

**A RADAR AND VISUAL STUDY OF NOCTURNAL BIRD AND BAT
MIGRATION AT THE PROPOSED FLAT ROCK WIND POWER
PROJECT, NEW YORK, FALL 2004**

FINAL REPORT

Prepared for

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EXECUTIVE SUMMARY

- This report presents the results of a radar and visual study of bird and bat migration conducted during 5 August–3 October 2004 at the proposed Flat Rock Wind Power project, located in the Tug-Hill Plateau of northern New York, in Lewis County. Radar and visual observations were conducted for ~6.5 h/night during 60 nights during the fall.
- The primary goal of this study was to collect information on the migration characteristics of nocturnally migrating birds, (especially passerines) and bats during the fall-migration period to provide an overall assessment of potential project-related impacts to birds and bats. Specifically, the objectives of this study were to: (1) collect baseline information on migration characteristics (i.e., flight direction, migration passage rates, flight altitudes) of nocturnally migrating birds and bats; (2) visually estimate the number and relative proportions of birds and bats within the potential rotor-swept area of the proposed wind turbines; and (3) determine the number of birds and bats that would pass within the rotor-swept area of the proposed wind turbines during the migratory season.
- In the fall, the mean flight direction of targets observed on radar was 184°.
- The mean nocturnal passage rate for the fall season was 158 ± 21 targets/km/h and ranged among nights between 5 and 704 targets/km/h. Fall passage rates varied among hours of the night, with lowest mean rates occurring during the earliest hour of the evening.
- The mean nocturnal flight altitude for the entire fall season was 415 ± 2 m agl. Mean flight altitudes observed on vertical radar were highly variable among nights and ranged from 194 to 691 m agl. Eight percent of all targets during fall 2004 were below the maximal height of the proposed wind turbines (125 m).
- Migration passage rates increased with tailwinds, crosswinds, and date. Flight altitudes increased with tailwinds, crosswinds, and date and decreased with wind speed.
- Assuming an average of 10 nocturnal h/d and 60 d in the fall study, we estimated a seasonal turbine passage rate index of 39–275 nocturnal songbird/bat migrants passing within the area occupied by each proposed turbine during fall 2004.
- We used visual sampling methods of night vision goggles and two, 2,000,000-Cp spotlights with red lenses to investigate low-altitude migration of birds and bats, and were able to identify ~81% of all targets as either birds or bats. During nocturnal hours, we observed a total of 1,383 birds (mainly passerines) and 179 bats (mainly small bats) at both sites. The proportions of birds and bats flying <~150 m agl (i.e., our effective sampling distance with the night-vision goggles and spotlights) were 91% birds and 9% bats ($n = 865$ identifiable targets) at the North site and 85% birds and 15% bats ($n = 697$ identifiable targets) at the South site.
- The key results of our of fall passerine and bat migration study were: (1) the mean overall passage rate (i.e., 158 targets/km/h) was comparable to other sites in New York; (2) mean nightly passage rates ranged from 5 to 704 targets/km/h; (3) the percentage of targets passing below 125 m agl (~8%) was similar to that for a small number of comparable studies; (4) an estimated turbine passage rate index of 39–275 nocturnal migrants passing within the airspace occupied by each proposed turbine during the 45-d fall migration season (equivalent to ~0.7–4.6 nocturnal migrants/turbine/d); and (5) migrants composed of ~85–91% birds and ~9–15% bats during this study.

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INTRODUCTION

Avian collisions with communication towers have been recorded in North America since 1948 (Kerlinger 2000), with neotropical migratory birds such as thrushes (Turdidae), vireos (Vireonidae), and warblers (Parulidae) seeming to be the most vulnerable to tower collisions during their nocturnal migrations (Manville 2000). Passerines also collide with wind turbines (Osborn et al. 2000, Erickson et al. 2001, 2002), composing >80% of the fatalities at wind power developments; ~50% of the fatalities at wind farms involve nocturnal migrants (Erickson et al. 2001). Studies examining the impacts of wind farms on birds in the US and Europe suggest that fatalities and behavioral modifications (e.g., avoidance of wind farms) occur in some, but not all, locations (Winkelman 1995, Anderson et al. 1999, Erickson et al. 2001). Both the documentation of bird fatalities at most wind power facilities studied in the US (Erickson et al. 2001) and the paucity of general information on nocturnal bird migration have generated concern about the potential of collisions between nocturnal migrants and the many proposed wind power developments throughout the country. Consideration of potential wind power impacts on nocturnal bird migration is particularly important because more birds migrate at night than during the daytime (Gauthreaux 1975, Kerlinger 1995). In particular, passerines (“songbirds”) may be more at risk of colliding with structures at night because these birds tend to migrate at lower altitudes than do other groups of birds (e.g., waterfowl, shorebirds; Kerlinger 1995).

Although bat fatalities at wind farms in the western U.S. generally are low (Erickson et al. 2002), recent data from Appalachian ridgetops in the eastern U.S. (Erickson 2004, Kerns 2004) have indicated that substantial bat kills are also possible at wind power projects. Most of the bat fatalities documented at wind farms have been associated with migratory species during seasonal periods of dispersal and migration in late summer and fall and several hypotheses have been posited, but not tested, to explain bat/turbine interactions (Kunz 2004).

Atlantic Renewable Energy Corporation proposes to build the Flat Rock Wind Power project, a ~322 MW wind power development in

the Tug-Hill Plateau (Lewis County) of northern New York (Fig. 1). Each of the proposed ~195 wind turbines will have a generating capacity of up to ~1.65 MW. The monopole towers will be ~80 m (262 ft) in height, and each turbine will have three rotor blades. The diameter of the rotor blades and hub will be 70.5 m (231 ft) or 77 m (253 ft), depending on the model selected for the project; thus, the total maximal height of a turbine will be approximately 119 m (389 ft) with a blade in the vertical position. The proposed development is located within the Tug Hill transition zone (Reschke 1990), a well-documented migration corridor for birds (Bull 1985, Bellrose 1976, Zalles and Bildstein 2000, Cooper and Mabee 2000).

OBJECTIVES

The primary goals of this study were to collect information on the migration characteristics of nocturnally migrating birds, especially passerines, during the fall-migration period and to assess the extent of use of the area by bats to provide an overall assessment of potential project-related impacts to birds and bats. Specifically, the objectives of this study were to: (1) collect baseline information on migration characteristics (i.e., flight direction, migration passage rates, flight altitudes) of nocturnally migrating birds and bats; (2) visually estimate the number and relative proportions of birds and bats within the potential rotor-swept area of the proposed wind turbines; and (3) determine the number of birds and bats that would pass within the rotor-swept area of the proposed wind turbines during the migratory season. We also evaluated the influence of weather on migration passage rates and flight altitudes.

STUDY AREA

The proposed project is located in the Tug-Hill Plateau of northern New York, in Lewis County (Fig. 1). The Tug-Hill Plateau is part of the Appalachian Plateaus physiographic province (USGS 2003) and is characterized by rolling hills ranging from 1,000 to 2,000 ft. (307–615 m) above sea level (ASL). The plateau rises gradually from the west and also drops off gradually, although there are some steeper hills. The proposed project ranges in elevation between ~1,600 and 1,950 ft. (492–600 m) ASL.

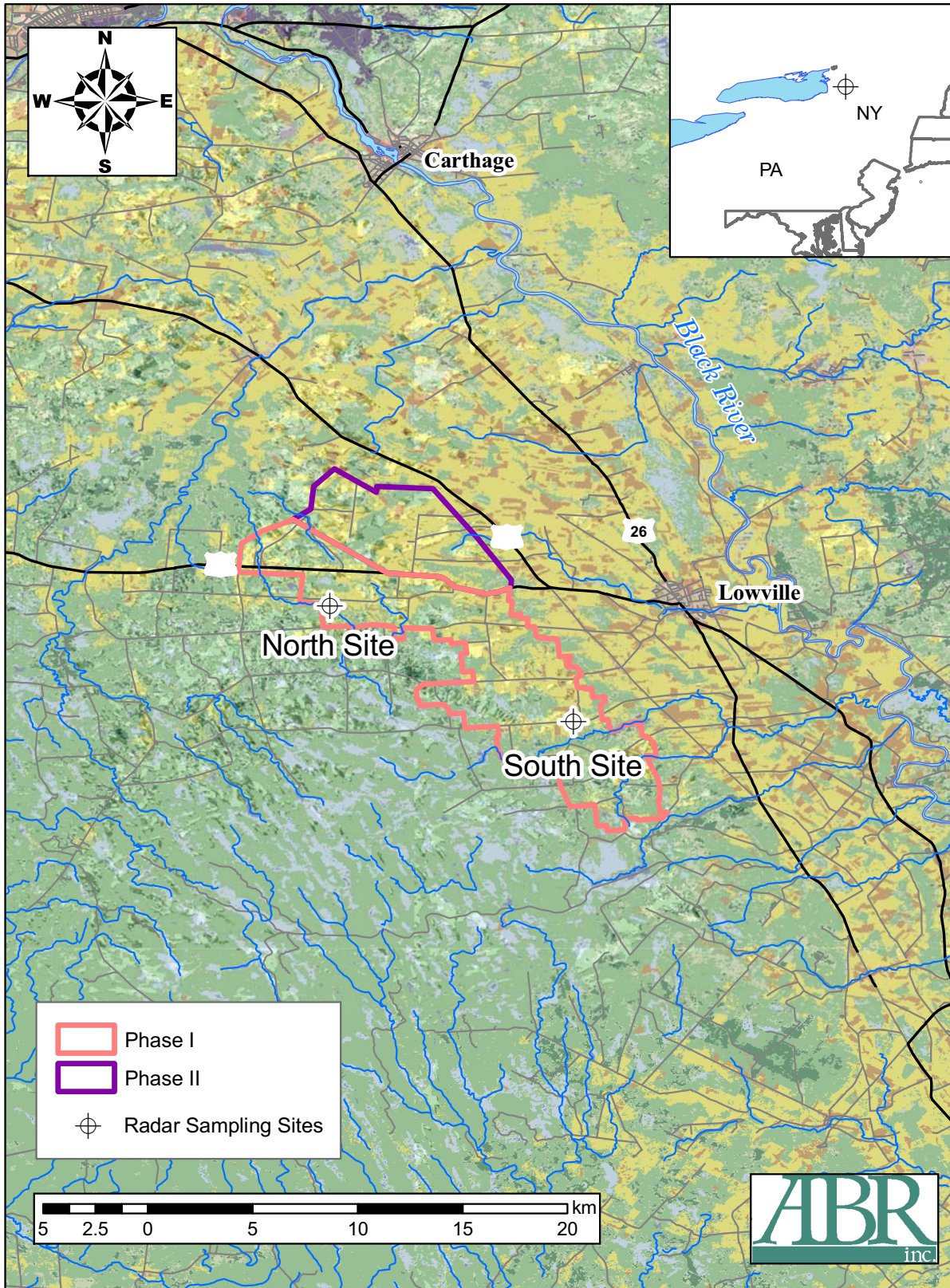


Figure 1. Map of the proposed Flat Rock Wind Power project in Lewis County, New York.

