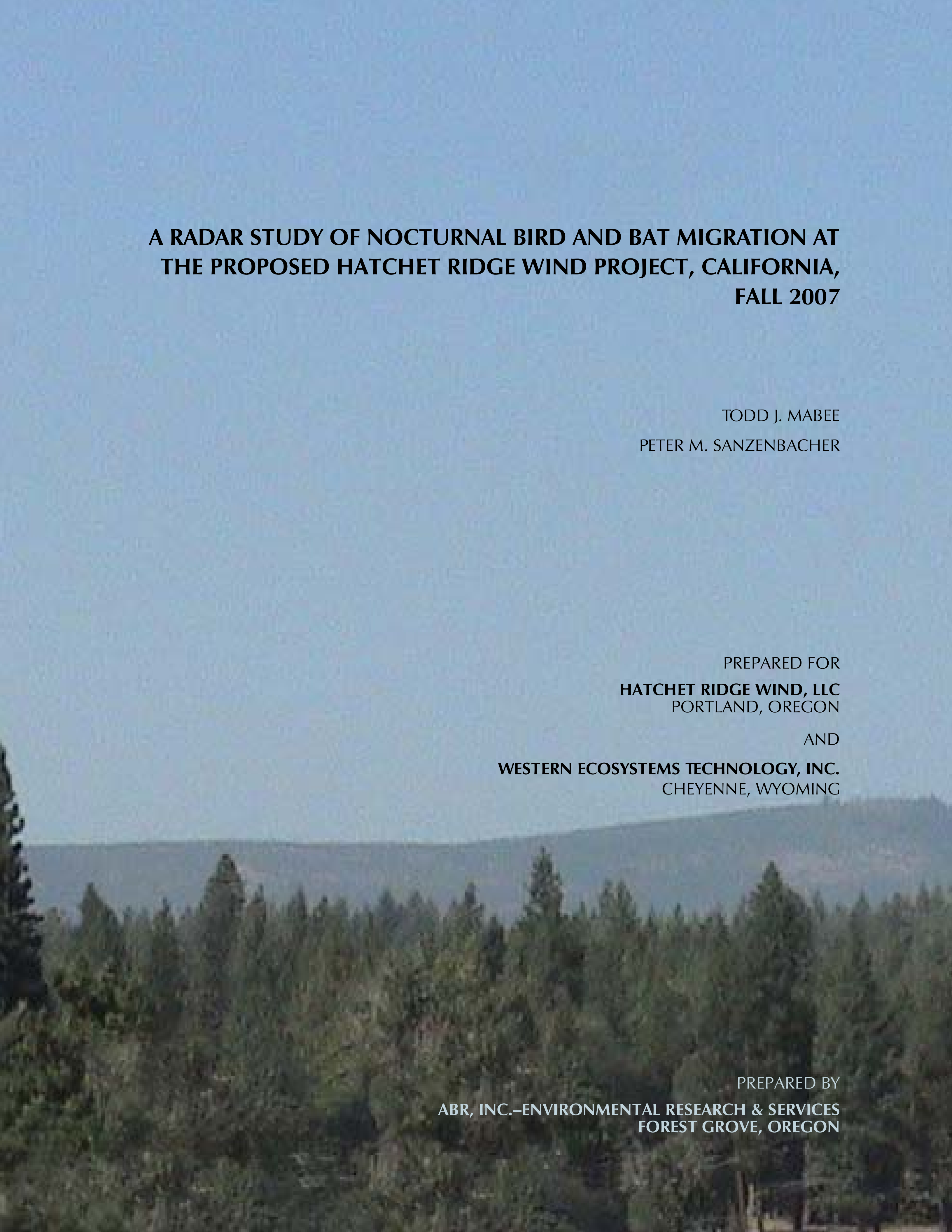

A RADAR STUDY OF NOCTURNAL BIRD AND BAT MIGRATION AT THE PROPOSED HATCHET RIDGE WIND PROJECT, CALIFORNIA, FALL 2007

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FINAL REPORT

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EXECUTIVE SUMMARY

- This report presents the results of radar studies of fall nocturnal bird and bat migration conducted from 7 September–15 October 2007 at the proposed Hatchet Ridge Wind Project, located in Shasta County, California. Each night we sampled at two stations (North and Saddle) within the proposed development area.
- The primary goal of this study was to collect information on the nocturnal migration characteristics of birds and bats (i.e., targets) during the peak of passerine migration during fall. Specifically, the objectives of this study were to: (1) collect baseline information on migration characteristics (i.e., flight direction, migration passage rates, flight altitudes) of nocturnally migrating targets; and (2) estimate the number of targets that would pass within the rotor-swept area of the proposed wind turbines during the migratory season. We also evaluated the influence of weather and date on migration passage rates and flight altitudes.
- The mean nocturnal flight direction of radar targets was 191° at North, 196° at Saddle, and 194° at both stations combined.
- The mean nocturnal passage rate was 231 ± 31 targets/km/h and 351 ± 39 targets/km/h at North and Saddle respectively. The overall mean passage rate at the combined stations was 290 ± 26. Nightly mean passage rates ranged from 31–1,159 targets/km/h.
- Altitude-specific passage rates (i.e., passage rates below 125 m agl) were 17 ± 3 targets/km/h at North and 39 ± 7 targets/km/h at Saddle. The overall mean altitude-specific passage rate at the combined stations was 28 ± 4. Across all study dates altitude-specific passage rates ranged from 0–171 targets/km/h.
- The mean nocturnal flight altitude was 474 ± 5 m agl at North and 463 ± 4 m agl at Saddle. Across all stations the mean nocturnal flight altitude was 468 ± 3. Mean flight altitudes among all nights ranged from 50–1,206 m agl.
- The percentage of targets recorded below 125 m agl was 7% at North, 9% at Saddle, and 8% across all stations.
- During fall migration passage rates were higher at the Saddle station and increased later in the season. Flight altitudes increased under favorable synoptic conditions (i.e., with tailwinds).
- Assuming an average of 10 nocturnal h/d, we calculated a turbine passage rate of 41–389 nocturnal migrants/turbine at North, 94–898 nocturnal migrants/turbine at Saddle, and 67–640/turbine at the combined stations over the course of our 39 day study period. Calculated as a daily index this equates to 1.1–10.0 nocturnal migrants/turbine/d at North, 2.4–23.0 nocturnal migrants/turbine/d at Saddle, and 1.7–16.4 nocturnal migrants/turbine/d at the combined stations.
- The key results of our study were as follows: (1) the mean passage rate was 231 ± 31 targets/km/h and 351 ± 39 targets/km/h at North and Saddle stations, respectively, and 290 ± 26 across both stations; (2) mean nightly passage rates were variable among nights and ranged from 31–1,159 targets/km/h; (3) mean flight altitude was 474 ± 5 m agl and 463 ± 4 m agl at the North and Saddle stations, respectively, and 468 ± 3 across both stations; (4) the percentage of targets passing below 125 m agl was 7% and 9% at the North and Saddle stations, respectively, and 8% across both stations; (5) the target passage rate below 125 m agl was 17 ± 3 targets/km/h and 39 ± 7 targets/km/h at the North and Saddle stations, respectively, and 28 ± 4 across both stations; (6) the estimated turbine passage rate of nocturnal migrants passing within the airspace occupied by each proposed turbine was 1.1–10.0 nocturnal migrants/turbine/d at North, 2.4–23.0 nocturnal migrants/turbine/d at Saddle, and 1.7–16.4 nocturnal migrants/turbine/d across both stations.

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ACKNOWLEDGMENTS

We thank Hatchet Ridge Wind, LLC for funding this study and WEST, Inc., for the opportunity to participate in this study. In particular we thank Dave Young (WEST) for assistance with project coordination and logistics. We appreciate the efforts of ABR employees Jeff Barna, Bob Burgess, and John Shook for their help with radar data collection. Also at ABR, Susan Cooper, and Delee Spiesschaert helped with office logistics and project coordination, Rich Blaha prepared report maps, Jon Plissner provided statistical assistance, and Pam Odom helped with report preparation.

INTRODUCTION

Wind energy is one of the fastest growing sources of energy production in the United States (GAO 2005). Studies examining the impacts of windfarms on birds in the United States 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). In the United States both resident and migratory birds sometimes collide with wind turbines (Erickson 2004, NWCC 2004) with the overall fatality rate being similar (~2.3–3.5 avian fatalities/MW/yr) on a regional scale in the United States (NRC 2007).

The makeup of these fatalities varies for some species groups, although passerines ("songbirds") comprise ~ 70–85% of the known bird collisions at wind power developments throughout the US (Erickson et al. 2001, Strickland and Johnson 2006). Neotropical migratory species of passerines such as thrushes (Turdidae), vireos (Vireonidae), and warblers (Parulidae) have a long history of colliding with above-ground structures (Kerlinger 2000, Longcore et al. 2005) and seem to be the most vulnerable to collisions during their nocturnal migrations (Manville 2005). This pattern also holds true at wind-energy developments, with ~50% of the fatalities at windfarms involving nocturnal passerine migrants (Erickson et al. 2001). This makes sense both because of poorer visibility at night and because passerines tend to migrate at lower altitudes than do other groups of birds (e.g., shorebirds, waterfowl; Kerlinger 1995, Alerstam 1990).

The paucity of general information on nocturnal bird migration in most areas has generated interest in conducting preconstruction studies of nocturnal migration at the growing number of proposed wind power developments throughout the country (CEC guidelines, Kunz et al. 2007a). 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) and frequently a large proportion (ranging from 0–80%) of the fatalities at wind-energy developments are from nocturnal passerine migrants (Erickson et al. 2001).

Bat fatalities have also occurred at wind farms in the United States with recent data from Appalachian ridgetops in the eastern US (Arnett 2005, Erickson 2004, Kerns 2004, Kunz et al. 2007a), the Tug Hill Plateau region in New York (Jain et al. 2007), prairie locations in both the US and Canada (see references in Barclay et al. 2007, Kunz et al. 2007a), indicating that substantial bat kills are possible at some wind power projects. Most of the bat fatalities documented at windfarms have been associated with migratory tree-roosting species during seasonal periods of dispersal and migration and the majority of these collisions occurred during the late summer and fall migratory periods (Arnett 2005, Barclay et al. 2007, Kunz et al. 2007a). There are many hypotheses as to why bats may collide with wind turbines (Kunz et al. 2007a) and ongoing research may yield patterns at a later point in time.

Hatchet Ridge Wind, LLC proposes to develop the Hatchet Ridge Wind Project (HRWP), a ~100 MW wind power development in Shasta County in northern California (Fig. 1). The development would consist of ~42 wind turbines, each with a generating capacity of up to ~2.4 MW. Characteristics of the proposed wind turbines include a monopole tower ~80 m in height and three rotor blades each extending ~47.5 m equating to a rotor area ~95 m in diameter. Thus, the total maximal height of each turbine will be ~127.5 m with a blade in the vertical position.

The proposed HRWP is located in a region with little information on the migratory pathways of nocturnal migrants such as passerines and bats. Within ~100–150 km to the north-northeast of the proposed development are a series of lakes and wildlife refuges (Fig. 1) that provide habitat for large numbers of migratory waterfowl, shorebirds, and songbirds (USFWS 1995) raising the possibility that birds from these regions may pass over HRWP en route to the Sacramento Valley and other over wintering areas during fall migration. We conducted the current study to provide baseline information on nocturnal migrants at the proposed HRWP during fall 2007.

