AN ACOUSTIC STUDY OF BAT ACTIVITY AT THE PROPOSED ROARING BROOK WIND PROJECT, NEW YORK, SPRING–FALL 2008

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FINAL REPORT

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January 2009

Printed on recycled paper.

EXECUTIVE SUMMARY

- This report presents results of a bat acoustic monitoring study conducted during a 181-day period (18 April–15 October 2008) at the proposed Roaring Brook Wind Project, Lewis County, New York. This project area is characterized by secondary forest interspersed with small wetlands. Each night we conducted bat acoustic monitoring for ~11–13 h/night (~1h < sunset to ~1h > sunrise).
- 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 (i.e., # bat passes/h, night, or tower) for migratory tree-roosting bats (e.g., hoary, Eastern red, 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.
- Peak mean activity (mean passes/tower) for all bats occurred in mid-July. Peak activity for migratory tree-roosting bats also occurred in mid-July and varied among species with higher activity levels of big brown/silver-haired bats preceding hoary and red bats.
- Mean activity for all bats was 9.4 ± 0.8 passes/tower/night across the entire study, and was higher in fall (12.0 ± 1.1) compared to spring (5.6 ± 0.6). Mean activity for migratory tree-roosting species was 4.4 ± 0.5 and also was higher in fall (5.8 ± 0.7) compared to spring (2.3 ± 0.3).
- Peak activity occurred 1–2 hours after sunset for all species during both seasons and for the entire study.
- Mean activity (passes/tower/night) for all bats across the entire study was higher at 1.5 m (7.1 ± 0.6) than at 44 m (2.3 ± 0.2). Big brown/silver-haired bats and *Myotis* spp. were detected more frequently at 1.5 m (big brown/silver-haired = 1.0 ± 0.1; *Myotis* spp. = 3.8 ± 0.3) than at 44 m (big brown/ silver-haired = 0.5 ± 0.1; *Myotis* spp. = 0.3 ± 0.1), whereas activity of Eastern red bats showed no difference between heights, and hoary bat activity was higher at 44 m (0.8 ± 0.1) compared to 1.5 m (0.5 ± 0.1).
- Variability in mean activity existed between towers in 2008, with higher activity at Joe's tower (10.9 ± 0.9 passes/night) compared to Fairbanks (7.9 ± 0.7 passes/night).
- Mean activity (passes/night) generally was higher at all towers in 2007 compared to 2008.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

ACKNOWLEDGMENTS

We thank Iberdrola Renewables for funding this study. We thank Jenny Burke (Iberdrola) for helping with project coordination and logistics and Dan Murdie (Iberdrola) for field assistance. We thank the staff and owners of Deer River Ranch for providing access and help with field logistics. At ABR, we thank Delee Spiesschaert and Susan Cooper for logistical support, Leslie Rodman and Matt Apling for help with data analysis and table preparation, Pam Odom for report preparation, and Rich Blaha for figure preparation.

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, growing by 27% and 46% in 2006 and 2007, respectively (Wiser and Bolinger 2008). In 2007, New York ranked 13th in the United States in newly installed wind-generating capacity at 55 MW and 11th overall for cumulative capacity at 425 MW (Wiser and Bolinger 2008). 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 suggests high fatality events occur across a variety of landscapes across North America, including agricultural, grassland prairies, and deciduous or coniferous forests (see Arnett et al. 2008, Barclay et al. 2007, Kunz et al. 2007a). 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. Several hypotheses explaining possible bat/turbine interactions exist (i.e., roost, landscape, acoustic or visual attraction), however, none have been tested (Arnett et al. 2005, Barclay et al. 2007, Cryan and Brown 2007, Kunz et al. 2007a). The lack of data on population estimates, migratory pathways, and flight behaviors around wind turbines of North American bats highlights the need for additional information to resolve these different hypotheses.

Nine species of bats are known to occur in New York. Of these, 1 (Indiana bat, *Myotis sodalis*) is listed as federally endangered by the U.S. Fish and Wildlife Service (USFWS 2008a). The New York State Department of Environmental Conservation (NYSDEC) also lists the Indiana bat as state endangered and the Eastern small-footed myotis (*Myotis lebeii*) as a species of concern (NYSDEC 2008). The remaining 7 species of bats (big brown; hoary; tri-colored- formerly Eastern pipistrelle, *Perimyotis subflavus*; Eastern red; little brown, *M. lucifugus*; Northern long-eared, *M. septentrionalis*; and silver-haired) are not granted special conservation status in New York. However, several species (i.e., hoary bat, Eastern red bat, and silver-haired bat) are of increasing concern, particularly with respect to wind development, because of high fatalities at most wind-energy facilities in the U.S. (Arnett et al. 2008). Because wind-energy development may negatively impact resident and migrating bat species (Arnett et al. 2008, Kunz et al. 2007a), it is important to study the nightly and seasonal variations in bat activity.

Iberdrola Renewables proposes to build the Roaring Brook Wind Project (Roaring Brook), an ~40 turbine facility capable of generating ~80 MW of wind energy. The height of each 2.0 MW turbine tower will be 100 m with a rotor diameter of 90 m for a total maximum turbine height of 145 m (with the blade in the vertical position). In 2008, we conducted bat acoustic monitoring at the proposed project. This study extended previous work conducted by ABR, Inc. at Roaring Brook during spring 2007 (i.e., a night-vision study of birds and bats, Mabee et al. 2008) and fall 2007 (i.e., a night-vision and bat acoustic monitoring study, Mabee and Schwab 2008).

OBJECTIVES

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 (i.e., # bat passes/h, night, or tower) for migratory tree-roosting bats (e.g., hoary, Eastern red, 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 Roaring Brook Wind Project is located in the Tug Hill Plateau, Lewis County, New York (Fig. 1). The area is located in the Appalachian Plateaus physiographic province (USGS 2003) and is characterized by rolling hills ranging from 307 to 615 m above sea level (asl). Although the region's elevation and proximity to Lake Ontario results in annual winter snowfall ≥500 cm with snow patches persisting into June, summer and early fall are warm with temperatures occasionally exceeding 35 °C (New York State Tug Hill Commission 2008).

This proposed development is located completely within a ~4,150 acre (~1,679 hectares) ranch (Deer River Ranch) approximately 15 km southwest of Lowville, New York. The area consists of secondary forest interspersed with wet meadows, small wetlands, beaver ponds, and the origins of three rivers: Roaring Brook (draining ~east into the Black River); Fish Creek (draining southeast); and Deer River (draining ~north). The entire landscape previously has been logged, with existing forests comprised of young mixed pine-hardwood stands. No residential development exists on the property except for a few seasonal cabins. Adjacent properties owned by The Nature Conservancy to the south and New York State (Tug Hill Wildlife Management Area) to the west also are relatively undeveloped. The northern boundary is part of the Tug Hill IBA (Important Bird Area; Burger and Liner 2005).

Our acoustic monitoring stations were located at 3 existing meteorological towers on the ranch (Fig. 1). The number and location of towers used in this study allowed us to capture the maximal amount of spatial variation at the proposed site. Our sampling stations were located at Joe's tower ([NAD 83] UTM Zone 18 0450784E, 4840800N), Birch tower (UTM Zone 18 0450940E, 4839445N), and Fairbanks tower (UTM Zone 18 0449496E, 483822N).

METHODS

EQUIPMENT

We used 6 Anabat SD1 broadband acoustic detectors (Titley Electronics, Ballina, New South Wales, Australia) positioned at 3 meteorological towers (Birch, Fairbanks, and Joe's) to record echolocation call sequences, or bat passes, onto 1 GB compact flash (CF) cards. 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 microphones on each tower at 1.5 m and 44 m above ground level (agl), respectively. We employed pulley systems secured to meteorological towers to raise microphones to 44 m sampling heights. 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) and outlined in New York's draft guidance document (NYSDEC 2007). We monitored bat acoustic activity during crepuscular and nocturnal hours (~1 h before sunset to ~1 h after sunrise), between 1657 and 838, with hours sampled ranging between 11 and 13 h/night. This sampling schedule provided coverage during times when bat are most active in the region (Reynolds 2006) and exceeds that of similar studies in the Eastern United States (Arnett et al. 2006, 2007b, Reynolds 2006, Young et al. 2006). Iberdrola staff visited each tower every other week during spring and summer, and weekly during fall to exchange CF cards and shipped them to ABR for analysis. We downloaded and analyzed data using Anabat CFC Read (version 4.2a) and AnalookW (version 3.5p) software respectively.

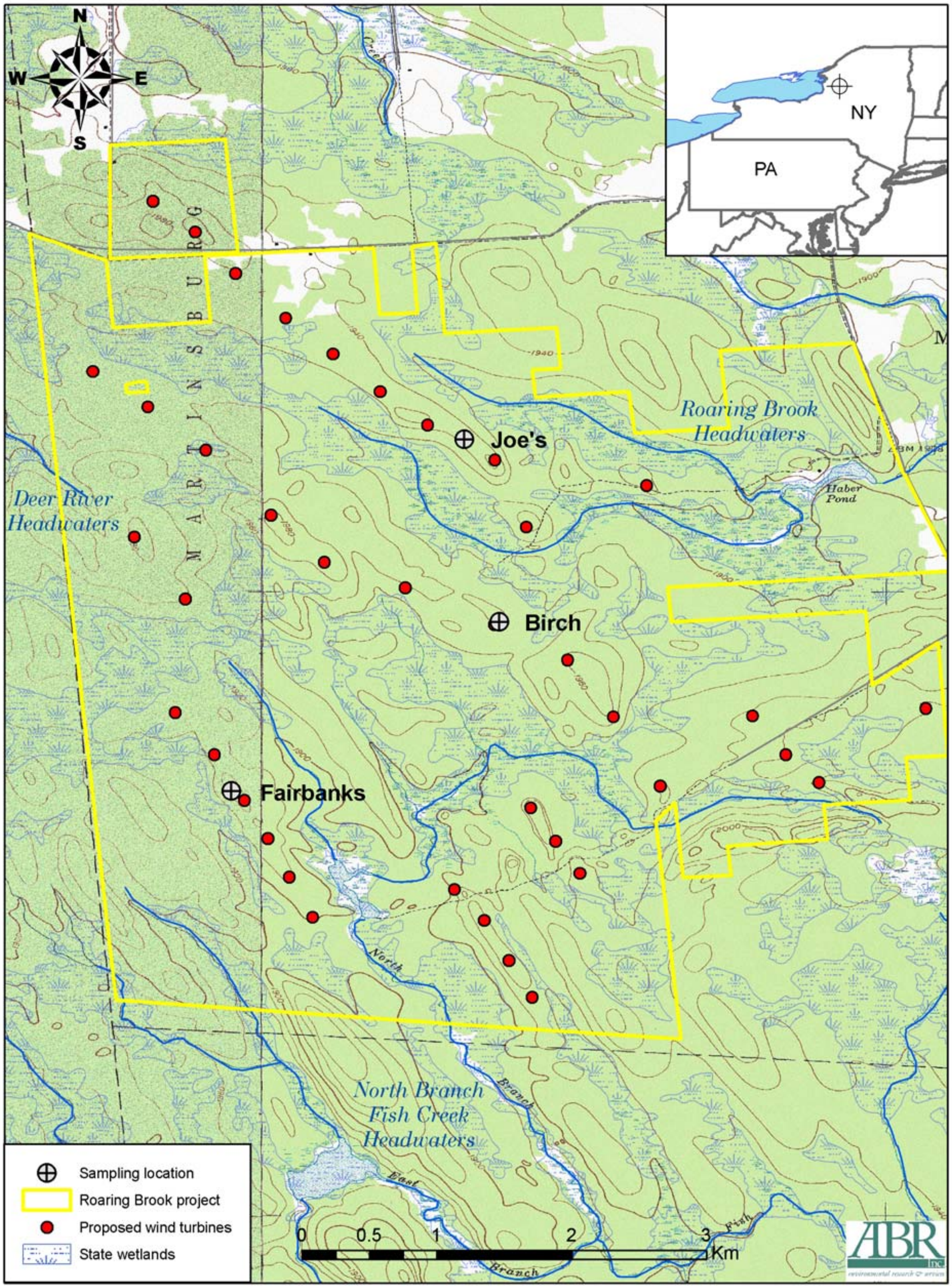

Figure 1. Map of the proposed Roaring Brook Wind Project in Lewis County, New York, 2008.

