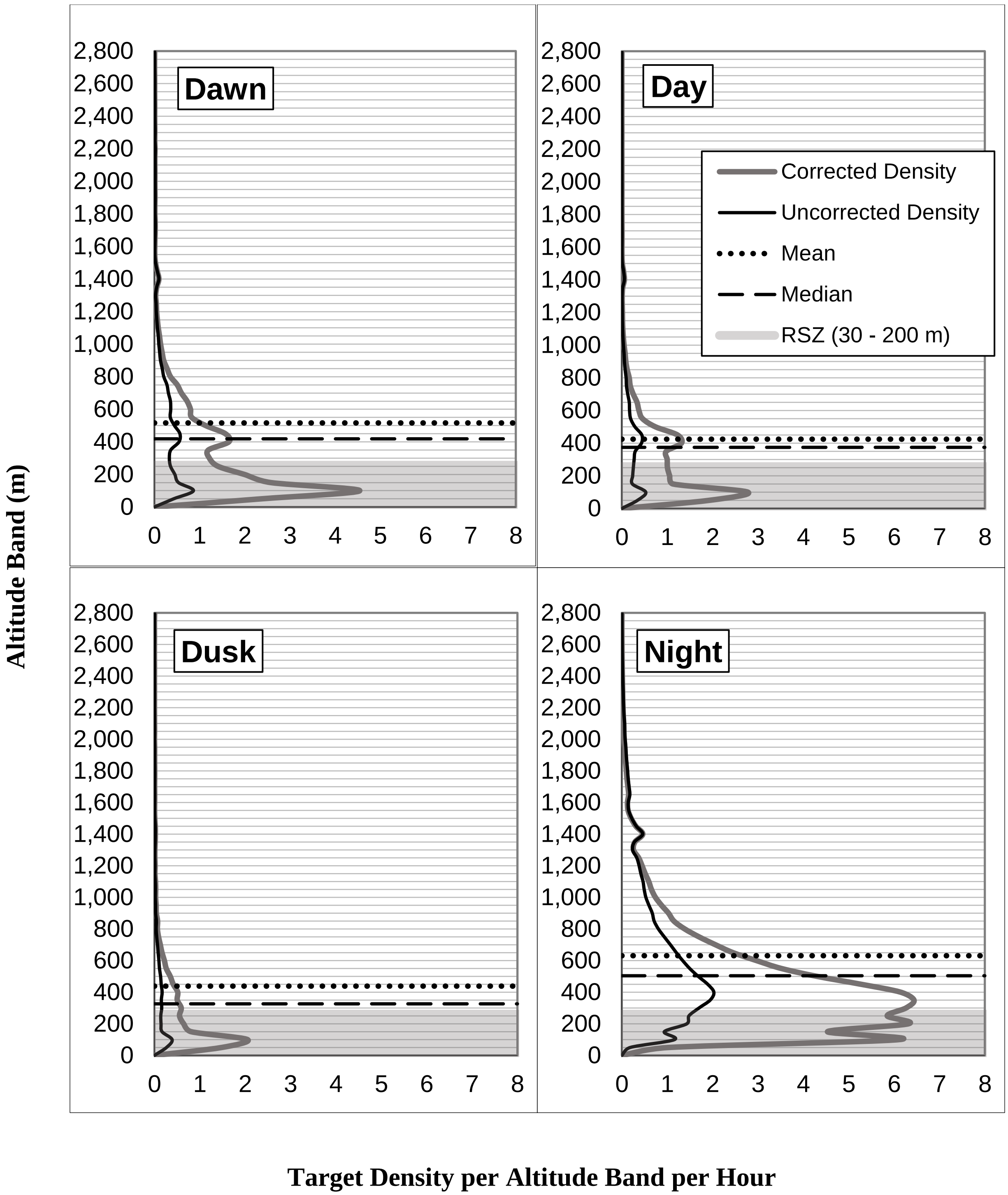

Figure 13. Altitude profile by biological time period for SANG, Macomb Co., MI, fall 2018. These graphs show the uncorrected (black) and corrected (gray) density estimates of targets moving on the VSR at different altitudes during the four biological time periods. The mean and median heights (dotted and dashed lines respectively) are shown for each time period. The rotor-swept zone (RSZ) is represented by shading at 30-200 m. The x-axis represents target density (targets/1,000,000 m^3) per 50-m altitude band.

