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NOCTURNAL BIRD MIGRATION IN NORTHEASTERN OREGON AND SOUTHEASTERN WASHINGTON

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ABSTRACT—We used marine radar to study nocturnal bird migration at the Vansycle Ridge and Stateline wind-energy projects in northeastern Oregon and southeastern Washington during fall 2000, spring 2001, and fall 2001. Our study was designed to monitor waterfowl, shorebird, and passerine movements during spring migration and passerine movements during fall migration. Flight directions (mean ± 1 angular deviation) of surveillance radar targets were in seasonally appropriate directions at Stateline and Vansycle Ridge during fall 2000 (169 ± 33°, 165 ± 39°), spring 2001 (10 ± 35°, 7 ± 32°) and fall 2001(160 ± 53°, 166 ± 53°), respectively. Passage rates (mean targets/km/h ± 1 $s_{\bar{x}}$) of targets were similar between Stateline and Vansycle Ridge and were higher during spring 2001 (45.1 ± 6.6, 48.3 ± 6.2) than during fall 2000 (20.8 ± 2.3, 19.0 ± 2.0) and fall 2001 (21.6 ± 2.5, 26.3 ± 2.5), respectively. Flight altitudes (mean altitudes ± 1 $s_{\bar{x}}$; collected from 0 to 1500 m above ground level) were similar between Stateline and Vansycle Ridge during spring 2001 (506 ± 4.7, 579 ± 4.8) and fall 2001 (647 ± 7.0, 606 ± 7.5), respectively, but fall altitudes were significantly higher than spring altitudes at both sites. A minimum of 85% (spring 2001) to 94% (fall 2001) of targets were observed at altitudes above proposed turbine heights at both sites. Understanding the basic components of nocturnal bird migration in specific locations can help site future development projects in a manner that will help conserve nocturnal migrants.

Key words: nocturnal bird migration, flight altitudes, passage rates, radar, wind turbines, Oregon, Washington

Records of avian collisions with tall structures date back to at least 1880, and collisions of birds with towers in North America have been documented since 1948 (Kerlinger 2000; Manville 2000). Neotropical migratory birds such as thrushes (Turdidae), vireos (Vireonidae), and warblers (Parulidae) seem to be the most vulnerable to collisions with communication towers during nocturnal migration (Manville 2000). Nocturnal migrants also have been recorded colliding with wind turbines (Osborn and others 2000). An understanding of the dynamics of nocturnal bird migration in specific locations is necessary to assess the potential for bird collisions with tall, human-made structures. Consideration of nocturnal migration is particularly important because considerably more birds migrate at night than during the daytime (Gauthreaux 1975). Of the nocturnal migrants, passerines, in particular, may be more at risk of collisions with structures because they tend to migrate at lower altitudes than other bird groups (for example, waterfowl, shorebirds; Kerlinger 1995).

The Pacific Northwest contains several mountain ranges, major river systems, wetlands, shrub-steppe habitats, and coastal habitats that all influence the migration characteristics of birds. Although Oregon and Washington contain several known migration corridors for diurnally migrating birds (Bellrose 1976), no comparable data are available for nocturnal migration. Given the prevalence of nocturnal migration and the avid interest in bird migration in general, it is surprising that baseline data on nocturnal bird migration are lacking or absent for most regions of the United States.

This lack of information on nocturnal bird migration caused concern about the likelihood of collisions between nocturnal migrants and wind turbines at a site being considered for wind-energy development on the Oregon–Washington border (Stateline Project). Wind-energy facilities are a rapidly developing source of new structures in the Pacific North-

