Arnold Schwarzenegger
Governor

EVALUATING PRECONSTRUCTION SAMPLING REGIMES FOR ASSESSING PATTERNS OF BAT ACTIVITY AT A WIND ENERGY DEVELOPMENT IN SOUTHERN CALIFORNIA

PIER FINAL PROJECT REPORT

Prepared For:
California Energy Commission
Public Interest Energy Research Program

Prepared By:
USDA Forest Service
Pacific Southwest Research Station

Pacific Southwest Research Station

July 2008
CEC-500-2008-037

Prepared By:
Theodore J. Weller
USDA Forest Service
Pacific Southwest Research Station
1700 Bayview Drive
Arcata, California 95521

Contract Number CEC 500-01-032
Subaward Number: S0181241

Prepared For:
Public Interest Energy Research (PIER) Program
California Energy Commission

Linda Spiegel
Contract Manager

Linda Spiegel
Program Area Lead
PIER Environmental Area

Mike Gravely
Office Manager

Martha Krebs, Ph.D.
PIER Research Director

Thom Kelly, Ph.D.
ENERGY RESEARCH & DEVELOPMENT DIVISION

Melissa Jones
Executive Director

Acknowledgments

This project was made possible through collaboration with PPM Energy and the Bats and Wind Energy Cooperative (BWEC). PPM Energy provided financial support and allowed unfettered access to its Dillon Wind Site for this project. In particular, Andy Linehan and Sara McMahon Parsons of PPM Energy were exemplary collaborators and professionals in facilitating a wide array of activities related to this project. Tyler Hoffbuhr of PPM Energy provided excellent and timely GIS support, and Craig Lee and Jerry Crescenti reliably provided meteorological data. BWEC contributed financial support and its considerable expertise in conducting similar projects was invaluable in the design and implementation of all phases of this project.

In particular, the author thanks Ed Arnett of Bat Conservation International (BCI) for his support, enthusiasm, patience, and focus on the big picture. Michael Schirmacher of BCI provided a wealth of information regarding tower setup and served as the field mentor in deploying portable towers in the field. Staff from Met Tower Services assisted in the installation of pulley systems on their meteorological towers. The author thanks Pacific Southwest Research Station (PSW) employees Joey Chong, Justin Garwood, Jenny Rechel, and Eric Russel for their able support in the field. Chet Ogan (PSW) provided reliable logistical support throughout the project as well as skillful fabrication and field support. The assistance of Jim Baldwin (PSW) with statistical analyses in a short time frame is greatly appreciated. Bernadette Jaquint, Garland Mason, Debbie Tarantino, David Weise, and Bill Zielinski (all PSW) provided important administrative support for this project. Finally the author would like to thank Linda Spiegel of California Energy Commission and Dawn Gable of the UCSC-PRG for their patient support of this project.

Please cite this report as follows:

Weller, T. J. 2007. *Evaluating Preconstruction Sampling Regimes for Assessing Patterns of Bat Activity at a Wind Energy Development in Southern California.* California Energy Commission, PIER Energy-Related Environmental Research Program. CEC-500-2008-037.

Preface

The California Energy Commission's Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program conducts public interest research, development, and demonstration (RD&D) projects to benefit California.

The PIER Program strives to conduct the most promising public interest energy research by partnering with RD&D entities, including individuals, businesses, utilities, and public or private research institutions.

PIER funding efforts are focused on the following RD&D program areas:

- Buildings End-Use Energy Efficiency
- Energy Innovations Small Grants
- Energy-Related Environmental Research
- Energy Systems Integration
- Environmentally Preferred Advanced Generation
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy Technologies
- Transportation

Evaluating Preconstruction Sampling Regimes for Assessing Patterns of Bat Activity at a Wind Energy Development in Southern California is the final report for the Evaluating Preconstruction Sampling Regimes for Assessing Patterns of Bat Activity at Proposed Wind Energy Developments in California project (contract number CEC-500-01-032), conducted by USDA Forest Service Pacific Southwest Research Station. The information from this project contributes to PIER's Energy-Related Environmental Research Program.

For more information about the PIER Program, please visit the Energy Commission's website at www.energy.ca.gov/pier or contact the Energy Commission at 916-654-5164.

Table of Contents

List of Figures

List of Tables

Abstract

Automated echolocation detectors were evaluated as a means of assessing patterns of bat activity at wind energy developments. The project was conducted at the Dillon Wind proposed wind energy development site in North Palm Springs, California. Echolocation detectors were attached at 2, 22, and 52 meters above ground on four meteorological towers to measure bat activity from October 25 to December 5, 2007. Bat activity during the sampling period was low, with a total of 61 detections resulting from 340 detector-nights of survey effort. Measured air temperature, wind speed, and wind direction were used in a modeling context to explain observed bat activity. Higher air temperatures and, to a lesser extent, lower wind speeds were important predictors of bat activity. Use of four meteorological towers produced precise estimates of mean bat activity at each of the three heights. Fewer towers would have resulted in relatively imprecise estimates, while more towers would not have appreciably improved precision during the sampling period. Additional towers have been installed, and concurrent echolocation and meteorological data collection will continue on-site until October 2008, which will allow bat activity—and the survey effort necessary to estimate it precisely—to be characterized throughout the year. In 2008, echolocation monitoring is being linked to fatality monitoring.

Keywords: Bats, bat detectors, echolocation, fall bat activity , meteorological conditions, wind turbine preconstruction, bat mortality risk assessment, Riverside County, San Gorgonio Pass Wind Resource Area, survey effort, winter bat activity

Executive Summary

Introduction

California has been a leader in wind energy production in the United States, and the role of wind energy in its generation portfolio is expected to expand in coming years. At the same time, California is committed to protecting wildlife in the state. Because wind energy is able to generate electricity without many of the environmental impacts associated with other energy sources, it is expected to produce a net benefit to wildlife species. Nevertheless, direct impacts in the form of bat and bird fatalities have been reported from wind energy facilities in a number of locations worldwide, including California. One consistent recommendation has been to monitor bat activity levels during the preconstruction phase of a wind turbine development to assess the relative risk that a specific development may pose to bats. However, it remains to be demonstrated whether preconstruction monitoring efforts are accurate predictors of bat fatality levels during operation of wind energy facilities. Work is urgently needed—in a variety of habitats, situations, and geographic locations—to better understand this relationship.

Project Objectives

This project evaluated the use of automated echolocation detectors as a means of estimating bat activity levels during the preconstruction phases of wind energy facilities. An intensive array of detectors was deployed at a wind energy development, and the resulting data were used to demonstrate the analytical methods for recommending a number and configuration of detectors sufficient to produce precise estimates of bat activity during a given period in this area and habitat. Additionally, the project demonstrated a model selection procedure to determine which variables (such as meteorology and detector location) were most important for explaining observed patterns of bat activity.

Methods

An array of 26 ANABAT II echolocation detectors was established at 12 locations to measure bat activity at the Dillon Wind project site near North Palm Springs, California. From October 25 to December 5, 2007, detectors were deployed on four meteorological towers at heights of 2, 22, and 52 meters (6.5, 72, and 170 feet) above the ground. Detectors were configured to automatically record echolocations from before dusk to after dawn each day. Eight additional bat monitoring towers were installed at the site between December 13 and 15, 2007, with detector microphones attached at 2 and 22 m above ground. The number of recorded bat echolocations was used as an index of bat activity and tabulated for each detector and each night.

Meteorological conditions (e.g., wind speed) were measured at the towers and linked to echolocation data from the same date for use in analyses. Generalized mixed models were used to establish relationship between bat activity, tower identity, tower height, and meteorological variables. The model that best fit the data was used to estimate the precision of estimates of bat activity that could be achieved with more or fewer towers.

Results

Sixty-one echolocation recordings were made over 340 detector-nights of data collection from October 25 to December 5, 2007. The mean amount of bat activity per night in the project area, using all detectors, was 1.69 bat passes, and the median was 1 bat pass per night using all detectors combined. Bat activity was recorded at all heights on all towers and there was no clear relationship between number of detections and height of detector microphones. Bat activity was greatest on nights with the highest temperatures and lowest wind speeds.

The best-fitting model, based on AIC (Akaike's information criterion), indicated that bat activity was best explained by air temperature, wind speed, wind direction, and detector height. The models clearly indicated that both mean air temperature (positive) and mean wind speed measured at a 30-m tower height (negative) play large roles in explaining the amount of nightly bat activity . Nevertheless, it is notable that the model that included only mean air temperature to explain the observed pattern of bat activity was 11.6 times less likely to be the model that best explained the data, and use of wind speed alone had an infinitesimally small chance of being the best model—indicating the importance of using multiple factors to explain bat activity.

Calculations based on project data indicate that use of three or four towers would produce relatively precise estimates of bat activity at each of three heights at this site under the conditions observed during late fall 2007. Use of more towers would offer small improvements in the precision of activity estimates, while use of only one or two towers would produce relatively imprecise estimates.

