FINAL REPORT

AN ACOUSTIC STUDY OF BAT ACTIVITY AT THE PROPOSED COYOTE CREST WIND POWER PROJECT, WASHINGTON, SPRING–FALL 2008

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FOREST GROVE, OREGON

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EXECUTIVE SUMMARY

- The primary goal of the study was to collect acoustic information on activity levels of bats during nocturnal hours, particularly during spring and fall migration. Specifically, our objectives were to: (1) collect baseline information on levels of bat activity (e.g.,bat passes/detector-night) for migratory tree-roosting bats (e.g., hoary and big brown/silver-haired bats) and other bat species, and (2) examine spatial (height and location) and temporal (nightly and seasonal) variations in bat activity.
- We conducted bat acoustic monitoring for 217 nights between 15 April and 17 November 2008 at the proposed Coyote Crest Wind Power Project in Lewis and Pacific Counties, Washington. Each night we conducted bat acoustic monitoring for 10.5–16 hours/night (1h < sunset to 1h > sunrise).
- We recorded bat activity from Anabat detectors positioned at 2 altitudes (~1.5 m and ~50 m agl) at 2 meteorological towers in spring and 3 meteorological towers in fall for a total of 1,148 potential detector nights (# detectors * # nights) in spring (15 April–30 June; *n* = 308 detector-nights) and fall (1 July–17 November; *n* = 840 detector-nights). We obtained useable data for the majority 92% (*n* = 1,052) of detector-nights throughout the study (spring = 79%, *n* = 242 detector-nights; fall = 96%, *n* = 810 detector-nights).
- Total bat passes from all detectors across the entire study was 1,414 (spring = 20; fall = 1,394).
- Peak activity (mean passes/tower) for all bats occurred in September. Mean activity for migratory tree-roosting bats varied during fall with higher levels of activity occurring from mid-August through September.
- Activity (mean passes/detector-night ± SE) for all bats was 1.3 ± 0.1 across the entire study, and was lower in spring (0.08 ± 0.02) than in fall (1.7 ± 0.2).
- Activity (mean passes/detector-night ± SE) for migratory tree-roosting bats was 0.9 ± 0.09 across the entire study, and was lower in spring (0.03 ± 0.01) than in fall (1.1 ± 0.1).
- Peak activity (mean passes/tower/hour) for all species at both heights generally occurred 1–2 hours past sunset. Activity remained relatively high between 1 and 7 hours past sunset at 1.5 m, but at 50 m activity remained relatively constant throughout the night.
- Activity (mean passes/detector-night ± SE) for all bats across the entire study was higher at 1.5 m (2.7 ± 0.3) than at 50 m (0.7 ± 0.1). Most phonic groups were detected more frequently at 1.5 m; however, activity of hoary bats was slightly higher at 50 m.
- Climate characteristics and landscape variability (i.e., topography and vegetation) among towers likely resulted in differences in mean activity (mean passes/detector-night ± SE) rates, with the highest activity in fall at Coyote Crest North 3 for both 1.5 m (Coyote Crest North 1 = 1.6 ± 0.2, Coyote Crest North 2 = 0.6 ± 0.2, Coyote Crest North 3 = 6.1 ± 0.9) and 50 m (Coyote Crest North 1 = 0.7 ± 0.1, Coyote Crest North 2 = 0.2 ± 0.04, Coyote Crest North 3 = 1.3 ± 0.4) detectors.

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ACKNOWLEDGMENTS

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INTRODUCTION

As energy demands increase worldwide, many countries are seeking ways to reduce fossil fuel consumption and generate alternative energy sources. Wind has been produced commercially in North America for nearly 4 decades and is one of the fastest growing forms of renewable energy (Arnett et al. 2007a). In recent years, the United States has led the world in wind capacity additions, including ~8,500 MW of new wind power capacity in 2008 (AWEA 2009). Currently, Washington ranks 5th in overall cumulative capacity at 1,447 MW and is one of only 7 states with >1,000 MW of installed wind power (AWEA 2009). Although wind-generated energy reduces carbon and other greenhouse gas emissions associated with global warming, it is not entirely environmentally neutral because wildlife and habitats can be directly and/or indirectly impacted by wind development (Arnett et al. 2007a).

Bat fatalities at wind-energy facilities have been documented since the early 1970s (Hall and Richards 1972). Previous studies have documented high fatality rates along forested ridges in the eastern United States (e.g., Mountaineer, WV, Kerns et al. 2005; Buffalo Mountain, TN, Fiedler 2004, Fiedler et al. 2007). However, recent data from the Midwest and Canada suggests high fatality events occur across a variety of landscapes across North America, including agricultural, grassland prairies, and deciduous or coniferous forests (Jain 2005, Barclay et al. 2007, Kunz et al. 2007a, Arnett et al. 2008). Most bat fatalities documented at wind farms involve migratory tree-roosting species [i.e., hoary (*Lasiurus cinereus*), Eastern red (*Lasiurus borealis*), big brown (*Eptesicus fuscus*), and silver-haired (*Lasionycteris noctivagans*)] bats during seasonal periods of migration in late summer and fall. Although several hypotheses (i.e., roost, landscape, acoustic or visual attraction) explaining possible bat/turbine interactions exist) none have been confirmed (Arnett 2005, Barclay et al. 2007, Cryan and Brown 2007, Kunz et al. 2007a). However, recent evidence suggests that bat/turbine interactions likely are non-random events. Using thermal infrared imaging, Horn et al. (2008) documented bats investigating turbine structures and foraging in and around the rotor swept area. Resolution of these different hypotheses requires additional data on population estimates, migratory pathways, and flight behaviors around wind turbines of North American bats.

Eleven species of bats are known to occur in the Washington Coast Range. Of these, 2 species (Keen's myotis, *Myotis keenii*; and Townsend big-eared bat, *Corynorhinus townsendii*) are listed as state candidate species and three species (western long-eared myotis, *M. evotis*; fringed myotis, *M. thysanodes*; and long-legged myotis, *M. volans*) also are listed on the State Monitor Species List by Washington Department of Fish and Wildlife (WDFW 2009). The remaining 6 species (California myotis, *M. californicus*; little brown myotis, *M. lucifugus*; Yuma myotis, *M. yumanensis*; big brown bat; silver-haired bat; and hoary bat) are not granted special conservation status in Washington. However, 2 species (silver-haired bat and hoary bat) are of increasing concern, particularly with respect to wind development, because high proportions of fatalities have been reported for these migratory tree-roosting bats at wind-energy facilities in the U.S. (Arnett et al. 2008). Because wind energy development may negatively impact resident and migrating bat species (Kunz et al. 2007b, Arnett et al. 2008), it is important to study the nightly and seasonal variations in bat activity.

OBJECTIVES

Everpower Wind Holdings, LLC. proposes to develop the Coyote Crest Wind Power Project (CCWPP), an ~55-turbine facility capable of generating ~110 MW of wind energy. The height of each 2.0 MW turbine tower will be 80 m with a rotor diameter of 92.5 m for a total maximum turbine height of 126.25 m (with the blade in the vertical position). In 2008, we conducted bat acoustic monitoring at the proposed project. The primary goal of the study was to collect acoustic information on activity levels of bats during nocturnal hours, particularly during spring and fall migration. Specifically, our objectives were to: (1) collect baseline information on levels of bat activity (bat passes/detector-night) for migratory tree-roosting bats (e.g., hoary and big brown/silver-haired bats) and other bat species (mainly *Myotis* spp.); and (2) examine spatial (height and location) and temporal (e.g., nightly and seasonal) variations in bat activity.

STUDY AREA

The proposed CCWPP consists of ~31,700 acres of mountainous terrain located in the Oregon Coast Range physiographic region (USGS 2003) of Lewis and Pacific Counties in southwestern Washington. The proposed development is located ~30 km east of the town of Raymond, Washington and ~30 km west of Chehalis, Washington (Fig. 1). The property is owned by Weyerhaeuser and managed as an industrial forest. Proposed turbine sites are located along a non-linear ridgeline consisting of a patchwork of clear cuts and managed young-age (second or third growth) coniferous forest. The convoluted ridge sytem is typical of other "ridges" in the area and generally runs northwest to southeast, with elevations ranging from ~500–725 m.

Our acoustic monitoring stations were located at 3 meteorological towers on the project site. The number and location of towers used in this study allowed us to capture the maximal amount of spatial variation on the CCWPP. Our sampling stations were located at Coyote Crest North 1 ([NAD 83] UTM Zone 10 473416.8E, 5176124.1N), Coyote Crest North 2 (UTM Zone 10 474742.4E, 5169326.3N), and Coyote Crest North 3 (UTM Zone 10 472440.0E, 5178400.5N).

METHODS

EQUIPMENT

We used 6 Anabat SD1 broadband acoustic detectors (Titley Electronics, Ballina, New South Wales, Australia) with an approximate detection range of ~20 m (actual range dependent on temperature, humidity, and frequency and intensity of echolocation call; Fig. 2). We positioned detectors at 3 meteorological (met) towers (Coyote Crest North 1, Coyote Crest North 2, and Coyote Crest North 3) to record echolocation call sequences, or bat passes, onto 1 GB compact flash (CF) cards. We installed acoustic detectors on Coyote Crest North 1 and Coyote Crest North 2 on 14 April 2008. On 8 July, detectors were installed at a newly constructed tower (Coyote Crest North 3). Prior to sampling, we calibrated each Anabat (sensitivity set at ~6) to minimize reception variability among detectors (Larson and Hayes 2000). We housed microphones in waterproof "bat-hats" (EME Systems, Berkley, California, USA). The bat-hat system consists of a protective shroud, reflector plate, and mounting bracket (version 1c –www.emesystems.com). We positioned 2 microphones on each tower at ~1.5 m and ~50 m above ground level (agl). We employed pulley systems secured to met towers to raise microphones to ~50 m, the maximum height allowed by these met towers. We enclosed all electronic equipment in waterproof Pelican cases (Pelican Products, Inc., Torrance, California, USA) located at the base of each tower. We used a photovoltaic system (Online Solar, Inc., Hunt Valley, Maryland, USA) to provide continuous solar power to all detectors.

DATA COLLECTION

For our study, we followed recommendations for conducting wildlife studies at wind-energy facilities described by Kunz et al. (2007b). We monitored bat acoustic activity during crepuscular and nocturnal hours (~1 h before sunset to ~1 h after sunrise), between 1658 and 0850 PST, with hours sampled ranging between 10.5 and 16 h/night. This sampling schedule provided coverage during times when bat are most active (Hayes 1997). ABR staff visited each tower every 2–4 weeks to exchange CF cards. We downloaded and analyzed data using Anabat CFC Read (version 4.2a) and AnalookW (version 3.5p) software, respectively. We removed extraneous noise from our data prior to analysis using customized filters derived from Britzke and Murray (2000).