This proposed development is located ~2–11 miles (~3.2–17.6km) west of Lowville, NY. The project area consists primarily of a mix of open farmland (dairy, corn, alfalfa, hay), forest, and small wetlands (usually < 1 acre), interspersed with limited residential development. Virtually all of the land previously has been logged, with existing forests consisting of a mix of hardwoods (beech, maple, white ash) and conifers (hemlock, red spruce, white pine) with most trees being young in age (few >40 yrs) and canopies seldom exceeding 40–50 ft. (12–15 m). Our radar sampling sites were located north of Highway 177 near Kubinski Road (UTM Zone 18 445636E 4850642N) in the northern part of the project, and north of Flat Rock road east of Centerville Road (UTM Zone 18 455911E 4842734N) in the southern portion of the proposed wind power development (Fig. 1).

METHODS

STUDY DESIGN

We conducted radar and visual observations on 60 nights between 5 August and 3 October 2004, to overlap with the peak of the passerine bird and tree-roosting bat migration periods during late summer and fall (Buffalo Ornithological Society 2002, Johnson 2004). We conducted radar observations during 57 nights (50 nights for visual observations); on the remaining three nights, we were unable to sample with either technique because of inclement weather (rain). Each night, we conducted ~3 h of radar and visual observations at both the northern and southern sites. We alternated the starting location and observer to balance the sampling schedule and minimize observer bias. Radar and visual surveys occurred between ~2000 and ~0230, to cover the peak hours of nocturnal passerine migration within nights (Lowery 1951, Gauthreaux 1971, Alerstam 1990, Kerlinger 1995). Because this temporal sample encompasses both the peak period and the majority (65%) of hours of migration within a night, the results and inferences based on them are suitable for characterizing migration characteristics.

RADAR EQUIPMENT

Our mobile radar laboratory consisted of a marine radar that was mounted on the roof of a van

and that functioned as both a surveillance and vertical radar. When the antenna was in the horizontal position (i.e., in surveillance mode), the radar scanned the area surrounding the lab (Fig. 2), and we manually recorded information on flight direction, flight behavior, passage rates, and groundspeeds of targets. When the antenna was placed in the vertical position (i.e., in vertical mode), the radar scanned the area in an arc across the top of the lab (Fig. 3), and we manually measured flight altitudes of targets with an index line on the monitor. All data was recorded manually into a laptop computer. A description of a similar radar laboratory can be found in Gauthreaux (1985a, 1985b) and Cooper et al. (1991), and a similar vertical radar configuration was described by Harmata et al. (1999).

The radar (Furuno Model FR-1510 MKIII; Furuno Electric Company, Nishinomiya, Japan) is a standard marine radar transmitting at 9.410 GHz (i.e., X-band) through a 2-m-long slotted waveguide (antenna) with a peak power output of 12 kW. The antenna had a beam width of 1.23° (horizontal) × 25° (vertical) and a variable sidelobe. Range accuracy is 1% of the maximal range of the scale in use or 30 m (whichever is greater) and bearing accuracy is ±1°.

This radar can be operated at a variety of ranges (0.5–133 km) and pulse lengths (0.07–1.0 µsec). We used a pulse length of 0.07 µsec while operating at the 1.5-km range. At shorter pulse lengths, echo resolution is improved (giving more accurate information on target identification, location, and distance), whereas, at longer pulse lengths, echo detection is improved (increasing the probability of detecting a target). An echo is a picture of a target on the radar monitor; a target is one or more birds (or bats) that are flying so closely together that the radar displays them as one echo on the display monitor. This radar has a digital color display with several scientifically useful features, including True North correction for the display screen (to determine flight directions), color-coded echoes (to differentiate the strength of return signals), and on-screen plotting of a sequence of echoes (to depict flight paths). Because targets plot every sweep of the antenna (i.e., every 2.5 sec) and because groundspeed is directly proportional to the distance between consecutive echoes, we were able to measure

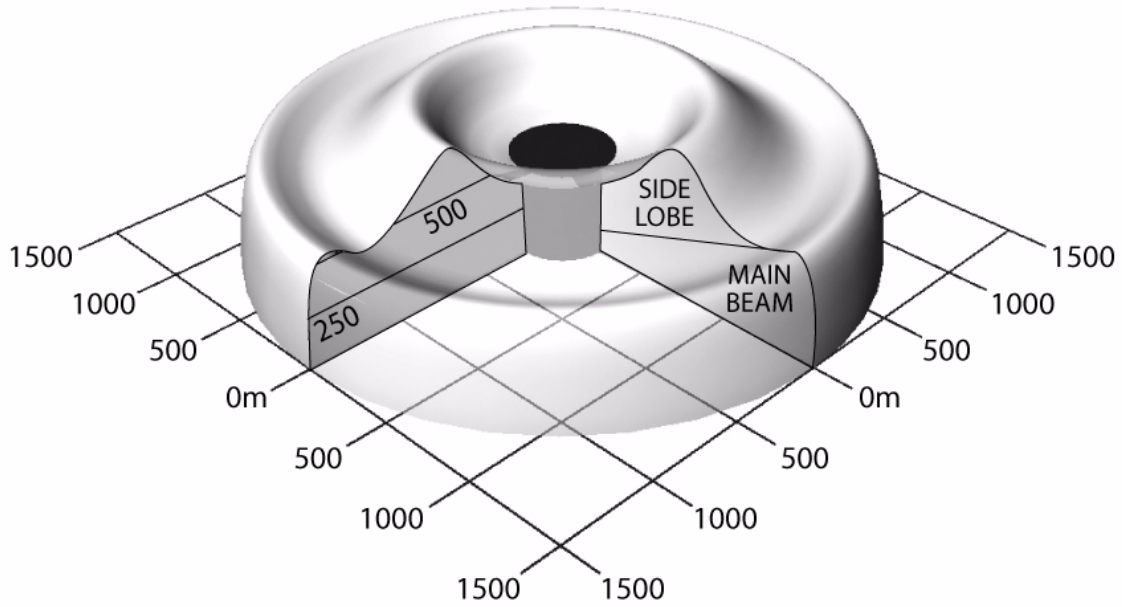


Figure 2. Approximate airspace sampled by Furuno FR-1510 marine radar when operating in the surveillance mode (antenna in the horizontal orientation) as determined by field trials with Rock Pigeons. Note that the distribution of the radar beam within 250 m of the origin (i.e., the darkened area) was not determined.

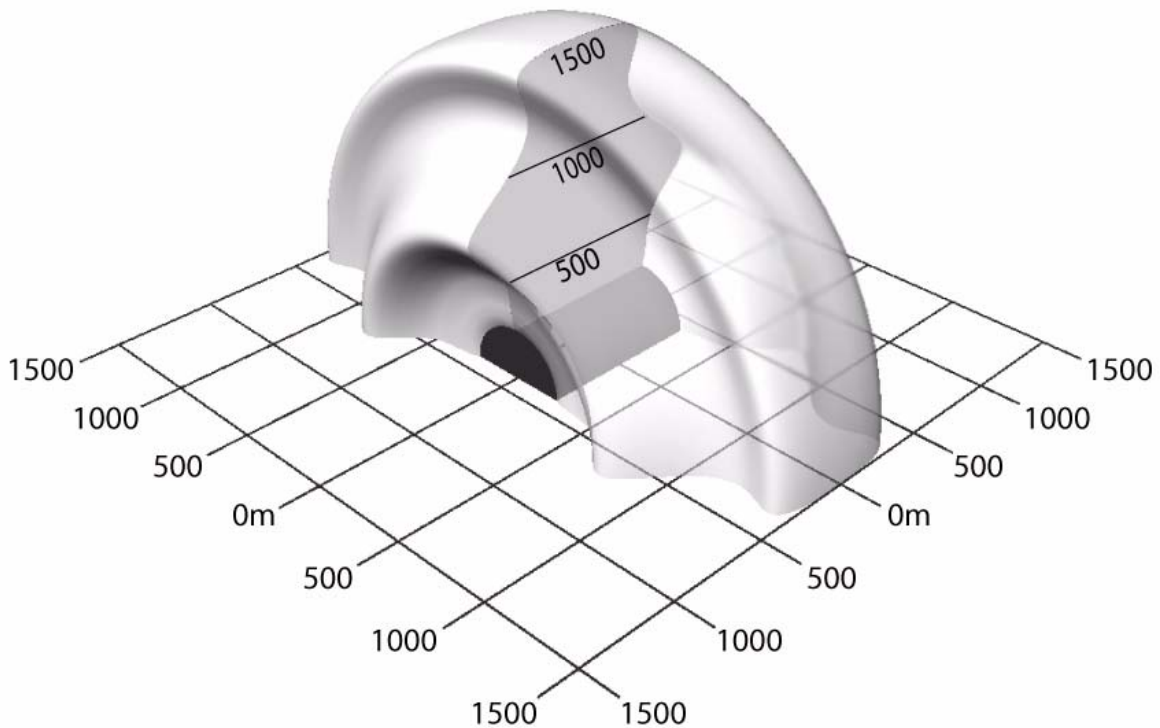


Figure 3. Approximate airspace sampled by Furuno FR-1510 marine radar when operating in the vertical mode (antenna in the vertical orientation) as determined by field trials with Rock Pigeons. Note that the distribution of the radar beam within 250 m of the origin (i.e., the darkened area) was not determined.

ground speeds of plotted targets to the nearest 5 mi/h (8 km/h) with a hand-held scale.

Energy reflected from the ground, surrounding vegetation, and other solid objects that surround the radar unit causes a ground-clutter echo to appear on the display screen. Because ground-clutter echoes can obscure targets, we minimized their occurrence by elevating the forward edge of the antenna by $\sim 15^\circ$ and by parking the mobile radar laboratory in locations that were surrounded fairly closely by low trees or low hills, whenever possible. These objects act as a radar fence that shields the radar from low-lying objects farther away from the lab and that produce only a small amount of ground clutter in the center of the display screen. For further discussion of radar fences, see Eastwood (1967), Williams et al. (1972), Skolnik (1980), and Cooper et al. (1991).

Maximal distances of detection of targets by the surveillance radar depends on radar settings (e.g., gain and pulse length), target body size, flock size, flight profile, proximity of targets in flocks, atmospheric conditions, and, to some extent, the amount and location of ground clutter. Flocks of waterfowl routinely were detected to 5–6 km, individual hawks usually were detected to 2–3 km, and single, small passerines were routinely detected out to 1–1.5 km (Cooper et al. 1991).

DATA COLLECTION

TARGET IDENTIFICATION ON RADAR

The species composition and size of a flock of birds or bats observed on the radar usually was unknown. Therefore, the term “target,” rather than “flock” or “individual,” is used to describe animals detected by the radar. Based on the study period and location, it is likely that the majority of targets that we observed were individual passerines, which generally do not migrate in tight flocks (Lowery 1951, Kerlinger 1995); it also is likely that a smaller number of targets were migratory bats. Differentiating among various targets (e.g., birds, bats, insects) is central to any radar study, especially with X-band radars that can detect small flying animals. Because bat flight speeds overlap with flight speeds of passerines (i.e., are >6 m/s; Tuttle 1988, Larkin 1991, Bruderer and Boldt 2001, Kunz and Fenton 2003; Cooper and Day, ABR Inc., unpubl. data), it was not possible to

separate bird targets from bat targets based solely on flight speeds. We were able to exclude foraging bats based on their erratic flight patterns; however, it is likely that migratory bats or any bats not exhibiting erratic flight patterns were included in our data.