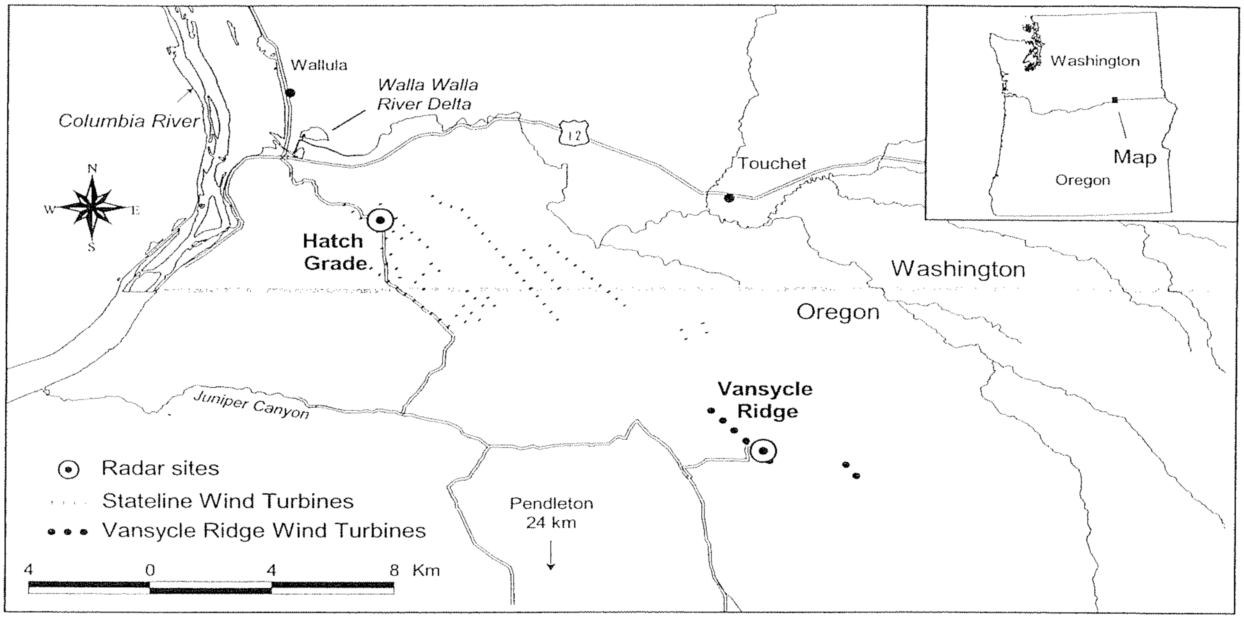

FIGURE 1. Map of the Stateline and Vansycle Ridge wind-energy facilities in Washington and Oregon and locations of the Stateline and Vansycle Ridge radar sampling sites.

west (AWEA 2004). Evaluating the potential for avian collisions with these structures is important because the appropriate siting of wind-energy facilities is 1 of the most important ways to minimize collisions with birds (Nelson and Curry 1995). Although some studies of birds at wind-energy facilities have documented fatalities of raptors during the day (Orloff and Flannery 1992), studies at Vansycle Ridge, Oregon, and in Minnesota and Wyoming have documented only small numbers of passerine fatalities, with about 30 to 50% of the total fatalities being probable nocturnal migrants (Erickson and others 2001).

We addressed these concerns with a study that quantified the main aspects of nocturnal bird migration in the Stateline project. Our objectives were to use radar to collect and compare baseline information on flight directions, migration intensity (passage rates), and flight altitudes of nocturnal bird migrants at the Stateline and Vansycle Ridge wind-energy facilities in southeastern Washington and northeastern Oregon during fall 2000, spring 2001, and fall 2001.

METHODS

Study Area

The Stateline and Vansycle Ridge wind-energy projects are located in southeastern Washington (Walla Walla County) and northeastern Oregon (Umatilla County), respectively (Fig. 1). Both projects are located on a series of rolling hills and ridges (about 500 to 600 m high) that extend in a northwest–southeast direction between the Cascade Mountains in Washington and the Blue Mountains in Oregon. The native shrub-steppe habitat in these locations largely has been converted to cultivated wheat fields that are interspersed with grasslands.

Although the Stateline project was proposed when we began our studies in 2000, construction of the project began during late spring 2001, was ongoing during fall 2001, and was completed by December 2001. The completed Stateline project consists of 399 Vestas V47 660-kW wind turbines about 75 m in height (rotor radius of 24 m) that produce about 263 MW of energy. Our radar-sampling site (called "Hatch Grade") was located at the northern end of the facilities (46°02′N, 118°51′W) at an elevation of about 511 m (Fig. 1). The Vansycle Ridge project consists of 38 Vestas 660-kW wind turbines about 75 m in height that produce about 25 MW of energy. The radar-sampling site was located in the center of those facilities (45°56′N, 118°39′W) at an elevation of about 610 m.

