

Keeler Obenshain PC

JOHN W. FLORA
Attorney at Law

jflora@kolawfirm.com
Direct: (540) 437-3111

90 North Main Street, Suite 201
Post Office Box 1287
Harrisonburg, Virginia 22803

Phone: (540) 437-3100
Facsimile: (540) 437-3101
www.kolawfirm.com

January 17, 2006

Via Federal Express

Mr. Joel H. Peck
Clerk of the Commission
State Corporation Commission
P.O. Box 1197
Richmond, VA 23219

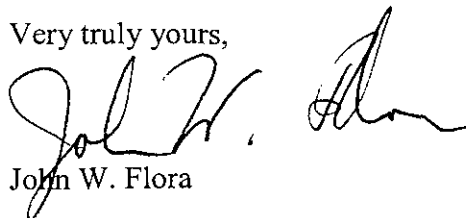
Re: Highland New Wind Development, LLC Application for Approval
to Construct, Own and Operate an Electric Generation Facility in
Highland County, Virginia
PUE-2005-00101

Dear Mr. Peck:

Enclosed for filing, please find an original and fifteen copies of A Radar and Visual Study of Nocturnal Bird and Bat Migration at the Proposed Highland New Wind Development Project, Virginia, Fall 2005, which was prepared by ABR, Inc., Environmental Research & Services.

Thank you for your assistance in this matter.

Very truly yours,


John W. Flora

cc: Wayne M. Smith, Esquire
Anthony Gambardella, Esquire
Wiley F. Mitchell, Jr., Esquire
Henry T. McBride, Jr., Manager,
Highland New Wind Development, LLC

Enclosures
JWF/mga/69555

January 17, 2006

Page 2

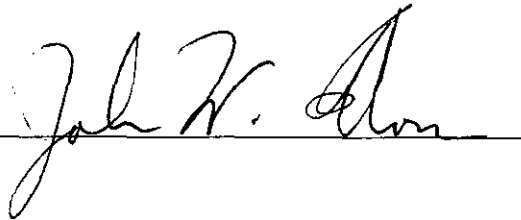
CERTIFICATE

I hereby certify that An Overview of the Current State of Knowledge of Bats with Specific Reference to the Potential Impacts of Wind Power, was mailed first class, postage prepaid this 17th day of January, 2006, to:

Wayne N. Smith
Senior Counsel
State Corporation Commission
Office of the General Counsel
P.O. Box 1197
Richmond, VA 23218-1197

Anthony Gambardella, Esquire
Woods Rogers PLC
823 East Main Street, Suite 1200
Richmond, VA 23219

Wiley F. Mitchell, Jr., Esquire
Willcox & Savage
One Commercial Place, Suite 1800
Norfolk, VA 23510



A handwritten signature in dark ink, appearing to read "John W. Smith", is written over a horizontal line.

**A RADAR AND VISUAL STUDY OF NOCTURNAL BIRD AND BAT
MIGRATION AT THE PROPOSED HIGHLAND NEW WIND
DEVELOPMENT PROJECT, VIRGINIA, FALL 2005**

FINAL REPORT

Prepared for
Highland New Wind Development, LLC
90 N. Main St.
PO Box 1287
Harrisonburg, Virginia 22803

Prepared by
Jonathan H. Plissner
Todd J. Mabee
Brian A. Cooper

ABR, Inc.—Environmental Research & Services
P.O. Box 249, Forest Grove, Oregon 97116

January 2006



Printed on recycled paper.

EXECUTIVE SUMMARY

- This report presents the results of radar and visual studies of bird and bat migration conducted during 16 August–14 October 2005 at the proposed Highland New Wind Development area, located in the Allegheny Mountains of western Virginia. Radar and visual observations were conducted at two sites within the project area for ~7 h/night during 58 nights.
- The primary goal of the study was to collect information on the migration characteristics of nocturnal birds (particularly passerines) during the fall migration period and secondarily to assess the extent of bat use to provide an overall assessment of the potential impacts to birds and bats from the proposed McBride Wind Project. Specifically, the objectives are to: (1) collect baseline information on migration characteristics (i.e., flight direction, migration passage rates, flight altitudes) of nocturnal targets (i.e., migratory birds and bats); (2) visually estimate the relative proportions of birds and bats within the rotor-swept area of the proposed wind turbines; and (3) estimate the number of birds and bats that would pass within the rotor swept area of the proposed wind turbines during the migratory season.
- No differences in passage rates, flight altitudes, or observed proportions of birds and bats were found between the two survey sites.
- Mean flight direction of targets observed on radar was 204°.
- The mean nocturnal passage rate was 385 ± 55 targets/km/h and ranged among nights between 9 and 2,762 targets/km/h. Passage rates varied among hours of the night, with lowest mean rates occurring during the first hour after sunset.
- The mean nocturnal flight altitude for the entire fall season was 442 ± 3 m agl. Mean flight altitudes observed on vertical radar were variable among nights, ranging from 211 to 721 m agl. Overall, 11.5% of targets flew ≤ 125 m agl.
- Migration passage rates increased later in the fall season, were lower under conditions of low cloud layers and fog, and varied with lunar phases. Flight altitudes varied inversely with wind speeds during this study.
- Using night-vision sampling methods to identify the taxa of low-altitude nocturnal migrants and other potential radar targets, we calculated the proportions of birds and bats below maximal turbine height to be 88% birds and 12% bats between 16 August and 29 September.
- Assuming an average of 10 nocturnal h/d, we calculated a turbine passage rate index of 3.4–24.7 avian migrants and bats passing within the area occupied by each proposed turbine each night at the project sites during fall 2005.

TABLE OF CONTENTS

EXECUTIVE SUMMARY	i
LIST OF FIGURES	iii
LIST OF TABLES	iv
LIST OF APPENDICES	v
ACKNOWLEDGMENTS	v
INTRODUCTION	1
OBJECTIVES	1
STUDY AREA	1
METHODS	3
STUDY DESIGN	3
RADAR EQUIPMENT	3
DATA COLLECTION	5
TARGET IDENTIFICATION ON RADAR	5
SAMPLING DESIGN	5
VISUAL OBSERVATIONS OF LOW-ALTITUDE BIRDS AND BATS	6
DATA ANALYSES	6
RADAR DATA	6
EFFECTS OF WEATHER ON MIGRATION PASSAGE RATES AND FLIGHT ALTITUDES	7
TURBINE PASSAGE RATE INDEX	9
RESULTS	9
FLIGHT DIRECTION	9
PASSAGE RATES	9
FLIGHT ALTITUDES	10
EFFECTS OF WEATHER ON MIGRATION	10
PASSAGE RATES	13
FLIGHT ALTITUDES	13
VISUAL DATA	13
TARGETS WITHIN THE PROPOSED TURBINE AREA	16
DISCUSSION	19
TIMING OF MIGRATION	21
PASSAGE RATES	21
FLIGHT ALTITUDES	22
MODELING MIGRATION PASSAGE RATES AND FLIGHT ALTITUDES	24
MIGRATION PASSAGE RATES	24
FLIGHT ALTITUDES	24
SPECIES COMPOSITION	24
TARGETS WITHIN THE PROPOSED TURBINE AREA	25
CONCLUSIONS	25
LITERATURE CITED	26

LIST OF FIGURES

Figure 1.	Map of radar sites for the proposed Highland New Wind Development in Highland County, Virginia	2
Figure 2.	Approximate airspace sampled by Furuno FR-1510 marine radar when operating in the surveillance mode as determined by field trials with Rock Pigeons	4

Figure 3.	Approximate airspace sampled by Furuno FR-1510 marine radar when operating in the vertical mode as determined by field trials with Rock Pigeons.....	4
Figure 4.	Synoptic weather codes used to depict the position of pressure systems or frontal systems relative to our study site.....	8
Figure 5.	Flight directions of radar targets at the proposed Highland New Wind Development, Virginia, during fall 2005	9
Figure 6.	Mean \pm 1 SE nightly passage rates for targets at all altitudes and for targets below 125 m agl at the proposed Highland New Wind Development, Virginia, during fall 2005...	10
Figure 7.	Percent of nightly passage rate relative to time past sunset for nights with 8 hours of nocturnal radar sampling at the proposed Highland New Wind Development, Virginia, during fall 2005	11
Figure 8.	Mean \pm 1 SE nightly flight altitudes at the proposed Highland New Wind Development, Virginia, during fall 2005	11
Figure 9.	Mean \pm 1 SE flight altitudes relative to time past sunset for nights with 6 hours of vertical radar sampling at the proposed Highland New Wind Development, Virginia, during fall 2005.....	12
Figure 10.	Mean numbers of birds/h and bats/h observed each hour after sunset during visual sampling at the proposed Highland New Wind Development, Virginia, during fall 2005	20
Figure 11.	Nightly mean numbers of birds/h or bats/h observed during visual sampling at the proposed Highland New Wind Development, Virginia, during fall 2005	20
Figure 12.	Flight directions of birds and bats observed during visual sampling at the proposed Highland New Wind Development, Virginia, during fall 2005	21

LIST OF TABLES

Table 1.	Nocturnal flight altitudes of radar targets detected at the 1.5-km range at the Highland New Wind Development, Virginia, fall 2005, by flight-altitude category	12
Table 2.	Linear mixed models explaining the influence of environmental factors on passage rates of bird and bat targets on surveillance radar at the proposed Highland New Wind Development, Virginia, fall 2005	14
Table 3.	Model-averaged parameter estimates from competitive models explaining the influence of environmental factors on passage rates of bird and bat targets at the proposed Highland New Wind Development, Virginia, fall 2005	16
Table 4.	Linear mixed models explaining the influence of environmental factors on flight altitudes of bird and bat targets on surveillance radar at the proposed Highland New Wind Development, Virginia, fall 2005.....	17
Table 5.	Model-averaged parameter estimates from competitive models explaining the influence of environmental factors on flight altitudes of bird and bat targets at the proposed Highland New Wind Development, Virginia, fall 2005	19
Table 6.	Birds and bats observed during nocturnal visual sampling at the Highland New Wind Development study sites, Virginia, fall 2005	19

LIST OF APPENDICES

Appendix 1.	Calculation of turbine passage rate indices at the proposed Highland New Wind Development, Virginia, during fall 2005	31
Appendix 2.	Comparisons among half-monthly periods of the migration sampling season for altitudes and passage rates of targets observed on 1.5-km radar during nocturnal surveys at the proposed Highland New Wind Development, Virginia, during fall 2005.....	32
Appendix 3.	Number of targets observed on 1.5-km vertical radar at each interval below 250 m and cumulative percent of all targets during nocturnal surveys at the Highland New Wind Development, Virginia, during fall 2005	33

ACKNOWLEDGMENTS

We thank Highland New Wind Development, LLC for funding this study and thank Dick Curry for helping to coordinate the study. At ABR, we thank Corey Grinnell, Tim Obritschkewitsch, Alice Stickney, and Hanna Mounce for help with radar sampling; and Corey Grinnell, Peter Sanzenbacher, and Rich Blaha for help with report preparation. We thank Tal McBride for his input and assistance and Henry "Mac" McBride and Lola McBride for their generous hospitality throughout the duration of the field study.

INTRODUCTION

Avian collisions with tall, manmade structures 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 collisions during their nocturnal migrations (Manville 2000). Passerines sometimes collide with wind turbines (Osborn et al. 2000, Erickson et al. 2001, 2002) and compose >80% of the fatalities at wind power developments, with ~50% of the fatalities at windfarms involving 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, Desholm and Kahlert 2005). Both the documentation of bird fatalities at most wind power facilities studied in the US (i.e., ~2 avian fatalities per turbine per year; Erickson et al. 2001) and the paucity of general information on nocturnal bird migration have generated interest in conducting preconstruction studies of nocturnal migration at 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).

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 (Arnett 2005).

While the precise relationship between nocturnal bird and bat use and fatality at wind power developments currently is unknown, the

current radar study was undertaken in fall 2005 to provide baseline information on nocturnal bird migration and bat activity at a proposed wind power development in the southern Allegheny Mountains, which contain well-documented migration corridors for birds (Bellrose 1976, Hall and Bell 1981, Zalles and Bildstein 2000). Highland New Wind Development, LLC proposes to build a 38-MW wind power development, comprised of ~19 turbines, on 88 ha in western Highland County, Virginia (Fig. 1). Each turbine will have a generating capacity of 2.0 MW. The monopole towers will be ~80 m high, and each turbine will have three rotor blades. The diameter of the rotor blades and hub will be ~80 m, resulting in a total maximal height of 120 m.