Of primary importance in target identification is the elimination of insect targets. We reduced insect contamination by (1) omitting small targets (the size of gain speckles) that only appeared within ~ 500 m of the radar and targets with poor reflectivity (e.g., targets that plotted erratically or inconsistently in locations having good radar coverage); and (2) editing data prior to analyses by omitting surveillance and vertical radar targets with corrected airspeeds <6 m/s (following Diehl et al. 2003). The 6 m/s airspeed threshold was based on radar studies that have determined that most insects have an airspeed of <6 m/s, whereas that of birds and bats usually is 6 m/s (Tuttle 1988, Larkin 1991, Bruderer and Boldt 2001, Kunz and Fenton 2003; Cooper and Day, ABR Inc., unpubl. data).

RADAR SAMPLING DESIGN

Each of the six 1-hr nocturnal radar sampling sessions/night consisted of: (1) one 10 min session to collect weather data and adjust the radar to surveillance mode; (2) one 10-min session with the radar in surveillance mode (1.5-km range) for collection of information on migration passage rates; (3) one 15-min session with the radar in surveillance mode (1.5-km range) for collection of information on groundspeed, flight direction, tangential range (minimal perpendicular distance to the radar laboratory), transect crossed (the four cardinal directions—north, south, east, and west), species (if known), and the number of individuals (if known); (4) one 10-min session to collect weather data and adjust the radar to vertical mode; and (5) one 15-min session with the radar in vertical mode (1.5-km range) to collect information on flight altitudes, speed, and direction. Previous tests of the adequacy of our sampling intensity showed that our current sampling time periods are more than adequate to characterize the variability in both migration passage rates and flight altitudes (T. Mabee, ABR Inc., unpubl. data).

For each vertical radar session, the antenna was oriented parallel to the main axis of migration

(determined by the overall flight direction seen during the previous surveillance radar session) to maximize the true flight speed of targets. True flight speeds of targets can be determined only for those targets flying parallel to the antenna's orientation because slower speeds are obtained when targets fly at an angle to this plane of orientation.

Weather data collected at the beginning of each hour consisted of the following: wind speed (collected with a "OMNI" anemometer in 5-mi/h [2.2-m/s] categories); wind direction (in ordinal categories to the nearest 45°); cloud cover (to the nearest 5%); ceiling height (in m agl; 1–50, 51–100, 100–150, 151–500, 501–1,000, 1,001–2,500, 2,501–5,000, >5,000); minimal visibility in a cardinal direction (in m; 0–50, 51–100, 101–500, 501–1,000, 1,001–2,500, 2,501–5,000, >5,000); precipitation level (no precipitation, fog, drizzle, light rain, heavy rain, snow flurries, light snowfall, heavy snowfall, sleet, hail); and air temperature (measured with a thermometer to the nearest 1°C). We could not collect radar data during rain because the electronic filtering required to remove the echoes of the precipitation from the display screen also removed those of the targets of interest. We also obtained weather data (wind speed and wind direction) from a 50-m high meteorological tower located near each site.

VISUAL OBSERVATIONS OF LOW-ALTITUDE BIRDS AND BATS

We conducted visual observations every night (~40–50 min/h) to assess relative numbers of birds and bats flying within the projected rotor-swept area (i.e., <125 m agl). During the first hour of surveys (prior to ~2030), observers used 10× power binoculars to scan for bat activity during crepuscular (twilight) periods. During subsequent hours, 2-million-Cp spotlights with red lens filters (to reduce the attractiveness of the light to insects, and possibly birds and bats) were used to illuminate targets flying overhead. One "fixed" spotlight was mounted on a tripod with the beam oriented vertically, while a second, handheld light was used to track and identify potential targets flying through the fixed beam. For each bird or bat detected visually, we recorded the species (when possible) or nearest taxon, flight direction, flight

altitude, and behavior (straight-line, erratic, circling). Bats were classified as "large bats" or "small bats" whenever possible in an attempt to discriminate the larger Hoary, Eastern Red, and Silver-haired bats from smaller species (e.g., *Myotis* spp.). Observers used 1X ATN-PVS7 Generation 3 night-vision goggles to enhance the detectability of targets. All observers were trained to distinguish birds and bats from insects by several methods: (1) repeated exposure to various sized bird and bat targets at different distances from the observer, (2) observation of bats off site (flying in and out of roost sites), and (3) concurrent observations with another observer (without night vision goggles) to assess the size of birds and bats.

DATA ANALYSES

RADAR DATA

We entered all radar data into MS Excel databases. Data files were checked visually for errors after each night and then were checked again electronically for irregularities at the end of the field season, prior to data analyses. All analyses were conducted with SPSS statistical software (SPSS 2003). For quality assurance, we cross-checked results of the SPSS analyses with hand-tabulations of small data subsets whenever possible. The level of significance (α) for all statistical tests was set at 0.05.

Radar data were not corrected for differences in detectability with distance from the radar unit. Correcting for differences in target detectability is confounded by several factors, including but not limited to the following: (1) variation in target size (i.e., species) across the study period; (2) an assumption that there is an equal distribution of targets throughout the sampling area (which would be violated if migrants responded to landform or microsite features on the landscape); (3) variation in the shape and size of the effective radar-sampling beam (see our preliminary assessment of the shape of our radar beam under one set of conditions in Figures 2 and 3). Thus, our passage rate estimates (and other estimates derived from passage rates) should be considered an index of the actual number of birds and bats passing through the area, useful for comparisons with our previous studies and other radar studies that use similar equipment.

Airspeeds (i.e., groundspeed corrected for wind speed and relative direction) of surveillance-radar targets were computed with the formula:

$$V_a = \sqrt{V_g^2 + V_w^2 - 2V_g V_w \cos\theta}$$

where V_a = airspeed, V_g = target groundspeed (as determined from the radar flight track), V_w = wind velocity, and θ is the difference between the observed flight direction and the direction of the wind vector. Targets that had corrected airspeeds <6 m/s (16.2% of surveillance data; 34.5% of vertical data) were deleted from all analyses.

We analyzed flight-direction data following procedures for circular statistics (Zar 1999) with Oriana software version 2.0 (Kovach 2003). The dispersion of flight directions is presented as the mean vector length (r), which varies from a value of 0 (maximal dispersion) to 1 (maximal concentration). Migration passage rates are reported as the mean \pm 1 standard error (SE) number of targets passing along 1 km of migratory front/h (targets/km/h \pm 1 SE). Passage rates of targets flying <125 m in altitude were derived for each hourly period by multiplying passage rates recorded from surveillance radar by the percentage of targets on vertical radar having flight altitudes <125 m. All flight-altitude data are presented in m agl (above ground level) relative to a horizontal plane passing through the radar-sampling site. Actual mean altitudes may be higher than those reported because an unknown number of birds fly above the 1.5-km range limit of our radar (Mabee and Cooper 2004).

For calculations of the daily patterns in migration passage rates and flight altitudes, we assumed that a day began at 0700 on one day and ended at 0659 the next day, so that a sampling night was not split between two dates. We used repeated-measures ANOVAs with the Greenhouse-Geisser epsilon adjustment for degrees of freedom (SPSS 2003), to compare passage rates among hours of the night for nights with data collected during all six sessions. Factors that decreased our sample size of the various summaries and analyses included insect contamination and inclement weather (rain).

Sample sizes therefore sometimes varied among the different summaries and analyses.

THE EFFECTS OF WEATHER ON MIGRATION PASSAGE RATES AND FLIGHT ALTITUDES

We examined the hourly relationships between passage rates, flight altitudes, and weather conditions because of the dynamic weather conditions within a night. This treatment of the data, however, may violate the assumption of statistical independence; therefore, our results may overemphasize the strength of the relationships presented.

We modeled the hourly influence of weather and date separately on the dependent variables passage rates and flight altitudes. We obtained our weather data (i.e., wind speed and direction) from a 50-m meteorological tower located <0.5 km from each radar sampling site. All wind categories except the calm category had a mean wind speed of ≥ 2.2 m/s (i.e., ≥ 5 mph) and were categorized as the following: headwinds ESE to SSW (i.e., 113°–248°), tailwinds WNW to ENE (i.e., 293°–068°), crosswinds (069°–112°; 249°–292°), and calm (0–2.2 m/s).

Prior to model specification, we examined the data for redundant variables (Spearman's $r_s > 0.70$) and retained four parameters for inclusion in the model set. We examined scatterplots and residual plots to ensure that variables met assumptions of analyses (i.e., linearity, normality, collinearity) and did not contain presumed outliers (> 4 SE). We used a logarithmic transformation on the dependent variable "passage rate" to make the data more normal, whereas we used a square root transformation on flight altitudes to make them normally distributed. We specified 8 models for passage rates and flight altitudes: a global model containing all variables and subset models representing potential influences of two weather variables (wind direction, wind speed), date, and radar sampling site on migration passage rates and flight altitudes. We analyzed all model sets with linear regression. Prior to model selection, we examined the fit of global models following recommendations of Burnham and Anderson (1998) that included examining residuals and measures of fit ($R^2 = 0.32$ for passage-rate models; $R^2 = 0.25$, for flight-altitude models).

Because the number of sampling sessions for both passage rates ($n = 305$) and flight altitudes ($n = 303$) was small relative to the number of parameters (K) in many models (i.e., $n/K < 40$), we used Akaike's Information Criterion corrected for small sample size (AIC_c) for model selection (Burnham and Anderson 1998). We used the formulas presented in Burnham and Anderson (1998) to calculate AIC_c for our least-squares (linear regression) methods. We ranked all candidate models according to their AIC_c values and considered the best-approximating model (i.e., most parsimonious) to be that model having the smallest AIC_c value (Burnham and Anderson 1998). We drew primary inference from models within 2 units of the minimal AIC_c value, although models within 4–7 units may have some empirical support (Burnham and Anderson 1998). We calculated Akaike weights (w_i) to determine the weight of evidence in favor of each model and to estimate the relative importance of individual parameters (Burnham and Anderson 1998). All analyses were conducted with SPSS software (SPSS 2003).

RESULTS

FLIGHT DIRECTION

Overall, most radar targets were traveling in seasonally appropriate directions for fall nocturnal migration (i.e., southerly), with a mean flight direction of 184° (mean vector length = 0.42; $n = 10,619$ targets; Fig. 4). Most (75%) of the nocturnal targets were traveling in a southerly direction, with over half (54%) of the flight directions occurring between SE (135°) and SW (225°). Mean flight directions were significantly different between the North (mean = 195° , $r = 0.51$; $n = 5,645$ targets) and South (mean = 167° , $r = 0.35$; $n = 4,974$ targets) stations (Fig. 4; $W = 479$, $P < 0.001$).

