# Patterns of pre-construction bat acoustic activity at the proposed Resolute Wind Energy Project, Wyoming, 2009–2010

## Final Project Report

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# EXECUTIVE SUMMARY

We initiated a multi-year, pre-construction study in mid-summer 2009 to investigate patterns of bat activity and evaluate the use of acoustic monitoring to predict mortality of bats at the proposed Resolute Wind Energy Project (RWEP) in east-central Wyoming. The primary objectives of this study were to: 1) determine levels and patterns of activity for three phonic groups of bats (high-frequency emitting bats, low-frequency emitting bats, and hoary bats) using the proposed wind facility prior to construction of turbines; 2) determine if bat activity can be predicted based on weather patterns; correlate bat activity with weather variables; and 3) combine results from this study with those from similar efforts to determine if indices of pre-construction bat activity can be used to predict post-construction bat fatalities at proposed wind facilities. We report results from two years of pre-construction data collection.

We recorded echolocation calls of bats with Anabat II zero-crossing ultrasonic detectors, programmed to record calls beginning ½-hour prior to sunset and ending ½-hour after sunrise each day of the study from 3 August–18 October 2009, and 2 June–30 September 2010. We assigned each bat pass to one of two phonic groups based on minimum frequency of the echolocation sequence; high frequency bats (≥33 kHz average minimum frequency; e.g., *Myotis* spp.) or low frequency bats (<33 kHz average minimum frequency; e.g., big brown, silver-haired, hoary bats). We also identified a third phonic group, hoary bats, a subset of the low frequency phonic group, because this species is vulnerable to wind-energy development and its echolocation sequences are relatively easy to distinguish among other low-frequency emitting bats. We used 5 meteorological (met) towers to position detector microphones at ~1.5 m and ~44 m above ground level (agl) to acoustically sample bat activity during this study.

In 2009, we recorded a total of 976 bat passes. We recorded 454 high frequency passes and 522 low frequency passes. Hoary bats comprised 22% (n = 114) of low frequency passes. In 2010, we recorded a total of 1,111 bat passes. We recorded 410 and 701 high frequency and low frequency passes, respectively. Hoary bats comprised 30% (n = 208) of low frequency passes.

Bat activity varied, by phonic groups, within and among nights. High frequency bats were most active 1–2 hours past sunset. Low frequency bat activity peaked during the middle of the night and hoary bats were most active within the first hour past sunset. Bat activity typically was highest between August and mid-September for all phonic groups. However, the timing and intensity of peak activity for each group differed between years.

Bat activity varied among phonic groups by height and among towers. We detected high frequency bats more often at 1.5 m agl with greatest activity recorded at tower 5042 in both 2009 and 2010. Low frequency bat activity was relatively consistent between heights and among towers for both years. We detected hoary bats more often at 44 m agl and recorded the greatest activity at towers 5032 and 5042 in 2009 and at tower 5032 in 2010. We recorded the fewest calls by any phonic group at tower 5034.

We modeled bat activity (passes/detector-night) in relation to tower location, temperature, and several measures of wind speed with 1) the probability of activity and 2) the estimated number of calls given that activity occurred. Tower location and temperature were consistently the most important factors in our models, accounting for ~5–29% of the variation in activity. However, location alone explained ~3–9.5% of the variation in activity. In general, we found the highest probability of activity and highest counts for each phonic group at towers on the western edge of the project. Both the probability of activity and estimated number of calls from each phonic group increased with increasing temperature. While some measure of wind was often important, it never explained more than an additional ~9% of the variation in activity. When included in the models, the effect of average wind speed on the probability of bat activity and estimated number of bat passes was always negative.

This study was conducted at a single proposed wind energy facility located on shrubland habitat in east-central Wyoming, and statistical inferences are limited to this site. However, we believe that our findings reflect patterns of bat activity on similar landscapes with comparable vegetation composition and topography in this region. Despite equipment malfunctions, we were able to quantify the spatial (vertical and horizontal) and temporal (seasonal and yearly) activity patterns of bats. These data may provide useful information for predicting when, where, and which bats may be most at risk of interactions with wind turbines at the RWEP. Moreover, specific timings and locations of peak activity may further refine the use of curtailment as a mitigation option.

## INTRODUCTION

As energy demands increase worldwide, many countries are seeking ways to reduce fossil fuel consumption and generate alternate forms of energy. Wind is one of the fastest growing forms of renewable energy and has been produced commercially in North America for nearly 4 decades (Pasqualetti et al. 2004, National Research Council 2007). In recent years, the United States has been a world leader in wind generating capacity, including 5,115 Megawatts (MW) of new capacity in 2010 (AWEA 2011). Currently, Wyoming ranks 10th in the U.S. for installed capacity at 1,412 MW. Although wind-generated energy reduces carbon and other greenhouse gas emissions associated with climate change, it is not environmentally neutral because wildlife and habitats can be directly or indirectly impacted by development.

Bat fatalities have been reported at wind facilities since the early 1970’s (Hall and Richards 1972, Dürr and Bach 2004, Johnson 2005, Kunz et al. 2007a, Arnett et al. 2008), but have received little attention until 2003 when an estimated 1,400–4,000 fatalities were reported at the Mountaineer Wind Energy Center, West Virginia (Kerns and Kerlinger 2004). High fatality rates also have been documented at other facilities along forest ridges across the eastern United States, including Meyersdale, PA (Kerns et al. 2005), Buffalo Mountain, Tennessee (Fielder 2004 and Fiedler et al. 2007), and Cassleman, PA (Arnett et al. 2009). However, data from the Midwestern US and Canada suggest high fatality events occur across a variety of landscapes, including agricultural fields, grassland prairies, and deciduous or coniferous forests (Jain 2011, Barclay et al. 2007, Kunz et al. 2007a, Arnett et al. 2008). Concerns regarding potential cumulative negative impacts of wind energy development on bat populations persist, particularly when many species of bats, especially tree-roosting species, are known or suspected to be in decline (Pierson 1998, Racey and Entwistle 2003, Winhold and Kurta 2006, Jones et al. 2009, Frick et al. 2010). Because bats provide numerous ecosystem services (e.g., insect suppression, or pollination and seed dispersal), adverse impacts of wind development on local bat populations could disrupt the ecological health and stability of a region (see Kunz et al. 2011).

Twelve species of bats occur in Wyoming and all are listed as Species of Special Concern and protected from take in Section 11 Chapter 52 in the Wyoming Game and Fish Commission Regulations (Hester and Greiner 2005). These species include western long-eared bat (*Myotis evotis*), small-footed bat (*M. ciliolabrum*), little brown bat (*M. lucifugus*), northern bat(*M. septentrionalis*), fringed bat (*M. thysanodes*), long-legged bat (*M. volans*), spotted bat (*Euderma maculatum)*, Townsend’s big-eared bat (*Corynorhinus townsendii*), pallid bat (*Antrozous pallidus*), big brown bat (*Eptesicus fuscus*), silver-haired bat (*Lasionycteris noctivagans*), and hoary bat (*Lasiurus cinereus)*. Of these species, the silver-haired bat and hoary bat are both of increasing concern in the region, particularly with respect to wind development, because high fatalities have been reported for these migratory tree-bats at wind-energy facilities across North America (Arnett et al. 2008). At the Foot Creek Rim Wind Energy Project in Wyoming, Gruver (2002) summarized carcasses collected from 1999–2001 and showed 92% of bats found during carcass searches were migratory tree bats (108 hoary and 5 silver-haired bats of the 123 carcasses found). Similarly, of the 337 bat fatalities collected at existing wind-energy facilites in the Columbia Plateau Ecoregion of Oregon and Washington, hoary and silver-haired bats comprised 93.5% (n=315) of the total (Johnson and Erickson 2008).

Although several attraction hypotheses (e.g., roost, landscape, acoustic, or visual) have been proposed, interactions between bats and wind turbines are poorly understood (Arnett 2005, Barclay et al. 2007, Cryan and Brown 2007, Kunz et al. 2007a). Resolution of these different hypotheses requires additional data on the flight behavior of bats. However, the combination of nocturnal habits, volancy, small size, and variation in resource dependence (i.e., species vary in roost, water, and food requirements; Findley 1993; Kunz and Fenton 2003), makes even a rudimentary understanding of how bats interface with their environment difficult to establish (Gannon et al. 2003). Available post-construction monitoring data from a few wind energy facilities have provided a baseline for bat behaviors and reported fatalities at these installations (Arnett et al. 2008, Horn et al. 2008). Our current understanding of bat fatalities at wind energy facilities allows for some conjecture regarding risk factors for certain species, but further information on nightly and seasonal activity patterns encompassing a facility or region is still necessary to place bat fatalities in an appropriate context (Fiedler 2004). Pre-construction bat activity surveys at wind-energy facilities commonly employ mist nets and acoustic detectors to assess local bat species presence and activity, but using this information to predict bat fatality and to quantify risk is unproven. Moreover, the ability to generate reliable risk assessments during early planning phases (i.e., prior to site selection and construction) often is hampered by lack of baseline data on distributions, densities, migratory patterns, and behavior of bats (O’Shea et al. 2003, Larkin 2006, Reynolds 2006, Cryan and Brown 2007) throughout much of North America. Thus, extensive planning (e.g., study design, survey intensity) for future wind developments is essential (EIA 2007, Kunz et al. 2007a, 2007b).

Acoustic monitoring allows researchers to detect and record various calls of echo-locating bats as a means of investigating relative activity and identifying species or species groups (Kunz et al. 2007b). Understanding bat activity patterns prior to construction of wind facilities may assist in identifying landscape features which pose high risk of fatality and aid with decision-making, such as specific placement of turbines (Fiedler 2004, Reynolds 2006). Acoustic monitoring also provides insight into nightly and seasonal activity patterns, which presumably will help refine the timing and extent of potential mitigation strategies (e.g., curtailment). However, acoustic detectors often are used in the field without a thorough understanding of underlying assumptions and limitations or standardized protocols (Hayes 2000, Gannon et al. 2003; Parsons and Szewczak 2009). In addition, a lack of information and agreement among stakeholders and scientists exists regarding what constitutes acceptable levels of risk in relation to bat activity and potential fatality of bats at wind facilities. Collectively, 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), yet confounding factors associated with these studies limit our ability to make inferences and develop a fundamental link necessary for understanding potential risk of wind facilities to bats.

## OBJECTIVES

Clipper Wind Power Development (Clipper) proposes to develop the Resolute Wind Energy Project (RWEP) in east-central Wyoming. In 2009, we initiated a multi-year, pre-construction acoustic monitoring study to assess the patterns of bat activity and evaluate the use of acoustic monitoring to predict fatality of bats following methods and objectives of similar studies (e.g., Arnett et al. 2006, 2007; Kunz et al. 2007b). The goal of Phase I of this study was to collect data on echolocation passes and develop indices of temporal and spatial activity patterns. The second phase, which will occur after turbines are installed and the site is operational, will involve post-construction fatality monitoring. Our objectives for this report were to: 1) report baseline information on activity levels for different phonic groups using the RWEP, 2) examine temporal and spatial patterns of bat activity with acoustic detectors positioned at five meteorological (met) towers at 2 heights, and 3) combine our results with those of similar studies to evaluate if indices of pre-construction bat activity can be used to predict relative risk of post-construction bat fatality at a site. This report focuses on objectives 1 and 2; results from this study will be combined with several similar ongoing efforts in the region to address Objective 3.

## STUDY AREA

The RWEP is a proposed 300 MW wind energy facility located in Converse County, near Casper in east-central Wyoming (Fig. 1). The habitat is mostly sagebrush shrublands (Wyoming Game and Fish Department [WGFD] 2010), with some trees in the foothills on the western edge of the project. We sampled 5 meteorological (‘met’) towers (5032, 5034, 5041, 5042, and 5043), which allowed us to characterize variation in bat activity across the RWEP. The RWEP is currently in the planning stage and the total number of turbines and their locations are not yet finalized.

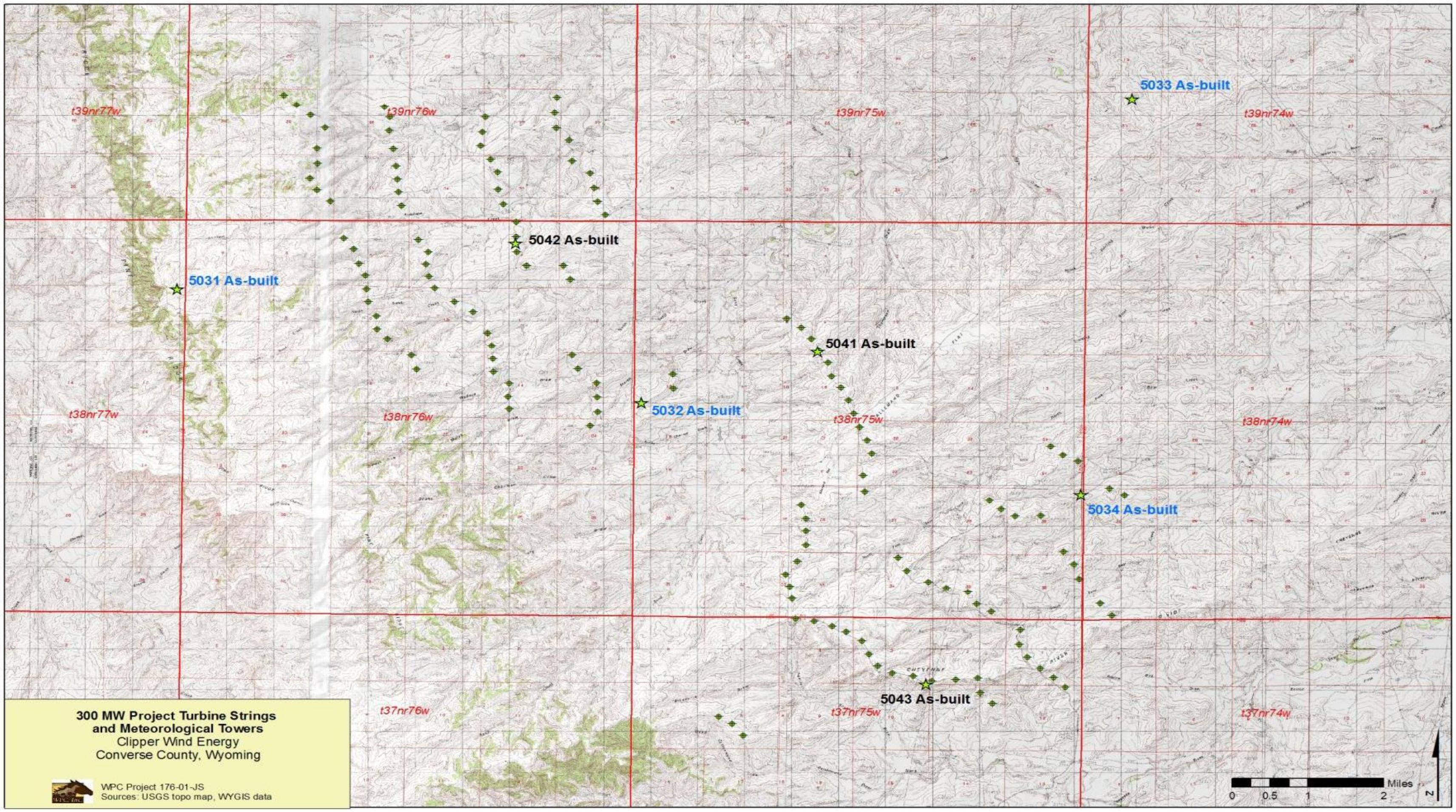
## METHODS

We followed recommendations for conducting wildlife studies at wind energy facilities described by Kunz et al. (2007b). We defined a bat pass as an echolocation sequence of ≥2 echolocation calls with a minimum duration of 10 ms (Thomas 1988, Hayes 2000, Sherwin et al. 2000, Gannon et al. 2003; Parsons and Szewczak 2009). We recognized that echolocation passes are reliably distinguished from other nocturnal sounds (e.g., birds, arthropods, wind, rain, mechanical noises), but the ability to differentiate species of bats is challenging and varies with 1) detectability (distance of bat to microphone), call intensity (loud vs. quiet species), 2) species call rates, 3) migratory vs. foraging call rates, 4) weather, 5) surrounding habitat, and 6) equipment used (Barclay 1999, Hayes 2000, Kunz et al. 2007b). We considered each pass a discrete event and each detector an independent observational unit repeatedly measured each night throughout the sampling period. We assumed that; 1) echolocation calls were consistent within a species, 2) species consistently called at either high or low frequencies, 3) 33 kHz (average minimum call frequency) represented an appropriate threshold to separate species into these two phonic groups, 4) simultaneous sampling at 5 sites/night would adequately account for spatial and temporal variation at the RWEP, and 5) the number of bat passes recorded indicated relative use by bats and did not reflect abundance (e.g., 100 bat passes may be a single bat recorded 100 different times or 100 different bats each recording a single pass; Kunz et al. 2007b).