OBJECTIVES

The primary goal of this study is to collect information on the migration characteristics of nocturnal birds (particularly passerines) during the fall migration period and secondarily to assess the extent of bat use to provide an overall assessment of the potential impacts to birds and bats from the proposed Highland New Wind Project. Specifically, the objectives are to: (1) collect baseline information on migration characteristics (i.e., flight direction, migration passage rates, flight altitudes) of nocturnal targets (i.e., migratory birds and bats); (2) visually estimate the relative proportions of birds and bats within the rotor-swept area of the proposed wind turbines; and (3) estimate the number of birds and bats that would pass within the rotor swept area of the proposed wind turbines during the migratory season.

STUDY AREA

The proposed project is located in western Highland County, Virginia (Fig. 1), adjacent to the West Virginia border and along the eastern edge of the Allegheny Mountain section of the Appalachian Plateaus physiographic province (USGS 2003). The region is characterized by a series of parallel ridges of uplifted sedimentary formations, oriented along a NNE-SSW axis and separated by deep valleys. Area forests are dominated by Northern Red Oaks (*Quercus rubra*) and other northern hardwoods, with smaller patches of red spruce (*Picea rubens*; Fleming et al.



Figure 1. Map of radar sites for the proposed Highland New Wind Development in Highland County, Virginia.

2005). The proposed development area consists primarily of grazed pastureland within a matrix of farmland and forest habitat. Two ridgetops have been identified as potential development sites within the area. Red Oak Knob ($38^{\circ}28'0''\text{N}$, $79^{\circ}39'45''\text{W}$) is largely unforested, with a maximal elevation of 1,290 m. Tamarack Ridge ($38^{\circ}28'57''\text{N}$, $79^{\circ}41'9''\text{W}$), with a maximal elevation of 1,330 m, lies 2.75 km NW of Red Oak Knob and is largely forested, with a 100–200-m-wide strip of grazed pastureland along the ridgeline. One radar monitoring site was established at each of the two sites, in order to evaluate possible differences in migration activity between sites on each ridge.

METHODS

STUDY DESIGN

We conducted radar and visual observations during a 60-night study period from 16 August to 14 October 2005, to overlap with the fall peaks of passerine (Hall 1981; Hall and Bell 1981) and bat migration (Johnson 2004) in the region. Each night, we conducted ~7 h of radar and visual observations. Although some individual hour sessions were lost because of rain, we were able to obtain data from one or more radar sessions during 58 of the 60 nights. During the first four nights of the study, we conducted surveys at each site on alternate nights. During all subsequent nights, we collected data for 3.5 h at each site, alternating the starting location and observer in order to balance the sampling schedule and minimize potential observer bias. Nightly starting times were adjusted during the course of the season such that surveys began ~45 min after sunset and coincided with the peak hours of nocturnal passerine migration within nights (Lowery 1951, Gauthreaux 1971, Alerstam 1990, Kerlinger 1995). We could not collect radar data during rain because the electronic filtering required to remove the echoes of precipitation from the display screen also removed those of the targets of interest.

From 16 August through 29 September, visual observations were conducted simultaneously with radar sessions to obtain information on relative numbers of birds and bats present during the period of overlap for peak migration of both passerines

and bats. Visual observations were subsequently curtailed during the final 15 days of the study, from 30 September through 14 October. Visual observations were not conducted when rain reduced detectability of birds and bats or when fog conditions limited vertical visibility to < 25 m above ground level (agl). As a result, visual data were obtained from 9,215 min of sampling on 41 of the first 45 nights of the study and from 347 min of surveys conducted on 8 of the final 15 days of the study.

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 were recorded manually into a laptop computer. Gauthreaux (1985a, 1985b) and Cooper et al. (1991) described a similar radar laboratory, and Harmata et al. (1999a) utilized a similar vertical radar configuration.

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) \times 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 $\pm 1^{\circ}$.

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

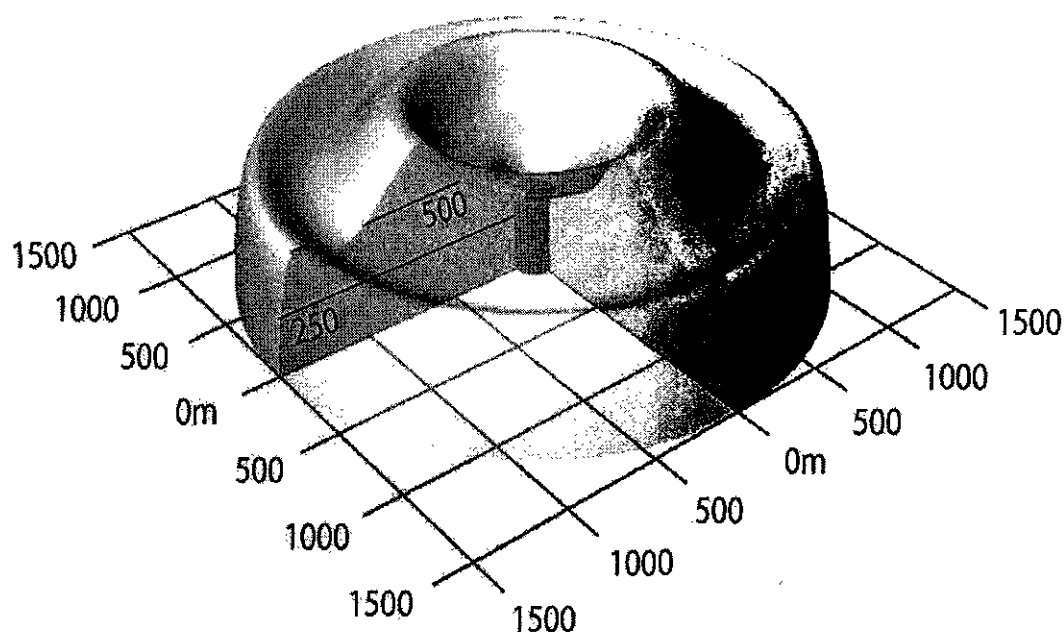


Figure 2. Approximate airspace sampled by Furuno FR-1510 marine radar when operating in the surveillance mode (antenna in the horizontal orientation) as determined by field trials with Rock Pigeons. Note that the distribution of the radar beam within 250 m of the origin (i.e., the darkened area) was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

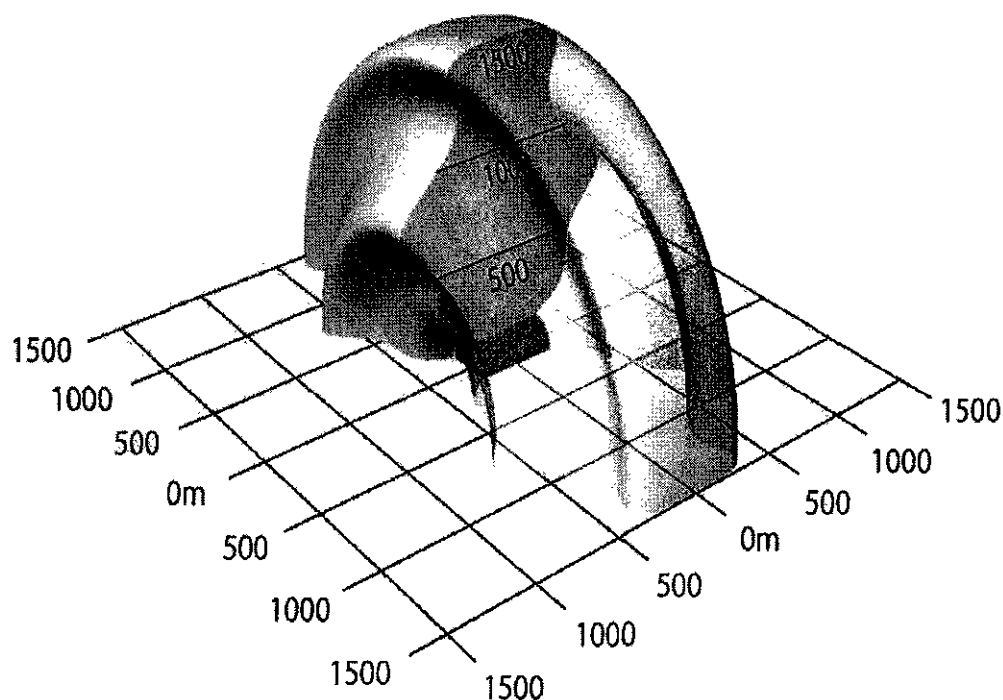


Figure 3. Approximate airspace sampled by Furuno FR-1510 marine radar when operating in the vertical mode (antenna in the vertical orientation) as determined by field trials with Rock Pigeons. Note that the distribution of the radar beam within 250 m of the origin (i.e., the darkened area) was not determined.

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 $\sim 15^\circ$ 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 radar "fences", shielding the radar from low-lying objects farther away from the lab, while producing only a small amount of ground clutter in the center of the display screen (see Eastwood 1967, Williams et al. 1972, Skolnik 1980, 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 (i.e., 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 night of the study period was subdivided into consecutive 60-min sampling sessions, beginning on the quarter-hour nearest 45 min after sunset. Each radar sampling session consisted of: (1) one 10-min period to collect weather data and adjust the radar to surveillance mode; (2) one 10-min period with the radar in surveillance mode (1.5-km range) for collection of information on migration passage rates; (3) one 15-min period

with the radar in surveillance mode (1.5-km range) for collection of information on ground speed, 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), number of individuals (if known); (4) one 10-min period to collect weather data and adjust the radar to vertical mode; and (5) one 15-min period with the radar in vertical mode (1.5-km range) to collect information on flight altitudes. For nights when surveys were conducted at both sites (all nights after 19 August), we completed three full sessions at each site, but only collected surveillance radar data during the fourth and eighth hours, because of time needed to travel between sites.

For the vertical radar sessions, the radar antenna was raised 90° and then oriented along the main axis of migration (determined by flight directions from the previous surveillance radar session), to maximize the speeds of targets that appear on the radar screen. True flight speeds of targets can be determined only for those targets flying parallel to the plane of antenna rotation; whereas slower speeds are observed for targets flying at angles to this plane. Observed speeds, therefore, are minimal estimates of true flight speeds and allowed for conservative selection of bird and bat targets (excluding insects) during analyses of the altitude data (see below).

Weather data collected twice each hour (at the beginning of each vertical and surveillance session) consisted of the following: wind speed, barometric pressure, and air temperature (measured with a "Kestrel 2500" pocket weather meter at ~4 m agl); wind direction; 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); and precipitation (none, fog, drizzle, light rain, heavy rain, snow flurries, light snowfall, heavy snowfall, sleet, hail). From 29 August through the end of the study, we also were able to obtain weather data (10-min averages of wind speed and direction) from a 40-m high meteorological tower erected at the Red Oak Knob radar site.

VISUAL OBSERVATIONS OF LOW-ALTITUDE BIRDS AND BATS

We conducted visual observations with Generation 3 night-vision goggles with a 1X eyepiece (Model ATN-PVS7; American Technologies Network Corporation, San Francisco, CA) every night of radar sampling to assess relative numbers and proportions of birds and bats flying at low altitudes (≤ 150 m agl, the approximate maximal distance that passerines and bats could be discerned). We used two 3 million-Cp spotlights with infrared lens filters to illuminate targets flying overhead while eliminating the attractiveness of the light to insects, birds, and bats. 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" spotlight's beam. For each bird or bat detected visually, the observer recorded the taxon (to species when possible), flight direction, flight altitude, and flight behavior (straight-line, erratic, circling). Whenever possible, bats were classified as "small bats" or "large bats," in an attempt to discriminate the larger Hoary (*Lasiurus cinereus*), Eastern Red (*Lasiurus borealis*), Big Brown (*Eptesicus fuscus*), and Silver-haired (*Lasionycteris noctivagans*) bats from smaller species (e.g., *Myotis* spp.). From 16 August through 29 September, we conducted two sampling sessions of 20–25 min each hour, concurrent with radar surveys. From 30 September through 14 October, after the peak period of bat activity, visual sampling was reduced to 5 min per hour and conducted between radar sessions.

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). 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 and methods.