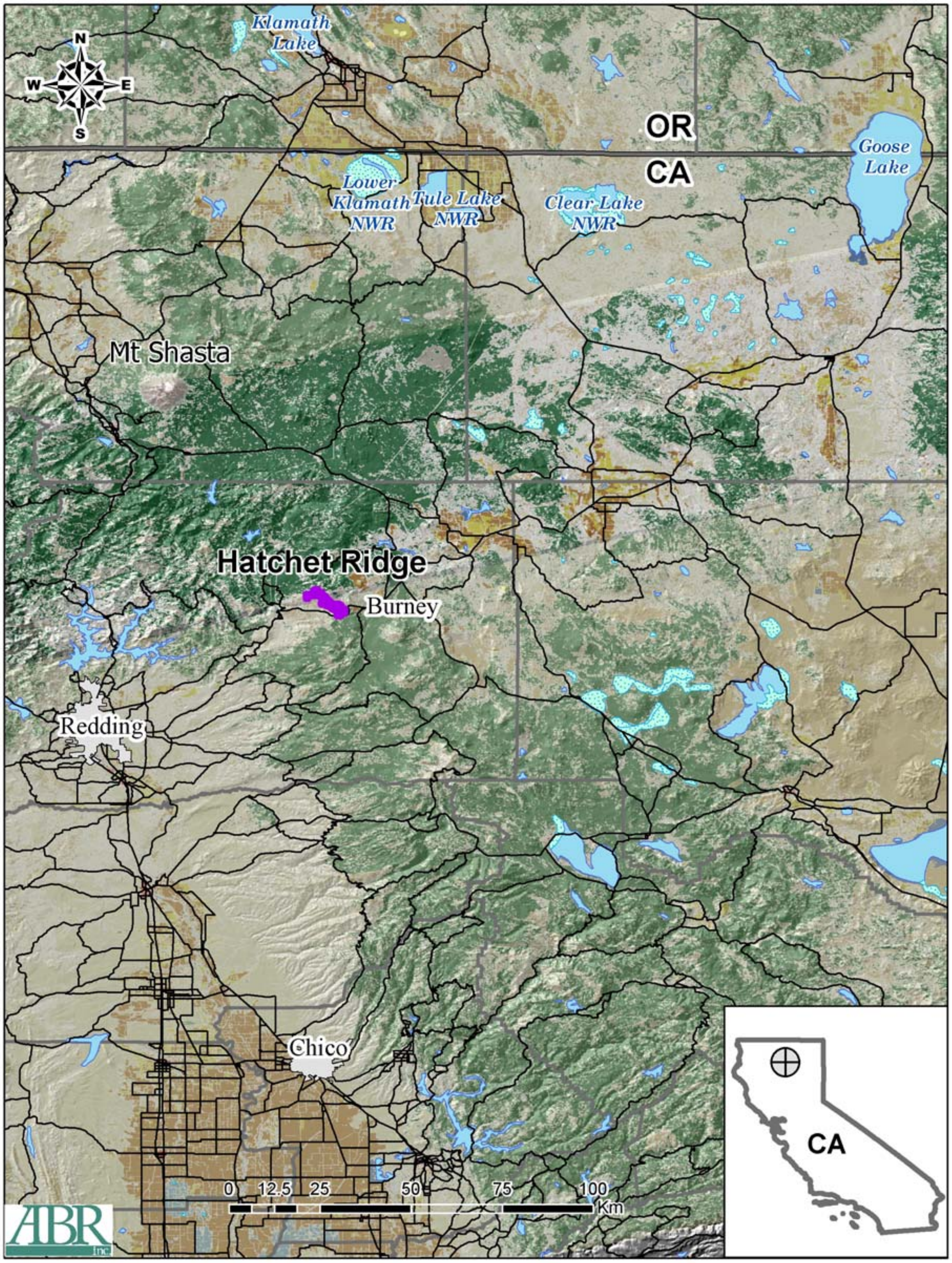

Figure 1. Map of the proposed Hatchet Ridge Wind Project and surrounding landscape features of Shasta County, California.

OBJECTIVES

The primary goal of this study was to collect information on the nocturnal migration patterns of targets (i.e., birds and bats) during the peak period of fall passerine migration at the proposed Hatchet Ridge Wind Project (HRWP). Specifically, the objectives of this study were to: (1) collect baseline information on migration characteristics (i.e., flight direction, migration passage rates, and flight altitudes) of nocturnal migrants; and (2) determine the number of targets that would pass within the rotor-swept area of the proposed wind turbines during the migratory season. We also evaluated the influence of weather on migration passage rates and flight altitudes.

STUDY AREA

The proposed Hatchet Ridge Wind Project (HRWP) is located along Hatchet Ridge in a rural area of Shasta County in northern California (Fig. 1). The development is located ~8 km west of the town of Burney, California and ~64 km northeast of Redding, California. Highway 299 runs along the southern boundary of the project area. Hatchet Ridge is situated along the southern edge of the Cascade Range. The general orientation of the ridgeline is northwest to southeast and elevations within the project area range from ~1,670 m asl in the northwest section to ~1,310 m asl in the southern portion near Hatchet Mountain Pass. The topography of the project area is primarily flat, broad ridge-top with moderate to steep side slopes. Average annual rain fall is ~127 cm and the average annual temperature is ~6°C. The natural dominant vegetation community is mixed conifer that includes a combination of white fir (*Abies concolor*), incense cedar (*Calocedrus decurrens*), sugar pine (*Pinus lambertiana*), ponderosa pine (*Pinus ponderosa*), Douglas-fir (*Pseudotsuga menziesii*), and black oak (*Quercus velutina*). Large portions of the ridgeline and project area burned in the Fountain Fire of 1992 and areas were replanted in 1996 with white fir and ponderosa pine.

Our study included two radar sampling stations located in open areas along Hatchet Ridge within the area of the proposed development (Fig. 2). The North station (N40.90863, W121.82530 WGS84) was located ~1,683 m asl in the northwest section of the development whereas the Saddle station (N40.88871, W121.79435 WGS84) was lower in elevation, ~1,541 m asl, and situated in the central portion of the proposed development.

METHODS

STUDY DESIGN

We conducted nightly radar observations at both sampling stations on 39 nights during fall 2007 (7 September to 15 October) during the general peak of passerine migration in this region (Harris 2005). This timing was chosen when it would be expected that many birds would be migrating through the area including passerines, shorebirds, waterfowl, and potentially bats.

We obtained useable data from radar observations during 36 and 34 nights at the North and Saddle stations, respectively. On the remaining nights, we were unable to conduct radar observations because of inclement weather (rain and snow). Each night we split sampling time between the two sampling stations to capture potential spatial variation in migration characteristics in the project area and we alternated the starting location on a nightly basis to reduce bias. Sampling started ~45 min after sunset and continued for a total of 7 h/night on most nights. Our sampling schedule provided coverage during the peak hours of nocturnal passerine migration within a night (Lowery 1951, Gauthreaux 1971, Alerstam 1990, Kerlinger 1995, Mabee et al., 2006a).

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. 3), 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. 4), and we manually measured flight altitudes of targets with an index

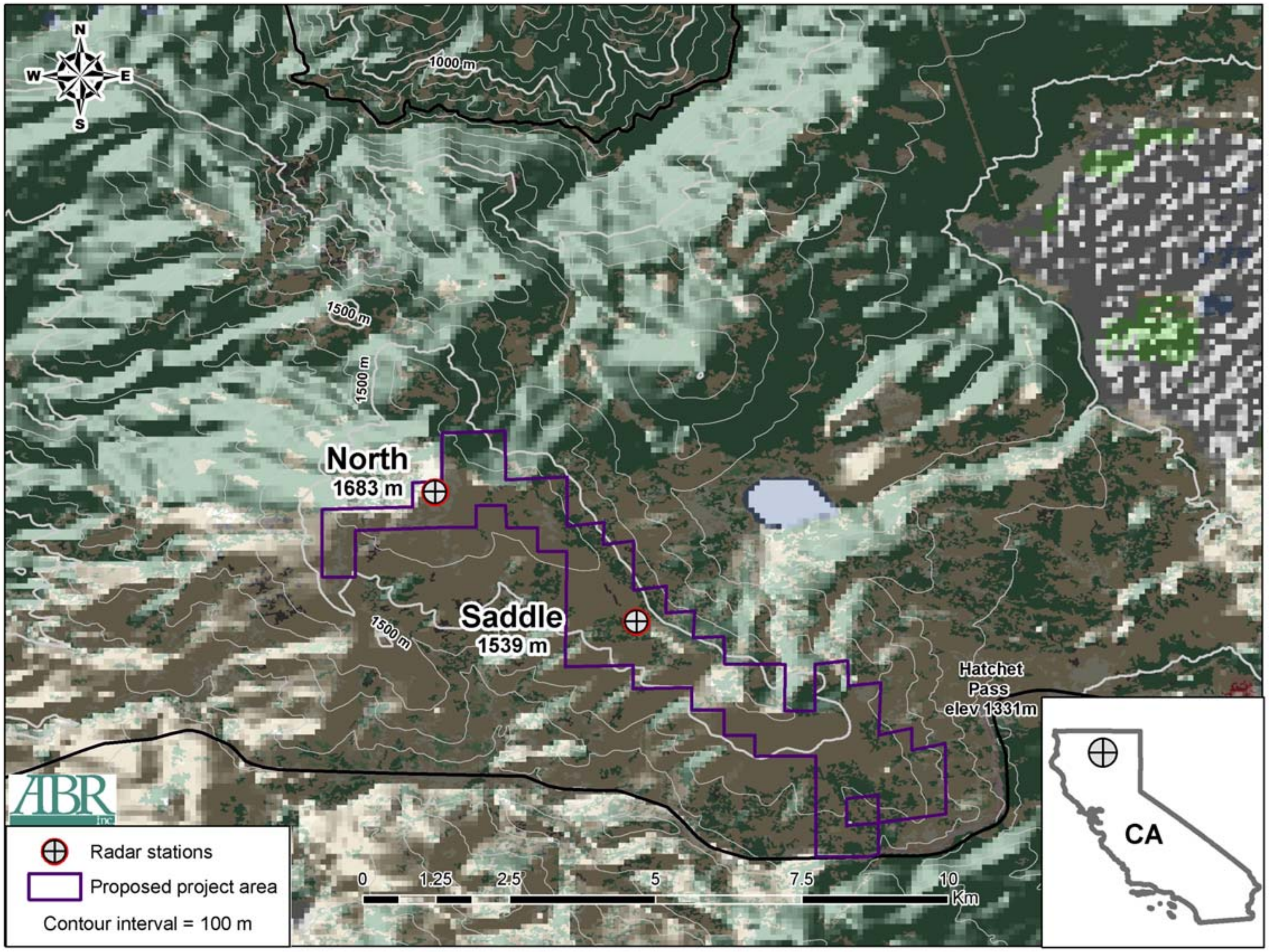

Figure 2. Map of the proposed Hatchet Ridge Wind Project and radar sampling stations in Shasta County, California, fall 2007.

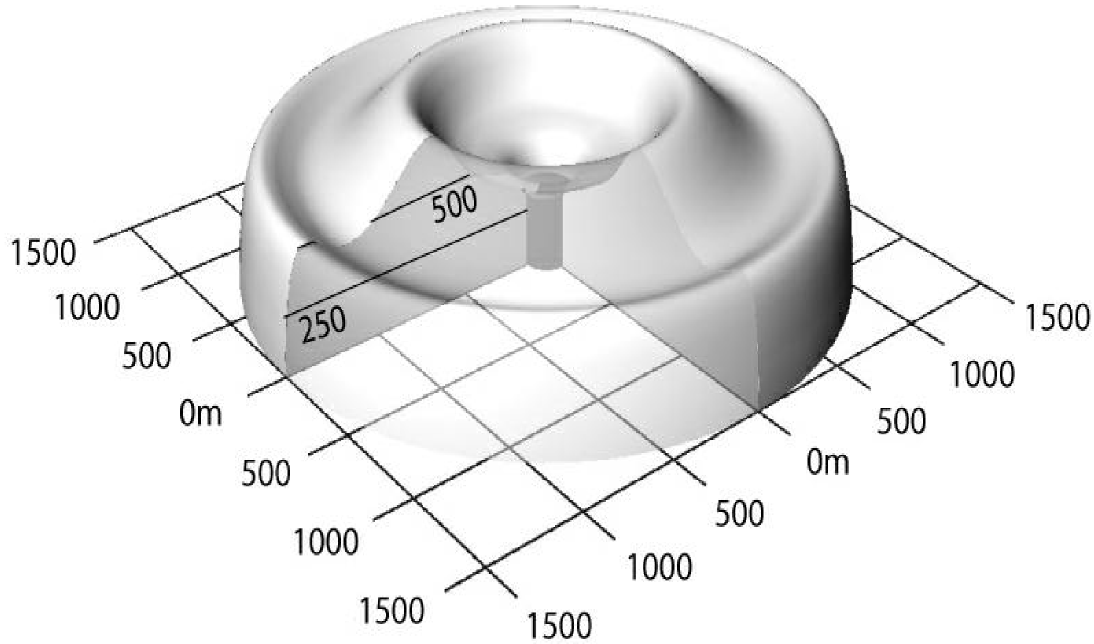

Figure 3. Approximate airspace sampled by Furuno FR–1510 marine radar when operating in the surveillance mode (antenna in the horizontal orientation) as determined by field trials with Rock Pigeons. Note that the distribution of the radar beam within 250 m of the origin (i.e., the darkened area) was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