### Equipment

We used Anabat II broadband acoustic detectors coupled with CF-ZCAIM storage units (Titley Electronics, Ballina, New South Wales, Australia) with an approximate detection range of 20 m (actual range is dependent on temperature, humidity, and frequency and intensity of echolocation sequences) to record bat echolocation sequences or passes. We positioned detector microphones at 2 heights (1.5 m and 44 m above ground level [agl]) on 5 met towers from 3 August to 18 October 2009 and 2 June to 30 September 2010 (Fig. 2). This spatial arrangement allowed us to sample bat activity at ground level and within the lower portion of the Rotor-Swept Area (RSA), across the proposed RWEP. Prior to sampling, we calibrated each Anabat unit (sensitivity set at approximately 6) to minimize variability among detectors (Larson and Hayes 2000). Additionally, each week we rotated detectors at each tower between the 2 heights to ensure no particular detector was consistently used at any one height. We housed microphones in waterproof “bat-hats” (EME Systems, Berkley, California, USA) attached to electrical cables extending to ground level, where detectors were placed in waterproof boxes (Figs. 3, 4). We used rechargeable batteries to provide power to all detector units.

Figure 1. Location of seven meteorological towers and proposed turbine locations at the Resolute Wind Project. Towers used for acoustic sampling include numbers 5032, 5034, 5041, 5042, and 5043. Towers 5031 and 5033 were not used in the study for either year.



## ANALYSIS

We visited each tower approximately every week to exchange CF cards and batteries. We downloaded and analyzed data using Anabat CFC Read (version 4.2a) and Analook (version 4.9j) software, respectively. Prior to analysis, we removed extraneous noise from our data using customized filters derived from Britzke and Murray (2000).

### Phonic group identification

We assigned each bat pass to one of 2 phonic groups based on minimum frequency of the echolocation sequence, in part because bats using these frequencies may differ in their use of habitat and in their response to environmental factors. To accomplish this, we constructed 2 filters to classify bat passes as being produced by either high frequency bats (≥33 kHz average minimum frequency; e.g., *Myotis* spp.) or low frequency bats (<33 kHz average minimum frequency; e.g., big brown, silver-haired, hoary bats). Both filters were derived from those developed by Britzke and Murray (2000), with a Smoothness = 15 and a Bodyover = 80. We adjusted frequency parameters to separate high and low echolocation sequences. For the low frequency phonic group filter, we set the maximum frequency at 33 kHz, and for the high frequency phonic group filter, we set the minimum frequency at 33 kHz. We visually scanned all files not assigned by the filters and placed them into the appropriate high or low group. We also identified a third phonic group, hoary bats, a subset of the low phonic group, using a customized filter, with a Soothness = 12, Bodyover = 110, MinFmin = 14, MaxFmin = 21, and CallNum = 1. We chose to identify the hoary bat to species because it is vulnerable to wind-energy development and its echolocation sequences are relatively easy to distinguish among other low-frequency emitting bats.

### Temperature and wind speed

We used civil sunrise and sunset data from the US Naval Observatory Astronomical Applications Department (http://aa.usno.navy.mil/data/docs/RS_OneYear.php) to define our crepuscular and nocturnal sampling period or “night”. We monitored bat activity each night between ½ hr before sunset to ½ hr after sunrise. This sampling schedule provided coverage during times when bats are most active (Hayes 1997). We adjusted met tower dates to “effective date” such that all morning hours within each night were assigned the previous calendar date value. We summarized data for each “effective date” and checked for missing observations or anomalous or unreasonable values. Mean ambient temperature and wind speed were recorded at 10-minute intervals on each met tower. Wind speed was measured at 50 m agl and 10 m agl on each tower and ambient temperature was measured at 2 m agl. We averaged wind speed data collected from two directions. At each met tower, we calculated 5 summary statistics for each night: mean temperature (T) = mean over all 10 minute averages, mean wind speed (WS) = mean over all 10 minute averages, proportion of 10-minute intervals during which average wind speed was greater than 3.5 m/s (PctG3.5), >5 m/s (PctG5), >6.5 m/s (PctG6.5), and <6.5 m/s (PctL6.5). We merged the total number of calls recorded by each phonic group with weather data for each location, height and night. Because of acoustic or meteorological equipment malfunctions, complete data on all sample nights were not available for analysis. We chose dates for each analysis to maximize coincident data recordings among the met towers.

We designed our analysis to examine the relationship of bat activity within three phonic groups to various measures of temperature and wind speed. Because our response variable, counts (i.e., number of bat passes/night) from each location and height, contained numerous zeros (i.e., nights with no bat activity recorded) our data naturally conformed to the sequential questions: 1) which variables relate to the probability of activity occurring on any given night/height/ location; and 2) given that activity occurs, which variables are associated with level of activity? To examine these two questions simultaneously, we used hurdle models (Zuur et al. 2009) which divide the response into two parts, the zero counts and the non-zero counts. In the first part, the probability of activity is modeled as a binomial (binary) response and can be related to explanatory covariates such as temperature or wind speed. In the second part (the count part), the activity rate can be modeled as a truncated Poisson or negative binomial response and also can be related to explanatory covariates. We modeled activity as a truncated negative binomial response to accommodate variation in bat passes/night that exceeded variation assumed from a Poisson distribution. We included location and mean ambient temperature in all models to account for the correlation of observations within these factors while including temperature as a surrogate for changing seasonal effects.

To explore how temperature and wind might affect the probability of activity and the activity rate of bats in the 3 phonic groups, we established 2 sets of candidate models (Appendices 1 and 2). The first set compared the activity of high and low frequency bats at 1.5 m, and consisted of 128 candidate models, including one null (no explanatory variables), three baseline models, and 124 plausible wind velocity models (Appendix 1). The null model included no covariates for either the binomial part (probability of activity) or the count part (activity rate) of the hurdle model. The three baseline models differed in the factors included in each part of the hurdle model (i.e., location, and temperature), excluding wind speed. The first baseline model (location model) included only location effects in both parts, whereas the second included location and mean ambient temperature. The third baseline model included location and the interaction between temperature and phonic group in both parts. The second set of models compared activity by low frequency or hoary bats at 44 m, and consisted of 40 candidate models including 1 null, a location model, a location and temperature model, and 37 wind models. Wind models built upon the third baseline model (full design model) and included covariates of nightly wind speed. To construct the suite of candidate wind models, we first incorporated WS both separately and simultaneously in the binomial and count parts of the hurdle model. Next, we maintained WS in the binomial part, and considered each wind speed measurement (i.e., PctG6.5, PctG5, or PctG3.5), and interactions between wind speed and temperature for the count part of the hurdle model. We repeated this process, but maintained WS in the count part and varied wind speed measurements and interactions in the binomial part. The same process was used for PctG3.5, PctG5 and PctG6.5, thus we considered wind speed for both parts of the hurdle model simultaneously. This method of candidate model construction allowed us to first relate higher wind speed thresholds to the probability of bat activity, and then given that activity occurred, examine relationships between the amount of activity and wind speed measurements up to and including the higher threshold.

We performed three separate AIC model selection analyses (Burnham and Anderson 2002), one for each of the three phonic groups (i.e., high frequency, low frequency, and hoary bats) to evaluate and select the most-parsimonious model given the data and set of candidate models. We established a confidence set of models (i.e., highly competing models) by including only those models within two AIC units of the best approximating model. We calculated Nagelkerke's pseudo-$R^2$ ($Rp^2$) as a rough indicator of model strength. We compared $Rp^2$ values of the location model and the full design model with the null model. We also compared additional $Rp^2$ values of the best approximating model with the full design model. We report results for all base models and all models within 4 AIC units of the best approximating model. If clear evidence indicated a specific wind model was better than the full design model, we interpreted the most parsimonious, highly competing wind model.

We examined the effects of changing ambient temperature and wind speed on the probability of bat activity and the amount of activity at different heights. We calculated parameter estimates, standard errors, and effects for coefficients of the best model for each phonic group and year. We evaluated the ecological importance of each variable by computing 95% confidence intervals for each coefficient and interpreted the values within these intervals (Gerard et al. 1998). Only factors whose 95% confidence intervals of odds ratios did not include 1 were interpreted as being related to bat activity.

## RESULTS

In 2009, we conducted bat acoustic monitoring for 77 nights from 3 August to 18 October from 2 heights at 5 towers for a total of 762 potential detector-nights (# detectors * # towers * # nights). All detectors were installed on 3 August 2009, with the exception of the 1.5 m detector on tower 5042; this detector became operational on 11 August. In addition, because of acoustic and meteorological equipment malfunctions, we only were able to use coincident data (i.e., nights when all detectors and weather equipment were operational for a specific height) for 506 (1.5 m = 229; 44 m = 277) detector-nights.

In 2010, we monitored bat activity for 121 nights from 2 June to 30 September from 2 heights at 5 towers for 1,089 potential detector-nights. All detectors were installed on 2 June, except for the 44 m detector at tower 5034, which was not in operation during the 2010 study period. Additionally, equipment malfunctions limited our coincident dataset to 591 (1.5 m = 341; 44 m = 250) detector-nights.

### General Bat Activity

In 2009, we recorded a total of 976 bat passes. At 1.5 m, we identified 447 and 203 passes as high frequency and low frequency bats, respectively. Of the low frequency recordings, we identified 17 as hoary bat passes. At 44 m, we identified 7 and 319 passes as high frequency and low frequency, respectively. Of the low frequency recording, we identified 97 as hoary bat passes. In 2010, we recorded a total of 1,111 bat passes. At 1.5

m, we identified 392 and 311 passes as high frequency and low frequency bats, respectively. Of the low frequency recordings, we identified 37 as hoary bat passes. At 44 m, we identified 18 and 390 passes as high frequency and low frequency bats, respectively. Of the low frequency recordings, we identified 171 as hoary bat passes.

### *Temporal Variation in Bat Activity*

We observed temporal variations in bat activity among phonic groups. High frequency bat activity peaked 1–2 hours past sunset and steadily decreased throughout the night in both years (Fig. 2). In contrast, low-frequency bat activity peaked later in the evening in 2009 and remained relatively high from sunset to two hours pre-sunrise. Hoary bat activity peaked within the hour past sunset in both years. Activity by hoary bats remained relatively low for the remaining hours of the night in 2009, but relatively high until one hour pre-sunrise in 2010.

Bat activity varied among nights, with the majority of activity occurring in August for both years (Fig. 3). In 2009, high frequency activity peaked in early August, but was more evenly distributed in 2010. Mean number of low frequency passes increased multiple times from mid-August to mid-September in 2009. In 2010, we observed a peak in low frequency bat activity in early August with smaller peaks in late August and early September. Hoary bat activity was low and relatively constant for both years, however we observed a peak in activity in early August 2010.

### *Spatial Variation in Bat Activity*

Bat activity varied among phonic groups by height and among towers (Fig. 4). We detected high frequency bats most often at 1.5 m in 2009 and 2010, and recorded the greatest activity at tower 5042 in both years. Low frequency bat activity was relatively uniform between heights and among towers for both years. We detected hoary bats most often at 44 m and recorded the greatest activity at towers 5032 and 5042 in 2009 and at tower 5032 in 2010. We recorded the fewest calls by any phonic group at tower 5034.

In 2009, the range of mean activity among towers at 1.5 m for high frequency, low frequency and hoary bats was between 0.16–4.21, 0.37–1.02, and 0.02–0.11 passes/night, respectively (Table 1). Among towers at 44 m, the range of mean activity for high frequency, low frequency, and hoary bats was between 0.00–0.07, 0.78–0.93, and 0.20–0.61 passes/night, respectively. On nights when bat passes were recorded at a station (i.e., excluding nights with zero activity), the range of mean activity among towers at 1.5 m was 2.5–6.0 times the average for high frequency bats, 2.3–5 times for low frequency bats, and 12–55 times for hoary bats. The range of mean activity among towers at 44 m was 16–46 times the average for high frequency bats, 1.8–3.0 times for low frequency bats, and 3.2–6 times for hoary bats. Although we recorded zero bat passes on the majority of nights, we detected at least one high frequency bat pass on 39% and 3% of detector-nights, one low frequency bat pass on 40% and 48% and 1 hoary bat pass on 6% and 24% of detector-nights at 1.5 m and 44 m, respectively (Table 2).

In 2010, the range of mean activity among towers at 1.5 m for high frequency, low frequency, and hoary bats was between 0.18–2.75, 0.42–1.44, and 0–0.27 passes/night, respectively (Table 3). Among towers at 44 m, the range of mean activity for high frequency, low frequency, and hoary bats was between 0–0.13, 1.13–2.09, and 0.20–0.61 passes/night, respectively. On nights when bat passes were recorded at a station (excluding nights with zero activity), the range of mean activity among towers at 1.5 m was 1.6–5.9 times the average for high frequency bats, 2.1–3.5 times for low frequency bats, and 7.3–32 times for hoary bats. The range of mean activity among towers at 44 m for nights when at least one pass was recorded was 11–32 times the average for high frequency bats, two times for low frequency bats, and 3–4 times for hoary bats. Although we recorded zero bat passes on the majority of nights, we detected at least one high frequency bat pass on 40% and 4% of detector-nights, one low frequency bat pass on 36% and 49% of detector-nights and one hoary bat pass on 7% and 34% of detector-nights at 1.5 m and 44 m, respectively (Table 4).

### *Bat Activity in Relation to Weather Variables*

In 2009, both high and low frequency bat activity at 1.5 m was negatively related to wind speed, and positively related to ambient temperature (Fig. 5). There was too little hoary bat activity at this height to statistically investigate relationships with either wind or ambient temperature. At 44 m, there was too little high frequency bat activity to determine whether any relationship existed with either wind or ambient temperature. Low frequency and hoary bat activity were positively related to temperature and negatively related to wind speed.

In 2010, high frequency bat activity was positively related to temperature and negatively related to wind speed at 1.5 m (Fig. 6). Low frequency bat activity was positively related to temperature, but showed little relation to wind speed. There was insufficient hoary bat activity at 1.5 m to determine the relationship between activity and either wind or temperature. At 44 m, there was insufficient high frequency bat activity to explore relationships between activity and either wind or temperature. Low frequency and hoary bat activity was positively related to temperature but appeared relatively insensitive to wind speed.