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. Wind data from the meteorological tower were used whenever available. Targets that had corrected airspeeds <6 m/s (19% of surveillance data; 22% 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 ± 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, correcting for the hypothetical maximum height of the surveillance radar beam. 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 h on one day and ended at 0659 h 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 nine sessions. Contrasts were used to identify differences between specific hours and the nightly means. We combined data from the two sites for all analyses, unless differences between the sites were found, based upon results of the Mardia-Watson-Wheeler (Uniform Scores) test for paired comparisons with flight directions and Wilcoxon paired-sample tests for comparisons of passage rates and flight altitudes. We used Spearman's rank correlation procedure to examine associations between visual observations of birds and bats (with straight-line flight < 150 m agl) and passage rates of radar targets below 125 m agl. Factors that decreased our sample size of the various summaries and analyses included insect contamination and rain events. Sample sizes therefore sometimes varied among the different summaries and analyses.

EFFECTS OF WEATHER ON MIGRATION PASSAGE RATES AND FLIGHT ALTITUDES

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 40-m meteorological tower located at the Red Oak Knob 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 during the fall as tail winds WNW to ENE (i.e., 293°–068°), head winds ESE to WSW (i.e., 113°–248°), eastern crosswinds (069°–112°), western crosswinds (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 seven 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 (>3 SD). We used a natural log transformation on the dependent variables "passage rate" and "flight altitude" to make the data normal in fall. We specified 26 models for passage rates and 21 models for flight altitudes: a global model containing all variables and subset models representing potential influences of three small-scale weather variables (wind speed, wind direction, and ceiling height [including fog]), one large-scale weather variable (synoptic—that reflected the position of pressure systems or frontal systems relative to our study site (Fig. 4), one variable reflecting the number of days between favorable migration conditions (i.e., the number of days since last tail wind, used only in

passage rate models), one variable describing the percent of the moon illuminated on a given night, and date. Synoptic weather codes were based on Gauthreaux (1980) and Williams et al. (2001). We analyzed all model sets with linear mixed models that treated nights as subjects and hourly sessions within a night as the repeated measure. This treatment of the data allows the full use of hourly sessions while properly modeling the appropriate covariance structure for this variable. Because the hourly sessions within a night were temporally correlated, we used a first-order autoregressive structure with heterogeneous variances for the covariance structure for both altitude and passage rate models.

Because the number of sampling sessions for both passage rates ($n = 405$ in fall) and flight altitudes ($n = 305$ in fall) 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

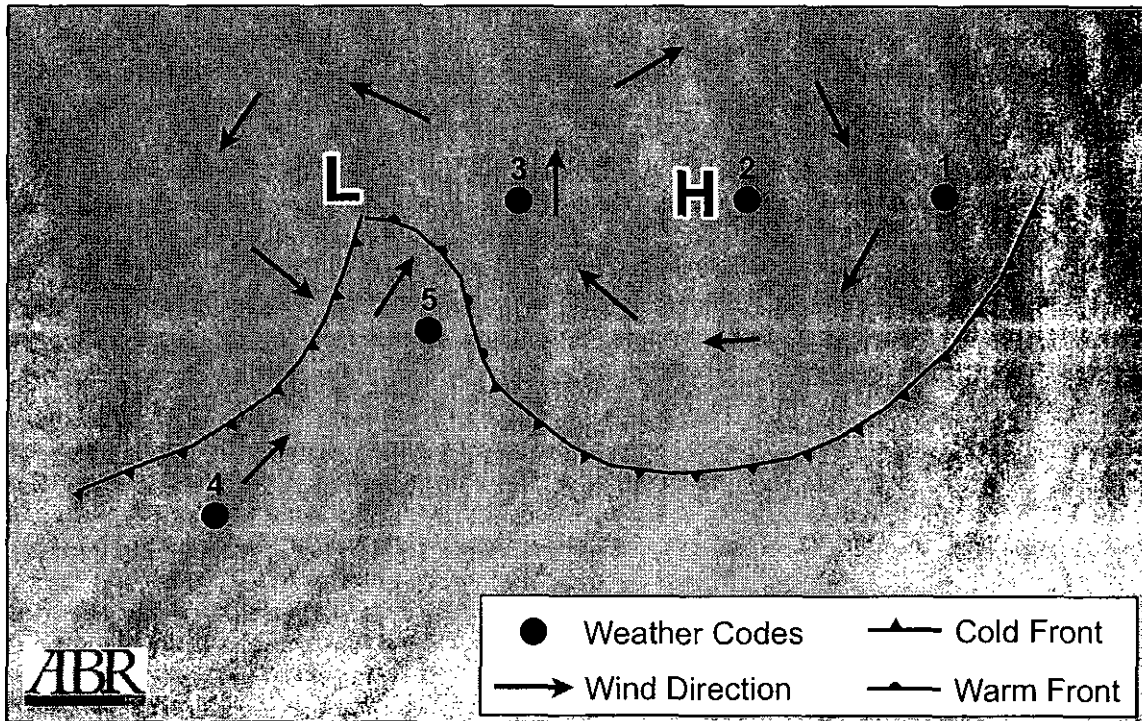


Figure 4. Synoptic weather codes used to depict the position of pressure systems or frontal systems relative to our study site. Code 1 = N or W of cold front, 2 = near center of high pressure system, 3 = W of high pressure system, 4 = S or E of cold front, 5 = S of warm front.

selection (Burnham and Anderson 2002). 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 2002). 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 2002). We calculated Akaike weights (w_i) to determine the weight of evidence in favor of each model (Burnham and Anderson 2002). All analyses were conducted with SPSS software (SPSS 2003).

TURBINE PASSAGE RATE INDEX

To describe migration passage rates within the potential turbine area we developed the turbine passage rate index, which represents an estimate of the number of nocturnal migrants flying within the turbine area throughout the study period. The turbine passage rate index is comprised of several components, including: (1) *passage rate of targets flying ≤ 125 m agl*; (2) *turbine area* that migrants would encounter when approaching turbines from the side (parallel to the plane of rotation) or from the front (perpendicular to the plane of rotation); (3) *study period* (number of nights during the migration period); and (4) *number of hours of migration/night* (estimated as the number of hours of darkness). These factors are combined as described in Appendix 1 to produce the turbine passage rate index.

We consider these estimates to be indices because they are based on several simplifying assumptions that may vary among projects. The assumptions for this specific project include: (1) the lower bound of the estimate assumes that migrants approach turbines parallel to the plane of rotation of the blades (i.e., encounter the side profile), whereas the upper bound assumes that flight directions are perpendicular to the plane of rotation (i.e., encounter the front profile), (2) 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), (3) a 60-d fall migration period, and (4) an average of 10 nocturnal hours/day of migration during fall migration.

RESULTS

FLIGHT DIRECTION

Most radar targets (65%) were traveling in seasonally appropriate directions for fall migration (i.e., southerly; Fig. 5), with a mean flight direction of 204° (mean vector length = 0.25; $n = 11,197$ targets). Mean flight directions at the two sites did not differ ($W = 1.87$, $p = 0.392$, $n = 51$ nights).

PASSAGE RATES

The mean nocturnal passage rate for the fall migration season was 385 ± 55 targets/km/h ($n = 58$ nights). Comparing passage rates at the two sites during 51 nights when both sites were surveyed, we did not find any difference in numbers of targets flying over each site ($Z = -1.05$; $P = 0.294$). Data from both sites were therefore combined for subsequent analyses. Mean nightly passage rates were highly variable among nights (Fig. 6) and during different portions of the season (Appendix 2). Mean hourly passage rates of greater than 300 targets/km/h occurred on over half ($n = 32$) of the nights of the study, with the highest mean rate

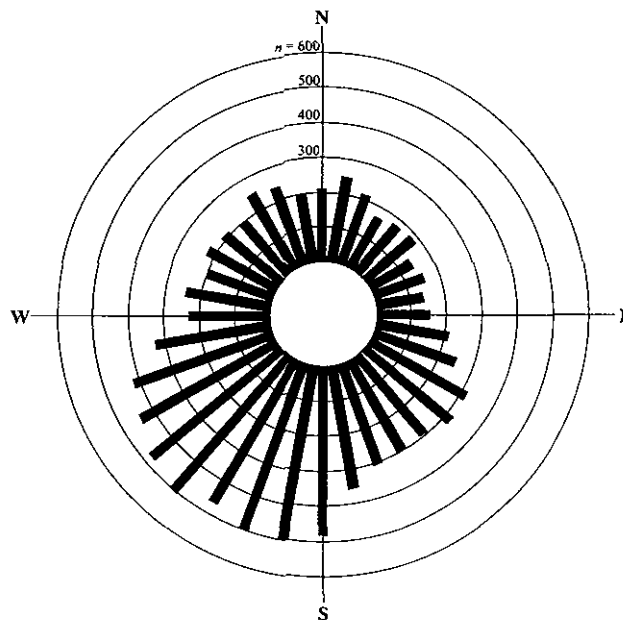


Figure 5. Flight directions of radar targets at the proposed Highland New Wind Development, Virginia, during fall 2005.

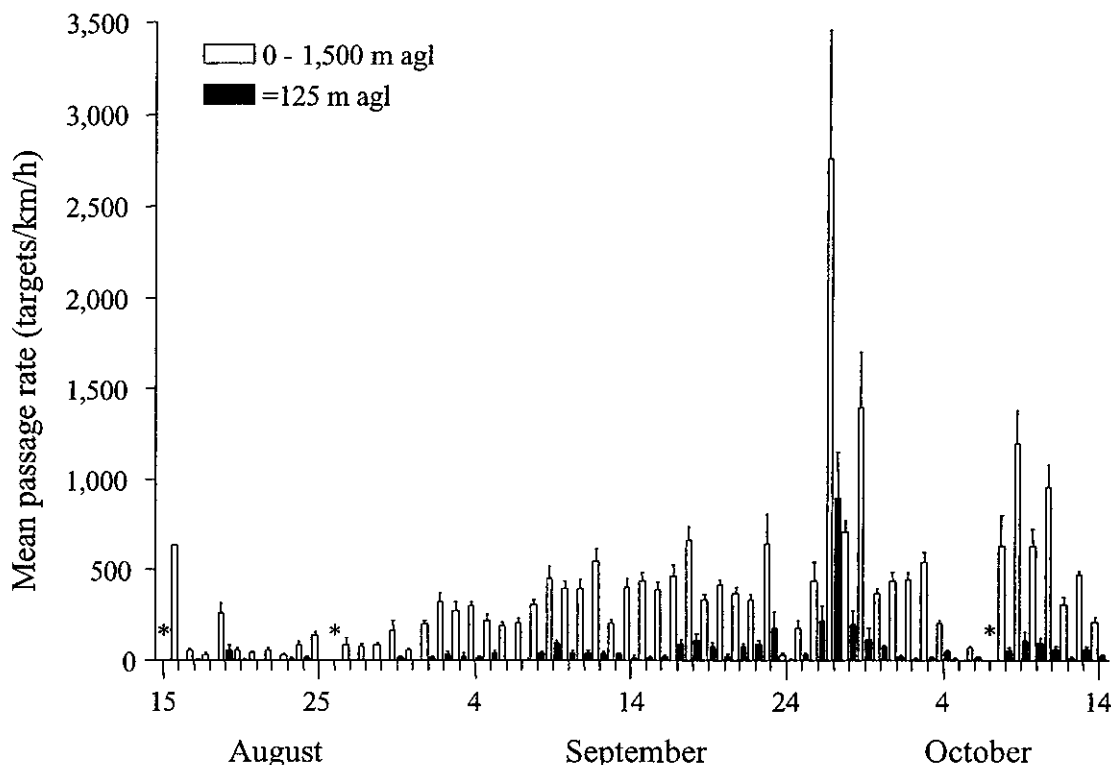


Figure 6. Mean \pm 1 SE nightly passage rates (targets/km/h) for targets at all altitudes and for targets below 125 m agl at the proposed Highland New Wind Development, Virginia, during fall 2005. Asterisks denote nights not sampled because of rain.

(2,762 targets/km/h) occurring on 27 September. Passage rates averaged less than 100 targets/km/h on 14 nights, with lowest rates (mean = 9 targets/km/h) recorded on the night of 5 October. Passage rates also varied among hours within nights ($F_{3,3,322} = 3.14$; $P = 0.023$; $n = 47$ nights, Fig. 7), with rates recorded during the first hour after sunset significantly lower than the nightly means.