PASSAGE RATES

The mean nocturnal passage rate index for the fall season was 158 ± 21 targets/km/h ($n = 57$ total nights). Mean passage rates did not differ significantly between the North (165.7 ± 27.2) and South (150.9 ± 19.2) stations ($Z_{paired} = -1.079$, $P = 0.28$, $n = 49$ paired nights). Mean nightly passage

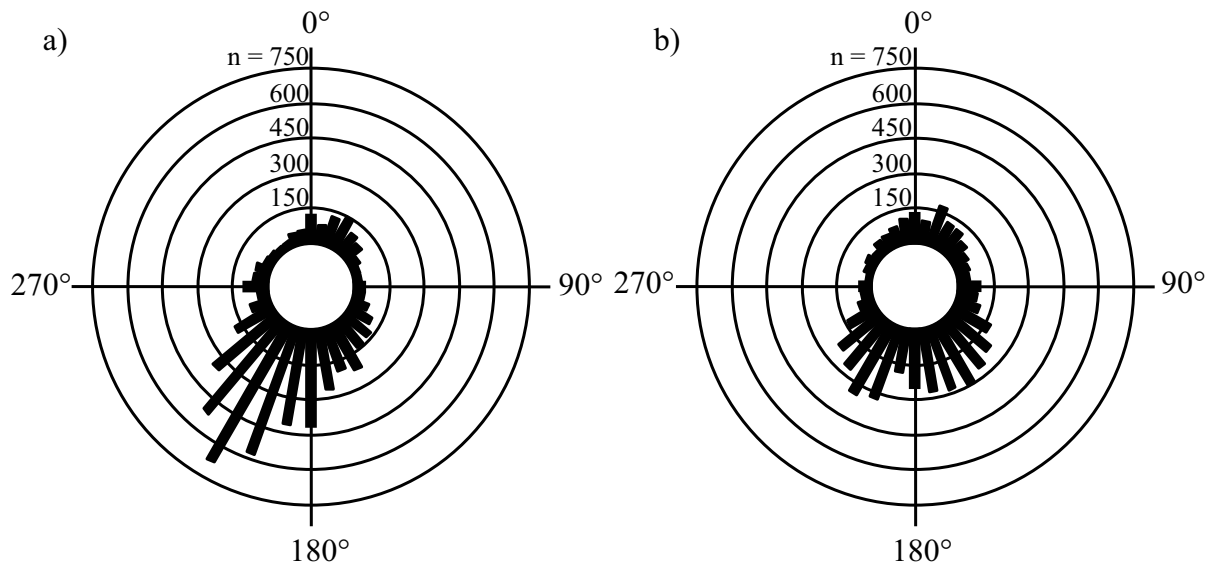


Figure 4. Flight directions of radar targets at the North (a) and South (b) radar sampling sites at the proposed Flat Rock Wind Power project, New York fall 2004.

rates were highly variable among nights at both the North (range = 5 – 704 targets/km/h) and South (range = 19 – 645 targets/km/h) sites; Fig.5). Passage rates varied significantly among hours of the night ($F_{2,6, 96,3} = 15.171$; $P < 0.001$; $n = 38$ full nights of sampling; Fig. 6), with lowest rates occurring during the first hour of darkness.

FLIGHT ALTITUDES

The mean nocturnal flight altitude for the entire fall season was 415 ± 2 m agl ($n = 12,803$ targets; median = 362 m agl). The mean flight altitude at the North site (430 ± 4 m agl) was slightly higher than that at the South site (399 ± 3 m agl; $t_{paired} = 2.094$, $p = 0.042$, $n = 47$ nights). Flight altitudes were highly variable among nights, with means ranging from 219 to 691 m agl at the North site and from 194 to 604 m agl at the South site (Fig. 7). The altitudinal distribution of targets did not appear to vary among hours between the North ($n = 54$ nights) and South ($n = 53$ nights) sites (Fig. 8). The overall distribution of targets in 100-m categories of flight altitudes varied from ~18–20% in the 201–300 m agl and 301–400 m agl intervals to 0.1% in the 1,401–1,500 m agl interval (Table 1). We determined that 7.2% of targets at the North site and 8.0% of targets at the South site flew <125 m, which is the approximate maximal height of the proposed wind turbines. A breakdown of cumulative percentages of targets within 25-m altitude categories (up to 250 m agl) is provided in Appendix 1 for additional information on this relationship.

EFFECTS OF WEATHER ON MIGRATION

We investigated the importance of weather (i.e., wind direction, wind speed, fog, ceiling height, site) and date on both the passage rates and flight altitudes of nocturnal migrants by building a series of models (combinations of the various weather variables and date), then using a model-selection technique (AIC) to quantify the statistical strength of those models. The AIC method allows one to (1) rank and identify the “best” model(s) (i.e., the most statistically supported models) from the full set of models, and (2) assess the statistical strength and relative importance of individual variables composing the “best” models.

PASSAGE RATES

The best-approximating model explaining migration passage rates of nocturnal migrants during fall migration was the global model containing the variables wind direction, wind speed, date, and site (Table 2). The next best model also received some empirical support ($\Delta AICc = 2.89$). The best model contained positive associations with tailwinds, crosswinds, and date, (i.e., passage rates increased during these wind conditions and also increased as the season progressed) and negative associations with wind speed and site (i.e., passage rates decreased when wind speeds increased, and passage rates were lower at the North site; Table 3). The weight of evidence in favor of the “best” model ($w_{best}/w_{second\ best}$) was 4.2 times that of the second best model. The Σw_i suggested that both wind direction (1.0), date (1.0), and wind speed (0.95) were more important than site (0.77).

FLIGHT ALTITUDES

The best-approximating model explaining flight altitudes of nocturnal migrants during fall migration was the model containing the variables wind direction, wind speed, and date (Table 4). The next two best models also received some empirical support ($\Delta AICc = 2.2$; Table 4). The top three models contained positive associations with tailwinds, crosswinds, and date (i.e., altitudes increased during these wind conditions and also increased as the season progressed), and strong negative associations with wind speed (i.e., altitudes decreased under these conditions; Table 5). Flight altitudes were not related to calm conditions, and site. The weight of evidence in favor of the “best” model ($w_{best}/w_{second\ best}$) was 2.3 times that of the second best model. The Σw_i suggested that both wind direction (1.0) and wind speed (1.0) were more important than date (0.81) and site (0.25).

TURBINE PASSAGE RATE INDEX

In the fall, the overall mean passage rate index of targets <125 m across both sites was 11.4 ± 1.4 targets/km/h (range 0 – 106 targets/km/h, $n = 53$ nights). The mean passage rate of targets <125 m was 10.3 ± 2.3 targets/km/h (range 0 – 106 targets/km/h, $n = 53$ nights) at the North site and

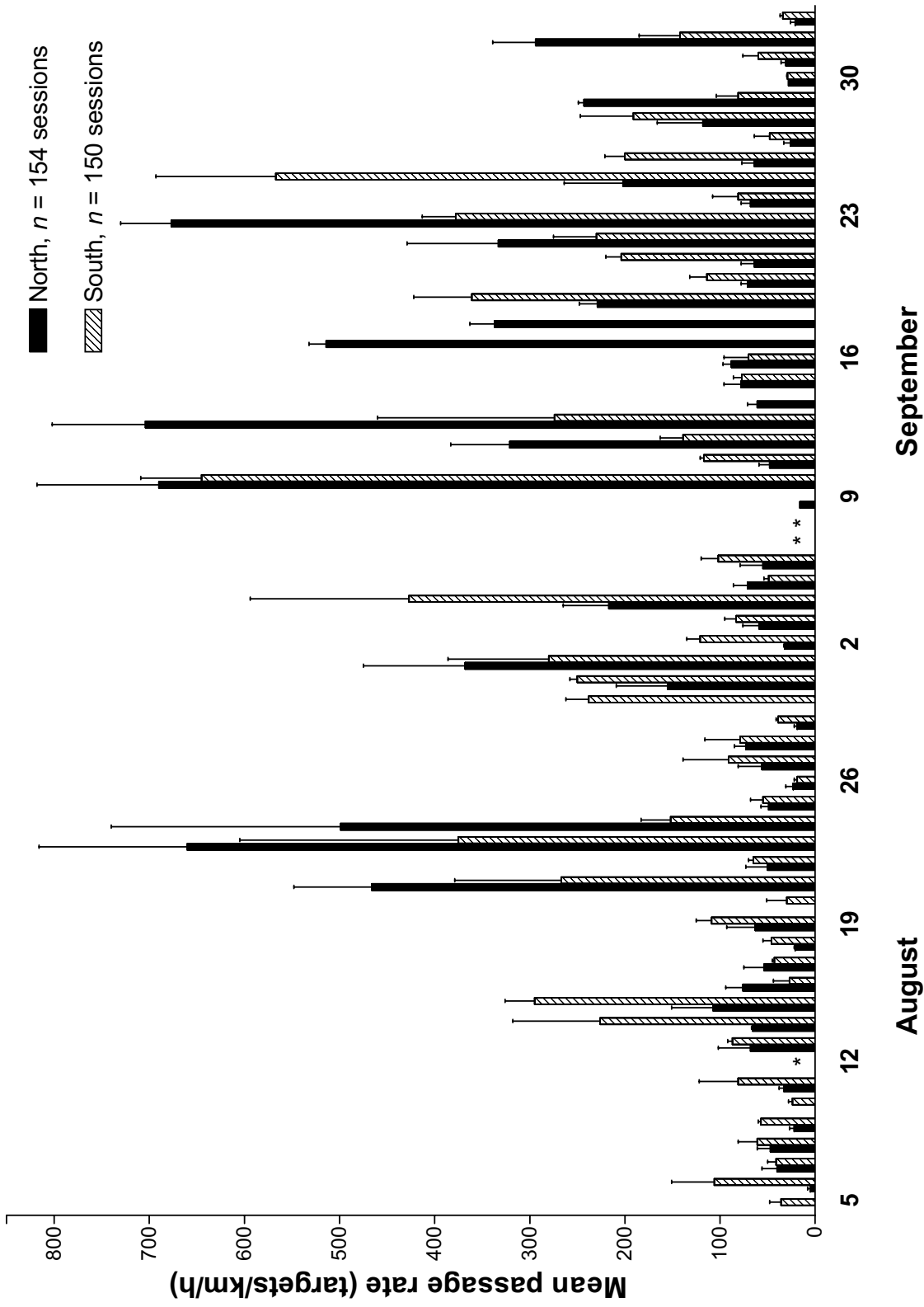


Figure 5. Mean \pm 1 SE nightly passage rates (targets/km/h) at the proposed Flat Rock Wind Power project, New York, fall 2004. Asterisks denote nights not sampled because of rain ($n = 3$).