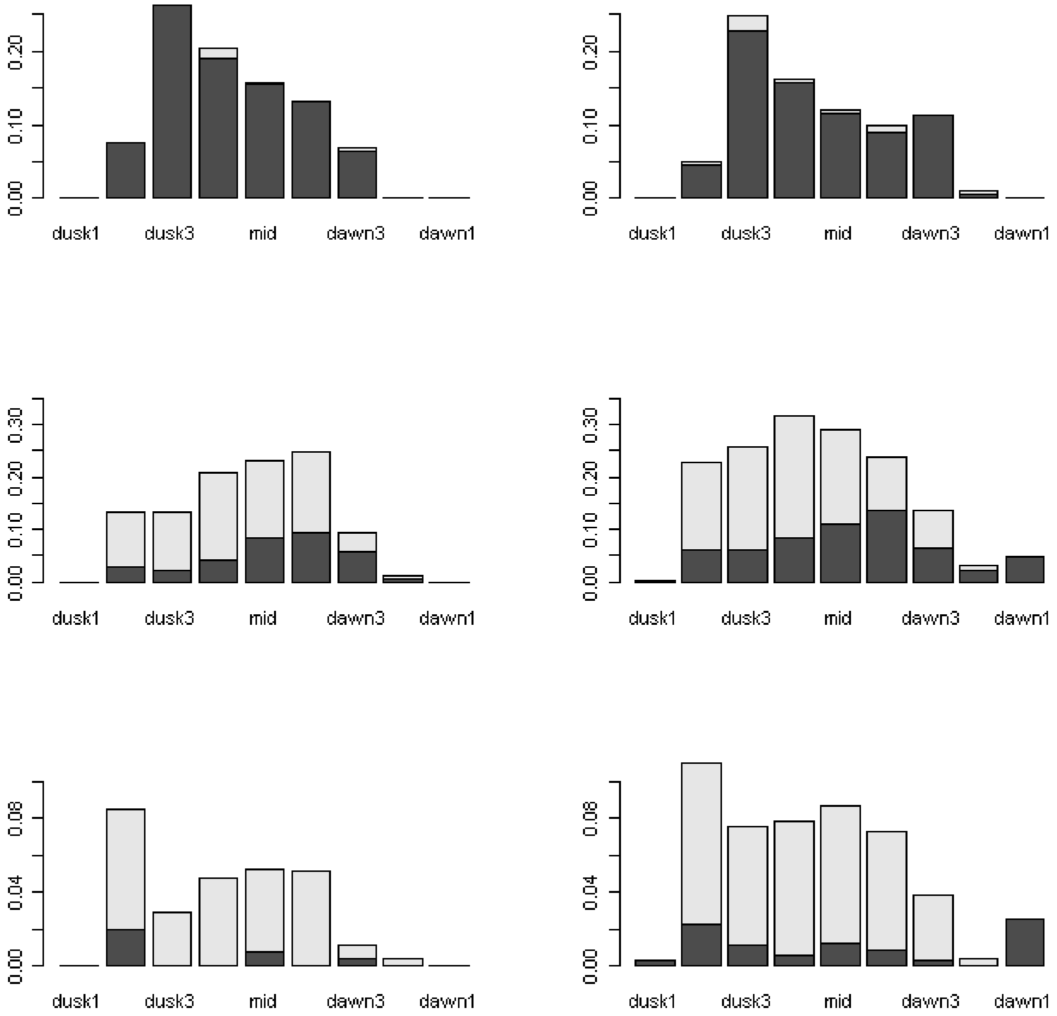


Figure 2. Mean number of passes/hour/tower at each height during the night for (top to bottom) high- (≥33kHz), low- (<33kHz) frequency bats and hoary bats at the proposed RWEP, 2009 (left) and 2010 (right). Dark and light shading represents activity at 1.5 m and 44 m, respectively.

Dusk1 = 1 hr pre-sunset – sunset
Dusk2 = sunset – 1 hr post-sunset
Dusk3 = 1 hr post sunset – 2hrs post-sunset
Dusk4 = 2 hrs post sunset – 3 hrs post-sunset
Mid = 3 hrs post sunset – 3 hrs pre-sunrise
Dawn4 = 3 hrs pre sunrise – 2 hrs pre-sunrise
Dawn3 = 2 hrs pre sunrise – 1 hrs pre-sunrise
Dawn2 = 1 hs pre sunrise – sunrise
Dawn1 = sunrise – 1 hr post-sunrise

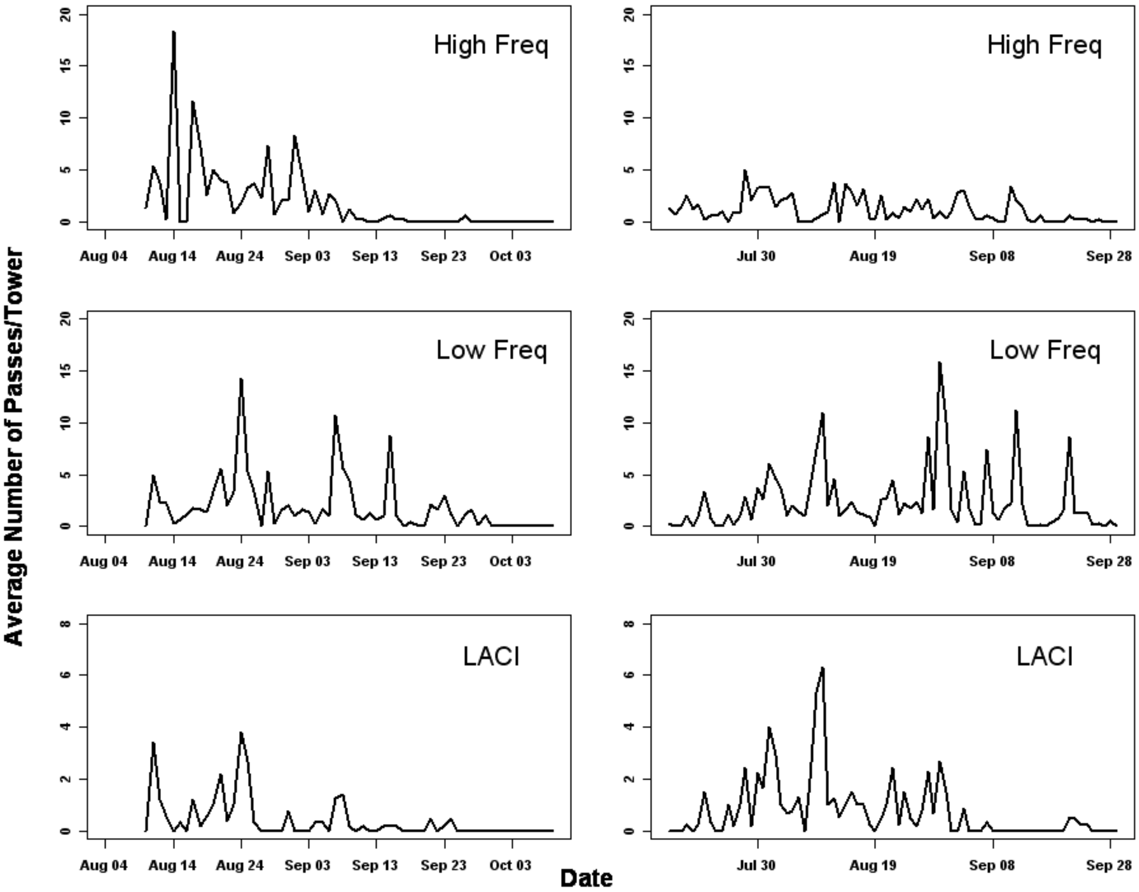


Figure 3. Mean passes/tower for each phonic group at the proposed RWEP, 2009 (left) and 2010 (right). High freq, low freq, and LACI represent high frequency, low frequency, and hoary bats, respectively.

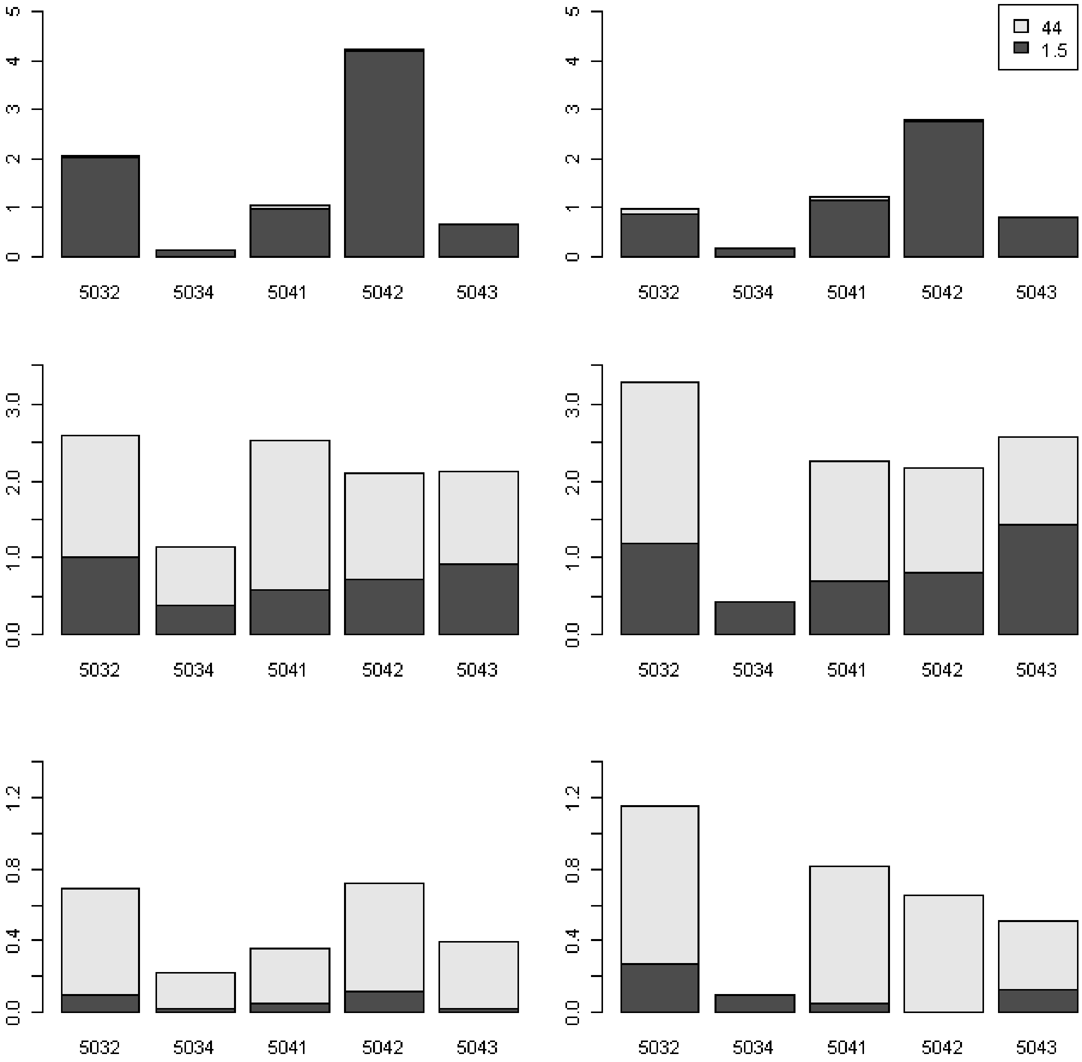


Figure 4. Mean passes/night at each tower and height for (top to bottom) high- (≥33kHz) and low- (<33kHz) frequency bats, and hoary bats at the proposed RWEP, 2009 (left) and 2010 (right). Dark and light shading represent activity at 1.5 m and 44 m, respectively.

**Table 1.** Summary of bat activity, by phonic group, recorded from 5 towers and 2 heights at the RWEP, Wyoming, 2009.

| **Height** | **Tower/ Phonic group** | **Mean passes/night** | **Mean passes/night (given activity)**[a] | **Maximum number of passes** | **Perecent nights with zero bat passes** |
|---|---|---|---|---|---|
| **1.5 m** | 5032 | | | | |
| | High | 2.02 | 5.21 | 22 | 0.61 |
| | Low | 1.02 | 2.42 | 15 | 0.58 |
| | LACI | 0.10 | 1.20 | 2 | 0.92 |
| | Overall | 3.03 | 5.53 | 28 | 0.45 |
| | 5034 | | | | |
| | High | 0.16 | 1.00 | 1 | 0.84 |
| | Low | 0.37 | 1.73 | 4 | 0.78 |
| | LACI | 0.02 | 1.00 | 1 | 0.98 |
| | Overall | 0.53 | 1.69 | 4 | 0.69 |
| | 5041 | | | | |
| | High | 0.98 | 2.39 | 7 | 0.59 |
| | Low | 0.59 | 1.74 | 8 | 0.66 |
| | LACI | 0.05 | 1.50 | 2 | 0.96 |
| | Overall | 1.57 | 3.03 | 10 | 0.48 |
| | 5042 | | | | |
| | High | 4.21 | 10.14 | 57 | 0.58 |
| | Low | 0.72 | 2.38 | 12 | 0.70 |
| | LACI | 0.11 | 1.50 | 3 | 0.92 |
| | Overall | 4.92 | 10.04 | 57 | 0.51 |
| | 5043 | | | | |
| | High | 0.65 | 2.77 | 9 | 0.76 |
| | Low | 0.91 | 2.63 | 15 | 0.65 |
| | LACI | 0.02 | 1.00 | 1 | 0.98 |
| | Overall | 1.56 | 3.58 | 16 | 0.56 |
| **44 m** | 5032 | | | | |
| | High | 0.06 | 1.00 | 1 | 0.94 |
| | Low | 1.57 | 2.85 | 9 | 0.45 |
| | LACI | 0.59 | 1.93 | 4 | 0.69 |
| | Overall | 1.63 | 2.96 | 9 | 0.45 |
| | 5034 | | | | |
| | High | 0.00 | NA | 0 | 1.00 |
| | Low | 0.78 | 2.38 | 5 | 0.68 |
| | LACI | 0.20 | 1.33 | 2 | 0.85 |
| | Overall | 0.78 | 2.38 | 5 | 0.68 |
| | 5041 | | | | |
| | High | 0.07 | 1.50 | 2 | 0.96 |
| | Low | 1.93 | 3.56 | 22 | 0.46 |
| | LACI | 0.30 | 1.75 | 5 | 0.83 |
| | Overall | 2.00 | 3.68 | 22 | 0.46 |
| | 5042 | | | | |
| | High | 0.02 | 1.00 | 1 | 0.98 |
| | Low | 1.39 | 2.67 | 11 | 0.48 |
| | LACI | 0.61 | 2.00 | 7 | 0.70 |
| | Overall | 1.41 | 2.71 | 11 | 0.48 |

**Table 1. Continued.**

| Height | Tower/ Phonic group | Mean passes/night | Mean passes/night (given activity)[a] | Maximum number of passes | Percent nights with zero bat passes |
|---|---|---|---|---|---|
| **44 m** | 5043 | | | | |
| | High | 0.00 | NA | 0 | 1.00 |
| | Low | 1.21 | 2.76 | 8 | 0.56 |
| | LACI | 0.38 | 1.64 | 4 | 0.77 |
| | Overall | 1.21 | 2.76 | 8 | 0.56 |

[a] Mean bat activity for nights in which at least 1 bat call was recorded.

**Table 2**. Number of detector-nights in which high frequency, low frequency, and hoary bats were detected/not detected at the listed rate at each of two heights for all towers combined at the RWEP, Wyoming, 2009.

| Year<br>Height | Number of Passes/Night | Phonic group<br>High | <br>Low | <br>Hoary |
|---|---|---|---|---|
| **2009** | | | | |
| **1.5 m** | 0 | 187 | 186 | 264 |
| | 1 | 32 | 49 | 10 |
| | 2 | 13 | 24 | 2 |
| | 3 | 11 | 9 | 1 |
| | 4 | 6 | 3 | 0 |
| | >4 | 28 | 6 | 0 |
| | Non-zero[a] | 90 | 91 | 13 |
| | Missing[b] | 33 | 33 | 33 |
| **44 m** | 0 | 223 | 119 | 175 |
| | 1 | 5 | 43 | 32 |
| | 2 | 1 | 24 | 11 |
| | 3 | 0 | 16 | 5 |
| | 4 | 0 | 9 | 4 |
| | >4 | 0 | 18 | 2 |
| | Non-zero[a] | 6 | 110 | 54 |
| | Missing[b] | 16 | 16 | 16 |

[a] Refers to the number of detector-nights with at least one bat pass recorded.

[b] Refers to the number of detector-nights during which data were not collected because of equipment malfunctions.