FLIGHT ALTITUDES

The mean nocturnal flight altitude for the entire fall season was 442 ± 3 m agl ($n = 13,606$ targets; median = 369 m agl). During 51 nights when both sites were surveyed, flight altitudes did not differ between the sites ($Z = -0.19$; $P = 0.851$). Mean flight altitudes varied among nights (Fig. 8), ranging from 211 m agl on 28 September to 721 m agl on 5 October, and also varied during different

portions of the season (Appendix 2) see comments above. The overall distribution of flight altitude targets in 100 m categories varied from 16.6% in the 101–200-m agl interval to 0.1% in the 1,401–1,500-m agl interval (Table 1). Mean flight altitudes varied among hours of the night (Fig. 9; $F_{3,6, 220} = 3.05$, $P = 0.02$, $n = 45$ nights), with altitudes recorded during the eighth hour after sunset significantly lower than the overall nightly mean ($F_{1,44} = 14.73$, $P < 0.001$). We determined that 11.5% of all targets flew ≤ 125 m agl. A breakdown of cumulative percentages of targets within 25-m altitude categories (up to 250 m agl) is provided in Appendix 3.

EFFECTS OF WEATHER ON MIGRATION

We investigated the importance of weather (i.e., wind direction, wind speed, ceiling height [including fog], synoptic weather, days since

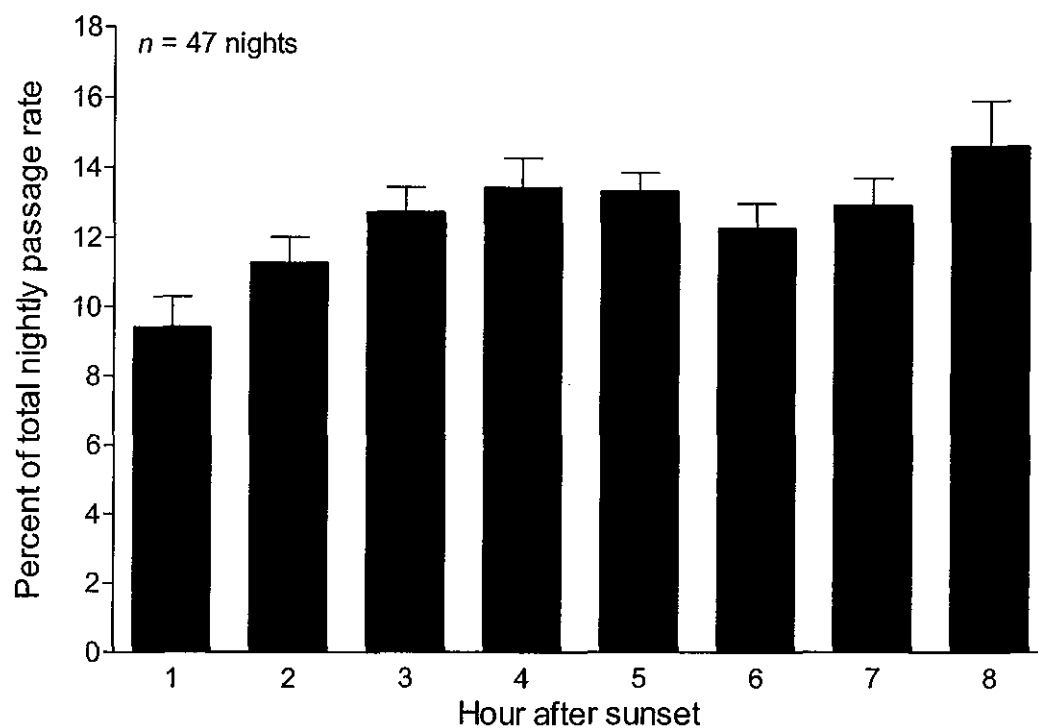


Figure 7. Percent of nightly passage rate (± 1 SE) relative to time past sunset for nights with 8 hours of nocturnal radar sampling at the proposed Highland New Wind Development, Virginia, during fall 2005.

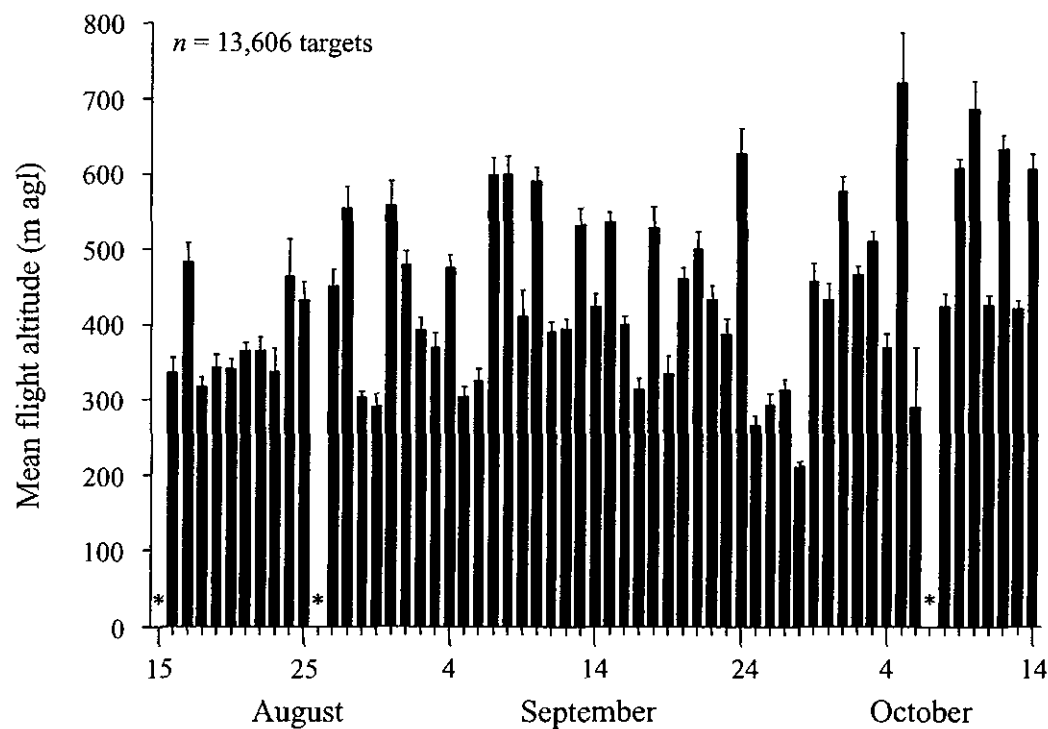


Figure 8. Mean ± 1 SE nightly flight altitudes (m agl) at the proposed Highland New Wind Development, Virginia, during fall 2005. Asterisks denote nights not sampled because of rain.

Results

Table 1. Nocturnal flight altitudes of radar targets (% of all targets) detected at the 1.5-km range at the Highland New Wind Development, Virginia, fall 2005, by flight-altitude category. Total $n = 13,603$ targets.

Flight altitude (m agl)	Per Category	Cumulative
0–100	8.0	8.0
101–200	16.6	24.6
201–300	16.1	40.7
301–400	13.7	54.4
401–500	11.3	65.7
501–600	8.2	73.9
601–700	6.1	80.0
701–800	5.5	85.5
801–900	4.8	90.3
901–1,000	3.4	93.7
1,001–1,100	2.4	96.1
1,101–1,200	1.9	98.0
1,201–1,300	1.3	99.3
1,301–1,400	0.6	99.9
1,401–1,500	0.1	100.0

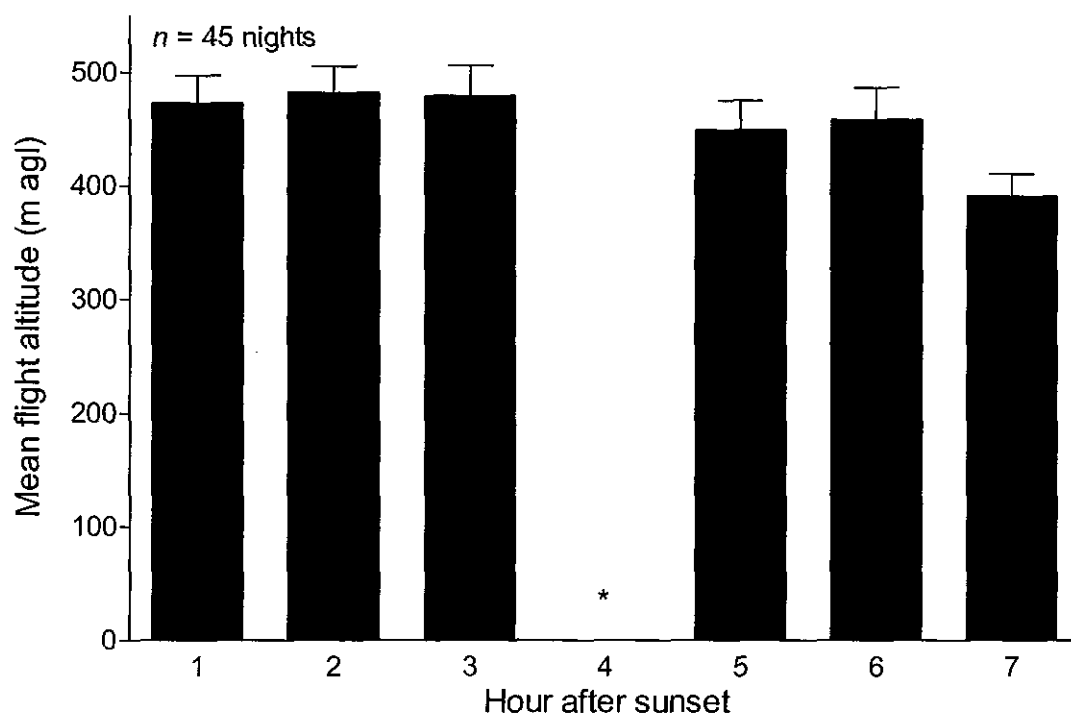


Figure 9. Mean ± 1 SE flight altitudes (m agl) relative to time past sunset for nights with 6 hours of vertical radar sampling at the proposed Highland New Wind Development, Virginia, during fall 2005. Asterisk denotes hour not sampled because of travel between survey sites.

favorable migration), lunar illumination, 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), and 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, ceiling height, synoptic weather, date, wind speed, number of days since favorable migration, and lunar illumination (Table 2). The second-best model contained the variables ceiling height, lunar illumination, and date and received similar empirical support ($\Delta AIC_c = 0.76$; Table 2). These models contained significant positive associations with date and lunar illumination indicating that passage rates were higher later in the season and when the moon was illuminated (Table 3). These models contained significant negative associations with ceiling height at ~ground level (fog) and ceiling height between 51 and 500 m agl indicating that passage rates decreased under these foggy or low ceiling conditions. Passage rates were not related to wind direction, synoptic weather, wind speed, and number of days since favorable migration. The weight of evidence in favor of the "best" model ($w_{\text{best}}/w_{\text{second best}}$) was 1.4 times that of the second-best model (Burnham and Anderson 2002).

FLIGHT ALTITUDES

The best-approximating model explaining flight altitudes of nocturnal migrants during fall migration was the model containing the variable wind speed (Table 4). The second-best model contained the variables wind direction and wind speed, although it received limited empirical support ($\Delta AIC_c = 5.7$; Table 4). The best model contained a strong negative association with wind speed indicating that flight altitudes decreased with

faster wind speeds (Table 5). Flight altitudes were not related to wind direction, date, synoptic, lunar illumination, or ceiling height. The weight of evidence in favor of the "best" model ($w_{\text{best}}/w_{\text{second best}}$) was 17.8 times that of the second-best model (Burnham and Anderson 2002).