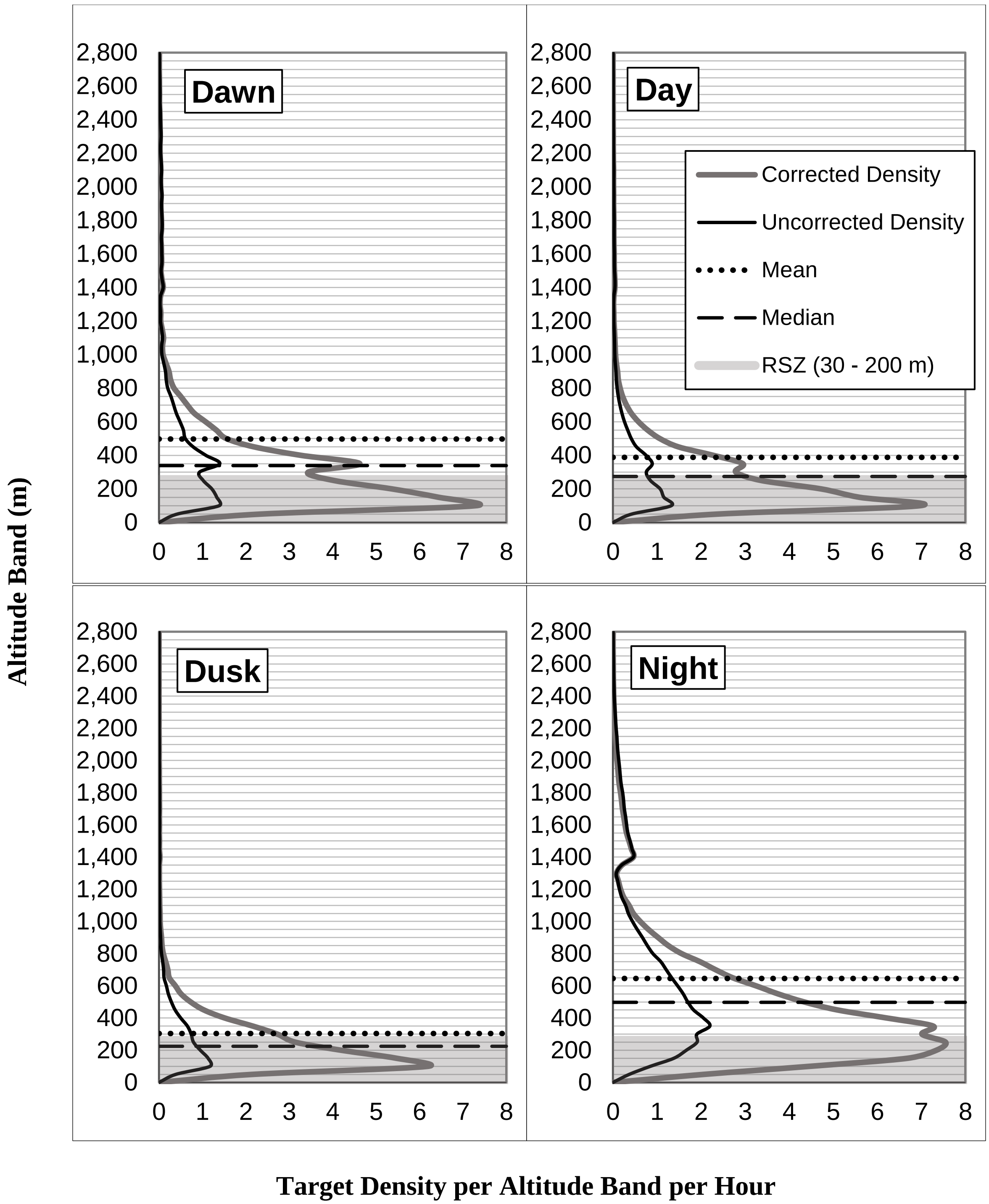

Figure 14. Altitude profile by biological time period for DETS, Wayne Co., MI, fall 2018. These graphs show the uncorrected (black) and corrected (gray) density estimates of targets moving on the VSR at different altitudes during the four biological time periods. The mean and median heights (dotted and dashed lines respectively) are shown for each time period. The rotor-swept zone (RSZ) is represented by shading at 30-200 m. The x-axis represents target density (targets/1,000,000 m^3) per 50-m altitude band.