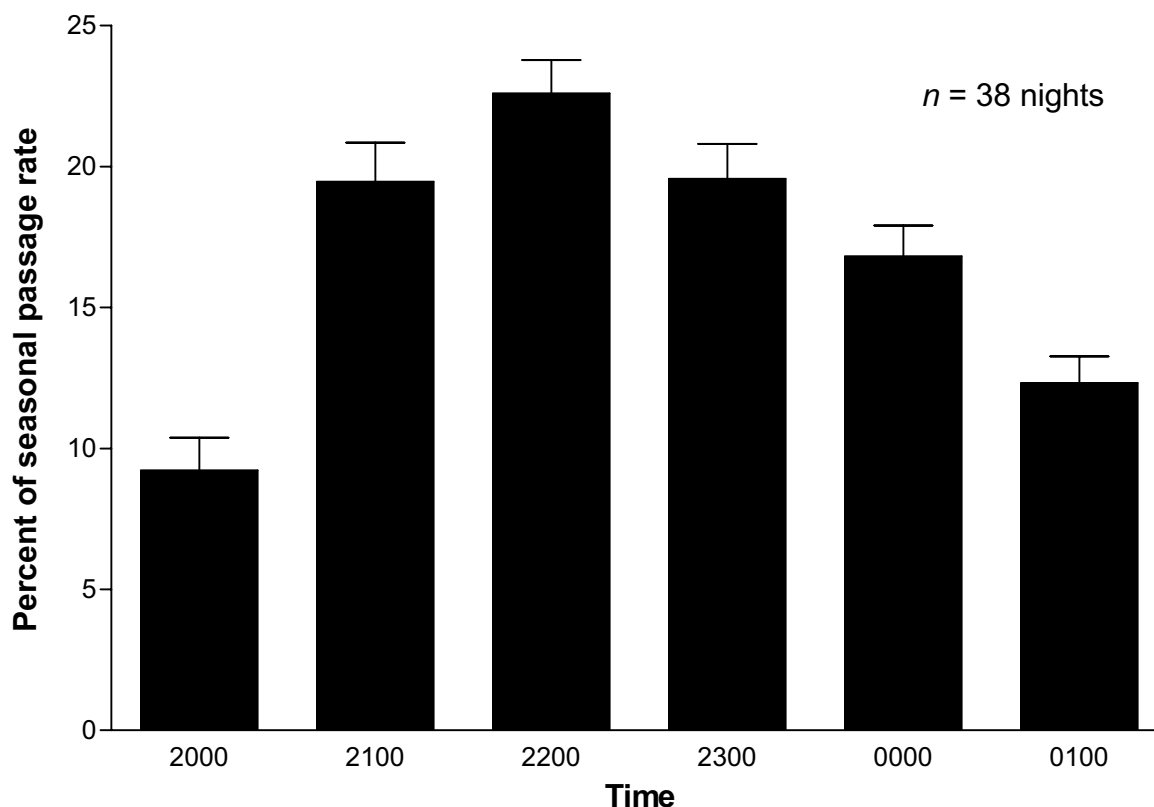


Figure 6. Percent of seasonal passage rate (\pm 1SE) by hour of the night (e.g., 2100–2159) at the proposed Flat Rock Wind Power project, New York, fall 2004.

12.4 \pm 1.7 targets/km/h at the South site (range 0 – 61 targets/km/h, n = 53 nights). We made several assumptions to estimate the turbine passage rate (i.e., the number of targets that would pass within the area occupied by each proposed turbine): (1) the minimal area occupied by the wind turbine (i.e., side profile), (2) the maximal area occupied by the wind turbine (i.e., front profile, including the rotor-swept area), (3) a worst-case scenario of the rotor blades turning constantly (i.e., used the entire rotor swept area, not just the area of the blades themselves), (4) 60 d in the study, and (5) an average of 10 nocturnal hours/day across the 60-d period. If all migrants approached the turbines from the side, an estimated 39 migrants would have passed within the area occupied by one turbine. If all migrants approached the turbines from the front, an estimated 275 migrants would

have passed within the area occupied by one turbine (Appendix 2).

VISUAL DATA

GENERAL BIRD AND BAT OBSERVATIONS

We collected visual data on 50 nights during the fall field season at the North (n = 6,085 min of sampling) and South (n = 5,668 min of sampling) sites, using night vision goggles and two 2-million-candlepower spotlights covered with red lens filters. We did not observe any bats moving during crepuscular sessions (~1930–2015) at either site (North: 449 min over 15 days; South: 396 min over 15 days). We were able to identify 82% of all targets (n = 1,049) at the North Site, and 79% of all targets (n = 878) at the South site as either birds or bats (Table 6).

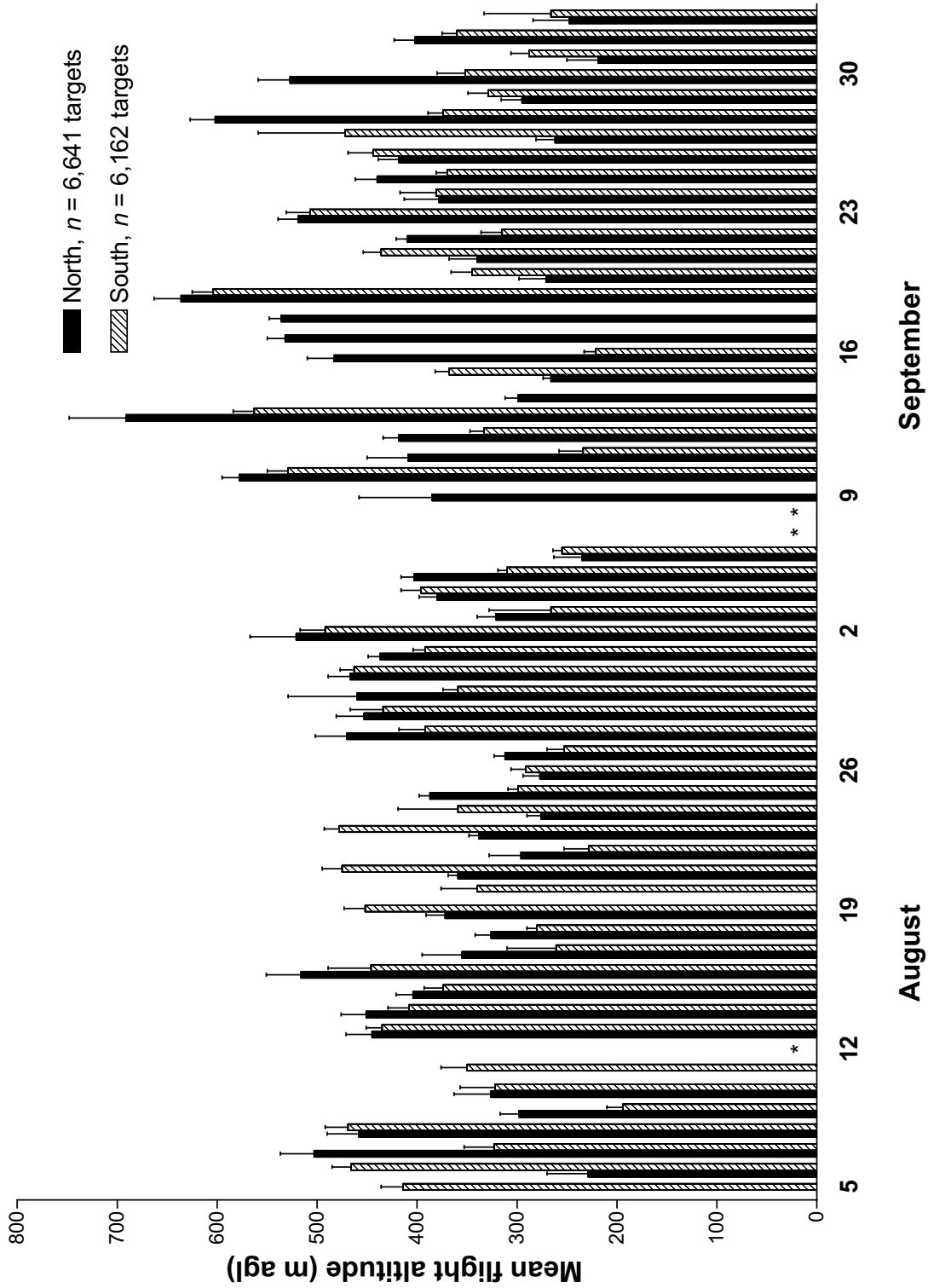


Figure 7. Mean \pm 1 SE nightly flight altitudes (m agl) at the proposed Flat Rock Wind Power project, New York, fall 2004. Asterisks denote nights not sampled because of rain ($n = 3$).

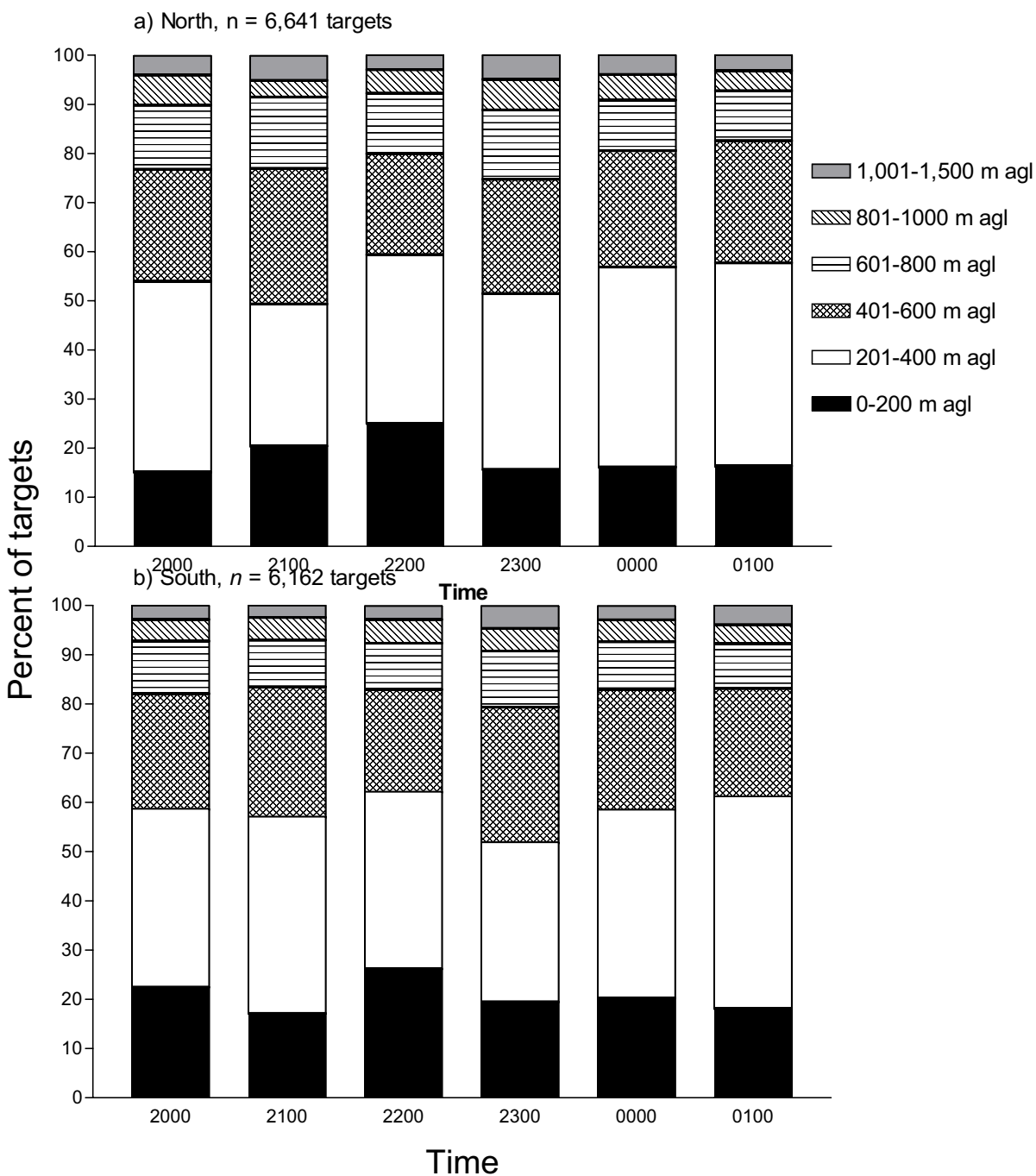


Figure 8. Percent of radar targets at each altitude at the proposed Flat Rock Wind Power project, New York, fall 2004, by hour of the night (e.g., 2100–2159).

