A RADAR AND VISUAL STUDY OF NOCTURNAL BIRD AND BAT MIGRATION AT THE PROPOSED PRATTSBURGH-ITALY...

FINAL REPORT

A RADAR AND VISUAL STUDY OF NOCTURNAL BIRD AND BAT MIGRATION AT THE PROPOSED PRATTSBURGH–ITALY WIND POWER PROJECT, NEW YORK, FALL 2004

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EXECUTIVE SUMMARY

- This report presents the results of a radar and visual study of bird and bat migration conducted during 14 August–29 September 2004 at the proposed Prattsburgh–Italy Wind Power project, located in Yates and Steuben counties, west-central New York. Radar and visual observations were conducted for ~6.5 h/night during 45 nights during the fall.
- The primary goal of this study was to collect information on the migration characteristics of nocturnally migrating birds, especially passerines, during the fall-migration period; the secondary goal was 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 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 177°.
- The mean nocturnal passage rate for the fall season was 200 ± 12 targets/km/h and ranged among nights between 18 and 863 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 365 ± 3 m agl. Mean flight altitudes observed on vertical radar were highly variable among nights and ranged from 202 to 584 m agl. Neither the mean flight altitude nor the altitudinal distribution of targets varied among hours within a night. Nine 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, calm conditions, easterly crosswinds, and westerly crosswinds and decreased with wind speed. Flight altitudes increased with tailwinds, calm conditions, westerly crosswinds, and date.
- Assuming an average of 10 nocturnal h/d and 45 d in the fall study, we estimated a turbine passage rate of 51–362 nocturnal songbird/bat migrants passing within the area occupied by each proposed turbine during fall 2004.
- We developed visual sampling methods to investigate low-altitude migration of birds and bats. During 14 August–13 September, we sampled with two, 2,000,000-Cp spotlights with red lenses and were able to identify as birds or bats 70% of all targets (*n* = 20) occurring within ~75 m agl. During 14–29 September, we sampled with both night-vision goggles and spotlights and were able to identify 75% of all targets (*n* = 106) occurring ~<150 m. Because of our shorter range to detect birds and bats with only spotlights, we only used data collected with night-vision goggles to calculate the proportion of birds and bats below ~<150 m agl (94% birds 6% bats; *n* = 80).
- The key results of our of fall passerine and bat migration study were: (1) the mean overall passage rate was moderate (i.e., 200 targets/km/h); (2) mean nightly passage rates ranged from 18 to 863 targets/km/h; (3) the percentage of targets passing below 125 m agl (9%) was similar to that for a small number of comparable studies; (4) an estimated turbine passage rate of 51–362 nocturnal migrants passing within the airspace occupied by each proposed turbine during the 45-d fall migration season; and (5) migrants flying below 150 m agl consisted of ~94% birds and ~6% bats during the late sampling period (i.e., mid- to late September).

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ACKNOWLEDGMENTS

We thank Ecogen for funding this study and Thomas Hagner for helping with field logistics. We thank Bill Evans for input on study design and for help with the selection of a study site. At ABR, we thank Peter Sanzenbacher and Corey Grinnell for help with radar sampling, Corey Grinnell for help with report preparation, and Rich Blaha for figure preparation.

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 windfarms involve nocturnal migrants (Erickson et al. 2001). Studies examining the impacts of windfarms on birds in the US and Europe suggest that fatalities and behavioral modifications (e.g., avoidance of windfarms) 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).

Ecogen LLC proposes to build the Prattsburgh–Italy Wind Power project, an ~80-MW wind power development in the Finger Lakes region (Yates and Steuben counties) of west-central New York (Fig. 1). Each of the 53 wind turbines will have a generating capacity of up to 1.5 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 glaciated Allegheny Plateau section of the Appalachian Plateaus physiographic province (USGS 2003), a well-documented migration corridor for birds (Bull 1985, Bellrose 1976, Zalles and Bildstein 2000, Cooper and Mabee 2000, Cooper et al. 2004).

OBJECTIVES

The primary goal of this study was to collect information on the migration characteristics of nocturnally migrating birds, especially passerines, during the fall-migration period; the secondary goal was 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 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 Finger Lakes region of central New York, in Yates and Steuben counties (Fig. 1). The Finger Lakes region is part of the Appalachian Plateaus physiographic province that was formed when the last Pleistocene ice cap melted and flooded valleys created by the advancing glacial ice (USGS 2003). This area is characterized by moderate valleys with ridges that range from ~980 ft to ~2100 ft (300–650 m) above the valley floors.

This proposed development is located ~20 miles (~32 km) south of Canandaigua, NY, and ~7 miles (~11 km) southeast of Naples, NY. The project area consists primarily of a mix of open farmland and wooded hillsides with limited residential development. Virtually all of the land previously has been logged. Our radar sampling site (UTM 17S 644523E 4360903N) was located north of Emerson Road, near the northern portion of the proposed wind power development (Fig. 1).