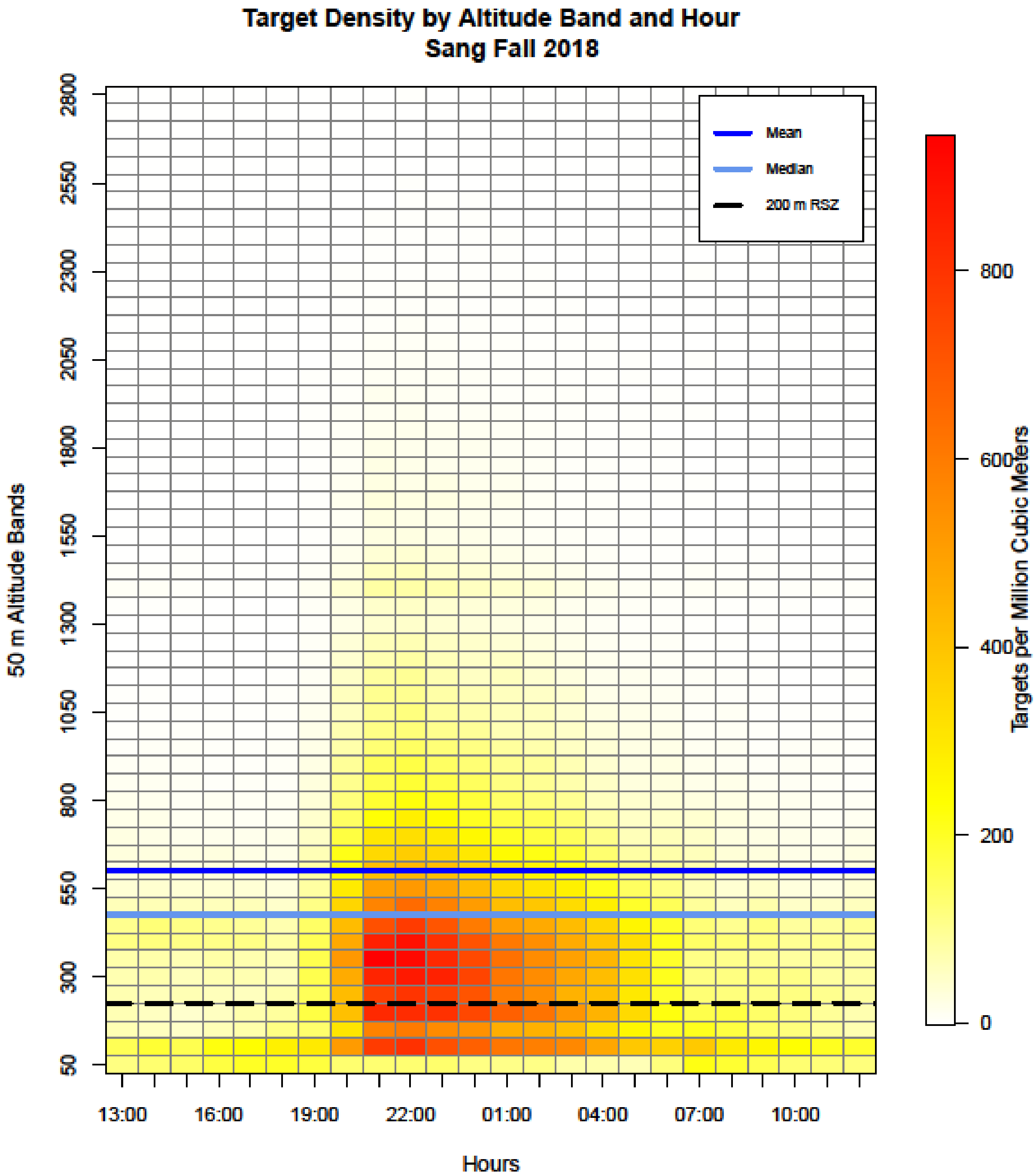

Figure 15. Altitude map for SANG, Macomb Co., MI, fall 2018. The y-axis depicts the altitude in 50-meter bands, the x-axis shows hours with midnight (0:00) as the center of the axis. Cell colors show migrant density at different altitude bands, with red and orange indicating higher densities. Uncorrected mean and median altitudes are shown in dark and light blue lines respectively. A 200 m rotor-swept zone is depicted by the dotted black line.