**Table 3.** Summary of bat activity, by phonic group, recorded from five towers and two heights at the RWEP, Wyoming, 2010.

| Height | Tower/Species Group | Mean passes/night | Mean passes/night (given activity)[a] | Maximum number of passes | Percent nights with zero bat passes |
|---|---|---|---|---|---|
| **1.5 m** | 5032 | | | | |
| | High | 0.86 | 2.11 | 5 | 0.59 |
| | Low | 1.20 | 2.93 | 18 | 0.59 |
| | LACI | 0.27 | 2.00 | 4 | 0.86 |
| | Overall | 2.06 | 3.49 | 23 | 0.41 |
| | 5034 | | | | |
| | High | 0.18 | 1.08 | 2 | 0.83 |
| | Low | 0.42 | 1.43 | 4 | 0.70 |
| | LACI | 0.10 | 1.17 | 2 | 0.92 |
| | Overall | 0.61 | 1.65 | 4 | 0.63 |
| | 5041 | | | | |
| | High | 1.16 | 3.70 | 9 | 0.69 |
| | Low | 0.69 | 2.44 | 8 | 0.72 |
| | LACI | 0.05 | 1.50 | 2 | 0.97 |
| | Overall | 1.84 | 3.93 | 14 | 0.53 |
| | 5042 | | | | |
| | High | 2.75 | 4.52 | 17 | 0.39 |
| | Low | 0.81 | 2.43 | 16 | 0.67 |
| | LACI | 0.00 | NA | 0 | 1.00 |
| | Overall | 3.57 | 5.47 | 19 | 0.35 |
| | 5043 | | | | |
| | High | 0.82 | 1.71 | 4 | 0.52 |
| | Low | 1.44 | 3.00 | 20 | 0.52 |
| | LACI | 0.13 | 1.13 | 2 | 0.89 |
| | Overall | 2.25 | 3.08 | 20 | 0.27 |
| **44 m** | 5032 | | | | |
| | High | 0.13 | 1.50 | 4 | 0.91 |
| | Low | 2.09 | 4.30 | 19 | 0.51 |
| | LACI | 0.88 | 2.73 | 11 | 0.68 |
| | Overall | 2.22 | 4.31 | 19 | 0.49 |
| | 5041 | | | | |
| | High | 0.08 | 1.67 | 2 | 0.95 |
| | Low | 1.56 | 2.86 | 11 | 0.45 |
| | LACI | 0.77 | 2.04 | 6 | 0.63 |
| | Overall | 1.64 | 2.92 | 13 | 0.44 |
| | 5042 | | | | |
| | High | 0.06 | 2.00 | 3 | 0.97 |
| | Low | 1.37 | 2.69 | 15 | 0.49 |
| | LACI | 0.65 | 1.71 | 7 | 0.62 |
| | Overall | 1.43 | 2.81 | 18 | 0.49 |
| | 5043 | | | | |
| | High | 0.00 | NA | 0 | 1.00 |
| | Low | 1.13 | 2.70 | 15 | 0.58 |
| | LACI | 0.38 | 1.50 | 4 | 0.75 |
| | Overall | 1.13 | 2.70 | 15 | 0.58 |

[a] Mean bat activity for nights in which at least one bat call was recorded.

**Table 4**. Number of detector-nights in which high frequency, low frequency, and hoary bats were detected/not detected at the listed rate at each of two heights for all towers combined at the RWEP, Wyoming, 2010.

| **Year** | **Number of** | **Phonic group** | | |
|---|---|---|---|---|
| **Height** | **Passes/Night** | **High** | **Low** | **Hoary** |
| **2010** | | | | |
| **1.5 m** | 0 | 206 | 218 | 316 |
| | 1 | 60 | 67 | 18 |
| | 2 | 22 | 21 | 4 |
| | 3 | 20 | 14 | 1 |
| | 4 | 9 | 4 | 2 |
| | >4 | 24 | 17 | 0 |
| | Non-zero[a] | 135 | 123 | 25 |
| | Missing[b] | 14 | 14 | 14 |
| **44 m** | 0 | 239 | 127 | 166 |
| | 1 | 7 | 47 | 43 |
| | 2 | 2 | 30 | 25 |
| | 3 | 1 | 16 | 5 |
| | 4 | 1 | 10 | 5 |
| | >4 | 0 | 20 | 6 |
| | Non-zero[a] | 11 | 123 | 84 |
| | Missing[b] | 34 | 34 | 34 |

[a] Refers to the number of detector-nights with at least one bat pass recorded.

[b] Refers to the number of detector-nights during which data were not collected because of equipment malfunctions.

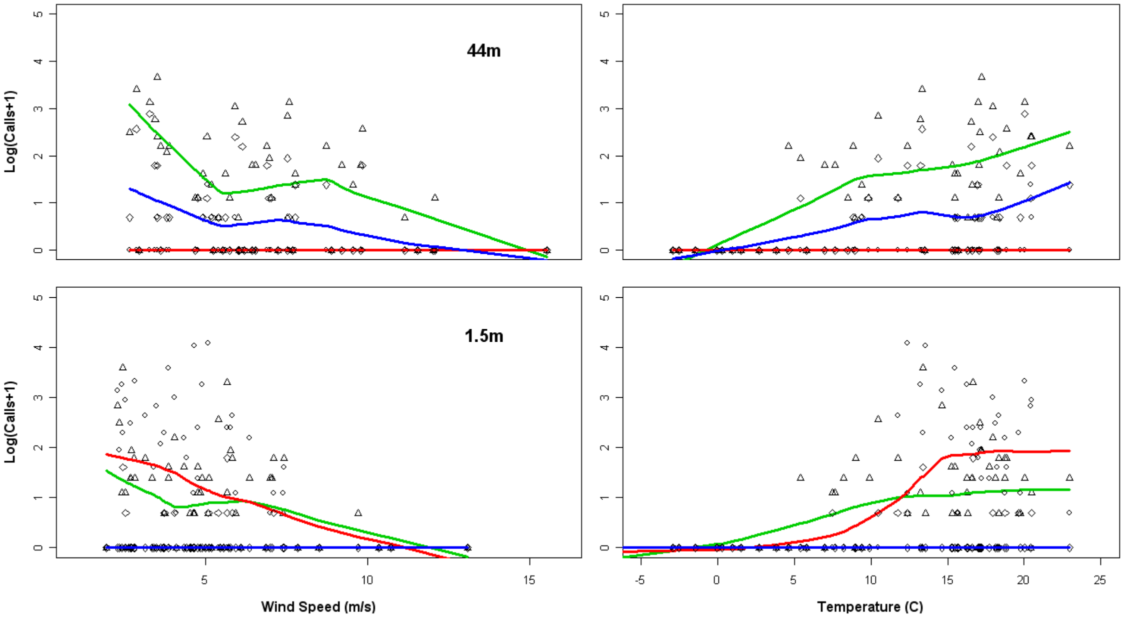


Figure 5. Log$_e$ (number of calls) of high frequency (○), low frequency (◊) and hoary (Δ) bats at each height at the proposed RWEP, 2009, related to wind speed (left column) and temperature (right column). Red, green and blue lines are the loess fits for high-, low-frequency and hoary bats, respectively.

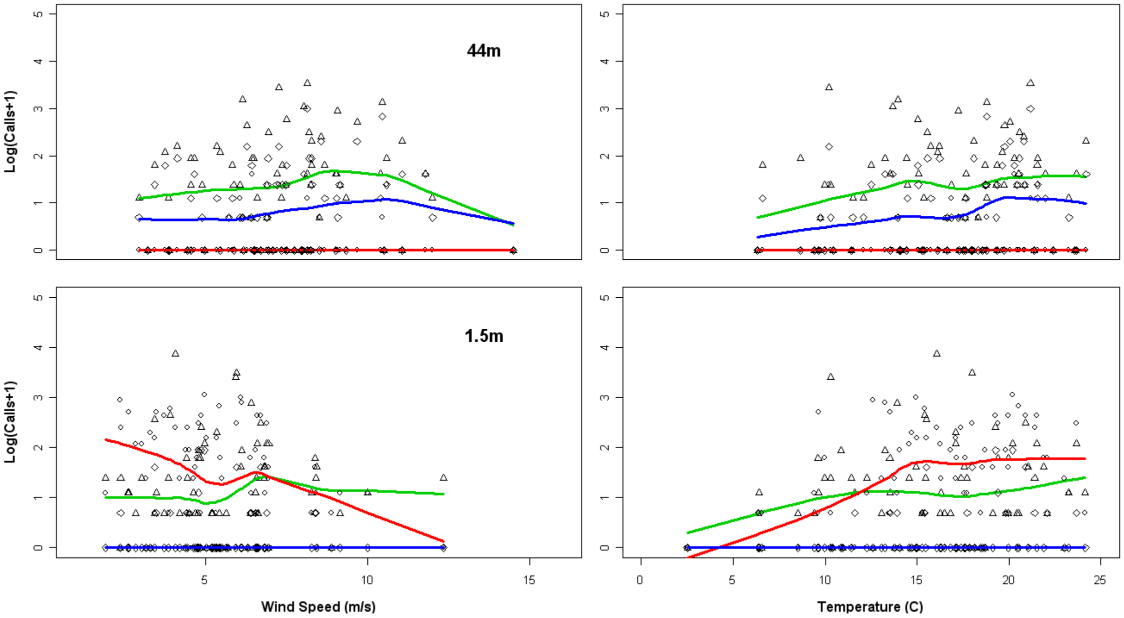


Figure 6. Log$_e$ (number of calls) of high frequency (○), low frequency (◊) and hoary (Δ) bats at each height at the proposed RWEP, 2010, related to wind speed (left column) and temperature (right column). Red, green and blue lines are the loess fits for high-, low-frequency and hoary bats, respectively.

## MODEL ANALYSIS

We were unable to model high frequency bat activity at 44 m because we only recorded seven and 18 passes in 2009 and 2010, respectively. Similarly, we were unable to model hoary bats at 1.5 m because we only recorded 17 and 37 passes in 2009 and 2010, respectively. We were able to compare high and low frequency bat activity at 1.5 m for both years.

## 2009

In 2009 at 1.5 m, mean wind speed and ambient temperature were 5.16 m/s (range = 1.18–14.15 m/s) and 11.97° C (range = -12.27–23.74° C), respectively (Table 5). At 44 m, mean wind speed and temperature were 6.76 m/s (range = 0.39–16.76 m/s) and 11.69° C (range = -3.30–23.74° C), respectively. On average at 1.5m, the proportion of the night during which wind speed ≥3.5 m/s (PctG3.5) was 67% and ranged from near 50% to 100%. The PctG5 and PctG6.5 averaged 48% (range = ~0–100%) and 30% (range = ~0–100%), respectively. At 44 m, the proportion of the night during which wind speed ≥3.5 m/s (PctG3.5) was 78% and ranged from near 0% to 100%. The PctG5 and PctG6.5 averaged 65% (range = ~0–100%) and 51% (range = ~0–100%), respectively.

### *High and Low Frequency Bats at 1.5m*

The best approximating model comparing high and low frequency bat activity at 1.5 m, with a 21.2% probability, was based on the full design model and incorporated the interaction of temperature, frequency, and wind speed in the probability part and contained wind speed in the count part of the hurdle model (Appendix 3). This model was 1.6 times more likely than the next best approximating model which contained the same parameters minus the interaction of ambient temperature in the probability part of the hurdle model. The confidence set (within 2 AIC Units of the best model) of models included the top six models with a sum of Akaike weights of 0.719, indicating a 71.9% chance that one of these models was the best approximating model given the data and set of candidate models. The location model was 34 AIC units better than the null model, accounting for approximately 9.5% of variation in activity at the site, while the full design model was 142 AIC units better than the null model, accounting for approximately 28.7% of variation. The full design model was not included in the confidence set of models, and was 40.46 AIC units away from the best approximating model, and only accounted for an additional 7.0% of the variation in activity.

On a night with average wind speed and temperature, the probability of activity at 1.5 m ranged from 8–24% over the locations (Table 6). For every 1° C increase in temperature, the odds of bat activity increased by 22–45% and 8–19% for high and low frequency bats, respectively. The probability of bat activity was positively related to decreasing wind speed, with odds of activity increasing by 40–105% and by 4–37% for every 1 m/s decrease in wind speed, for high and low frequency bats respectively. Given activity, the expected number of high frequency passes at 1.5 m on nights with mean temperature and wind speed, ranged from 0.36 to 3.09 across the locations. Low frequency passes were estimated to be 20–90% less than high frequency bat passes. We found no strong evidence of a relationship between activity and ambient temperature for either frequency group.

### *Low Frequency Bats at 44m*

The best approximating model for low frequency bat activity, with a probability of 30.5%, was based on the full design model and incorporated average wind speed in the probability and count parts of the hurdle model (Appendix 3). This model was 1.6 times more likely than the next best approximating model, which incorporated PctL6.5 in both parts of the hurdle model. The confidence set of models included the top 3 models with a sum of Akaike weights of 0.611. Location alone accounted for approximately 3.7% of variation in activity at the site, while the full design model was 39 AIC units better than the null model, accounting for approximately 23.6% of variation. The best fitting model was roughly 23 AIC units better than the full design model, accounting for an additional 8.9% of the variation in activity beyond the full design model.

On a night with average wind speed and ambient temperature, the probability of low frequency activity at 44 m ranged from 28–58% across locations (Table 6). For every 1°C increase in temperature, the odds of low frequency bat activity increased 11–23%. The probability of activity was positively related to decreasing wind speed, with odds of activity increasing by 13–45% for every 1 m/s decrease in wind speed. Given activity, the expected number of low frequency passes at 44 m on nights with mean temperature and wind speed ranged from 0.7–1.7 across locations (Table 6). For every 1° C increase in temperature, the expected number of passes increased 0.1–14%.  Expected number of passes/night decreased 6–25% for every 1m/s increase in wind speed.

### *Hoary bats at 44 m*

The best approximating model for hoary bat activity, with a probability of 13.7%, was based on the full design model and incorporated wind speed in both parts of the hurdle model (Appendix 3). This model was 1.4 times more likely than the next best approximating model which contained the same parameters minus wind speed in the count part of the model. The confidence set of models included the top 8 models with a sum of Akaike weights of 0.64. The location model only accounted for approximately 3.8% of variation in activity at the site, while the full design model was 16 AIC units better than the null model, accounting for approximately 18% of variation. The best fitting model was roughly 10 AIC units better than the full design model, accounting for an additional 6.3% of the variation in activity beyond the full design model.

On a night with average wind speed and temperature, the probability of hoary bat activity at 44 m ranged from 11 to 25% across locations (Table 6). For every 1° C increase in temperature, the odds of hoary bat activity increased 8–23%. The probability of bat activity was positively related to decreasing wind speed, with odds of hoary bat activity increasing 8–31% for every 1 m/s decrease in wind speed.

Given the observed bat activity, the expected number of passes, on nights with mean temperature and wind speed, ranged from 0.16 to 0.46 across the locations (Table

6). We found little evidence of change in mean passes/night with temperature or wind speed.

**Table 5.** Mean, standard deviation (SD), minimum and maximum for temperature (°C), wind speed (m/s), and proportion of night with wind speed >3.5 m/s (PctG3.5), >5 m/s (PctG5), and >6.5 m/s (PctG6.5) from each of 5 meteorological towers at the RWEP, Wyoming, 2009.

| **Height/Tower** | **Variable** | **Mean** | **SD** | **Minimum** | **Maximum** |
|---|---|---|---|---|---|
| **1.5 m** | | | | | |
| **5032** | Temperature | 12.92 | 7.50 | -11.98 | 23.74 |
| | Wind Speed | 5.12 | 2.49 | 1.50 | 14.15 |
| | PctG3.5 | 0.66 | 0.29 | 0.07 | 1.00 |
| | PctG5 | 0.49 | 0.31 | 0.00 | 1.00 |
| | PctG6.5 | 0.30 | 0.29 | 0.00 | 0.97 |
| **5034** | Temperature | 11.95 | 6.85 | -3.01 | 22.92 |
| | Wind Speed | 5.54 | 2.58 | 2.19 | 13.82 |
| | PctG3.5 | 0.71 | 0.27 | 0.20 | 1.00 |
| | PctG5 | 0.53 | 0.32 | 0.03 | 1.00 |
| | PctG6.5 | 0.33 | 0.32 | 0.00 | 1.00 |
| **5041** | Temperature | 11.45 | 7.41 | -12.27 | 22.51 |
| | Wind Speed | 5.30 | 2.23 | 1.94 | 12.53 |
| | PctG3.5 | 0.69 | 0.28 | 0.07 | 1.00 |
| | PctG5 | 0.47 | 0.30 | 0.00 | 1.00 |
| | PctG6.5 | 0.31 | 0.27 | 0.00 | 0.98 |
| **5042** | Temperature | 10.84 | 6.55 | -3.30 | 22.18 |
| | Wind Speed | 4.53 | 2.26 | 1.18 | 12.39 |
| | PctG3.5 | 0.60 | 0.31 | 0.05 | 1.00 |
| | PctG5 | 0.40 | 0.30 | 0.00 | 0.98 |
| | PctG6.5 | 0.23 | 0.26 | 0.00 | 0.90 |
| **5043** | Temperature | 12.52 | 7.78 | -12.02 | 23.47 |
| | Wind Speed | 5.29 | 2.33 | 1.69 | 12.48 |
| | PctG3.5 | 0.68 | 0.25 | 0.07 | 1.00 |
| | PctG5 | 0.50 | 0.29 | 0.00 | 1.00 |
| | PctG6.5 | 0.31 | 0.28 | 0.00 | 0.98 |
| **All Towers** | Temperature | 11.97 | 7.26 | -12.27 | 23.74 |
| | Wind Speed | 5.16 | 2.40 | 1.18 | 14.15 |
| | PctG3.5 | 0.67 | 0.28 | 0.05 | 1.00 |
| | PctG5 | 0.48 | 0.31 | 0.00 | 1.00 |
| | PctG6.5 | 0.30 | 0.29 | 0.00 | 1.00 |
| **44 m** | | | | | |
| **5032** | Temperature | 12.50 | 7.22 | -2.56 | 23.74 |
| | Wind Speed | 6.59 | 2.93 | 2.31 | 16.56 |
| | PctG3.5 | 0.76 | 0.25 | 0.22 | 1.00 |
| | PctG5 | 0.64 | 0.30 | 0.09 | 1.00 |
| | PctG6.5 | 0.50 | 0.31 | 0.00 | 1.00 |