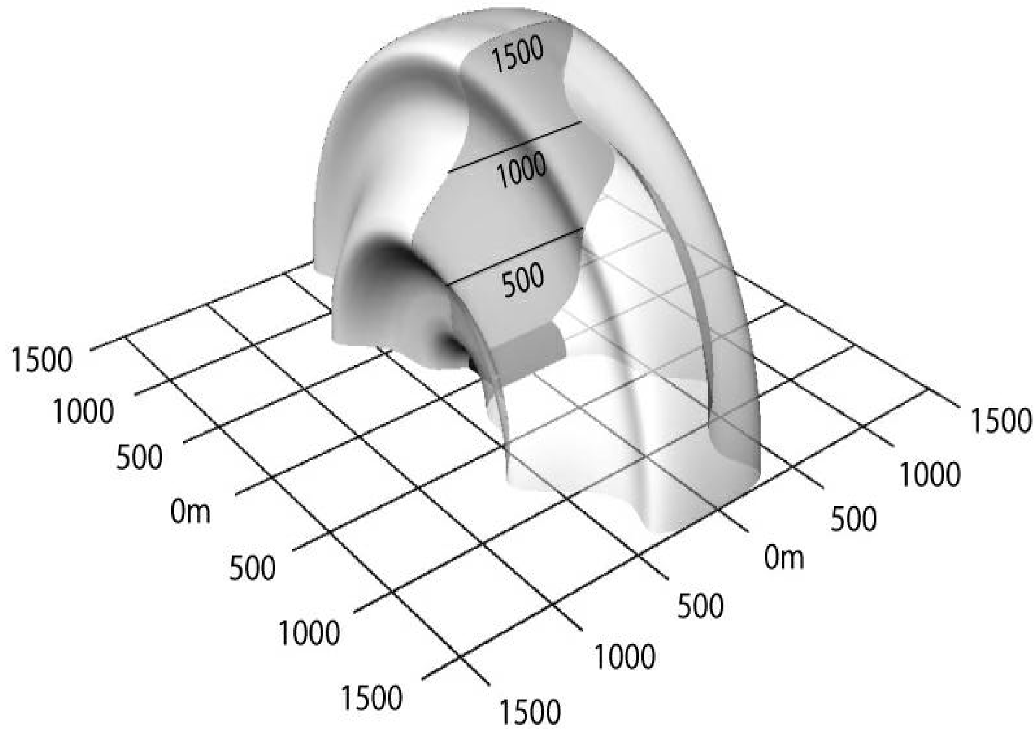

Figure 4. Approximate airspace sampled by Furuno FR–1510 marine radar when operating in the vertical mode (antenna in the vertical orientation) as determined by field trials with Rock Pigeons. Note that the distribution of the radar beam within 250 m of the origin (i.e., the darkened area) was not determined.

line on the monitor. All data were recorded manually into a laptop computer. A description of a similar radar laboratory can be found in Gauthreaux (1985a, 1985b) and Cooper et al. (1991), and a similar vertical radar configuration was described by Harmata et al. (2003) and Mabee et al. (2006a).

The radar (Furuno Model FR-1510 MKIII; Furuno Electric Company, Nishinomiya, Japan) is a standard marine radar transmitting at 9.410 GHz (i.e., X-band) through a 2-m-long slotted waveguide (antenna) with a peak power output of 12 kW. The antenna had a beam width of 1.23° (horizontal) × 25° (vertical) and a sidelobe of 10–20°. Range accuracy is 1% of the maximal range of the scale in use or 30 m (whichever is greater) and bearing accuracy is ± 1°.

This radar can be operated at a variety of ranges (0.5–133 km) and pulse lengths (0.07–1.0 μsec). We used a pulse length of 0.07 μsec while operating at the 1.5-km range. At shorter pulse lengths, echo resolution is improved (giving more accurate information on target identification, location, and distance), whereas, at longer pulse lengths, echo detection is improved (increasing the probability of detecting a target). An echo is a picture of a target on the radar monitor; a target is one or more birds (or bats) that are flying so closely together that the radar displays them as one echo on the display monitor. This radar has a digital color display with several scientifically useful features, including True North correction for the display screen (to determine flight directions), color-coded echoes (to differentiate the strength of return signals), and on-screen plotting of a sequence of echoes (to depict flight paths). Because targets plot every sweep of the antenna (i.e., every 2.5 sec) and groundspeed is directly proportional to the distance between consecutive echoes, we were able to measure ground speeds of plotted targets to the nearest ~10 km/h with a hand-held scale.

Energy reflected from the ground, surrounding vegetation, and other solid objects that surround the radar unit causes a ground-clutter echo to appear on the display screen. Because ground-clutter echoes can obscure targets, we minimized their occurrence by elevating the forward edge of the antenna by ~15° and by parking the mobile radar laboratory in locations that were surrounded by low trees or low hills, whenever possible. These objects act as a radar fence that shields the radar from low-lying objects farther away from the lab and that produces only a small amount of ground clutter in the center of the display screen. Both sampling stations at the proposed Hatchet Ridge Wind Project were ideal for radar and allowed for maximal radar coverage with minimal ground clutter. For further discussion of radar fences, see Eastwood (1967), Williams et al. (1972), Skolnik (1980), and Cooper et al. (1991).

Maximal distances of detection of targets by the surveillance radar depends on radar settings (e.g., gain and pulse length), target body size, flock size, flight profile, proximity of targets in flocks, atmospheric conditions, and, to some extent, the amount and location of ground clutter. Cooper et al. (1991) found that flocks of waterfowl routinely were detected at distances of 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 target size, 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). Targets were initially classified as small (<4mm diameter or length) or large (4mm diameter or length) in the field, although after analyzing the data target sizes were lumped together because only a small percentage (3.6%) of the targets were “large” in this study. Large targets were believed to be either shorebirds or waterfowl based on their size and speed (relative to typical passerine targets) and their small contribution to the overall numbers suggest that these taxa (shorebirds and waterfowl) were not common migrants during this study. It also is likely that a smaller number of targets were migratory bats, although this proportion is unknown.

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, migratory bats or any bats not exhibiting erratic flight patterns were included in our data.

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

SAMPLING DESIGN

Each of the seven, one-hr radar sampling sessions consisted of: (1) one 10-min session to collect weather data and adjust the radar to surveillance mode; (2) one 10-min session with the radar in surveillance mode (1.5-km range) for collection of information on migration passage rates; (3) one 15-min session with the radar in surveillance mode (1.5-km range) for collection of information on groundspeed, flight direction, tangential range (minimal perpendicular distance to the radar laboratory), transect crossed (the four cardinal directions—north, south, east, and west), species (if known), and the number of individuals (if known); (4) one 10-min session to collect weather data and adjust the radar to vertical mode; and (5) one 15-min session with the radar in vertical mode (1.5-km range) to collect information on flight altitudes, speed, and direction. The exception was session four when following surveillance radar data collection we traveled between stations and then finished the hour with an abbreviated 10-min vertical radar data collection.

For each vertical radar session, the antenna was oriented parallel to the main axis of migration (determined by the modal flight direction seen during the previous surveillance radar session) to maximize the true flight speed of targets. True flight speeds of targets can be determined only for those targets flying parallel to the antenna's orientation because slower speeds are obtained when targets fly at an angle to this plane of orientation. We also examined the flight behavior of vertical radar targets during by recording whether targets were ascending from the ground clutter, ascending at a steep angle above the ground clutter (extrapolated flight path would have intersected the ground clutter on the monitor), flying at a level altitude, descending at a steep angle (extrapolated flight path would have intersected the ground clutter on the monitor), and descending into the ground clutter.

Weather data collected twice each hour consisted of the following: wind speed (in KPH, collected with a Kestrel® weather instrument [Nielsen-Kellerman Company, Boothwyn, PA]); wind direction (measured with a compass to the nearest 5°); cloud cover (estimated to the nearest 5%); ceiling height (in m agl; 1–50, 51–100, 101–150, 151–500, 501–1,000, 1,001–2,500, 2,501–5,000, >5,000); minimal visibility in a cardinal direction (in m; 0–50, 51–100, 101–500, 501–1,000, 1,001–2,500, 2,501–5,000, >5,000); precipitation level (no precipitation, fog, drizzle, light rain, heavy rain, snow flurries, light snowfall, heavy snowfall, sleet, hail); barometric pressure (in in Hg measured with a Kestrel® weather instrument); and air temperature (measured to the nearest 1°C with a Kestrel® weather instrument). We also obtained weather data (wind speed and wind direction) from a 60-m high meteorological tower located within the project boundary. We could not collect radar data during rain because the electronic filtering required to remove the echoes of the precipitation from the display screen also removed those of the targets of interest.

DATA ANALYSES

RADAR DATA

We entered all radar data into MS Access 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 2005). For quality assurance, we cross-checked results of the SPSS analyses with hand-tabulations of small data subsets whenever possible. The level of significance (α) for all statistical tests was set at 0.05.

Radar data were not corrected for differences in detectability with distance from the radar unit. Correcting for differences in target detectability is confounded by several factors, including but not limited to the following: (1) variation in target size (i.e., species) across the study period; (2) an assumption that there is an equal distribution of targets throughout the sampling area (which would be violated if migrants responded to landform or microsite features on the landscape); (3) variation in the shape and size of the effective radar-sampling beam (see our preliminary assessment of the shape of our radar beam under one set of conditions in Figures 3 and 4). 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:

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

where V_a = airspeed, V_g = target groundspeed (as determined from the radar flight track), V_w = wind velocity, and θ is the difference between the observed flight direction and the direction of the wind vector. Targets that had corrected airspeeds <6 m/s (17.8% at North, 14.7% at Saddle, and 16.2% overall from surveillance data) were deleted from all analyses.

We calculated mean and median flight directions of radar targets to provide insight on the orientation of bird movements. Equally important, we present a metric to describe the dispersion of flight directions. This metric, the mean vector length (r), varies from a value of 0 (maximal dispersion) to 1 (maximal concentration). Mean flight directions coupled with high r values indicate strong patterns in flight orientation whereas mean flight directions coupled with low r values indicate weak to no directionality in flight movements. We analyzed flight-direction data following procedures for circular statistics (Zar 1999) with Oriana software version 2.0 (Kovach 2003).

Migration passage rates are reported as the mean ± 1 standard error (SE) number of targets passing along 1 km of migratory front/h (targets/km/h ± 1 SE). Passage rates of targets flying <125 m in altitude were derived for each hourly period by multiplying passage rates recorded from surveillance radar by the percentage of targets on vertical radar having flight altitudes <125 m, correcting for the hypothetical maximal height of the surveillance radar beam (861 m). All flight-altitude data are presented in m agl (above ground level) relative to a horizontal plane passing through the radar-sampling site. Actual mean altitudes may be higher than those reported because an unknown number of birds fly above the 1.5-km range limit of our radar (Mabee and Cooper 2004).

For calculations of the daily patterns in migration passage rates and flight altitudes, we assumed that a day began at 0700 h on one day and ended at 0659 h the next day, so that a sampling night was not split between two dates. We summarized and presented radar data separately for each station because of potential differences in migration activity at the two sampling stations. We used paired t-tests (SPSS 2005) to compare nightly passage rates (overall and <125 m agl) and flight altitudes between stations. We used a PROC MIXED repeated-measures analysis with an AR1 covariance structure and adjustment for small sample sizes (SPSS 2005), to compare passage rates and flight altitudes among hours of the night for nights with data collected during all sessions. Factors that decreased our sample size of the various summaries and analyses included insect contamination and precipitation. 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 60-m meteorological tower located near the radar sampling sites. All wind categories except the calm category had a mean wind speed of ≥2.2 m/s (i.e., ≥5 mph) and were categorized as the following during fall: tail winds WNW to ENE (i.e., 293°–068°), head winds ESE to SSW (i.e., 113°–248°), eastern crosswinds (069°–112°), western crosswinds (249°–292°), and calm (0–2.1 m/s).