General Sampling Strategy

We conducted radar observations at night during late shorebird migration and the peak of passerine migration (Hudson 2000) during fall and throughout the migratory period for waterfowl, shorebirds, and passerines during spring. We sampled for 29 nights between 24 August and 17 October 2000, for 45 nights between 15 March and 15 May 2001, and for 30 nights between 4 September and 17 October 2001. We sampled at both sites concurrently with 2 mobile radar labs. Sampling intensity (about 5.5 to 6.5 h/night) during the period 1830 to 0300 provided coverage of the peak period of nocturnal migration within a night (Lowery 1951; Gauthreaux 1971; Kerlinger 1995).

Radar Equipment

We used a mobile radar laboratory with a marine radar mounted on a pickup-truck camper. We operated the surveillance radars (Furuno Model FCR–1411 and Furuno Model FR–1510 Mark 3) in the horizontal orientation (surveillance mode) to scan the surrounding area and we manually recorded information on flight directions, passage rates, and ground speeds of targets into a computer. Because data on winds aloft were not available for eastern Oregon and Washington, we could not correct our ground speed data to calculate air speeds. The newer FR–1510 eventually replaced the older FCR–1411 during our study. In the vertical orientation (vertical mode) described by Harmata and others (1999), the FR–1510 radar measured flight altitudes of birds. We used the index line on our monitor to measure the flight altitude of targets and recorded this manually into the computer. These radar units were standard marine radars transmitting at 9410 MHz (X-band) with a peak power output of 10–12 kW. Our 2-m-antenna radiator was a slotted waveguide array with a beamwidth of 1.23° (horizontal) × 20° (vertical) and a sidelobe of ±10°. In the surveillance mode, we operated both radars at a range of about 1.5 km and a pulse length of about 0.07 μsec. In the vertical mode, we operated the FR–1510 at ranges of 1.5 and 3.0 km and pulse lengths of 0.15 and 0.50 μsec, respectively. When using these radars, flocks of waterfowl were detectable up to 5 to 6 km away, and small passerines were detectable up to 1–2 km away (Cooper and others 1991). Maximum distances of detection of birds by the radar depends on body size, flock size, flight profile, atmospheric conditions, the pulse length setting of the radar, and the amount and location of ground clutter.

Data Collection

During each 60-min sampling period, we operated in the surveillance mode at the about 1.5-km range for 15 to 20 min and in the vertical mode for 10 to 15 min at the 1.5-km range and 5 to 10 min at the 3.0-km range. Two short breaks were spent collecting weather information and switching the radar between vertical and horizontal orientations. In the surveillance mode, we recorded numbers and flight directions (to the nearest 5° relative to true north) of radar targets. A target was at least 1 bird, although multiple birds flying close together may be displayed as 1 echo on the monitor. In the vertical mode, we recorded a representative (unbiased) sample of flight altitudes at the 1.5 and 3.0 km range-settings. We collected flight-altitude data (m above ground level [agl]) only during spring and fall 2001.

Differentiating the various target types encountered (for example, birds, bats, insects) is central to any radar study, especially with X-band radars that can detect small flying animals. Because usually it was not possible to separate bird targets from bat targets, some bat targets may be included in our data. However, of primary importance is removing insect targets from the data. Our spring sampling season had a nominal number of nights with obvious insect contamination, but during the fall seasons the issue was more prevalent because of nocturnally migrating moths. We used a combination of techniques to reduce insect contamination in the data when possible, and omitted sessions (or whole nights) when insects severely contaminated our sample. We reduced insect contamination by 1) shifting sampling times to later evening hours when insect activity decreased, 2) omitting targets with poor reflectivity (for example, targets that plotted erratically or inconsistently in locations with good radar coverage), 3) omitting targets with limited range (targets only observed within about 500 to 800 m of the radar), and 4) omitting targets with ground speeds ≤9 m/s (about 20 mph). Although not possible in this study, future studies should attempt to acquire data on winds aloft so that ground speeds of targets can be corrected to calculate air speeds and remove insect contamination from the data (Lar-

TABLE 1. Mean nocturnal flight directions (± angular deviation) of radar targets at Hatch Grade, Washington, and Vansycle Ridge, Oregon, during fall 2000, spring 2001, and fall 2001. Sample size (*n*) = number of radar targets.