**Table 5.** Continued.

| Height/Tower | Variable | Mean | SD | Minimum | Maximum |
|---|---|---|---|---|---|
| **44 m** | | | | | |
| **5034** | Temperature | 11.79 | 7.47 | -3.01 | 22.92 |
| | Wind Speed | 7.48 | 3.13 | 3.00 | 16.76 |
| | PctG3.5 | 0.83 | 0.19 | 0.38 | 1.00 |
| | PctG5 | 0.70 | 0.29 | 0.00 | 1.00 |
| | PctG6.5 | 0.58 | 0.32 | 0.00 | 1.00 |
| **5041** | Temperature | 11.12 | 6.96 | -3.04 | 22.51 |
| | Wind Speed | 6.87 | 2.95 | 0.39 | 14.37 |
| | PctG3.5 | 0.78 | 0.26 | 0.00 | 1.00 |
| | PctG5 | 0.65 | 0.31 | 0.00 | 1.00 |
| | PctG6.5 | 0.52 | 0.32 | 0.00 | 1.00 |
| **5042** | Temperature | 10.72 | 6.93 | -3.30 | 22.18 |
| | Wind Speed | 6.19 | 2.86 | 2.13 | 15.22 |
| | PctG3.5 | 0.74 | 0.26 | 0.19 | 1.00 |
| | PctG5 | 0.61 | 0.31 | 0.05 | 1.00 |
| | PctG6.5 | 0.44 | 0.31 | 0.00 | 1.00 |
| **5043** | Temperature | 12.27 | 7.21 | -2.71 | 23.47 |
| | Wind Speed | 6.80 | 2.76 | 1.46 | 14.67 |
| | PctG3.5 | 0.80 | 0.23 | 0.18 | 1.00 |
| | PctG5 | 0.66 | 0.28 | 0.00 | 1.00 |
| | PctG6.5 | 0.50 | 0.31 | 0.00 | 1.00 |
| **5043** | Temperature | 12.52 | 7.78 | -12.02 | 23.47 |
| | Wind Speed | 5.29 | 2.33 | 1.69 | 12.48 |
| | PctG3.5 | 0.68 | 0.25 | 0.07 | 1.00 |
| | PctG5 | 0.50 | 0.29 | 0.00 | 1.00 |
| | PctG6.5 | 0.31 | 0.28 | 0.00 | 0.98 |
| **All Towers** | Temperature | 11.69 | 7.15 | -3.30 | 23.74 |
| | Wind Speed | 6.76 | 2.94 | 0.39 | 16.76 |
| | PctG3.5 | 0.78 | 0.24 | 0.00 | 1.00 |
| | PctG5 | 0.65 | 0.30 | 0.00 | 1.00 |
| | PctG6.5 | 0.51 | 0.32 | 0.00 | 1.00 |

**Table 6.** Model parameter estimates, standard error (SE), parameter effects, and 95% confidence limits for probability and count models of bat activity at the RWEP, Wyoming, 2009. Tower effects estimate the probability of activity (Probability) or estimated number of calls (Count) on a night with mean temperature and wind speed. Additional parameter effects are interpreted as odds ratios.

| Height/Phonic Group/ Model | Coefficient | Estimate | SE | Effect | Lower 95% CL | Upper 95% CL |
|---|---|---|---|---|---|---|
| 1.5 m/Low and High | | | | | | |
| Probability[a] | Loc 5032 | -1.338 | 0.306 | 0.208 | 0.126 | 0.323 |
| | Loc 5034 | -2.460 | 0.366 | 0.079 | 0.040 | 0.149 |
| | Loc 5041 | -1.144 | 0.304 | 0.242 | 0.149 | 0.366 |
| | Loc 5042 | -1.334 | 0.312 | 0.209 | 0.125 | 0.327 |
| | Loc 5043 | -1.970 | 0.339 | 0.122 | 0.067 | 0.213 |
| | Freq Low | 0.679 | 0.285 | 1.973 | 1.127 | 3.452 |
| | Temp (High Freq) | 0.284 | 0.043 | 1.328 | 1.219 | 1.446 |
| | Temp (Low Freq) | 0.127 | 0.026 | 1.135 | 1.079 | 1.193 |
| | WS (High Freq) | -0.527 | 0.100 | 0.591 | 0.486 | 0.718 |
| | WS (Low Freq) | -0.174 | 0.071 | 0.840 | 0.731 | 0.965 |
| Count[b] | Loc 5032 | 0.749 | 1.065 | 2.114 | 0.262 | 17.046 |
| | Loc 5034 | -1.021 | 1.190 | 0.360 | 0.035 | 3.711 |
| | Loc 5041 | -0.294 | 1.091 | 0.746 | 0.088 | 6.324 |
| | Loc 5042 | 1.129 | 0.980 | 3.094 | 0.453 | 21.125 |
| | Loc 5043 | 0.454 | 1.106 | 1.574 | 0.180 | 13.754 |
| | Freq Low | -1.287 | 0.550 | 0.276 | 0.094 | 0.812 |
| | Temp (High Freq) | -0.097 | 0.076 | 0.908 | 0.781 | 1.054 |
| | Temp (Low Freq) | -0.026 | 0.072 | 0.974 | 0.847 | 1.122 |
| 44 m/Low | | | | | | |
| Probability[a] | Loc 5032 | 0.023 | 0.339 | 0.506 | 0.345 | 0.665 |
| | Loc 5034 | -0.946 | 0.394 | 0.280 | 0.152 | 0.457 |
| | Loc 5041 | 0.300 | 0.342 | 0.575 | 0.409 | 0.725 |
| | Loc 5042 | 0.048 | 0.345 | 0.512 | 0.348 | 0.673 |
| | Loc 5043 | -0.534 | 0.346 | 0.369 | 0.229 | 0.536 |
| | Temp | 0.158 | 0.027 | 1.171 | 1.111 | 1.234 |
| | WS | -0.248 | 0.063 | 0.780 | 0.690 | 0.883 |
| Count[b] | Loc 5032 | -0.101 | 0.431 | 0.904 | 0.388 | 2.106 |
| | Loc 5034 | -0.399 | 0.529 | 0.671 | 0.238 | 1.892 |
| | Loc 5041 | 0.507 | 0.377 | 1.661 | 0.793 | 3.481 |
| | Loc 5042 | -0.133 | 0.432 | 0.876 | 0.375 | 2.042 |
| | Loc 5043 | -0.076 | 0.445 | 0.927 | 0.388 | 2.216 |
| | Temp | 0.065 | 0.032 | 1.067 | 1.001 | 1.137 |
| | WS | -0.174 | 0.058 | 0.841 | 0.750 | 0.942 |
| 44 m/Hoary | | | | | | |
| Probability[a] | Loc 5032 | -1.265 | 0.368 | 0.220 | 0.121 | 0.367 |
| | Loc 5034 | -2.107 | 0.497 | 0.108 | 0.044 | 0.244 |
| | Loc 5041 | -1.826 | 0.431 | 0.139 | 0.065 | 0.273 |
| | Loc 5042 | -1.089 | 0.367 | 0.252 | 0.141 | 0.408 |
| | Loc 5043 | -1.685 | 0.403 | 0.156 | 0.078 | 0.290 |
| | Temp | 0.144 | 0.033 | 1.154 | 1.082 | 1.232 |
| | WS | -0.227 | 0.072 | 0.797 | 0.692 | 0.917 |

**Table 6.** Continued.

| Height/Phonic Group/ Model | Coefficient | Estimate | SE | Effect | Lower 95% CL | Upper 95% CL |
|---|---|---|---|---|---|---|
| 44 m/Hoary | | | | | | |
| Count[b] | Loc 5032 | -0.767 | 0.793 | 0.464 | 0.098 | 2.194 |
| | Loc 5034 | -1.851 | 1.175 | 0.157 | 0.016 | 1.570 |
| | Loc 5041 | -0.799 | 0.949 | 0.450 | 0.070 | 2.889 |
| | Loc 5042 | -0.493 | 0.675 | 0.611 | 0.163 | 2.290 |
| | Loc 5043 | -1.328 | 0.980 | 0.265 | 0.039 | 1.808 |
| | Temp | 0.093 | 0.062 | 1.098 | 0.973 | 1.239 |
| | WS | -0.163 | 0.099 | 0.849 | 0.699 | 1.032 |

[a] Zero Hurdle Model: Binomial with Logit Link.
[b] Count Model: Truncated Negative Binomial with Log Link.
[c] Theta estimates the extra variation of the count distribution.
[d] Theta does not apply as the count date were modeled as a Poisson distributed random variable.

**2010**

In 2010 at 1.5 m, mean wind speed and temperature were 5.48 m/s (range = 1.28–12.85 m/s) and 15.7° C (range = -2.13°–25.2° C), respectively (Table 7). At 44 m, mean wind speed and temperature were 7.30 m/s (range = 2.36–14.73 m/s) and 16.70 °C (range = 5.35°–25.16° C), respectively. On average at 1.5 m, the proportion of the night during which wind speed ≥3.5 m/s was 72% (range = ~7–100%). The PctG5 and PctG6.5 averaged 52% (range = ~0–100%) and 34% (range = ~0–100%), respectively. At 44 m, the proportion of the night during which wind speed ≥3.5 m/s was 84% (range = ~16–100%). The PctG5 and PctG6.5 averaged 71% (range = ~8–100%) and 56% (range = ~0–100%), respectively.

*High and Low Frequency Bats at 1.5m*

The best approximating models comparing high- and low frequency bat activity at 1.5m, with an 11.8% probability, was based on the full design model and incorporated the interaction of frequency with PctG5 in the probability model and contained an additional interaction of temperature with PctG5 in the count part of the hurdle model (Appendix 3). This model was only 1.02 times more likely than the next best approximating model which contained the same parameters minus the interaction of temperature with PctG5 in the count part of the hurdle model. The confidence set of models included the top 9 models with a sum of Akaike weights of 0.700. The location model was 41 AIC units better than the null model, accounting for approximately 8.7% of variation in activity at the site, while the full design model was 49 AIC units better than the null model, accounting for approximately 11.5% of variation. Although the full design model was not included in the confidence set of models, it was 19 AIC units away from the best approximating model, and only accounted for an additional 4.3% of the variation in activity.

On a night with average wind speed and temperature, the probability of activity at 1.5 m ranged from 25–50%. For every 1° C increase in temperature, the odds of high frequency bat activity increased 8–21% and the odds of low frequency bat activity increased 1.3–13%. The odds of high frequency bat activity was negatively related to PctG5, with odds decreasing by 10–25% with every 10 percent increase in the proportion of night with wind speeds >5 m/s.

Given the observed bat activity, the expected number of high frequency passes at 1.5 m on nights with mean temperature and wind speed ranged from 0.35 to 0.77 (Table 8). The expected number of passes of high frequency bats was negatively related to PctG5, with 6–29% decrease in mean passes/night with every 10% increase in the proportion of night with wind speeds >5 m/s. We found no strong evidence of a relationship of activity with PctG5 for low frequency bats or with ambient temperature for either frequency group.

### *Low Frequency Bats at 44m*

The best approximating model for low frequency bat activity at 44 m, with a 40.9% probability, was based on the full design model and incorporated the interaction of ambient temperature and wind speed in the count part of the model (Appendix 3). This model was 2.5 times more likely than the next best approximating model that incorporated the interaction between ambient temperature and wind speed in both parts of the model. The confidence set of models included the top 3 models with a sum of Akaike weights of 0.725. The location model accounted for approximately 2.7% of variation in activity at the site, while the full design model was only 4.7 AIC units lower than the null model, accounting for approximately 4.6% of variation in activity. The best fitting model was roughly 8.7 AIC units better than the full design model, accounting for an additional 4.9% of the variation in activity beyond the full design model.

On a night with average wind speed and temperature, the probability of low frequency bat activity at 44 m ranged from 42–55% (Table 8). We found no strong evidence that the odds of low frequency bat activity was related to ambient temperature.

Given the observed bat activity, the expected number of passes on nights with mean ambient temperature and wind speed at 44 m ranged from 0.8–3.3 across locations (Table 8). The odds of low frequency bat activity were negatively related to wind speed, but this relationship varied with ambient temperature. At cool temperatures (8° C) there was little change in activity with wind speed. At 16° C, the expected number of passes decreased by 5–73%and at 24 °C, the expected number of passes decreased by 19–88% with every 1 m/s increase in wind speed.

### *Hoary bats at 44m*

The best approximating model for hoary bat activity, with a 17.4% probability, incorporated the full design model and an interaction between temperature and wind speed in the count parts of the model (Appendix 3). This model was 1.6 times more likely than the next best approximating model that was similar, but contained PctL6.5 in the count part of the model. The confidence set of models included the top two models with a sum of Akaike weights of 0.283. The location model accounted for approximately 4% of variation in activity at the site, while the full design model was only two AIC units better than the null model, accounting for approximately 7.7% of variation in activity.  The best fitting model was roughly 4 AIC units better than the full design model, accounting for an additional 3.3% of the variation in activity beyond the full design model.

On a night with mean wind speed and ambient temperature, the probability of hoary bat activity at 44 m ranged from 25–40 % (Table 8). We found a 2.6–17% increase in odds of hoary bat activity with every 1° C increase in temperature.

Given the observed bat activity, the expected number of hoary bat passes at 44 m, on nights with mean temperature and wind speed ranged from 0.4–1.9  (Table 8). We found no strong evidence of a relationship of expected number of hoary bat passes/night with wind speed at any temperature.