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 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" and "terminal" phase passes typically are used to target and capture insect prey and can vary widely within a species. A bat pass is a standard term used to identify bat activity (Kunz et al. 2007b), although other terms also have been used synonymously, including "calls" (Ecology and Environment 2006, Woodlot 2006b, Young et al. 2006), and "call sequences" (Woodlot 2006b).

We compared echolocation call characteristics of each unknown bat pass (e.g., minimum frequency, duration) 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. For this study, we placed passes into 7 phonic groups: (1) big brown/silver-haired bat (EPFU/LANO), (2) Eastern red bat (LABO), (3) hoary bat (LACI), (4) little brown bat/northern long-eared bat/Eastern small-footed bat/Indiana bat (MYOTIS), (5) tri-colored bat-formerly Eastern pipistrelles (PESU), (6) unidentified high frequency (>35 kHz; i.e., *Myotis* spp., Eastern red, tri-colored bats (UNHI), and (7) unidentified low frequency (≤35 kHz; i.e., big brown/silver-haired, hoary) bats (UNLO) following criteria similar to other studies within the region (Betts 1998, Gannon et al. 2003, Reynolds 2006, Mabee and Schwab 2008). 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, TREEBATS, which includes several phonic groups (EPFU/LANO, LABO, LACI, and UNLO) that are most impacted at wind-energy facilities. We include UNLO in this category because the phonic group is comprised exclusively of big brown/silver-haired and hoary bats. We created a single category, ALLBATS, comprised of all phonic groups combined.

We divided our study into 2 seasons (spring and fall). 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 (18 April–30 June, n = 74 days) season. We based our fall season (1 July–15 October, n = 107 days) on recent data from the region (Jain et al. 2007, Mabee and Schwab 2008) showing high levels of activity and fatality beginning in July and continuing through September and because nearly 90% of bat fatalities occur in late summer/early fall (Erickson et al. 2002). To statistically compare activity data between 2007 and 2008, we created a third dataset (20 July–15 October) with dates consistent with Mabee and Schwab (2008).

Because our data were not normally distributed, we used non-parametric statistical tests for all analyses. We compared mean bat activity between towers at 1.5m, 44m, and across all heights using the Mann-Whitney U (M-W test) test. We also used the M-W test to compare mean activity between seasons and between years (fall 2007 and fall 2008). We pooled height data from Joe's and Fairbanks towers and used Wilcoxon signed rank test to compare mean activity between1.5 m and 44 m detectors. We used repeated-measures ANOVAs with Greenhouse-Geisser epsilon adjustment for degrees of freedom (SPSS 2007) to compare mean activity among hours of the night when bats were detected. We define mean activity as mean passes/tower/night unless stated otherwise. 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.

RESULTS

We conducted bat acoustic monitoring at 3 meteorological towers for 181 nights between 18 April and 15 October 2008 (spring = 74 nights; fall = 107 nights). We obtained useable data on all 181 nights (100%) from both detector heights at Joe's and Fairbanks towers and 152 nights (84%) at Birch 1.5 m. We were unable to use data collected at Birch 44 m due to inconsistencies in equipment functionality. Although equipment at Birch 44 m passed our field quality control checks throughout the year, data recorded were unsuitable for analyses because of intermittent equipment problems. Because Birch 44 m detector was nonoperational, results presented includes only data recorded at Joe's and Fairbanks towers unless stated otherwise.

GENERAL BAT ACTIVITY

We recorded 4,914 total bat passes from all 3 towers at 2 heights (except Birch 44 m) during the entire study (Table 1). Overall, most passes (74.5%) were identified to species or species groups represented in descending order by MYOTIS, EPFU/LANO, LACI, LABO, PESU, with the remaining passes (25.5%) identified as UNHI and UNLO. The group TREEBATS (EPFU/LANO, LABO, LACI, and UNLO) represented 46.9% of passes recorded. Because only 2 PESU calls were recorded during this study, this phonic group was excluded from further analyses.

Total number of bat passes varied between spring (n = 1,048) and fall (n = 3,866) seasons (Tables 2, 3). Most passes (spring = 81.1%; fall = 72.7%) were identified to species or species groups. Relative order of species activity in spring was consistent with the entire study period, but in fall, LACI was the second most detected species. The group TREEBATS accounted for 42.9% and 47.9% of bat activity in spring and fall, respectively.

TEMPORAL DIFFERENCES IN ACTIVITY

SEASONAL

Mean activity (mean passes/tower) for ALLBATS varied among nights with low activity levels recorded in early spring and late fall (Fig. 2). Spring activity peaked in early June with highs on 9 June (mean = 14.5) and 6 June (mean = 12.7) for 1.5 m and 44 m detectors, respectively. In fall, activity at both heights peaked in mid-July with several nights of high activity between 16 July and 23 July. Several smaller peaks in activity occurred between late July and late August.

We observed variations in mean 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; Figs. 3, 4). The EPFU/LANO group showed high levels of activity at 1.5 m during early July with several nights of relatively high activity at 44 m throughout the month. Activity of EPFU/LANO decreased in August and maintained low levels of activity through October. Activity of LACI peaked in late July with high rates across both heights. Few LACI calls were detected after late August. Overall, LABO was detected infrequently, but the majority (94%, n = 32) of calls occurred in fall with highs in activity occurring at both heights in late July.

Mean activity (passes/tower/night) of ALLBATS for the entire study across both heights was 9.4 ± 0.8 and increased between spring (5.6 ± 0.6) and fall (12.0 ± 1.1) seasons (M-W test Z = -3.8, P < 0.001; Fig. 5). Mean activity of TREEBATS was 4.4 ± 0.5 and increased (Z =

Table 1. Number of bat passes (N) identified as big brown/silver-haired (EPFU/LANO), Eastern red (LABO), hoary (LACI), *Myotis* spp. (MYOTIS), tri-colored (PESU), unidentified high frequency (UNHI), and unidentified low frequency (UNLO) bats recorded across all detectors at the proposed Roaring Brook Wind Project, New York, 2008. Percentages represent the proportion of bat passes at a given tower and altitude.

	Joe's		Birch[a]		Fairbanks		Total	
Altitude/phonic group	N	%	N	%	N	%	N	%
Bat passes at 1.5 m								
EPFU/LANO	206	4.2	274	5.6	149	3.0	629	12.8
LABO	7	0.1	9	0.2	3	0.1	19	0.4
LACI	123	2.5	198	4.0	73	1.5	394	8.0
MYOTIS	858	17.5	657	13.3	531	10.8	2046	41.6
PESU	1	0.0	1	0.0	0	0.0	2	0.0
UNHI	188	3.8	132	2.7	108	2.2	428	8.7
UNLO	186	3.8	234	4.8	142	2.9	562	11.5
TOTAL	*1569*	*31.9*	*1505*	*30.6*	*1006*	*20.5*	*4080*	*83.0*
Bat passes at 44 m								
EPFU/LANO	72	1.5			103	2.1	175	3.6
LABO	9	0.2			6	0.1	15	0.3
LACI	133	2.7			156	3.2	289	5.9
MYOTIS	49	1.0			44	0.9	93	1.9
PESU	0	0.0			0	0.0	0	0.0
UNHI	28	0.6			16	0.3	44	0.9
UNLO	118	2.4			100	2.0	218	4.4
TOTAL	*409*	*8.4*			*425*	*8.6*	*834*	*17.0*
All altitudes								
EPFU/LANO	278	5.7	274	5.6	252	5.1	804	16.4
LABO	16	0.3	9	0.2	9	0.2	34	0.7
LACI	256	5.2	198	4.0	229	4.7	683	13.9
MYOTIS	907	18.5	657	13.3	575	11.7	2139	43.5
PESU	1	0.0	1	0.0	0	0.0	2	0.0
UNHI	216	4.4	132	2.7	124	2.5	472	9.6
UNLO	304	6.2	234	4.8	242	4.9	780	15.9
TOTAL	*1978*	*40.3*	*1505*	*30.6*	*1431*	*29.1*	*4914*	*100.0*

[a]Missing data at Birch 44 m attributed to inconsistencies and detector functionality.

Table 2. Number of bat passes (N) in spring identified as big brown/silver-haired (EPFU/LANO), Eastern red (LABO), hoary (LACI), *Myotis* spp. (MYOTIS), tri-colored (PESU), unidentified high frequency bats (UNHI), and unidentified low frequency (UNLO) bats recorded across all detectors at the proposed Roaring Brook Wind Project, New York, 2008. Percentages represent the proportion of bat passes at a given altitude.

	Joe's		Birch[a]		Fairbanks		Total	
Altitude/phonic group	N	%	N	%	N	%	N	%
Bat passes at 1.5 m								
EPFU/LANO	66	6.3	72	6.9	47	4.4	185	17.7
LABO	0	0.0	1	0.1	0	0.0	1	0.1
LACI	10	1.0	8	0.8	2	0.2	20	1.9
MYOTIS	253	24.1	91	8.6	159	15.2	503	48.0
PESU	1	0.1	0	0.0	0	0.0	1	0.1
UNHI	26	2.5	9	0.9	8	0.8	43	4.1
UNLO	29	2.7	34	3.2	22	2.1	85	8.1
TOTAL	*385*	*36.7*	*215*	*20.5*	*238*	*22.7*	*838*	*80.0*
Bat passes at 44 m								
EPFU/LANO	25	2.4			47	4.5	72	6.9
LABO	1	0.1			0	0.0	1	0.1
LACI	14	1.3			15	1.4	29	2.8
MYOTIS	21	2.0			17	1.6	38	3.6
PESU	0	0.0			0	0.0	0	0.0
UNHI	10	1.0			2	0.2	12	1.1
UNLO	40	3.8			18	1.7	58	5.5
TOTAL	*111*	*10.6*			*99*	*9.4*	*210*	*20.0*
All altitudes								
EPFU/LANO	91	8.7	72	6.9	94	9.0	257	24.5
LABO	1	0.1	1	0.1	0	0.0	2	0.2
LACI	24	2.3	8	0.8	17	1.6	49	4.7
MYOTIS	274	26.1	91	8.6	176	16.8	541	51.6
PESU	1	0.1	0	0.0	0	0.0	1	0.1
UNHI	36	3.4	9	0.9	10	1.0	55	5.3
UNLO	69	6.6	34	3.2	40	3.8	143	13.6
TOTAL	*496*	*47.3*	*215*	*20.5*	*337*	*32.2*	*1048*	*100.0*

[a] Missing data at Birch 44 m attributed to inconsistencies and detector functionality.