Table 1. Nocturnal flight altitudes of radar targets (% of all targets) detected at the 1.5-km range at the Flat Rock Wind Power project, NY, fall 2004, by flight-altitude category. Total $n = 12,803$ targets.

Flight altitude (m agl)	Percent of radar targets	
	North, $n = 6,641$ targets	South, $n = 6,162$ targets
0–100	4.9	5.1
101–200	13.3	15.9
201–300	18.2	19.6
301–400	18.3	17.9
401–500	13.6	14.8
501–600	10.2	9.3
601–700	7.9	6.1
701–800	4.7	3.8
801–900	2.8	2.6
901–1,000	2.2	1.8
1,001–1,100	1.7	1.4
1,101–1,200	1.3	0.8
1,201–1,300	0.6	0.6
1,301–1,400	0.3	0.2
1,401–1,500	0.1	0.0

During nocturnal hours, we observed a total of 1,383 birds and 179 bats at both sites (Table 6). The vast majority of birds were passerines ($n = 1,211$), with smaller numbers of Canada Geese ($n = 132$), unidentified ducks ($n = 4$), and American Crows ($n = 2$; Table 6). Most bats ($n = 154$) observed were small in size, although some larger bats ($n = 21$) were also observed (Table 6). Overall patterns in the rates of bird and bat movements at the North (mean = 10.3 individuals/h) and South (mean = 9.3 individuals/h) sites were similar, with relatively low rates of bat movement at both sites and higher rates of bird movement (Fig. 9). In general, the percentage of birds increased during the study period, with a corresponding decrease in the percentages of bats (Table 7). Observation rates of small bats generally were higher than those of large bats throughout the study period (Table 7). The proportions of birds and bats flying $< \sim 150$ m agl (i.e., our effective sampling distance with the night-vision goggles and spotlights) were 91% birds and 9% bats ($n = 865$ identifiable targets) at the North site and 85% birds and 15% bats ($n = 697$ identifiable targets) at the South site.

BIRD AND BAT BEHAVIORAL OBSERVATIONS

We recorded whether birds reacted to our spotlights (i.e., noticeably changed flight direction, paused while in the light) throughout the fall. Overall, 72% of birds 50 m agl reacted, whereas only 34% of the birds 51 m agl reacted to light. In contrast, very few bats ($< 2\%$) reacted to spotlights at any altitude.

We investigated bat flight behavior by recording whether bats flew directly across our field of view (i.e., had an overall linear flight path) or if they had an erratic flight path (characterized by zig-zag flight patterns). Overall, small bats ($n = 162$ bats) flew in a linear (74%), erratic (25%), or circular (1%) flight paths, whereas, large bats ($n = 24$ bats) flew in a linear (92%) or erratic (8%) flight paths.

We also examined a subset of bat flight observations where bats were flying 55 m agl over the meteorological towers and could have potentially reacted with the guy wires or meteorological tower pole ($n = 91$ bat

Table 2. Linear-regression models explaining the influence of environmental factors on migration passage rates of bird and bat targets on surveillance radar at the Flat Rock Wind Power project, NY, fall 2004 ($n = 305$ sampling sessions). Model weights (w_i) were based on Akaike's Information Criterion (AIC).

Model	RSS ^a	K ^b	AIC ^c	Δ AIC ^d	w_i ^e
Global model: wind direction + wind speed + date + site	52.69	8	-519.06	0.00	0.77
Wind direction + wind speed + date	53.56	7	-516.17	2.89	0.18
Wind direction + date	54.39	6	-513.58	5.48	0.05
Wind direction	59.31	5	-489.25	29.81	0.00
Wind direction + wind speed	59.16	6	-487.94	31.12	0.00
Date	65.49	3	-463.14	55.92	0.00
Wind speed	72.33	3	-432.84	86.22	0.00
Site	77.27	3	-412.69	106.37	0.00

^a Residual sum of squares.

^b Number of estimable parameters in approximating model.

^c Akaike's Information Criterion corrected for small sample size.

^d Difference in value between AIC_c of the current model versus the best approximating model with the minimal AIC_c value.

^e Akaike weight—probability that the current model (i) is the best approximating model among those being considered.

Table 3. Parameter estimates from the best-approximating model explaining the influence of environmental factors on passage rates of bird and bat targets at the Flat Rock Wind Power project, NY, fall 2004 ($n = 305$ sampling sessions). Coefficients (B) of the categorical variables (wind direction, site) were calculated relative to headwinds and the South site.

Model	B	SE	R ²
Global model: wind direction + wind speed + date + site			0.320
Intercept	-0.063	0.348	
Wind direction = tailwind	0.480	0.068	
Wind direction = calm	0.098	0.160	
Wind direction = crosswind	0.341	0.065	
Site = North	-0.109	0.049	
Wind speed	-0.032	0.013	
Date	0.008	0.001	

observations). A reaction was defined as a noticeable shift in flight direction by the bat. Forty-seven % of the bats reacted and avoided the guy wires or pole, 23% did not react but simply flew by and did not collide with the guy wires or pole, and 30% flew underneath the guy wires and did not need to react to avoid colliding with any structure. Bat reaction distances (i.e., the distance at which a bat noticeably changed flight direction to avoid colliding with a guy wire or the meteorological pole) were recorded for a reduced subset of bats ($n = 28$ bats). On average bats flared to avoid colliding with a guy wire at $4.9 \text{ m} \pm 0.80 \text{ SE}$.

DISCUSSION

Predictions of the effects of wind power development on migratory birds and bats are hampered by a lack of detailed knowledge about patterns of the nocturnal migration and behavior of birds and bats around wind turbines. We have documented some of the key migration characteristics that can be used both to assess the risk of collision with wind turbines and to describe general properties of nocturnal bird and bat migration at the proposed project site.

TIMING OF MIGRATION

Understanding the timing of migration at multiple temporal scales (e.g., within nights, within

seasons, and seasonally within years) allows the determination of patterns of peak migration that can be used with other information, especially weather, to develop predictive models of avian and bat collision risks. Such models may be useful for both pre-construction siting decisions and for the consideration of operational strategies to reduce fatalities.

Within nights, fall passage rates increased ~1–2 h after sunset, peaked prior to midnight, then decreased slightly later in the evening. Several studies have found a pattern similar to this, in which the intensity of nocturnal bird migration begins to increase ~30–60 min after sunset, peaks around midnight, and declines steadily thereafter until dawn (Lowery 1951, Gauthreaux 1971, Kerlinger 1995, Farnsworth et al. 2004).

Within seasons, nocturnal migration often is a pulsed phenomenon (Alerstam 1990; Cooper and Day, ABR, unpubl. data). In this study, moderate–large mean nightly passage rates (>300 targets/km/h) occurred on 14 nights: 21, 23, 24 August and 1, 4, 10, 12, 13, 17, 18, 19, 22, 23, and 25 September. Overall, fall migration peaked at 704 targets/km/h on 13 September. Thus, the migratory period we studied was characterized by many migratory pulses throughout the season. In general, most fall songbird migration in this part of New York occurs between late August and mid-October (Cooper and Mabee 2000; Buffalo Ornithological Society 2002; W. Evans, Old Bird

Table 4. Linear-regression models explaining the influence of environmental factors on mean flight altitudes of bird and bat targets on vertical radar targets at the Flat Rock Wind Power project, NY, fall 2004 ($n = 303$ sampling sessions). Model weights (w_i) were based on Akaike's Information Criterion (AIC).

Model	RSS ^a	K ^b	AIC _c ^c	Δ AIC _c ^d	w_i ^e
Wind direction + wind speed + date	2109.26	7	602.31	0.00	0.56
Global model: wind direction + wind speed + date + site	2105.99	8	603.95	1.64	0.25
Wind direction + wind speed	2139.27	6	604.49	2.18	0.19
Wind direction	2332.82	5	628.66	26.35	0.00
Wind direction + date	2325.95	6	629.84	27.53	0.00
Wind speed	2412.55	3	634.72	32.41	0.00
Date	2879.70	3	688.35	86.04	0.00
Site	2881.56	3	688.54	86.23	0.00

^a Residual sum of squares.

^b Number of estimable parameters in approximating model.

^c Akaike's Information Criterion corrected for small sample size.

^d Difference in value between AIC_c of the current model versus the best approximating model with the minimal AIC_c value.

^e Akaike weight—probability that the current model (i) is the best approximating model among those being considered.

Table 5. Parameter estimates from the best-approximating model explaining the influence of environmental factors on mean flight altitudes of radar targets at the Flat Rock Wind Power project, NY, fall 2004 ($n = 303$ sampling sessions). Coefficients (B) of the categorical variables wind direction were calculated relative to headwinds.

Model	B	SE	R ²
Wind direction + wind speed + date			0.272
Intercept	17.199	2.232	
Wind direction = tailwind	1.918	0.435	
Wind direction = calm	-0.845	0.897	
Wind direction = crosswind	1.635	0.412	
Wind speed	-0.480	0.087	
Date	0.019	0.009	

Table 6. Birds and bats observed during nocturnal visual sampling at the North and South sites at the Flat Rock Wind Power project, NY, fall 2004.

Species group	Station				Total	
	North		South			
Passerines	649	(61.9%)	562	(64.0%)	1,211	(62.8%)
Non passerines ^a	126	(12.0%)	12	(1.4%)	138	(7.2%)
Unidentified birds	16	(1.5%)	18	(2.1%)	34	(1.8%)
Total birds	791	(75.4%)	592	(67.4%)	1,383	(71.8%)
Small bats	63	(6.0%)	91	(10.4%)	154	(8.0%)
Large bats	10	(1.0%)	11	(1.3%)	21	(1.1%)
Unidentified bats	1	(0.1%)	3	(0.3%)	4	(0.2%)
Total bats	74	(7.1%)	105	(12.0%)	179	(9.3%)
Unidentified (bird or bat)	184	(17.5%)	181	(20.6%)	365	(18.9%)
Total	1,049	(100.0%)	878	(100.0%)	1,927	(100.0%)

^a Includes Canada Geese ($n = 132$), Unidentified duck ($n = 4$), and American Crows ($n = 2$).