Conclusions

This project demonstrated the field and analytical methods useful for estimating bat activity using automated echolocation detectors, linking that data to on-site meteorological conditions, and estimating the survey effort necessary to produce precise estimates of activity. The firmest conclusion that can be drawn to date is that bat activity in the Dillon Wind project area was low during late fall 2007 relative to echolocation studies elsewhere. However, echolocation activity measured during this period does not allow prediction of bat activity at the site at other times of year. However, the procedures used in this study can be profitably applied to additional data on a periodic basis (monthly, quarterly) to assess whether the form and/or magnitude of these relationships change seasonally. The four meteorological towers used to measure echolocation activity produced relatively precise estimates of bat activity during this period; additional bat monitoring towers will allow determination of whether this estimate holds during other times throughout the year.

Future Steps

Echolocation monitoring at the Dillon Wind site is scheduled to continue until October 2008 and will cover the first months of operation of the wind facility. This will allow characterization of bat activity throughout the year and, potentially, observation of bat response to wind turbine construction and operation. Additionally, a fatality monitoring program is scheduled to begin in spring 2008, which will allow linkages to be established between the number of fatalities and echolocation activity measured on-site.

Benefits to California

This project helps to establish California as a leader in development of the science to predict risk to wildlife, particularly bats, from wind energy development.

1.0 Introduction

1.1. Background and Overview

California has been a leader in wind energy production in the United States and the role of wind energy in its generation portfolio is expected to expand in coming years. The state has set a goal requiring 20% of electricity sold in the state to come from renewable sources, including wind, by 2010. At the same time, California is committed to protecting wildlife resources in the state. Because wind energy is able to generate electricity without many of the environmental impacts associated with other energy sources, it is expected to produce a net benefit to wildlife species. Nevertheless, direct impacts in the form of bat and bird fatalities have been reported from wind energy facilities in a number of locations worldwide, including California (Kerns and Kerlinger 2004; Arnett 2005; Kerlinger et al. 2006).

The California Energy Commission and the California Department of Fish and Game have issued guidelines for assessing and minimizing impacts to birds and bats from wind energy developments (2007). However, survey methodologies for monitoring bats at wind energy sites are not well developed, especially compared to those for birds, and additional information is needed. One consistent recommendation has been to monitor bat activity levels at the site *before* turbine construction, to help assess the relative risk that the development may pose to bats. However, it remains to be demonstrated whether preconstruction monitoring can accurately predict bat fatality levels during actual operation of wind energy facilities. Work is urgently needed, in a variety of habitats, situations, and geographic locations, to better understand this relationship. For preconstruction monitoring to be broadly applied as a tool for risk assessment it must be able to characterize bat activity in an accurate and cost-effective fashion. If it does not, attempts to link activity levels to future impacts may be inaccurate or incorrect.

The San Gorgonio Pass Wind Resource Area near Palm Springs, California, has been a mainstay of the state's wind energy production since the 1980s and continues to be an active area of new and updated wind energy development. However, a continuing lack of information on bat activity patterns in this portion of the state makes it difficult to determine the periods when bats may be most active in this area and potentially at the greatest risk of collision with wind turbines. Information from other areas of the state and country has indicated that bats are at greatest risk during migratory periods of spring and, especially, fall (Kerns and Kerlinger 2004; Arnett 2005; Kerlinger et al. 2006; Kunz et al. 2007b). However, owing to a lack of knowledge regarding (1) bat activity patterns in this area and (2) migration routes of bats within the state—coupled with the presence of year-round, warm temperatures that are often associated with increased bat activity—it is unclear when the highest levels of bat activity may occur in this wind resource area.

Although large numbers of bat fatalities have not been reported from the San Gorgonio Pass area, very little monitoring effort has been directed specifically at bats. There is speculation that bat fatalities may be high at wind facilities in the southwestern United States (Kunz et al. 2007b). Thus, besides improving bat monitoring techniques, there is a need to understand the basic biological patterns of bat activity in this important wind resource area.

1.2. Project Objectives

This project investigated the use of automated echolocation detectors as a cost-effective means of characterizing bat activity levels at proposed wind energy facilities. The effectiveness of echolocation detectors, which sense and record the ultrasonic sounds produced by bats, to characterize activity patterns by bats is well established. However, little work has been done in the types of habitats where wind energy developments are often sited or at heights where bats are at highest risk of collision with turbines.

This project deployed an intensive array of echolocation detectors prior to and during construction of a wind energy facility in the San Gorgonio Pass Wind Resource Area near Palm Springs, California. The study was designed to exceed the number of locations presumed necessary to characterize bat activity in the area, such that statistical methods could be used to estimate the density and distribution of echolocation detectors necessary to gain a similar understanding of activity patterns with less effort.

Additionally, this project was intended to demonstrate analytical methods by which bat activity can be related to meteorological conditions measured on-site (e.g., temperature, wind speed, wind direction).

This study provides a foundation for future phases of work wherein bat activity levels can be related to estimated numbers of bat fatalities at the project site. The strength of this relationship, and the ability to predict it based on meteorological conditions, will provide valuable insights into the efficacy of echolocation monitoring technologies as a tool for assessing risk to bats from wind energy facilities in this important wind resource area in California.

Specific objectives of the project were to:

- Describe the amount of bat activity in the project area during late fall by two groups of species that differ in their echolocation frequencies (hereafter referred to as low- and high-frequency bats).
- Determine the number of spatial replicates (i.e., tower locations) necessary to adequately describe the activity of low- and high-frequency bats in the project area.
- Assess the relative effectiveness of echolocation detectors at different heights for describing the activity levels of low- and high-frequency bats.
- Determine which meteorological variables are the best predictors of activity levels of low- and high-frequency bats in the project area.

2.0 Methods

2.1. Study Area

The study was conducted at the Dillon Wind project site in the San Gorgonio Pass Wind Resource Area, in Riverside County near Palm Springs, California (Figure 1). The Dillon Wind Site is being developed by PPM Energy (part of Iberdrola Renewable Energies USA) and will result in the construction of forty-five 1-MW turbines. The site is divided into three development areas, two with twenty turbines apiece and a third (not depicted in Figure 1) with five additional turbines. Bat activity was measured in the two largest areas of development, each of which encompasses approximately one square mile.

The Dillon Wind Site was selected for several reasons. First and foremost, the short time frame of this project required a wind energy developer who would provide access to a site with preexisting meteorological towers that could be equipped with echolocation detection equipment. Second, to make the most effective and efficient use of research funds, the project sought a site with high probability of construction such that preconstruction echolocation monitoring could be linked to post-construction fatality data in future phases of the project. Additionally, the San Gorgonio Pass Wind Resource Area has been and continues to be an important area of wind energy development in California. Nevertheless, because there is little information on patterns of bat activity or fatality in the San Gorgonio Pass area, it is important, from a statewide perspective, to understand how bats use this area and the potential risks they may be facing. This task is complicated by a lack of basic information on how and when bats are most active in desert regions of southeastern California and whether this area is a migration corridor or wintering area for bats. All of these factors conspired to suggest that the Dillon Wind Site would be a useful place to begin research into the relationships between bats and wind energy in California.