Season and location	Mean direction (°)	Angular deviation (°)	*n*
Fall 2000			
Hatch Grade	169	33	1278
Vansycle Ridge	165	39	1043
Spring 2001			
Hatch Grade	10	35	2522
Vansycle Ridge	7	32	2449
Fall 2001			
Hatch Grade	160	53	1131
Vansycle Ridge	166	53	1024

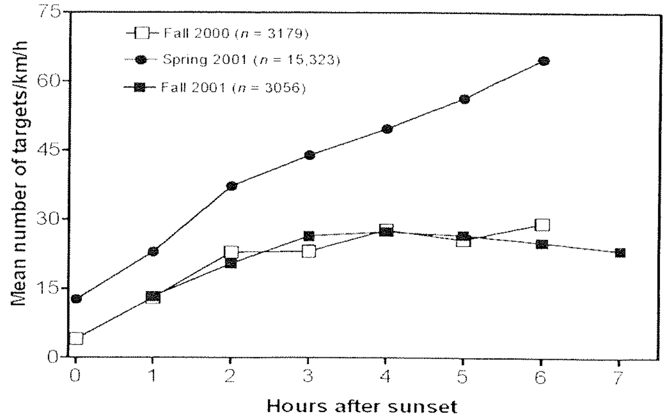

FIGURE 2. Migration passage rates (mean number of targets/km/h) on surveillance radar by hour after sunset at both the Hatch Grade, Washington, and Vansycle Ridge, Oregon, sites combined, during fall 2000, spring 2001, and fall 2001.

kin 1991). Despite these limitations, we were able to collect enough data during all seasons to characterize the migration characteristics of interest in this study.

Data Analyses

We used non-parametric statistics in our analyses when the data did not conform to parametric assumptions. We analyzed flight-direction data following procedures for circular data (Zar 1999). Migration passage rates are reported as the mean number of targets passing along 1 km of migratory front per hour (targets/km/h ± 1 $s_{\bar{x}}$). Because winds aloft data were not available at our study site and because our sites were relatively close together (about 20 km) and on the same ridge, we assumed winds aloft did not confound our comparison of migration rates. We used Wilcoxon signed-ranks tests to compare mean nightly migration passage rates of paired sites (sites sampled on the same night) and Kruskal-Wallis tests followed by multiple comparisons tests (Conover 1980) to compare mean passage rates among seasons at each site. We used Wilcoxon signed-rank tests for paired sites (fall 2001) and Mann-Whitney *U*-tests for unpaired sites (only 1 radar collected flight altitude data during spring 2001) to compare mean daily flight altitudes (SPSS, Inc. 1999). All comparisons of flight altitude data were made with the 1.5-km-scale data because this scale provided adequate target resolution within 0–1,500 m agl, whereas the 3.0-km range did not provide adequate target resolution at low altitudes. Confounding factors that decreased our sample size included insects and rain. Therefore, our sample sizes for statistical tests vary with the site and comparison because of these factors. The level of significance (α) for all tests was set at 0.05.

RESULTS

Flight Direction and Migration Passage Rates

At night, most targets were generally flying in seasonally appropriate directions during both fall (southeastern) and spring (northward) migration. Within each season, mean directions at the 2 sites also were highly similar (Table 1). Within a night, migration rates increased noticeably about 1 h after sunset (Fig. 2). They leveled off about 3 h after sunset in fall but continued to increase throughout the night in spring. Nightly passage rates were low to moderate at both sites during the fall (Fig. 3). Nightly passage rates were significantly higher at Vansycle Ridge than at Hatch Grade during fall 2001 but not 2000 (Table 2). Nightly passage rates were higher overall and more variable during spring than during fall but were not significantly different between sites (Fig. 4). Passage rates also varied among seasons at Hatch Grade and Vansycle Ridge, respectively (Kruskal-Wallis $\chi^2 = 5.5$, df = 2, $P = 0.06$; $\chi^2 = 14.3$, df = 2, $P = 0.001$). Multiple comparisons indicated that mean passage rates within each site were higher in spring 2001 than fall 2000 at both sites but were higher in fall 2001 than fall 2000 only at Vansycle Ridge.