VISUAL DATA

We conducted 9,562 min of visual surveys during 49 nights of the fall field season, recording a total of 1,919 birds and bats (Table 6). Observation rates did not differ between the two sites ($Z = -0.65$; $P = 0.514$; $n = 43$ nights) or among hours of the night (Fig. 10; $n = 34$ nights; $F_{\text{birds}, 1,3, 165} = 1.60$, $P = 0.22$; $F_{\text{bats}, 1,3, 165} = 1.92$, $P = 0.17$). During the period of intensive visual sampling (16 August - 29 September, $n = 41$ nights), mean nocturnal visual rates were 8.2 ± 2.0 birds/h and 1.4 ± 0.2 bats/h. After 29 September, no bats and a mean rate of 1.9 ± 0.7 birds/h ($n = 171$ min during 8 nights) were observed during the final 15 days of the study, when weather conditions often resulted in poor visibility and further reduced sampling efforts. Mean nightly visual-observation rates were highly variable for both birds and bats (Fig. 11), although the range in rates was much greater for birds (0–59 individuals/h) than for bats (0–6 individuals/h). On nights with at least 1.0 h of observations ($n = 40$), bats were observed on 31 nights (77.5%), and birds were observed during 87.5% of the nights. The peak number of bats was recorded during the first night of the study (16 August, 5.8 bats/h), although few bats were seen again until mid-September (Fig. 11). Numbers of birds observed began to increase in early September and had two distinctive peaks, on the nights of 12 September and 27 September. Nightly visual observation rates of migratory birds and bats were correlated with mean passage rates of low altitude (< 125 m agl) radar targets (Spearman's $\rho = 0.822$, $n = 39$ nights).

Of the 1,342 birds observed, 92% were identified as passerines, with only 22 non-passerines reported (2%; including a flock of 15 unknown duck species, two barn owls [*Tyto alba*], one common nighthawk [*Chordeiles minor*], one northern saw-whet owl [*Aegolius acadicus*], and three unidentified individuals). Further

Table 2. Linear mixed models explaining the influence of environmental factors on passage rates of bird and bat targets on surveillance radar at the proposed Highland New Wind Development, Virginia, fall 2005 ($n = 405$ sampling sessions). Model weights (w_i) were based on Akaike's Information Criterion (AIC).

Model	-2 Log Likelihood ^a	K ^b	AIC _c ^c	Δ AIC _c ^d	w_i ^e
Global model: wind direction + ceiling height + synoptic ^f + date + wind speed + favorable migration(d)* + lunar illumination	573.02	24	624.18	0.00	0.52
Ceiling height + lunar illumination + date	593.70	15	624.93	0.76	0.36
Ceiling height + date	598.39	14	627.47	3.29	0.10
Wind direction + ceiling height + date	595.77	17	631.35	7.18	0.01
Favorable migration(d) + date	610.66	13	637.59	13.41	0.00
Synoptic + date	605.69	16	639.09	14.92	0.00
Wind direction + favorable migration(d) + date	608.90	16	642.30	18.12	0.00
Lunar illumination + date	617.24	13	644.15	19.99	0.00
Date	622.93	12	647.72	23.55	0.00
Wind direction + lunar illumination + date	615.29	16	648.69	24.52	0.00
Wind direction + lunar illumination + wind speed + date	614.25	17	649.83	25.66	0.00
Wind direction + date	621.06	15	652.29	28.12	0.00
Wind direction + wind speed + date	620.11	16	653.51	29.34	0.00
Synoptic	636.12	14	665.20	41.03	0.00
Ceiling height + favorable migration	640.64	13	667.57	43.40	0.00
Ceiling height + lunar illumination	640.86	13	667.79	43.61	0.00
Favorable migration(d)	647.57	11	670.24	46.07	0.00
Ceiling height	646.58	12	671.38	47.20	0.00
Lunar illumination	649.07	11	671.74	47.57	0.00

Table 2. Continued.

Model	-2 Log Likelihood ^a	K ^b	AIC _c ^c	Δ AIC _c ^d	w _i ^e
Wind direction + favorable migration(d)	647.13	14	676.21	52.03	0.00
Wind speed	654.41	11	677.08	52.91	0.00
Wind direction + ceiling height	646.00	15	677.24	53.06	0.00
Wind direction + lunar illumination	648.54	14	677.62	53.44	0.00
Wind direction + lunar illumination + wind speed	647.48	15	678.72	54.54	0.00
Wind direction	655.11	13	682.04	57.87	0.00
Wind direction + wind speed	654.11	14	683.19	59.01	0.00

^a Calculated with the Maximum Likelihood method.^b Number of estimable parameters in approximating model (see methods for explanation).^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.^f Synoptic weather^g Number of days since favorable migration conditions (tailwinds)

Table 3. Model-averaged parameter estimates from competitive models ($\Delta AICc = 2$) explaining the influence of environmental factors on passage rates of bird and bat targets at the proposed Highland New Wind Development, Virginia, fall 2005. Coefficients (B) of the categorical variables (ceiling height, wind direction, and synoptic) were calculated relative to high ceiling conditions (> 500 m agl), headwinds, and S of warm front, respectively. Asterisks indicate 95% confidence intervals that do not overlap zero.

Parameters	B	SE
Intercept	4.05	0.41*
Wind direction = tailwind	0.11	0.10
Wind direction = eastern crosswind	0.12	0.12
Wind direction = western crosswind	0.02	0.05
Ceiling height = fog	-0.75	0.18*
Ceiling height = 51–500 m agl	-0.36	0.11*
Synoptic = N or W of cold front	-0.03	0.41
Synoptic = near center of high pressure system	0.22	0.38
Synoptic = W of high pressure system	-0.29	0.44
Synoptic = S or E of cold front	-0.41	0.41
Date	0.11	0.00*
Date (quadratic)	<-0.01	0.00
Wind speed	0.00	0.01*
Favorable migration (d)	-0.08	0.04*
Lunar illumination	0.33	0.14*

classification of the remaining 7% of birds observed could not be determined. Of the 199 bats observed, 32% were distinguished as small (e.g., *Myotis* spp. or *Pipistrellus subflavus*) species, and 11% were identified as larger species; however, size categories of 57% of the bats observed were not determined. Observation rates of birds and bats (total and by size category) did not differ between the two sites (all $P > 0.1$). Of the total number of visual targets at or below maximal turbine height and which could be identified as either birds or bats ($n = 1,328$), the proportions were 88% birds and 12% bats.

Most birds were traveling in seasonally appropriate directions for fall migration (i.e., southerly; Fig 12a), with a mean flight direction of 198° (mean vector length = 0.59; $n = 1,334$; median and modal direction = 180°). Flight directions of bats were considerably more

dispersed (Fig 12b; mean = 230° , median = 225° , mode = 270° , mean vector length = 0.32, $n = 172$).

TARGETS WITHIN THE PROPOSED TURBINE AREA

For the fall study period, the mean passage rate of targets at or below the maximum turbine height (120 m agl) was 56.3 ± 15.7 targets/km/h. If all migrants approached the turbines from the side, an estimated 3.4 migrants would have passed within the area occupied by one turbine each night during the fall migration period (Appendix 1). If all migrants approached the turbines from the front, an estimated nightly average of 24.7 individuals would have passed within the area occupied by one turbine (Appendix 1). For the entire fall season, these rates correspond to 203–1,483 migrants

Table 4. Linear mixed models explaining the influence of environmental factors on flight altitudes of bird and bat targets on surveillance radar at the proposed Highland New Wind Development, Virginia, fall 2005 ($n = 305$ sampling sessions). Model weights (w_i) were based on Akaike's Information Criterion (AIC).

Model	-2 Log Likelihood ^a	K ^b	AIC _c ^c	Δ AIC _c ^d	w_i ^e
Wind speed	215.36	9	233.97	0.00	0.89
Wind direction + wind speed	212.43	13	239.68	5.71	0.05
Wind direction + wind speed + date	211.32	14	240.77	6.80	0.03
Wind direction + lunar illumination + wind speed	212.38	14	241.83	7.86	0.02
Wind direction + lunar illumination + wind speed + date	211.32	15	242.98	9.02	0.01
Synoptic ^f	221.89	12	246.96	13.00	0.00
Global model: wind direction + ceiling height + synoptic + date + wind speed + lunar illumination	203.37	21	248.64	14.67	0.00
Synoptic + date	221.74	13	248.99	15.03	0.00
Ceiling height + date	226.75	11	249.65	15.69	0.00
Date	231.46	9	250.07	16.10	0.00
Lunar illumination	231.81	9	250.42	16.45	0.00
Ceiling height	229.98	10	250.73	16.77	0.00
Ceiling height + lunar illumination + date	226.55	12	251.62	17.65	0.00
Lunar illumination + date	231.07	10	251.82	17.85	0.00
Ceiling height + lunar illumination	229.32	11	252.23	18.26	0.00

Table 4. Continued.

Model	-2 Log Likelihood ^a	K ^b	AIC _c ^c	ΔAIC_c^d	w _i ^e
Wind direction	231.32	12	256.39	22.42	0.00
Wind direction + ceiling height + date	225.95	15	257.61	23.64	0.00
Wind direction + date	230.61	13	257.86	23.89	0.00
Wind direction + lunar illumination	230.74	13	257.99	24.02	0.00
Wind direction + ceiling height	228.79	14	258.24	24.27	0.00
Wind direction + lunar illumination + date	230.21	14	259.66	25.69	0.00

^a Calculated with the Maximum Likelihood method.^b Number of estimable parameters in approximating model (see methods for explanation).^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.^f Synoptic weather

Table 5. Model-averaged parameter estimates from competitive models ($\Delta AIC_c = 2$) explaining the influence of environmental factors on flight altitudes of bird and bat targets at the proposed Highland New Wind Development, Virginia, fall 2005. Asterisks indicate 95% confidence intervals that do not overlap zero.

Parameters	B	SE
Intercept	6.31	0.07*
Wind speed	-0.02	0.01*

Table 6. Birds and bats observed during nocturnal visual sampling at the Highland New Wind Development study sites, Virginia, fall 2005. Percentages are relative to the total number of targets identifiable as birds or bats. Number of minutes sampled at Red Oak and Tamarack sites = 4,993 and 4,569 respectively.

Species group	Project site					
	Red Oak		Tamarack		Combined	
Total birds	750	(89.2%)	592	(84.5%)	1342	(87.1%)
Passerines	705	(83.8%)	526	(75.1%)	1231	(79.1%)
Non passerines	3	(0.4%)	19	(2.7%)	22	(1.4%)
Unidentified birds	42	(5.0%)	47	(6.7%)	89	(5.8%)
Total bats	91	(10.8%)	108	(15.4%)	199	(12.9%)
Small bats	25	(3.0%)	39	(5.6%)	64	(4.2%)
Large bats	7	(0.8%)	15	(2.1%)	22	(1.4%)
Unidentified bats	57	(7.0%)	54	(7.7%)	113	(7.3%)
Unidentified (bird or bat)	214		164		378	
Total	1055		864		1919	

passing through the area occupied by each turbine over a 60-day period (Appendix 1).

Applying the percentages of birds and bats observed during night vision surveys, we estimate an average bat passage rate of 0.5–3.5 bats/turbine/night (depending upon orientation of the turbine axis relative to flight directions) between 16 August and 29 September. During the same period, we estimate that an average of 3.1–23.0 birds/night passed through the area potentially occupied by each turbine. Assuming that numbers of bats present after 29 September were negligible (no bats were seen during 347 min of observations), estimated turbine passage rates for the entire study period range from 0.4 to 2.7

bats/turbine/night and 3.0 to 22.0 birds/turbine/night.