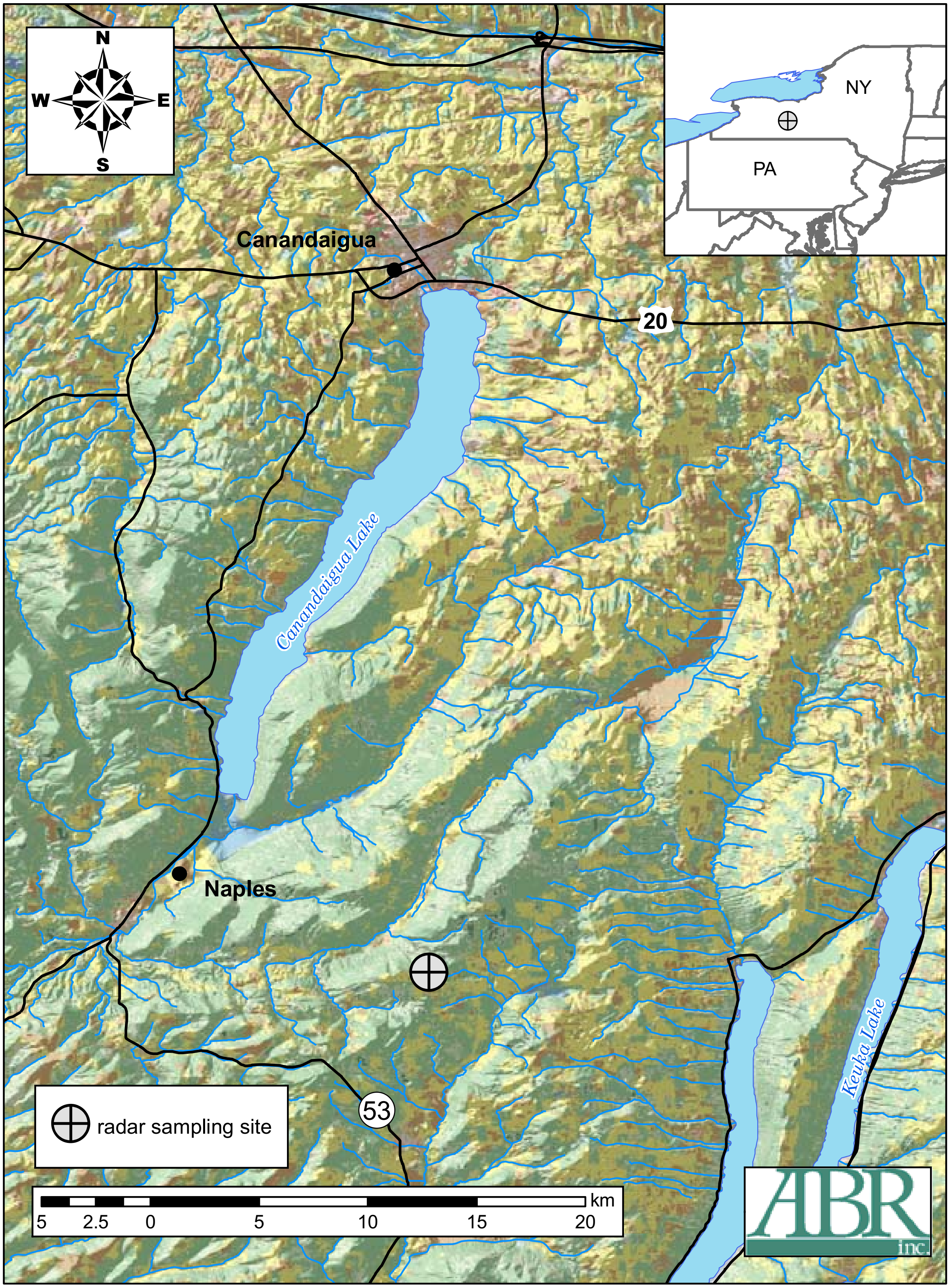

Figure 1. Map of the proposed Prattsburgh–Italy Wind Power project in Yates and Steuben Counties, New York.

METHODS

STUDY DESIGN

We conducted radar and visual observations on 45 nights between 14 August and 29 September 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 41 nights (39 nights for visual observations); on the remaining four nights, we were unable to sample with either technique because of inclement weather (rain). Each night, we conducted ~6.5 h of radar and visual observations at the site. 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).

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 sidelobe of ±10–20°. 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 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 ~15° 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,

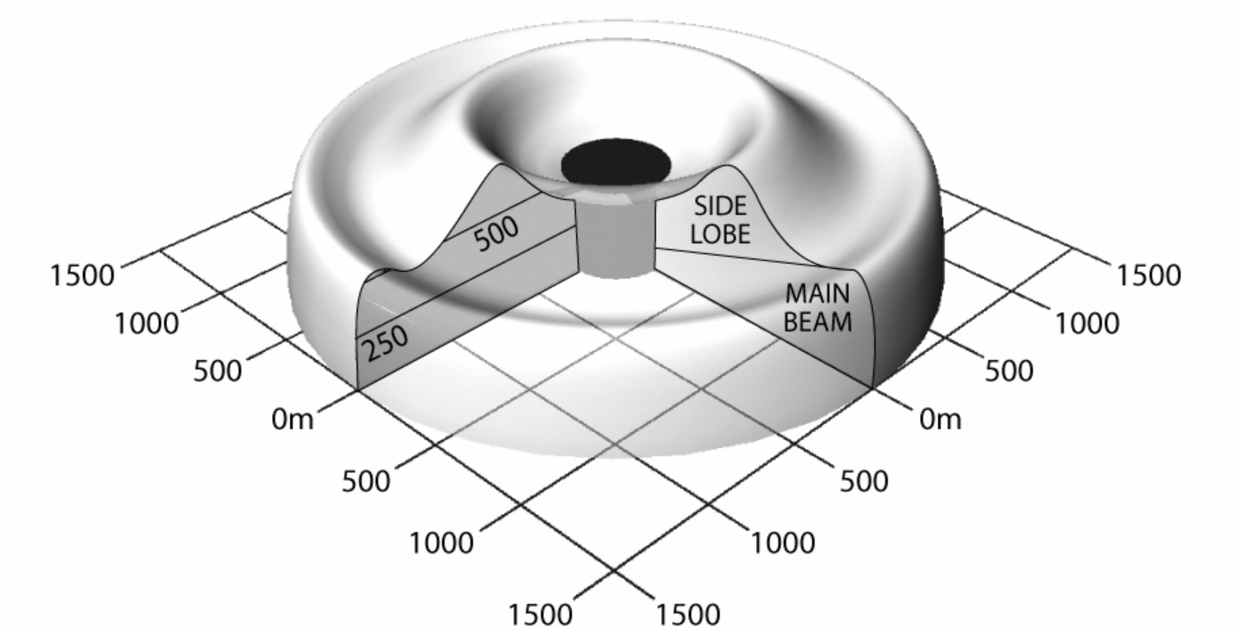

Figure 2. Approximate airspace sampled by Furuno FR–1510 marine radar when operating in the surveillance mode (antenna in the horizontal orientation) as determined by field trials with Rock Pigeons. Note that the distribution of the radar beam within 250 m of the origin (i.e., the darkened area) was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

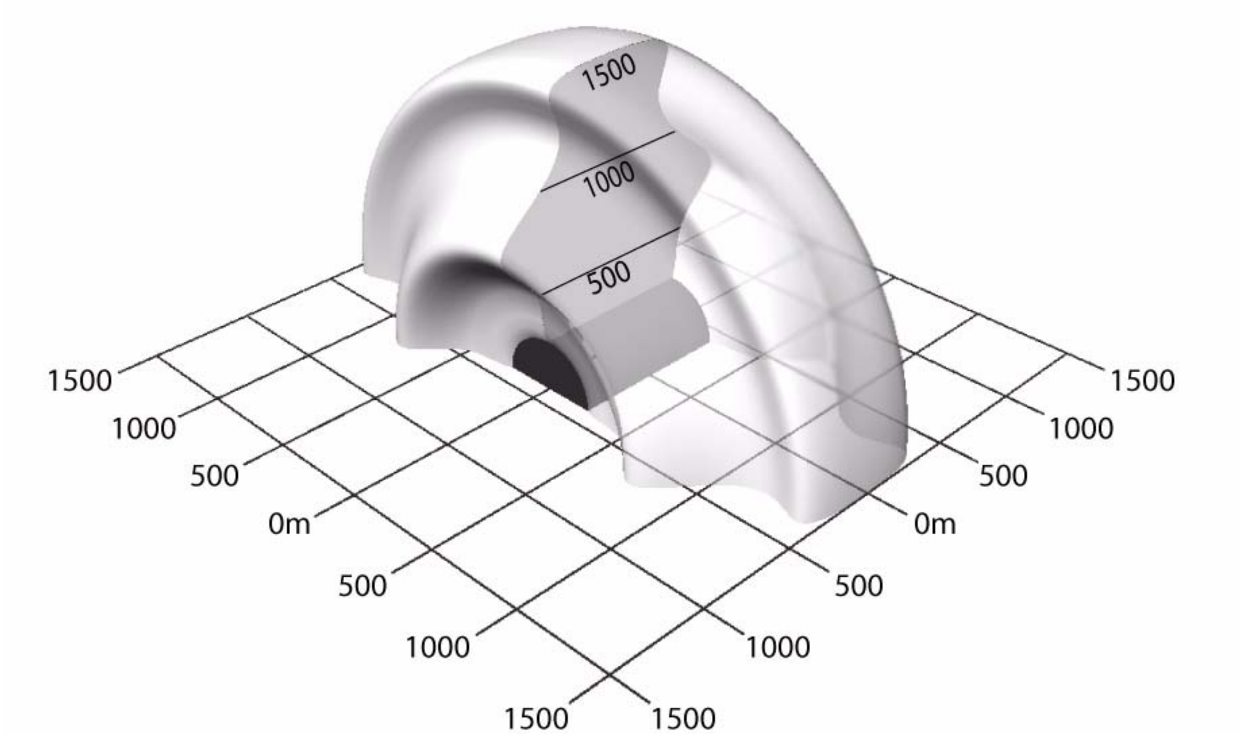

Figure 3. Approximate airspace sampled by Furuno FR–1510 marine radar when operating in the vertical mode (antenna in the vertical orientation) as determined by field trials with Rock Pigeons. Note that the distribution of the radar beam within 250 m of the origin (i.e., the darkened area) was not determined.