Table 3. Number of bat passes (N) in fall identified as big brown/silver-haired (EPFU/LANO), Eastern red (LABO), hoary (LACI), *Myotis* spp. (MYOTIS), tri-colored (PESU), unidentified high frequency bats (UNHI), and unidentified low frequency (UNLO) bats recorded across all detectors at the proposed Roaring Brook Wind Project, New York, 2008. Percentages represent the proportion of bat passes at a given altitude.

	Joe's		Birch[a]		Fairbanks		Total	
Altitude/phonic group	N	%	N	%	N	%	N	%
Bat passes at 1.5 m								
EPFU/LANO	140	3.6	202	5.3	102	2.7	444	11.5
LABO	7	0.2	8	0.2	3	0.1	18	0.5
LACI	113	2.9	190	4.9	71	1.8	374	9.7
MYOTIS	605	15.6	566	14.6	372	9.6	1543	39.9
PESU	0	0.0	1	0.03	0	0.0	1	0.03
UNHI	162	4.2	123	3.2	100	2.6	385	10.0
UNLO	157	4.1	200	5.2	120	3.1	477	12.3
TOTAL	*1184*	*30.6*	*1290*	*33.4*	*768*	*19.9*	*3242*	*83.9*
Bat passes at 44 m								
EPFU/LANO	47	1.2			56	1.5	103	2.7
LABO	8	0.2			6	0.2	14	0.4
LACI	119	3.1			141	3.6	260	6.7
MYOTIS	28	0.7			27	0.7	55	1.4
PESU	0	0.0			0	0.0	0	0.0
UNHI	18	0.5			14	0.3	32	0.8
UNLO	78	2.0			82	2.1	160	4.1
TOTAL	*298*	*7.7*			*326*	*8.4*	*624*	*16.1*
All altitudes								
EPFU/LANO	187	4.8	202	5.3	158	4.1	547	14.2
LABO	15	0.4	8	0.2	9	0.2	32	0.8
LACI	232	6.0	190	4.9	212	5.5	634	16.4
MYOTIS	633	16.3	566	14.6	399	10.3	1598	41.3
PESU	0	0.0	1	0.03	0	0.0	1	0.03
UNHI	180	4.7	123	3.2	114	3.0	417	10.8
UNLO	235	6.1	200	5.2	202	5.2	637	16.5
TOTAL	*1482*	*38.3*	*1290*	*33.4*	*1094*	*28.3*	*3866*	*100.0*

[a] Missing data at Birch 44 m attributed to inconsistencies and detector functionality.

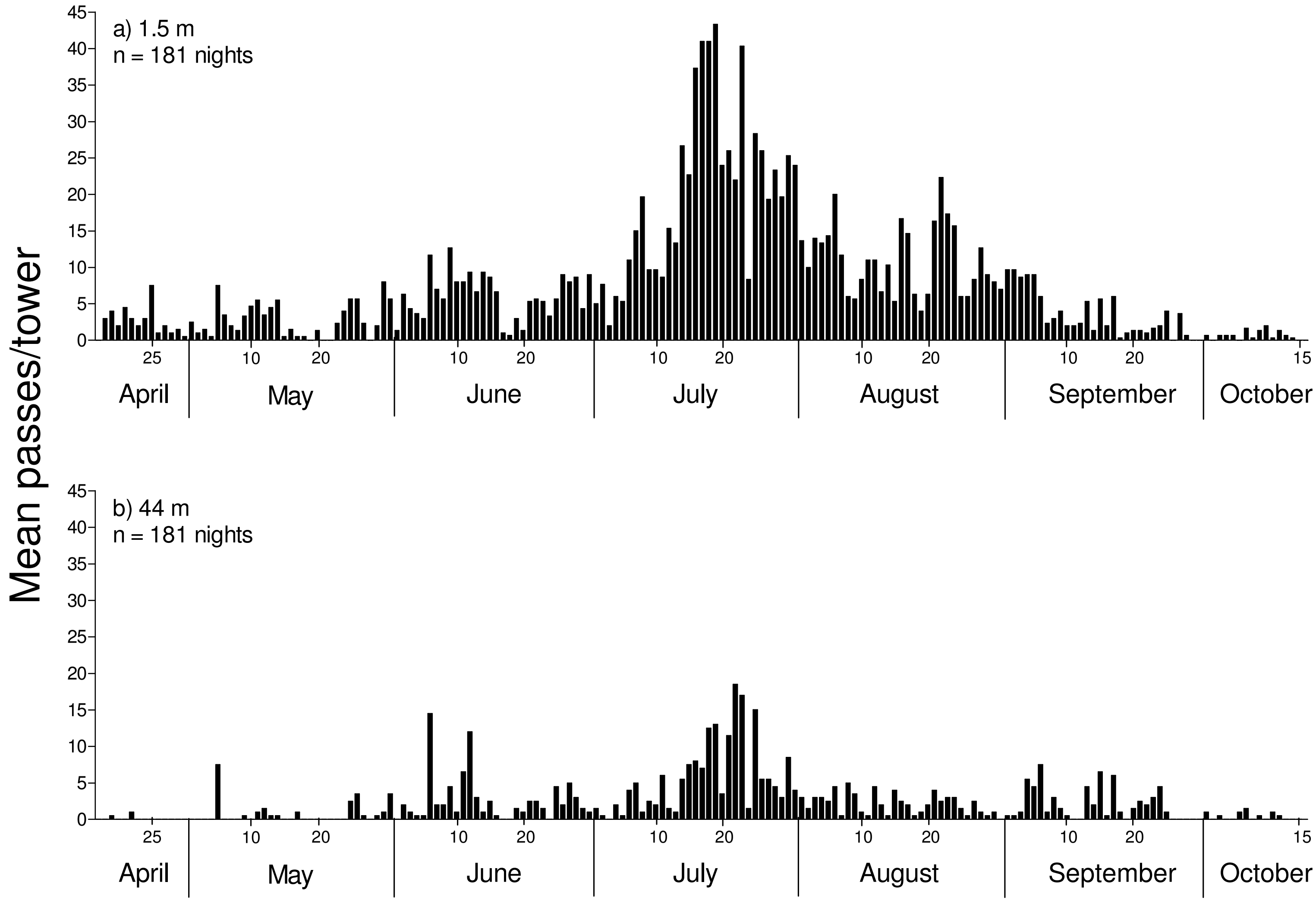

Figure 2. Mean bat passes/tower across all phonic groups by date for a) 1.5 m agl (with Birch Tower), and b) 44 m agl (without Birch Tower) at the proposed Roaring Brook Wind Project, New York, 2008.

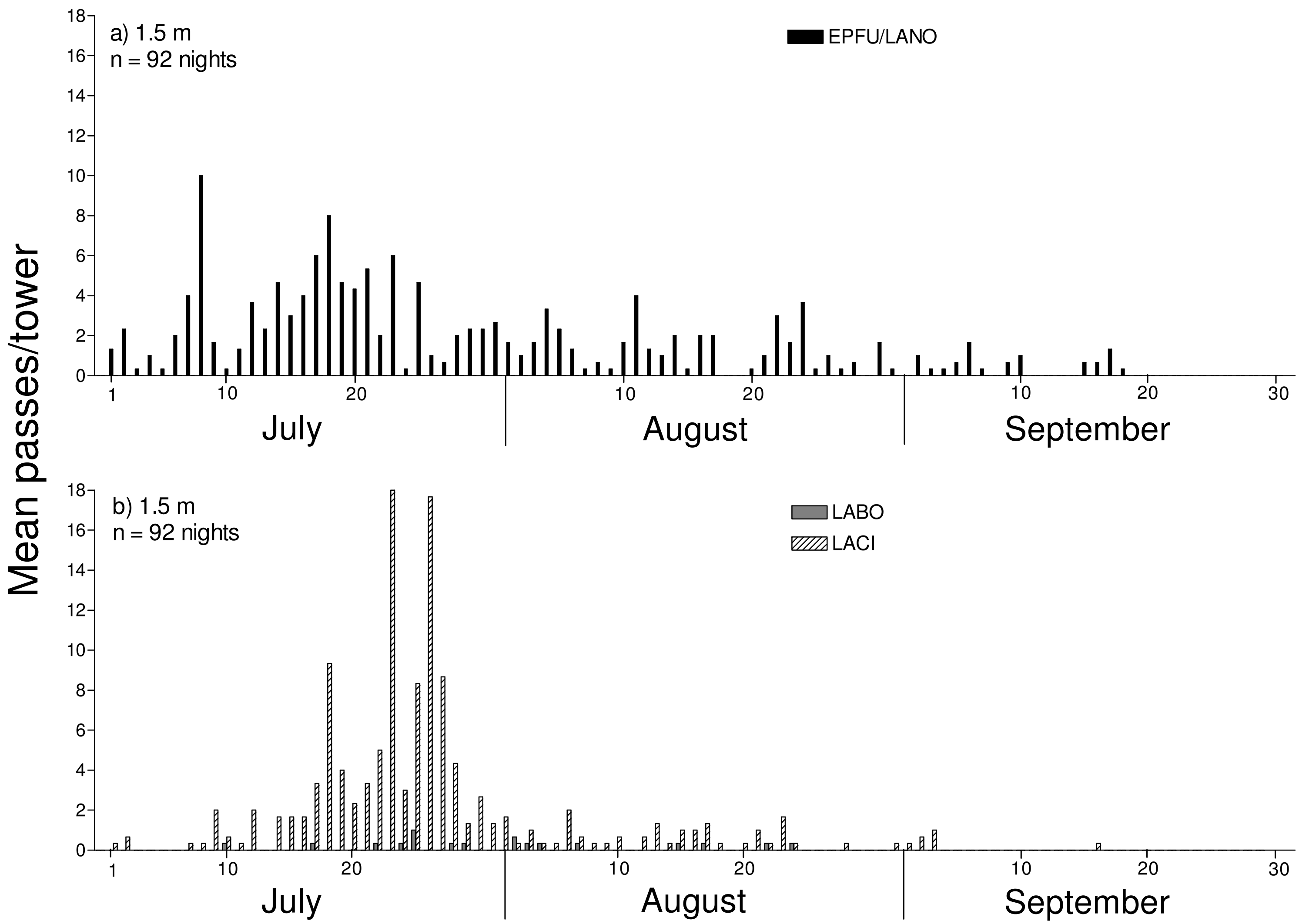

Figure 3. Mean bat passes/tower by date at 1.5 m agl (with Birch Tower) for a) big brown/silver-haired (EPFU/LANO) bats, and b) Eastern red (LABO) and hoary (LACI) bats at the proposed Roaring Brook Wind Project, New York, 2008.