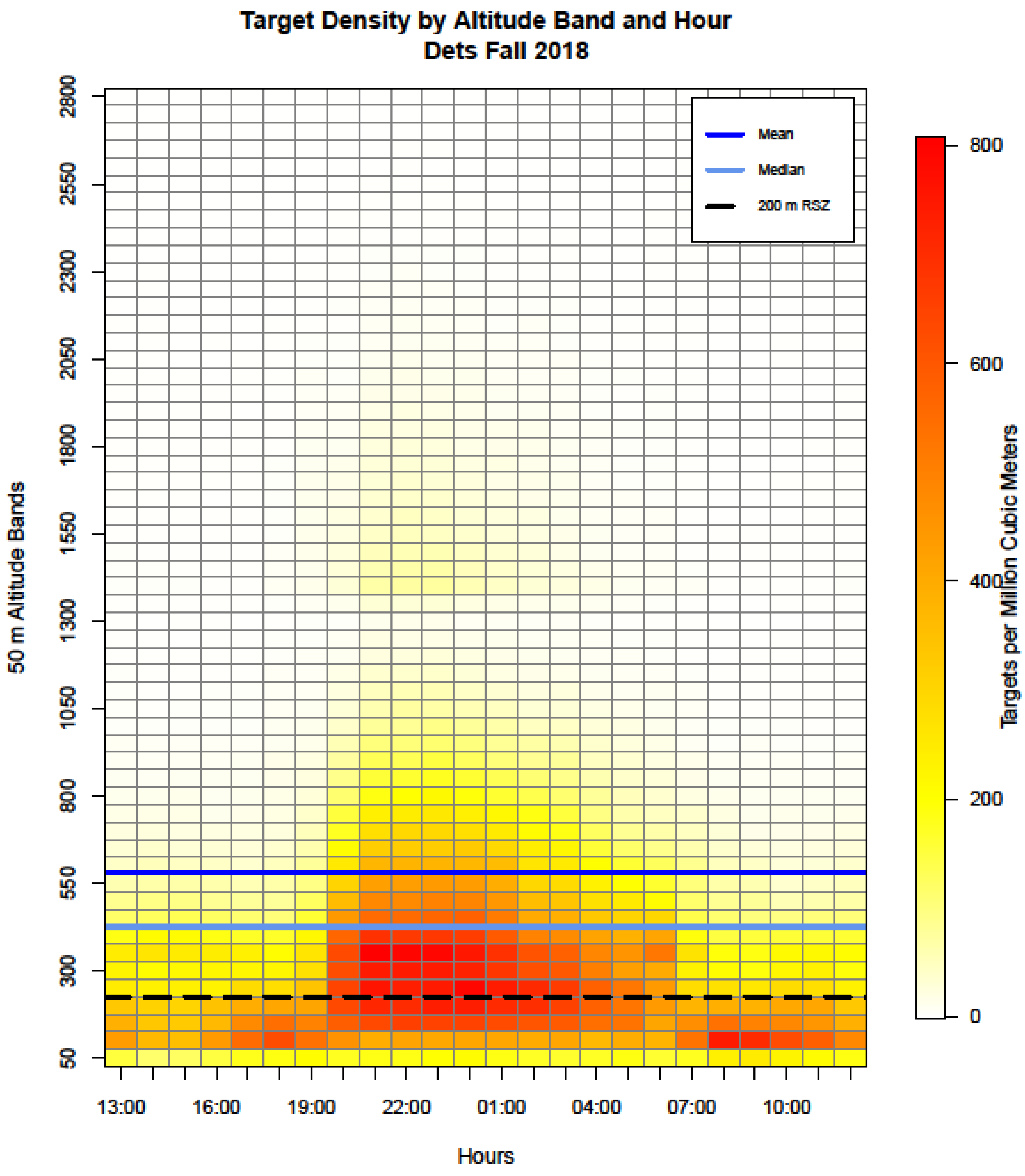

Figure 16. Altitude map for DETS, Wayne Co., MI, fall 2018. The y-axis depicts the altitude in 50-meter bands, the x-axis shows hours with midnight (0:00) as the center of the axis. Cell colors show migrant density at different altitude bands, with red and orange indicating higher densities. Uncorrected mean and median altitudes are shown in dark and light blue lines respectively. A 200 m rotor-swept zone is depicted by the dotted black line.

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