Prior to model specification, we examined the data for redundant variables (Spearman's r_s>0.70) and retained eight parameters for inclusion in the passage rate model set and seven parameters in the altitude 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 SE). We used a natural logarithm transformation on the dependent variables "passage rate" and "flight altitude" to make the data normal. We specified 45 models for passage rates and 34 models for flight altitudes: a global model containing all variables and subset models representing potential influences of three small-scale weather variables (wind direction, the interaction of wind direction and wind speed, and ceiling height [including fog]), one large-scale weather variable (synoptic —that reflected the position of pressure systems relative to our study site [Fig. 5]), one variable reflecting the number of days between favorable migration conditions (i.e.,

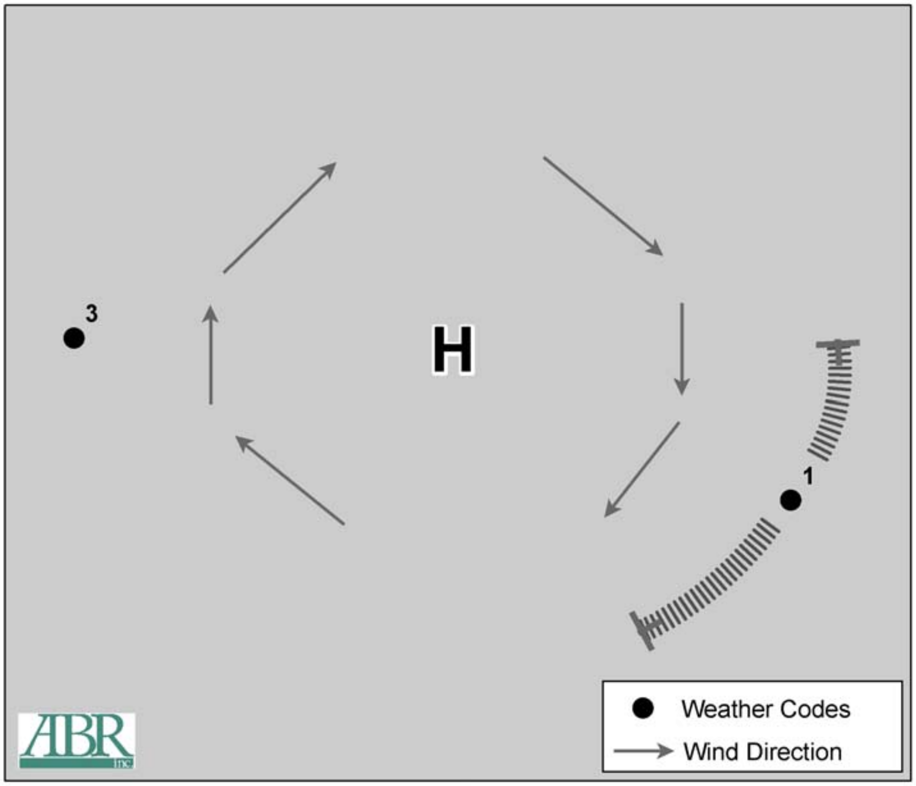

Figure 5. Synoptic weather codes used to depict the position of the study site relative to a high pressure system. Code 1 = study site situated to the east or southeast of a high pressure system, Code 2 = no well-developed pressure system in the vicinity of the study site (not visually depicted), Code 3 = study site situated to the west of a high pressure system.

the number of days since last tail wind, used only in passage rate models), one variable describing the percent of the moon illuminated and visible on a given night (the interaction of percent moon illumination and cloud cover), one variable to account for geographic and topographic differences (station), and date on migration passage rates and flight altitudes (Appendix 1).

Synoptic weather codes were based on Gauthreaux (1980) and Williams et al. (2001) but were modified to reflect the movement of pressure systems along the Pacific coast. The synoptic classification reflects the position of our study site relative to a high pressure system—1) situated to the east or southeast of a high pressure system, 2) no well-developed pressure system near our site, 3) situated to the west of a high pressure system (Fig. 5). 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 the passage rate and altitude models.

Because the number of sampling sessions for both passage rates (n = 225) and flight altitudes (n = 223) was small relative to the number of parameters (K) in many models (i.e., $n/K < 40$), we used Akaike's Information Criterion corrected for small sample size (AIC_c) for model selection (Burnham and Anderson 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 2005).

TURBINE PASSAGE RATE INDEX

To describe migration passage rates within the potential turbine area we developed the turbine passage rate index (the number of nocturnal migrants flying within the turbine area each night). The turbine passage rate index is comprised of several components, including: (1) *passage rate of targets flying <125 m agl* (calculated by multiplying passage rates from surveillance radar by the percentage of targets on vertical radar with flight altitudes <125 m agl, correcting for the maximal height of the surveillance radar beam); (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 sampling period); and (4) *number of hours of migration/night* (estimated as the number of nocturnal hours). These factors are combined as described 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) minimal (i.e., side profile) and maximal (i.e., front profile, including the area from the ground up through the entire rotor-swept area) areas occupied by the wind turbines relative to the flight directions of migrants, (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 39-d migration sampling period, and (4) an average of 10 nocturnal hours/day of migration during fall migration.

RESULTS

FLIGHT DIRECTION

Most nocturnal radar targets were traveling in seasonally appropriate directions for fall migration (i.e., southerly), with a mean flight direction of 191° at North (mean vector length = 0.49; median = 205°; n = 3,581 targets; Fig. 6a), 196° at Saddle (mean vector length = 0.51; median = 210°; n = 3,950 targets; Fig. 6b), and 194° across both stations (mean vector length = 0.50; median = 210°; n = 7,531 targets; Fig 6c). A large proportion (48%) of targets was traveling in a southerly

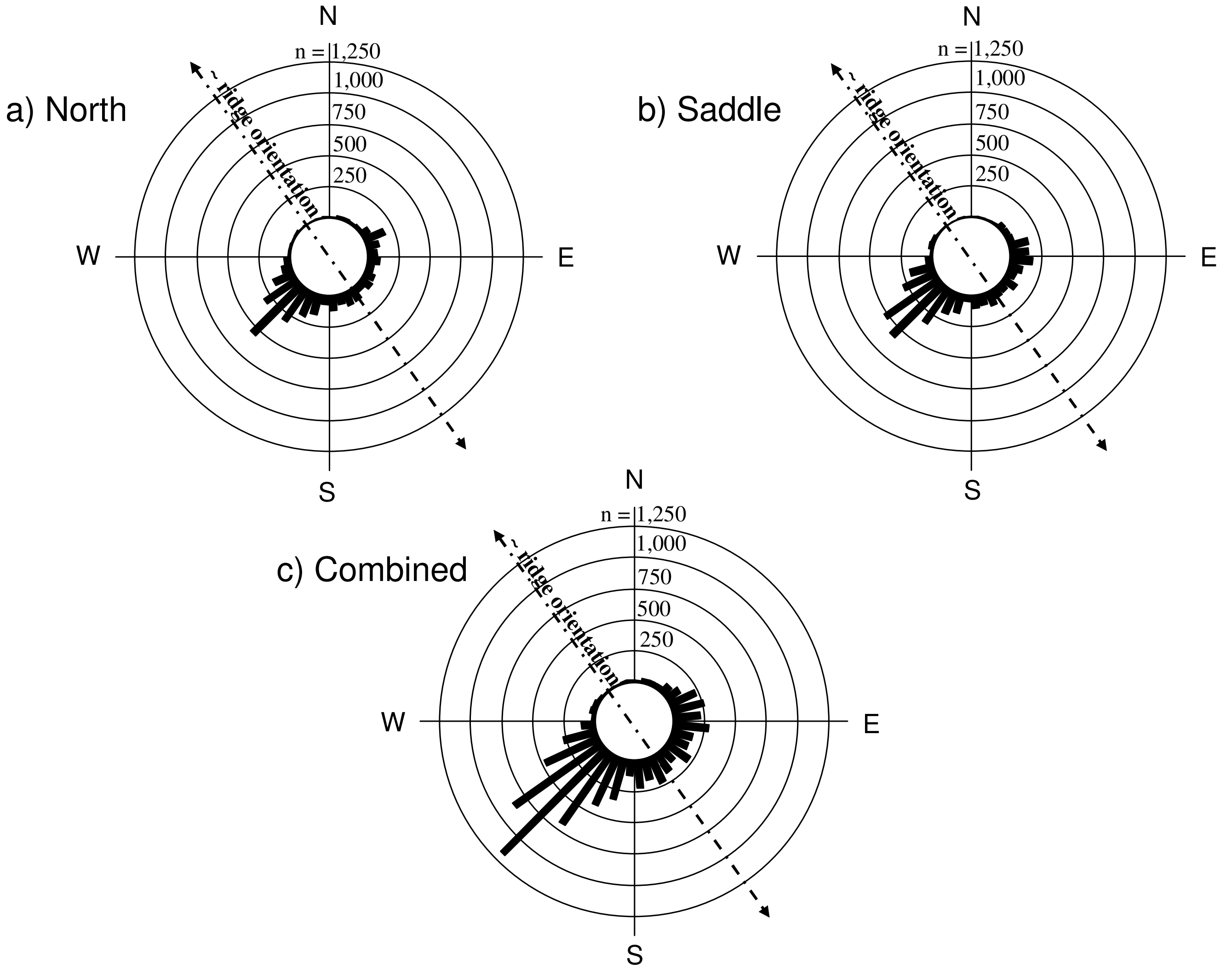

Figure 6. Flight directions of radar targets at the a) North, b) Saddle, and c) combined radar sampling stations of the proposed Hatchet Ridge Wind Project, California, fall 2007. Lines with arrows indicate approximate orientation of the ridgeline.

direction between SE (135°) and SW (225°) across both stations. Most targets were traveling in a direction nearly perpendicular to the ridge and hence were crossing, rather than following the ridge (Fig. 6).

PASSAGE RATES

The mean nocturnal passage rate for the fall season was 231 ± 31 targets/km/h (*n* = 36 nights) at North and 351 ± 38 targets/km/h (*n* = 35 nights) at Saddle stations with an overall rate of 290 ± 26 across both stations. Nightly comparisons indicate mean passage rates differed significantly between the North and Saddle stations ($Z_{\text{paired}} = -3.770$, $P = <0.001$, $n = 29$ paired nights). Overall, mean nightly passage rates were highly variable among nights at both North (range = 34–936 targets/km/h; Fig. 7a) and Saddle (range = 31–1,159 targets/km/h; Fig. 7b) stations as well as during different time periods of the migratory season (Appendix 2). Passage rates increased throughout the season on a bi-monthly basis for both stations (Appendix 2), however, the Saddle station rates tended to increase more in the final two weeks of the season than the North station rates. Passage rates did not vary among nocturnal sampling hours ($F_{6,119.6} = 0.934$, $P = 0.473$, $n = 29$ nights; Fig. 8).

FLIGHT ALTITUDES

The mean nocturnal flight altitude at North was 474 ± 5 m agl (*n* = 3,747 targets; median = 412 m agl) and at Saddle stations was 463 ± 4 m agl (*n* = 4,371 targets; median = 408 m agl) with a mean flight altitude of 468 ± 3 m agl (*n* = 8,118 targets; median = 410 m agl) across both stations. There was no difference in mean nightly flight altitudes between the North and Saddle stations (mean difference = 40 ± 22 m agl, $Z = -1.410$, $P = 0.158$, $n = 34$ paired nights). Mean flight altitudes observed on vertical radar (1.5-km range) were moderately variable among most nights, with occasional nights of higher altitudes (Fig. 9). Flight altitudes ranged from 272–950 m agl at North (Fig. 9a) and from 243–578 m agl at Saddle (Fig. 9b) stations.

Flight altitudes also were variable among different two-week segments of the migratory season (Appendix 2) with altitudes decreasing at North as time progressed but not at the Saddle station. Mean flight altitudes did not vary among nocturnal sampling hours ($F_{6,145.7} = 1.4$; $P = 0.211$; $n = 30$ nights; Fig. 10).

The overall distribution of targets in 100-m categories of nocturnal flight altitudes at North varied from 16.0% in the 201–300 m agl interval to 0.1% in the interval from 1,401–1,500 m agl and at Saddle varied from 14.8% in the 201–300 m agl interval to 0.1% in the interval from 1,401–1,500 m agl (Table1). Across both stations flight altitudes varied from 15.4% in the 201–300 m agl interval to 0.1% in the interval from 1,401–1500 m agl (Table 1).

We provide a detailed examination of the cumulative percentage of targets within 250 m agl (by 25-m categories) for both stations and sampling periods in Appendix 3. We determined that the percentages of targets flying <125 m agl (i.e., within the approximate maximal height of the wind turbines selected for the proposed HRWP) were 7.2% of all targets at North, 9.3% of all targets at Saddle, and 8.3% of all targets across both stations.

LOW ALTITUDE PASSAGE RATES

We combined our passage rate and flight altitude data to produce altitude specific passage rates of targets flying <125 m agl (Fig 11). The mean <125 m agl passage rate at North was 17 ± 3 targets/km/h (*n* = 34 nights) and at Saddle was 39 ± 7 targets/km/h (*n* = 33 nights). At both stations combined the mean <125 m agl passage rate was 28 ± 4 targets/km/h (*n* = 34 nights). Mean <125 m agl passage rates were significantly different between the North and Saddle stations ($Z = -2.92$, $P = <0.01$, $n = 31$ paired nights) and nightly differences averaged 22 ± 8 targets/km/h higher at Saddle than North.

Overall, mean <125 m agl passage rates were highly variable among nights at North (range = 0–61 targets/km/h; Fig. 11a) and at Saddle (range = 0–171 targets/km/h; Fig. 11b) stations. Mean passage rates below 125 m also varied among different two-week segments of the migratory season with consistently higher rates at the Saddle station and with rates highest at both stations during the last sampling segment (Appendix 2).