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).

SAMPLING DESIGN

Each of the six 1-hr nocturnal radar and visual sampling sessions/night consisted of: (1) one 5–10 min session to conduct visual observations; (2) one 5–10 min session to collect weather data and adjust the radar to surveillance mode; (3) one 10-min session with the radar in surveillance mode (1.5-km range) for collection of information on migration passage rates; (4) one 10-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); (5) one 10-min session to collect weather data and adjust the radar to vertical mode; and (6) one 15-min session with the radar in vertical mode (1.5-km range) to collect information on flight altitudes, speed, and direction. After the completion of the six hourly sessions, we also conducted an additional 30-min radar session in the surveillance mode (as above).

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. We also randomly selected a session each night to conduct intensive sampling sessions (continuous 25-min samples divided into 5-min periods) both for passage rates (surveillance mode) and mean flight altitudes (vertical mode) to determine whether our sampling intensity was adequate.

Weather data collected twice each hour consisted of the following: wind speed (collected with a "OMNI" anemometer in 5-mph [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 the site.

VISUAL OBSERVATIONS OF LOW-ALTITUDE BIRDS AND BATS

We conducted visual observations every night 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, 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 taxon (to species when possible), 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.). Prior to 14 September, observers conducted 5–10 min of unaided visual observations during each hour of radar surveys. Because of our limited range (i.e., from 0 to ~75 m agl) in which to detect birds and bats while using only spotlights, observers after 13 September used 1X ATN-PVS7 Generation 3 night-vision goggles to enhance the detectability of targets; we also increased our sampling intensity by sampling an additional 15 min before the first radar sampling session and 45 min after the last radar sampling session.

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. Radar data were not corrected for differences in detectability with distance from the radar unit. The level of significance (α) for all statistical tests was set at 0.05.

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

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

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). Migration passage rates are reported as the mean ± 1 standard error (SE) number of targets passing along 1 km of migratory front/h (targets/km/h ± 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 and flight altitudes among hours of the night for nights with data collected during all six sessions. We examined the effects of session length on the accuracy of estimating passage rates and flight altitudes by regressing the different counts in each 5-min time interval to that obtained from a continuous 25 min sample. 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 <1 km from the 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., 113º–248º), tailwinds WNW to ENE (i.e., 293º–068º), eastern crosswinds (069º–112º), western crosswinds (249º–292º), 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 five 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 the flight altitudes were normally distributed. We specified 16 models for passage rates and flight altitudes: a global model containing all variables and subset models representing potential influences of four weather variables (wind speed, wind direction, the presence of fog, and ceiling height) and date 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 = 0.39 for passage-rate models; R^2 = 0.21, for flight-altitude models).

Because the number of sampling sessions for both passage rates (n = 241) and flight altitudes (n = 195) 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

At night, most radar targets were traveling in seasonally appropriate directions for fall migration (i.e., southerly), with a mean flight direction of

177° for the fall season (mean vector length = 0.39; *n* = 3,854 targets; Fig. 4). Most (74%) of the nocturnal targets were traveling in a southerly direction, with half (52%) of the flight directions occurring between SE (135°) and SW (225°).

PASSAGE RATES

The mean nocturnal passage rate for the fall season was 200 ± 12 targets/km/h (*n* = 41 nights). Overall mean nightly passage rates were highly variable among nights (range = 18–863 targets/km/h) with relatively small numbers of targets below 125 m agl (Fig.5). Passage rates varied significantly among hours of the night ($F_{3.6, 93.7} = 4.551$; $P = 0.003$; $n = 27$ nights; 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 365 ± 3 m agl (*n* = 6,856 targets; median = 325 m agl). Mean flight altitudes observed on vertical radar (1.5-km range) were highly variable among nights and ranged from 202 to 584 m agl (Fig. 7). Mean flight altitudes did not vary among hours of the night ($F_{5, 95} = 0.298$, $P = 0.913$, $n = 35$ nights; Fig. 8), and the altitudinal distribution of targets did not appear to vary among hours during 41 nights (Fig. 9). The overall distribution of targets in 100-m categories of flight altitudes varied from 21.3% in the 201–300 m agl interval to 0% in the 1,301–1,400 and 1,401–1,500 m agl intervals (Table 1). We determined that 9.2% of all targets flew <125 m, which is the approximate maximal height of the proposed wind turbines.

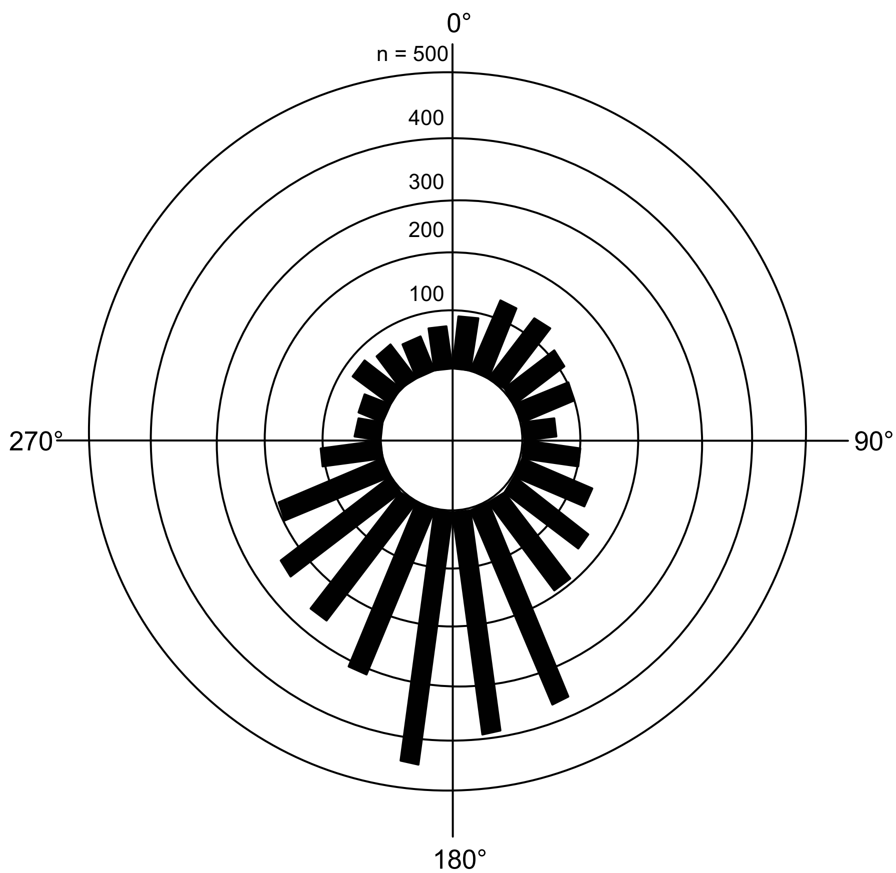

Figure 4. Flight directions of radar targets at the proposed Prattsburgh–Italy Wind Power project, New York fall 2004.