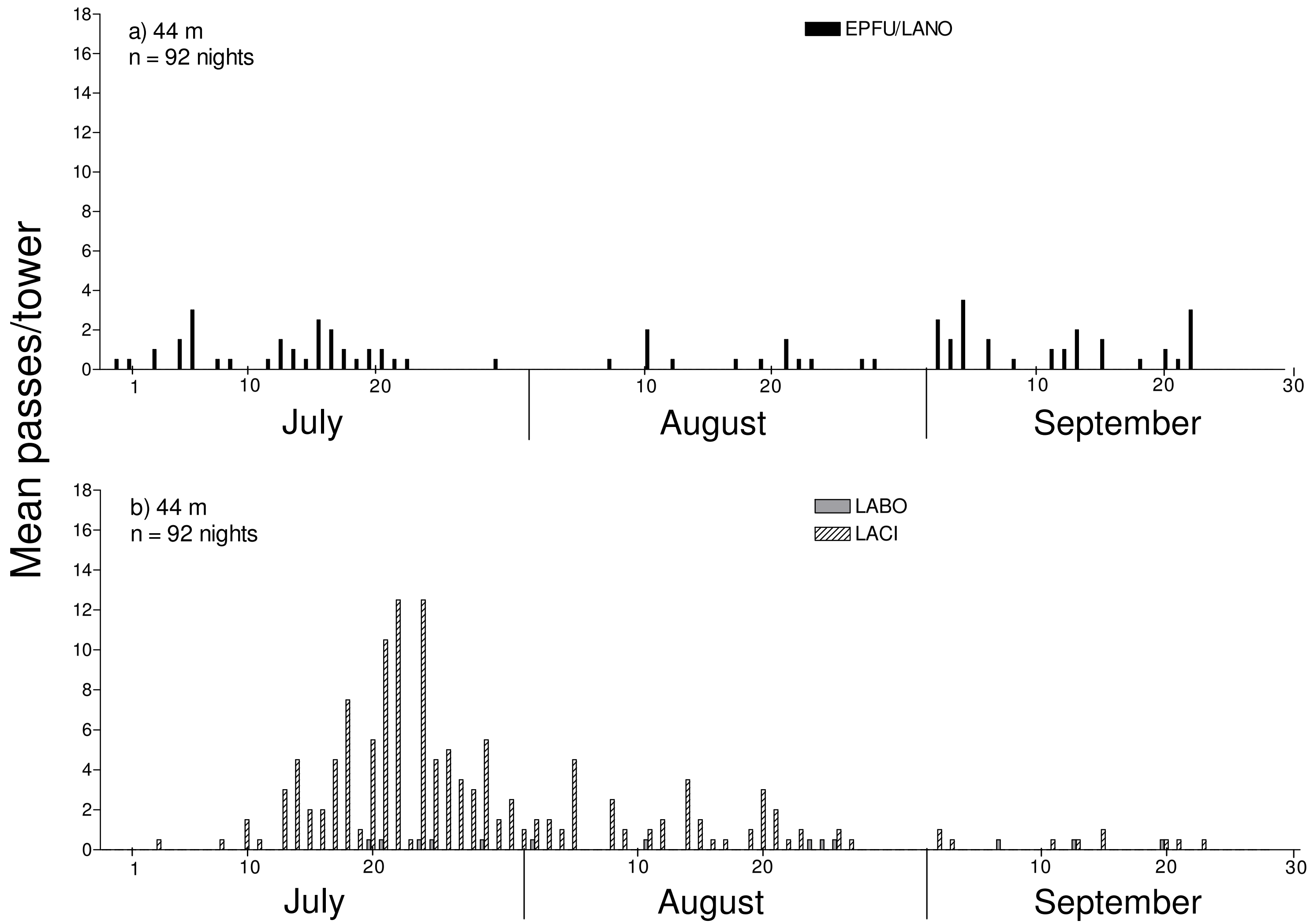

Figure 4. Mean bat passes/tower by date at 44 m agl (without Birch Tower) for a) big brown/silver-haired (EPFU/LANO) bats, and b) Eastern red (LABO) and hoary (LACI) bats at the proposed Roaring Brook Wind Project, New York, 2008.

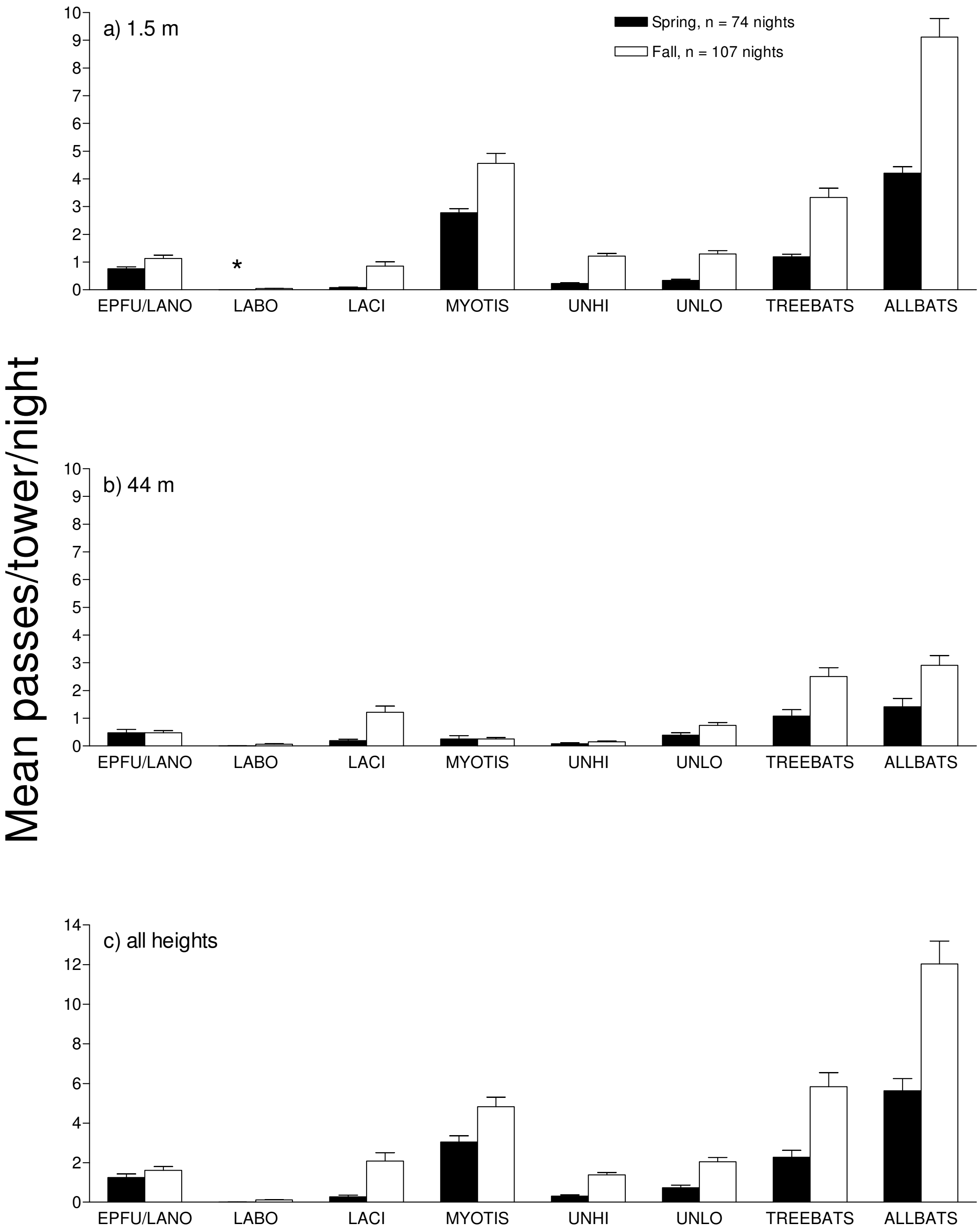

Figure 5. Mean bat passes/tower/night across spring and fall seasons for big brown/silver-haired (EPFU/LANO), Eastern red (LABO), hoary (LACI), *Myotis* spp. (MYOTIS), unidentified high frequency bats (UNHI), unidentified low frequency bats (UNLO), migratory tree-roosting bats (TREEBATS), and phonic groups combined (ALLBATS) at a) 1.5 m agl, b) 44 m agl, and c) all heights at the proposed Roaring Brook Wind Project, New York, 2008. Asterisk denotes no recorded LABO calls at 1.5 m agl in spring.

-4.35, P < 0.001) from spring (2.3 ± 0.3) to fall (5.8 ± 0.7). Most phonic groups also were detected more frequently in fall compared to spring, particularly LACI (spring = 0.3 ± 0.07, fall = 2.1 ± 0.4; Z = -4.1, P <0.001) and TREEBATS (spring = 2.3 ± 0.8, fall = 5.8 ± 0.7; Z = -5.3, P = 0.001). Mean activity of ALLBATS at 1.5 m increased (Z = -3.2, P = 0.002) between spring (4.2 ± 0.4) and fall (9.1 ± 0.9; Fig. 5a). Activity of all phonic groups increased between seasons, particularly LACI (spring = 0.08 ± 0.03, fall = 0.9 ± 0.2; Z = -4.4, P < 0.001) and TREEBATS (spring = 1.2 ± 0.2, fall = 3.3 ± 0.4; Z = -3.4, P = 0.001). Mean activity increased (Z = -4.2, P < 0.001) at 44 m for ALLBATS between spring (1.4 ± 0.3) and fall (2.9 ± 0.3). Although mean activity remained relatively constant for most phonic groups, LACI (spring = 0.2 ± 0.05, fall = 1.2 ± 0.2) and TREEBATS (spring = 1.1 ± 0.2, fall = 2.5 ± 0.3) were detected more often in fall (LACI: Z = -3.8, P < 0.001; TREEBATS: Z = -4.2, P < 0.001).

NIGHTLY

Within night bat activity (mean passes/h) was generally similar across phonic groups at both heights for the entire study (Fig. 6). However, activity rates varied among nocturnal hours for nights with 10 hours sampled/night ($F_{4.3, 799.6}$ = 45.3, P < 0.001, n = 181). Peak nightly activity at 1.5 m and 44 m occurred 2 hr and 1 hr past sunset, respectively, with activity at both heights declining thereafter. These trends were consistent among phonic groups. Similar trends were observed for both spring ($F_{4.9, 358.6}$ = 19.43, P < 0.001, n = 74; Fig. 7) and fall ($F_{4.0, 428.9}$ = 31.76, P < 0.001, n = 107; Fig. 8).

SPATIAL DIFFERENCES IN ACTIVITY

BETWEEN HEIGHTS

For the entire study, activity of ALLBATS was higher (Wilcoxon Z = -10.3, P < 0.001) at 1.5 m (7.1 ± 0.6) compared to 44 m (2.3 ± 0.2; Fig. 9). Most phonic groups were detected more frequently at 1.5 m. In contrast, LABO showed little difference in activity between heights and LACI activity was higher at 44 m (Z = -4.1, P < 0.001). Activity of ALLBATS was higher at 1.5 m (spring = 4.2 ± 0.4; fall = 9.1 ± 0.3) compared to 44 m (spring = 1.4 ± 0.3; fall = 2.9 ± 0.3) during both spring (Z = -6.9, P < 0.001) and fall (Z = -7.7, P < 0.001). Activity of most phonic groups showed little differences between heights during spring, except MYOTIS (Z = -7.3, P < 0.001) which was detected more frequently at 1.5 m (2.8 ± 0.2) than at 44 m (0.3 ± 0.1). In fall, activity was higher at 1.5 m for all phonic groups except LABO which remained relatively constant between heights, and LACI which showed higher activity (1.5 m = 0.9 ± 0.2, 44 m = 1.2 ± 0.2; Z = -3.2, P < 0.001) at 44 m.