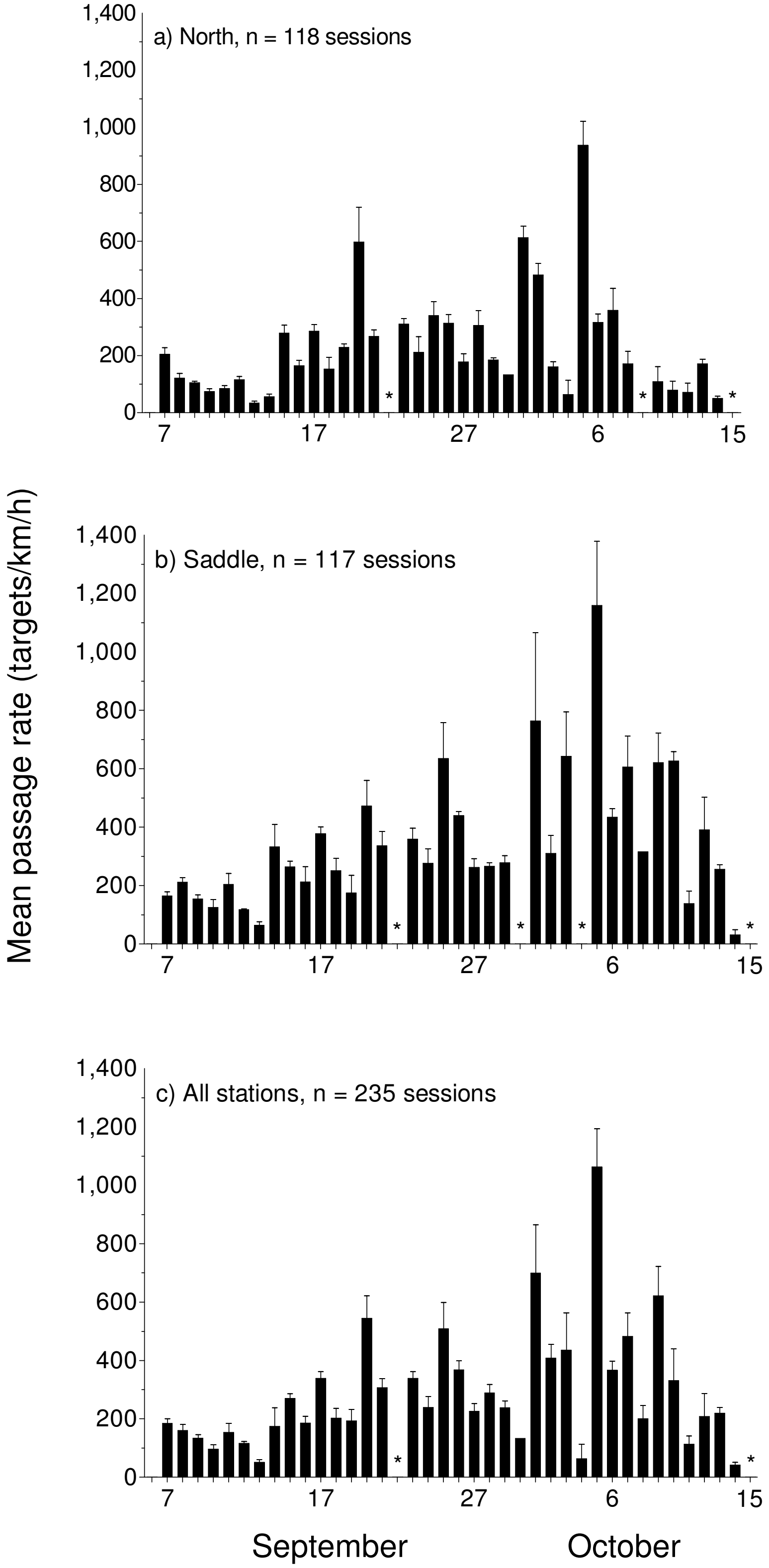

Figure 7. Mean ± 1 SE nightly passage rates (targets/km/h) at the a) North station, b) Saddle station, and c) all stations combined at the proposed Hatchet Ridge Wind Project, California, fall 2007. Asterisks (*) denote nights not sampled because of rain.

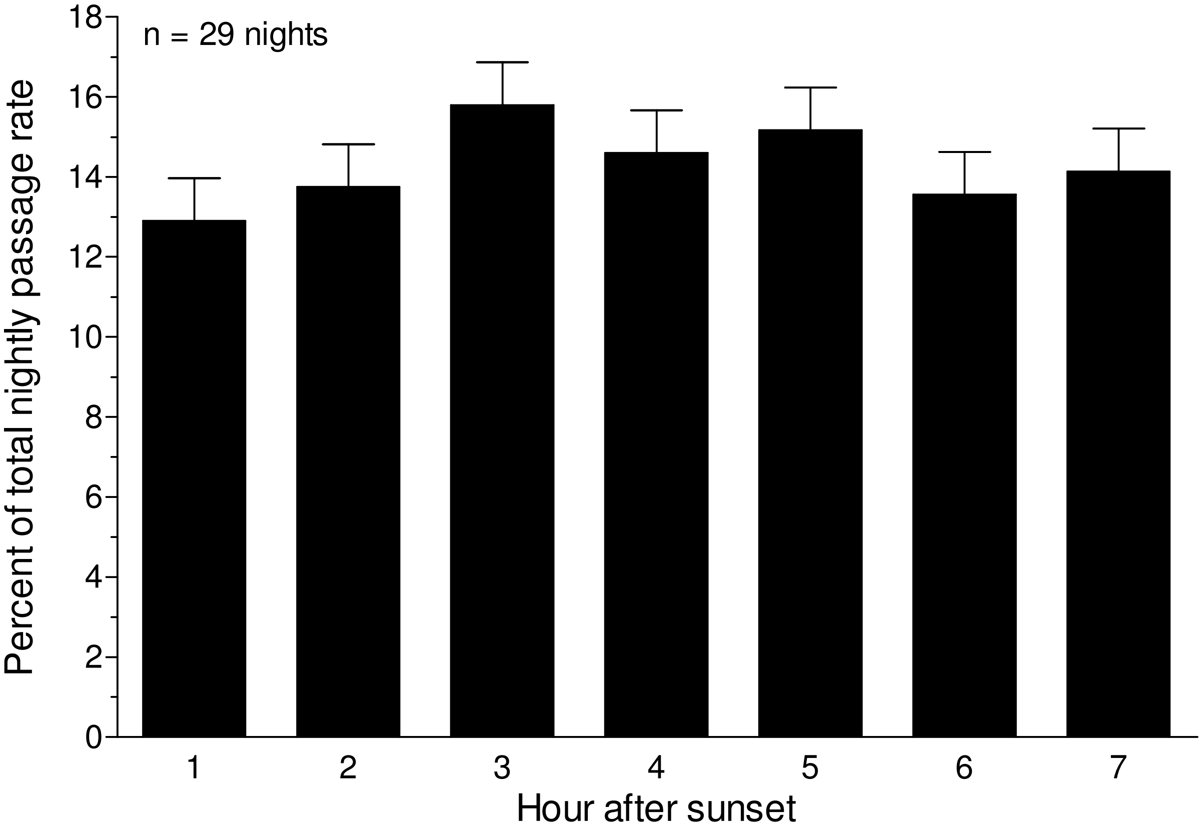

Figure 8. Percent of nightly passage rate (± 1 SE) relative to time past sunset for nights with full sampling at both radar stations at the proposed Hatchet Ridge Wind Project, California, fall 2007.

EFFECTS OF WEATHER ON MIGRATION

We investigated the importance of weather (i.e., wind direction, wind speed, ceiling height [including fog], synoptic weather, and days since favorable migration [passage rate models only]), 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 at the proposed development was the model containing the variables date and station (Table 2). This model contained significant positive associations with date and station (Table 3) indicating that passage rates increased later in the season and were higher at the Saddle station. The second-best model was the global model containing all model variables but was not well supported ($\Delta AIC_c = 6.01$; Appendix 4). The weight of evidence in favor of the "best" model ($w_{best}/w_{second\ best}$) was > 20 times that of the second-best model (Burnham and Anderson 2002). The complete passage rate model can be found in Appendix 4 for the reader interested in examining all models and their associated statistical metrics.

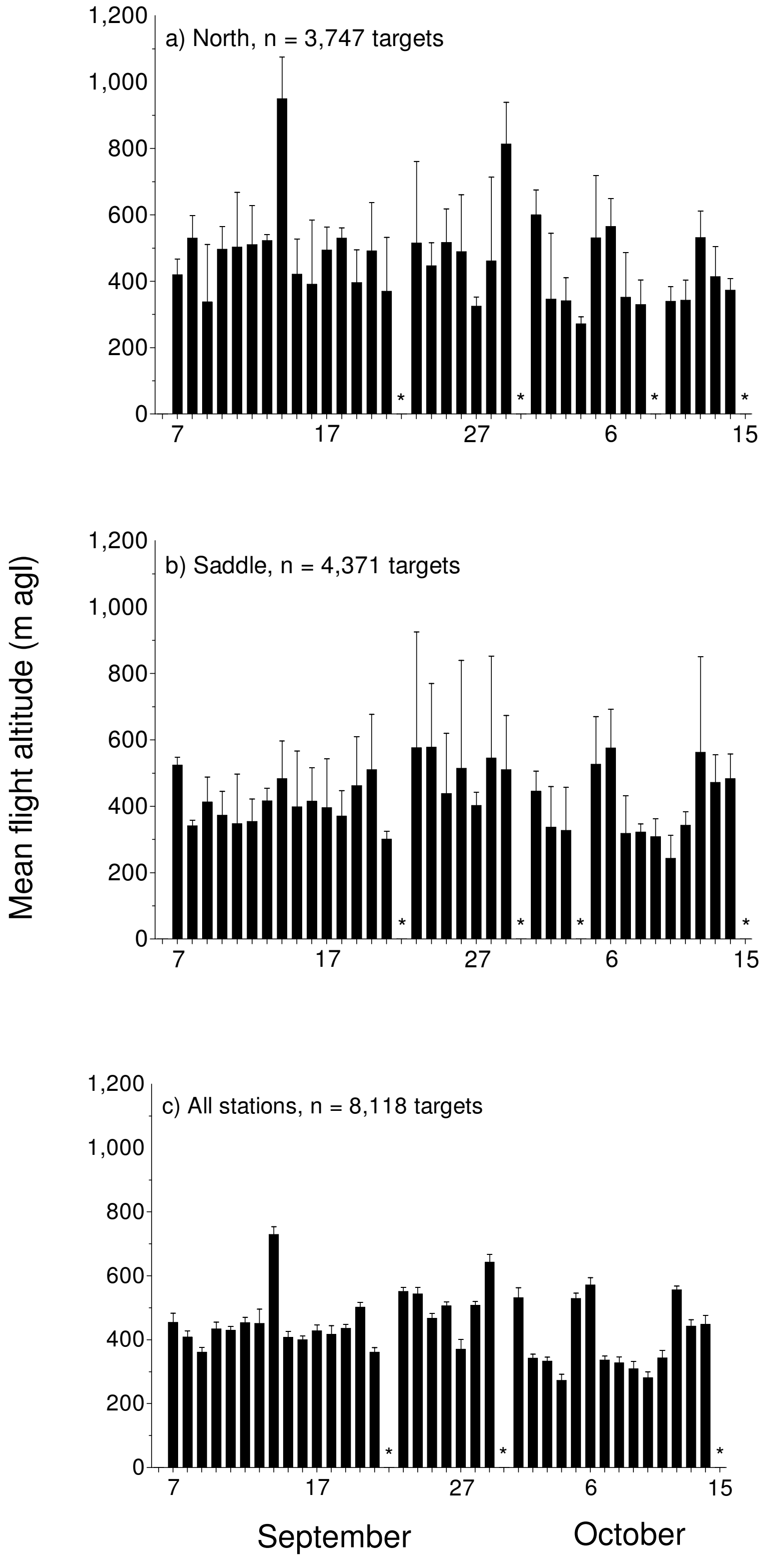

Figure 9. Mean ± 1 SE nightly flight altitude (m agl) of radar targets at the a) North station, b) Saddle station, and c) all stations combined at the proposed Hatchet Ridge Wind Project, California, fall 2007. Asterisks (*) denote nights not sampled because of rain.