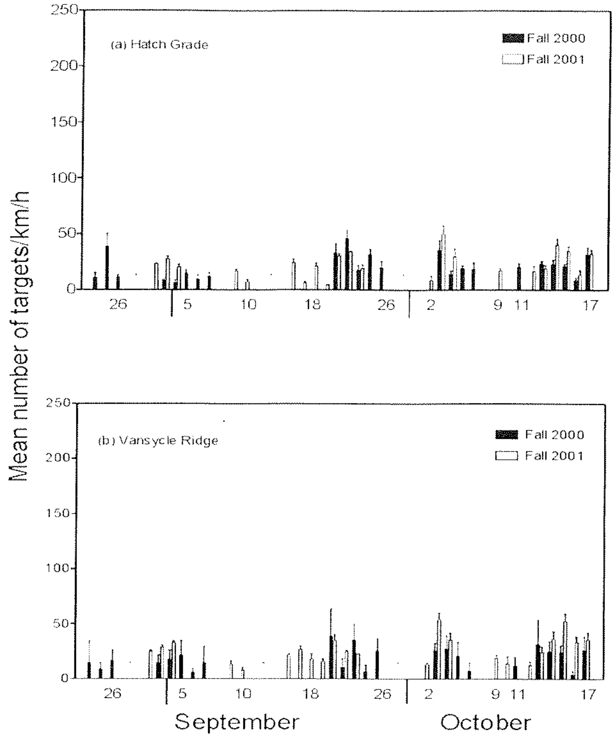

FIGURE 3. Migration passage rates (mean number of targets/km/h ± 1 $s_{\bar{x}}$) on surveillance radar at (a) Hatch Grade, Washington, and (b) Vansycle Ridge, Oregon, during fall 2000 and fall 2001. Asterisks denote periods not sampled.

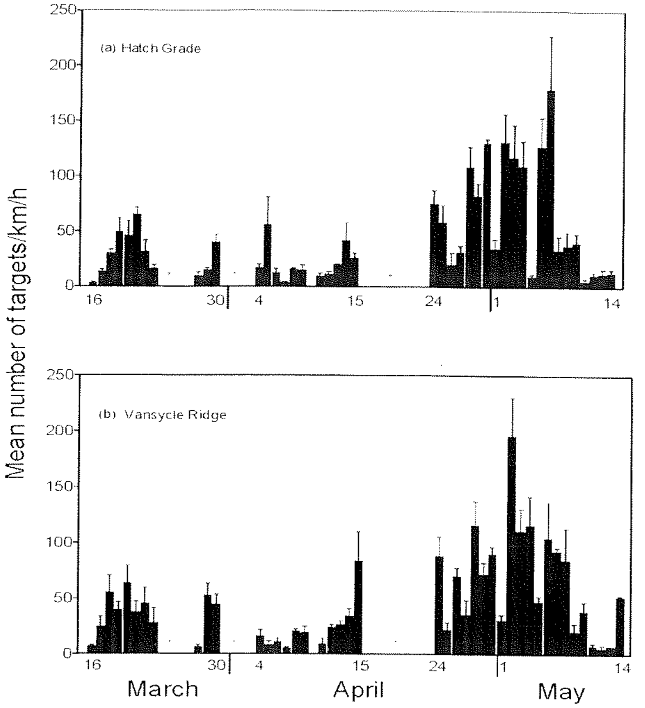

FIGURE 4. Migration passage rates (mean number of targets/km/h ± 1 $s_{\bar{x}}$) on surveillance radar at (a) Hatch Grade, Washington, and (b) Vansycle Ridge, Oregon, during spring 2001. Asterisks denote periods not sampled.

Flight Altitude

Mean nocturnal flight altitudes (≤1.5 km agl) were variable among nights during spring and fall 2001 (Fig. 5). Overall, the distributions of the vertical flight altitudes appeared similar at both sites during spring and fall 2001, with about 2 to 15% of all targets flying below the approximate turbine height (about 100 m agl; Table 3). At both sites, higher percentages of targets flew below turbine height in spring 2001 than in fall 2001. The proportion of targets within a season was approximately even over the 100-m altitude categories from 100 m to 1000 m, at which point it began decreasing.