**Table 7.** Mean, standard deviation (SD), minimum and maximum for temperature (° C), wind speed (m/s), and proportion of night with wind speed >3.5 m/s (PctG3.5), >5 m/s (PctG5), and >6.5 m/s (PctG6.5) from each of five meteorological towers at the RWEP, Wyoming, 2010. No data collected from tower 5034, 44 m.

| **Height/Tower** | **Variable** | **Mean** | **SD** | **Minimum** | **Maximum** |
|---|---|---|---|---|---|
| **1.5 m** | | | | | |
| **5032** | Temperature | 16.38 | 4.82 | 2.53 | 25.16 |
| | Wind Speed | 5.63 | 2.24 | 1.51 | 12.63 |
| | PctG3.5 | 0.70 | 0.27 | 0.07 | 1.00 |
| | PctG5 | 0.55 | 0.30 | 0.00 | 1.00 |
| | PctG6.5 | 0.38 | 0.27 | 0.00 | 1.00 |
| **5034** | Temperature | 15.60 | 4.66 | 2.42 | 23.96 |
| | Wind Speed | 5.61 | 1.92 | 2.15 | 11.89 |
| | PctG3.5 | 0.75 | 0.23 | 0.24 | 1.00 |
| | PctG5 | 0.55 | 0.27 | 0.04 | 1.00 |
| | PctG6.5 | 0.36 | 0.27 | 0.00 | 0.97 |
| **5041** | Temperature | 15.11 | 4.62 | 2.56 | 23.72 |
| | Wind Speed | 5.55 | 1.93 | 2.23 | 12.85 |
| | PctG3.5 | 0.74 | 0.22 | 0.22 | 1.00 |
| | PctG5 | 0.52 | 0.27 | 0.00 | 1.00 |
| | PctG6.5 | 0.33 | 0.26 | 0.00 | 0.97 |
| **5042** | Temperature | 15.04 | 4.73 | 2.13 | 23.92 |
| | Wind Speed | 4.99 | 2.09 | 1.28 | 11.70 |
| | PctG3.5 | 0.66 | 0.27 | 0.07 | 1.00 |
| | PctG5 | 0.47 | 0.28 | 0.01 | 1.00 |
| | PctG6.5 | 0.29 | 0.26 | 0.00 | 0.97 |
| **5043** | Temperature | 16.29 | 4.69 | 2.86 | 24.53 |
| | Wind Speed | 5.64 | 1.94 | 2.34 | 12.57 |
| | PctG3.5 | 0.75 | 0.20 | 0.10 | 1.00 |
| | PctG5 | 0.53 | 0.26 | 0.00 | 1.00 |
| | PctG6.5 | 0.34 | 0.27 | 0.00 | 0.99 |
| **All Towers** | Temperature | 15.69 | 4.72 | 2.13 | 25.16 |
| | Wind Speed | 5.48 | 2.03 | 1.28 | 12.85 |
| | PctG3.5 | 0.72 | 0.24 | 0.07 | 1.00 |
| | PctG5 | 0.52 | 0.28 | 0.00 | 1.00 |
| | PctG6.5 | 0.34 | 0.27 | 0.00 | 1.00 |
| **44 m** | | | | | |
| **5032** | Temperature | 17.57 | 4.34 | 6.72 | 25.16 |
| | Wind Speed | 7.34 | 2.60 | 2.61 | 14.70 |
| | PctG3.5 | 0.82 | 0.21 | 0.20 | 1.00 |
| | PctG5 | 0.70 | 0.25 | 0.12 | 1.00 |
| | PctG6.5 | 0.56 | 0.30 | 0.00 | 1.00 |
| **5041** | Temperature | 16.68 | 3.90 | 6.59 | 23.72 |
| | Wind Speed | 7.42 | 2.23 | 3.16 | 14.54 |
| | PctG3.5 | 0.85 | 0.17 | 0.35 | 1.00 |
| | PctG5 | 0.74 | 0.22 | 0.22 | 1.00 |
| | PctG6.5 | 0.58 | 0.26 | 0.05 | 1.00 |

**Table 7.** Continued.

| **Height/Tower** | **Variable** | **Mean** | **SD** | **Minimum** | **Maximum** |
|---|---|---|---|---|---|
| **44 m** | | | | | |
| **5042** | Temperature | 15.71 | 4.46 | 5.35 | 23.92 |
| | Wind Speed | 7.02 | 2.53 | 2.36 | 13.98 |
| | PctG3.5 | 0.79 | 0.22 | 0.16 | 1.00 |
| | PctG5 | 0.67 | 0.25 | 0.14 | 1.00 |
| | PctG6.5 | 0.54 | 0.29 | 0.01 | 1.00 |
| **5043** | Temperature | 16.78 | 4.43 | 6.71 | 24.53 |
| | Wind Speed | 7.45 | 2.20 | 3.62 | 14.73 |
| | PctG3.5 | 0.89 | 0.14 | 0.38 | 1.00 |
| | PctG5 | 0.75 | 0.21 | 0.08 | 1.00 |
| | PctG6.5 | 0.57 | 0.26 | 0.00 | 1.00 |
| **All Towers** | Temperature | 16.70 | 4.32 | 5.35 | 25.16 |
| | Wind Speed | 7.30 | 2.40 | 2.36 | 14.73 |
| | PctG3.5 | 0.84 | 0.19 | 0.16 | 1.00 |
| | PctG5 | 0.71 | 0.24 | 0.08 | 1.00 |
| | PctG6.5 | 0.56 | 0.28 | 0.00 | 1.00 |

**Table 8.** Model parameter estimates, standard error (SE), parameter effects, and 95% confidence limits for probability and count models of bat activity at the RWEP, Wyoming, 2010. Tower effects estimate the probability of activity (Probability) or estimated number of calls (Count) on a night with mean ambient temperature and wind speed. Additional parameter effects are interpreted as odds ratios. No data collected at tower 5034, 44 m.

| Height/Phonic Group/ Model | Coefficient | Estimate | SE | Effect | Lower 95% CL | Upper 95% CL |
|---|---|---|---|---|---|---|
| 1.5m/Low and High | | | | | | |
| Probability[a] | Loc 5032 | -0.324 | 0.203 | 0.420 | 0.327 | 0.518 |
| | Loc 5034 | -1.119 | 0.220 | 0.246 | 0.175 | 0.334 |
| | Loc 5041 | -0.747 | 0.215 | 0.321 | 0.237 | 0.419 |
| | Loc 5042 | -0.010 | 0.196 | 0.497 | 0.403 | 0.592 |
| | Loc 5043 | -0.040 | 0.195 | 0.490 | 0.396 | 0.585 |
| | Freq Low | -0.164 | 0.167 | 0.849 | 0.612 | 1.178 |
| | Temp (High Freq) | 0.132 | 0.030 | 1.141 | 1.076 | 1.209 |
| | Temp (Low Freq) | 0.066 | 0.027 | 1.068 | 1.013 | 1.126 |
| | PctG5 (High Freq) | -0.201 | 0.047 | 0.818 | 0.745 | 0.897 |
| | PctG5 (Low Freq) | -0.014 | 0.044 | 0.986 | 0.904 | 1.075 |
| Count[b] | Loc 5032 | -0.919 | 0.826 | 0.399 | 0.079 | 2.014 |
| | Loc 5034 | -2.719 | 0.966 | 0.066 | 0.010 | 0.438 |
| | Loc 5041 | -0.434 | 0.788 | 0.648 | 0.138 | 3.036 |
| | Loc 5042 | -0.266 | 0.770 | 0.766 | 0.169 | 3.466 |
| | Loc 5043 | -1.059 | 0.833 | 0.347 | 0.068 | 1.774 |
| | Freq Low | 0.437 | 0.272 | 1.548 | 0.908 | 2.638 |
| | Temp (High Freq) | 0.076 | 0.050 | 1.079 | 0.980 | 1.189 |
| | Temp (Low Freq) | -0.003 | 0.050 | 0.997 | 0.904 | 1.100 |
| | PctG5 (High Freq) | -0.203 | 0.074 | 0.816 | 0.706 | 0.943 |
| | PctG5 (Low Freq) | 0.000 | 0.076 | 1.000 | 0.861 | 1.161 |
| 44m/Low | | | | | | |
| Probability[a] | Loc 5032 | -0.107 | 0.246 | 0.473 | 0.357 | 0.593 |
| | Loc 5034 | | | | | |
| | Loc 5041 | 0.191 | 0.253 | 0.548 | 0.425 | 0.665 |
| | Loc 5042 | 0.086 | 0.256 | 0.521 | 0.398 | 0.643 |
| | Loc 5043 | -0.340 | 0.275 | 0.416 | 0.293 | 0.550 |
| | Temp | 0.054 | 0.030 | 1.056 | 0.995 | 1.120 |
| Count[b] | Loc 5032 | 1.182 | 0.444 | 3.259 | 1.366 | 7.777 |
| | Loc 5034 | | | | | |
| | Loc 5041 | 0.517 | 0.457 | 1.677 | 0.685 | 4.110 |
| | Loc 5042 | 0.100 | 0.506 | 1.106 | 0.410 | 2.983 |
| | Loc 5043 | -0.168 | 0.550 | 0.845 | 0.288 | 2.482 |
| | WS\|Temp=8 | -0.195 | 0.159 | 0.822 | 0.602 | 1.124 |
| | WS\|Temp=16 | -0.683 | 0.319 | 0.505 | 0.270 | 0.944 |
| 44m/Hoary | | | | | | |
| Probability[a] | Loc 5032 | -0.846 | 0.268 | 0.300 | 0.202 | 0.420 |
| | Loc 5034 | | | | | |
| | Loc 5041 | -0.526 | 0.262 | 0.371 | 0.261 | 0.497 |
| | Loc 5042 | -0.416 | 0.265 | 0.398 | 0.282 | 0.526 |
| | Loc 5043 | -1.122 | 0.316 | 0.246 | 0.149 | 0.377 |
| | Temp | 0.092 | 0.034 | 1.096 | 1.026 | 1.172 |

**Table 8.** Continued.

| Height/Phonic Group/ Model | Coefficient | Estimate | SE | Effect | Lower 95% CL | Upper 95% CL |
|---|---|---|---|---|---|---|
| 44 m/Hoary | | | | | | |
| Count[b] | Loc 5032 | 1.182 | 0.444 | 3.259 | 1.366 | 7.777 |
| | Loc 5034 | | | | | |
| | Loc 5041 | 0.517 | 0.457 | 1.677 | 0.685 | 4.110 |
| | Loc 5042 | 0.100 | 0.506 | 1.106 | 0.410 | 2.983 |
| | Loc 5043 | -0.168 | 0.550 | 0.845 | 0.288 | 2.482 |
| | WS\|Temp=8 | -0.195 | 0.159 | 0.822 | 0.602 | 1.124 |
| | WS\|Temp=16 | -0.683 | 0.319 | 0.505 | 0.270 | 0.944 |

[a] Zero Hurdle Model: Binomial with Logit Link.
[b] Count Model: Truncated Negative Binomial with Log Link.
[c] Theta estimates the extra variation of the count distribution.
[d] Theta does not apply as the count date were modeled as a Poisson distributed random variable.

## DISCUSSION

We found that bat activity generally was highest in August with little activity past late September, consistent with other pre-construction monitoring studies. Another study in Converse County, Wyoming recorded relatively fewer bats in August, with activity peaking in September; however, malfunctioning equipment may have accounted for low activity rates recorded in August (Johnson et al. 2008). Johnson et al. (2009) found high activity from mid-July through mid-September with a few peaks in August at another wind energy site in Wyoming. Temporal patterns of acoustic activity observed at the RWEP are similar to those reported with fatalities from post-construction fatality studies in Wyoming. Gruver (2002) summarized carcasses collected from 1999–2001 and showed 92% of bats found during carcass searches were migratory tree bats (108 hoary bats and 5 silver-haired bats) with 96% and 100% of hoary bat and silver-haired bat carcasses, respectively, found during a 2 month period from 15 July to 15 September. Association between timing of bat activity and overall incidence of bat fatality previously reported (Arnett et al. 2008) suggests that temporal patterns of activity may prove useful for predicting the timing of fatalities. Fall migration by bats varies spatially (Baerwald and Barclay 2009), temporally (Cryan 2003), and by species (Baerwald 2011). Among-night variation in activity, as well as turbine-related fatality, during late summer and fall may be attributed to changes in insect abundance and availability, weather, timing of migration, migratory routes (Baerwald and Barclay 2009), life history traits of certain bat species (e.g., preparations for hibernation or migration, and reproductive condition; Horn et al. 2008), or mating behaviors (Cryan 2008). In addition, if bats are attracted to wind turbines during migration, wind energy facilities may act as population ‘sinks’ when and where large proportions of affected populations concentrate in space and time (Cryan 2011).

We recorded greater activity by high frequency bats at 1.5 m and greater activity by hoary bats at 44 m. Numerous studies have documented the importance of sampling at higher altitudes to adequately describe bat activity in an area (Jung et al. 1999, Kalcounis et al. 1999, Hayes and Gruver 2000, Menzel et al. 2005, Lacki et al. 2007, Collins and

Jones 2009). Moreover, acoustic monitoring studies at proposed or existing wind facilities also have reported similar findings (Arnett et al. 2006, 2007, Redell et al. 2006, Reynolds 2006, Baerwald and Barclay 2009, Baerwald 2011). The airspace in which certain species of bats occur generally can be predicted by their echomorphology (e.g., 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 (e.g., higher vegetation, increased tree density) habitats. The majority of available acoustic studies in Wyoming only sampled at ground level (Gruver 2002, Johnson et al. 2008, Johnson et al. 2009), thus it remains unknown whether vertical acoustic sampling increases predictability of fatality events, particularly in areas with open habitat. Because bat fatalities found at wind sites are predominately comprised of low frequency species (e.g., hoary bats; Johnson 2005, Kunz et al. 2007a, Arnett et al. 2008), and because low frequency bats generally fly at higher altitudes (i.e., in and around the rotor-swept area), it is important to account for altitudinal variation during acoustic surveys (Baerwald and Barclay 2009, Collins and Jones 2009). Our findings support this concern and we suggest that pre-construction acoustic surveys must include detectors placed as high as possible above ground to sample the airspace within the rotor-swept area.

Location and ambient temperature were consistently the most important factors in predicting bat activity, with the full design model explaining ~9–29% of the variation in activity. However, location alone explained ~3–9.5% of the variation in activity. In general, we found the highest probability of activity and highest counts for each phonic group at towers on the western edge of the project. Although it is not surprising to see spatial variation in bat activity across a project site (Arnett et al. 2006, Reynolds et al. 2006, Mabee and Schwab 2008, Hein et al. 2009), specific reasons for variability among towers remain unknown, but may be attributed to differences in landscape features (e.g., proximity to water, forest edge, canyons, cliff faces, or foothills) among towers, which may attract foraging or roosting bats. Baerwald and Barclay (2009) demonstrated increasing fatalities, at turbines of similar size with increasing proximity to the foothills of the Rocky Mountains in Alberta, Canada. Piorkowski and O’Connell (2010) observed higher fatalities at individual turbines closer to ravine edges. Although more data are needed, we recorded lower activity levels at towers surrounded by flat topography on the eastern end, and higher activity levels on more rugged terrain near the western end of the RWEP. If bat activity and fatalities are related to landscape features, altering turbine placement away from these features may reduce fatalities.

Bat activity was positively related to ambient temperature. Arnett et al. (2006) and Redell et al. (2006) reported a similar relationship in Pennsylvania and Wisconsin, respectively. Low frequency bats were more active at cooler temperatures, but overall we recorded little activity below $10^{o}$ C. Reynolds (2006) also found little activity of bats at a proposed wind facility in New York when ambient temperatures were below $10.5^{o}$ C. Erickson and West (2002) reported that regional patterns of climatic conditions as well as local weather events can be used to predict bat activity. Relationships between bat activity and temperature could be explained by the availability of insect prey. Insect flight occurrence decreases with ambient temperature and little or no flight activity may occur below 10$^o$ C (Taylor 1963, Anthony et al. 1981). Insect migrations are known to be positively related to temperature (e.g., Sparks et al. 2005, Fleming and Eby 2003, McCracken et al. 2007). High frequency bats, which were more active at low altitudes, were more responsive to temperature than low frequency bats, whereas low frequency bats were more responsive to temperature changes at higher altitudes. This may be related to differences in body size and energetic relationships. Body temperature and body size have profound impacts on how animals function, and even small changes in body temperature can have significant effects on small mammals such as bats (Speakman and Thomas 2003). Larger animals are better equipped physiologically to deal with lower ambient temperatures than are smaller ones because they have a relatively lower surface area to volume ratio through which heat is lost (Speakman and Thomas 2003). Thus, it is plausible that smaller bodied, high frequency bats are more sensitive to lower ambient temperature and consequently more active during warmer nights relative to larger, low frequency bats. Another possibility is that low frequency bats are more likely to be migrating through the area (Cryan 2003, Cryan and Brown 2007) and these bats may be less responsive to temperature than local, foraging species of high frequency bats because they are occupying the site for different reasons.

While some measure of wind speed was often important in predicting activity, it never explained more than an additional 9% of the variation. However, when parameter estimates included mean wind speed, the effect on odds of bat activity and estimated number of bat passes was typically negative. Strong winds influence insect abundance and activity, which in turn influence bat activity; bats are known to suppress their activity during periods of rain, low ambient temperatures, and strong winds (Anthony et al. 1981, Erkert 1982, Erickson and West 2002, Lacki et al. 2007). Wind speed and direction affected habitat use by hoary bats and silver-haired bats in Canada, with higher activity detected on the lee side of a ridge (Barclay 1985). In the Netherlands, Verboom and Spoelstra (1999) reported that foraging and commuting activity of pipistrelle bats was concentrated closer to the leeward sides of trees as wind speed increased. Patterns of bat activity and wind speed also generally corroborate recent studies of bat fatality and the relationships with wind. At Buffalo Mountain in Tennessee, Fiedler (2004) found a negative relationship between bat fatality and wind speed. Kerns et al. (2005) reported that the majority of bats killed at the Meyersdale, Pennsylvania and Mountaineer, West Virginia facilities occurred on low wind nights, and fatalities tended to increase just before and after the passage of storm fronts. Capitalizing on the negative relationship between bat activity and wind speed, Baerwald et al. (2009) and Arnett et al. (2011) demonstrated how increasing turbine cut-in speeds (i.e., the speed at which turbines begin generating electricity) to 5.5 m/s, and 5.0 m/s and 6.5 m/s can reduce bat fatalities up to 60% and 93%, respectively. Using the same cut-in treatments as Arnett et al. (2011), Good et al. (2011) reported a 50% and 78% reduction in bat fatalities compared to fully operational turbines. Young et al. (2010) showed that feathering turbine blades so that they revolve less than once per minute prior to normal operational cut-in speed (4.0 m/s) can reduce bat fatality significantly.