DATA ANALYSIS

Interpretation of bat acoustic data is subject to several important caveats. The metric "bat pass" is an index of relative activity, but may not correlate to individual numbers of bats (e.g., 100 bat passes may be a single bat recorded 100 different times or 100 bats each recording a single pass; Kunz et al. 2007b). Activity also may not be proportional to abundance because of variation attributed to: (1) detectability (loud vs. quiet species); (2) species call rates; (3) migratory vs. foraging call rates; and (4) attraction or avoidance of bats to the sampling

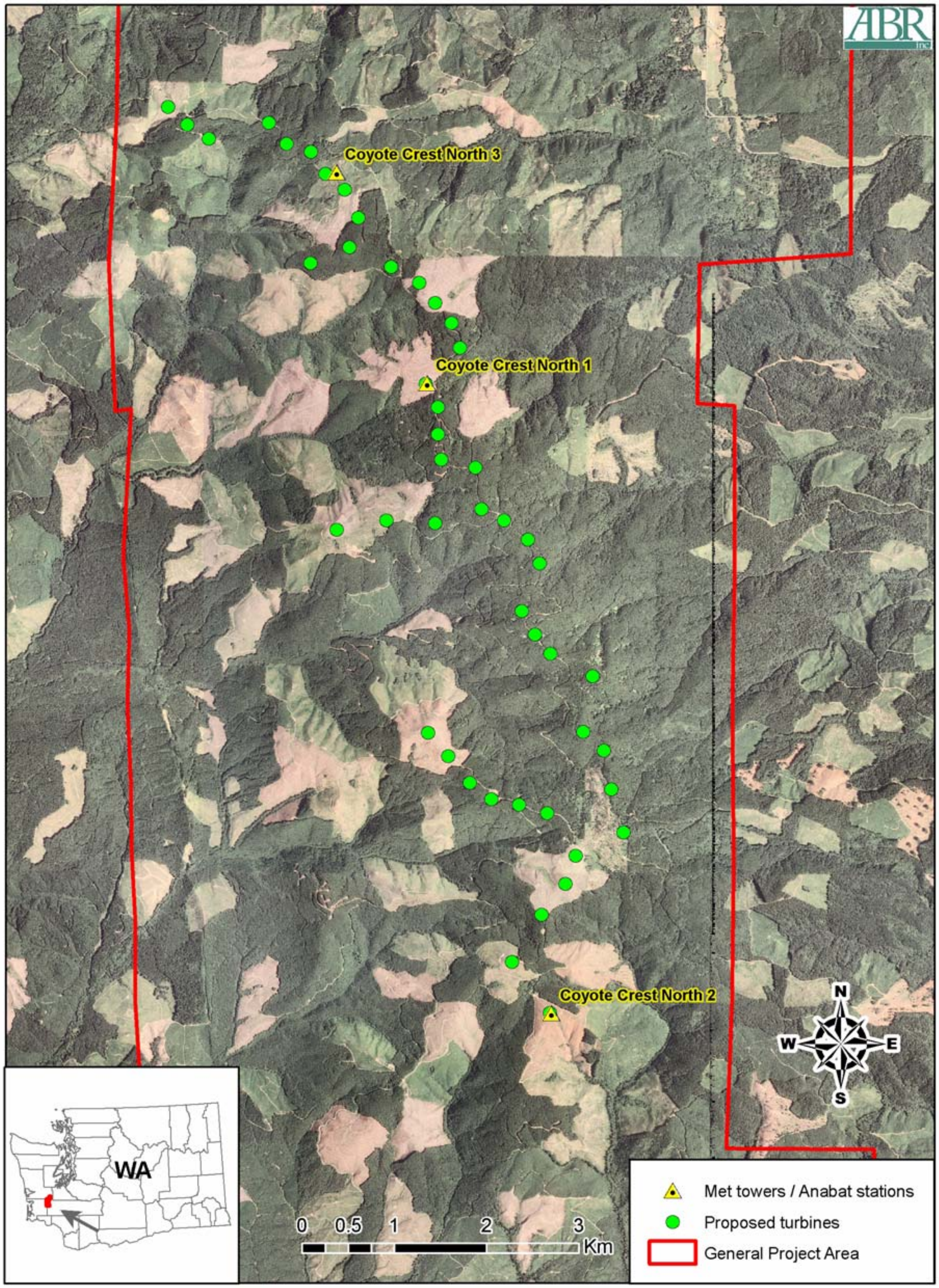

Figure 1. Map of the proposed Coyote Crest Wind Power Project, Lewis County, Washington, 2008.

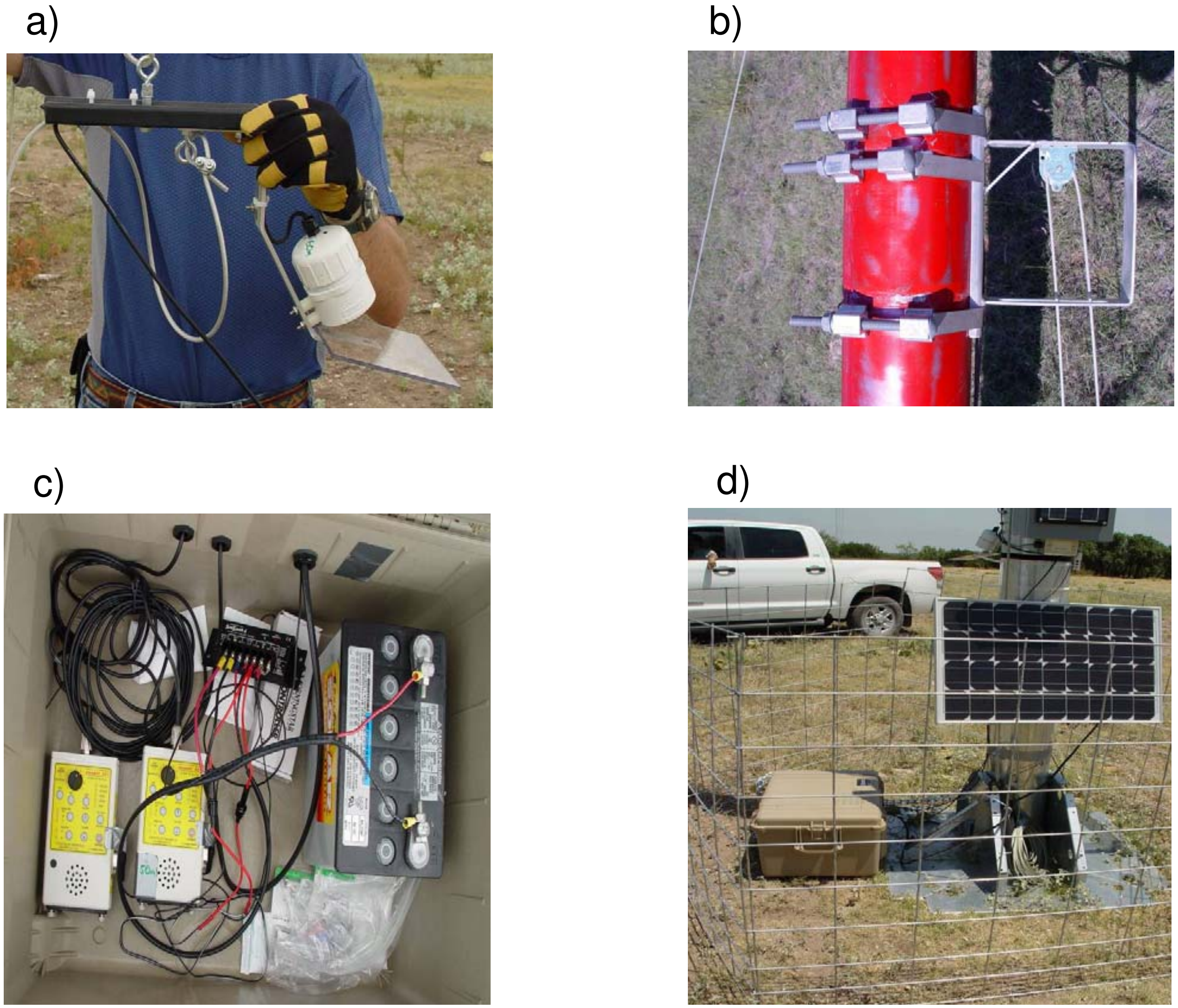

Figure 2. Photographs of bat acoustic monitoring equipment depicting a) “bat-hat” system used to raise and secure acoustic microphone to base of pulley bracket, b) ABR’s pulley bracket attached to a meteorological tower, c) Anabat detectors and solar battery housed in a water-proof Pelican case, and d) solar panel secured to tower.

area (Kunz et al. 2007b). However, interpreted properly, the index of relative activity may provide critical information of bat use at a proposed wind facility by characterizing temporal (hourly, nightly and seasonal) and spatial (height and location) patterns.

We defined a bat pass as a search-phase echolocation sequence of ≥2 echolocation pulses with a minimum pulse duration of 10 ms within each sequence separated by >1 second (Fenton 1970, Thomas 1988, Gannon et al. 2003). Search-phase passes are used by bats to detect objects at long ranges and are generally consistent within a species. In contrast, approach-phase and terminal-phase passes typically are used to target and capture insect prey and can vary widely within a species. Although approach and terminal passes may be used to identify presence, they are unsuitable for species identification. A bat pass is a standard term used to identify bat activity (Kunz et al. 2007b), although other terms also have been used synonymously (e.g., calls or call sequences; Ecology and Environment 2006, Woodlot 2006b, Young et al. 2006).

We qualitatively compared echolocation call characteristics (e.g., minimum frequency, duration) of each unknown bat pass to a reference library containing bat passes of known species. Qualitative species identification can be relatively accurate when comparing unknown passes to known reference libraries (O'Farrell and Gannon 1999; O'Farrell et al. 1999). We assigned each unknown pass to a "phonic group"—a species or a group of species whose echolocation search-phase calls possess similar characteristics. Based on species known to occur in the project area, we placed passes into 8 phonic groups: (1) big brown/silver-haired bat, (2) hoary bat, (3) California myotis/Yuma myotis, (4) western long-eared myotis/Keen's myotis/fringed myotis, (5) long-legged myotis/little brown myotis, (6) Townsend's big-eared bat, (7) unidentified high frequency (>35 kHz; i.e., *Myotis* spp.) bats, and (8) unidentified low frequency (≤35 kHz; i.e., big brown/silver-haired, hoary, Townsend's big-eared) bats following criteria similar to Ober (2007). We classified bat passes as unidentified if they did not contain sufficient information to determine the species identification (i.e., highly fragmented calls, approach or terminal phase calls). Migratory tree bats consistently have higher fatality rates than other species, therefore, we created an additional category, (9) tree bats, which includes several phonic groups (big brown/silver-haired, hoary, and unknown low-frequency bats) that are negatively affected by wind-energy facilities. We include unknown low-frequency bats in this category because the phonic group is comprised predominantly of big brown/silver-haired and hoary bats.

We divided our study into 2 seasons (spring and fall) based on migratory activity patterns of bats from the region (Cryan 2003, Cryan and Brown 2007, Fitzgerald et al. 1994). The spring season includes both the period of migration and reproductive period (pregnancy and lactation-when mothers nurse their young). The fall season encompasses the periods of juvenile volancy (ability to fly), swarming (pre-migration activity), and migration. Currently, a paucity of information exists regarding seasonal patterns of bat activity and fatality during spring and summer, making it difficult to define these seasons. Therefore, we grouped these seasons together for our "spring" (15 April–30 June, $n = 77$ nights) season. We based our "fall" season (1 July–17 November, $n = 140$ nights) on data from the region showing high levels of bat activity and fatality beginning in July and continuing through October, and because nearly 90% of bat fatalities occur in late summer/early fall (Arnett et al. 2008, Erickson et al. 2002, Gruver 2002).

Because our data were not normally distributed, we used both non-parametric statistical tests and bootstrapping simulations for all analyses. We compared bat activity between or among towers at 1.5 m, 50 m, and across all heights using the Mann-Whitney U (M-W test) or Kruskal-Wallis (K-W test) tests, respectively. We also used the M-W test to compare activity between seasons. To examine activity between altitudes, we used the Wilcoxon signed rank test, pooling height data from all 3 towers including only those nights when both detectors/tower were operational. We compared our observed within-night activity rates for hours relative to sunset to a probability distribution based on 5,000 bootstrap simulations. For each simulation, we randomly ordered the observed hourly activity rate within each night and calculated a new average for each hour. We define mean activity as mean passes/detector-night (unless otherwise stated), which is a common metric used to standardize bat activity and helpful in comparing activity among bat acoustic studies. We report all mean bat passes as mean ± standard error (SE). We used SPSS v.16.0 for all statistical comparisons using a level of statistical significance (α) = 0.05 (SPSS 2007).

RESULTS

We conducted bat acoustic monitoring for 217 nights between 15 April and 17 November 2008 at 2 altitudes (~1.5 m and ~50 m) at 2 met towers in spring and 3 met towers in fall for a total of 1,148 potential detector-nights (# detectors * # nights). In spring, we were unable to collect data from 12–20 June (*n* = 9 nights; equipment malfunctions) and 21 June–30 June (10 nights; tower maintenance) at Coyote Crest North 1 and 19–30 June at Coyote Crest North 2 (12 nights; tower maintenance). In fall, we were unable to collect data from 1–2 July (*n* = 2 nights) at both Coyote Crest North 1 and 2 because of tower maintenance. In addition, we were unable to collect data at Coyote Crest North 3 from 1–7 July (tower installed 8 July), and from 20–22 September and on 25 September because of equipment malfunctions. Therefore, we obtained useable data for the majority (92%, *n* = 1,052) of detector-nights throughout the study (spring = 79%, *n* = 242 detector-nights; fall = 96%, *n* = 810 detector-nights) and for each tower [Coyote Crest North 1 (spring = 73%, *n* = 112; fall = 99%, *n* = 276), Coyote Crest North 2 (spring = 84%, *n* = 130; fall = 99%, *n* = 276), Coyote Crest North 3 (fall = 92%, *n* = 258)]. Coyote Crest North 3 only recorded data during fall, we exclude this tower from our statistical analyses comparing seasons and only use Coyote Crest North 1 and Coyote Crest North 2.