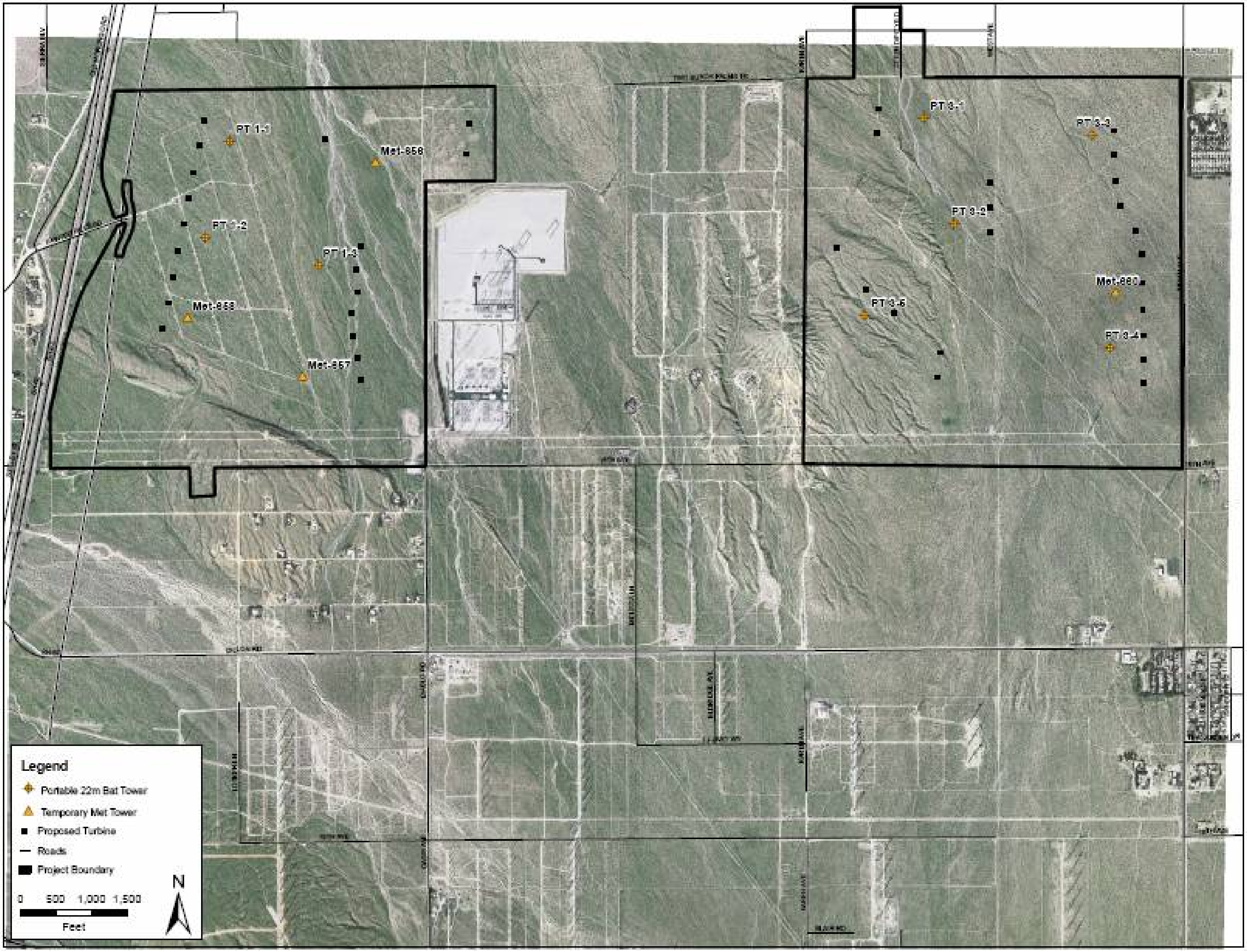


Figure 1. Aerial view of the Dillon Wind project area in North Palm Springs, California, depicting locations of bat echolocation monitoring towers in relation to proposed locations of wind turbines at the site (Photo by Ted Weller**)**

2.2. Monitoring Bat Activity

Bat activity was monitored using ANABAT II echolocation detectors which stored time-versus-frequency displays of echolocation calls to compact flash cards (CF cards) after processing by Zero-Crossings Analysis Interface Modules (ZCAIMs). Zero-crossings analysis is a method of displaying the time-versus-frequency content of audio signals. The ANABAT detectors were calibrated relative to each other using the methods of Larson and Hayes (2000). One detector was selected at random and set to a sensitivity of 6. This sensitivity level was chosen based on previous experience and on-site pilot studies that indicated this level represented an appropriate balance between maximizing the number of echolocation detections and minimizing the number of non-bat sounds recorded (e.g., wind or cables striking the tower). The sensitivity of all other detectors was set relative to that of the first randomly selected detector and ranged from 5.9–7.3. The only detectors that required sensitivity settings above 6.4 were older detectors (circa 1999) employed on the project.

Detector microphones were housed in weatherproof casings (a.k.a. bat hats) from EME Systems in Berkeley, California. Polycarbonate sound reflector plates on the microphone enclosures were positioned at 45 degrees below horizontal so that angle of call reception was upward at 45 degrees (Weller and Zabel 2002, Figure 2A). Pre-amp drivers were installed in each microphone enclosure to prevent loss due to cable length. All microphones were oriented due west, into the prevailing wind direction, and it was assumed that data gathered in this direction is representative of bat activity at each location. Microphones were connected via Canare brand electronics cables to bat detection and recording systems, which were housed on the ground in weather- and dust-proof containers (Figure 2B). Detectors and ZCAIM units were powered by a 12-V battery, recharged daily by a 10-W solar panel attached to the tower (Figure 2C). Detectors and ZCAIMs were configured to begin monitoring ~ 30 minutes before sunset and continue until ~ 30 minutes after sunrise. Detector systems were capable of cycling on and off and collecting data for multiple days unattended. Detector systems were visited approximately weekly to ensure they were operating properly and to download data from the CF cards.

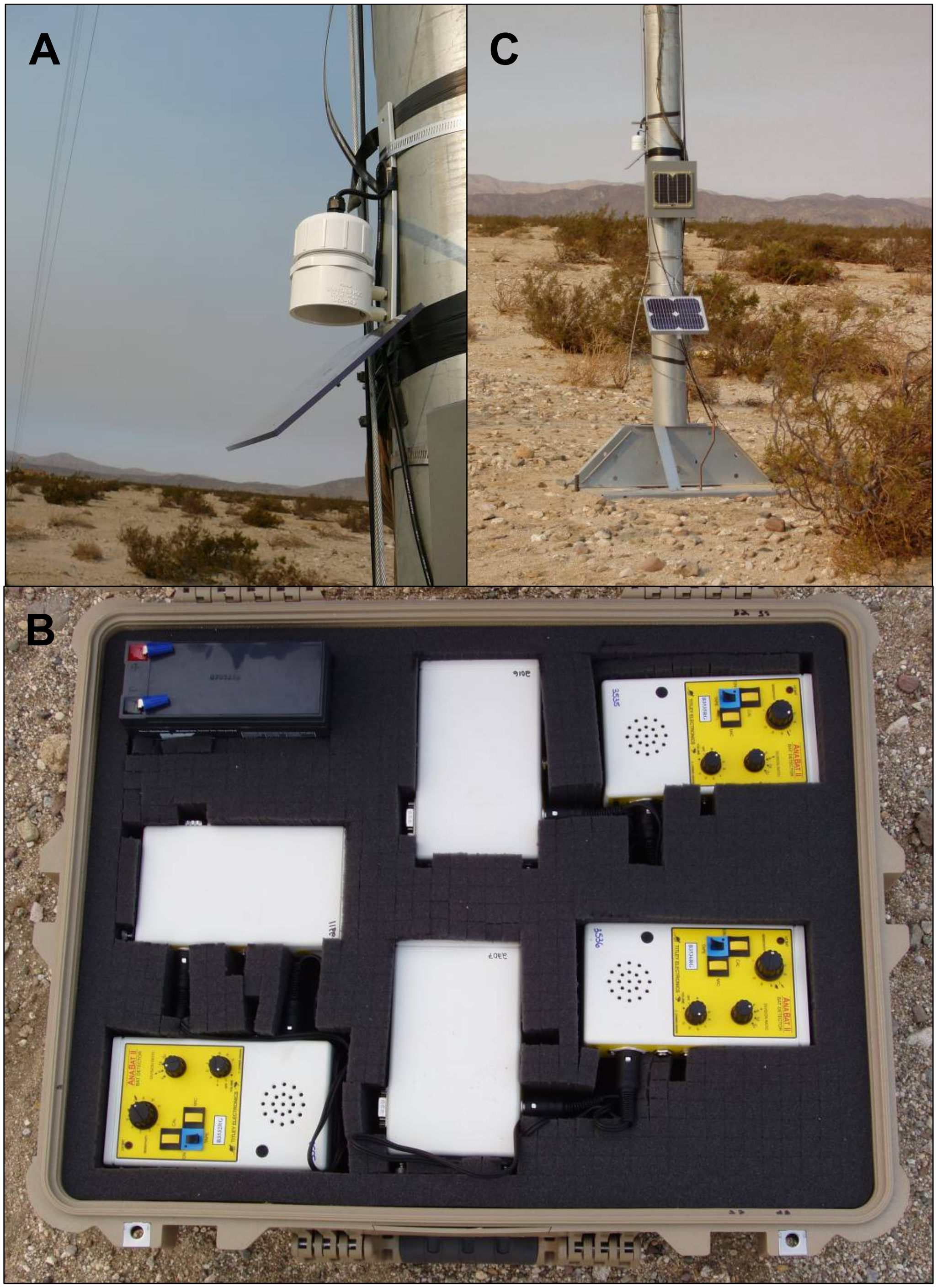


Figure 2. Echolocation detection systems as deployed on meteorological towers at Dillon Wind Site in North Palm Springs, California: (A) Bat hat attached at 2 m; (B) ANABAT detectors and Storage ZCAIMs in element-proof container; (C) 10-W solar panel used to power system. (Photos by Ted Weller**)**

2.2.1. Detector Heights

Detector microphones in bat hats were mounted on four meteorological towers (MET towers) and eight portable bat monitoring towers (Figure 1). Locations of the 60-meter-tall MET towers were selected in consultation with PPM Energy to provide an adequate characterization of the wind resource on-site while avoiding turbine construction zones. Bats hats were mounted at heights of 2, 22, and 52 meters above ground on the MET towers (Figure 3A) during Phase I of this project between October 25 and 26, 2007. Bat hats were attached to towers via a pulley box (Arnett et al. 2006) which had been attached during the raising of MET towers in September 2007 (Figure 3B). This system allows installation and recovery of bat detector microphones without the need to disassemble the tower.