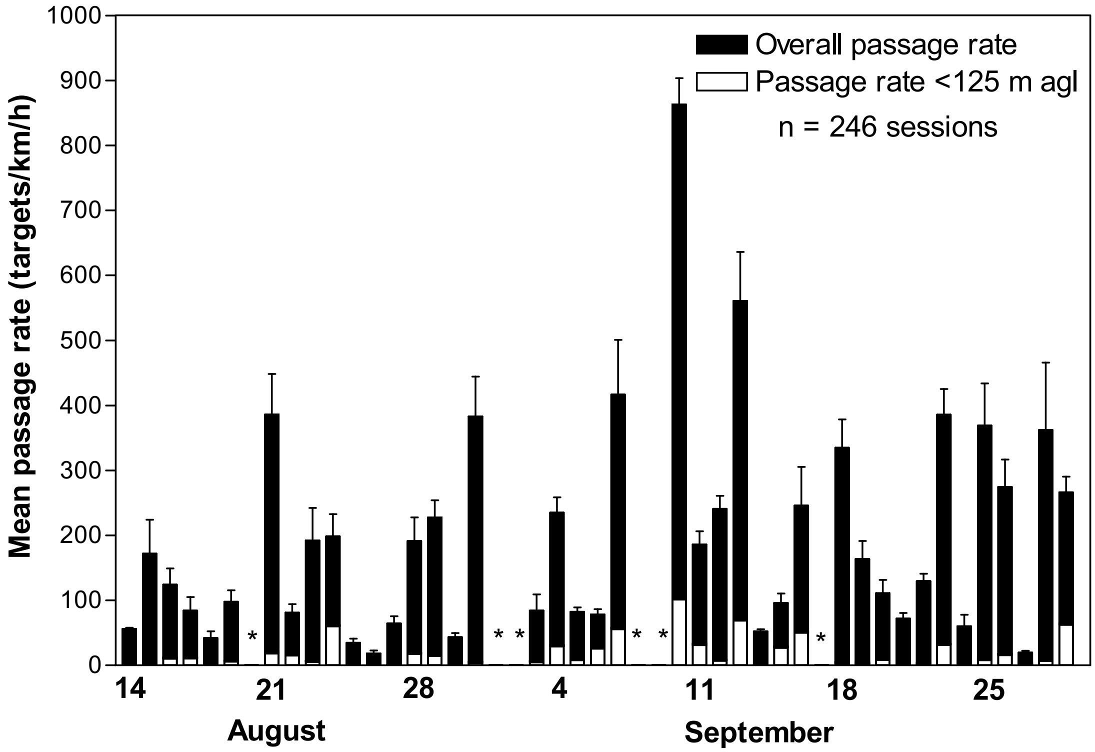

Figure 5. Mean ± 1 SE nightly passage rates (targets/km/h) at the proposed Prattsburgh–Italy Wind Power project, New York, fall 2004. Asterisks denote nights not sampled because of rain (n = 4) or technical difficulties (n = 2).

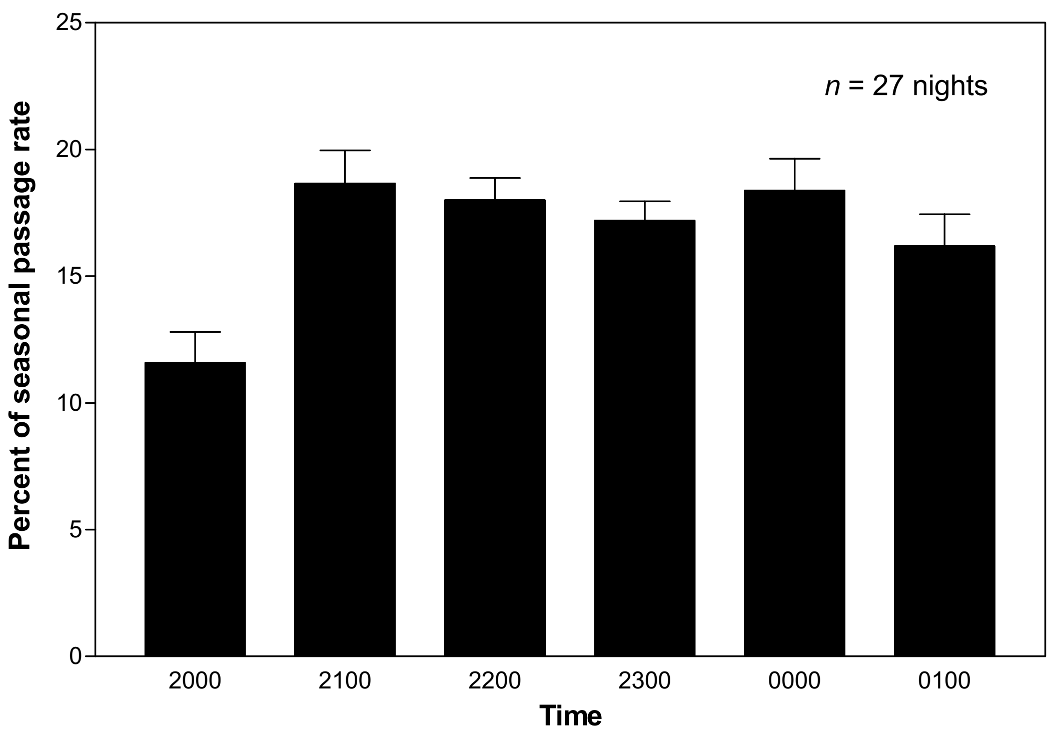

Figure 6. Percent of seasonal passage rate (± 1SE) by hour of the night (e.g., 2000–2059) at the proposed Prattsburgh-Italy Wind Power project, New York, fall 2004.