GENERAL BAT ACTIVITY

We recorded 1,414 total bat passes from all detectors during the entire study (Table 1). Overall, we identified 83.9% (*n* = 1,187) of bat passes to phonic groups represented in descending order by big brown/silver-haired, California/Yuma myotis, hoary, long-legged/little brown myotis, and western long-eared/Keen's/fringed myotis bats, with the remaining passes (16.1%, *n* = 227) unidentifiable (unidentified high-frequency [*Myotis* spp.; 4.5%, *n* = 63] and unidentified low-frequency [big brown/silver-haired, hoary, and Townsend's big-eared; 11.6%, *n* = 164]) bats. The tree bat phonic group (big brown/silver-haired, hoary, and unidentified low-frequency bats) represented 63.7% (*n* = 897) of total passes recorded. Since no identifiable passes were classified as Townsend's big-eared bats, we did not include this species in our analysis. Total number of bat passes was relatively low in spring (*n* = 20) and higher in fall (*n* = 1,394; Tables 2, 3). Because so few bats were recorded in spring, we limit our discussion on trends across the entire study and focus on spatial and temporal activity patterns during the fall season.

TEMPORAL DIFFERENCES IN ACTIVITY

SEASONAL

Overall, activity (mean passes/tower) varied among nights and across the entire study (Fig. 3). We recorded few bat passes during spring, but higher activity levels were observed in late summer and fall. Activity began to decline in early October; however, bats were present on site through mid-November including one night of relatively high activity. Across the study, activity typically was higher at 1.5 m than at 50 m. Mean activity at both altitudes (1.5 m = 25.7; 50 m = 10.0) peaked in mid-September and late September, respectively.

We observed variations in activity (mean passes/tower) by migratory tree-roosting bats during times when these species appear to be most vulnerable to wind development (i.e., fall migration; Figs. 4, 5). Mean activity of big brown/silver-haired bats at 1.5 m was variable with increased activity in mid-August and mid-September. At 50 m, big brown/silver-haired bat activity was higher in late September and late October. Hoary bat activity was sporadic at both altitudes, with few passes recorded during July and October. Hoary bat passes were recorded more frequently from August to September with peaks in mid-September.

Activity (mean passes/detector-night) for the entire study across all stations (including detectors at Coyote Crest North 3) was 1.3 ± 0.1 with lower activity in spring (0.08 ± 0.03) and higher levels in fall (1.7 ± 0.2). Mean activity for migratory

Table 1. Number of bat passes (N) identified as big brown/silver-haired (EPFU/LANO), hoary (LACI), California/Yuma (MYCAYU), western long-eared/Keen's/fringed (MYEVKETH), long-legged/little brown (MYVOLU), unidentified high frequency (UNHI), and unidentified low frequency (UNLO) bats recorded across all detectors during spring[a] and fall seasons at the proposed Coyote Crest Wind Power Project, Washington, 2008. Percentages represent the proportion of bat passes at a given tower and altitude.

	Coyote Crest North 1		Coyote Crest North 2		Coyote Crest North 3		Total	
Altitude/phonic group	N	%	N	%	N	%	N	%
Bat passes at 1.5 m								
EPFU/LANO	119	8.4	54	3.8	290	20.5	463	32.7
LACI	15	1.1	1	<0.1	13	0.9	29	2.1
MYCAYU	35	2.5	11	0.8	292	20.6	338	23.9
MYEVKETH	4	0.3	3	0.2	13	0.9	20	1.4
MYVOLU	17	1.2	9	0.6	63	4.5	89	6.3
UNHI	7	0.5	5	0.4	50	3.5	62	4.4
UNLO	32	2.2	18	1.3	70	5.0	120	8.5
TOTAL	*229*	*16.3*	*101*	*7.1*	*791*	*55.9*	*1,121*	*79.3*
Bat passes at 50 m								
EPFU/LANO	50	3.5	13	0.9	133	9.4	196	13.9
LACI	18	1.3	5	0.4	25	1.8	48	3.4
MYCAYU	2	0.1	0	0	0	0	2	0.1
MYEVKETH	0	0	0	0	0	0	0	0
MYVOLU	2	0.1	0	0	0	0	2	0.1
UNHI	1	<0.1	0	0	0	0	1	<0.1
UNLO	24	1.7	9	0.6	11	0.8	44	3.1
TOTAL	*97*	*6.8*	*27*	*1.9*	*169*	*12.0*	*293*	*20.7*
All altitudes								
EPFU/LANO	169	12.0	67	4.7	423	29.9	659	46.6
LACI	33	2.3	6	0.4	38	2.7	77	5.5
MYCAYU	37	2.6	11	0.8	292	20.6	340	24.0
MYEVKETH	4	0.3	3	0.2	13	0.9	20	1.4
MYVOLU	19	1.3	9	0.6	63	4.5	91	6.4
UNHI	8	0.6	5	0.4	50	3.5	63	4.5
UNLO	56	4.0	27	1.9	81	5.7	164	11.6
TOTAL	*326*	*23.1*	*128*	*9.0*	*960*	*67.9*	*1,414*	*100.0*

[a] Spring includes data from Coyote Crest North 1 and Coyote Crest North 2 only; Coyote Crest North 3 was not operational during spring.

Table 2. Number of bat passes (N) in spring[a] identified as big brown/silver-haired (EPFU/LANO), hoary (LACI), California/Yuma (MYCAYU), western long-eared/Keen's/fringed (MYEVKETH), long-legged/little brown (MYVOLU), unidentified high frequency (UNHI), and unidentified low frequency (UNLO) bats recorded across all detectors at the proposed Coyote Crest Wind Power Project, Washington, 2008. Percentages represent the proportion of bat passes at a given tower and altitude.

	Coyote Crest North 1		Coyote Crest North 2		Total	
Altitude/phonic group	N	%	N	%	N	%
Bat passes at 1.5 m						
EPFU/LANO	3	15.0	2	10.0	5	25.0
LACI	0	0.0	0	0.0	0	0.0
MYCAYU	1	5.0	6	30.0	7	35.0
MYEVKETH	1	5.0	0	0.0	1	0.0
MYVOLU	0	0.0	5	25.0	5	25.0
UNHI	0	0.0	0	0.0	0	0.0
UNLO	0	0.0	0	0.0	0	0.0
TOTAL	*5*	*25.0*	*13.0*	*65.0*	*18.0*	*90.0*
Bat passes at 50 m						
EPFU/LANO	1	5.0	0	0.0	1	5.0
LACI	1	5.0	0	0.0	1	5.0
MYCAYU	0	0.0	0	0.0	0	0.0
MYEVKETH	0	0.0	0	0.0	0	0.0
MYVOLU	0	0.0	0	0.0	0	0.0
UNHI	0	0.0	0	0.0	0	0.0
UNLO	0	0.0	0	0.0	0	0.0
TOTAL	*2.0*	*10.0*	*0*	*0.0*	*2.0*	*10.0*
All altitudes						
EPFU/LANO	4	20.0	2	10.0	6	30.0
LACI	1	5.0	0	0.0	1	5.0
MYCAYU	1	5.0	6	30.0	7	35.0
MYEVKETH	1	5.0	0	0.0	1	5.0
MYVOLU	0	0.0	5	25.0	5	25.5
UNHI	0	0.0	0	0.0	0	0.0
UNLO	0	0.0	0	0.0	0	0.0
TOTAL	*7.0*	*35.0*	*13.0*	*65.0*	*20.0*	*100.0*

[a] Spring includes data from Coyote Crest North 1 and Coyote Crest North 2 only; Coyote Crest North 3 was not operational during spring.

Table 3. Number of bat passes (N) in fall identified as big brown/silver-haired (EPFU/LANO), hoary (LACI), California/Yuma (MYCAYU), western long-eared/Keen's/fringed (MYEVKETH), long-legged/little brown (MYVOLU), unidentified high frequency (UNHI), and unidentified low frequency (UNLO) bats recorded across all detectors at the proposed Coyote Crest Wind Power Project, Washington, 2008. Percentages represent the proportion of bat passes at a given tower and altitude.

	Coyote Crest North 1		Coyote Crest North 2		Coyote Crest North 3		Total	
Altitude/phonic group	N	%	N	%	N	%	N	%
Bat passes at 1.5 m								
EPFU/LANO	116	8.3	52	3.7	290	20.8	458	32.9
LACI	15	1.1	1	<0.1	13	0.9	29	2.1
MYCAYU	34	2.4	5	0.4	292	21.0	331	23.7
MYEVKETH	3	0.2	3	0.2	13	0.9	19	1.4
MYVOLU	17	1.2	4	0.3	63	4.5	84	6.0
UNHI	7	0.5	5	0.4	50	3.6	62	4.4
UNLO	32	2.3	18	1.3	70	5.0	120	8.6
TOTAL	*224*	*16.0*	*88*	*6.3*	*791*	*56.7*	*1103*	*79.1*
Bat passes at 50 m								
EPFU/LANO	49	3.5	13	0.9	133	9.5	195	14.0
LACI	17	1.2	5	0.4	25	1.8	47	3.4
MYCAYU	2	0.1	0	0.0	0	0.0	2	0.1
MYEVKETH	0	0.0	0	0.0	0	0.0	0	0.0
MYVOLU	2	0.2	0	0.0	0	0.0	2	0.1
UNHI	1	<0.1	0	0.0	0	0.0	1	<0.1
UNLO	24	1.7	9	0.6	11	0.8	44	3.2
TOTAL	*95*	*6.8*	*27*	*1.9*	*169*	*12.1*	*291*	*20.9*
All altitudes								
EPFU/LANO	165	11.8	65	4.6	423	30.3	653	46.8
LACI	32	2.3	6	0.4	38	2.7	76	5.5
MYCAYU	36	2.6	5	0.4	292	21.0	333	23.9
MYEVKETH	3	0.2	3	0.2	13	0.9	19	1.4
MYVOLU	19	1.4	4	0.3	63	4.5	86	6.2
UNHI	8	0.6	5	0.4	50	3.6	63	4.5
UNLO	56	4.0	27	1.9	81	5.8	164	11.7
TOTAL	*319*	*22.9*	*115*	*8.2*	*960*	*68.8*	*1394*	*100.0*

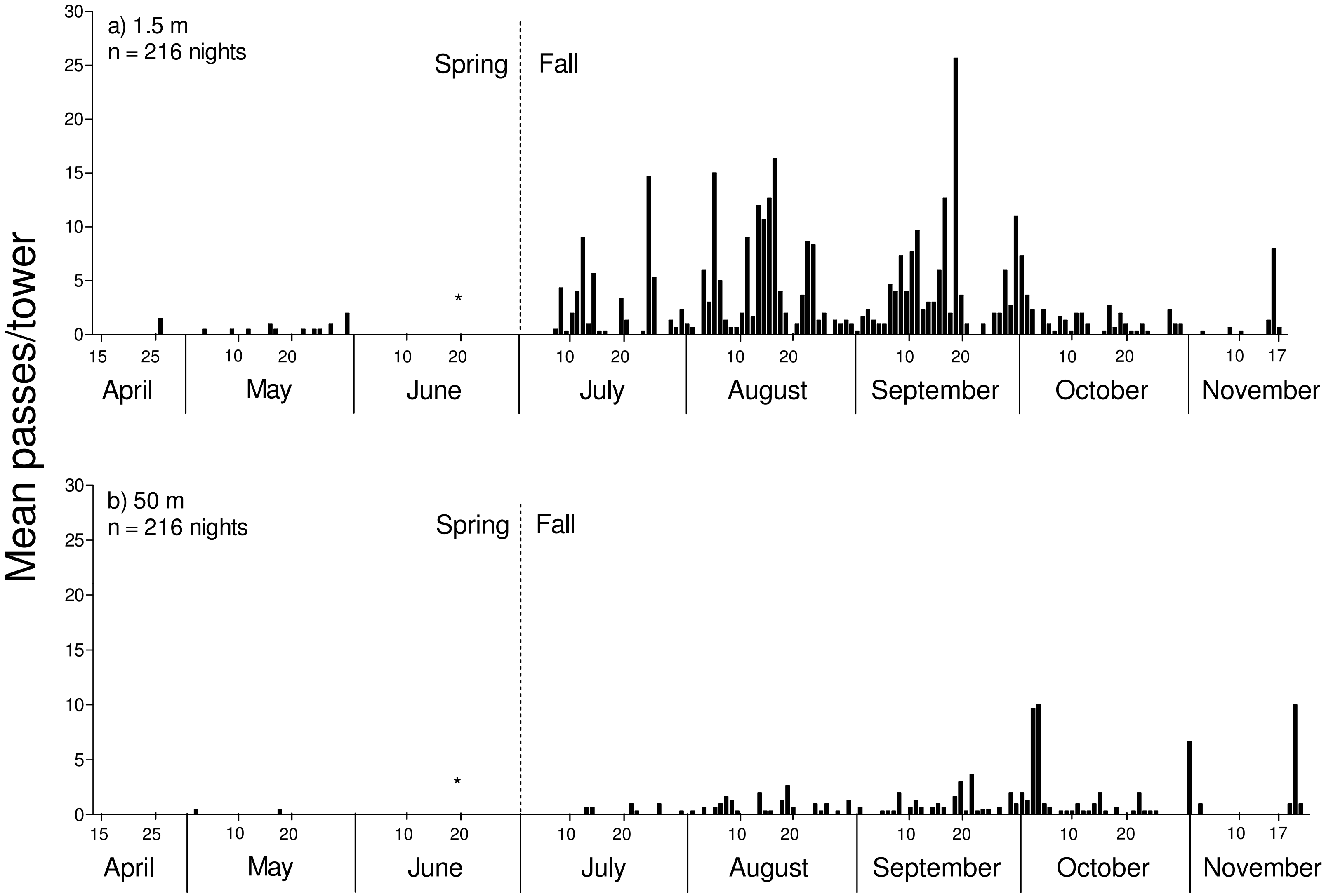

Figure 3. Mean bat passes/tower across all phonic groups by date for a) 1.5 m agl and b) 50 m agl at the proposed Coyote Crest Wind Power Project, Washington, 2008. Asterisks indicate missing data (1.5 m: 19 June-2 July; 50 m: 19 June-2 July).