## SCOPE, LIMITATIONS, and NEXT STEPS

Although numerous acoustic monitoring surveys at wind-energy facilities in North America have been conducted, most of these studies are from the northeastern United States. Similar acoustic studies are rare for Wyoming and adjacent states. Because a paucity of information concerning the spatial and temporal activity of bats in this region exists, 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). Our pre-construction study follows these recommendations and in doing so, we were able to provide comparative baseline information on both spatial and temporal patterns of bat activity, particularly for migratory tree-roosting bats.

Several factors, including microphone position, orientation, and weatherproofing, influence the quality and quantity of recorded bat calls. Britzke et al. (2010) reported that the weatherproofing approach we used for our microphones, commonly referred to as "bat-hats," led to recording significantly fewer call sequences, pulses per file, and species per site, and resulted in generally lower quality calls compared with other weatherproofing options (e.g., using a curved PVC tube) and non-weatherproofed microphones. However, a similar study contradicted these findings and determined that microphones equipped with bat-hats recorded more calls than other weatherproofing systems (Gruver et al. 2009). Britzke et al. (2010) suggested that possible detrimental effects of weatherproofing microphones likely vary with local site conditions. Moreover, where the goal is to determine relative activity levels among sites, as is the case for the broad assessment of activity in relation to fatality, any weatherproofing or orientation may be acceptable as long as deployment is similar among sampling locations (Britzke et al. 2010). Because there is no reason to believe that the bias associated with our weatherproofing system differed among our sampling points, we believe we were able to adequately sample the relative bat activity at the RWEP.

This study was conducted at a single proposed wind energy facility located on shrubland habitat in east-central Wyoming, and statistical inferences are limited to this site. Additional studies in the region will determine whether our findings reflect patterns of bat activity on similar sites with comparable vegetation composition and topography in this region. Despite equipment malfunctions, we were able to quantify the spatial (vertical and horizontal) and temporal (seasonal and yearly) activity patterns of bats in the vicinity of a proposed wind-energy facility. These data may provide useful information for predicting when, where, and which bats may be most at risk of interactions with wind turbines at the RWEP. Combining acoustic data from this site and with data from other facilities in the region, and correlating activity to the corresponding fatality data will help determine if risk can be predicted with reasonable certainty. In addition, understanding the specific timings and locations of peak activity may assist with refining the use of raising turbine cut-in speeds to reduce bat fatalities (Arnett et al. 2011).

Our analyses are exploratory, in part because so little data exist upon which to develop *a priori*, confirmatory hypotheses and associated candidate models. We performed our analysis using weather data gathered only from met towers located on site; future modeling may incorporate additional weather data gathered from local weather stations to model broad-scale weather events and bat activity. The current analysis only estimates activity rates and differences in activity patterns of three phonic groups (high and low frequency bats and hoary bats), at two heights from five towers. High variation in levels of activity has consequences with respect to sampling design and level of effort required to obtain accurate estimates of activity; as fewer nights are sampled, there is an increased probability of obtaining mean estimates of activity that differ greatly from those calculated from large datasets (Hayes 1997). Low-intensity sampling could result in under- or over-estimates of activity and the most precise and accurate estimates will likely come from intensive sampling efforts (Hayes 1997, M. Huso, Oregon State University, unpublished data). Future analyses should evaluate the trade-offs among various sampling efforts regarding accuracy and precision of estimates of bat activity, with the ultimate goal of optimizing sampling designs and data requirements for employing acoustic monitoring to predict bat fatality at wind facilities.

There is a paucity of information relating pre-construction activity with post-construction fatality of bats. Although several studies, collectively, 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 RWEP are useful in resolving potential negative impacts of wind development on bat populations. After turbines are constructed at the RWEP, we intend to gather post-construction activity and fatality data. Data from this report in combination with similar data from other studies will be used to determine if relationships exist between pre-construction acoustic monitoring and post-construction fatality.

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**Appendix 1.** List of 128 models used to predict probability of activity and expected number of passes for high and low frequency bats at 1.5 m at the RWEP, Wyoming, 2009–2010.

| Model | Probability of Activity Model | Count Model |
|---|---|---|
| **null.mod** | 1 | 1 |
| **base.loc** | L | L |
| **base.temp** | L + T | L + T |
| **base.temp*freq** | L + T*F | L + T*F |
| **Wind1** | L + T*F + WS | L + T*F |
| **Wind2** | L + T*F + T*WS | L + T*F |
| **Wind3** | L + T*F + F*WS | L + T*F |
| **Wind4** | L + T*F + T*F*WS | L + T*F |
| **Wind5** | L + T*F | L + T*F + WS |
| **Wind6** | L + T*F | L + T*F + T*WS |
| **Wind7** | L + T*F | L + T*F + F*WS |
| **Wind8** | L + T*F | L + T*F + F*T*WS |
| **Wind9** | L + T*F + WS | L + T*F + WS |
| **Wind10** | L + T*F + T*WS | L + T*F + WS |
| **Wind11** | L + T*F + F*WS | L + T*F + WS |
| **Wind12** | L + T*F + T*F*WS | L + T*F + WS |
| **Wind13** | L + T*F + WS | L + T*F + T*WS |
| **Wind14** | L + T*F + WS | L + T*F + F*WS |
| **Wind15** | L + T*F + WS | L + T*F + T*F*WS |
| **Wind16** | L + T*F + T*WS | L + T*F + T*WS |
| **Wind17** | L + T*F + F*WS | L + T*F + T*WS |
| **Wind18** | L + T*F + T*F*WS | L + T*F + T*WS |
| **Wind19** | L + T*F + T*WS | L + T*F + F*WS |
| **Wind20** | L + T*F + T*WS | L + T*F + T*F*WS |
| **Wind21** | L + T*F + F*WS | L + T*F + F*WS |
| **Wind22** | L + T*F + T*F*WS | L + T*F + F*WS |
| **Wind23** | L + T*F + F*WS | L + T*F + T*F*WS |
| **Wind24** | L + T*F + T*F*WS | L + T*F + T*F*WS |
| **Wind25** | L + T*F + PctG3.5 | L + T*F |
| **Wind26** | L + T*F + T*PctG3.5 | L + T*F |
| **Wind27** | L + T*F + F*PctG3.5 | L + T*F |
| **Wind28** | L + T*F + T*F*PctG3.5 | L + T*F |
| **Wind29** | L + T*F | L + T*F + PctG3.5 |
| **Wind30** | L + T*F | L + T*F + T*PctG3.5 |
| **Wind31** | L + T*F | L + T*F + F*PctG3.5 |
| **Wind32** | L + T*F | L + T*F + F*T*PctG3.5 |
| **Wind33** | L + T*F + PctG3.5 | L + T*F + PctG3.5 |
| **Wind34** | L + T*F + T*PctG3.5 | L + T*F + PctG3.5 |
| **Wind35** | L + T*F + F*PctG3.5 | L + T*F + PctG3.5 |
| **Wind36** | L + T*F + T*F*PctG3.5 | L + T*F + PctG3.5 |
| **Wind37** | L + T*F + PctG3.5 | L + T*F + T*PctG3.5 |
| **Wind38** | L + T*F + PctG3.5 | L + T*F + F*PctG3.5 |
| **Wind39** | L + T*F + PctG3.5 | L + T*F + T*F*PctG3.5 |
| **Wind40** | L + T*F + T*PctG3.5 | L + T*F + T*PctG3.5 |
| **Wind41** | L + T*F + F*PctG3.5 | L + T*F + T*PctG3.5 |

**Appendix 1.** Continued.

| Model | Probability of Activity Model | Count Model |
|---|---|---|
| **Wind42** | L + T*F + T*F*PctG3.5 | L + T*F + T*PctG3.5 |
| **Wind43** | L + T*F + T*PctG3.5 | L + T*F + F*PctG3.5 |
| **Wind44** | L + T*F + T*PctG3.5 | L + T*F + T*F*PctG3.5 |
| **Wind45** | L + T*F + F*PctG3.5 | L + T*F + F*PctG3.5 |
| **Wind46** | L + T*F + T*F*PctG3.5 | L + T*F + F*PctG3.5 |
| **Wind47** | L + T*F + F*PctG3.5 | L + T*F + T*F*PctG3.5 |
| **Wind48** | L + T*F + T*F*PctG3.5 | L + T*F + T*F*PctG3.5 |
| **Wind49** | L + T*F + PctG5 | L + T*F |
| **Wind50** | L + T*F + T*PctG5 | L + T*F |
| **Wind51** | L + T*F + F*PctG5 | L + T*F |
| **Wind52** | L + T*F + T*F*PctG5 | L + T*F |
| **Wind53** | L + T*F | L + T*F + PctG5 |
| **Wind54** | L + T*F | L + T*F + T*PctG5 |
| **Wind55** | L + T*F | L + T*F + F*PctG5 |
| **Wind56** | L + T*F | L + T*F + F*T*PctG5 |
| **Wind57** | L + T*F + PctG5 | L + T*F + PctG5 |
| **Wind58** | L + T*F + T*PctG5 | L + T*F + PctG5 |
| **Wind59** | L + T*F + F*PctG5 | L + T*F + PctG5 |
| **Wind60** | L + T*F + T*F*PctG5 | L + T*F + PctG5 |
| **Wind61** | L + T*F + PctG5 | L + T*F + T*PctG5 |
| **Wind62** | L + T*F + PctG5 | L + T*F + F*PctG5 |
| **Wind63** | L + T*F + PctG5 | L + T*F + T*F*PctG5 |
| **Wind64** | L + T*F + T*PctG5 | L + T*F + T*PctG5 |
| **Wind65** | L + T*F + F*PctG5 | L + T*F + T*PctG5 |
| **Wind66** | L + T*F + T*F*PctG5 | L + T*F + T*PctG5 |
| **Wind67** | L + T*F + T*PctG5 | L + T*F + F*PctG5 |
| **Wind68** | L + T*F + T*PctG5 | L + T*F + T*F*PctG5 |
| **Wind69** | L + T*F + F*PctG5 | L + T*F + F*PctG5 |
| **Wind70** | L + T*F + T*F*PctG5 | L + T*F + F*PctG5 |
| **Wind71** | L + T*F + F*PctG5 | L + T*F + T*F*PctG5 |
| **Wind72** | L + T*F + T*F*PctG5 | L + T*F + T*F*PctG5 |
| **Wind73** | L + T*F + PctG6.5 | L + T*F |
| **Wind74** | L + T*F + T*PctG6.5 | L + T*F |
| **Wind75** | L + T*F + F*PctG6.5 | L + T*F |
| **Wind76** | L + T*F + T*F*PctG6.5 | L + T*F |
| **Wind77** | L + T*F | L + T*F + PctG6.5 |
| **Wind78** | L + T*F | L + T*F + T*PctG6.5 |
| **Wind79** | L + T*F | L + T*F + F*PctG6.5 |
| **Wind80** | L + T*F | L + T*F + F*T*PctG6.5 |
| **Wind81** | L + T*F + PctG6.5 | L + T*F + PctG6.5 |
| **Wind82** | L + T*F + T*PctG6.5 | L + T*F + PctG6.5 |
| **Wind83** | L + T*F + F*PctG6.5 | L + T*F + PctG6.5 |
| **Wind84** | L + T*F + T*F*PctG6.5 | L + T*F + PctG6.5 |
| **Wind85** | L + T*F + PctG6.5 | L + T*F + T*PctG6.5 |
| **Wind86** | L + T*F + PctG6.5 | L + T*F + F*PctG6.5 |
| **Wind87** | L + T*F + PctG6.5 | L + T*F + T*F*PctG6.5 |
| **Wind88** | L + T*F + T*PctG6.5 | L + T*F + T*PctG6.5 |

**Appendix 1.** Continued.

| Model | Probability of Activity Model | Count Model |
|---|---|---|
| **Wind89** | L + T*F + F*PctG6.5 | L + T*F + T*PctG6.5 |
| **Wind90** | L + T*F + T*F*PctG6.5 | L + T*F + T*PctG6.5 |
| **Wind91** | L + T*F + T*PctG6.5 | L + T*F + F*PctG6.5 |
| **Wind92** | L + T*F + T*PctG6.5 | L + T*F + T*F*PctG6.5 |
| **Wind93** | L + T*F + F*PctG6.5 | L + T*F + F*PctG6.5 |
| **Wind94** | L + T*F + T*F*PctG6.5 | L + T*F + F*PctG6.5 |
| **Wind95** | L + T*F + F*PctG6.5 | L + T*F + T*F*PctG6.5 |
| **Wind96** | L + T*F + T*F*PctG6.5 | L + T*F + T*F*PctG6.5 |
| **Wind97** | L + T*F + PctG3.5L6.5 | L + T*F |
| **Wind98** | L + T*F + T*PctG3.5L6.5 | L + T*F |
| **Wind99** | L + T*F + F*PctG3.5L6.5 | L + T*F |
| **Wind100** | L + T*F + T*F*PctG3.5L6.5 | L + T*F |
| **Wind101** | L + T*F | L + T*F + PctG3.5L6.5 |
| **Wind102** | L + T*F | L + T*F + T*PctG3.5L6.5 |
| **Wind103** | L + T*F | L + T*F + F*PctG3.5L6.5 |
| **Wind104** | L + T*F | L + T*F + F*T*PctG3.5L6.5 |
| **Wind105** | L + T*F + PctG3.5L6.5 | L + T*F + PctG3.5L6.5 |
| **Wind106** | L + T*F + T*PctG3.5L6.5 | L + T*F + PctG3.5L6.5 |
| **Wind107** | L + T*F + F*PctG3.5L6.5 | L + T*F + PctG3.5L6.5 |
| **Wind108** | L + T*F + T*F*PctG3.5L6.5 | L + T*F + PctG3.5L6.5 |
| **Wind109** | L + T*F + PctG3.5L6.5 | L + T*F + T*PctG3.5L6.5 |
| **Wind110** | L + T*F + PctG3.5L6.5 | L + T*F + F*PctG3.5L6.5 |
| **Wind111** | L + T*F + PctG3.5L6.5 | L + T*F + T*F*PctG3.5L6.5 |
| **Wind112** | L + T*F + T*PctG3.5L6.5 | L + T*F + T*PctG3.5L6.5 |
| **Wind113** | L + T*F + F*PctG3.5L6.5 | L + T*F + T*PctG3.5L6.5 |
| **Wind114** | L + T*F + T*F*PctG3.5L6.5 | L + T*F + T*PctG3.5L6.5 |
| **Wind115** | L + T*F + T*PctG3.5L6.5 | L + T*F + F*PctG3.5L6.5 |
| **Wind116** | L + T*F + T*PctG3.5L6.5 | L + T*F + T*F*PctG3.5L6.5 |
| **Wind117** | L + T*F + F*PctG3.5L6.5 | L + T*F + F*PctG3.5L6.5 |
| **Wind118** | L + T*F + T*F*PctG3.5L6.5 | L + T*F + F*PctG3.5L6.5 |
| **Wind119** | L + T*F + F*PctG3.5L6.5 | L + T*F + T*F*PctG3.5L6.5 |
| **Wind120** | L + T*F + T*F*PctG3.5L6.5 | L + T*F + T*F*PctG3.5L6.5 |
| **Wind121** | L + T*F + WS | L + T*F |
| **Wind122** | L + T*F + T*WS | L + T*F |
| **Wind123** | L + T*F + F*WS | L + T*F |
| **Wind124** | L + T*F + T*F*WS | L + T*F |
| **Wind125** | F*PctG3.5L6.5 | F*PctG3.5L6.5 |
| **Wind126** | T*F*PctG3.5L6.5 | F*PctG3.5L6.5 |
| **Wind 127** | F*PctG3.5L6.5 | T*F*PctG3.5L6.5 |
| **Wind128** | T*F*PctG3.5L6.5 | T*F*PctG3.5L6.5 |