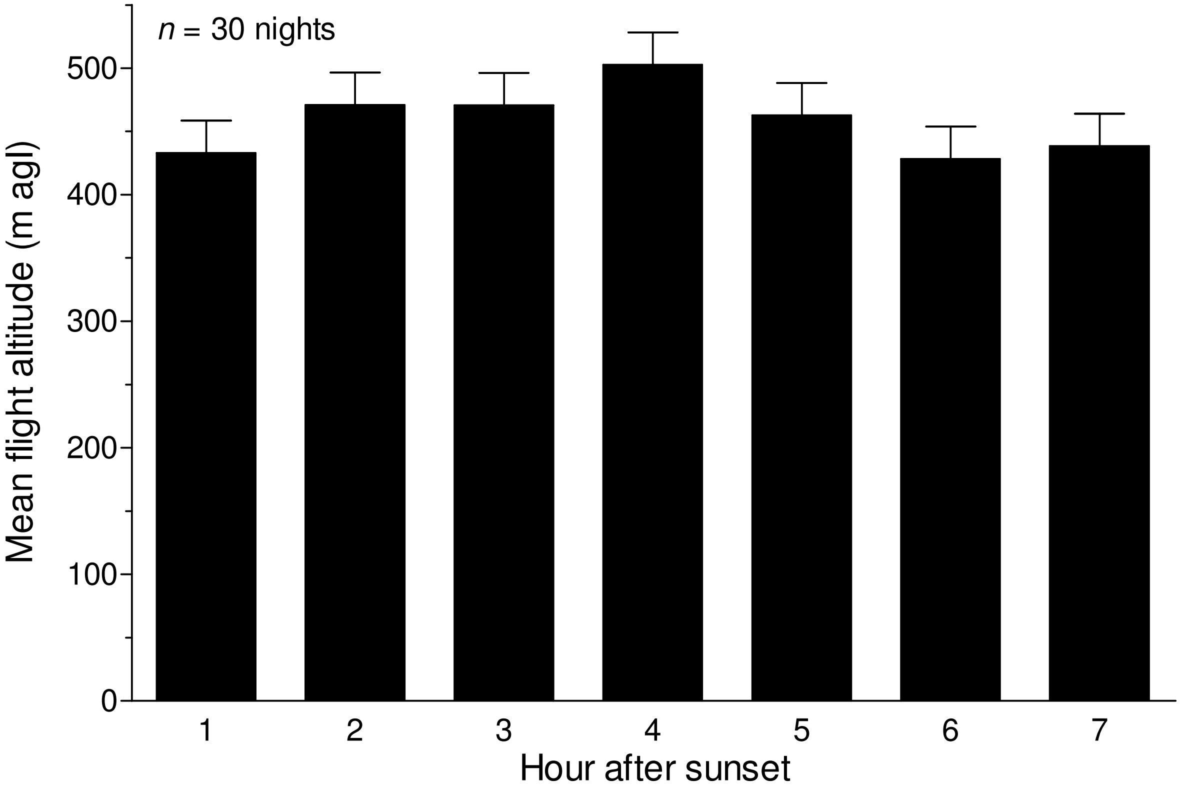

Figure 10. Mean flight altitude (± 1 SE) relative to time past sunset for nights with full sampling at both radar stations at the proposed Hatchet Ridge Wind Project, California, fall 2007.

Table 1. Nocturnal flight altitudes of radar targets (% of all targets) detected at the 1.5-km range at the proposed Hatchet Ridge Wind Project, California, fall 2007, by 100 m agl flight altitude category and station.

	Percent of radar targets		
Flight altitude (m)	North (n = 3,747 targets)	Saddle (n = 4,371 targets)	All stations (n = 8,118 targets)
1–100	5.0	5.8	5.4
101–200	11.7	14.0	12.9
201–300	16.0	14.8	15.4
301–400	15.4	14.5	14.9
401–500	13.2	12.8	13.0
501–600	11.6	11.0	11.3
601–700	6.9	6.7	6.8
701–800	5.2	5.7	5.5
801–900	4.4	5.2	4.8
901–1,000	3.2	3.5	3.4
1,001–1,100	2.4	3.1	2.8
1,101–1,200	2.2	1.7	1.9
1,201–1,300	2.0	0.7	1.3
1,301–1,400	0.7	0.4	0.5
1,401–1,500	0.1	0.1	0.1

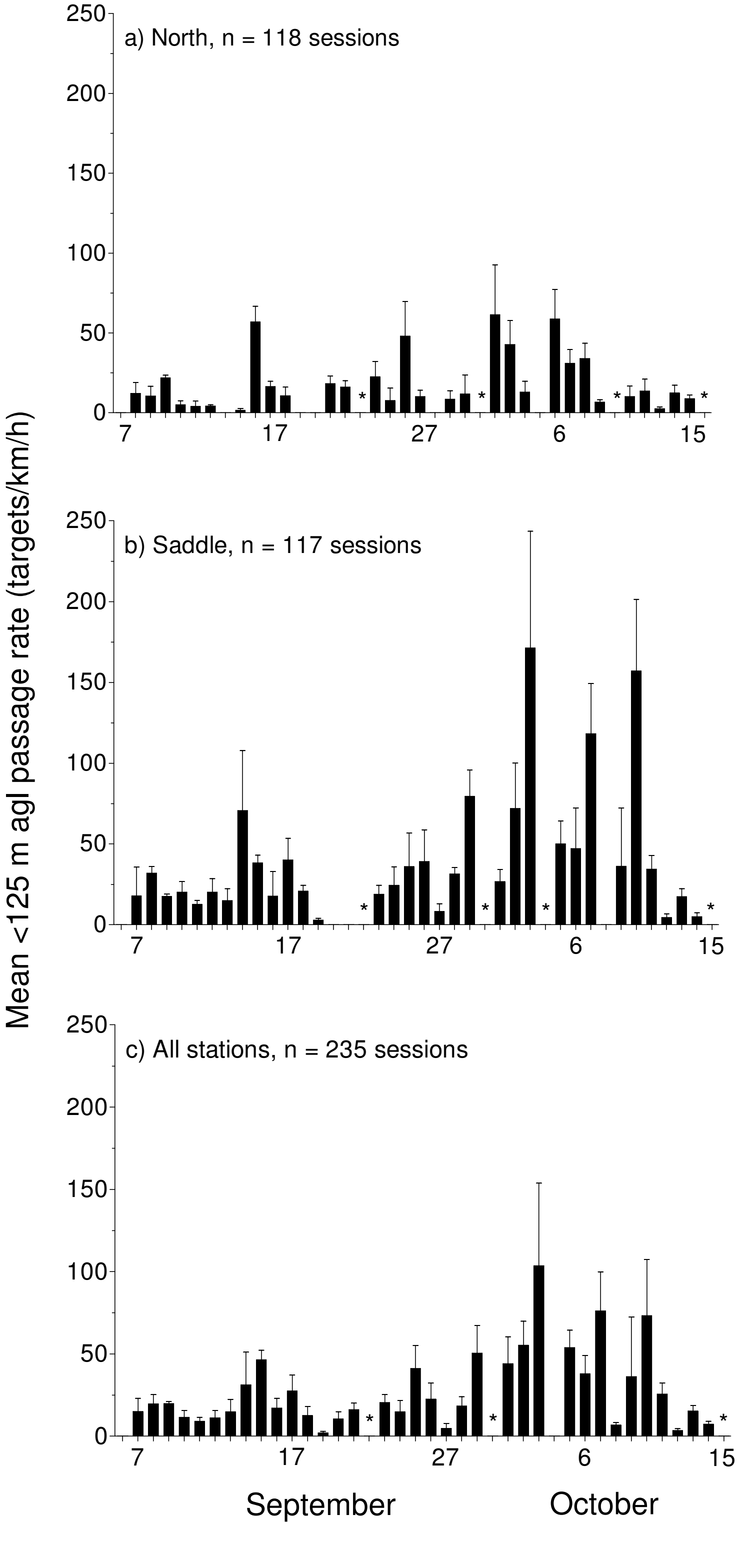

Figure 11. Mean ± 1 SE nightly below 125 m agl passage rates (targets/km/h) at the a) North station, b) Saddle station, and c) all stations combined at the proposed Hatchet Ridge Wind Project, California, fall 2007. Asterisks (*) denote nights not sampled because of rain.

Table 2. Linear mixed model estimates from competitive models ($AIC_c \leq 2$) explaining the influence of environmental factors on passage rates (surveillance radar, n = 225 sampling sessions) and flight altitudes (vertical radar, n = 223 sampling sessions) of radar targets at the proposed Hatchet Ridge Wind Project, California, fall 2007. Model weights (w_i) were based on Akaike's Information Criterion (AIC).

Analysis/Model	-2 Log Likelihood[a]	K[b]	AIC_c[c]	ΔAIC_c[d]	w_i[e]
Rates					
Date + station	345.94	12	371.41	0.00	0.81
Flight altitudes					
Synoptic	-86.01	11	-62.75	0.00	0.41
Synoptic + station	-88.17	12	-62.68	0.07	0.39
Synoptic + date	-86.80	12	-61.31	1.44	0.20

[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.

Table 3. Model-averaged parameter estimates from competitive models ($\Delta\ AIC_c \le 2$) explaining the influence of environmental factors on passage rates and flight altitudes of radar targets at the proposed Hatchet Ridge Wind Project, California, fall 2007.

Analysis/parameter	B[a]	SE[b]
Rates		
Intercept	4.263	0.396*
Date	0.134	0.035*
Date (quadratic)	-0.003	0.001*
Station = Saddle	0.374	0.174*
Flight altitude		
Intercept	5.883	0.056*
Date	-0.003	0.003*
Station = Saddle	-0.050	0.033*
Synoptic weather = SE to E of a high pressure system	0.192	0.057*
Synoptic weather = W of a high pressure system	0.521	0.118*

[a] Coefficients (B) of the categorical variables, station and synoptic weather were calculated relative to the Saddle station and to no nearby pressure system, respectively.

[b] Asterisks (*) indicate 95% confidence intervals that do not overlap zero.

FLIGHT ALTITUDES

The best-approximating model explaining flight altitudes of nocturnal migrants during fall migration at the proposed development was the model containing the variable synoptic (Table 2). The second-best model contained the variables synoptic and station ($\Delta AIC_c = 0.07$; Table 2), and a third model with the variables synoptic and date ($\Delta AIC_c = 1.44$) also received some empirical support (Table 2). These models contained strong positive associations with both synoptic conditions indicating that altitudes increased under both favorable and unfavorable conditions and decreased when there was no pressure system nearby (Table 3). These models contained slight negative associations with date and station indicating that flight altitudes decreased later in the season and were lower at the Saddle station (Table 3). The weight of evidence in favor of the "best" model ($w_{best}/w_{second\ best}$) was 1.1 times that of the second-best model (Burnham and Anderson 2002). The complete flight altitude model set can be found in Appendix 4 for the reader interested in examining all models and their associated statistical metrics.

TARGETS WITHIN THE PROPOSED TURBINE AREA

We made several assumptions to estimate the turbine passage rate (i.e., the number of targets that would pass within the area occupied by each proposed turbine): (1) the minimal area occupied by the wind turbine (i.e., side profile), (2) the maximal area occupied by the wind turbine (i.e., front profile, including the entire rotor-swept area), (3) a worst-case scenario of the rotor blades turning constantly, (4) 39 d in the study during fall, and (5) an average of 10 nocturnal hours/day across the fall study period. If all migrants approached the turbines from the side, an estimated 41 migrants at North, 94 migrants at Saddle, and 67 across both stations would have passed within the area occupied by one turbine (Appendix 5). If all migrants approached the turbines from the front, an estimated 389 migrants at North, 898 migrants at Saddle, and 640 across both stations would have passed within the area occupied by one turbine during our fall study period (Appendix 5). An alternate way to look at this relationship is on a per day basis; these estimates would be equivalent to an estimate of 1.1–10.0 migrants at North, 2.4–23.0 migrants at Saddle, and 1.7–16.4 across both stations passing through the area of a single turbine each day (Appendix 5).

DISCUSSION

Wind energy is a promising source of renewable energy and one of the fastest growing sectors of energy production in the United States (GAO 2005, EIA 2007). In an increasing number of states there are mandates to encourage development of alternative energies and increase the proportion of energy derived from renewable sources. For instance, the state of California has mandated that investor owned utilities generate at least 20 percent of their electricity from renewable sources (e.g., wind) by the year 2010 (State Bill 107, Rogers 2006). In light of the potential for bird and bat fatalities at new and existing wind generating facilities the state of California has published a set of voluntary guidelines for reducing impacts to birds and bats from wind energy development (CEC and CCDFG 2007). However, predictions of the effects of wind power development on migratory birds and bats are hampered by a lack of basic information on their relative abundance at low altitudes, their flight altitudes relative to wind turbine RSA's, and their flight behaviors around turbines (i.e., their ability to detect and avoid structures), and the causal relationship between their abundance and fatalities at wind turbines. In this study, we addressed some of these issues and documented some of the key characteristics of nocturnal migration of birds at the proposed project site.

Our results can be compared with those of similar studies in the region as an initial assessment of geographic differences in migration characteristics; however, additional assumptions must be considered before making this assessment. Methodological differences among studies often hamper appropriate comparisons of results and such differences may include type of radar used, radar settings (e.g., gain and ground clutter reduction), data collection techniques (manual vs. automated), criteria for removal of insects, and data analyses. The overall comparability among studies can be determined by assessing the methodological similarities, the study period, the sampling effort, and the study location in Appendix 6.