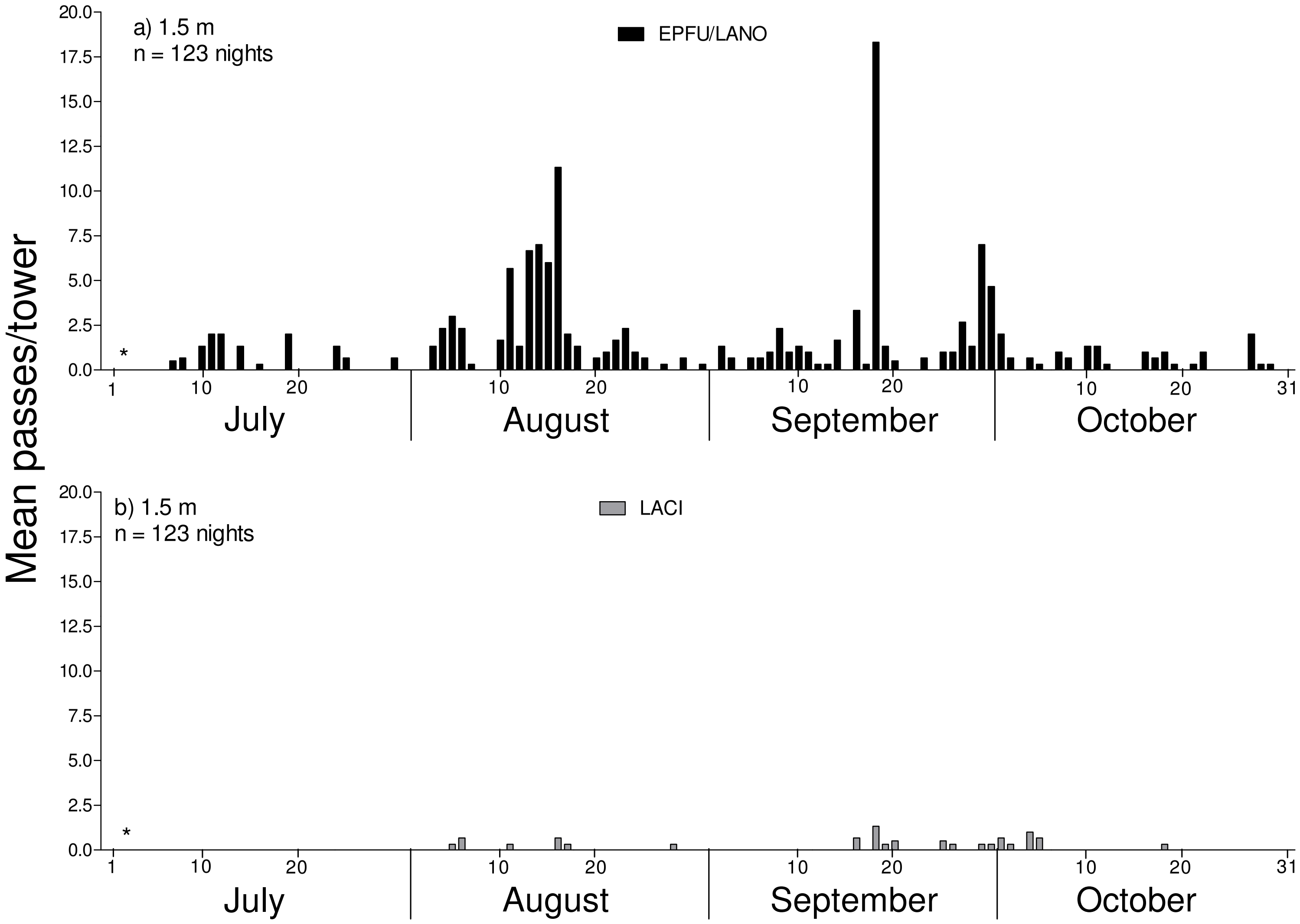

Figure 4. Mean bat passes/tower by date at 1.5 m agl for a) big brown/silver-haired (EPFU/LANO) bats, and b) hoary (LACI) bats at the proposed Coyote Crest Wind Power Project, Washington, 2008. Asterisks indicate missing data (1-2 July).

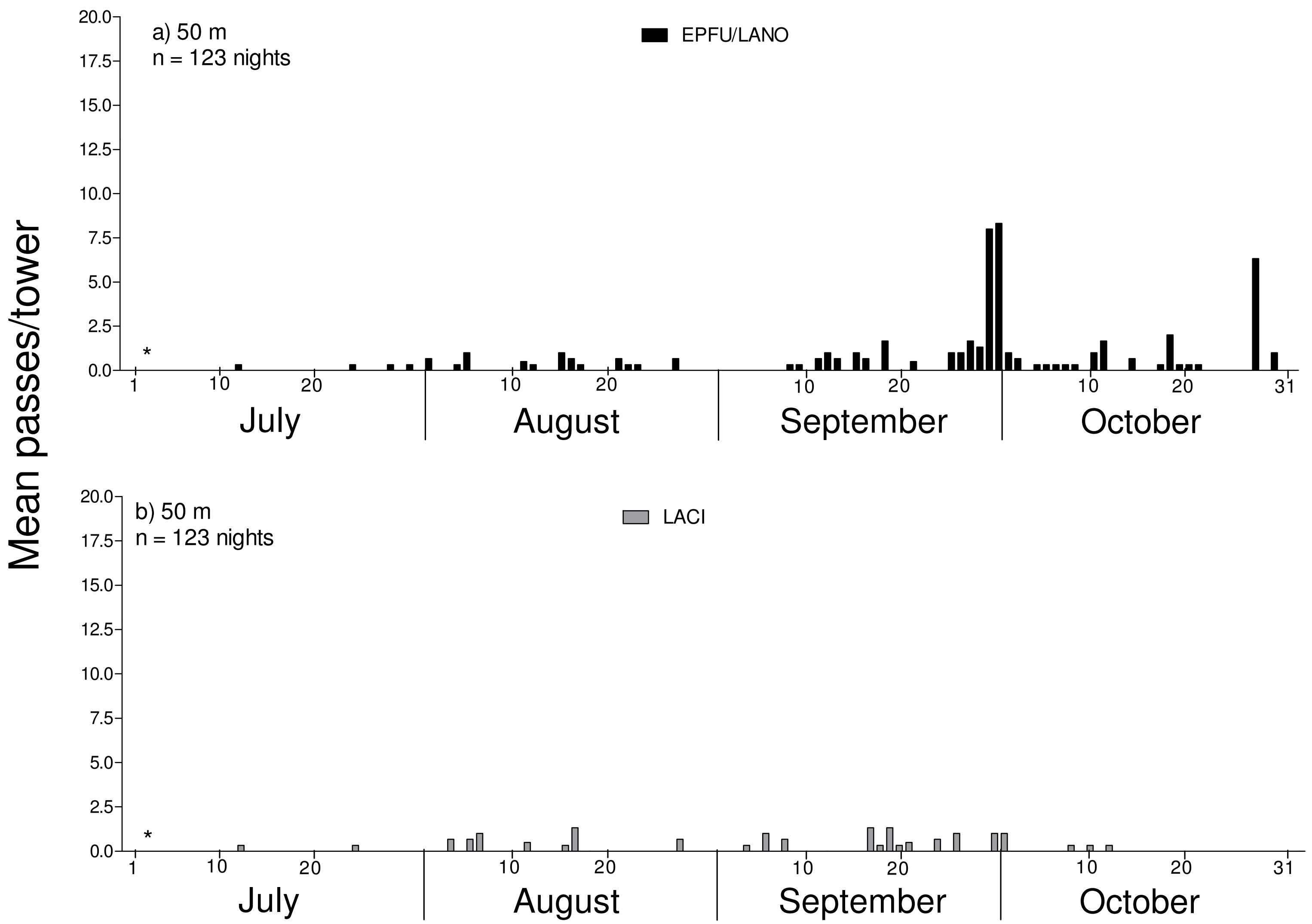

Figure 5. Mean bat passes/tower by date at 50 m agl for a) big brown/silver-haired (EPFU/LANO) bats, and b) hoary (LACI) bats at the proposed Coyote Crest Wind Power Project, Washington, 2008. Asterisks indicate missing data (1–2 July).

tree-roosting bats for the entire study across all stations (including detectors at Coyote Crest North 3) was 0.9 ± 0.09 with lower activity in spring (0.03 ± 0.01) than in fall (1.1 ± 0.1). We observed seasonal differences in activity at both heights using data from Coyote Crest North 1 and Coyote Crest North 2 (Coyote Crest North 3 was excluded from this analysis because it only was operational in fall; Fig. 6, Appendix 1). Overall, activity was higher in fall at both 1.5 m (spring = 0.1 ± 0.01, fall = 1.1 ± 0.1) and 50 m (spring = 0.02 ± 0.01, fall = 0.4 ± 0.1). Fall activity also was higher for each phonic group at both altitudes, particularly for migratory tree-roosting bats.

NIGHTLY

We observed within-night variations in activity (mean passes/tower/hour). Based on limited spring data, overall activity typically occurred within a few hours after sunset (Fig 7). In fall, activity of all bats differed among hours of the night at 1.5 m, with the higher activity rates occurring between 1 and 7 hours past sunset (Fig. 8). Based on our bootstrapping simulations, activity at this height was greater than expected between 1 and 2 hours after sunset. Within-night activity at 50 m generally was similar across hours of the night, but also was greater than expected between 1 and 2 hours after sunset. We observed limited activity prior to sunset at 1.5 m, and no activity during this time at 50 m. Activity for migratory tree-roosting bats was greater than expected 1–3 hours past sunset at 1.5 m and 1–2 hours past sunset at 50 m.

SPATIAL DIFFERENCES IN ACTIVITY

BETWEEN HEIGHTS

We recorded more bat passes at 1.5 m than at 50 m for each season and across the entire study (Fig 9, Appendix 2). All phonic groups, except hoary bats, also were detected more frequently at the 1.5 m detector, regardless of season. Hoary bats were more active at 50 m in both seasons. In fall, bat activity (mean passes/detector-night) was higher at 1.5 m (2.7 ± 0.3) compared to 50 m (0.7 ± 0.1) All phonic groups were detected more frequently at 1.5 m, including big brown/silver-haired bats (1.5 m = 1.1 ± 0.2, 50 m = 0.5 ± 0.1), than at 50 m except for hoary bats (1.5 m = 0.07 ± 0.02, 50 m = 0.1 ± 0.09). *Myotis* species were rarely detected (*n* = 5 bat passes) at the 50 m detector.

AMONG TOWERS

We found differences in activity (mean passes/detector-night) among towers at both 1.5 m and 50 m during fall (Fig 10, Appendix 3). Although, activity levels were generally similar between Coyote Crest North 1 and Coyote Crest North 2, we detected more bat passes at Coyote Crest North 1. We recorded the highest number of total bat passes at Coyote Crest North 3 at both the 1.5 m (Coyote Crest North 1 = 1.6 ± 0.2, Coyote Crest North 2 = 0.6 ± 0.2, Coyote Crest North 3 = 6.1 ± 0.9) and 50 m (Coyote Crest North 1 = 0.7 ± 0.1, Coyote Crest North 2 = 0.2 ± 0.04, Coyote Crest North 3 = 1.3 ± 0.4) detectors. We recorded the most bat passes for each phonic group at Coyote Crest North 3 1.5 m. At 50 m, both big brown /silver-haired and hoary bats were each detected more often at Coyote Crest North 3, than at the other 2 towers.