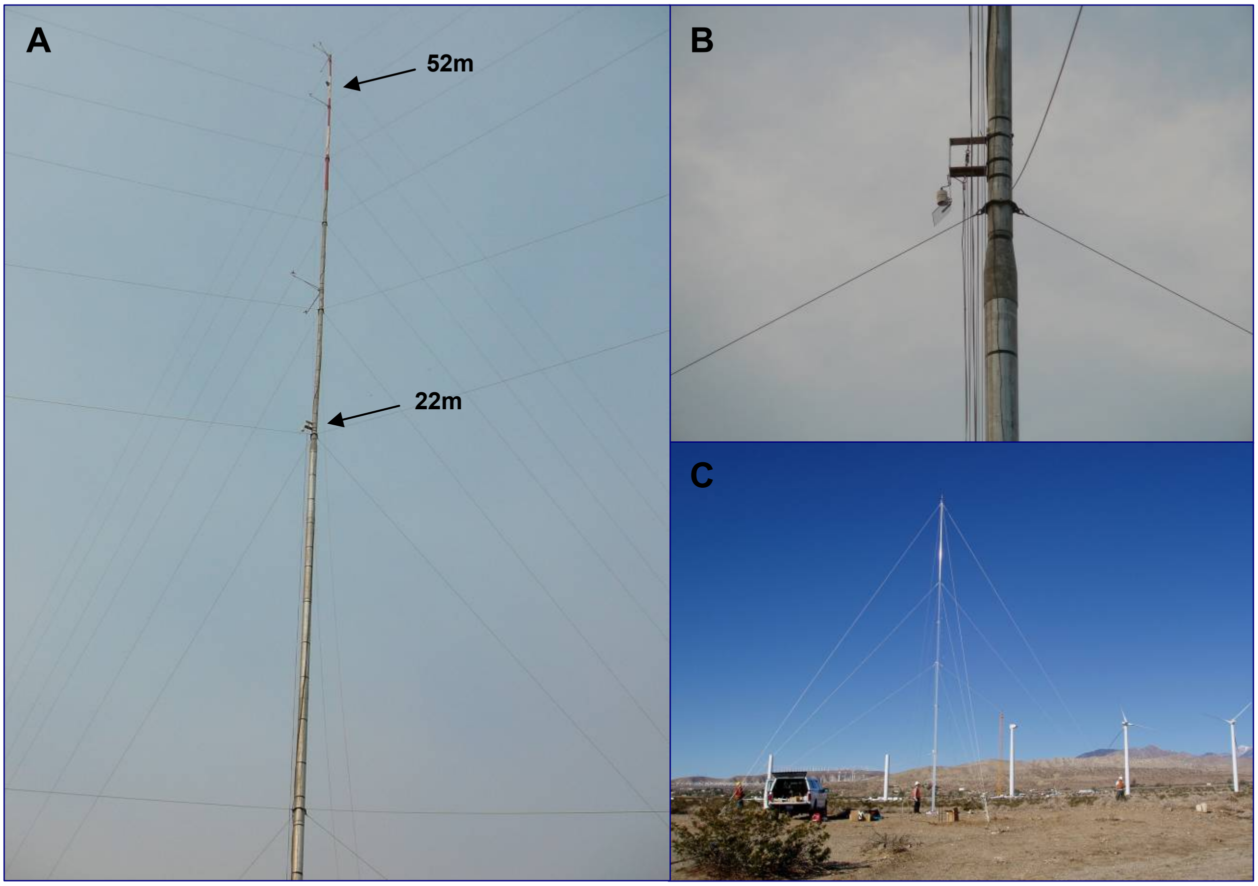


Figure 3. Echolocation detection towers: (A) Detector microphones mounted at 22 m and 52 m on a MET tower; (B) Detail of pulley system used to position microphones on MET towers; (C) Portable bat monitoring tower (Photos by Ted Weller)

Bat hats were attached at 2 m and 22 m above ground on portable bat monitoring towers (Figure 3C; Force12 Inc., Paso Robles, California) during Phase II of this project between December 13 and 15, 2007. The portable towers were sited to provide systematic sampling of bat activity in the vicinity of proposed turbine locations while avoiding turbine construction zones and other site constraints (e.g., overhead transmission lines). The size of the portable towers was chosen based on trade-offs between maximum height, cost, and ease of installation. Identical towers have been successfully used on bat monitoring projects at other wind developments in the U.S. (Arnett et al. 2006; Redell et al. 2006).

2.2.2. Meteorological Data

An intensive set of meteorological data was collected to meet PPM Energy's needs for characterizing conditions on-site. The project used a subset of that information to characterize conditions at each MET tower on each night. Specifically, mean wind speed, mean temperature, and mean wind direction were calculated based on measurements at 30 m high on each MET tower. Because wind speed is a circular variable, it was converted into its sine and cosine components for analysis. Meteorological data were collected every 10 minutes and post-processed to generate mean values that corresponded to the hours in which echolocation data were collected (i.e., only nighttime values).

2.3. Processing Echolocation Data

A bat pass was defined as a series of ≥ 2 echolocation calls each with a duration ≥ 2 ms (Hayes 1997; Weller et al. 2007). This definition balanced trade-offs between excluding non-bat sounds, which were prevalent on windy nights, and minimizing the number of "missed" bat detections.

Potential echolocations by bats were separated from non-bat ultrasound via the sequential use of two filters. The first filter, derived from those developed by Britzke and Murray (2000), has been used successfully for similar purposes by bat/wind energy studies in other regions of the U.S. (Arnett et al. 2006). This filter specified the minimum length of the body of calls, "Bodyover," to be at least 80 µs with a minimum frequency ≥ 18 kHz and "Smoothness" value of 25 (Smoothness refers to the distance between successive points before they are considered part of the same call).

Because this filter excluded echolocation calls with minimum frequencies < 18 kHz, it may exclude calls from some species in the deserts of Southern California. Therefore, a custom filter was designed for this project to separate echolocation calls with the lowest frequencies from non-bat sounds. This filter employed a Bodyover of 80 µs, Smoothness of 20, minimum frequencies ≥ 7 kHz, and duration of at least 4 ms. Although this duration exceeded the basic definition for a bat echolocation call, it was a reasonable value for species echolocating at low frequencies in open habitat and was necessary to exclude the large number of non-bat noises recorded on some nights.

The time-versus-frequency plot of each ANABAT file that passed these filters was visually inspected to determine whether it was a bat pass, based on the presence of a series of discrete pulses that generally sweep from higher to lower frequencies over time. Bat passes were then further identified as to whether they were produced by high (≥ 35 kHz) or low (< 35 kHz) frequency echolocating bats, based on their minimum frequency.

2.4. Data Analyses

Data analyses were conducted using echolocation and meteorological data collected from October 25 to December 5, 2007. The number of bat passes recorded at each height on each MET tower constituted the dependent variable in all analyses. The number of bat passes is used as an index of bat activity throughout this report.

2.4.1. Modeling Approach

Generalized additive models (GAMs) were used to suggest an appropriate form of the relationship between bat activity and meteorological variables for use in further modeling efforts. This approach was intended to limit the number of models under consideration relative to one where each potential form of the relationships was included as a separate model. GAMs were run using the statistical software PROGRAM R.

Generalized linear mixed models (PROC GLIMMIX in SAS) were used to model patterns of bat activity with respect to independent variables including Dillon Wind sub-area, MET tower, detector height, and meteorological variables. Meteorological variables included:

- Mean_Temp—mean air temperature (°C).
- Mean_Speed_30—mean wind speed (m/s) measured at 30 m above ground.
- Sin_mean and Cos_mean—two variables to characterize mean nightly wind direction.

Owing to the low number of detections on a nightly basis and a high proportion of nights with no bat detections, the mean of the number of bat files was assumed to follow a Poisson distribution with the log of the mean being a linear combination of the independent variables.

On the basis of results from other studies of bats in wind resource areas (Arnett et al. 2006; Redell et al. 2006) and inspection of plots of the raw data, nine potential models were proposed to explain observed patterns of bat activity. An information-theoretic approach (Burnham and Anderson 2002) was used to select the most likely models to explain the data. Candidate models were ranked using AICc rather than QAIC because there did not appear to be a large enough amount of overdispersion.[1] Attempts were made to incorporate the repeated measures aspect of the design (different heights on the same tower on the same night), but the small amount of overdispersion, the near-zero estimates of such variance components, and the lack of convergence of PROC GLIMMIX for some models, including the random effects, did not indicate that a more complex model, with respect to the covariance structure, was warranted. Thus, the models assume independence of observations among towers and project sub-areas, which fits with impressions garnered from the raw data.

2.4.2. Estimating Number of Towers

The mean and standard error of expected amount of bat activity per night at each height were adjusted from the raw data by applying the means and standard errors from the top-ranked at the mean values of all the covariates. That standard error corresponds to what is expected with four towers (se_4).