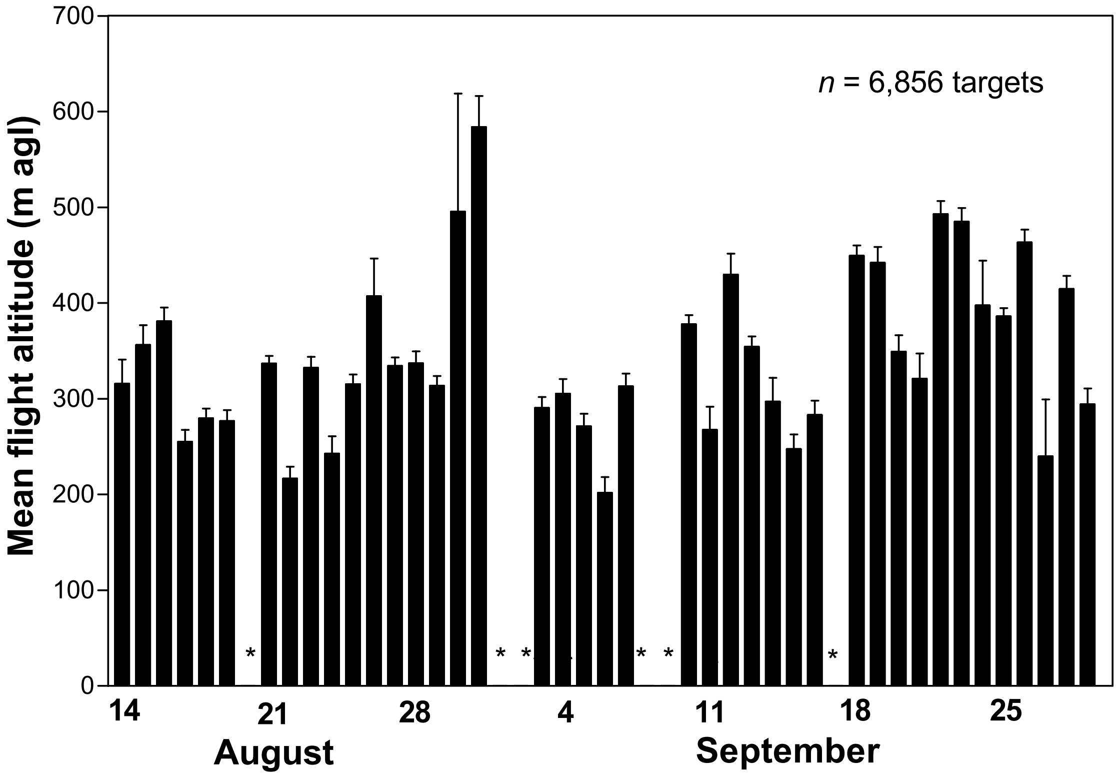

Figure 7. Mean ± 1 SE nightly flight altitudes (m agl) at the proposed Prattsburgh–Italy Wind Power project, New York, fall 2004. Asterisks denote nights not sampled because of rain (*n* = 4) or technical difficulties (*n* = 2).

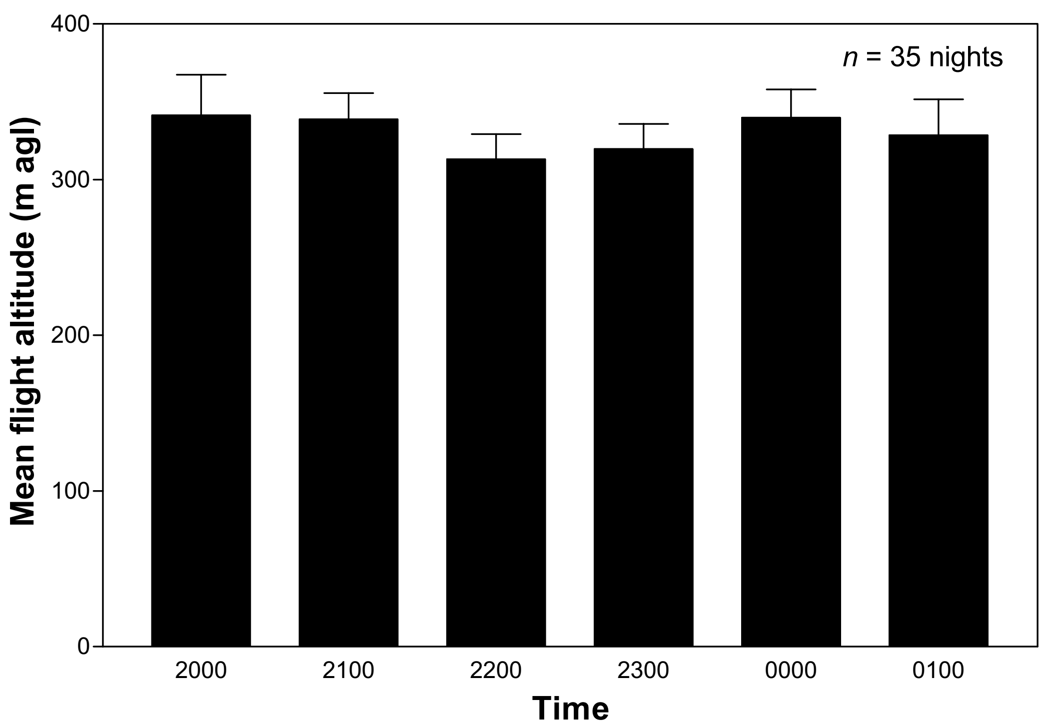

Figure 8. Mean ± 1 SE flight altitude (m agl) by hour of the night (e.g., 2000–2059) at the proposed Prattsburgh–Italy Wind Power project, New York, fall 2004.

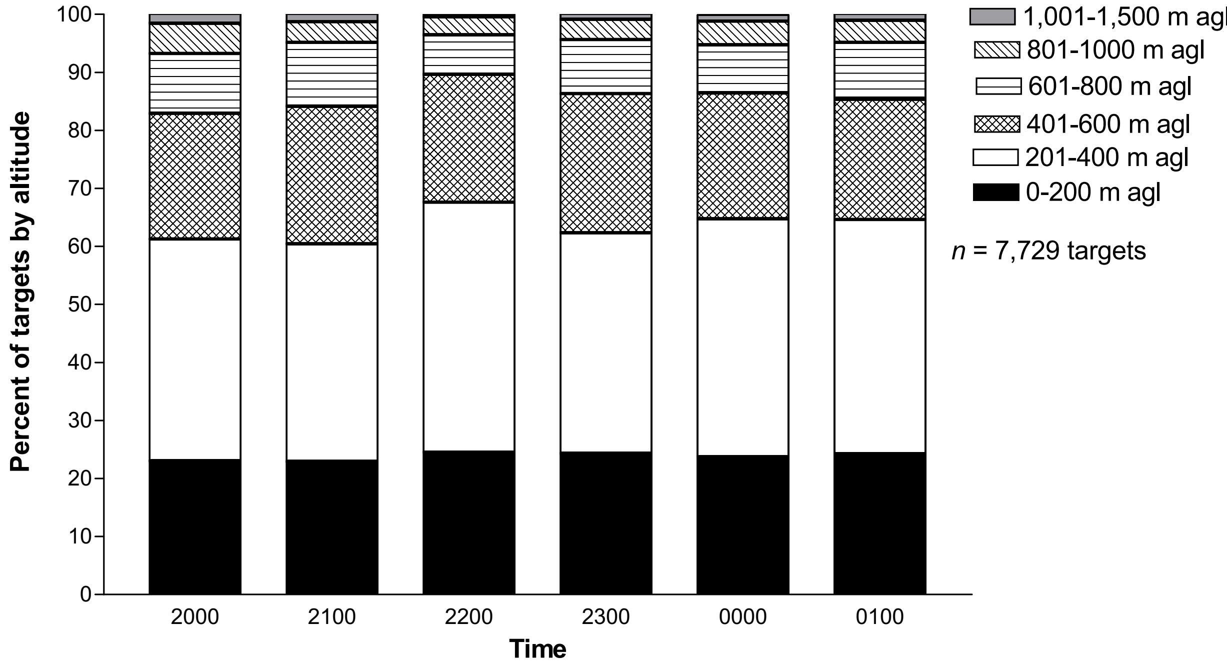

Figure 9. Percent of radar targets at each altitude at the proposed Prattsburgh–Italy Wind Power project, New York, fall 2004, by hour of the night (e.g., 2000–2059).