DISCUSSION

Although numerous acoustic monitoring surveys at wind-energy facilities in North America have been conducted, a majority of these studies are from the Northeast (Appendix 4a, b). Currently, similar acoustic studies are rare for Washington and not publicly available in surrounding states. Because a paucity of information exists concerning the spatial and temporal activity of bats in this region, predicting impacts of wind power development on resident and migratory species can be problematic and thus strengthens the rationale for additional studies in western states. Furthermore, differences in species assemblages and identification, landscape characteristics (e.g., habitat, elevation, and climate), sampling effort (e.g., number of detectors or towers, sampling dates, altitude of detectors, detector position) and analytical methods can make comparing bat activity among studies difficult. To minimize variability associated with sampling design and analysis, recent publications have presented recommendations for acoustic monitoring surveys (Hayes 2000, Gannon et al. 2003, Kunz et al. 2007b). Furthermore, to ensure sampling periods

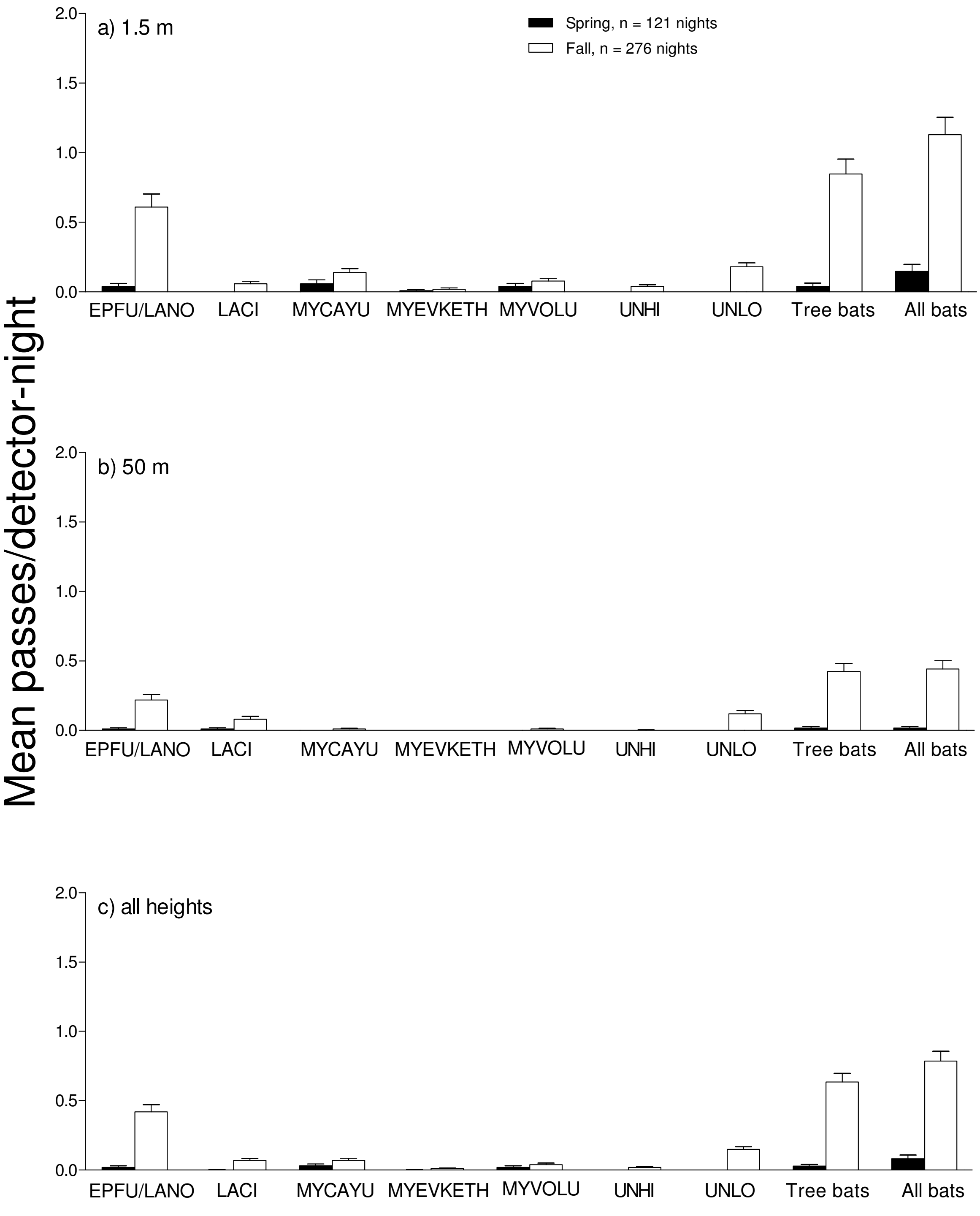

Figure 6. Mean bat passes/detector-night across spring and fall seasons for big brown/silver-haired (EPFU/LANO), hoary (LACI), California/Yuma (MYCAYU), western long-eared/Keen's/fringed (MYEVKETH), long-legged/little brown (MYVOLU), unidentified high-frequency (UNHI), unidentified-low frequency (UNLO), migratory tree-roosting (Tree bats) bats, and all phonic groups combined (All bats) at a) 1.5 m agl, b) 50 m agl, and c) all heights at the proposed Coyote Crest Wind Power Project, Washington, 2008. Includes only data from Coyote Crest North 1 and Coyote Crest North 2.

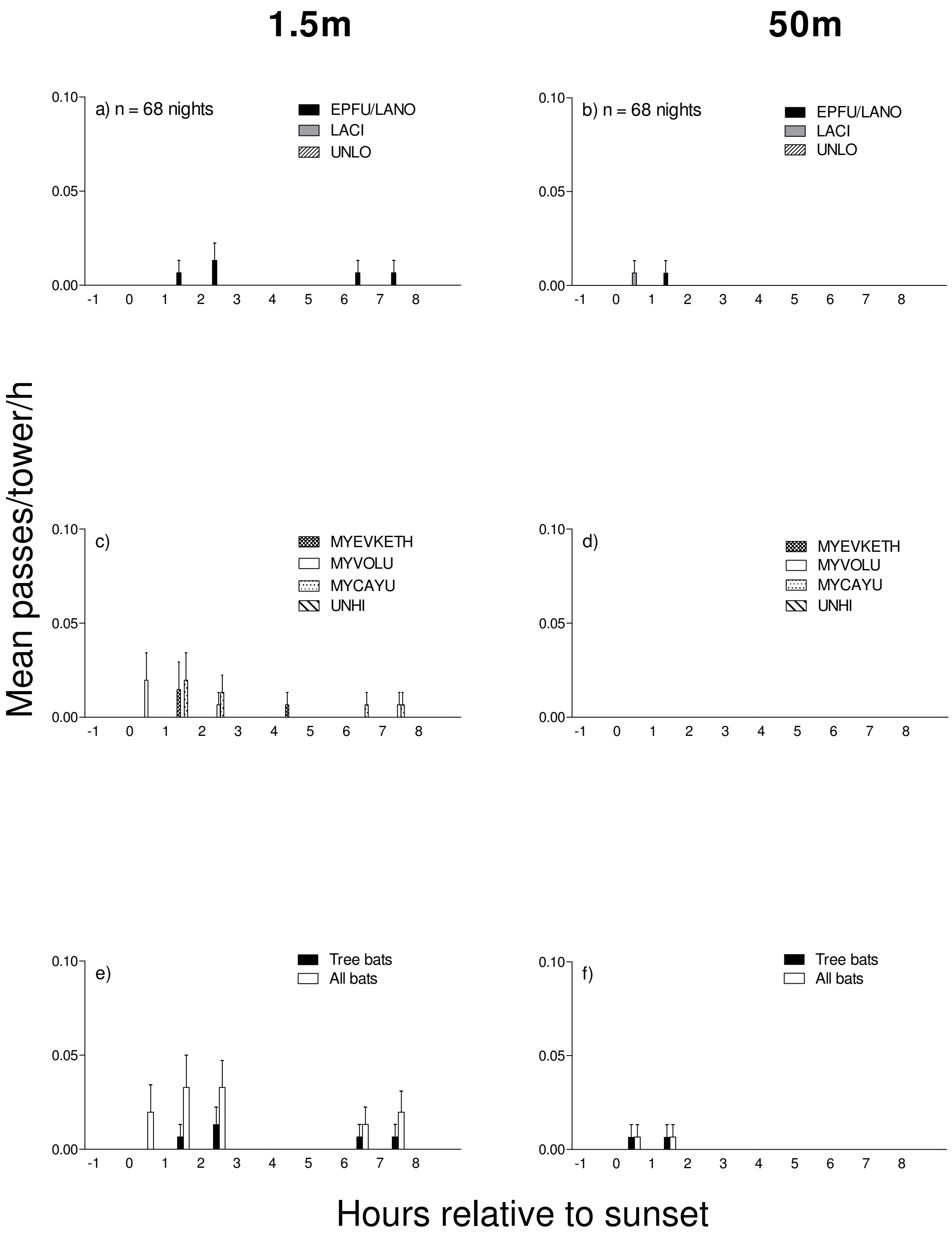

Figure 7. Mean bat passes/tower/hour relative to sunset across spring for big brown/silver-haired (EPFU/LANO), hoary (LACI), California/Yuma (MYCAYU), western long-eared/Keen's/fringed (MYEVKETH), long-legged/little brown (MYVOLU), unidentified high-frequency (UNHI), unidentified-low frequency (UNLO), migratory tree-roosting (Tree bats) bats, and all phonic groups combined (All bats) at 1.5 m agl (a, c, e) and 50 m agl (b, d, f) at the proposed Coyote Crest Wind Power Project, Washington, 2008.

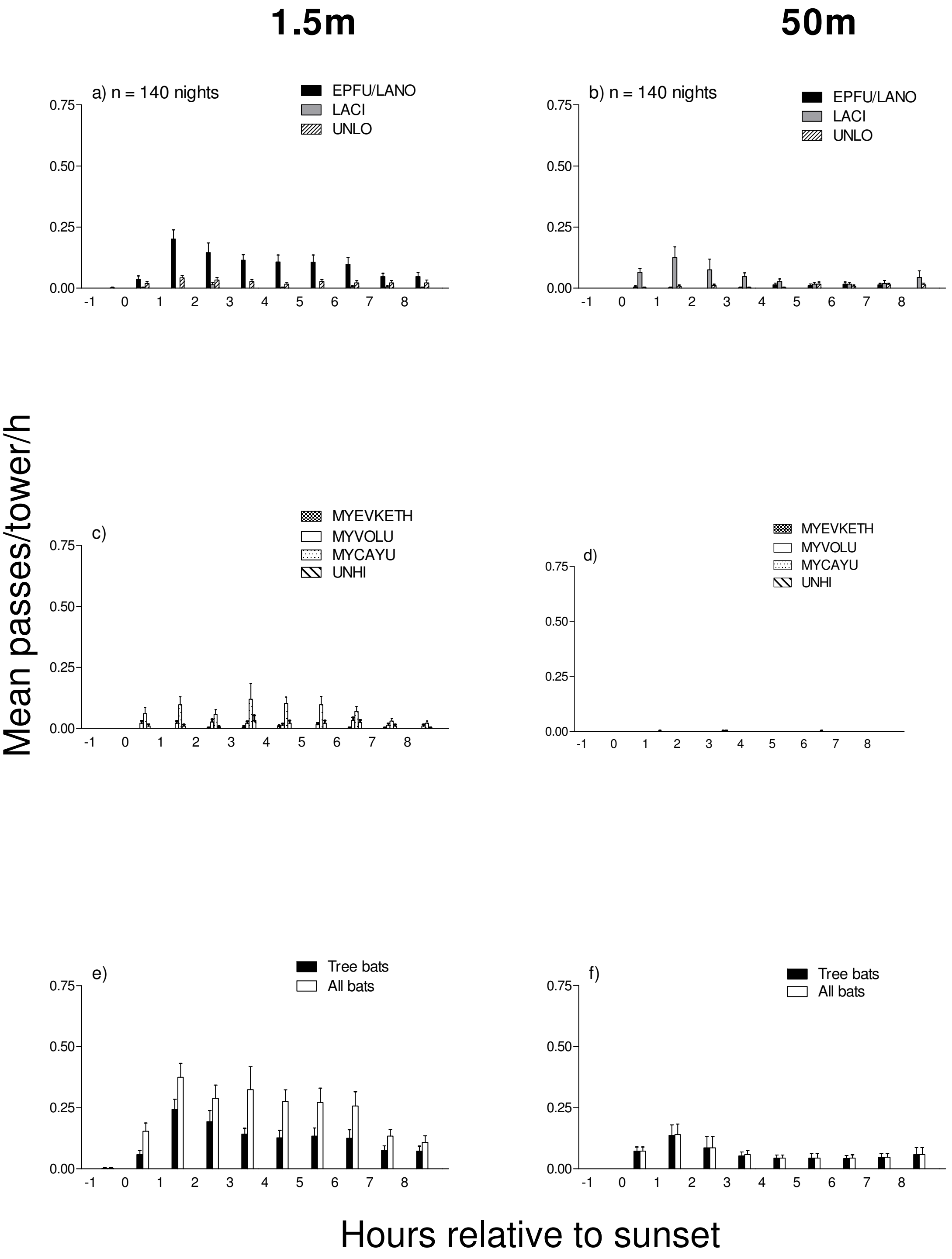

Figure 8. Mean bat passes/tower/hour relative to sunset across fall for big brown/silver-haired (EPFU/LANO), hoary (LACI), California/Yuma (MYCAYU), western long-eared/Keen's/fringed (MYEVKETH), long-legged/little brown (MYVOLU), unidentified high-frequency (UNHI), unidentified-low frequency (UNLO), migratory tree-roosting (Tree bats) bats, and all phonic groups combined (All bats) at 1.5 m agl (a, c, e) and 50 m agl (b, d, f) at the proposed Coyote Crest Wind Power Project, Washington, 2008.