TABLE 2. Mean migration passage rates (targets/km/h ± 1 $s_{\bar{x}}$) of targets observed on surveillance radar (1.5-km range) at Hatch Grade, Washington, and Vansycle Ridge, Oregon, during fall 2000, spring 2001, and fall 2001. Sample size (n) = number of concurrent sampling nights.

Season and location	Passage rate			Wilcoxon signed-ranks test		
	Mean	$s_{\bar{x}}$	n	Z	n	P
Fall 2000						
Hatch Grade	20.8	2.3	23			
Vansycle Ridge	19.0	2.0	23	−0.08	23	0.94
Spring 2001						
Hatch Grade	45.1	6.6	43			
Vansycle Ridge	48.3	6.2	43	−1.2	43	0.23
Fall 2001						
Hatch Grade	21.6	2.5	23			
Vansycle Ridge	26.3	2.5	23	−2.18	23	0.03

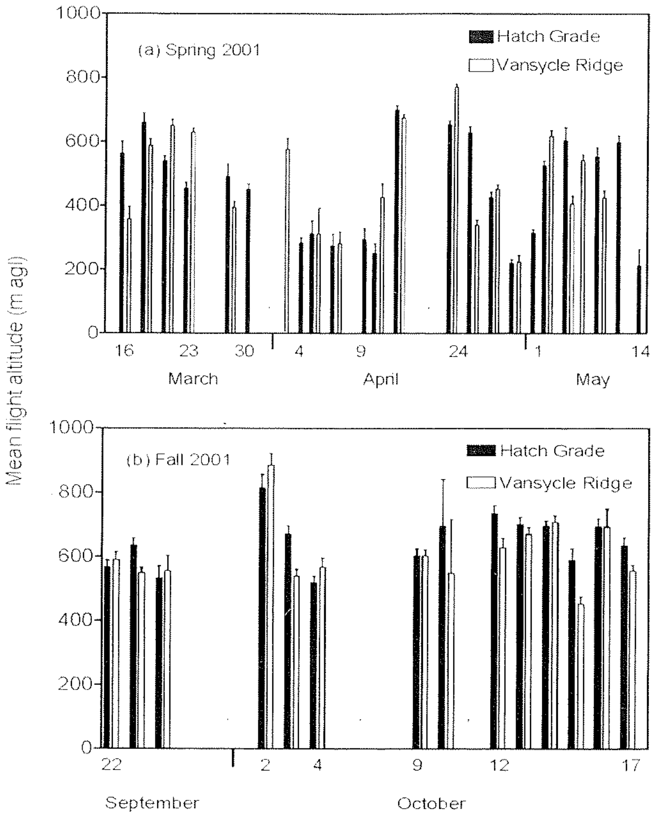

FIGURE 5. Mean flight altitudes (m agl ± 1 $s_{\bar{x}}$) of migrating birds at Hatch Grade, Washington, and Vansycle Ridge, Oregon, during (a) spring 2001 and (b) fall 2001. Asterisks denote periods not sampled; agl = above ground level.

Mean nocturnal flight altitudes were similar between sites during spring and fall 2001 (Table 4). Among seasons, mean flight altitudes were higher at both Hatch Grade and Vansycle during fall 2001 than spring 2001 (Table 4).

Results from our 3.0-km-range sampling indicate that 80% of the nights during spring 2001 (*n* = 35) and 100% of the nights during fall 2001 (*n* = 14) contained some targets flying 1500 to 3000 m agl. Overall, about 17% of all targets occurred above 1500 m during spring 2001. Unfortunately, we were unable to calculate this percentage from our fall 2001 data because of our methods during this season. Regardless, our 3.0-km sampling indicates that, because of additional targets above 1500 m, our mean flight altitudes calculated with the 1.5 km-range data clearly are minima and the percentage of those targets by altitude category are maxima.