Table 1. Nocturnal flight altitudes of radar targets (% of all targets) detected at the 1.5-km range at the Prattsburgh–Italy Wind Power project, NY, fall 2004, by flight-altitude category. Total *n* = 6,856 targets.

Flight altitude (m agl)	Percent of radar targets
0–100	6.0
101–200	18.0
201–300	21.3
301–400	18.3
401–500	13.4
501–600	9.0
601–700	5.7
701–800	3.6
801–900	2.6
901–1,000	1.2
1,001–1,100	0.5
1,101–1,200	0.2
1,201–1,300	0.1
1,301–1,400	0.0
1,401–1,500	0.0

INTENSIVE SAMPLING PERIODS

Over 90% of the variation in a 25-min passage-rate sampling session was explained by a 5-min count of passage rate, and ~96% was explained by our current method of conducting a 10-min count (Fig. 10). Nearly 95% of the variation in a 25-min flight-altitude sampling session was explained by using our current method of sampling for 15 min (Fig 10).

EFFECTS OF WEATHER ON MIGRATION

We investigated the importance of weather (i.e., wind direction, wind speed, fog, ceiling height) 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 model containing the variables wind direction, wind speed, and date (Table 2). The second-best model contained the variables wind direction and wind speed ($\Delta AIC_c = 0.78$), and a third model containing wind direction, wind speed, date, and fog ($\Delta AIC_c = 0.85$) also received similar empirical support (Table 2). The top two models contained

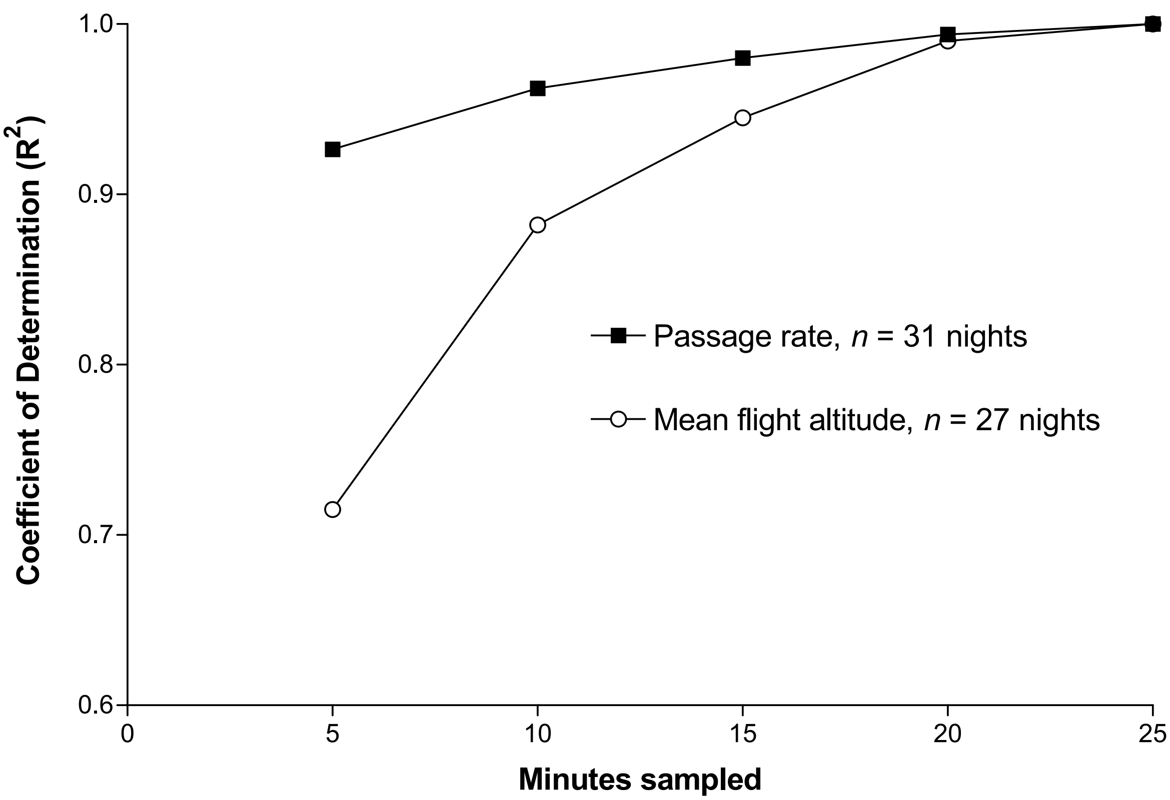

Figure 10. Variation in passage rate and flight altitude counts by length of sampling session at the proposed Prattsburgh–Italy Wind Power project, New York, fall 2004. The Coefficient of Variation (R^2) expresses the amount of variation in a 25-min count (the maximal time sampled) explained by counts of shorter duration.

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 Prattsburgh–Italy Wind Power project, NY, fall 2004 (n = 241 sampling sessions). Model weights (w_i) were based on Akaike's Information Criterion (AIC).

Model	RSS[a]	K[b]	AIC_c[c]	ΔAIC_c[d]	w_i[e]
Wind direction + wind speed + date	29.6	8	–489.17	0.00	0.39
Wind direction + wind speed	29.9	7	–488.39	0.78	0.27
Wind direction + wind speed + date + fog	29.4	9	–488.32	0.85	0.26
Global model: wind direction + wind speed + date + fog + ceiling height	29.4	10	–486.13	3.04	0.09
Wind speed	32.8	3	–474.47	14.70	0.00
Wind direction	32.3	6	–471.69	17.48	0.00
Wind direction + date	32.1	7	–471.06	18.11	0.00
Wind direction + fog	32.2	7	–470.54	18.63	0.00
Wind direction + date + fog	32.0	8	–470.04	19.12	0.00
Wind direction + ceiling height	32.3	7	–469.94	19.23	0.00
Wind direction + date + ceiling height	32.1	8	–469.15	20.02	0.00
Date + fog	43.7	4	–403.60	85.57	0.00
Date	45.4	3	–396.36	92.81	0.00
Fog	45.6	3	–394.98	94.19	0.00
Date + ceiling height	45.4	4	–394.29	94.88	0.00
Ceiling height	47.3	3	–386.32	102.85	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 two best-approximating models explaining the influence of environmental factors on passage rates of bird and bat targets at the Prattsburgh–Italy Wind Power project, NY, fall 2004 (*n* = 241 sampling sessions). Coefficients (B) of the categorical variable wind direction were calculated relative to headwinds.