Statistical theory dictates that the standard error will change as the reciprocal of the square root of the number of towers, at least when the number of towers is similar to the four used in this study. Specifically, the standard error expected with a single tower (se_1) should be:

---

1. AIC, or Akaike's information criterion, is an operational way of trading off the complexity of an estimated model against how well the model fits the data. AICc is AIC with a second order correction for small sample sizes. QAIC stands for "quasi-AIC."

$$se_n = \frac{se_1}{\sqrt{n}}$$

where *n* is the number of towers. Because se_4 is known, we can solve for se_1:

$$se_1 = se_4 \cdot \sqrt{4} = 2se_4$$

So for any other number of towers the standard error can be estimated to be:

$$se_n = \frac{2se_4}{\sqrt{n}}$$

Data collected at four MET towers from October 25 to December 5, 2007, were used to estimate the standard error and coefficient of variation that would be achieved using from 1–12 towers, which represents the range in number of towers that were eventually deployed on-site.

3.0 Results

Between 6 and 11 detectors on MET towers were operational on 36 nights from October 25 to December 5, 2007, for a total of 340 detector-nights (Figure 4). The number of operational echolocation detectors was less than the maximum number deployed (4 towers x 3 heights) due to equipment malfunctions. No bats were detected on 16 nights and on all but one night the number of active echolocation detectors on MET towers exceeded the number of bat passes recorded (Figure 4). The mean number of bat passes recorded per night in the project area, using all detectors, was 1.69 and the median was 1 bat pass per night using all detectors combined. On a per-tower basis, the mean number of bat passes per night ranged from 0.18–0.5 and the number of nights without bat activity exceeded the number of nights with bat activity at every tower (median = 0 for all towers). The maximum number of bat passes at a single detector location was four at the 52-m detector on Tower # DIL651 on October 26, 2007.

At most towers there was no clear pattern to the heights at which bat activity was detected; however, at DIL651 there was some indication of more bat activity at 52 m (Figure 5).

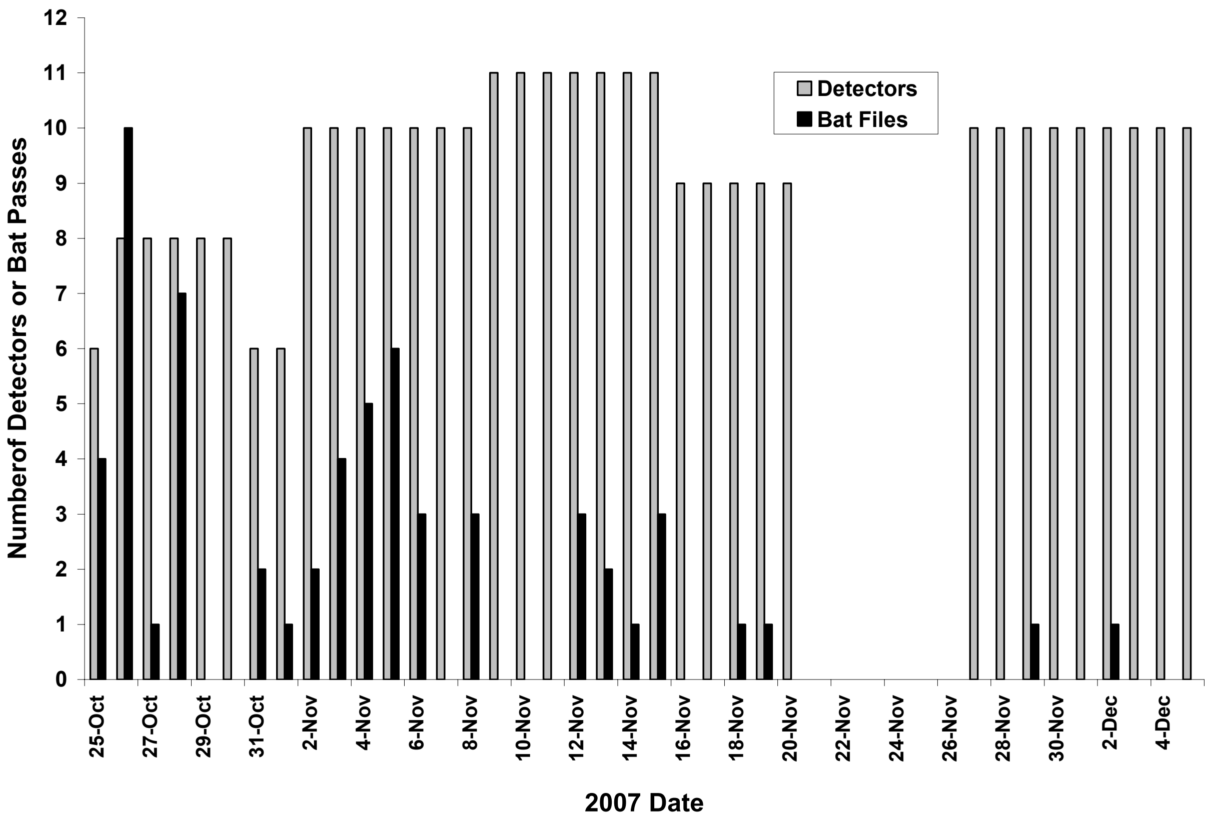


Figure 4. Number of echolocation detectors deployed and total number of bat passes recorded from October 25 to December 5, 2007, at the Dillon Wind Site, North Palm Springs, California

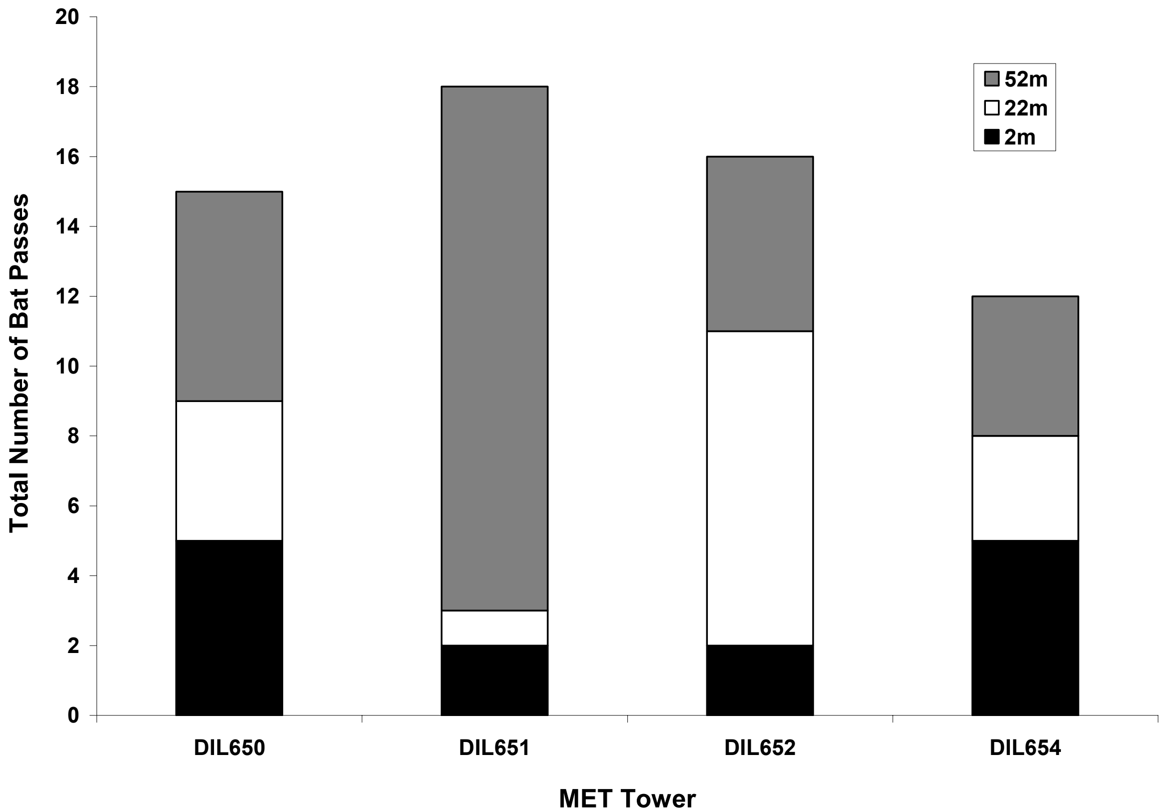
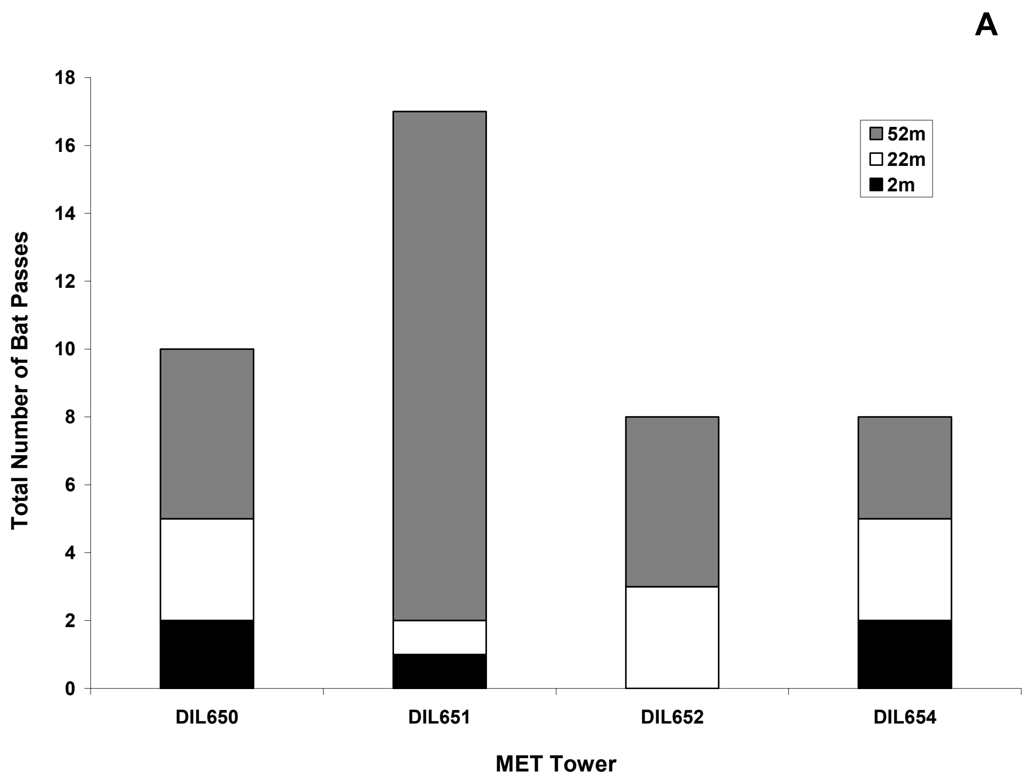