DISCUSSION

Predictions of the effects of wind power development on migratory birds and bats are hampered by both a lack of detailed knowledge about patterns of the nocturnal migration and behavior of birds and bats around wind turbines and by the fact that the precise relationship between bird abundance and bird fatalities at wind turbines currently is unknown. In this study, we addressed the first of these issues and documented some of the key characteristics of nocturnal

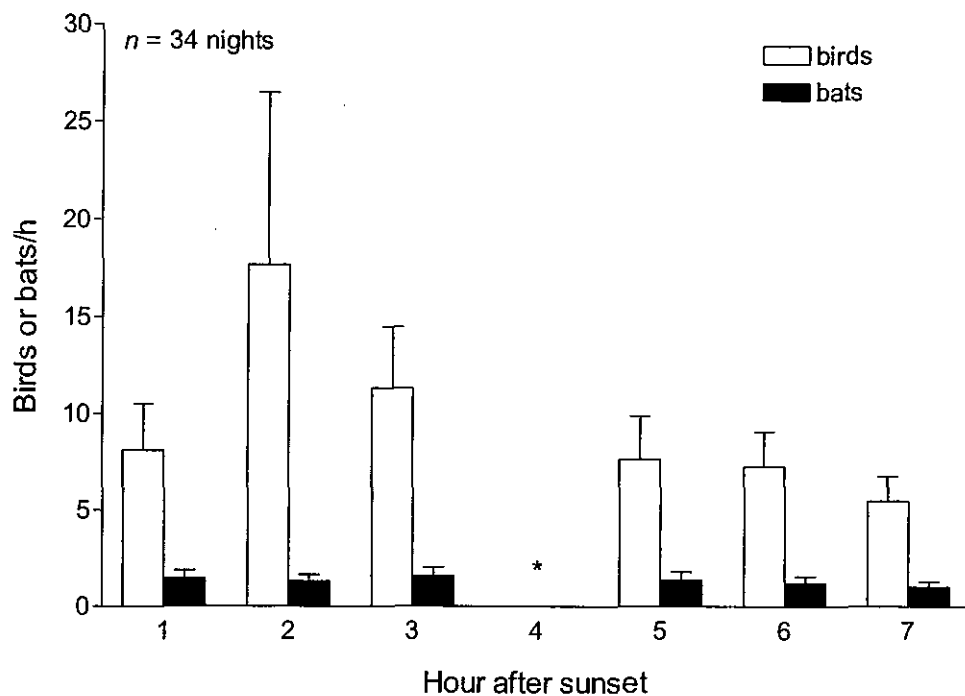


Figure 10. Mean (± 1 SE) numbers of birds/h and bats/h observed each hour after sunset during visual sampling at the proposed Highland New Wind Development, Virginia, during fall 2005. Asterisk denotes hour not sampled because of travel between survey sites.

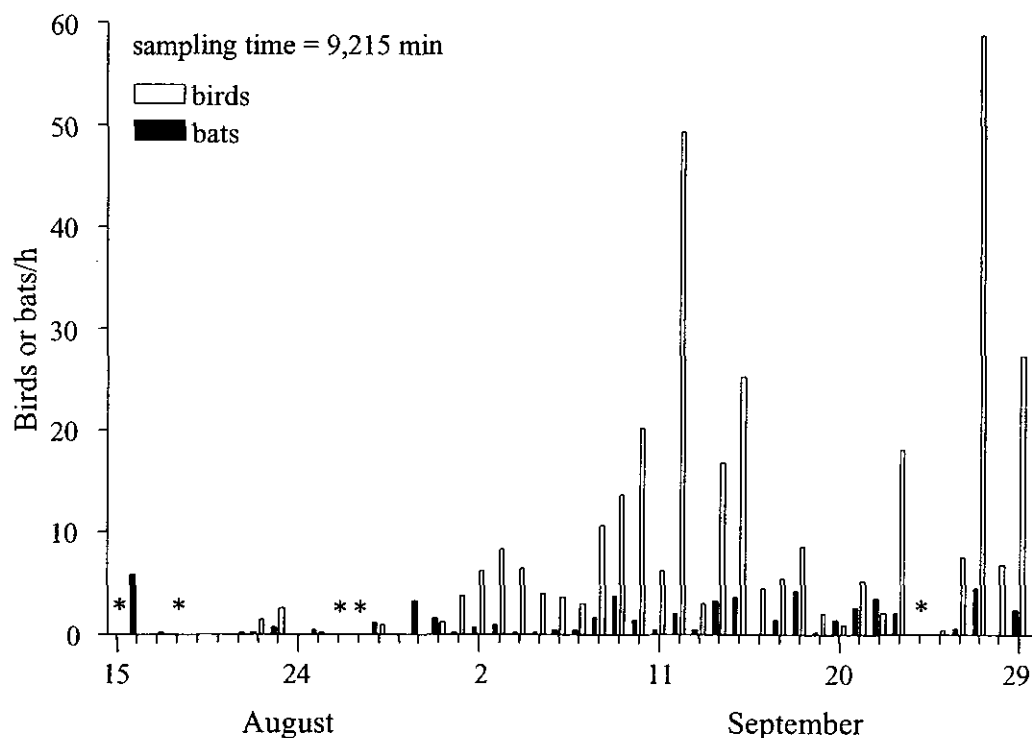


Figure 11. Nightly mean (± 1 SE) numbers of birds/h or bats/h observed during visual sampling at the proposed Highland New Wind Development, Virginia, during fall 2005. Asterisks denote nights not sampled because of rain or fog.

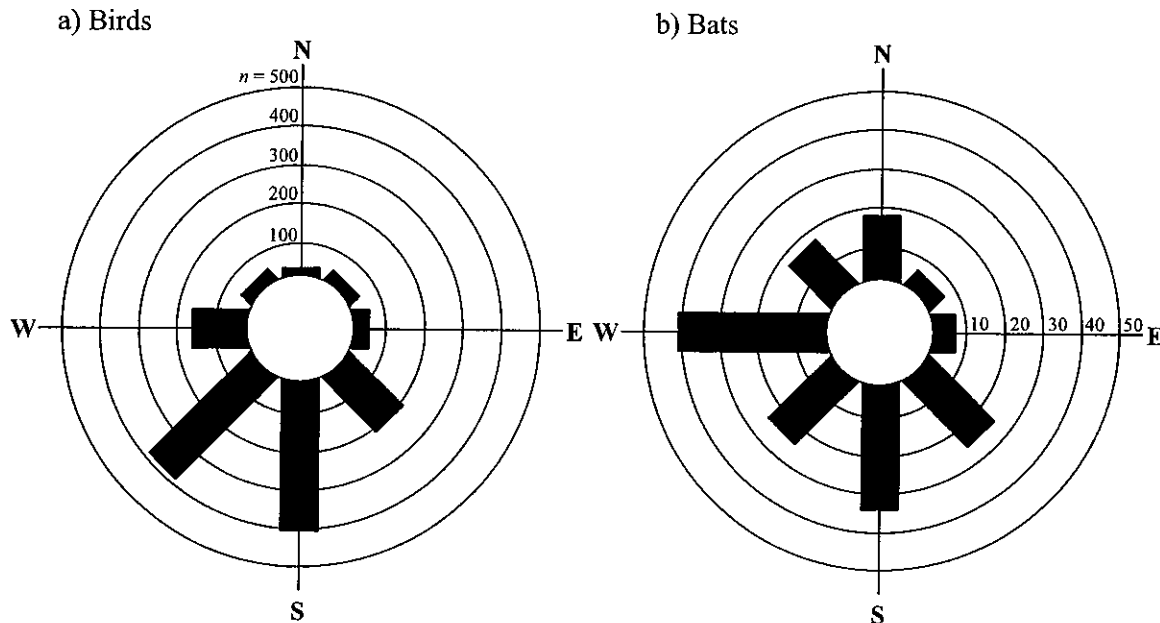


Figure 12. Flight directions of (a) birds and (b) bats observed during visual sampling at the proposed Highland New Wind Development, Virginia, during fall 2005.

migratory activity, in order to describe some of the general properties of nocturnal bird migration and bat activity 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 use. Such models may be useful for both pre-construction siting decisions and for the consideration of operational strategies to reduce fatalities, if correlations between bird abundance and fatality at wind turbines are demonstrated.

Within nights, passage rates increased after the first hour post-sunset and then remained fairly consistent during subsequent hours. Similar patterns have been reported for radar studies in West Virginia (Mabee et al. 2004) and New York (Mabee et al. 2005a). Other studies have indicated a pattern 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, Mabee et al. 2005b).

Within seasons, nocturnal migration often is a pulsed phenomenon (Alerstam 1990; Mabee and Cooper 2004, Cooper and Day, ABR, unpubl. data). In this study, high mean nightly passage rates (> 300 targets/km/h) occurred on 32 nights during the fall, with only one heavy migration nights occurring before 1 September. Passage rates were particularly high (greater than one standard deviation of the mean) during four nights: 27 and 29 September and 9 and 11 October. Pulses of fall migrants during the fall season have been documented over many years at the Allegheny Front Migration Observatory, in the Dolly Sods Wilderness Area, West Virginia (Hall 1981; R. Bell and J. Pattison, unpubl. data).

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 bird use of several sites

being considered for wind power development. 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 bird activity in the vicinity of wind farm sites, the second metric is especially well suited for this comparison because of its altitude-specific nature.

Comparisons with passage rates from other ABR studies can be categorized into two groups. *Primary comparisons* can be made among studies using similar radar equipment (i.e., the same type of radar and configuration) and methods incorporating a speed-based criterion for removal of insects. These studies include the Mt. Storm project in West Virginia (Mabee et al. 2004); and the Flat Rock (Mabee et al. 2005b), Prattsburgh–Italy (Mabee et al. 2005a), and Chautauqua (Cooper et al. 2004) projects in New York. *Secondary comparisons* are for studies using comparable equipment but which utilized a subjective criterion for removal of insects. These include all studies conducted before 2001 in New York (Harrisburg [Cooper and Mabee 2000], Wethersfield [Cooper and Mabee 2000], Carthage [Cooper et al. 1995a]), the Midwest (Day and Byrne 1990), and the western states (Stateline and Vansycle projects in Oregon and Washington [Mabee and Cooper 2004]). Secondary comparisons may be considered valid if insect contamination was unlikely to be a confounding factor in the study.

The observed passage rates in the project area during fall were much higher than those at other locations in the eastern US where we have conducted fall migration studies with similar equipment and methods. The mean fall nocturnal passage rate in this study was 385 targets/km/h. Elsewhere in the southern Allegheny Mountains, 199–241 targets/km/h were reported during the fall at Mt. Storm, WV (Mabee et al. 2004). Fall passage rates in New York were 122 targets/km/h at Harrisburg (Cooper and Mabee 2000); 158 targets/km/h at the proposed Flat Rock wind power development (Mabee et al. 2005b), 168 targets/km/h at Wethersfield (Cooper and Mabee 2000); 200 targets/km/h at the proposed Prattsburgh–Italy wind power development

(Mabee et al. 2005b); 225 targets/km/h at Carthage (Cooper et al. 1995a), and 238 targets/km/h at Chautauqua (Cooper et al. 2004). Much 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 western states (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 during fall (56.3 targets/km/h flying 120 m agl) were higher than those calculated at other sites in the eastern US. Estimated rates below maximal turbine height at the Mount Storm site in West Virginia were 36.3 targets/km/h flying <125 m agl (Mabee et al. 2004). In New York, estimates of fall passage rate indices were estimated to be 20.0 targets/km/h flying <125 m agl at the proposed Prattsburgh–Italy wind power project (Mabee et al. 2005b) and 11.4 targets/km/h flying <125 m agl at the proposed Flat Rock wind power development (Mabee et al. 2005c).

FLIGHT ALTITUDES

Flight altitudes are critical for understanding the vertical distribution of nocturnal migrants in the airspace. 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.

Flight altitudes of migratory bats are poorly known. Hoary bats (*Lasiorycter 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.

Comparisons with flight altitudes from other ABR studies can be categorized into three groups. As with comparisons of passage rates, *primary comparisons* can be made among studies using similar radar equipment (i.e., the same type of radar and configuration) and methods incorporating a speed-based criterion for removal of insects (Flat Rock and Prattsburgh–Italy in New York and the Mt. Storm project in West Virginia). Similarly, *secondary comparisons* are made among studies using comparable equipment but which utilized a subjective criterion for removal of insects (Chautauqua, NY, and the Stateline and Vansycle projects in Oregon). Altitude results from other studies (including pre-2001 studies in the Midwest and in Harrisburg, Wethersfield, and Carthage, New York) are considered inappropriate for direct comparisons because of the use of different radar equipment.

Mean flight altitudes at the proposed project site during fall were higher (442 m agl) than those at the Mt. Storm project site in West Virginia (mean = 410 m agl) and intermediate compared with fall studies conducted in New York (the proposed Prattsburgh–Italy wind power development, mean = 365 m agl; Flat Rock wind power development, mean = 415 m agl; Chautauqua, mean = 532 m agl). Other published studies that used a variety of radar systems and analyses have also 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). A summary of radar results from the eastern US concluded that three-quarters of passerines migrate <600 m agl (Kerlinger 1995).