BETWEEN TOWERS

We found differences in mean activity (mean passes/night) across all heights between Joe's and Fairbanks towers (Fig. 10). Activity of ALLBATS was higher (M-W test Z = -2.62, P = 0.009) at Joe's (10.9 ± 0.9) compared to Fairbanks (7.9 ± 0.7). This pattern also was observed in fall (Joe's = 13.8 ± 1.3, Fairbanks = 10.2 ± 1.0; Z = -2.1, P = 0.03), but little difference in activity was recorded in spring. The MYOTIS and UNHI groups accounted for the disparity between towers with higher activity at Joe's (MYOTIS 5.0 ± 0.4; UNHI 1.2 ± 0.1) than Fairbanks (MYOTIS 3.2 ± 0.3; UNHI 0.7 ± 0.1) in both spring (MYOTIS Z = -2.2, P = 0.03; UNHI Z = -2.6, P = 0.01) and fall (MYOTIS Z = -2.8, P = 0.06; UNHI Z = -2.2, P = 0.02), whereas all other phonic groups showed little difference between the 2 towers.

COMPARISONS WITH 2007 ACOUSTIC MONITORING STUDY

Although Mabee and Schwab (2008) reported higher levels of mean activity (mean passes/night) for ALLBATS at Joe's tower in 2007, we found no statistical difference (M-W test Z = -1.67, P = 0.1) between the 2007 (22.1 ± 2.8, n = 85) and our 2008 study (12.8 ± 1.4, n = 89; Fig. 11). Most phonic groups showed higher activity rates at Joe's in 2007 with the exception of LACI which was detected more frequently in 2008. We found little difference in activity of ALLBATS at Fairbanks tower between 2007 (11.7 ± 1.9, n = 80) and 2008 (8.9 ± 1.1, n = 87). Similar to Joe's, most phonic groups were detected more often in 2007, except for EPFU/LANO and LACI. Although activity of ALLBATS across all 3 sites at 1.5 m was higher in 2007 (39.3 ± 5.1, n = 88) than 2008 (26.2 ± 2.9, n = 89; Fig. 12), we detected no statistical difference

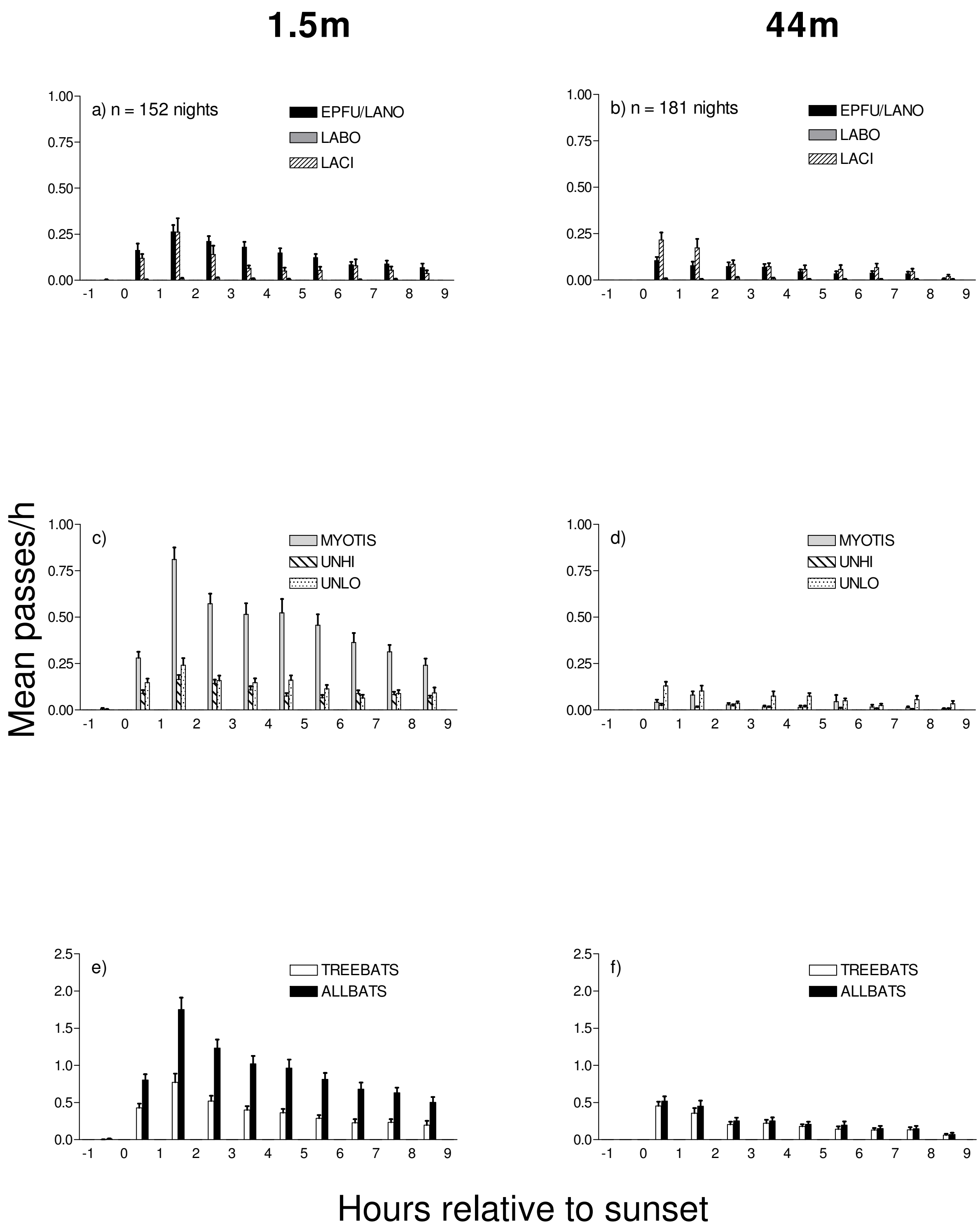

Figure 6. Mean bat passes/hour relative to sunset across the entire study for big brown/silver-haired (EPFU/LANO), Eastern red (LABO), hoary (LACI), *Myotis* spp. (MYOTIS), unidentified high frequency bats (UNHI), unidentified low frequency bats (UNLO) migratory tree-roosting bats (TREEBATS) and all phonic groups combined (ALLBATS) at 1.5 m agl (a, c, e) and 44 m agl (b, d, f) at the proposed Roaring Brook Wind Project, New York, 2008.

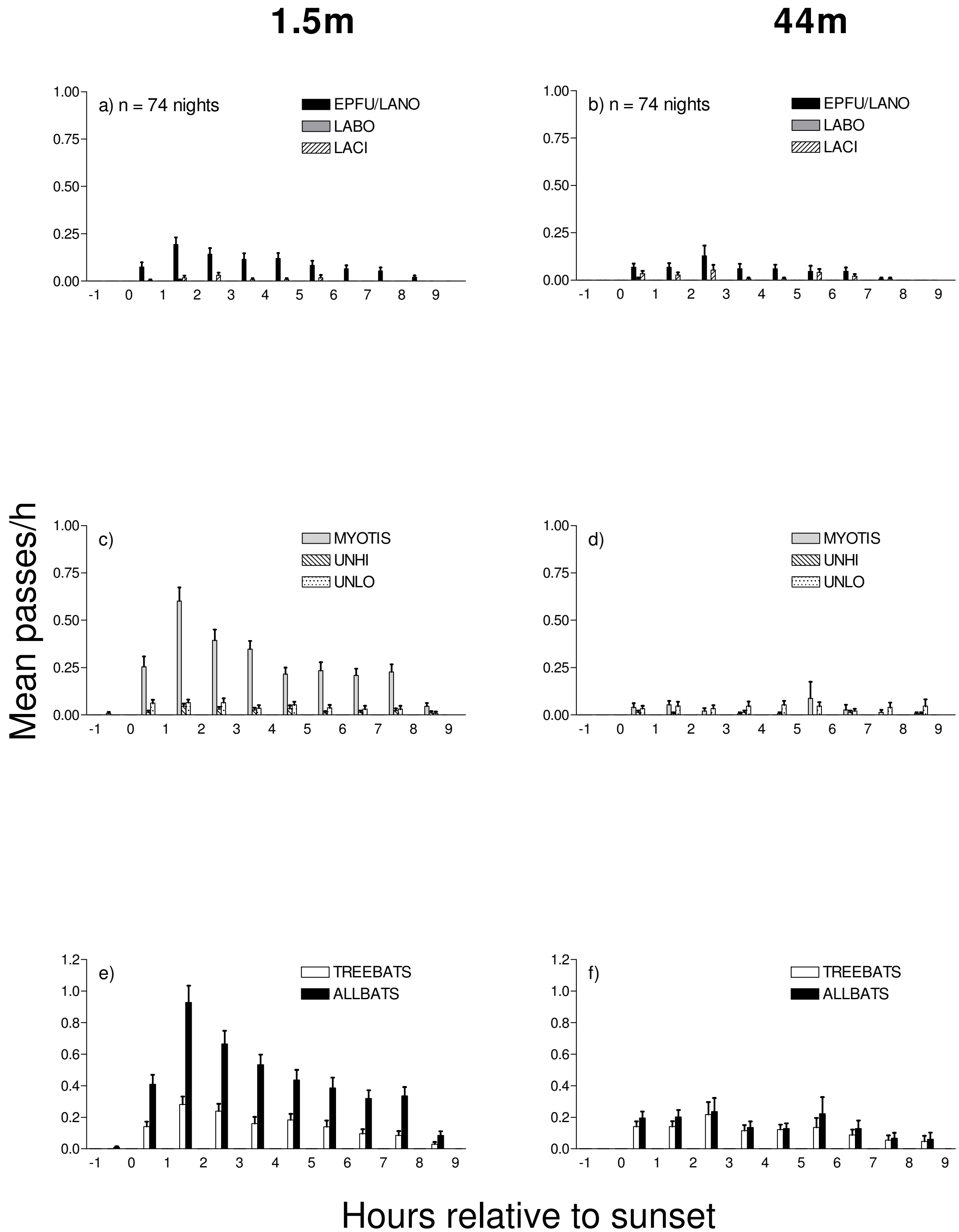

Figure 7. Mean bat passes/hour relative to sunset across spring for big brown/silver-haired (EPFU/LANO), Eastern red (LABO), hoary (LACI), *Myotis* spp. (MYOTIS), unidentified high frequency bats (UNHI), unidentified low frequency bats (UNLO) migratory tree-roosting bats (TREEBATS) and all phonic groups combined (ALLBATS) at 1.5 m agl (a, c, e) and 44 m agl (b, d, f) at the proposed Roaring Brook Wind Project, New York, 2008.