Model	B	SE	R^2
Wind direction + wind speed			0.368
Intercept	2.269	0.100	
Wind direction = tailwind	0.310	0.070	
Wind direction = calm	0.295	0.109	
Wind direction = E crosswind	0.373	0.167	
Wind direction = W crosswind	0.215	0.070	
Wind speed	-0.047	0.110	
Wind direction + wind speed + date			0.375
Intercept	1.537	0.448	
Wind direction = tailwind	0.290	0.071	
Wind direction = calm	0.254	0.112	
Wind direction = easterly crosswind	0.371	0.166	
Wind direction = westerly crosswind	0.169	0.075	
Wind speed	-0.049	0.110	
Date	0.003	0.002	

the same significant positive associations with tailwinds, calm conditions, and eastern and western crosswinds (Table 3). Date and wind speed were not related to passage rates. The weight of evidence in favor of the "best" model ($w_{best}/w_{second\ best}$; Burnham and Anderson 1998) was 1.4 times that of the second-best model (Burnham and Anderson 1998). The sum of Akaike weights (Σw_i) of parameters across all models provided evidence for the relative importance of variables from these models, with wind direction and wind speed (1.00) being more important than date (0.73), fog (0.34), and ceiling height (0.09).

FLIGHT ALTITUDES

The best-approximating model explaining flight altitudes of nocturnal migrants during fall migration was the model containing the variables wind direction and date (Table 4). The next three best models also received empirical support (ΔAICc < 2; Table 4). The top two models contained strong positive associations with tailwinds, calm winds, western crosswinds, and date (Table 5). Flight altitudes were not related to eastern crosswinds and fog. The weight of evidence in favor of the "best" model ($w_{best}/w_{second\ best}$) was 1.7 times that of the second best model. The Σw_i suggested that both wind direction (1.00) and date (0.91) were more important than fog (0.33), wind speed (0.29), and ceiling height (0.20).

TARGETS WITHIN THE PROPOSED TURBINE AREA

In the fall, the mean passage rate of targets <125 m was 20.0 ± 3.7 targets/km/h. 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, (4)

Table 4. Linear-regression models explaining the influence of environmental factors on mean flight altitudes of bird and bat targets on vertical radar at the Prattsburgh–Italy Wind Power project, NY, fall 2004 (n = 195 sampling sessions). Model weights (w_i) were based on Akaike's Information Criterion (AIC).

Model	RSS[a]	K[b]	AIC_c[c]	ΔAIC_c[d]	w_i[e]
Wind direction + date	1,842,000.0	7	1799.50	0.00	0.31
Wind direction + date + fog	1,831,310.0	8	1800.54	1.04	0.18
Wind direction + date + ceiling height	1,834,599.0	8	1800.89	1.39	0.15
Wind direction + wind speed + date	1,835,284.0	8	1800.97	1.46	0.15
Wind direction + wind speed + date + fog	1,824,268.0	9	1801.99	2.49	0.09
Global model: wind direction + wind speed + date + fog + ceiling height	1,821,139.0	10	1803.88	4.38	0.03
Wind direction	1,905,267.0	6	1803.94	4.43	0.03
Wind direction + fog	1,892,815.0	7	1804.81	5.31	0.02
Wind direction + wind speed	1,899,937.0	7	1805.54	6.04	0.02
Wind direction + ceiling height	1,900,213.0	7	1805.57	6.07	0.01
Wind speed	2,087,084.0	3	1815.39	15.89	0.00
Date	2,136,473.0	3	1819.95	20.45	0.00
Date + ceiling height	2,132,745.0	4	1821.70	22.19	0.00
Date + fog	2,136,456.0	4	1822.03	22.53	0.00
Ceiling height	2,301,564.0	3	1834.47	34.96	0.00
Fog	2,302,377.0	3	1834.53	35.03	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 minimum 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 two best-approximating models explaining the influence of environmental factors on mean flight altitudes of radar targets at the Prattsburgh–Italy Wind Power project, NY, fall 2004 (*n* = 195 sampling sessions). Coefficients (B) of the categorical variables "wind direction" and "fog" were calculated relative to headwinds and fog conditions.

Model	B	SE	R^2
Wind direction + date			0.200
Intercept	–48.282	131.401	
Wind direction = tailwind	79.375	18.211	
Wind direction = calm	92.710	22.046	
Wind direction = easterly crosswind	54.705	41.618	
Wind direction = westerly crosswind	69.989	23.005	
Wind direction + date + fog			0.205
Intercept	–97.975	139.668	
Wind direction = tailwind	80.666	18.248	
Wind direction = calm	98.877	22.813	
Wind direction = easterly crosswind	54.732	41.607	
Wind direction = westerly crosswind	70.258	23.000	
Date	1.328	0.529	
Fog	54.193	51.731	

45 d in the study, and (5) an average of 10 nocturnal hours/day across the 45-d period. If all migrants approached the turbines from the side, an estimated 51 migrants would have passed within the area occupied by one turbine. If all migrants approached the turbines from the front, an estimated 362 migrants would have passed within the area occupied by one turbine (Appendix 1).

VISUAL DATA

We collected visual data on 39 nights during the fall field season. We did not observe any bats moving during crepuscular sessions (~1930–2015). During our initial period of spotlight observations (14 August–13 September), we observed low numbers of birds and bats (mean = 1.98 visual targets/h; Fig. 11) and were able to identify 70% of all targets (*n* = 20) as either birds or bats. By using night-vision goggles with the filtered spotlights (14–29 September), we were able to identify 75% of the targets observed (*n* = 106). In addition, we generally observed higher passage rates of birds and bats with this improved method (mean = 5.23 visual targets/h; Fig. 11). During this time period (14–29 September), proportions of birds and bats flying <~150 m agl (our effective sampling distance with the night-vision goggles) were 94% birds and 6% bats (*n* = 80).

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 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