Figure 5. Total number of bat passes, by detector height, recorded at each of four MET towers at the Dillon Wind Site in North Palm Springs, California, from October 25 to December 5, 2007

Low-frequency bats accounted for 43 of the 61 echolocation detections recorded. Low-frequency bats tended to be recorded more frequently at 52 m than at 2 or 22 m (Figure 6A). No MET tower had more than two detections of a low-frequency bat at the 2-m detector over the entire period of operation. Conversely, high-frequency bats were infrequently recorded at the 52-m detectors, with a single detection of a high-frequency bat at three of the towers and none at the other (Figure 6B).

Three-dimensional plots of the raw data indicated that the number of bat detections was greatest on nights with the highest temperatures and lowest wind speeds (Figure 7).

GAM analyses provided little evidence of nonlinear relationships between any of the meteorological variables and the nightly number of bat passes (Figure 8); this is evidenced by the mean values of relationships fitting symmetrically between the confidence intervals (Figure 8).



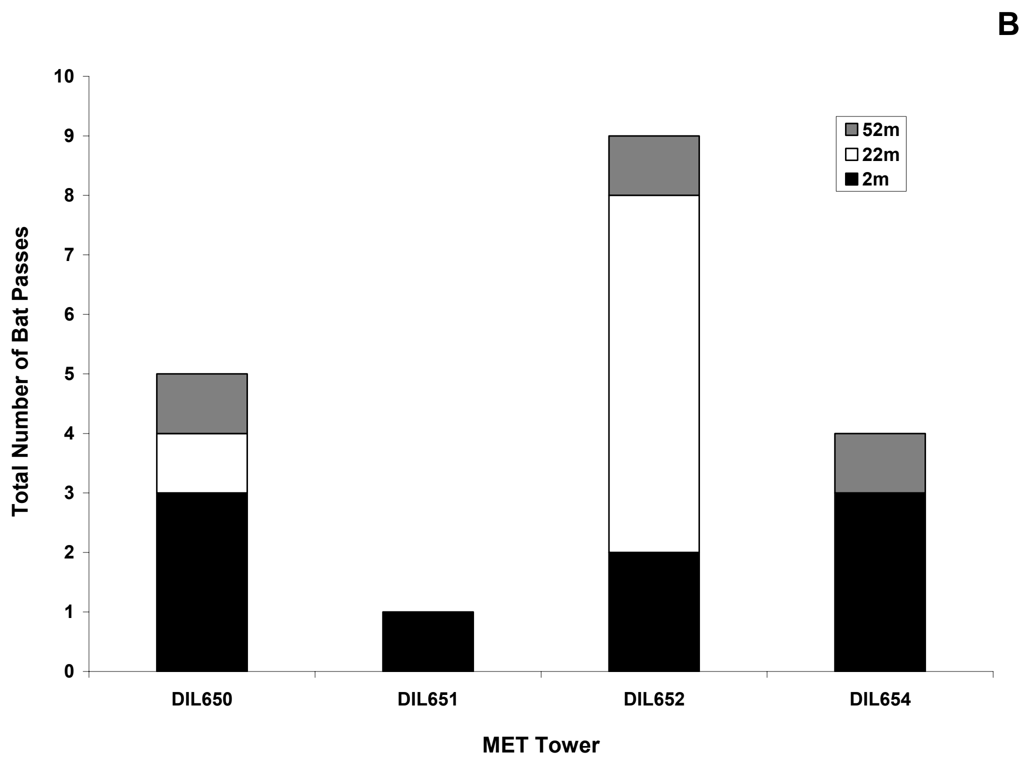


Figure 6. Total number of detections of (A) low-frequency (<35 kKz) and (B) high-frequency (≥35 kHz) bats in Dillon Wind project area, October 25 to December 5, 2007

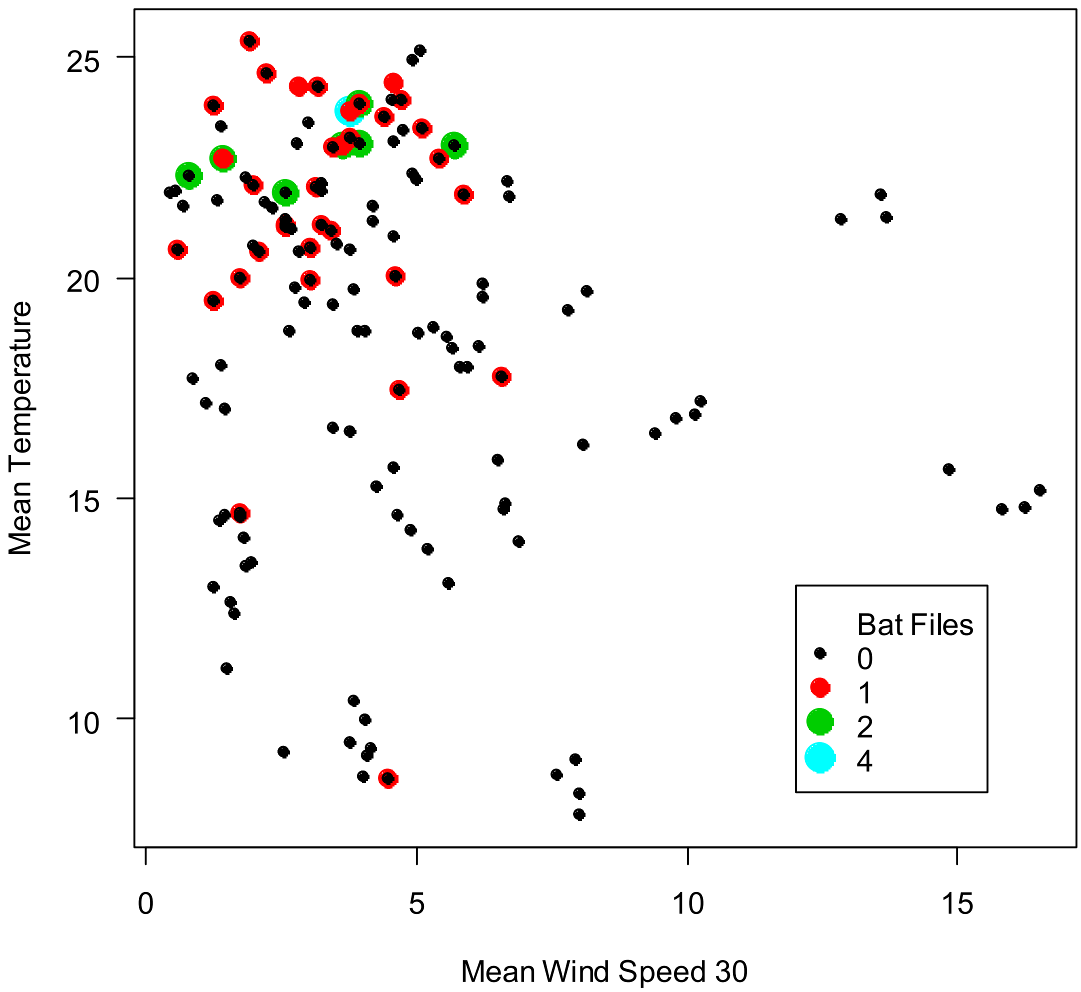


Figure 7. Relationship among mean air temperature, mean wind speed at 30 m high on the tower, and number of bat passes at each height on each MET tower at the Dillon Wind Site from October 25 to December 5, 2007