TIMING OF MIGRATION

Understanding the timing of animal movements at multiple temporal scales (e.g., within nights, within seasons, and seasonally within years) allows the determination of patterns of peak movements that may be useful information for both pre-construction siting decisions and for operational strategies to reduce fatalities (if animal abundance and fatalities are correlated). Several radar studies have found a pattern similar to that observed in this study, in which the intensity of avian nocturnal migration begins to increase ~30–60 min after sunset, peaks around midnight, and then either levels off (Mabee et al. 2005b, 2006a, 2006b; Plissner et al. 2005, 2006a, 2006b, 2006c) or declines steadily thereafter until dawn (Lowery 1951, Gauthreaux 1971, Kerlinger 1995, Farnsworth et al. 2004, Mabee et al. 2006a).

The proposed HRWP is located in an area with a diverse community of migratory bird species including songbirds, shorebirds, and waterfowl and the timing and intensity of migration will differ among these avian species groups. Based on the fact that songbirds comprise the majority of known collisions with wind farms (Osborn et al. 1996; Erickson et al. 2001, 2002; Manville 2005) we selected our span of study dates (9 September–15 October) to coincide with the peak of songbird migration through the region (Burnett and King 2004, Harris 2005). Our observations indicate a general pattern of increasing nightly passage rates until early October and then a decrease until the end of the study, suggesting that we captured a major peak of the fall songbird migration.

Within a season, migration generally occurs in pulses and the intensity of migration may differ greatly from one night to the next (Alerstam 1990, Mabee and Cooper 2004, Mabee et al. 2006a). Clearly this was the case during fall migration at the proposed HRWP. We recorded mean nightly passage rates >2 SD of the seasonal mean on two nights at the North station (1, 5 October) and on seven nights at the Saddle station (25 September and 1, 3, 5, 7, 9–10 October). Overall, nightly spring migration rates at both stations peaked on 5 October with 936 targets/km/h at North and 1,159 targets/km/h at Saddle.

PASSAGE RATES

Passage rates are an index of the number of targets (birds and bats) flying past a location and are a widely-used metric in studies of migration activity at proposed wind power developments (Mabee et al. 2006a). Thus, documenting passage rates allows for comparisons of relative bird use among different sites and regions. In this study, we derived passage rates both separately for the two sampling stations and across both stations and used the passage-rate data in two ways: (1) to examine the passage rate of all migrants passing over our study site, and (2) to examine the passage rate of migrants within the height of the proposed wind turbines (<125 m agl). Although both metrics are useful for characterizing bird activity at proposed wind power developments and existing windfarms, the second metric is especially well-suited for these comparisons since it describes migration activity within the vertical range of new generation wind turbines such as those proposed for installation at the HRWP.

In this study, mean passage rates across both stations were 290 ± 26 targets/km/h and rates differed between the North (231 ± 31 targets/km/h) and Saddle (351 ± 39 targets/km/h) stations, although they were situated only ~3.2 km apart along the ridge. The cause of these differences in rates is unknown, although multiple potential explanations exist, including: 1) differences in station elevation and topography (i.e., higher use of the saddle in the ridgeline); 2) variation in the radar sampling coverage; and 3) stations were not paired in time (i.e., stations were sampled sequentially, not simultaneously) and that by chance alone, sampling occurred at the Saddle station under conditions with higher migration rates.

Of these potential explanations (and others may exist), the first possibility (differences in station elevation and topography) is possible because the saddle station is ~ 144 m lower than the North station) and nocturnal migrants may choose this "pass" when traveling through the mountains; the second possibility (variation between radar sites) is unlikely because both sites had excellent coverage of the area; the third possibility (higher rates explained by chance) is also unlikely because the station differences (i.e., greater passage rates at Saddle than North station) were consistent throughout the study periods (see Appendix 2). This pattern of differences in passage rates on a small scale has also been observed in other studies (Mabee et al. 2006).

Ultimately, it may be most appropriate for assessing site use to simply acknowledge the potential variation between these stations and use the combined metric to evaluate the overall use of this site by nocturnal migrants. The combined station rate from HRWP (290 targets/km/h) was similar to the only other study available for comparison in California, the proposed Bear River Ridge wind development (i.e., 269 targets/km/h; Appendix 6). Bear River Ridge is a coastal site located ~200 km to the west of HRWP. We emphasize the lack of additional studies for comparison in this region, highlighting the general lack of information on nocturnal migration rates in the Western US, and warranting the cautious interpretation of results. For comparison at a continental scale, fall passage rates ranged from 64–661 targets/km/h at 18 sites in Eastern US and 19–269 targets/km/h at three sites in the Pacific Northwest (Appendix 6).

Within the range of the proposed turbine heights (<125 m agl) the mean altitude-specific passage rates (i.e., targets <125 m agl) during our study was 28 ± 4 targets/km/h across both stations, with differences at the North (17 ± 3 targets/km/h) and Saddle (39 ± 7 targets/km/h) stations, mirroring the differences observed in overall passage rates between these stations. The low-altitude passage rates observed across both stations in this study were lower than that observed at the Bear River Ridge wind development (33.0 targets/km/hr) in coastal California.

Beyond California, the only other fall migration studies with comparable altitude-specific data includes the following: New York (11–38 targets/km/h; Mabee et al. 2005c, Mabee et al. 2006c); Pennsylvania (two sites with16 targets/km/h, Plissner et al. 2005, 2006b; one site with 10 targets/km/h, Plissner et al. 2006c); and Virginia and West Virginia (56 targets/km/h, Plissner et al. 2006a, 36 targets/km/h, Mabee et al.

2006a, 72 targets/km/h, Plissner et al. 2006b). In the Eastern US, fall turbine passage rate estimates are higher at sites in the southern Allegheny Mountain areas than further north. Differences in these rates may reflect differences in overall numbers of birds moving through an area, differences in flight altitudes, or both. We emphasize the same caution as previously mentioned when making comparisons with the California data.

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; Longcore et al. 2005) indicate that large numbers of these birds fly <500 m agl on at least some nights and their flight altitude may be influenced by lights on the towers. Based on radar studies, however, most nocturnal migration occurs below ~ 1–1.5 km agl (Larkin 2006, Mabee and Cooper 2004, Mabee et al. 2006a, CUROL 2007). Our results from the vertical distribution of radar targets in this study and those from other published studies indicate that the majority of nocturnal migrants fly below 600 m agl (Bellrose 1971; Gauthereaux 1972, 1978, 1991; Bruderer and Steidinger 1972; Cooper and Ritchie 1995, Kerlinger 1995).

Flight altitudes of migratory bats are poorly known, especially for the migratory tree-roosting bats that appear more prone to collisions with wind turbines (Reynolds 2006). Hoary bats, Eastern red bats, and Silver-haired bats 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.

Similar to our migration studies elsewhere (Cooper and Ritchie 1995; Cooper et al. 1995a, 1995b; Cooper and Mabee 2000; Mabee and Cooper 2004; Mabee et al. 2006a), we recorded large among-night variation in mean flight altitudes at both sites during fall migration, although mean flight altitudes always were above the proposed turbine heights. 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.

Flight altitudes were similar between sampling stations and the mean flight altitude across both stations was (468 ± 3 m agl), ~343 m higher than the height of the proposed turbines (~125 m). Mean flight altitudes from the fall sampling period were higher than the Bear River Ridge wind project along coastal California (329 m agl), were lower than studies at two sites in the Pacific Northwest (606–647 m agl; Appendix 6), and fell in the middle of values from studies in the Eastern US (333–532 m agl; Appendix 6).

We also examined the percentage of targets below the proposed maximal turbine height (i.e., <125 m agl) and calculated that 7% of targets at North, 9% at Saddle, and 8% across both stations flew <125 m agl during the sampling period (Appendix 6). These percentages were similar to those from the Bear River Wind project, California (11%), two sites in the Pacific Northwest (3–9 %), and within the range of those from the Eastern US (4–13%; Appendix 6).

MODELING MIGRATION PASSAGE RATES AND FLIGHT ALTITUDES

PASSAGE RATES

It is a well-known fact that general weather patterns and their associated temperatures and winds affect migration (Richardson 1978, 1990, Gauthreaux et al. 2005). 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, Gauthreaux et al. 2005). Conversely, more intense spring migration tends to occur in the eastern parts of lows, the western or central parts of highs, or in intervening transitional areas.

We examined the influence of weather (i.e., wind direction, wind speed * wind direction, ceiling height [including fog], synoptic weather, [days since favorable migration—passage rate models only]), lunar illumination (percent illumination * cloud cover), station, and date on migration passage rates and flight altitudes. During the fall sampling period, passage rates were higher at the Saddle station and increased later in the season. The strong station differences (discussed previously) had the strongest influence explaining relationships between passage rates and all variables modeled in this study. That passage rates increased later in the season simply reflects the general increase in migratory activity during this time.

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, flight altitudes appeared to increase under both favorable and unfavorable synoptic conditions (i.e., with tailwinds and with headwinds). Flight altitudes tend to increase under tailwind conditions (Alerstam 1990) consistent with our findings, but the reverse was surprising. A closer examination of the data revealed that the normal relationship was built from a large sample size (~ 2/3 of the data set) whereas the reverse relationship was built on a very small sample size—raising the possibility that the contrary finding was a spurious result. Flight altitudes decreased later in the season and were lower at the Saddle station (although by only 11 m, not biologically meaningful).

Although no strong association was apparent between ceiling height (including fog) and flight altitudes in this study, the need to understand how nocturnal migrants respond to fog and low ceiling height conditions is warranted. The largest single-night kill for nocturnal avian migrants at a wind power project in the US 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, Trapp 1988, Erickson et al. 2001) and have occurred under similar conditions at an offshore platform in Germany (Huppop et al. 2006).

SPECIES COMPOSITION

Observations at existing windfarms and other tall man-made structures indicate that certain species groups are at greater risk of collision with structures, particularly migratory songbirds and bats (Manville 2005). Determination of species-specific risks to nocturnal migrants at existing and proposed developments requires the identification of species migrating through the area of interest. Although supplemental techniques such as night vision optics (Kunz et al. 2007a) to identify low-altitude migrants were not used in this study, we did initially categorize targets as “small” (most likely individual passerines or bats) and “large” (most likely groups of shorebirds or waterfowl) to help assess coarse differences in targets. Only small proportions (3.6%) of targets were “large” during the fall season, suggesting that the majority of targets were likely individual passerines or bats. Large targets such as shorebirds and waterfowl may be expected to approach from the ~ NE from major staging areas in the Lower Klamath NWR, Tule Lake NWR, Clear Lake NWR, and Goose Lake (Warnock et al. 1998, USFWS 2008) and head in a southwesterly direction to over wintering areas in the Sacramento Valley, coastal California, and beyond.

TARGETS WITHIN THE PROPOSED TURBINE AREA

In this study we calculated a turbine passage rate index (number of birds and bats passing within the area occupied by each turbine each night) at both sampling stations and averaged across both stations. Differences among stations mirrored the differences in overall passage rates (i.e., Saddle > North). Across both stations the estimated turbine passage rate was 1.7–16.4 nocturnal migrants/turbine/d (Appendix 5).

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 the abundance of either birds or bats is strongly correlated with fatality rates at wind power developments. There are a variety of factors (e.g., weather) that may correlate more strongly with fatality rates than do numbers of individuals present prior to project construction. Studies of concurrent bird/bat 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/bat fatalities at such developments.

In addition to these questions about the unknown relationships among abundance, weather, and fatality, there also are few data available on the proportion of nocturnal migrants that (1) do not collide with turbines because of their avoidance behavior (i.e., birds that alter either their flight paths or altitude to avoid colliding with turbines) 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 accuracy of fatality estimates relies heavily upon avoidance rates (Chamberlain et al. 2006). The proportion of nocturnal migrants that detect and avoid turbines is currently unknown in the US (but see Winkleman 1995 and Desholm and Kahlert 2005 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, Desholm et al. 2006, Whitfield and Madders 2006, and Band et al. 2007 for proposed methods to address this question). We speculate, however, that most birds are able to detect and/or avoid turbines, considering the low avian fatality rates reported at existing wind power developments in the US (Erickson et al. 2002, Strickland and Johnson 2006) and the high percentage of waterbirds that avoided an offshore windfarm in Denmark (Desholm et al. 2006).

CONCLUSIONS

This study focused on nocturnal migration patterns of targets (i.e., birds and bats) during the peak period of fall passerine migration, at the proposed Hatchet Ridge Wind Project in California. The key results of our study were as follows: (1) the mean passage rate was 231 ± 31 targets/km/h and 351 ± 39 targets/km/h at North and Saddle stations, respectively, and 290 ± 26 across both stations; (2) mean nightly passage rates were variable among nights and ranged from 31–1,159 targets/km/h; (3) mean flight altitude was 474 ± 5 m agl and 463 ± 4 m agl at the North and Saddle stations, respectively, and 468 ± 3 across both stations; (4) the percentage of targets passing below 125 m agl was 7% and 9% at the North and Saddle stations, respectively, and 8% across both stations; (5) the target passage rate below 125 m agl was 17 ± 3 targets/km/h and 39 ± 7 targets/km/h at the North and Saddle stations, respectively, and 28 ± 4 across both stations; (6) the estimated turbine passage rate of nocturnal migrants passing within the airspace occupied by each proposed turbine was 1.1–10.0 nocturnal migrants/turbine/d at North, 2.4–23.0 nocturnal migrants/turbine/d at Saddle, and 1.7–16.4 nocturnal migrants/ turbine/d across both stations.