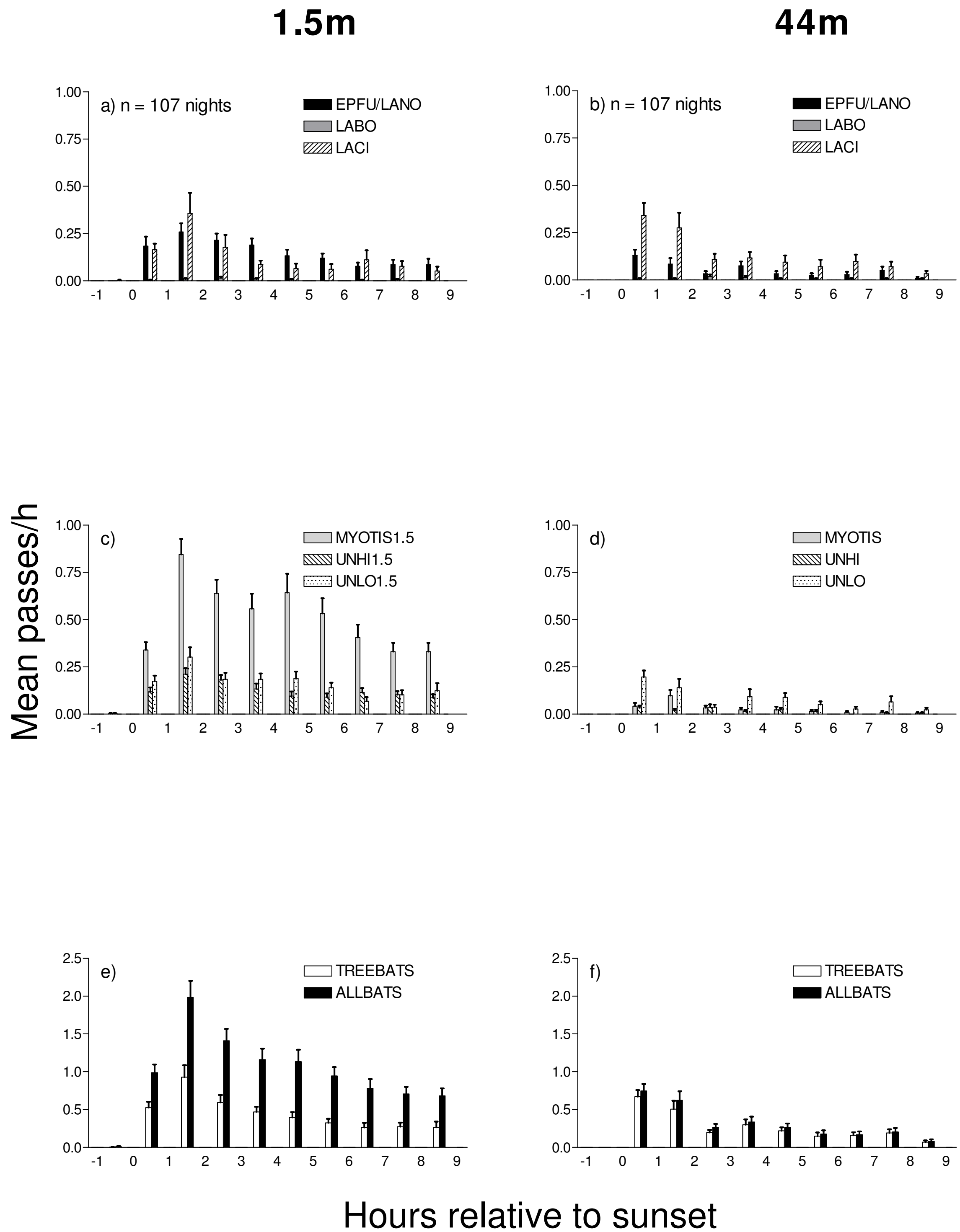

Figure 8. Mean bat passes/hour relative to sunset across fall for big brown/silver-haired (EPFU/LANO), Eastern red (LABO), hoary (LACI), *Myotis* spp. (MYOTIS), unidentified high frequency bats (UNHI), unidentified low frequency bats (UNLO) migratory tree-roosting bats (TREEBATS) and all phonic groups combined (ALLBATS) at 1.5 m agl (a, c, e) and 44 m agl (b, d, f) at the proposed Roaring Brook Wind Project, New York, 2008.

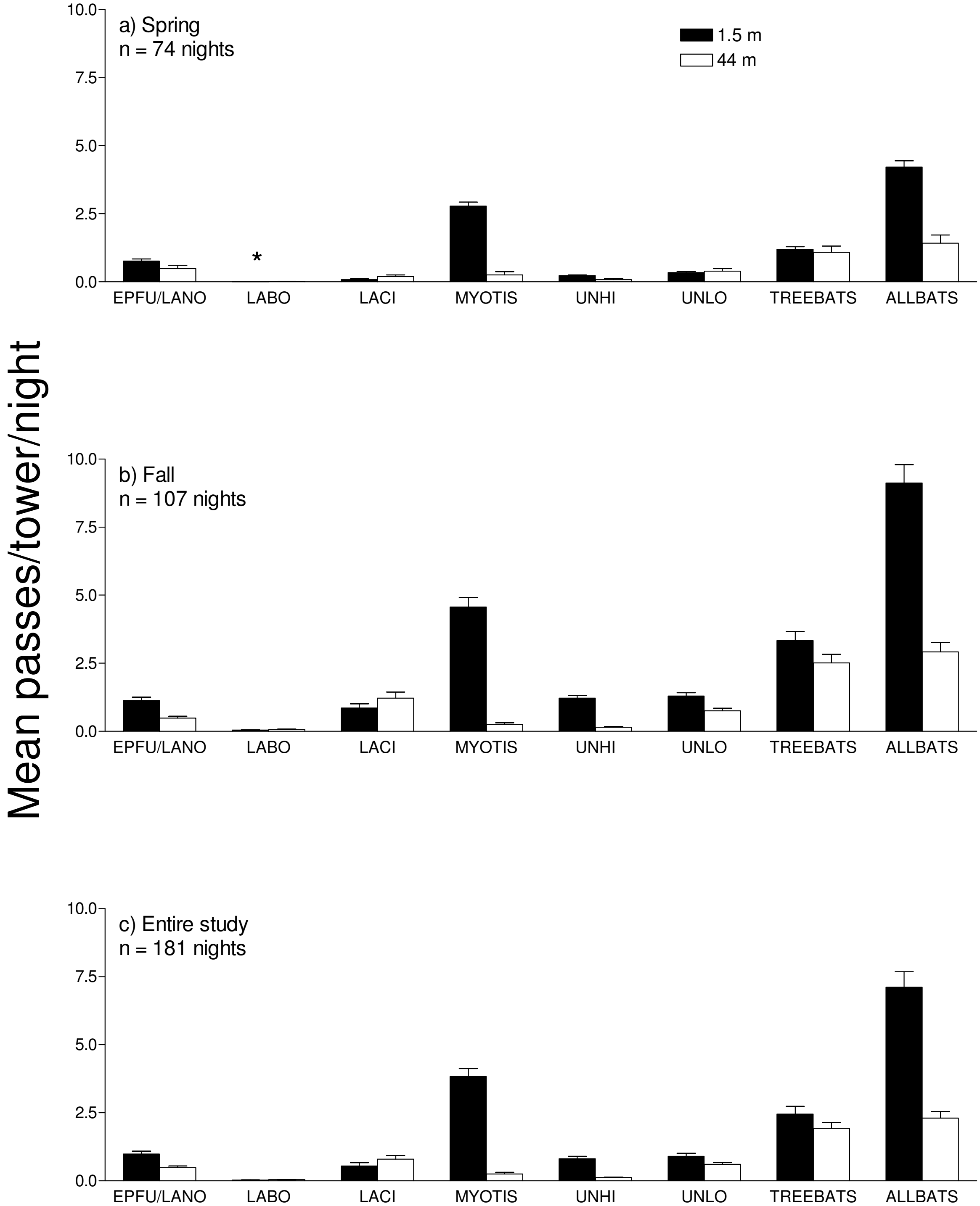

Figure 9. Mean bat passes/tower/night across 1.5 m agl and 44 m agl for big brown/silver-haired (EPFU/LANO), Eastern red (LABO), hoary (LACI), *Myotis* spp. (MYOTIS), unidentified high frequency bats (UNHI), unidentified low frequency bats (UNLO), migratory tree-roosting bats (TREEBATS), and all phonic groups combined (ALLBATS) for a) spring, b) fall, and c) entire study at the proposed Roaring Brook Wind Project, New York, 2008. Asterisk denotes no recorded LABO calls in spring at 1.5 m agl.

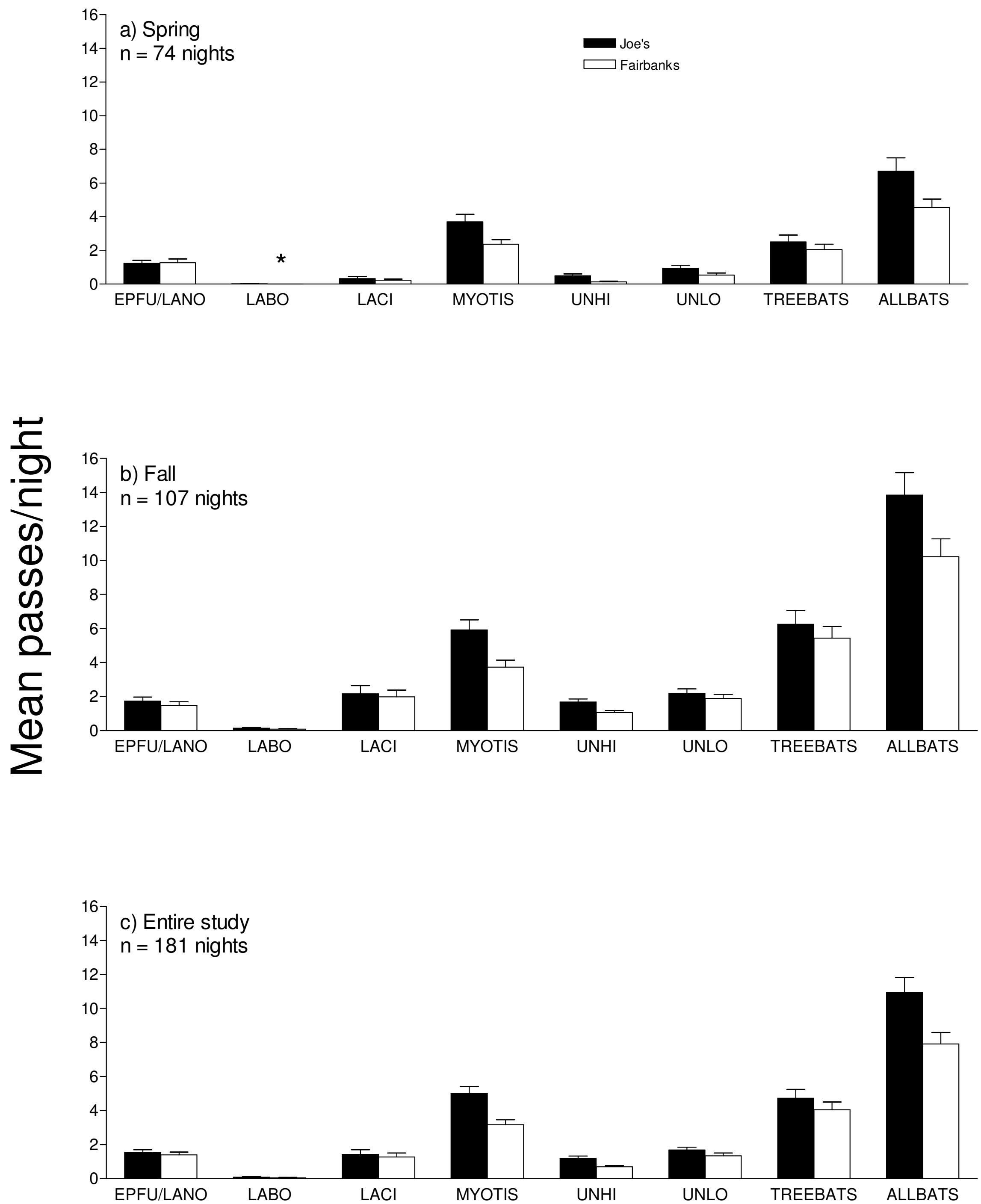

Figure 10. Mean bat passes/night across Joe's and Fairbanks towers for big brown/silver-haired (EPFU/LANO), Eastern red (LABO), hoary (LACI), *Myotis* spp. (MYOTIS), unidentified high frequency bats (UNHI), unidentified low frequency bats (UNLO) migratory tree-roosting bats (TREEBATS) and all phonic groups combined (ALLBATS) for a) spring, b) fall, and c) entire study at the proposed Roaring Brook Wind Project, New York, 2008. Asterisk denotes no recorded LABO calls at Fairbanks tower in spring.