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) during fall and estimated that 11.5% flew ≤ 125 m agl at this study site, lower than the percentage at the proposed Mt. Storm, WV wind power development (13–16% flew <125 m agl (Mabee et al. 2004), but higher than the percentage at the proposed Prattsburgh–Italy, NY wind power development (9.2% < 125 m agl, Mabee et al. 2005b), and the Flat Rock, NY wind power project (7–8% < 125 m agl, Mabee et al. 2005b). The only other sites available for comparisons during spring are Chautauqua, NY (4% <140 m agl; Cooper et al. 2004), and the Vansycle and Stateline wind power facilities in eastern Oregon (3–9% <125 m agl; Mabee and Cooper 2004). Percentages of targets below turbine height may vary for multiple reasons—including differences in weather conditions, date, and species composition of migrants.

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 generally were above the proposed turbine heights (observed minimum = 211 m agl during fall). 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 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, ceiling height [including fog], synoptic weather, and the number of days since favorable migration conditions), date, and lunar illumination on migration passage rates. During fall migration passage rates increased later in the season and when the moon was illuminated, whereas rates decreased when ceiling height was ≤ 500 m agl (fog or low ceiling heights). The variables identified as important in this study generally are 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 head winds are minimized and tail winds are maximized (Bruderer et al. 1995). Because wind strength generally increases with altitude, bird migration generally takes place at lower altitudes in head winds and at higher altitudes in tail winds (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 during fall migration flight altitudes decreased with higher wind speeds, consistent with the pattern of birds flying at heights at which head winds are minimized and tail winds are maximized (Bruderer et al. 1995). Although fog and low ceiling heights apparently were not important to flight altitudes in this study, the need to determine how birds respond to foggy conditions is warranted. 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. Although other nocturnal migrants, such as waterfowl and shorebirds, were likely included in our counts, most migratory activity of these groups differs geographically and temporally from the scope of this study. Furthermore, our visual observations confirmed the dominance of passerines (98% of identifiable birds and 80% of all known birds or bats) in the lower air layers (i.e., <150 m agl).

In general, fatality rates of bats are significantly higher at the few sites examined in the eastern US than at windfarms in the central and western US (Erickson et al. 2002, Johnson 2004). Substantial bat kills have been observed at two wind energy facilities located along the same Appalachian ridgeline in northern West Virginia and Pennsylvania (Arnett 2005). 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, Johnson 2004). Of the 86 bats observed during this study that could be classified by size, 22 (26%) were probable tree-roosting (large) bats. Currently, no comparable data on movement rates of bats are available for other sites in the southern and central Appalachians. In New York, bats comprised 9% of nocturnal targets identified during a fall study at the proposed Flat Rock wind power project, compared to 13% of identifiable targets observed during the present study.

TARGETS WITHIN THE PROPOSED TURBINE AREA

We estimated a turbine passage rate of 3.4–24.7 nocturnal migrants/turbine/d passing within the area occupied by each proposed turbine during the fall study period at the proposed development sites. Currently, the only additional data available for comparison are from the proposed Flat Rock and Prattsburgh-Italy wind power developments in New York, where 0.7–4.6 and 1.1–8.0 nocturnal migrants/turbine/d, respectively, were estimated to have passed within

the area occupied by each proposed turbine during fall migration.

Estimated turbine passage rates may be considered as a starting point for developing a complete avian and bat risk assessment. Currently, however, it is unknown whether abundance of either birds or bats are strongly correlated with fatality at wind power developments. There are a variety of factors (especially weather) that may correlate more strongly with fatality rates than numbers of individuals present prior to project construction. Studies of concurrent bird use, weather, and fatality data at operational wind power developments would be necessary to determine whether bird use and/or weather conditions can be used to predict the likelihood of bird fatalities at wind power developments.

In addition to these questions about the unknown relationship between fatality, weather, and abundance, there also are few data available on the proportion of nocturnal 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 with the flight speeds of individual migrants. 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). Ongoing studies of bats at wind power facilities are addressing such issues, but similar studies of avian nocturnal migrants have not been conducted. We speculate, however, that most birds are able to detect and/or avoid turbines, considering the relatively low avian fatality rates reported at existing 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 passerine and bat migration during fall 2005 at the proposed Highland New Wind Development in Highland County, Virginia. The key results of our study were: (1) the mean overall fall

passage rate was 385 targets/km/h; (2) mean nightly passage rates ranged from 9 to 2,762 targets/km/h; (3) the percentage of targets passing below 125 m agl was 11.5%; (4) the estimated turbine passage rate of nocturnal migrants passing within the airspace occupied by each proposed turbine was 3.4–24.7 migrants/turbine/d during the fall study period; (5) fall migrants flying at or below maximal turbine height consisted of 88% birds and 12% bats; and (6) passage rates, flight altitudes, and visual observation rates of birds and bats did not differ between the two survey sites within the project area.

LITERATURE CITED

- Able, K. P. 1970. A radar study of the altitude of nocturnal passerine migration. *Bird-Banding* 41: 282–290.
- Able, K. P. 1973. The role of weather variables and flight direction in determining the magnitude of nocturnal migration. *Ecology* 54: 1031–1041.
- Able, K. P. 1974. Environmental influences on the orientation of free-flying nocturnal bird migrants. *Animal Behaviour* 22: 224–238.
- Alerstam, T. 1990. Bird migration. Cambridge University Press, Cambridge, United Kingdom. 420 pp.
- Allen, G. M. 1939. Bats. Dover Publications, New York, NY. 358 pp.
- Altringham, J. D. 1996. Bats: biology and behavior. Oxford University Press, Inc., New York, NY 262 pp.
- Anderson, R., M. Morrison, K. Sinclair, and D. Strickland. 1999. Studying wind energy/bird interactions: a guidance document. Metrics and methods for determine or monitoring potential impacts on birds at existing and proposed wind energy sites. National Wind Coordinating Committee, Washington, DC. 87 pp. Available at <http://www.nationalwind.org/pubs/default.htm>
- Arnett, E. B. 2005. Relationships between bats and wind turbines in Pennsylvania and West Virginia: an assessment of bat fatality search protocols, patterns of fatality, and behavioral interactions with wind turbines. Unpublished report prepared for Bats and Wind Energy Cooperative. Bat Conservation International, Austin, TX. 187 pp.
- Avery, M. L., P. F. Springer, and N. S. Dailey. 1980. Avian mortality at manmade structures: an annotated bibliography (revised). U.S. Fish and Wildlife Service, Biological Services Program, Report No. FWS/OBS–80/54. 152 pp.
- Bellrose, F. C. 1967. Radar in orientation research. Proceedings XIV International Ornithological Congress. pp. 281–309.
- Bellrose, F. C. 1971. The distribution of nocturnal migration in the air space. *Auk* 88: 397–424.
- Bellrose, F. C. 1976. Ducks, geese, and swans of North America. 2nd ed. Stackpole Books, Harrisburg, PA. 540 pp.
- Bellrose, F. C., and R. R. Graber. 1963. A radar study of flight directions of nocturnal migrants. Proceedings XIII International Ornithological Congress. pp. 362–389.
- Blokpoel, H. 1971. The M33C track radar (3-cm) as a tool to study height and density of bird migration. Canadian Wildlife Service Report Series 14: 77–94.
- Blokpoel, H., and M. C. Gauthier. 1974. Migration of lesser Snow and Blue geese in spring across southern Manitoba, Part 2: Influence of weather and prediction of major flights. Canadian Wildlife Service Report Series 32: 1–28.
- Blokpoel, H., and J. Burton. 1975. Weather and the height of nocturnal migration in east-central Alberta: a radar study. *Bird-Banding* 46: 311–328.
- Bruderer, B., and P. Steidinger. 1972. Methods of quantitative and qualitative analysis of bird migration with a tracking radar. Pages 151–168 in Galler, S.R., Schmidt-Koenig, K., Jacobs, G.S., Belleville, R.E., eds. Animal orientation and navigation: a symposium. NASA SP262. U.S. Government Printing Office, Washington, DC.

- Bruderer, B., T. Steuri, and M. Baumgartner. 1995. Short-range high-precision surveillance of nocturnal migration and tracking of single targets. *Israeli Journal of Zoology* 41: 207–220.
- Bruderer, B., and A. Boldt. 2001. Flight characteristics of birds I. Radar measurements of speeds. *Ibis* 143: 178–204.
- Burnham, K. P., and D. R. Anderson. 2002. Model selection and multimodel inference: a practical information-theoretic approach. Second edition. Springer-Verlag, New York, NY. 488 pp.
- Cooper, B. A., R. H. Day, R. J. Ritchie, and C. L. Cranor. 1991. An improved marine radar system for studies of bird migration. *Journal of Field Ornithology* 62: 367–377.
- Cooper, B. A., and R. J. Ritchie. 1995. The altitude of bird migration in east-central Alaska: a radar and visual study. *Journal of Field Ornithology* 66: 590–608.
- Cooper, B. A., C. B. Johnson, and R. J. Ritchie. 1995a. Bird migration near existing and proposed wind turbine sites in the eastern Lake Ontario region. Unpublished report prepared for Niagara-Mohawk Power Corporation, Syracuse, NY, by ABR, Inc., Forest Grove, OR. 71 pp.
- Cooper, B. A., C. B. Johnson, and E. F. Neuhauser. 1995b. The impact of wind turbines in upstate New York. Pages 607–611 in LGL Ltd. ed. *Proceedings of National Avian-Wind Power planning meeting II* September 1995, Washington, DC. Available at <http://www.nationalwind.org/pubs/avian95/default.htm>
- Cooper, B. A., and T. J. Mabee. 2000. Bird migration near proposed wind turbine sites at Wethersfield and Harrisburg, New York. Unpublished report prepared for Niagara-Mohawk Power Corporation, Syracuse, NY, by ABR, Inc., Forest Grove, OR. 46 pp.
- Cooper, B. A., A. A. Stickney, and T. J. Mabee. 2004. A radar study of nocturnal bird migration at the proposed Chautauqua wind energy facility, New York, fall 2003. Unpublished report prepared for Chautauqua Windpower LLC, Lancaster, NY, by ABR, Inc.—Environmental Research & Services, Forest Grove, OR. 26 pp.
- Day, R. H., and L. C. Byrne. 1990. Avian research program for the Over-the-Horizon Backscatter Central Radar System: radar studies of bird migration, fall 1989. Unpublished report prepared for Metcalf & Eddy/Holmes & Narver, Wakefield, MA, by Alaska Biological Research, Inc., Fairbanks, AK. 102 pp.
- Desholm, M., and J. Kahlert. 2005. Avian collision risk at an offshore wind farm. *Biology Letters* 1: 296–298.
- Diehl, R. H., R. P. Larkin, and J. E. Black. 2003. Radar observations of bird migration over the Great Lakes. *Auk* 120: 278–290.
- Eastwood, E. 1967. *Radar ornithology*. Methuen and Co., Ltd., London, United Kingdom. 278 pp.
- Eastwood, E., and G. C. Rider. 1965. Some radar measurements of the altitude of bird flight. *British Birds* 58: 393–426.
- Erickson, W. 2004. Patterns of daily mortality searches at Meyersdale, Pennsylvania. Talk presented at the National Wind Coordinating Committee meeting, “Onshore wildlife interactions with wind developments: Research Meeting V”, 3–4 November 2004, Lansdowne, Virginia.
- Erickson, W. P., G. D. Johnson, M. D. Strickland, D. P. Young, Jr., K. J. Sernka, and R. E. Good. 2001. Avian collisions with wind turbines: a summary of existing studies and comparisons to other sources of avian collision mortality in the United States. National Wind Coordinating Committee, Washington, DC. 62 pp. Available at <http://www.nationalwind.org/pubs/default.htm>
- Erickson, W. P., G. D. Johnson, D. P. Young, Jr., M. D. Strickland, R. E. Good, M. Bourassa, K. Bay, and K. Sernka. 2002. Synthesis and comparison of baseline avian and bat use, raptor nesting, and mortality information from