**Appendix 2.** List of 40 models used to predict probability of activity and expected number of passes for low frequency bats and hoary bats at 44 m at the RWEP, Wyoming, 2009–2010.

| Model | Probability of Activity Model | Count Model |
|---|---|---|
| **null.mod** | 1 | 1 |
| **base.loc** | L | L |
| **base.temp** | L + T | L + T |
| **Wind1** | L + T + WS | L + T |
| **Wind2** | L + T | L + T + WS |
| **Wind3** | L + T + WS | L + T + WS |
| **Wind4** | L + T*WS | L + T |
| **Wind5** | L + T*WS | L + T + WS |
| **Wind6** | L + T | L + T*WS |
| **Wind7** | L + T + WS | L + T*WS |
| **Wind8** | L + T*WS | L + T*WS |
| **Wind9** | L + T + PctG3.5 | L + T |
| **Wind10** | L + T | L + T + PctG3.5 |
| **Wind11** | L + T + PctG3.5 | L + T + PctG3.5 |
| **Wind12** | L + T*PctG3.5 | L + T |
| **Wind13** | L + T*PctG3.5 | L + T + PctG3.5 |
| **Wind14** | L + T | L + T*PctG3.5 |
| **Wind15** | L + T + PctG3.5 | L + T*PctG3.5 |
| **Wind16** | L + T*PctG3.5 | L + T*PctG3.5 |
| **Wind17** | L + T + PctG5 | L + T |
| **Wind18** | L + T | L + T + PctG5 |
| **Wind19** | L + T + PctG5 | L + T + PctG5 |
| **Wind20** | L + T*PctG5 | L + T |
| **Wind21** | L + T*PctG5 | L + T + PctG5 |
| **Wind22** | L + T | L + T*PctG5 |
| **Wind23** | L + T + PctG5 | L + T*PctG5 |
| **Wind24** | L + T*PctG5 | L + T*PctG5 |
| **Wind25** | L + T + PctG6.55 | L + T |
| **Wind26** | L + T | L + T + PctG6.55 |
| **Wind27** | L + T + PctG6.55 | L + T + PctG6.55 |
| **Wind28** | L + T*PctG6.55 | L + T |
| **Wind29** | L + T*PctG6.55 | L + T + PctG6.55 |
| **Wind30** | L + T | L + T*PctG6.55 |
| **Wind31** | L + T + PctG6.55 | L + T*PctG6.55 |
| **Wind32** | L + T*PctG6.55 | L + T*PctG6.55 |
| **Wind33** | L + T + PctG3.5L6.5 | L + T |
| **Wind34** | L + T | L + T + PctG3.5L6.5 |
| **Wind35** | L + T + PctG3.5L6.5 | L + T + PctG3.5L6.5 |
| **Wind36** | L + T*PctG3.5L6.5 | L + T |
| **Wind37** | L + T*PctG3.5L6.5 | L + T + PctG3.5L6.5 |
| **Wind38** | L + T | L + T*PctG3.5L6.5 |
| **Wind39** | L + T + PctG3.5L6.5 | L + T*PctG3.5L6.5 |
| **Wind40** | L + T*PctG3.5L6.5 | L + T*PctG3.5L6.5 |

**Appendix 3.** Model selection for the confidence set and baseline models by year, height and phonic group at the RWEP, Wyoming, 2009-2010. AIC = AIC values, ΔAIC = difference in AIC units between the given model and the "best" model, Wt = Akaike weight for the model, Rel. Wt = , Cumm Wt = sum of Akaike weight for given model and all previous models, $pR^2$ = Nagelkerke's pseudo-$R^2$, $aR^2$ = additional $R^2$.

| Year/Height/Group | Probability Model | Count Model | AIC | ΔAIC | Wt | Rel. Wt | Cumm. Wt | $pR^2$ | $aR^2$ |
|---|---|---|---|---|---|---|---|---|---|
| 2009/1.5m/Both | T*F*WS | WS | 1232.183 | 0.000 | 0.212 | 1.000 | 0.212 | 0.356 | 0.070 |
| | F*WS | WS | 1233.080 | 0.897 | 0.136 | 1.566 | 0.348 | 0.350 | 0.063 |
| | T*F*WS | L+T | 1233.164 | 0.981 | 0.130 | 1.633 | 0.478 | 0.352 | 0.066 |
| | F*WS | L+T | 1234.060 | 1.878 | 0.083 | 2.557 | 0.561 | 0.346 | 0.059 |
| | T*F*WS | F*WS | 1234.132 | 1.949 | 0.080 | 2.650 | 0.641 | 0.356 | 0.070 |
| | T*F*WS | T*WS | 1234.179 | 1.997 | 0.078 | 2.714 | 0.719 | 0.356 | 0.070 |
| | T*F*WS | T*F*WS | 1234.331 | 2.148 | 0.073 | 2.928 | 0.792 | 0.361 | 0.075 |
| | F*WS | F*WS | 1235.029 | 2.846 | 0.051 | 4.150 | 0.843 | 0.350 | 0.063 |
| | F*WS | T*WS | 1235.076 | 2.893 | 0.050 | 4.249 | 0.893 | 0.350 | 0.063 |
| | F*WS | T*F*WS | 1235.228 | 3.045 | 0.046 | 4.584 | 0.939 | 0.355 | 0.068 |
| | L+T*F | L+T*F | 1272.658 | 40.475 | 0.000 | >1000 | 1.000 | 0.287 | 0.000 |
| | L+T | L+T | 1279.694 | 47.512 | 0.000 | >1000 | 1.000 | 0.265 | -0.022 |
| | L | L | 1380.259 | 148.076 | 0.000 | >1000 | 1.000 | 0.095 | -0.192 |
| | 1 | 1 | 1414.726 | 182.544 | 0.000 | >1000 | 1.000 | 0.000 | -0.287 |
| 2009/44m/Low | WS | WS | 668.867 | 0.000 | 0.305 | 1.000 | 0.305 | 0.325 | 0.089 |
| | PctL6.5 | PctL6.5 | 669.813 | 0.946 | 0.190 | 1.605 | 0.495 | 0.322 | 0.086 |
| | WS | T*WS | 670.793 | 1.927 | 0.116 | 2.620 | 0.611 | 0.325 | 0.089 |
| | T*WS | WS | 670.867 | 2.000 | 0.112 | 2.718 | 0.723 | 0.325 | 0.089 |
| | T*PctL6.5 | PctL6.5 | 671.690 | 2.823 | 0.074 | 4.102 | 0.798 | 0.322 | 0.086 |
| | PctL6.5 | T*PctL6.5 | 671.780 | 2.913 | 0.071 | 4.292 | 0.869 | 0.322 | 0.086 |
| | L+T | WS | 684.715 | 15.849 | 0.000 | >1000 | 0.999 | 0.266 | 0.031 |
| | L+T | L+T | 691.574 | 22.708 | 0.000 | >1000 | 1.000 | 0.236 | 0.000 |
| | 1 | 1 | 730.184 | 61.317 | 0.000 | >1000 | 1.000 | 0.000 | -0.236 |
| | L | L | 737.837 | 68.970 | 0.000 | >1000 | 1.000 | 0.037 | -0.198 |

**Appendix 3.** Continued.

| Year/Height/Group | Probability Model | Count Model | AIC | ΔAIC | Wt | Rel. Wt | Cumm. Wt | $pR^2$ | $aR^2$ |
|---|---|---|---|---|---|---|---|---|---|
| 2009/44m/Hoary | WS | WS | 362.719 | 0.000 | 0.137 | 1.000 | 0.137 | 0.243 | 0.063 |
| | WS | L+T | 363.424 | 0.704 | 0.097 | 1.422 | 0.234 | 0.231 | 0.051 |
| | PctG3.5L6.5 | L+T | 363.694 | 0.974 | 0.084 | 1.628 | 0.318 | 0.230 | 0.050 |
| | PctL6.5 | L+T | 363.972 | 1.252 | 0.073 | 1.870 | 0.392 | 0.229 | 0.049 |
| | PctG3.5L6.5 | PctG3.5L6.5 | 364.247 | 1.528 | 0.064 | 2.147 | 0.455 | 0.236 | 0.056 |
| | T*WS | WS | 364.259 | 1.540 | 0.064 | 2.160 | 0.519 | 0.245 | 0.065 |
| | PctL6.5 | PctL6.5 | 364.263 | 1.544 | 0.063 | 2.164 | 0.582 | 0.236 | 0.056 |
| | WS | T*WS | 364.624 | 1.904 | 0.053 | 2.591 | 0.635 | 0.243 | 0.063 |
| | PctG3.5L6.5 | T*PctG3.5L6.5 | 364.828 | 2.109 | 0.048 | 2.870 | 0.683 | 0.242 | 0.063 |
| | T*PctL6.5 | L+T | 364.875 | 2.156 | 0.047 | 2.938 | 0.730 | 0.233 | 0.054 |
| | T*WS | L+T | 364.964 | 2.244 | 0.045 | 3.072 | 0.775 | 0.233 | 0.053 |
| | T*PctL6.5 | PctL6.5 | 365.167 | 2.447 | 0.040 | 3.400 | 0.815 | 0.241 | 0.061 |
| | T*PctG3.5L6.5 | L+T | 365.344 | 2.625 | 0.037 | 3.715 | 0.852 | 0.231 | 0.052 |
| | T*PctG3.5L6.5 | PctG3.5L6.5 | 365.897 | 3.178 | 0.028 | 4.899 | 0.880 | 0.238 | 0.058 |
| | T*WS | T*WS | 366.164 | 3.445 | 0.025 | 5.597 | 0.905 | 0.245 | 0.065 |
| | PctL6.5 | T*PctL6.5 | 366.262 | 3.543 | 0.023 | 5.878 | 0.928 | 0.236 | 0.056 |
| | T*PctG3.5L6.5 | T*PctG3.5L6.5 | 366.478 | 3.759 | 0.021 | 6.550 | 0.949 | 0.244 | 0.064 |
| | L+T | L+T | 372.869 | 10.150 | 0.001 | 159.962 | 0.995 | 0.180 | 0.000 |
| | 1 | 1 | 388.997 | 26.277 | 0.000 | >1000 | 1.000 | 0.000 | -0.180 |
| | L | L | 397.905 | 35.186 | 0.000 | >1000 | 1.000 | 0.038 | -0.142 |

**Appendix 3.** Continued.

| Year/Height/Group | Probability Model | Count Model | AIC | ΔAIC | Wt | Rel. Wt | Cumm. Wt | $pR^2$ | $aR^2$ |
|---|---|---|---|---|---|---|---|---|---|
| 2010/1.5m/Both | F*PctG5 | T*F*PctG5 | 1734.634 | 0.000 | 0.118 | 1.000 | 0.118 | 0.158 | 0.043 |
| | F*PctG5 | F*PctG5 | 1734.681 | 0.047 | 0.115 | 1.024 | 0.233 | 0.153 | 0.038 |
| | F*PctG6.5 | F*PctG6.5 | 1734.858 | 0.223 | 0.106 | 1.118 | 0.339 | 0.152 | 0.037 |
| | F*PctG6.5 | PctG6.5 | 1735.428 | 0.793 | 0.079 | 1.487 | 0.419 | 0.149 | 0.034 |
| | F*PctG6.5 | T*F*PctG6.5 | 1735.720 | 1.086 | 0.069 | 1.721 | 0.487 | 0.157 | 0.042 |
| | F*WS | F*WS | 1735.839 | 1.205 | 0.065 | 1.826 | 0.552 | 0.151 | 0.036 |
| | F*PctG6.5 | T*PctG6.5 | 1736.265 | 1.631 | 0.052 | 2.260 | 0.604 | 0.150 | 0.035 |
| | F*PctG5 | PctG5 | 1736.405 | 1.771 | 0.049 | 2.424 | 0.653 | 0.148 | 0.033 |
| | F*PctG5 | T*PctG5 | 1736.466 | 1.832 | 0.047 | 2.499 | 0.700 | 0.150 | 0.035 |
| | F*WS | T*F*WS | 1737.491 | 2.857 | 0.028 | 4.173 | 0.728 | 0.154 | 0.039 |
| | T*F*PctG6.5 | F*PctG6.5 | 1737.822 | 3.188 | 0.024 | 4.922 | 0.752 | 0.154 | 0.039 |
| | F*PctG6.5 | L+T | 1738.099 | 3.465 | 0.021 | 5.655 | 0.773 | 0.142 | 0.028 |
| | T*F*PctG5 | T*F*PctG5 | 1738.286 | 3.651 | 0.019 | 6.207 | 0.792 | 0.159 | 0.044 |
| | T*F*PctG5 | F*PctG5 | 1738.332 | 3.698 | 0.019 | 6.354 | 0.811 | 0.153 | 0.038 |
| | F*PctG5 | L+T | 1738.372 | 3.738 | 0.018 | 6.483 | 0.829 | 0.142 | 0.027 |
| | T*F*PctG6.5 | PctG6.5 | 1738.392 | 3.758 | 0.018 | 6.545 | 0.847 | 0.150 | 0.035 |
| | L+T | L+T | 1748.231 | 13.597 | 0.000 | 896.649 | 0.999 | 0.112 | -0.003 |
| | L+T*F | L+T*F | 1753.889 | 19.254 | 0.000 | >1000 | 1.000 | 0.115 | 0.000 |
| | L | L | 1761.758 | 27.124 | 0.000 | >1000 | 1.000 | 0.087 | -0.028 |
| | 1 | 1 | 1802.856 | 68.222 | 0.000 | >1000 | 1.000 | 0.000 | -0.115 |
| 2010/44m/Low | | | | | | | | | |
| | L+T | T*WS | 823.113 | 0.000 | 0.409 | 1.000 | 0.409 | 0.095 | 0.049 |
| | T*WS | T*WS | 824.957 | 1.844 | 0.163 | 2.514 | 0.572 | 0.103 | 0.057 |
| | WS | T*WS | 825.068 | 1.955 | 0.154 | 2.657 | 0.725 | 0.095 | 0.049 |
| | 1 | 1 | 827.136 | 4.022 | 0.055 | 7.472 | 0.780 | 0.000 | -0.046 |
| | L+T | L+T | 831.821 | 8.708 | 0.005 | 77.771 | 0.941 | 0.046 | 0.000 |
| | L | L | 832.636 | 9.523 | 0.003 | 116.918 | 0.959 | 0.027 | -0.019 |

**Appendix 3.** Continued.

| Year/Height/Group | Probability Model | Count Model | AIC | ΔAIC | Wt | Rel. Wt | Cumm. Wt | $pR^2$ | $aR^2$ |
|---|---|---|---|---|---|---|---|---|---|
| 2010/44m/Hoary | L+T | T*WS | 554.396 | 0.000 | 0.174 | 1.000 | 0.174 | 0.110 | 0.033 |
| | L+T | T*PctL6.5 | 555.323 | 0.927 | 0.109 | 1.590 | 0.283 | 0.106 | 0.029 |
| | WS | T*WS | 556.395 | 2.000 | 0.064 | 2.718 | 0.347 | 0.110 | 0.033 |
| | L+T | PctL5 | 556.564 | 2.169 | 0.059 | 2.957 | 0.406 | 0.093 | 0.016 |
| | L+T | PctL6.5 | 556.799 | 2.403 | 0.052 | 3.325 | 0.458 | 0.092 | 0.015 |
| | L+T | WS | 556.980 | 2.584 | 0.048 | 3.640 | 0.506 | 0.091 | 0.014 |
| | L+T | PctL3.5 | 557.144 | 2.749 | 0.044 | 3.952 | 0.550 | 0.091 | 0.013 |
| | L+T | T*PctL5 | 557.199 | 2.804 | 0.043 | 4.063 | 0.593 | 0.099 | 0.021 |
| | PctL6.5 | T*PctL6.5 | 557.217 | 2.821 | 0.042 | 4.099 | 0.635 | 0.107 | 0.029 |
| | T*WS | T*WS | 558.064 | 3.669 | 0.028 | 6.261 | 0.663 | 0.112 | 0.034 |
| | L+T | L+T | 558.356 | 3.961 | 0.024 | 7.246 | 0.687 | 0.077 | 0.000 |
| | 1 | 1 | 560.228 | 5.832 | 0.009 | 18.470 | 0.881 | 0.000 | -0.077 |
| | L | L | 563.053 | 8.657 | 0.002 | 75.841 | 1.000 | 0.040 | -0.037 |