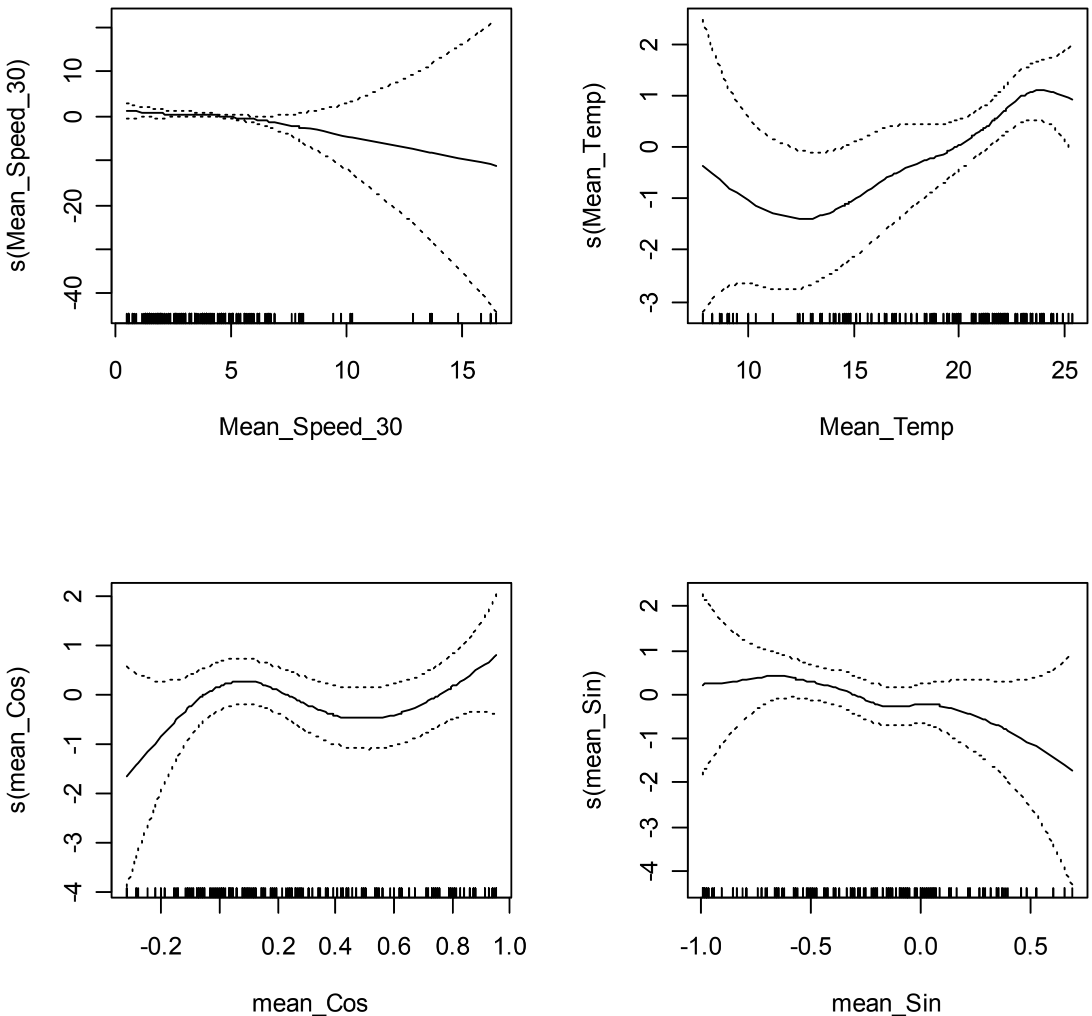


Figure 8. Form of relationships between number of bat passes and mean meteorological variables on a nightly basis, as determined from generalized additive models. Dotted lines represent two standard deviations around the mean. Mean_Speed_30 is wind speed (m/s) at 30-m height, Mean_Temp is air temperature (°C), and mean_Cos and mean_Sin are components describing wind direction.

The top-ranked model for explaining bat activity was the global model that included air temperature, wind speed, wind direction, and height of detectors (Table 1). This model was 24% more likely to be the best model to explain the data than the next-best model, which included only mean air temperature and mean wind speed. Examination of the top-ranked models indicates that wind speed and, in particular, air temperature were the most important variables for explaining the pattern of bat detections observed in this dataset. However, it is notable that the model that included only mean air temperature to explain the observed pattern of bat detections is 11.6 times less likely to be the model that best explains the data, and use of wind speed alone has an infinitesimally small chance of being the best model.

Table 1. Results of model selection procedure to explain amount of bat activity at each echolocation detector position on a nightly basis

Model	AIC_c	Δ AIC_c	AIC_c weight	Rel. Weight
Mean_Temp Mean_Speed_30 mean_Sin mean_Cos Height	294.934	0.0000	0.33461	1.00
Mean_Temp Mean_Speed_30	295.358	0.4246	0.27061	1.24
Mean_Temp|Mean_Speed_30 Height	296.691	1.7576	0.13896	2.41
Mean_Temp|Mean_Speed_30 mean_Sin mean_Cos Height	297.028	2.0945	0.11741	2.85
Mean_Temp|Mean_Speed_30	297.405	2.4712	0.09726	3.44
Mean_Temp	299.837	4.9035	0.02882	11.61
Mean_Temp mean_Sin mean_Cos Height	301.536	6.6023	0.01233	27.13
Mean_Speed_30	338.247	43.3129	0.00000	- - -
Height	347.109	52.1748	0.00000	- - -

Model = variables included in the model as defined in text.
| indicates that all possible interaction terms with variables following were considered.
AIC_c = small-sample-corrected Akaike's Information Criterion.
Δ AIC_c = difference in the model from the best model in the set.
AIC_c weight = Akaike weight of the model.

Table 2. Mean number of bat passes per night at each height as estimated from the top-ranked model using data collected from October 25 to December 5, 2007, at the Dillon Wind project area and the predicted standard error (SE) and coefficient of variation (CV) expected at each height for 1–12 towers

	Height = 2 Mean = 0.0533		Height = 22 Mean = 0.0892		Height = 52 Mean = 0.1044	
Towers	SE	CV	SE	CV	SE	CV
1	0.0365	69%	0.0577	65%	0.0606	58%
2	0.0258	48%	0.0408	46%	0.0429	41%
3	0.0211	40%	0.0333	37%	0.0350	34%
4	0.0183	34%	0.0288	32%	0.0303	29%
5	0.0163	31%	0.0258	29%	0.0271	26%
6	0.0149	28%	0.0235	26%	0.0247	24%
7	0.0138	26%	0.0218	24%	0.0229	22%
8	0.0129	24%	0.0204	23%	0.0214	21%
9	0.0122	23%	0.0192	22%	0.0202	19%
10	0.0116	22%	0.0182	20%	0.0192	18%
11	0.0110	21%	0.0174	20%	0.0183	18%
12	0.0105	20%	0.0166	19%	0.0175	17%

Results from the best model were used to estimate the number of towers that would be necessary to achieve similarly precise estimates for the amount of bat activity at each height during the study period (Table 2). These results show that only small improvements in precision, ≤ 3% as measured using coefficient of variation, would be achieved by using more than four towers at this site, during this time period. In fact, similarly precise estimates for the amount of bat activity (within 6%) could have been achieved for this dataset using only three MET towers. Use of one to two towers to measure bat echolocation activity at the site during this time period would produce relatively imprecise estimates (Table 2).

4.0 Conclusions

The most important result of this project was to demonstrate effective logistic and analytic methods for estimating the amount of bat activity using automated echolocation detectors, linking that data to on-site meteorological conditions, and determining the survey effort necessary to produce precise estimates of bat activity. Such methods will be valuable for evaluating these relationships using larger datasets in additional time periods—including potential migration periods during spring and fall—and in other study areas.

Project analyses indicated that measuring bat activity at four MET towers produced reasonably precise estimates for the amount of bat activity at each height in the Dillon Wind project area during late fall 2007. Additional towers would have provided little improvement on precision of estimates during this time period. Nevertheless, as specified in the study plan to the Energy Commission, eight additional towers with detectors at 2 and 22 m above ground were installed at the project site between December 13 and 15, 2007, such that there were a total of 26 detectors on 12 towers. Data from these detectors will be used to confirm or refine the precision estimates using data collected beginning December 15, 2007. If bat activity patterns at other times of the year differ greatly from those observed during late fall 2007, this may alter the number of spatial replicates, in the form of towers, needed to produce precise estimates of bat activity.