- proposed and existing wind developments. Unpublished report prepared for Bonneville Power Administration, Portland, OR, by WEST, Inc., Cheyenne, WY. 124 pp.
- Evans, W. E. 1998. Deadly towers. *Living Bird* 17: 5.
- Farnsworth, A., S. A. Gauthreaux, Jr., and D. van Blaricon. 2004. A comparison of nocturnal call counts of migrating birds and reflectivity measurements on Doppler radar. *Journal of Avian Biology* 35:365–369.
- Fleming, G. P., P. P. Coulling, K. D. Patterson, and K. Taverna. 2005. The natural communities of Virginia: classification of ecological community groups. Second approximation. Version 2.1. Virginia Department of Conservation and Recreation, Division of Natural Heritage, Richmond, VA. <http://www.dcr.virginia.gov/dnh/ncintro.htm>.
- Gauthreaux, S. A., Jr. 1971. A radar and direct visual study of passerine spring migration in southern Louisiana. *Auk* 88: 343–365.
- Gauthreaux, S. A., Jr. 1972. Behavioral responses of migrating birds to daylight and darkness: a radar and direct visual study. *Wilson Bulletin* 84: 136–148.
- Gauthreaux, S. A. Jr. 1975. Radar ornithology: bird echoes on weather and airport surveillance radars. Clemson University Press, Clemson, SC.
- Gauthreaux, S. A., Jr. 1978. Migratory behavior and flight patterns. Pages 12–26 in M. Avery, ed. Impacts of transmission lines on birds in flight. U.S. Fish and Wildlife Service, Office of Biological Services, Report No. FWS/OBS–78/48. 151 pp.
- Gauthreaux, S. A., Jr. 1980. Direct visual and radar methods for the detection, quantification, and prediction of bird migration. Special publication no. 2, Department of Zoology, Clemson University, Clemson, SC.
- Gauthreaux, S. A., Jr. 1985a. Radar, electro-optical, and visual methods of studying bird flight near transmission lines. Unpublished final report prepared for Electric Power Research Institute, Palo Alto, CA, by Clemson University, Clemson, SC. 76 pp.
- Gauthreaux, S. A., Jr. 1985b. An avian mobile research laboratory: hawk migration studies. Pages 339–346 in M. Harwood, ed. Proceedings of Hawk Migration Conference IV. Hawk Migration Association of North America, Washington, CT.
- Gauthreaux, S. A., Jr. 1991. The flight behavior of migrating birds in changing wind fields: radar and visual analyses. *American Zoologist* 31: 187–204.
- Graber, R. R., and S. S. Hassler. 1962. The effectiveness of aircraft-type (APS) radar in detecting birds. *Wilson Bulletin* 74: 367–380.
- Hall, G. A. 1981. Fall migration patterns of wood warblers in the southern Appalachians. *Journal of Field Ornithology* 52: 43–49.
- Hall, G. A. and R. K. Bell. 1981. The diurnal migration of passerines along an Appalachian ridge. *American Birds* 35:135–138.
- Harmata, A. R., K. M. Podrutzny, J. R. Zelenak, and M. L. Morrison. 1999. Using marine surveillance radar to study bird movements and impact assessment. *Wildlife Society Bulletin* 27: 44–52.
- Hassler, S. S., R. R. Graber, and F. C. Bellrose. 1963. Fall migration and weather: a radar study. *Wilson Bulletin* 75: 56–77.
- Johnson, G. D. 2004. A review of bat impacts at wind farms in the U.S. Presentation at the National Wind Coordinating Committee meeting, “Wind energy and birds/bats workshop: understanding and resolving bird and bat impacts,” 17–19 May 2004, Washington, DC.
- Johnson, G. D., W. P. Erickson, M. D. Strickland, M. F. Shepherd, and D. A. Shepherd. 2003. Mortality of bats at a large-scale wind power development at Buffalo Ridge, Minnesota. *American Midland Naturalist* 150: 332–342.

- Kerlinger, P. 1995. How birds migrate. Stackpole Books, Mechanicsburg, PA. 228 pp.
- Kerlinger, P. 2000. Avian mortality at communication towers: a review of recent literature, research, and methodology. Unpublished report prepared for U.S. Fish and Wildlife Service, Office of Migratory Bird Management, by Curry & Kerlinger LLC, Cape May Point, NJ. 38 p.
- Kerlinger, P. 2003. FAA lighting of wind turbines and bird collisions. Presentation at the NWCC Wildlife Working Group Meeting, 18 November 2003, Washington DC. Available at <http://www.nationalwind.org/events/wildlife/20031117/presentations/default.htm>
- Kerlinger, P., and F. R. Moore. 1989. Atmospheric structure and avian migration. Pages 109–141 in D. M. Power ed. *Current Ornithology*. Vol. 6.
- Kerns, J. 2004. Patterns from daily mortality searches at Backbone Mountain, West Virginia. Talk presented at the National Wind Coordinating Committee meeting, "Onshore wildlife interactions with wind developments: Research Meeting V", 3–4 November 2004, Lansdowne, Virginia.
- Kovach, W. 2003. Oriana version 2.0. Kovach Computing Services, Anglesey, Wales, United Kingdom.
- Kunz, T. H., and M. B. Fenton. 2003. Bat ecology. University of Chicago Press, Chicago, IL. 779 pp.
- Larkin, R. P. 1991. Flight speeds observed with radar, a correction: slow "birds" are insects. *Behavioral Ecology and Sociobiology* 29: 221–224.
- Liechti, F., M. Klaassen, and B. Bruderer. 2000. Predicting migratory flight altitudes by physiological migration models. *Auk* 117: 205–214.
- Lowery, G. H., Jr. 1951. A quantitative study of the nocturnal migration of birds. University of Kansas Museum of Natural History 3: 361–472.
- Mabee, T. J., and B. A. Cooper. 2004. Nocturnal bird migration in northeastern Oregon and southeastern Washington. *Northwestern Naturalist* 85: 39–47.
- Mabee, T. J., B. A. Cooper, and J. H. Plissner. 2004. A radar study of nocturnal bird migration at the proposed Mount Storm wind-power development, West Virginia, fall 2003. Unpublished report prepared for Western Ecosystems Technology, Inc., Cheyenne WY, and Nedpower US LLC, Chantilly, VA by ABR, Inc., Forest Grove, OR. 40 pp.
- Mabee, T. J., J. H. Plissner, and B. A. Cooper. 2005a. A radar and visual study of nocturnal bird and bat migration at the proposed Prattsburgh-Italy wind power project, New York, fall 2004. Unpublished report prepared for Ecogen LLC, West Seneca, NY, by ABR, Inc., Forest Grove, OR. 26 pp.
- Mabee, T. J., J. H. Plissner, and B. A. Cooper. 2005b. A radar and visual study of nocturnal bird and bat migration at the proposed Flat Rock wind power project, New York, fall 2004. Unpublished report prepared for Atlantic Renewable Energy Corporation, Dickerson, MD, by ABR, Inc., Forest Grove, OR. 30 pp.
- Manville A. M. 2000. The ABCs of avoiding bird collisions at communication towers: the next steps. In *Proceedings of the December 1999 workshop on avian interactions with utility structures*, Charleston, SC. Electric Power Research Institute, Palo Alto, CA. Report No. 1000736.
- Nisbet, I. C. T. 1963. Measurements with radar of the height of nocturnal migration over Cape Cod, Massachusetts. *Bird-Banding* 34: 57–67.
- Osborn R. G., K. F. Higgins, R. E. Usgaard, C. D. Dieter, and R. D. Neiger. 2000. Bird mortality associated with wind turbines at the Buffalo Ridge Wind Resource Area, Minnesota. *American Midland Naturalist* 143: 41–52.
- Peurach, S. C. 2003. High-altitude collision between an airplane and a hoary bat, *Lasiurus cinereus*. *Bat Research News* 44: 2–3.

- Richardson, W. J. 1971. Spring migration and weather in eastern Canada: a radar study. *American Birds* 25: 684–690.
- Richardson, W. J. 1972. Autumn migration and weather in eastern Canada: a radar study. *American Birds* 26: 10–16.
- Richardson, W. J. 1978. Timing and amount of bird migration in relation to weather: a review. *Oikos* 30: 224–272.
- Richardson, W. J. 1990. Timing of bird migration in relation to weather: updated review. Pages 79–100 in E. Gwinner, ed. *Bird migration*. Springer-Verlag, Berlin, Germany.
- Skolnik, M. I. 1980. *Introduction to radar systems*. McGraw-Hill, New York, NY. 581 pp.
- SPSS. 2003. *SPSS for Windows, version 12.0*. SPSS, Inc., Chicago, IL.
- Tucker, V. A. 1996. A mathematical model of bird collisions with wind turbine rotors. *ASME Journal of Solar Energy Engineering* 118: 253–262.
- Tuttle, M. D. 1988. *America's neighborhood bats*. University of Texas Press, Austin, TX. 96 pp.
- USGS (U.S. Geological Survey). 2003. *Physiographic regions of the US*. Available at <http://tapestry.usgs.gov/physiogr/physio.html>.
- Weir, R. D. 1976. *Annotated bibliography of bird kills at man-made obstacles: a review of the state of the art and solutions*. Canadian Wildlife Service, Ottawa, ON, Canada. 85 pp.
- Williams, T. C., J. Settel, P. O'Mahoney, and J. M. Williams. 1972. An ornithological radar. *American Birds* 26: 555–557.
- Williams, T. C., J. M. Williams, P. G. Williams, and P. Stokstad. 2001. Bird migration through a mountain pass studied with high resolution radar, ceilometers, and census. *Auk* 118: 389–403.
- Winkelman, J. E. 1995. Bird/wind turbine investigations in Europe. Pages 43–47 and 110–140 in LGL Ltd. ed. *Proceedings of National Avian-Wind Power Planning Meeting I*, Lakewood, CO. Available at <http://www.nationalwind.org/pubs/avian94/default.htm>
- Zalles, J. I., and K. L. Bildstein, eds. 2000. *Raptor Watch: a global directory of raptor migration sites*. Birdlife International, Cambridge, United Kingdom, and Hawk Mountain Sanctuary, Kempton, PA. Birdlife Conservation Series No. 9.
- Zar, J. H. 1999. *Biostatistical analysis*. 3rd ed. Prentice-Hall, Inc., Englewood Cliffs, NJ. 663 pp.

Appendix 1. Calculation of turbine passage rate indices (estimated number of targets passing within the area occupied by each proposed turbine) at the proposed Highland New Wind Development, Virginia, during fall 2005.

Calculation parameter	
TURBINE CHARACTERISTICS	
(A) Total turbine height (m)	120
(B) Blade radius (m)	40
(C) Height below blade (m)	40
(D) Approximate front-to-back width (m)	6
(E) Minimal (side profile) area (m ²) = A × D	720
(F) Maximal (front profile) area (m ²) = (C × D) + (π × B ²)	5,266
PASSAGE RATE	
(G) Mean rate below 120 m agl (targets/km/h)	56.3
(H) Area sampled below 120 m agl = 120 × 1,000 (m ²)	120,000
(I) Mean passage rate through zone of risk (targets/h/m ²)	0.00047
TURBINE PASSAGE RATE INDEX	
(J) Duration of study period (# nights)	60
(K) Mean number of hours of darkness (h/night)	10
(L) Minimum number of targets/km/h in zone of risk = E × I	0.34
(M) Maximum number of targets/km/h in zone of risk = F × I	2.47
(N) Minimum number of targets in zone/d = K × L	3.4
(O) Maximum number of targets in zone/d = K × M	24.7
(P) Minimum number of targets in zone of risk during study period = J × N	203
(Q) Maximum number of targets in zone of risk during study period = J × O	1,483

Appendix 2. Comparisons among half-monthly periods of the migration sampling season for altitudes and passage rates of targets observed on 1.5-km radar during nocturnal surveys at the proposed Highland New Wind Development, Virginia, during fall 2005.

	16-31 August	1-15 September	16-30 September	1-15 October	Total
Number of nights	15	15	15	13	58
Mean altitude (m agl)	392 ± 6	456 ± 5	379 ± 5	514 ± 5	442 ± 3
Mean overall passage rate (targets/km/h)	123 ± 40	325 ± 29	634 ± 171	470 ± 94	385 ± 55
Mean passage rate at or below 120 m agl (targets/km/h)	8 ± 4	33 ± 5	141 ± 55	42 ± 10	56 ± 16
Percentage of bats (relative to all identified birds and bats)	41	10	13	--	12

Appendix 3. Number of targets observed on 1.5-km vertical radar at each interval below 250 m and cumulative percent of all targets during nocturnal surveys at the Highland New Wind Development, Virginia, during fall 2005.

Flight altitude (m agl)	N	Cumulative %
0-25	68	0.5
26-50	204	2.0
51-75	367	4.7
76-100	449	8.0
101-125	517	11.8
126-150	571	16.0
151-175	558	20.1
176-200	626	24.7
201-225	571	28.9
226-250	571	33.1
251-1,500	9,100	100.0
Total	13,603	