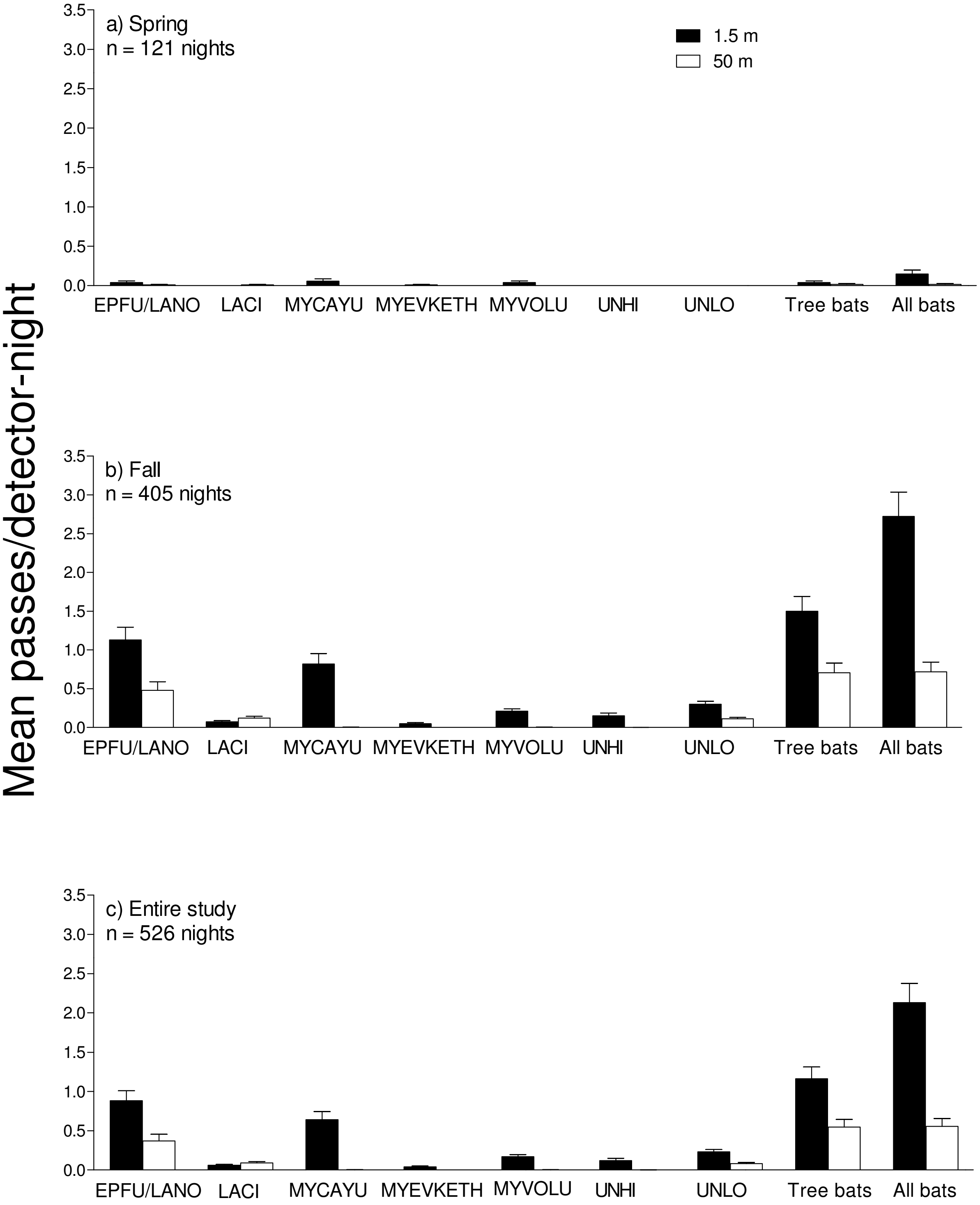

Figure 9. Mean bat passes/detector-night across 1.5 m agl and 50 m agl for big brown/silver-haired (EPFU/LANO), hoary (LACI), California/Yuma (MYCAYU), western long-eared/Keen's/fringed (MYEVKETH), long-legged/little brown (MYVOLU), unidentified high-frequency (UNHI), unidentified-low frequency (UNLO), migratory tree-roosting (Tree bats) bats, and all phonic groups combined (All bats) for a) spring, b) fall, and c) entire study at the proposed Coyote Crest Wind Power Project, Washington, 2008.

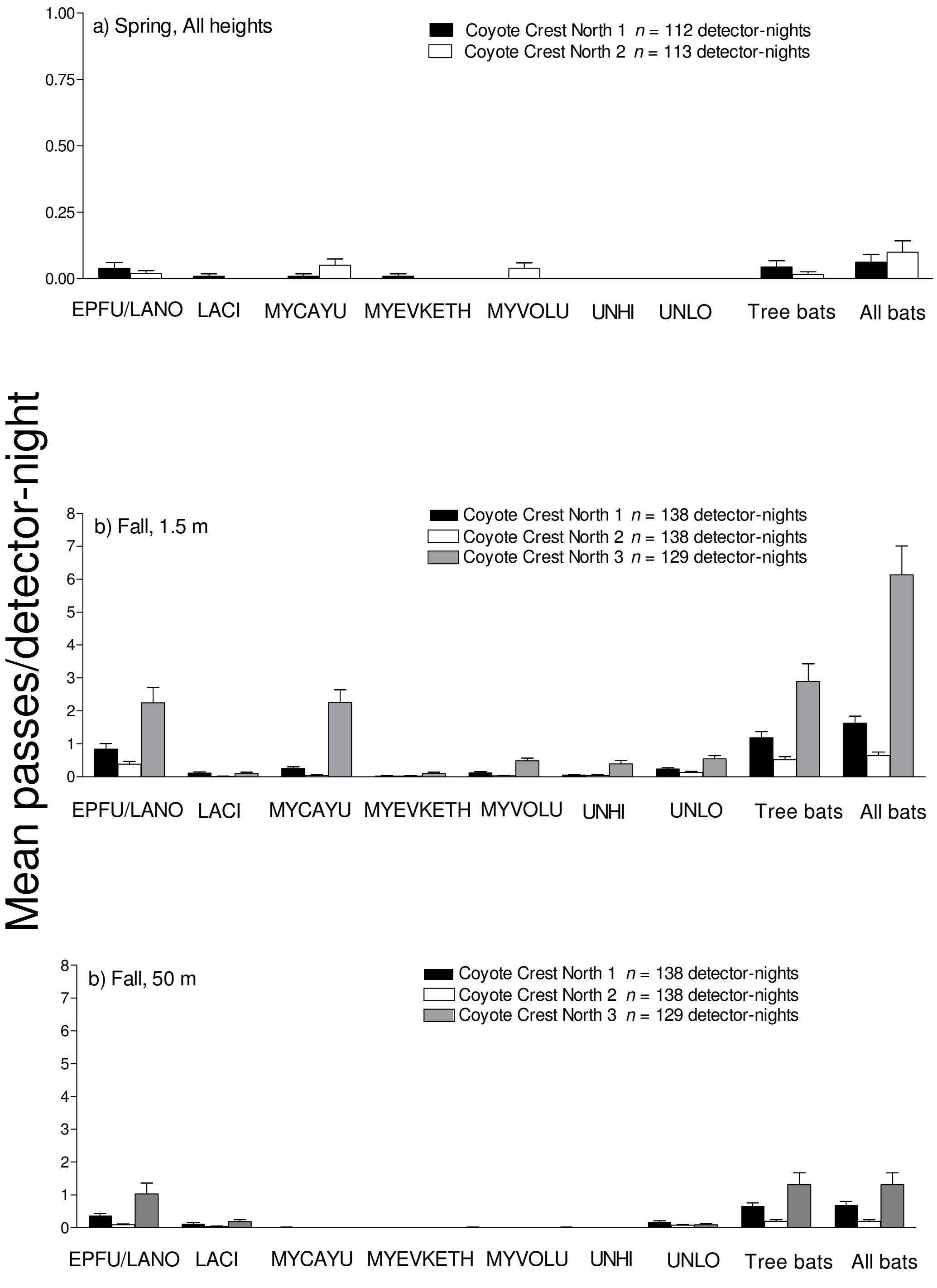

Figure 10. Mean bat passes/detector-night across Coyote Crest North 1, Coyote Crest North 2, and Coyote Crest North 3 for big brown/silver-haired (EPFU/LANO), hoary (LACI), California/Yuma (MYCAYU), western long-eared/Keen’s/fringed (MYEVKETH), long-legged/little brown (MYVOLU), unidentified high-frequency (UNHI), unidentified-low frequency (UNLO), migratory tree-roosting (Tree bats) bats, and all phonic groups combined (All bats) for a) spring, b) fall, and c) entire study at the proposed Coyote Crest Wind Power Project, Washington, 2008. Spring data includes Coyote Crest North 1 and Coyote Crest North 2 only; Coyote Crest North 3 was not operational during this season.

encompass all of migration, it is recommended that studies begin and end monitoring prior to and after expected migratory periods for a given region (Kunz et al. 2007b). Our pre-construction study follows these recommendations and in doing so, we were able to provide baseline information on both spatial (horizontal and vertical) and temporal (nightly and seasonal) patterns of bat activity, particularly for migratory tree-roosting bats. Despite periodic difficulties with equipment functionality, our sampling effort allowed us to characterize bat activity across the CCWPP during the entire study period.

At the CCWPP, we recorded a total of 1,414 (spring = 20, fall = 1,394) bat passes across the entire study. Although the activity recorded at this site was lower than other locations, particularly for spring, our results are within the range of similar acoustic studies conducted at approximately the same latitude across the United States (Appendix 4a, b). However, bat activity at the CCWPP was much lower than the 56,595 bat passes (mean = 148.3 passes/detector-night) recorded at Saddleback Wind Resource Area (SWRA), Skamania, WA (Johnson et al. 2009). Although these 2 sites are located on mountainous ridges surrounded by industrial forests, the placement of detectors at each site may account for differences in activity levels. At the SWRA, detectors were placed in areas of concentrated bat activity (e.g., near ponds and linear forested corridors). Because bats tend to forage and commute above and along these habitat features, it is not surprising to observe elevated levels of activity at these sites (Hein et al. 2009).

We found higher levels of activity for species considered vulnerable to wind development (i.e., hoary and big brown/silver-haired bats) between mid-August and late September, suggesting behavioral changes (e.g., migration) are likely occurring during this time. Similarly, activity data from the Golden Hills Wind Resource Area, Sherman Co., OR showed higher activity in fall with peaks in early August and early to mid-September (Jeffrey et al. 2008). Several studies at wind-energy facilities in eastern Oregon and Washington also have reported higher incidents of bat fatalities during August and September (Erickson et al. 2000, 2003, 2008, Johnson et al. 2003, Young et al. 2003, Gritski et al. 2008a, b, Jeffrey et al. 2008). These observations suggest that fall migration by bats is an episodic event. Among night variations in both bat activity and fatality at wind-energy facilities may be attributed to changes in insect abundance and availability, as well as life history traits of certain bat species (i.e., preparations for hibernation or migration, and reproductive condition; Horn et al. 2008). Furthermore, bat activity along migratory routes likely will increase at specific times during the year.