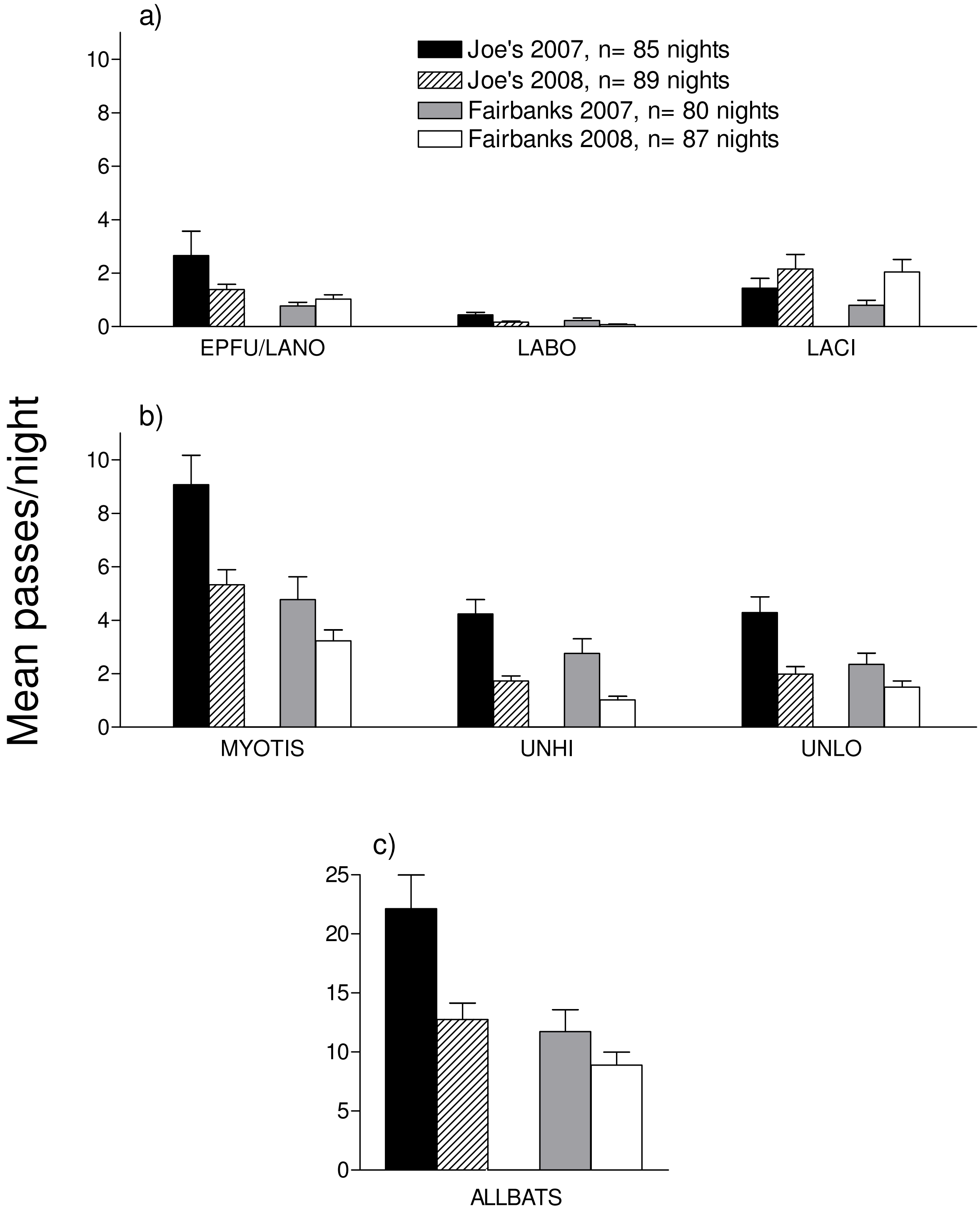

Figure 11. Mean bat passes/night by year across Joe's and Fairbanks towers for a) big brown/silver-haired (EPFU/LANO), Eastern red (LABO), and hoary (LACI) bats, b) *Myotis* spp. (MYOTIS), unidentified high frequency bats (UNHI), and unidentified low frequency bats (UNLO), and c) migratory tree-roosting bats (TREEBATS) and all phonic groups combined (ALLBATS) at the proposed Roaring Brook Wind Project, New York, 2008.

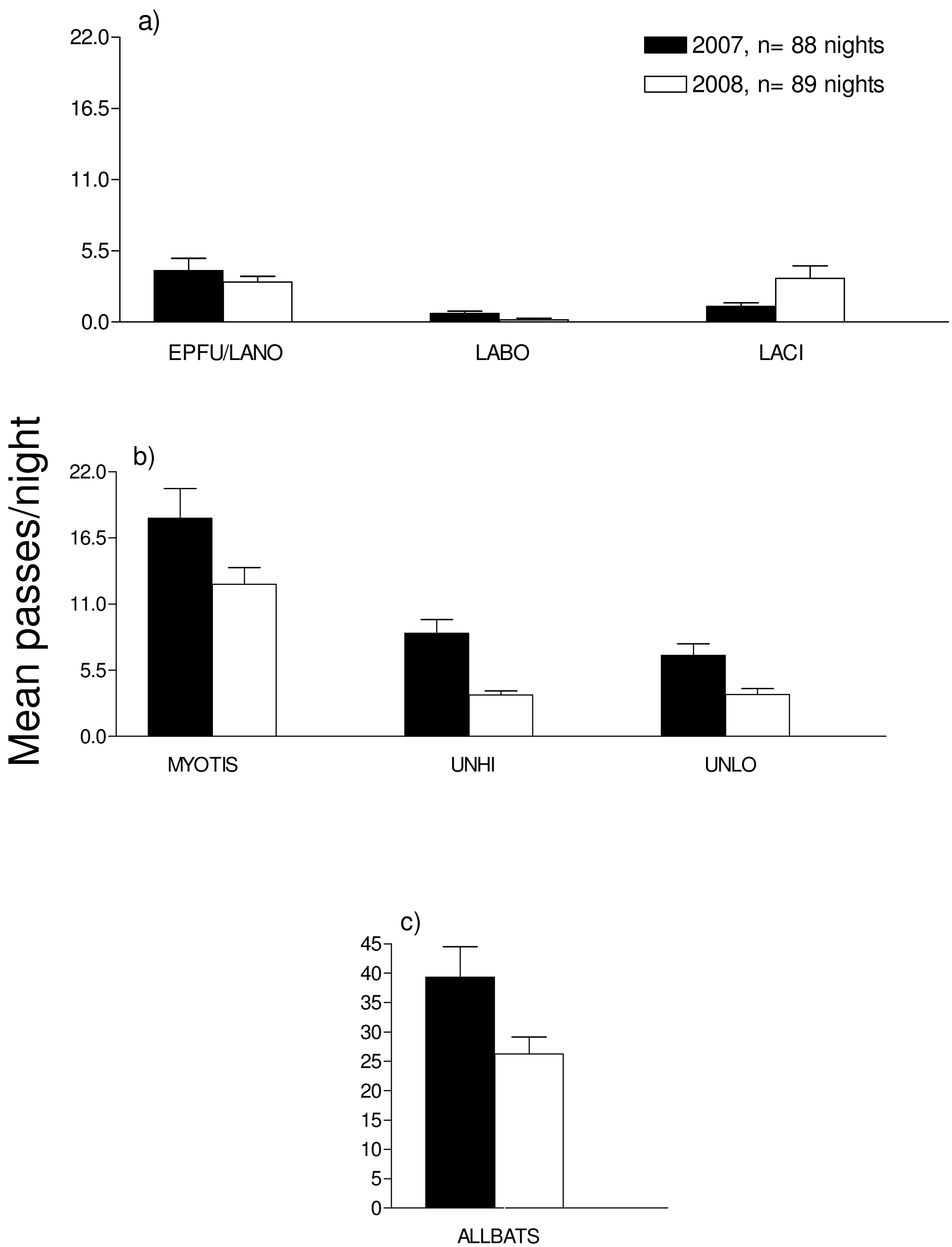

Figure 12. Mean bat passes/night by year across all towers at 1.5 m agl for a) big brown/silver-haired (EPFU/LANO), Eastern red (LABO), and hoary (LACI) bats, b) *Myotis* spp. (MYOTIS), unidentified high frequency bats (UNHI), and unidentified low frequency bats (UNLO), and c) migratory tree-roosting bats (TREEBATS) and all phonic groups combined (ALLBATS) at the proposed Roaring Brook Wind Project, New York, 2008.

between studies (Z = -0.7, P = 0.5). All phonic groups except LACI were detected more frequently at 1.5 m in 2007 than 2008.

DISCUSSION

Because a paucity of information exists concerning many life history traits of bats, predicting impacts of wind power development on migratory species can be problematic. Recent articles have presented recommendations for acoustic monitoring studies to capture both the spatial (horizontal and vertical strata) and temporal (nightly, seasonal, and annual) variability in bat activity (Gannon et al. 2003, Hayes 2000, Kunz et al. 2007). Furthermore, many states have provided protocols for bat studies at commercial wind-energy sites, including New York (NYSDEC 2007). Our pre-construction study is one of a new generation of studies to follow these protocols and in doing so, we were able to provide baseline information on both spatial and temporal activity patterns of bats, particularly migratory tree-roosting bats at the proposed Roaring Brook site.

This study was conducted at a proposed wind-energy facility located on secondary forest habitat interspersed with small wetlands, so statistical inferences are limited to this site. Because of difficulties with equipment functionality, we were unable to use activity data collected at Birch 44 m for the entire study period. However, our sampling effort did allow us to characterize both spatial (location and height) and temporal (nightly, seasonal, and annual) patterns of bat activity across the remaining 2 towers on the project area.