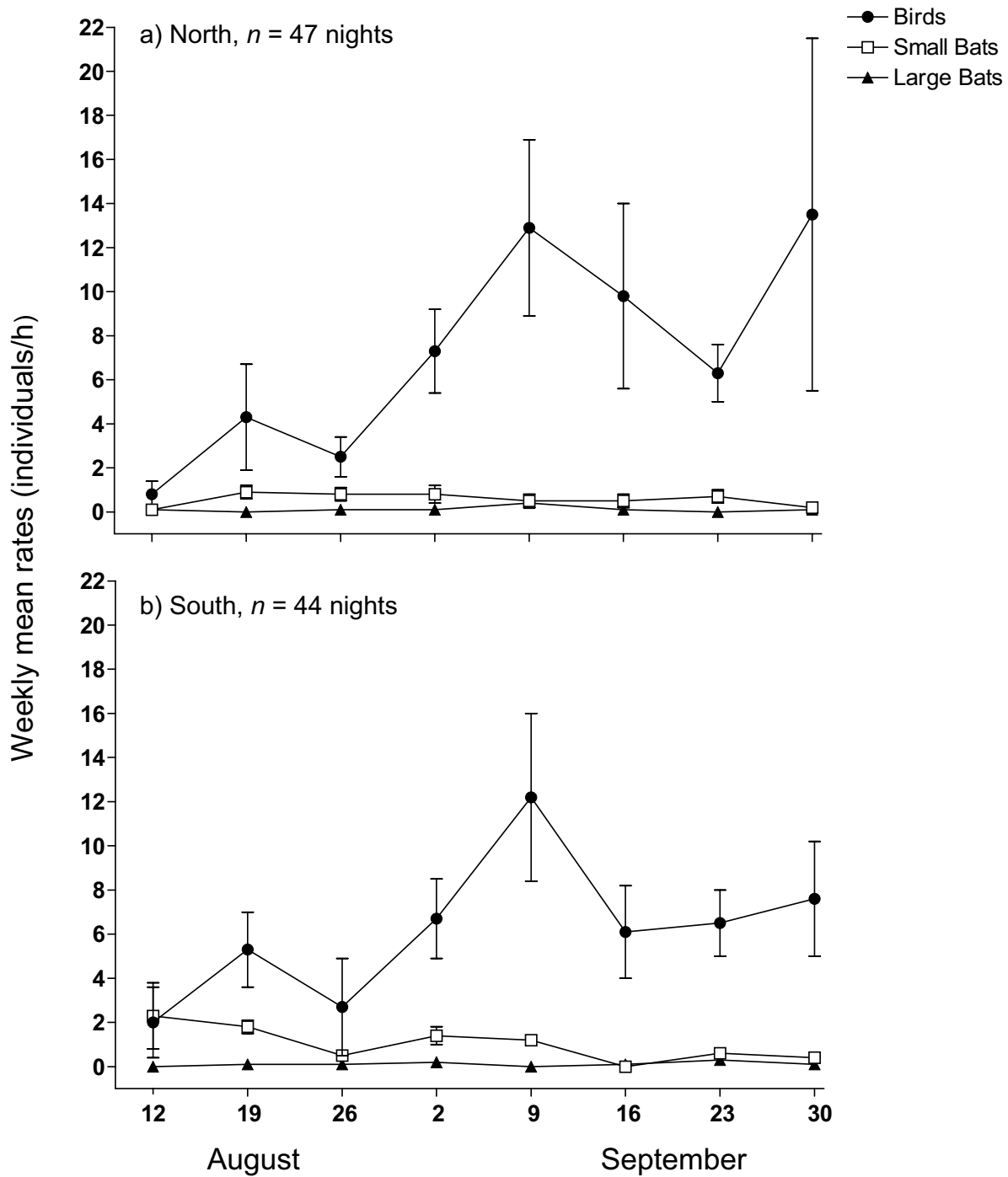


Figure 9. Weekly mean rates (number of individuals/h) of birds and bats observed during visual sampling at the proposed Flat Rock Wind Power project, New York, fall 2004. Asterisks denote nights not sampled because of rain ($n = 3$).

Table 7. Birds and bats observed during nocturnal visual sampling at the North and South sites at the Flat Rock Wind Power project, NY, fall 2004. Values represent observation rates [number of animals/h (%)] by week.

Dates	Station					
	North			South		
	Birds	Small bats	Large bats	Birds	Small bats	Large bats
8/10-8/16	0.9 (74%)	0.1 (13%)	0.1 (13%)	1.7 (48%)	1.9 (52%)	0.0 (0%)
8/17-8/23	3.4 (78%)	1.0 (22%)	0.0 (0%)	5.2 (73%)	1.8 (25%)	0.1 (2%)
8/24-8/30	2.8 (75%)	0.8 (21%)	0.2 (4%)	3.1 (81%)	0.6 (16%)	0.1 (3%)
8/31-9/6	7.3 (90%)	0.8 (9%)	0.1 (1%)	6.5 (80%)	1.4 (17%)	0.2 (3%)
9/7-9/13	15.1 (93%)	0.6 (4%)	0.4 (3%)	11.7 (91%)	1.1 (9%)	0.0 (0%)
9/14-9/20	11.4 (95%)	0.5 (4%)	0.2 (1%)	6.1 (98%)	0.0 (0%)	0.1 (2%)
9/21-9/27	6.3 (90%)	0.7 (10%)	0.0 (0%)	6.2 (88%)	0.6 (9%)	0.2 (3%)
9/28-10/4	15.0 (97%)	0.3 (2%)	0.1 (1%)	8.8 (95%)	0.4 (4%)	0.1 (1%)

Inc., pers. comm.) and it is believed that bat migration occurs in late July through mid-late September (Johnson 2004).

PASSAGE RATES

Passage rates are an index of the number of migrants flying past a location; thus, they may be useful to assess the relative importance of several sites being considered for wind power development. The high daily variation in migration passage rates during the fall (5–704 targets/km/h) seen in this study illustrates the importance of continuous sampling throughout each entire migration period to identify these few, but important, migration nights.

In this study we used our passage-rate data in two ways: (1) to examine the passage rate of all migrants passing over our study area, and (2) to examine the passage rate of migrants within the height of the proposed wind turbines (~125 m). Although both metrics are useful for comparing the relative importance of sites, the second metric is especially well suited for site comparisons among wind power developments because of its altitude-specific nature. This second metric also can be used as the starting point for a more in-depth risk assessment. Previous studies that conducted all night sampling at multiple sites showed that during early morning hours (i.e., ~midnight to sunrise) passage rates declined (Day and Byrne 1990) and flight altitudes either increased or were fairly constant (Day and Byrne 1990) or declined slightly (Day and Byrne 1990, Cooper and Ritchie 1995). We believe, therefore, that our estimate of the passage rate within the height of the proposed wind turbines is suitable for characterizing the whole night in this study.

The observed passage rates in the project area were comparable to those at other locations in New York where we have conducted fall migration studies with similar equipment and methods. The mean fall nocturnal passage rate in this study was 158 targets/km/h, compared with fall passage rates of 122 targets/km/h at Harrisburg, NY (located ~10 km northwest of Lowville, NY; Cooper and Mabee 2000); 168 targets/km/h at Wethersfield, NY (located ~246 km southwest of Lowville, NY; Cooper and Mabee 2000); 225 targets/km/h at Carthage, NY (located ~21 km northwest of

Lowville, NY; Cooper et al. 1995b), and 238 targets/km/h at Chautauqua, NY (located ~377 km southwest of Lowville, NY; Cooper et al. 2004). Fall passage rates in other locations in the eastern US were similar to what we recorded here (e.g., 199–241 targets/km/h at Mt. Storm, WV; Mabee et al. 2004). In contrast, lower passage rates have generally been observed in the Midwest (e.g., 27–108 targets/km/h at four sites in South Dakota and Minnesota; Day and Byrne 1990) and the West (e.g., 19–26 targets/km/h at the Stateline and Vansycle wind power facilities in eastern Oregon; Mabee and Cooper 2004).

Our estimates of passage rate indices below the proposed turbine height in the project area (11.4 targets/km/h flying <125 m agl) were lower than fall rates at the Chautauqua site in western New York (20.8 targets/km/h flying <140 m agl; Cooper et al. 2004) and less than those rates observed at the Mount Storm site along an Appalachian ridgeline in West Virginia (36.3 targets/km/h flying <125 m agl; Mabee et al. 2004). Unfortunately, we do not believe that it is appropriate to compare passage rates within turbine height in this study with other New York sites studied before 2001 (Wethersfield, Harrisburg, Carthage) because of different equipment (i.e., a different vertical radar configuration) used to measure flight altitude in those studies.

FLIGHT ALTITUDES

Flight altitudes are critical for understanding the vertical distribution of nocturnal migrants in the airspace and are another important metric for assessing the risk of avian fatality events at proposed wind power development sites. In general, passerines migrate at lower flight altitudes than do other major groups of over-land migrants such as shorebirds and waterfowl (Kerlinger 1995). Large kills of birds at tall, human-made structures (generally lighted and guyed communications towers; Avery et al. 1980) and the predominance of nocturnal migrant passerines at such kills (Manville 2000) indicate that large numbers of these birds fly <500 m agl on at least some nights. In New York, two long-term studies (since ~1966) have documented ~500 avian fatalities/fall season under communication towers ranging from

750–1,076 ft tall, suggesting that at least some birds migrate at relatively low altitudes, especially during fall migration (Towerkill 2000).

Flight altitudes of migratory bats are poorly known. Hoary bats (*Lasiorycterus cinereus*), Eastern Red bats (*L. borealis*), and Silver-haired bats (*L. noctivagans*) are all long-range migrants that have been killed at wind power projects during their migratory periods, suggesting that at least some bats migrate below ~125 m agl. Allen (1939) observed bats migrating during the daytime near Washington, D.C. at 46–140 m agl, Altringham (1996) reported that at least some bats migrate well-above 100 m agl, and Peurach (2003) documented a hoary bat collision with an airplane at an altitude of 2,438 m agl over Oklahoma during October 2001.

Mean flight altitudes at the proposed project site were lower (415 m agl) than those at other sites studied in the fall in New York (Chautauqua, mean = 532 m agl) and similar to those in West Virginia (Mt. Storm, mean = 410 m agl). Again, we do not believe that it is appropriate to compare flight altitudes in this study with those at other New York sites studied before 2001 (Wethersfield, Harrisburg, Carthage) because of different equipment (i.e., a different vertical radar configuration) that probably resulted in a low altitude bias. Similar to our results from the current study, however, other studies that used a variety of radar systems and analyses have indicated that the majority of nocturnal migrants fly below 600 m agl (Bellrose 1971; Gauthreaux 1972, 1978, 1991; Bruderer and Steidinger 1972; Cooper and Ritchie 1995). Kerlinger (1995) summarized radar results from the eastern US and concluded that three-quarters of passerines migrate <600 m agl.

In contrast to these results, other researchers have found that peak nocturnal densities extend over a broad altitudinal range up to ~2,000 m (Harper 1958, *in* Eastwood 1967; Graber and Hassler 1962, Nisbet 1963, Bellrose and Graber 1963, Eastwood and Rider 1965, Bellrose 1967, Blokpoel 1971; Richardson 1971, 1972; Blokpoel and Burton 1975). We suspect that differences between the two groups of studies are largely due to differences in location, species-composition of migrating birds, local topography, radar equipment used, and perhaps weather conditions. It has been suggested that limitations in equipment and

sampling methods of some previous radar studies may have been responsible for their overestimation of the altitude of bird migration (Able 1970, Kerlinger and Moore 1989). For example, the radars used by Bellrose and Graber (1963), Blokpoel (1971), and Nisbet (1963) could not detect birds below 450 m, 370 m, and 180 m agl, respectively. In contrast, our vertical radar could detect targets down to ~10–15 m agl, allowing us to detect low-altitude migrants.