Our understanding of the broad regional migratory patterns of bats is limited (see Cryan 2003). Kerns et al. (2005) documented a strong positive correlation in the timing of fatalities of migratory tree bats between 2 sites within the same year. However, these sites were located only ~90 km apart. If bats are migrating across large areas of North America then regional patterns in activity and fatality will likely exist. In southern Alberta, Canada, researchers documented higher levels of both activity and fatality in August (Brown and Hamilton 2006, Baerwald 2008). In Washington and Oregon, activity and fatality typically peak between mid-August and September. Kerlinger et al. (2006) reported 70% of bat fatalities occurred in September. Thus, at a broader scale, migratory activity occurs at different times based on latitudinal difference among study sites.

We observed seasonal variations in bat activity with fewer bat passes recorded in spring than in fall. Reduced bat activity in spring is likely attributed to climatic conditions and elevation. Bat activity generally decreases with temperature (Hayes 1997, Hein 2008). Cold spring temperatures and high elevations at the CCWPP may have limited insect abundance and availability, and provided less optimal roosting opportunities for bats (Cryan et al. 2000, Ford et al. 2002). In addition, reproductively active female bats tend to use forests at lower elevations, presumably to increase foraging efficiency and minimize thermoregulatory costs associated with roosting (see Lacki et al. 2008). Furthermore, occupancy patterns may be the result of seasonal variations in migration. Migratory bats often segregate (by sex and age class) and use different routes in spring and fall (Cryan 2003). Therefore, we might expect limited bat presence during spring given these characteristics at the CCWPP.

In fall, we observed within-night differences in overall bat activity with the majority of passes occurring between 2–7 hours past sunset at 1.5 m and throughout the night at 50 m. This pattern generally was consistent among phonic groups. In contrast, numerous studies have reported nightly peaks shortly (1–2 hours) after sunset, with a second, smaller peak closer to sunrise (Kunz 1973, Erkert 1982, Taylor and O'Neil 1988, Maier 1992, Hayes 1997). Variations in nightly activity patterns are not unusual and may be attributed to behavioral patterns of bats, changes in insect prey abundance and availability, and climate and landscape characteristics. Within-night patterns also may shift throughout a season or year (Hayes 1997). The habitat (i.e., clear cut and young-aged forest stands) in and around the detector locations is not considered quality roosting habitat for bats in the region (Barclay and Kurta 2007), but may offer suitable commuting or foraging opportunities. Because bats typically emerge from roosts within ~1 hour past sunset (Hayes 1997), higher activity levels later in the evening are likely the result of traveling times from roosts to potential foraging sites by bats.

Our results are consistent with other studies showing variations in bat activity at different altitudes (Kalcounis et al. 1999, Hayes and Gruver 2000). Overall and for most phonic groups, with the exception of hoary bats, activity was higher at 1.5 m compared to 50 m. Several studies have reported higher activity by high-frequency bats (e.g., *Myotis* species) at lower altitudes and higher activity by low-frequency bats (e.g., hoary bats) at higher altitudes (Arnett et al. 2006, 2007b, Redell et al. 2006). The airspace in which certain species of bats occur generally can be predicted by their echomorpholgy (body size, wing shape, call frequency; Aldridge and Rautenbach 1987). Larger, less maneuverable bats with lower call frequencies typically fly higher and in more open habitats, whereas smaller, more maneuverable bats with higher call frequencies fly lower to the ground and in more cluttered (higher vegetation, increased tree density) habitats. Bats in our study followed similar trends, but low-frequency species (e.g., big brown/silver-haired bats) also were more active at lower altitudes. This is likely attributed to the more open, uncluttered habitat adjacent to our detectors and because met towers were located at higher elevations. In addition, big brown bats are considered generalists and may use a greater area of airspace when foraging (Brigham 1991, Owen et al. 2004, Schirmacher et al. 2008, Hein et al. 2009).

We found the highest activity of all bats at Coyote Crest North 3. Coyote Crest North 1 and Coyote Crest North 2 had similar activity rates throughout the study. Although it is not surprising to see spatial variations in bat activity across a project site (Mabee and Schwab 2008, Hein et al. 2009), specific reasons for the variability among towers are unknown at this time, but are likely attributed to differences in landscape features and climate conditions among towers. Coyote Crest North 1 and Coyote Crest North 2 were located along the ridgeline, at higher elevations, and in clear-cut stands, which presumably made them more exposed to the elements (e.g., colder temperatures and higher wind speeds) compared to Coyote Crest North 3 which was positioned within a younger-aged stand. The more sheltered location of Coyote Crest North 3 may have offered protection from wind making flying conditions more favorable for bats.

This study was conducted at a proposed wind-energy facility located along a mountainous ridge surrounded by an industrial forest landscape in western Washington. The results presented in this report may not represent bat activity patterns throughout the region. However, our ability to identify activity patterns of bats within a season, night, altitude, and location may provide useful information for predicting when, where, and which bats may be most at risk of collisions with wind turbines at the CCWPP. Because migratory tree-roosting bats comprise a disproportionately high percentage of fatalities (Arnett et al. 2008), it is important for acoustic monitoring studies to provide the highest resolution in identification rather than consolidate bats into total bat calls or high and low frequency phonic groups (Kunz et al. 2007b). Proper species (or species group) identification will aid in determining species movement patterns and offer additional insight into making decisions on turbine placement and operation.

A paucity of information exists relating pre-construction activity with post-construction fatality of bats. Although several studies have shown a positive correlation (r = 0.79) between total number of bat calls/night and estimated fatalities/turbine/year, confounding factors limit our ability to make inferences from these reports (see Kunz et al. 2007b). The lack of information regarding such relationships further supports the necessity for additional acoustic studies. Because bat acoustic monitoring can provide spatial and temporal activity patterns of bats, studies such as the one at the CCWPP are useful in resolving potential negative impacts of wind development on bat populations. Additionally, alternative methodologies (i.e., night vision optics, marine radar and NEXRAD doppler radar) may provide additional insight into nightly and seasonal behavior and emergence patterns of bats near wind-energy facilities (Mabee et al. 2006, Horn and Kunz 2008, Mabee and Schwab 2008).

SUMMARY

The key results of our bat acoustic monitoring study were: (1) total bat passes from all detectors across the entire study was 1,414 (spring = 20; fall = 1,394); (2) peak mean activity (passes/tower) for all bats occurred in September; (2) mean activity of migratory tree-roosting bats varied during fall with higher levels of activity occurring from mid-August through September; (3) mean bat activity (passes/detector-night) for all bats was 1.3 ± 0.1 across the entire study, and was lower in spring (0.08 ± 0.02) than in fall (1.7 ± 0.2) (4) mean activity (passes/detector-night) for migratory tree-roosting bats was 0.9 ± 0.09 across the entire study, and was lower in spring (0.03 ± 0.01) than in fall (1.1 ± 0.1); (5) peak activity for all species generally occurred 1–2 hours past sunset at both heights. Activity remained relatively high between 1 and 7 hours at 1.5 m, but at 50 m activity remained relatively constant throughout the night; (6) Mean activity (passes/detector-night) for all bats across the entire study was higher at 1.5 m (2.7 ± 0.3) than at 50 m (0.7 ± 0.1). Most phonic groups were detected more frequently at 1.5 m; however, hoary bat activity was slightly higher at 50 m; and (7) climate characteristics and landscape variability (i.e., topography and vegetation) among towers likely resulted in differences in mean activity (passes/detector-night) rates, with the highest activity at Coyote Crest North 3 for both 1.5 m (Coyote Crest North 1 = 1.6 ± 0.2, Coyote Crest North 2 = 0.6 ± 0.2, Coyote Crest North 3 = 6.1 ± 0.9) and 50 m (Coyote Crest North 1 = 0.7 ± 0.2, Coyote Crest North 2 = 0.2 ± 0.04, Coyote Crest North 3 = 1.3 ± 0.4) detectors.

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Appendix 1. Mean (passes/detector-night) and standard error (SE) between seasons by height for passes identified as big brown/silver-haired (EPFU/LANO), hoary (LACI), California/Yuma (MYCAYU), western long-eared/Keen's/fringed (MYEVKETH), long-legged/little brown (MYVOLU), unidentified high frequency (UNHI), unidentified low frequency (UNLO), migratory tree-roosting (Tree bats) bats, and all phonic groups combined (All bats) at the proposed Coyote Crest Wind Power Project, Washington, 2008. Seasons (spring = 15 April–30 June, 242 detector-nights; fall = 1 July–17 November, 552 detector-nights). Mann-Whitney U-test compares between season differences by height.

	Spring 2008[a]		Fall 2008		All Seasons		Mann-Whitney U	
Altitude/phonic group	Mean	SE	Mean	SE	Mean	SE	Z	P
1.5 m								
EPFU/LANO	<0.1	<0.1	0.6	0.1	0.4	0.1	-5.7	<0.001
LACI	0.0	<0.1	0.1	<0.1	<0.1	<0.1	-2.3	0.020
MYCAYU	0.1	<0.1	0.1	<0.1	0.1	<0.1	-2.0	0.047
MYEVKETH	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	-0.9	0.348
MYVOLU	<0.1	<0.1	0.1	<0.1	0.1	<0.1	-1.2	0.243
UNHI	0.0	0.0	<0.1	<0.1	<0.1	<0.1	-2.3	0.020
UNLO	0.0	0.0	0.2	<0.1	0.1	<0.1	-4.4	<0.001
Tree bats	<0.1	<0.1	0.8	0.1	0.6	0.1	-6.8	<0.001
All bats	0.1	<0.1	1.1	0.1	0.8	0.1	-6.4	<0.001
50 m								
EPFU/LANO	<0.1	<0.1	0.2	<0.1	0.2	<0.1	-4.4	<0.001
LACI	<0.1	<0.1	0.1	<0.1	0.1	<0.1	-2.4	0.014
MYCAYU	0.0	0.0	<0.1	<0.1	<0.1	<0.1	-0.9	0.348
MYEVKETH	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.000
MYVOLU	0.0	0.0	<0.1	<0.1	<0.1	<0.1	-0.9	0.348
UNHI	0.0	0.0	<0.1	<0.1	<0.1	<0.1	-0.7	0.508
UNLO	0.0	0.0	0.1	<0.1	0.1	<0.1	-3.5	<0.001
Tree bats	<0.1	<0.1	0.4	0.1	0.3	<0.1	-5.6	<0.001
All bats	<0.1	<0.1	0.4	0.1	0.3	<0.1	-5.8	<0.001
All altitudes								
EPFU/LANO	<0.1	<0.1	<0.1	<0.1	0.3	<0.1	-7.1	<0.001
LACI	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	-3.4	0.001
MYCAYU	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	-2.1	0.350
MYEVKETH	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	-0.9	0.104
MYVOLU	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	-1.4	0.167
UNHI	0.0	0.0	0.0	0.0	<0.1	<0.1	-2.4	0.016
UNLO	0.0	0.0	0.0	0.0	0.1	<0.1	-5.6	<0.001
Tree bats	<0.1	<0.1	<0.1	<0.1	0.5	<0.1	-8.8	<0.001
All bats	0.1	0.0	0.1	<0.1	0.6	0.1	-8.5	<0.001

[a] Spring includes data from Coyote Crest North 1 and Coyote Crest North 2 only; Coyote Crest North 3 was not operational during spring.

Appendix 2. Mean (passes/detector-night) and standard error (SE) between heights by season for passes identified as big brown/silver-haired (EPFU/LANO), hoary (LACI), California/Yuma (MYCAYU), western long-eared/Keen’s/fringed (MYEVKETH), long-legged/little brown (MYVOLU), unidentified high frequency (UNHI), unidentified low frequency (UNLO), migratory tree-roosting (Tree bats) bats, and all phonic groups combined (All bats) at the proposed Coyote Crest Wind Power Project, Washington, 2008. Seasons (spring = 15 April–30 June, 242 detector-nights; fall = 1 July–17 November, 552 detector-nights). Wilcoxon test compares all detector-nights (*n* = 526) when both 1.5 m and 50 m were operational.