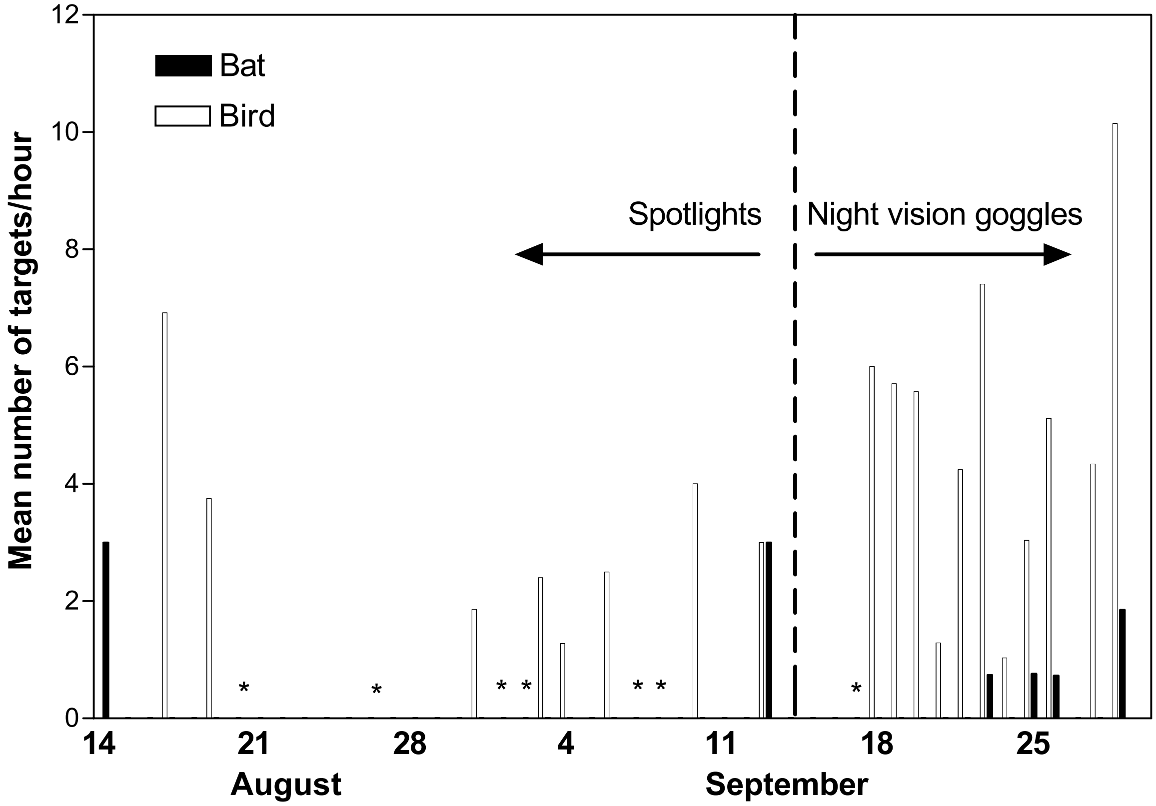

Figure 11. Mean number of birds or bats/h observed during visual sampling at the proposed Prattsburgh–Italy Wind Power project, New York, fall 2004. Asterisks denote nights not sampled because of rain (n = 4) or technical difficulties (n = 2).

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 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 9 nights: 21 and 31 August and 7, 10, 13, 18, 23, 25, and 28 September. Overall, fall migration peaked at 863 targets/km/h on 10 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 Inc., pers. comm.).

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 (18–863 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.

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 200 targets/km/h, compared with fall passage rates of 122 targets/km/h at Harrisburg, NY (located ~190 km northeast of this study site; Cooper and Mabee 2000); 168 targets/km/h at Wethersfield, NY (located ~80 km northwest of this study site; Cooper and Mabee 2000); 225 targets/km/h at Carthage, NY (located ~200 km northeast of this study site; Cooper et al. 1995b), and 238 targets/km/h at Chautauqua, NY (located ~190 km southwest of this study site; 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 rates below the proposed turbine height in the project area (20.0 targets/km/h flying <125 m agl) were similar to fall rates at the Chautauqua site in western New York (20.8 targets/km/h flying <140 m agl; Cooper et al. 2004) and were lower 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 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) used 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.

Mean flight altitudes at the proposed project site were lower (365 m agl) than those at other sites studied in the fall in New York (Chautauqua, mean = 532 m agl) and West Virginia (Mt. Storm, mean = 410 m agl). Unfortunately, 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, 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 ~9% flew <125 m agl at this study site, compared with 4% <140 m agl at Chautauqua, NY (Cooper et al. 2004), 13–16% <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 did not vary among 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 = 202 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.

INTENSIVE SAMPLING PERIODS

Our current method of sampling for 10 min/h to obtain a representative passage-rate count (targets/km/h) appears to be justified, judging from the high degree of correlation between estimates based upon 10-min samples and those from 25-min samples (i.e., R^2 = 0.96). Similarly, our current method of sampling for 15 min/h to obtain a representative mean flight altitudes also appears justified, judging by the high degree of correlation (R^2 = 0.95) between 15-min and 25-min samples.

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 fall migration (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 speed, wind direction, date, fog, and ceiling height) on migration passage rates and identified wind direction and wind speed as the most important factors. Fall migration passage rates increased with tailwinds, calm conditions, and eastern and western crosswinds and decreased with wind speed. Fog and low ceiling height, however, occurred rarely during this study (n = 3 nights with fog; n = 2 nights with ceiling height <150 m agl), and their influence on passage rates could not be determined. The variables identified as important in this study are generally consistent with results of 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 this study, flight altitudes increased with tailwinds, calm conditions, western crosswinds, and date (higher mean altitudes later in the season), consistent with findings of Alerstam (1990). Because of the rare occurrence of fog and low ceiling height during this study we could not ascertain possible relationships between these conditions and flight altitudes. The need to understand how birds respond to foggy conditions is warranted, however, as the largest single-night kill for nocturnal migrants at a wind power project occurred on a foggy night during spring migration, when 27 passerines fatally 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 = 10.1 ± 0.04 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. Furthermore, our visual observations confirmed the presence of both passerines and bats in the lower air layers (i.e., <150 m agl). The method used during the beginning of the project (August 14–September 13, 2004), in which we used two 2,000,000-CP spotlights with red lenses, provided only limited information for estimating the proportion of birds and bats within the entire rotor-swept area (i.e., <125 m agl), although the data collected during that early period do provide some information on the occurrence of birds and bats at lower altitudes (i.e., <~75 m agl). We believe that the improved method using night vision goggles from 14 to 29 September provides data that are adequate for estimating the proportion of birds and bats within ~150 m agl (94% birds and 6% bats) for that time period.

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 seven bats observed during this study, two 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).

TARGETS WITHIN THE PROPOSED TURBINE AREA

We estimated a turbine passage rate of 51–362 nocturnal migrants passing within the area occupied by each proposed turbine at the Prattsburgh–Italy Wind Power project during our 45-d fall study period. Our late-season estimate of 96% birds and 4% bats may underestimate the proportion of bats over the whole fall season, based upon the timing of bat fatalities at other wind power sites earlier in the season (Johnson 2004). Regardless, our estimated turbine passage rate 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 as well as the flight speeds of individual migrants. 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 Prattsburgh–Italy 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 was moderate (i.e., 200 targets/km/h); (2) mean nightly passage rates ranged from 18 to 863 targets/km/h; (3) the percentage of targets passing below 125 m agl (9%) was similar to that for a small number of comparable studies; (4) an estimated turbine passage rate of 51–362 nocturnal migrants passing within the airspace occupied by each proposed turbine during the 45-d fall migration season; and (5) migrants flying below 150 m agl consisted of ~94% birds and ~6% bats during the late sampling period (i.e., mid- to late September).

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Appendix 1. Calculation of the turbine passage rate (the number of targets that would pass within the area occupied by each proposed turbine) over the entire 45-day fall 2004 study period at the Prattsburgh–Italy Wind Power project, NY...

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) + ($\pi \times B^2$)	5,024
PASSAGE RATE	
(G) Mean rate below 125 m agl (targets/km/h)	20.0
(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	0.00016
TURBINE PASSAGE RATE	
(J) Duration of study period (# nights)	45
(K) Mean number of hours of darkness (h/night)	10
(L) Minimal number of targets/h within turbine area = E × I	0.11424
(M) Maximal number of targets/h within turbine area = F × I	0.80390
(N) Minimal number of targets within turbine area (side profile) during 45-night period = J x K × L	51
(O) Maximal number of targets within turbine area (front profile) during 45-night period = J x K × M	362