This report is based on a sample of data from the Dillon Wind project area during late fall 2007. As such, conclusions that can be drawn regarding relationships between meteorological data, detector heights, and number of echolocation recordings are limited to this site during this time period. Additionally, owing to the paucity of detections during this period, a few additional detections at one tower or height could significantly alter preliminary conclusions. The firmest conclusion that can be drawn from the data to date is that bat activity in the Dillon Wind project area was low during late fall 2007. Per-tower detection rates at Dillon Wind (< 0.43 detections/tower/night) are far lower than ~ 5 passes/tower/night recorded during July–September 2005 monitoring in Wisconsin (Redell et al. 2006) and August–October 2005 monitoring in Pennsylvania (Arnett et al. 2006). However, it is important to note that bat activity dropped off significantly toward the end of the monitoring periods in both the Wisconsin and Pennsylvania studies, and this time period corresponds to the beginning of data collection on this project.

The current dataset provides little insight into amounts or patterns of bat activity at the Dillon Wind project area at other times of the year. The data collected to date demonstrate that bat activity is linked to temperature, and because these data were collected during the cool portion of the year, bat activity may be shown to increase as collection efforts continue during warmer periods. Additionally, bat activity may increase if the project area is in the spring or fall migratory pathway for bats. Finally, it is possible that bat activity may increase with the presence of wind turbines on-site (Cryan 2008), though demonstration of such an effect would be difficult at this site because of the limited period of preconstruction echolocation monitoring.

The selected models clearly indicated that both mean air temperature (positive) and mean wind speed at 30 m (negative) play large roles in explaining the amount of bat activity on a nightly basis. Wind direction and detector height help explain observed patterns but play much less important roles. Parameter estimates of top-ranked models indicate that mean temperature plays the larger role. These results mirror those of other studies of bat activity at proposed wind energy developments (Arnett et al. 2006; Redell et al. 2006; Reynolds 2006). Future analyses will explore the effects of alternative meteorological metrics (e.g., maximum wind speed) on bat activity.

The total number of bat passes was used as the dependent variable in all analyses due to the low amount of activity recorded. Future analyses will consider low-frequency and high-frequency bats separately in terms of the number and configuration of detectors necessary to precisely estimate activity levels and the meteorological variables that best explain activity patterns. Nevertheless, raw project data indicated that low-frequency bats made up the majority of detections and were detected more frequently at the 52-m height. The migratory species *Lasionycteris noctivagans* (silver-haired bats), *Lasiurus cinereus* (hoary bat), and *Tadarida brasiliensis* (Mexican free-tailed bat), among others, fall into the low-frequency bat category. Patterns of activity observed during the study were not indicative of migratory activity (e.g., a large number of detections in a single night was not observed) but it is noteworthy that low-frequency bats tend to be detected—by this study and others—at the highest detector locations even outside migratory periods (Arnett et al. 2006; Redell et al. 2006; Reynolds 2006).

4.1. Future Steps

This project demonstrated a set of statistical and analytical procedures useful for evaluating relationships between bat echolocation data, detector height, and meteorological data. These procedures can be profitably applied to additional data on a periodic basis (e.g., monthly, quarterly) to assess whether the form and/or magnitude of these relationships change seasonally.

This project is scheduled for continuous collection of echolocation and meteorological data at the Dillon Wind Site until at least October 31, 2008, to gain a better understanding of the annual pattern of bat activity on-site. This continued work will be supported by PPM Energy, the Bats and Wind Energy Cooperative, and the USDA Forest Service Pacific Southwest Research Station. The methods demonstrated in this project will be applied to the full annual dataset, and the time period (e.g., month, season) will be included as a covariate in analyses. This will not only allow the amount of bat activity measured during late fall 2007 to be placed into an annual context, but will also allow reevaluation of requirements for sample size and detector configuration at other times of the year, as well as reevaluation of relationships with meteorological variables during these time periods.

Additionally, the Dillon Wind Energy project is expected to begin operation in spring 2008 and an avian and bat fatality monitoring program will be conducted by WEST, Inc., following Energy Commission guidelines. Pacific Southwest Research, PPM Energy, BWEC, and WEST, Inc., are teaming to develop a cost-effective means of linking bat fatality monitoring and concurrent echolocation monitoring to draw the strongest inferences regarding the efficacy of echolocation monitoring as a tool for predicting bat fatalities. This new phase of research will provide a value-added component to this PIER-funded work, as it will help address larger questions of risk assessment for bats at wind energy facilities in California.

Studies similar to this one need to be conducted in other areas to better understand seasonal patterns of bat activity, the effect of meteorological conditions on patterns of activity, and the amount and configuration of survey effort necessary to characterize bat activity in a variety of habitats where wind energy developments are proposed in California. The methods used in this project will provide a good starting point for designing such studies, but inevitably they will need to be adapted to meet the logistical and ecological conditions at the particular site.

The use of echolocation detectors is but one of the methods that can be used to estimate the amount of bat activity at a site. Thermal infrared imaging and mobile radar units are two additional tools that can be employed to estimate the amount of bat activity at a site (Kunz et al. 2007a). Each of these tools has its strengths and limitations and work is needed to develop linkages among the data produced by each method, establish their complementarity, and determine cost efficiencies (Kunz et al. 2007a). The Energy Commission should consider supporting such comparative research in California as it will help advance the science regarding prediction of wind turbine risk to bats (and birds) in California and throughout the world.

4.2. Benefits to California

This project helps to establish California as a leader in development of the science to predict risk to bats from wind energy development.

5.0 References

Arnett, E. B. (technical editor). 2005. *Relationships between bats and wind turbines in Pennsylvania and West Virginia: an assessment of bat fatality search protocols, patterns of fatality, and behavioral interactions with wind turbines.* A final report submitted to the Bats and Wind Energy Cooperative. Bat Conservation International, Austin, Texas.

Arnett, E. B., J. P. Hayes, and M. M. P. Huso. 2006. *An evaluation of the use of acoustic monitoring to predict bat fatality at a proposed wind facility in south-central Pennsylvania*. An annual report submitted to the Bats and Wind Energy Cooperative. Bat Conservation International, Austin, Texas.

Britzke, E. R., and K. L. Murray. 2000. "A quantitative method for selection of identifiable search-phase calls using the Anabat system." *Bat Research News* 41: 33–36.

Burnham, K. P., and D. R. Anderson. 2002. *Model selection and multi-model inference: a practical information-theoretic approach*. 2nd ed. Springer-Verlag, New York, 488 pp.

California Energy Commission and California Department of Fish and Game. 2007. *California Guidelines for Reducing Impacts to Birds and Bats from Wind Energy Development*. Commission Final Report. California Energy Commission, Renewables Committee, and Energy Facilities Siting Division, and California Department of Fish and Game, Resources Management and Policy Division. CEC-700-2007-008-CMF.

Cryan, P. M. 2008. "Mating behavior as a possible cause of bat fatalities at wind turbines." *Journal of Wildlife Management* 72: In press.

Hayes, J. P. 1997. Temporal variation in activity of bats and the design of echolocation-monitoring studies." *Journal of Mammalogy* 78:514–524.

Kerlinger, P., R. Curry, L. Culp, A. Jain, C. Wilkerson, B. Fischer, and A. Hasch. 2006. *Post-construction avian and bat fatality monitoring study for the High Winds Power Project, Solano County, California: two year report*. Curry and Kerlinger, L.L.C, McLean, Virginia.

Kerns, J., and P. Kerlinger. 2004. *A study of bird and bat collision fatalities at the MWEC Wind Energy Center, Tucker County, West Virginia: Annual report for 2003.* Technical report prepared by Curry and Kerlinger, LLC for FPL Energy and MWEC Wind Energy Center Technical Review Committee.

Kunz, T. H., E. B. Arnett, B. M. Cooper et al. 2007a. "Assessing impacts of wind-energy development on nocturnally active birds and bats: a guidance document". *Journal of Wildlife Management* 71: 2449–2486.

Kunz, T. H., E. B. Arnett, W. P. Erickson et al. 2007b. "Ecological impacts of wind energy development on bats: questions, research needs, and hypotheses." *Frontiers in Ecology and the Environment* 5: 315–324.

Larson D. J., and J. P. Hayes. 2000. "Variability in sensitivity of Anabat II bat detectors and a method of calibration." *Acta Chiropterologica* 2(2):209-213.

Redell, D., E. B. Arnett, and J. P. Hayes. 2006. *Patterns of pre-construction bat activity determined using acoustic monitoring at a proposed wind facility in south-central Wisconsin.* A final report submitted to the Bats and Wind Energy Cooperative. Bat Conservation International, Austin, Texas.

Reynolds, D. S. 2006. "Monitoring the potential impact of a wind development site on bats in the Northeast." *Journal of Wildlife Management* 70: 1219–1227.

Weller, T. J., and C.J. Zabel. 2002. "Variation in bat detections due to detector orientation in a forest." *Wildlife Society Bulletin* 30(3):922-930.

Weller, T. J., S. A. Scott, T. J. Rodhouse, P. C. Ormsbee, and J. M. Zinck. 2007. "Field identification of the cryptic vespertilionid bats, *Myotis lucifugus* and *M. yumanensis*." *Acta Chiropterologica* 9:133–147.