DISCUSSION

Birds exhibit varied migration strategies, both in terms of how they migrate (for example soaring migrants vs. powered migrants) and when they migrate (diurnal vs. nocturnal migrants). Soaring migrants include many raptors, storks, pelicans, and cranes that depend on thermals for lift and, therefore, are limited to diurnal migration. Powered migrants include birds that migrate during the day (blackbirds, finches, crows, blue jays, and swallows), at night (warblers, tanagers, vireos, orioles, kinglets, thrushes, gnatcatchers, many sparrows, cuckoos, catbirds, thrashers, owls, herons, and egrets; Kerlinger 1995), or during either the day or night (loons, waterfowl, gulls, terns, and shorebirds; Bellrose 1976; Gauthreaux 1978; Kessel 1984; Alerstam 1990). Overall, considerably more birds migrate at night

TABLE 3. Nocturnal flight altitudes (m agl) of radar targets (% of targets) detected at the 1.5-km range at Hatch Grade, Washington, and Vansycle Ridge, Oregon, during spring and fall 2001. Sample size (*n*) = number of radar targets; agl = above ground level.

Flight altitude (m agl)	Spring 2001		Fall 2001	
	Hatch Grade (*n* = 6295)	Vansycle Ridge (*n* = 6521)	Hatch Grade (*n* = 2167)	Vansycle Ridge (*n* = 2546)
0–100	14.7	12.3	1.6	6.1
101–200	13.6	9.9	8.1	9.5
201–300	9.6	8.7	8.5	8.5
301–400	8.1	7.9	7.8	7.9
401–500	8.7	8.3	8.9	10.1
501–600	7.9	7.7	11.0	9.7
601–700	7.1	7.3	12.0	9.3
701–800	6.7	6.9	11.3	8.3
801–900	5.9	6.5	8.4	8.4
901–1,000	5.7	6.7	7.5	7.5
1,001–1,500[1]	12.0	17.9	15.1	14.6

[1] Interval of 500 m.

TABLE 4. Mean nocturnal flight altitudes (m agl ± 1 $s_{\bar{x}}$) of targets from vertical radar (1.5-km range) at Hatch Grade, Washington, and Vansycle Ridge, Oregon, during spring and fall 2001. Mean altitudes were calculated from total number of targets (n_{total}), whereas tests were based on number of sampling nights (n_{nights}). Test statistics are Mann-Whitney (U) and Wilcoxon signed-rank (Z) values. Agl = above ground level.

Comparison and season	Location	Flight altitude				Test results		
		Mean	$s_{\bar{x}}$	n_{total}	U	Z	n_{nights}	P
Intra-seasonal[1]								
Spring 2001	Hatch Grade	505.6	4.7	6296				
	Vansycle Ridge	578.5	4.8	6521	181.0		40	0.64
Fall 2001	Hatch Grade	647.4	7.0	2172				
	Vansycle Ridge	605.6	7.5	2553		−1.60	14	0.11
Inter-seasonal								
Spring 2001	Hatch Grade	454.8	33.9					
Fall 2001	Hatch Grade	649.4	21.9		45.0		36	<0.01
Spring 2001	Vansycle Ridge	481.1	36.3					
Fall 2001	Vansycle Ridge	610.8	27.9		69.0		32	0.03

[1] One FR-1510 vertical radar was alternated between sites during spring 2001, whereas 2 radars sampled concurrently during fall 2001.

than during the day (Gauthreaux 1975; Kerlinger 1995).

Timing of nocturnal migration is important at 2 temporal scales—nightly and seasonal. Understanding the timing of migration within a night is important as this information could forewarn people about when nocturnal migration will peak and could be used to develop mitigating measures (for example, reduced operation of wind facilities during peak times of migration within a night). In our study, migratory passages increased noticeably about 1 h after sunset (both spring and fall) and continued to increase throughout the duration of the sampling period (spring), or leveled off several hours after sunset (fall). Several studies have found a pattern similar to our fall pattern, in which the intensity of nocturnal migration begins to increase about 30 to 60 min after sunset, peaks around midnight, and declines steadily thereafter until dawn (Lowery 1951; Gauthreaux 1971; Kerlinger 1995). That the passage rates continued to increase throughout the night during spring indicates that sampling beyond about 0300 is warranted to fully document the peak rates of movement during this season in our location. The observed seasonal differences in the temporal movement patterns may be related to factors such as seasonal differences in the distance between suitable staging habitats (to the north or south) and the study area itself. Continued sampling beyond nocturnal hours (during the predawn and postdawn hours) may also be warranted at some locations to investigate if low altitude ''morning flight'' of passerines occurs in a project area (Wiedner and others 1992).