We also examined the percentage of targets below approximate turbine height (i.e., 125 m agl) and estimated that ~8% flew <125 m agl at this study site, compared with 4% <140 m agl at Chautauqua, NY (Cooper et al. 2004), 13–16% flew <125 m agl at Mt. Storm, WV (Mabee et al. 2004), and 3–9% <125 m agl at the Stateline and Vansycle wind power facilities in eastern Oregon (Mabee and Cooper 2004). Based on observations made during this study, mean flight altitudes and the proportion of targets flying 200 m agl remained fairly similar within hours of the night.

Similar to our migration studies elsewhere (Cooper and Ritchie 1995; Cooper et al. 1995a, 1995b; Cooper and Mabee 2000; Mabee and Cooper 2004), we recorded large among-night variation in mean flight altitudes during the fall migration season, although mean flight altitudes always were above the proposed turbine heights (observed minimum = 194 m agl). Daily variation in mean flight altitudes may have reflected changes in species composition, vertical structure of the atmosphere, and/or weather conditions. Variation among days in the flight altitudes of migrants at other locations has been associated primarily with changes in the vertical structure of the atmosphere. For example, birds crossing the Gulf of Mexico appear to fly at altitudes where favorable winds minimize the energetic cost of migration (Gauthreaux 1991). Kerlinger and Moore (1989), Bruderer et al. (1995), and Liechti et al. (2000) have concluded that atmospheric structure is the primary selective force determining the height at which migrating birds fly.

MODELING MIGRATION PASSAGE RATES AND FLIGHT ALTITUDES

MIGRATION PASSAGE RATES

It is a well-known fact that general weather patterns and their associated temperatures and winds affect migration (Richardson 1978, 1990). In the Northern Hemisphere, air moves counterclockwise around low-pressure systems and clockwise around high-pressure systems. Thus, winds are warm and southerly when an area is affected by a low to the west or a high to the east and are cool and northerly in the reverse situation. Clouds, precipitation, and strong, variable winds are typical in the centers of lows and near fronts between weather systems, whereas weather usually is fair with weak or moderate winds in high-pressure areas. Numerous studies in the Northern Hemisphere have shown that, in fall, most bird migration tends to occur in the western parts of lows, the eastern or central parts of highs, or in intervening transitional areas. In contrast, warm fronts, which are accompanied by southerly (unfavorable) winds and warmer temperatures, tend to slow migration in the fall (Lowery 1951, Gauthreaux 1971; Able 1973, 1974; Blokpoel and Gauthier 1974, Richardson 1990). Conversely, more intense spring migration tends to occur in the eastern parts of lows, the western or central parts of highs, or in intervening transitional areas.

We examined the influence of weather (i.e., wind direction, wind speed), date, and sampling site on migration passage rates and identified wind direction, wind speed, date, and sampling location all as important factors. In the fall, migration passage rates increased with tailwinds, crosswinds and date, decreased with wind speed, and were lower at the South site. We were unable to investigate the effects of fog and low ceiling height on passage rates, as these conditions were rare during this study (fog absent = 302 sessions, fog present = 2 sessions; ceiling height <500 m agl = 5 sessions, ceiling height 500 m agl = 299 sessions). The variables identified as important in this study are generally consistent with other studies (Lowery 1951, Gauthreaux 1971; Able 1973, 1974; Blokpoel and Gauthier 1974; Richardson 1990; Mabee et al. 2004).

FLIGHT ALTITUDES

Radar studies have shown that wind is a key factor in migratory flight altitudes (Alerstam 1990). Birds fly mainly at heights at which headwinds are minimized and tailwinds are maximized (Bruderer et al. 1995). Because wind strength generally increases with altitude, bird migration generally takes place at lower altitudes in headwinds and at higher altitudes in tailwinds (Alerstam 1990). Most studies (all of those cited above except Bellrose 1971) have found that clouds influence flight altitude, but the results are not consistent among studies. For instance, some studies (Bellrose and Graber 1963, Hassler et al. 1963, Blokpoel and Burton 1975) found that birds flew both below and above cloud layers, whereas others (Nisbet 1963, Able 1970) found that birds tended to fly below clouds.

In the fall, flight altitudes increased with tailwinds, crosswinds, and date (higher mean altitudes later in the season), consistent with findings of Alerstam (1990). We were unable to test for relationships between flight altitudes and fog or ceiling height, because those conditions were rare during this study (see above). The need to understand how birds respond to foggy conditions is warranted, as the largest single-night kill for nocturnal migrants (27 passerines) at a wind power project occurred on a foggy night during spring migration, when they collided with a turbine near a lit substation at the Mountaineer wind power development in West Virginia (Kerlinger 2003). Fatality events of this magnitude are rare at wind power developments, although large kills of migratory birds have sporadically occurred at other, taller structures (e.g., guyed and lighted towers >130 m high) in many places across the country during periods of heavy migration, especially on foggy, overcast nights in fall (Weir 1976, Avery et al. 1980, Evans 1998, Erickson et al. 2001).

SPECIES COMPOSITION

Determination of species-specific risks to nocturnal migrants requires the identification of species migrating through the area of interest. Flight speeds observed on surveillance radar (mean = 10.4 ± 0.03 m/s) suggested that most of the avian radar targets we observed in this study were

passerines, rather than faster-flying bird species such as shorebirds or waterfowl. Further, our visual observations confirmed the presence of both passerines and bats in the lower air layers (i.e., <150 m agl). We believe that our method of using night vision goggles in conjunction with two, 2 million Cp spotlights provide data that are adequate to estimate the proportion of birds (91–85%) and bats (9–15%) within ~150 m agl at both sites.

Most (86%) of the bat fatalities at wind power developments and other tall structures occur during mid-July to mid-September and involve long-range migratory tree-roosting bat species such as Hoary (*Lasiurus cinereus*), Eastern Red (*Lasiurus borealis*), and Silver-haired (*Lasionycteris noctivagans*) bats (Erickson et al. 2002, Johnson et al. 2003, Erickson et al. 2004, Kerns 2004). Of the 179 bats observed during this study, 21 (12%) appeared to be tree-roosting bats. In general, fatality rates of bats are much lower in the central and western US (Erickson et al. 2002) than in the eastern US, where substantial bat kills have been observed along an Appalachian ridgeline in West Virginia and Pennsylvania (Erickson 2004, Kerns 2004). Unfortunately, there are no data available for migration passage rates or species composition during migration from the two locations that have had high bat mortality.

TURBINE PASSAGE RATE INDEX

We estimated a turbine passage rate index of 39–275 nocturnal migrants passing within the area occupied by each proposed turbine at the Flat Rock Wind Power project during our 60-d fall study period, equivalent to ~0.7–4.6 migrants/per turbine/d. Our estimated turbine passage rate index provides a starting point for developing a complete avian risk assessment; however, our estimate must be combined with an estimate of the proportion of migrants that (1) do not collide with turbines because of their avoidance behavior and (2) safely pass through the turbine blades by chance alone — a proportion that will vary with the speed at which turbine blades are turning. Once this information is known, one may be able to assess the likelihood of avian and bat fatalities at proposed wind power projects. The proportion of nocturnal migrants that detect and avoid turbines is currently unknown in the US (but see Winkleman 1995 for studies in

Europe), and there are no empirical data that predict a species' ability to pass safely through the rotor-swept area of a turbine (but see Tucker 1996 for a hypothetical model). We speculate, however, that the values are high for both of these missing pieces of information, considering the relatively low avian fatality rates at wind power developments in the US (Erickson et al. 2002).

CONCLUSIONS

This study focused on nocturnal migration patterns and flight behaviors during the peak periods of fall passerine and bat migration at the proposed Flat Rock Wind Power project in New York. The key results of our of fall passerine and bat migration study were: (1) the mean overall passage rate (i.e., 158 targets/km/h) was comparable to other sites in New York; (2) mean nightly passage rates ranged from 5 to 704 targets/km/h; (3) the percentage of targets passing below 125 m agl (~8%) was similar to that for a small number of comparable studies; (4) an estimated turbine passage rate of 39–275 nocturnal migrants passing within the airspace occupied by each proposed turbine during the 45-d fall migration season (equivalent to ~0.7–4.6 nocturnal migrants/turbine/d); and (5) migrants composed of ~85–91% birds and ~9–15% bats during this study.

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Appendix 1. Number of targets observed on 1.5-km vertical radar at each 25-m interval below 250 m and cumulative percent of all targets during nocturnal surveys at the North and South sampling sites at the proposed Flat Rock Wind Power project, NY, fall 2004.

Alt (m agl)	North		South		Combined sites	
	N	Cumulative %	N	Cumulative %	N	Cumulative %
0–25	0	0.0	0	0.0	0	0.0
26–50	45	0.7	43	0.7	88	0.7
51–75	120	2.5	121	2.7	241	2.6
76–100	159	4.9	148	5.1	307	5.0
101–125	166	7.4	193	8.2	359	7.8
126–150	189	10.2	214	11.7	403	10.9
151–175	217	13.5	268	16.0	485	14.7
176–200	314	18.2	305	21.0	619	19.5
201–225	277	22.4	284	25.6	561	23.9
226–250	285	26.7	306	30.5	591	28.5
251–1,500	4,867	100.0	4,280	100.0	9,147	100.0
Total	6,639		6,162		12,801	

Appendix 2. Calculation of the turbine passage rate (the number of targets that would pass within the area occupied by each proposed turbine) over the entire 60-day fall 2004 study period at the Flat Rock Wind Power project, NY, fall 2004.

Calculation parameter	
WIND-TURBINE CHARACTERISTICS	
(A) Total turbine height (m)	119
(B) Blade radius (m)	39
(C) Height below blade (m)	41
(D) Approximate front-to-back width (m)	6
(E) Minimal (side profile) area (m ²) = A × D	714
(F) Maximal (front profile) area (m ²) = (C × D) + (π × B ²)	5,024
PASSAGE RATE	
(G) Mean rate below 125 m agl (targets/km/h) across both sampling sites	11.4
(H) Area sampled below 125 m agl = 125 x 1,000 (m ²)	125,000
(I) Mean passage rate per unit area (targets/m ² /h) = G/H	0.000091
TURBINE PASSAGE RATE INDEX	
(J) Duration of study period (# nights)	60
(K) Mean number of hours of darkness (h/night)	10
(L) Minimal number of targets/h within turbine area = E × I	0.065117
(M) Maximal number of targets/h within turbine area = F × I	0.45822
(N) Minimal number of targets within turbine area (side profile)/d = K × L	0.7
(O) Maximal number of targets within turbine area (front profile)/d = K × M	4.6
(N) Minimal number of targets within turbine area (side profile) during 45-night period = J x K × L	39
(O) Maximal number of targets within turbine area (front profile) during 45-night period = J x K × M	275