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Appendix 1. Full model set from analyses employing Akaike’s Information Criterion (AIC) to investigate the influence of environmental factors on passage rates of radar targets at the proposed Hatchet Ridge Wind Project, California, fall 2007. The full model set examining flight altitudes was the same with the exception that models with the quadratic form of date and the variable for favorable migration were excluded.

Model
Global: wind direction + wind direction*wind speed + favorable migration(d) + ceiling height + lunar illumination*cloud cover + synoptic + date + station
Wind direction
Wind direction + wind direction*wind speed
Wind direction + favorable migration (d)[a]
Wind direction + ceiling height
Wind direction + lunar illumination*cloud cover
Wind direction + date
Wind direction + station
Wind direction + wind direction*wind speed + favorable migration (d)[a]
Wind direction + wind direction*wind speed + ceiling height
Wind direction + wind direction*wind speed + lunar illumination*cloud cover
Wind direction + wind direction*wind speed + date
Wind direction + wind direction*wind speed + station
Wind direction + wind direction*wind speed + favorable migration (d) + date[a]
Wind direction + wind direction*wind speed + ceiling height + date
Wind direction + wind direction*wind speed + lunar illumination*cloud cover + date
Wind direction + wind direction*wind speed + ceiling height + lunar illumination*cloud cover[b]
Wind direction + wind direction*wind speed + ceiling height + lunar illumination*cloud cover + date[b]
Wind direction + wind direction*wind speed + favorable migration (d) + ceiling height[a]
Wind direction + wind direction*wind speed + favorable migration (d) + ceiling height + date[a]
Wind direction + wind direction*wind speed + favorable migration (d) + ceiling height + lunar illumination*cloud cover[a]
Wind direction + wind direction*wind speed + favorable migration (d) + ceiling height + lunar illumination*cloud cover + date[a]
Wind direction*wind speed
Wind direction*wind speed + favorable migration (d)[a]
Wind direction*wind speed + ceiling height
Wind direction*wind speed + lunar illumination*cloud cover
Wind direction*wind speed + date
Wind direction*wind speed + station
Favorable migration (d)[a]

Appendix 1. Continued.

Model
Favorable migration (d) + ceiling height[a]
Favorable migration (d) + lunar illumination*cloud cover[a]
Favorable migration (d) + date[a]
Favorable migration (d) + station[a]
Ceiling height
Ceiling height + lunar illumination*cloud cover
Ceiling height + date
Ceiling height + station
Ceiling height + lunar illumination*cloud cover + date
Lunar illumination*cloud cover
Lunar illumination*cloud cover + date
Lunar illumination*cloud cover + station
Synoptic
Synoptic + date
Synoptic + station
Date
Date + station
Station

[a] Indicates model not included in flight altitude analyses.
[b] Indicates model not included in passage rate analyses.

Appendix 2. Mean passage rates, altitude specific passage rates (<125 m agl), and flight altitudes of nocturnal radar targets observed at the 1.5-km range during half-month periods of fall migration and over the full sampling season at the proposed Hatchet Ridge Wind Project, California, fall 2007.

Station/metric	September		October	Total
	7–15	16–30	1–15	
North				
Passage rate (targets/km/h)	119	262	275	231
<125 m agl passage rate (targets/km/h)	15	13	23	17
Flight altitude (m agl)	522	483	425	474
Number nights sampled[a]	9	14	13	36
Saddle				
Passage rate (targets/km/h)	182	334	484	351
<125 m agl passage rate (targets/km/h)	27	27	62	39
Flight altitude (m agl)	392	502	441	463
Number nights sampled[a]	9	13	13	35
All stations				
Passage rate (targets/km/h)	150	297	380	290
<125 m agl passage rate (targets/km/h)	21	30	41	28
Flight altitude (m agl)	460	494	433	468
Number nights sampled[a]	9	14	13	36

[a] We were unable to sample 1–2 nights at each station in September and October because of rain.

Appendix 3. Nocturnal flight altitudes of radar targets (% of all targets) detected at the 1.5-km range at the proposed Hatchet Ridge Wind Project, California, fall 2007, by 25 m agl flight altitude category and station.

	Cumulative % of radar targets		
Flight altitude (m agl)	North (n = 3,747 targets)	Saddle (n = 4,371 targets)	All stations (n = 8,118 targets)
1–25	0.3	0.2	0.3
1–50	1.0	1.3	1.2
1–75	2.3	3.3	2.9
1–100	5.0	5.7	5.5
1–125	7.2	9.2	8.4
1–150	10.2	12.4	11.5
1–175	13.6	16.4	15.3
1–200	16.7	19.6	18.4
1–225	20.7	22.8	22.0
1–250	24.8	26.8	26.0
1–1,500	100.0	100.0	100.0

Appendix 4. Linear mixed models with weights (w_i) >0 explaining the influence of environmental factors on passage rates (surveillance radar, n = 225 sampling sessions) and flight altitudes (vertical radar, n = 223 sampling sessions) of radar targets at the proposed Hatchet Ridge Wind Project, California, fall 2007. Model weights (w_i) were based on Akaike's Information Criterion (AIC).

Analysis/Model	-2 Log Likelihood[a]	K[b]	AIC_c[c]	ΔAIC_c[d]	w_i[e]
Rates					
Date + station	345.935	12	371.407	0.00	0.81
Global: wind direction + wind direction*wind speed + favorable migration(d) + ceiling height + lunar illumination*cloud cover + synoptic + date + station	315.739	27	377.414	6.01	0.04
Ceiling height + station	352.132	12	377.603	6.20	0.04
Station	356.784	10	377.812	6.40	0.03
Favorable migration (d) + station	356.101	11	379.340	7.93	0.02
Lunar illumination* cloud cover + station	351.288	13	379.013	7.61	0.02
Synoptic + station	353.642	12	379.114	7.71	0.02
Ceiling height + date	352.019	13	379.744	8.34	0.01
Flight altitudes					
Synoptic	-86.005	11	-62.754	0.00	0.41
Synoptic + station	-88.170	12	-62.684	0.07	0.39
Synoptic + date	-86.799	12	-62.313	1.44	0.20

[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.

Appendix 5. Calculation of turbine passage rate indices (estimated number of targets passing within the area occupied by each proposed turbine) during nocturnal periods of fall 2007, at the proposed Hatchet Ridge Wind Project, California.

Calculation parameter	North	Saddle	All stations
WIND-TURBINE CHARACTERISTICS			
(A) Total turbine height (m)	127.5	127.5	127.5
(B) Blade radius[a] (m)	47.5	47.5	47.5
(C) Height below blade (m)	32.5	32.5	32.5
(D) Approximate front-to-back width (m)	6	6	6
(E) Minimal (side profile) area (m^2) = A × D	765	765	765
(F) Maximal (front profile) area (m^2) = (C × D) + ($\pi \times B^2$)	7,283.2	7,283.2	7,283.2
PASSAGE RATE			
(G) Mean rate below 125 m agl (targets/km/h)	17.13	39.50	28.15
(H) Area sampled below 125 m agl = 125 x 1,000 (m^2)	125,000	125,000	125,000
(I) Mean passage rate per unit area (targets/m^2/h) = G/H	0.000137	0.000316	0.000225
TURBINE PASSAGE RATE INDEX			
(J) Duration of study period (# nights)	39	39	39
(K) Mean number of hours of darkness (h/night)	10	10	10
(L) Minimum number of targets/km/h in zone of risk = E x I	0.104836	0.241740	0.172278
(M) Maximum number of targets/km/h in zone of risk = F x I	0.998095	2.301502	1.640185
(N) Minimum number of targets in zone/d = K x L	1.1	2.4	1.7
(O) Maximum number of targets in zone/d =K x M	10.0	23.0	16.4
(P) Minimum number of targets in zone of risk during 39-night study period = J x K x L	41	94	67
(Q) Maximum number of targets in zone of risk during 39-night study period = J x K x M	389	898	640

Appendix 6. Results of fall migration studies conducted at proposed (pre-construction) US wind power development areas, using X-band mobile radar systems.

Project	Study period	Nights	Passage rate ± SE (targets/km/h)	Methods[a]	Flight altitude ± SE (m agl)	% Targets ≤125 m agl	Methods[a]	Source
EASTERN U.S								
Bliss, NY	9/09 – 10/31/05	8	444	3	411	13	3	Yonker & Landon 2005
Chautauqua, NY	9/02 – 9/25/03, 10/05 – 10/10/03	29	238 ± 48	2	532 ± 3	4	2	Cooper et al. 2004
Clinton County, NY	8/15 – 10/13/05	57	197 ± 31	1	333 ± 1	12	1	Mabee et al. 2006c
Copenhagen, NY	9/02 – 10/09/94	29	371 ± 85	2	na	na	3	Cooper et al. 1995a
Dairy Hills, NY	8/15 – 10/15/05	57	64 ± 3	2	466 ± 2	10	2	Young et al. 2006
Harrisburg, NY	9/02 – 10/01/98	13	135 ± 42	2	na	na	3	Cooper & Mabee 2000
Howard, NY	9/01 – 10/15/98	39	481 ± 52	2	491 ± 14	2% < 91m	2	Woodlot 2005
Maple Ridge, NY	8/05 – 10/03/06	57	158 ± 21	1	415 ± 2	8	1	Mabee et al. 2005c
Martinsburg, NY	9/02 – 10/09/94	6	661 ± 353	2	na	na	3	Cooper et al. 1995a
Prattsburgh, NY	8/26 – 11/03/04	30	193 ± 21	2	516 ± 17	3	2	Roy et al. 2005
Prattsburgh–Italy, NY	8/15 – 9/30/04	41	200 ± 12	1	365 ± 3	9	1	Mabee et al. 2005b
Wethersfield, NY	9/02 – 10/01/98	19	175 ± 42	2	na	na	3	Cooper & Mabee 2000
Bedford County, PA	8/16 – 10/14/06	29	438 ± 67	1	379 ± 3	10	1	Plissner et al. 2007
Casselman, PA	8/15 – 10/15/04	30	174 ± 31	1	436 ± 3	7	1	Plissner et al. 2005
Fayette County, PA	8/15 – 10/13/05	26	297 ± 61	1	426 ± 3	5	1	Plissner et al. 2006b
Somerset County, PA	8/16 – 10/14/06	29	316 ± 60	1	374 ± 3	8	1	Plissner et al. 2007
Swallow Farm, PA	8/16 – 10/14/05	58	166 ± 17	1	402 ± 2	5	1	Plissner et al. 2006c
Mt. Storm, WV[b]	9/03 – 10/17/03	40	241 ± 33	1	410 ± 2	13	1	Mabee et al. 2004
Preston County, WV	8/15 – 10/13/05	26	379 ± 91	1	420 ± 4	10	1	Plissner et al. 2006b
Highland New Wind, VA	8/16 – 10/14/05	58	385 ± 55	1	442 ± 3	12	1	Plissner et al. 2006a
WESTERN U.S.								
Bear River Ridge, CA	8/16 – 10/14/06	60	269 ± 11	1	329 ± 2	11	1	Sanzenbacher et al. 2007
Hatchet Ridge, CA	**9/07 – 10/15/07**	**39**	**290 ± 26**	**1**	**468 ± 3**	**8**	**1**	**Current study**
Cotterel, ID	8/31 – 10/14/03	30	32 ± 9	1	565 ± 6	3	1	Cooper et al. 2004
Vansycle, OR	8/24 – 10/17/00	29	19 ± 2	2	na	na	3	Mabee & Cooper 2004
Vansycle, OR	9/04 – 10/17/01	23	26 ± 3	2	606 ± 8	9	2	Mabee & Cooper 2004
Nine Canyon, WA	9/4 – 10/9/00	9	273 ± 122	3	472 ± 7	na	3	Mabee & Cooper 2000
Stateline, WA	8/24 – 10/17/00	29	21 ± 2	2	na	na	3	Mabee & Cooper 2004
Stateline, WA	9/4 – 10/17/01	23	22 ± 3	2	647 ± 7	3	2	Mabee & Cooper 2004

[a] 1 = equipment and methods similar to current study (comparable), 2 = differences in radar settings, method of data collection, or data analysis (unknown comparability), 3 = major differences in equipment or methods (not comparable). Overall comparability of studies must also consider study period and duration.