	1.5 m		50 m		All Altitudes		Wilcoxon Test	
Season/phonic group	Mean	SE	Mean	SE	Mean	SE	Z	P
Spring 2008[a]								
EPFU/LANO	<0.1	<0.1	<0.1	<0.1	<0.1	0.0	-1.4	0.157
LACI	0.0	0.0	<0.1	<0.1	<0.1	<0.1	-1.0	0.317
MYCAYU	0.1	<0.1	0.0	0.0	<0.1	<0.1	-2.1	0.038
MYEVKETH	<0.1	<0.1	0.0	0.0	<0.1	<0.1	-1.0	0.317
MYVOLU	<0.1	<0.1	0.0	0.0	<0.1	<0.1	-1.9	0.059
UNHI	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.000
UNLO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.000
Tree bats	<0.1	<0.1	<0.1	<0.1	0.0	<0.1	-1.0	0.317
All bats	0.1	<0.1	<0.1	<0.1	0.1	<0.1	-2.6	0.010
Fall 2008								
EPFU/LANO	1.1	0.2	0.5	0.1	0.8	0.1	-6.1	<0.001
LACI	0.1	<0.1	0.1	<0.1	0.1	<0.1	-1.8	0.07
MYCAYU	0.8	0.1	<0.1	<0.1	0.4	0.1	-8.1	<0.001
MYEVKETH	0.1	<0.1	0.0	0.0	<0.1	<0.1	-3.4	0.001
MYVOLU	0.2	<0.1	<0.1	<0.1	0.1	<0.1	-6.6	<0.001
UNHI	0.2	<0.1	<0.1	<0.1	0.1	<0.1	-5.3	<0.001
UNLO	0.3	<0.1	0.1	<0.1	0.2	<0.1	-4.8	<0.001
Tree bats	1.5	0.2	0.7	0.1	1.1	0.1	-6.5	<0.001
All bats	2.7	0.3	0.7	0.1	1.7	0.2	-9.7	<0.001
All Seasons								
EPFU/LANO	0.9	0.1	0.4	0.1	0.6	0.1	-6.3	<0.001
LACI	0.1	<0.1	0.1	<0.1	0.1	0.0	-1.9	0.06
MYCAYU	0.6	0.1	<0.1	<0.1	0.3	0.1	-8.3	<0.001

Appendix 2. Continued.

	1.5 m		50 m		All Altitudes		Wilcoxon Test	
Season/phonic group	Mean	SE	Mean	SE	Mean	SE	Z	P
MYEVKETH	<0.1	<0.1	0.0	0.0	0.0	0.0	-3.6	<0.001
MYVOLU	0.2	<0.1	<0.1	<0.1	0.1	0.0	-6.8	<0.001
UNHI	0.1	<0.1	<0.1	<0.1	0.1	0.0	-5.3	<0.001
UNLO	0.2	<0.1	0.1	<0.1	0.2	0.0	-4.8	<0.001
Tree bats	1.2	0.1	0.5	0.1	0.9	0.1	-6.6	<0.001
All bats	2.1	0.2	0.6	0.1	1.3	0.1	-10.0	<0.001

[a] Spring includes data from Coyote Crest North 1 and Coyote Crest North 2 only; Coyote Crest North New was not operational during spring.

Appendix 3. Mean (passes/detector-night) and standard error (SE) among towers by season for passes identified as big brown/silver-haired (EPFU/LANO), hoary (LACI), California/Yuma (MYCAYU), western long-eared/Keen's/fringed (MYEVKETH), long-legged/little brown (MYVOLU), unidentified high frequency (UNHI), unidentified low frequency (UNLO), migratory tree-roosting (Tree bats) bats, and all phonic groups combined (All bats) at the proposed Coyote Crest Wind Power Project, Washington, 2008. Seasons (spring = 15 April–30 June, 242 detector-nights; fall = 1 July–17 November, 552 detector-nights). Mann-Whitney U-test compares between tower differences in spring. Kruskal-Wallis test used to compare among tower differences in fall.

	Coyote Crest North 1		Coyote Crest North 2		Coyote Crest North 3		Statistical Test	
Season/phonic group	Mean	SE	Mean	SE	Mean	SE	Statistic	P
Spring 2008[a]								
EPFU/LANO	<0.1	<0.1	<0.1	<0.1			-0.6	0.530
LACI	<0.1	<0.1	0.0	0.0			-1.1	0.281
MYCAYU	<0.1	<0.1	0.1	<0.1			-1.2	0.232
MYEVKETH	<0.1	<0.1	0.0	0.0			-1.1	0.281
MYVOLU	0.0	0.0	<0.1	<0.1			-1.9	0.062
UNHI	0.0	0.0	0.0	0.0			0.0	1.000
UNLO	0.0	0.0	0.0	0.0			0.0	1.000
Tree bats	<0.1	<0.1	<0.1	<0.1			-1.0	0.308
All bats	0.1	<0.1	0.1	<0.1			-0.6	0.565
Fall 2008 1.5 m								
EPFU/LANO	0.8	0.2	0.4	0.1	2.3	0.5	26.8	<0.001
LACI	0.1	<0.1	<0.1	<0.1	0.1	<0.1	8.6	0.013
MYCAYU	0.3	0.1	<0.1	<0.1	2.3	0.4	79.9	<0.001
MYEVKETH	<0.1	<0.1	<0.1	<0.1	0.1	<0.1	4.4	0.111
MYVOLU	0.1	<0.1	<0.1	<0.1	0.5	0.1	46.3	<0.001
UNHI	0.1	<0.1	<0.1	<0.1	0.4	0.1	23.3	<0.001
UNLO	0.2	<0.1	0.1	<0.1	0.5	0.1	18.3	<0.001
Tree bats	1.2	0.2	0.5	0.1	2.9	0.5	33.9	<0.001
All bats	1.6	0.2	0.6	0.1	6.1	0.9	63.4	<0.001
Fall 2008 50 m								
EPFU/LANO	0.4	0.1	0.1	<0.1	1.0	0.3	13.5	0.001
LACI	0.1	<0.1	<0.1	<0.1	0.2	0.1	4.6	0.102
MYCAYU	<0.1	<0.1	0.0	0.0	0.0	0.0	3.9	0.144

Appendix 3. Continued.

Season/phonic group	Coyote Crest North 1		Coyote Crest North 2		Coyote Crest North 3		Statistical Test	
	Mean	SE	Mean	SE	Mean	SE	Statistic	P
MYEVKETH	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.000
MYVOLU	<0.1	<0.1	0.0	0.0	0.0	0.0	3.9	0.144
UNHI	0.0	<0.1	0.0	0.0	0.0	0.0	1.9	0.380
UNLO	0.2	<0.1	0.1	<0.1	0.1	<0.1	5.4	0.068
Tree bats	0.7	0.1	0.2	<0.1	1.3	0.4	18.1	<0.001
All bats	0.7	0.1	0.2	<0.1	1.3	0.4	19.4	<0.001

[a] Spring includes data from Coyote Crest North 1 and Coyote Crest North 2 only; Coyote Crest North 3 was not operational during spring.

Appendix 4a. Summary of spring bat acoustic studies at wind-energy projects across North America. An X denotes data unavailable.

Project	Study period	Detector-nights	Total passes	Detectors/ station	Stations	Mean passes/ detector - night	Detector Height (m)	Methods[a]	Source
Northeast									
Deerfield, VT	4/14/06–6/13/06	107	4	2	2	0.04[c]	10, 20	2	Woodlot 2006d
		50	7	2	2	0.14[c]	15, 35	2	
		37	4	1	1[b]	0.11[c]	23	3	
Bliss, NY	4/20/05–6/13/05	54	6,032	2	1[d]	55.85[c]	15, 30	3	Ecology & Environment 2006
Centerville, NY	4/06/06–6/07/06	126	270	2	1	2.15	10, 25	2	Woodlot 2006e
Cohocton, NY	5/2/05–5/30/05	29	21	1	1	0.72	X	3	Woodlot 2006c
Dairy Hills, NY	5/20/05–6/01/05	10	27	1	1	2.70	1	3	Young et al. 2006
Howard, NY	4/15/06–6/6/06	116	50	3	1	0.43	8, 20, 50	2	Woodlot 2006b
Jordanville, NY	4/14/05–5/13/05	29	15	1	1	0.52	30	3	Woodlot 2005a
Maple Ridge, NY	4/10/05–6/22/05	74	459	3	2	1.03[c]	7, 25, 50	2	Reynolds 2006
Prattsburgh, NY	4/15/05–5/30/05	57	16	2	1	0.28[c]	15, 30	2	Woodlot 2005c
Wethersfield, NY	4/06/06–6/07/06	126	192	2	1	1.52	10, 25	2	Woodlot 2006e
Pacific Northwest									
Coyote Crest, WA	**4/15/08–6/30/08**	**242**	**20**	**2**	**2**	**0.08**	**1.5, ~50**	**1**	**Hein et al. 2009 – this study**

[a] 1 = methodology, sampling intensity (spatial and vertical), sampling dates, and analysis similar to current study (comparable), 2 = differences in methodology, sampling intensity, sampling dates, or analysis (unknown comparability), 3 = multiple differences in methodology, sampling intensity, sampling dates, and analysis (not comparable).

[c] Detector(s) located in areas of concentrated bat activity (i.e., tree line or pond).

[c] Calculated value, not presented in literature.

[d] Detector mounted on a silo.

Appendix 4b. Summary of fall bat acoustic studies at wind development projects across North America. An X denotes data unavailable.

Project	Study period	Detector-nights	Total passes	Detectors /station	Station	Mean passes/ detector-night	Detector Height (m)	Methods[a]	Source
Northeast									
Hoosac, MA	7/26/06–11/11/06	1635	4,816	3	5	2.95[c]	10, 31, 39	2	Arnett et al. 2007b
Bliss, NY	8/15/05–10/9/05	55	3,725	2	1[b]	33.86[c]	15, 30	3	Ecology & Environment 2006
Centerville, NY	7/25/06–10/10/06	89	5	2	1	0.06	15, 35	3	Woodlot 2006a
Cohocton, NY	8/3/05–10/15/05	122	191	2	1	1.57	15, 23	3	Woodlot 2006c
Dairy Hills, NY	8/16/05–10/14/05	83	306	2	1	3.69	1, ~50	3	Young et al. 2006
Howard, NY	8/3/05–8/19/05	25	60	2	1	2.40[c]	27, 48	3	Woodlot 2005b
	8/3/05–8/27/05	25	1,439	1	1[e]	57.56[c]	2	3	
Roaring Brook, NY	7/20/07–10/15/07	528	4,257	2	3	8.06[c]	1.5, 44	2	Mabee and Schwab 2008
Wethersfield, NY	7/25/06–10/09/06	80	22	2	1	0.28	15, 35	3	Woodlot 2006a
Somerset, PA	8/1/05–11/1/05	93	9,162	3, 2	5, 7	6.57[c]	1.5, 22, 44	2	Arnett et al. 2006
Buffalo Mtn., TN	9/1/00–9/30/03	149	X	X	X	23.70	X	3	Fiedler 2004
Mountaineer, WV	8/31/04–9/11/04	33	X	X	X	38.20	X	3	Arnett (unpublished data)
Liberty Gap, WV	9/15/04 – 11/6/04	14	91	2	1	6.50[c]	15, 30	3	Woodlot 2005d
Midwest									
Top of Iowa, IA	5/10/04–9/29/04	84	3,001	1	2	35.73[c]	~1	3	Jain 2005
Buffalo Ridge, MN	6/15/01–9/15/02	216	452	1	3	2.09[c]	X	3	Johnson et al. 2004
		77	3,718	1	1[e]	48.29[c]	~1	3	
Butler Ridge, WI	7/19/05–9/30/05	1,786	26,495	3, 2	3, 5	14.80[c]	2, 22, 48	2	Redell et al. 2006
West									
Foote Creek, WY	6/26/00–8/13/01	80	4,315	1–3	1–3[e]	53.93[c]	~1, 15	3	Gruver 2002
Pacific Northwest									
Alberta, Canada	7/15/06–9/30/06	282	1,488[d]	3	1	5.28	1, 30, 67	2	Baerwald 2008
	7/15/07–9/30/07	299	1,592[d]	3	1	5.45	1, 30, 67		
Coyote Crest, WA	**7/1/08–11/17/08**	**810**	**1,394**	**3**	**2**	**1.72**	**1.5, ~50**	**1**	**Hein et al. 2009 – this study**
Saddleback, WA	7/3/08–10/7/08	97	56,595	1	3[e]	148.34	1	3	Johnson et al. 2009
Golden Hills, OR	7/27/07–10/28/07	294	1,552	1	4	5.30[c]	<1	3	Jeffery et al. 2008

[a] 1 = methodology, sampling intensity (spatial and vertical), sampling dates, and analysis similar to current study (comparable), 2 = differences in methodology, sampling intensity, sampling dates, or analysis (unknown comparability), 3 = multiple differences in methodology, sampling intensity, sampling dates, and analysis (not comparable).

[b] Detector mounted on a silo.

[c] Calculated value, not presented in literature.

[d] Data only includes mean passes of migratory tree-roosting bats.

[e] Detector(s) located in areas of concentrated bat activity (i.e., tree line or pond).