Seasonal patterns of nocturnal migration are critical to identify when collisions with wind turbines may be most expected. Nocturnal migration is often a pulsed phenomenon, and seasonal peaks of passage have been observed (Alerstam 1990; BA Cooper and RH Day, ABR Inc., unpubl. data). In this study, we observed very few large daily pulses of migration during the fall seasons, but we did observe higher daily passage rates during late April to mid May in the spring season.

Passage rates are an index of the number of migrants flying past a location and can be used to assess the relative importance of sites being considered for wind turbine development. Putting our results from this study in context is difficult, as there are few published data on nocturnal passage rates available for other locations in the Pacific Northwest. On a broad scale, however, both locations within our study area appeared to have experienced low to moderate rates of migration as the mean passage rates of nocturnal migrants at both sites generally fell within the low to moderate range of values from Alaska, South Dakota, Minnesota, and New York, where we have conducted similar nocturnal migration radar studies (BA Cooper and RH Day, ABR Inc., unpubl. data). A brief investigation of nocturnal migration through ''moonwatching'' during fall documented passage rates in the western United States that were markedly less than those in the eastern United States, but the limited sampling effort in the western United States precluded a definitive generalization (Lowery and Newman 1966).

Flight altitudes are critical for understanding the vertical distribution of nocturnal migrants and are another important metric used to assess the suitability of a site for wind turbine development. In general, passerines migrate at the lowest flight altitudes, whereas shorebirds and waterfowl tend to migrate at higher altitudes (Kerlinger 1995). Because we know that birds were often flying above 1.5 km in this study (based on our 3.0-km-range sampling), our mean flight altitudes based on 1.5-km-range data are minima, and the percentage of targets within 100 m agl (and all other categories) are maxima. Even so, other radar studies of nocturnal passerine migration reported flight altitudes comparable to the means at our sites, with most migrants occurring below about 500 m agl (Bellrose 1971; Gauthreaux 1972, 1991; Cooper and Ritchie 1995), below 600 m (Kerlinger 1995), at about 610 m (Hilgerloh 1989), or below 900 m (Kerlinger and Moore 1989). Because mean flight altitudes were well above the proposed turbine heights on all nights in this study (about 500 to 650 m agl), and a maximum of 2 to 15% of all targets were within the proposed turbine heights, it is likely the collision risk generally is low in our study area. Studies investigating the behavior of nocturnal migrants are needed to quantify the risk of birds that fly at altitudes similar to turbine heights. This phenomenon has not been studied in the United States, but in Europe, some studies have shown that birds alter their flight paths to avoid colliding with wind turbines (Winkelman 1995).

Lastly, the identity of the species migrating through the area is needed to determine which species actually are at risk (especially threatened or endangered species). Although radar generally is unable to provide species-specific information, auditory monitoring of nocturnal flight calls can identify many species of birds (Evans 1994). Nearly 200 species of North American birds are known to produce flight calls during nocturnal migration (Fristrup 1999), with 35 species of migrant landbirds identifiable to species and an additional 31 species identifiable to species-complexes (Evans and Rosenberg 1999). Although not conducted during this study, concurrent auditory monitoring could provide valuable information for future development projects.

Conservation of nocturnally migrating birds requires both understanding the key characteristics of nocturnal migration and using this information to reduce potential collisions with above-ground structures. The information on nocturnal bird migration characteristics from the 1st year of our study allowed a utility company to make decisions on the placement of wind-turbine strings in the developing Stateline wind-energy facility. Careful placement of proposed structures is an effective way to minimize bird collisions with wind turbines (Nelson and Curry 1995) and could have important conservation implications. Given the current decline of many species of nocturnal Neotropical migrants and the increase in the number of above-ground structures being built, we hope that future development projects (for example, wind turbines, communications towers, power lines) also will consider nocturnal migration of birds when siting their facilities to help make sound conservation and management decisions.

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