We found higher activity levels (mean passes/tower/night) in spring compared to similar studies conducted in New York. In fall, our results were within the range of variability of several studies across the eastern United States (Appendix 1). Variability in activity rates among studies are likely the result of differences in habitat, landscape, elevation, and climate. The habitat features (forests interspersed with wetlands) at Roaring Brook presumably provides quality foraging areas for bats compared to other landscapes (e.g., agricultural areas at Maple Ridge) in the region. However, variations in activity also may be attributed to differences in sampling effort (i.e., number of detectors or towers), sampling dates, altitude of detectors, detector position (e.g., tower vs. guy-wires) and analytical methods. We characterized the different key sampling attributes of previous studies so that appropriate comparisons can be made to this study (i.e., only comparing metrics from studies with “comparable” or perhaps “unknown comparability” to metrics from this study). In general, comparability among acoustic monitoring studies may be problematic, thus strengthening the rationale for standard methodology (Arnett et al. 2008, Gannon et al. 2003, Hayes 2000, Kunz et al. 2007b).

We found the highest levels of bat activity in mid-July which is consistent with data recorded at proposed wind-energy facilities at Roaring Brook, NY (Mabee and Schwab 2008) and Hoosac, MA (Arnett et al. 2007b), and high mortality rates reported at Maple Ridge, NY (Jain et al. 2007) and Foote Creek Rim, WY (Gruver 2002). However, studies at lower latitudes have reported peaks in activity later in fall (early to mid August) at Casselman, PA (Arnett et al. 2006) and Butler Ridge, WI (Redell et al. 2006). Data from these studies suggests that variations in seasonal peak activity may be attributed to differences in latitude. Although, Kerns et al. (2005) documented a strong positive correlation in the timing of fatalities between sites (Meyersdale, PA and Mountaineer, WV) located ~90 km apart, no studies to date have examined these patterns at larger scales.

We observed differences in peak activity among species of migratory tree-roosting bats during fall. In our study, periods of high activity by cavity-roosting species (EPFU/LANO) preceded those of foliage-roosting bats (LACI and LABO). Migratory patterns among bats also appear to vary during spring (Reynold 2006). Because these species 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 may offer wind-energy developers better information for making decisions on turbine placement and operation..

We recorded higher levels of activity (overall and for most phonic groups) in fall compared to spring. Similar to our acoustic data, many studies have reported higher fatality rates in fall (Arnett et al. 2008). Increases in bat activity and mortality at wind-energy facilities at certain times may be attributed to seasonal increases in insect abundance and availability within particular habitats, as well as life history traits of certain bat species (i.e., preparations for hibernation or migration, and mating; Horn et al. 2008). Furthermore, if wind-energy facilities are located along fall migratory routes, bat activity may increase at specific times during this season.

We observed within night peaks in activity between 1–2 hours past sunset which is consistent with studies conducted in the region (Arnett 2006, 2007b). This pattern of nightly behavior also was observed in both spring and fall. Many studies have reported a second, smaller peak in bat activity closer to sunrise (Erkert 1982, Hayes 1997, Maier 1992, Kunz 1973, Taylor and O'Neil 1988) however, our results showed a steady decline after the initial peak. We found nightly activity varied slightly between heights with the highest activity at 1.5 m and 44 m occurring at 2 hr and 1 hr past sunset, respectively. This is likely attributed to temporal variations in insect abundance and availability at different heights (Hayes 2000).

Our results are consistent with other studies showing variations in bat activity at different altitudes (Hayes and Gruver 2000, Kalcounis et al. 1999). 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) habitats. Several pre-construction studies reported higher activity by high frequency calling bats (e.g., MYOTIS, PESU, LABO) at lower detectors and higher activity by low frequency calling bats (e.g., EPFU/LANO, LACI) at higher detectors (Arnett et al. 2006, 2007b, Redell et al. 2006). Bats in our study followed similar trends, with most phonic groups, particularly MYOTIS, detected more frequently at 1.5 m in both spring and fall, whereas LACI were recorded more often at 44 m in both seasons.

Similar to Mabee and Schwab (2008), we found higher bat activity at Joe's tower compared to Fairbanks. In 2007, 4 phonic groups (EPFU/LANO, LABO, MYOTIS, and UNHI) had higher rates at Joes, compared to only 2 groups (MYOTIS and UNHI) in 2008. Although it is not surprising to see spatial variations in bat activity at a project site, specific reasons for the variability between towers are still unknown, but presumably are the result of differences in landscape features between Joe's and Fairbanks. The close proximity of Joe's tower to 2 branches of the Roaring Brook River may offer more favorable foraging areas for bats which often forage over or near water.

Although differences in mean activity between years at Joe's tower and at 1.5 m across all towers were not statistically significant, Mabee and Schwab (2008) detected more bats in 2007 compared to this study. Because local habitat conditions remained similar between seasons, variations in activity levels between years are likely due to changes in climate or population levels. We observed declines in activity between years of many cave-roosting species (e.g., *Myotis* spp. and big brown bats), that are impacted by White Nose Syndrome (WNS; USFWS 2008b). Currently, population survey estimates suggest a two-year bat population decline in cave-roosting species in excess of 75% attributed to WNS (Blehert et al. 2008). Because WNS has decimated many cave populations in New York and surrounding states, declines in overall activity and activity of specific species are not surprising.

Overall, our ability to identifying 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. No available information exists comparing pre-construction activity levels with post-construction fatalities. However, several studies have shown a positive correlation ($r = 0.79$) between total number of bat calls/night and estimated fatalities/turbine/year (see Kunz et al.

2007b), suggesting acoustic monitoring may be useful in resolving potential negative impacts of wind development on bat populations.

CONCLUSIONS

The key results of our bat acoustic monitoring study were: (1) peak mean activity (passes/tower) for ALLBATS occurred in mid-July; (2) peak activity of TREEBATS also occurred in mid-July and varied among species with higher activity levels of EPFU/LANO proceeding LABO and LACI; (3) mean activity for ALLBATS was 9.4 ± 0.8 passes/tower/night across the entire study, and was higher in fall (12.0 ± 1.1) compared to spring (5.6 ± 0.6); (4) mean activity rate for TREEBATS was 4.4 ± 0.5 passes/tower/night (spring = 2.3 ± 0.3; fall = 5.8 ± 0.7); (5) peak activity occurred 1–2 hours after sunset for all species in both seasons and for the entire study; (6) Mean activity (passes/tower/night) for ALLBATS across the entire study was higher at 1.5 m (7.1 ± 0.6) than at 44 m (2.3 ± 0.2). EPFU/LANO and MYOTIS groups were detected more frequently at 1.5 m (EPFU/LANO = 1.0 ± 0.1; MYOTIS = 3.8 ± 0.3) than at 44 m (EPFU/LANO = 0.5 ± 0.1; MYOTIS = 0.3 ± 0.1), whereas activity of LABO showed no difference between heights, and LACI activity was higher at 44 m (0.8 ± 0.1) compared to 1.5 m (0.5 ± 0.1); (7) variability in mean activity (mean passes/night) existed between towers in 2008, with higher activity at Joe's tower (10.9 ± 0.9) compared to Fairbanks (7.9 ± 0.7); and (8) Mean activity (passes/night) generally was higher at all towers in 2007 compared to 2008.

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Appendix 1. Summary of bat acoustic studies at wind power development projects from New York and other states. An X denotes data not provided in literature. Current project in boldface.

Project	Study period	Nights[a]	Total passes	Dectors/ tower	Towers	Mean passes/ tower/ night	Mean passes/ detector - night	Detector Height (m)	Methods[b]	Source
Spring										
Bliss Windpark, NY	4/20/05–6/13/05	55	6,032	2	1[c]	109.67	54.84	15, 30	3	Ecology & Environment 2006
Centerville, NY	4/06/06–6/07/06	63	270	2	1	4.29	2.1	10, 25	3	Woodlot 2006e
Cohocton, NY	5/2/05–5/30/05	29	21	1	1	0.72	0.72	X	3	Woodlot 2006c
Dairy Hills Wind, NY	4/15/05–6/02/05	10*	27	1	1	2.7	2.7	1.0	3	Young et al. 2006
Howard, NY	4/15/06–6/7/06	116*	50	3	1	1.29	0.43	8, 20, 50	3	Woodlot 2006b
Jordanville, NY	4/14/05–5/13/05	29	15	1	1	0.52	0.52	30	3	Woodlot 2005a
Maple Ridge, NY	4/10/05–6/22/05	74	459	3	2	3.10	1.03	7, 25, 50	2	Reynolds 2006
Prattsburgh, NY	4/15/05–5/30/05	45	16	2	1	0.36	0.28	15, 30	3	Woodlot 2005c
Roaring Brook, NY	**4/18/08–6/30/08**	**74**	**838**	**2**	**2**	**5.66**	**2.83**	**15, 44**		**Hein et al. 2008-this study**
Wethersfield, NY	4/06/06–6/07/06	63	192	2	1	3.05	1.5	10, 25	3	Woodlot 2006e
Deerfield Wind, VT	4/14/06–6/13/06	194*	15	2	2	0.16	0.08	~15, ~30	2	Woodlot 2006d
Fall										
Bliss Windpark, NY	8/15/05–10/9/05	56	3,725	2	1[c]	66.52	33.26	15, 30	3	Ecology & Environment 2006
Centerville, NY	7/25/06–10/10/06	89*	5	2	2	0.12	0.06	15, 35	2	Woodlot 2006a
Cohocton, NY	9/3/05–10/15/05	122*	191	2	1	3.14	1.57	15, 23	3	Woodlot 2006c
Dairy Hills Wind, NY	8/16/05–10/14/05	83*	296	2	1	7.13	3.56	1.0, 50	3	Young et al. 2006
Howard, NY	8/3/05–8/19/05	27*	60	2	1	4.44	2.22	27, 48	3	Woodlot 2005b
Roaring Brook, NY	7/20/07–10/15/07	88	4,257	2	3	16.13	8.06	1.5, 44	1	Mabee et al. 2008
Roaring Brook, NY	**7/01/08–10/15/08**	**107**	**2,576**	**2**	**2**	**12.04**	**6.02**	**1.5, 44**		**Hein et al. 2008-this study**
Wethersfield, NY	7/25/06–10/09/06	80*	22	2	2	0.6	0.3	15, 35	2	Woodlot 2006a
Hoosac Wind, MA	7/26/06–11/11/06	109	4,816	3	5	8.9	3.0	10, 31, 39	2	Arnett et al. 2007b
Somerset County, PA	8/1/05–11/1/05	93	9,162	3	5	19.70	6.57	1.5, 22, 44	2	Arnett et al. 2006
Buffalo Mountain, TN	9/1/00–9/30/03	149*	X	X	X	X	23.7	X	3	Fiedler 2004
Mountaineer, WV	8/31/04–9/11/04	33*	X	X	X	X	38.2	X	3	Arnett (unpublished data)
Top of Iowa, IA	9/4/03–10/9/03 5/10/04–9/29/04	42*	1,465	X	X	X	34.9	X	3	Jain 2005
Buffalo Ridge, MN	6/15/01–9/15/01 6/15/02–9/15/02	216*	452	X	X	X	2.1	X	3	Johnson et al. 2004

[a]Asterisks denotes detector-nights because number of sample nights not provided in literature.
[b]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]Detectors mounted on silos