Arnold Schwarzenegger
Governor

EVALUATING PRE-CONSTRUCTION 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

December 2007
CEC-500-01-032

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

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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 their Dillon Wind Site for this project. In particular, Andy Linehan and Sara McMahon Parsons of PPM Energy were exemplary collaborators and consummate 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 their considerable expertise in conducting similar projects was invaluable in the design and implementation of all phases of this project. In particular, I thank 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 set-up and served as our field mentor in deploying portable towers in the field. Staff from MTS assisted in the installation of pulley systems on their meteorological towers. I thank 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 on 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 I 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 Pre-construction Sampling Regimes for Assessing Patterns of Bat Activity at a Wind Energy Development in Southern California*. PIER Energy-Related Environmental Research Program. CEC-500-01-032.

Preface

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

The PIER Program, managed by the California Energy Commission (Energy Commission), 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.

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- Transportation

Evaluating Pre-construction Sampling Regimes for Assessing Patterns of Bat Activity at a Wind Energy Development in Southern California is the final report for the Evaluating Pre-construction 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.

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Abstract

This report describes a project aimed at evaluating the use of automated echolocation detectors as a tool for assessing patterns of bat activity at wind energy developments in California. The project was conducted at the Dillon Wind energy development site in North Palm Springs California. Echolocation detectors were attached at 2, 22, and 52m above ground on four meteorological towers to measure bat activity from 25 October to 5 December 2007. Twelve additional bat monitoring towers were added to the project area December 13 – 15, 2007. Air temperature, wind speed, and wind direction were measured at meteorological towers and were used in a modeling context to explain the amount of observed bat activity. Bat activity during the sampling period was low with a total of 61 detections resulting from 340 detector-nights of survey effort. Wind speed and, especially, air temperature were important predictors of observed bat activity with highest periods of activity on nights with the highest temperatures and the lowest wind speeds. Use of 4 meteorological towers produced precise estimates of mean bat activity at each of 3 heights, which indicated that use of additional towers would not have appreciably improved estimates during the sampling period. Concurrent echolocation and meteorological data collection is scheduled to continue on-site until late-fall 2008 which will allow bat activity, and the survey effort necessary to estimate it precisely, to be characterized throughout the year. Additionally, echolocation monitoring will be linked to fatality monitoring at the site beginning in spring 2008.

Keywords: bats, bat detectors, echolocation, fall, meteorological conditions, pre-construction, risk assessment, Riverside County, San Gorgonio Pass Wind Resource Area, survey effort, winter

Executive Summary

Introduction

California has been a leader in wind energy production in the United States and the role of wind energy in its energy portfolio is expected to expand in coming years. 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. One consistent recommendation has been to monitor activity levels of bats during pre-construction with the expectation that this would help assess the relative risk that a development may pose to bats. However it remains to be demonstrated whether pre-construction 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 was intended to evaluate the use of automated echolocation detectors as a means of estimating bat activity levels during the pre-construction phases of wind energy development. An intensive array of detectors was deployed at a wind energy development and the resulting data was used to demonstrate the analytical methods used to recommend the number and configuration of detectors necessary to produce precise estimates of bat activity during a given time period. Additionally the project demonstrated a model selection procedure to determine which design variables (e.g., meteorological, 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 Energy project site near North Palm Springs, California. From 25 October 25 – 5 December, 2007 detectors were deployed on 4 meteorological towers at heights of 2, 22, and 52m above ground. Detectors were configured to automatically record echolocations from before dusk to after dawn each day. Eight additional bat monitoring towers were added to the site on Dec 13 – 15 2007 with detector microphones attached at 2 and 22m above ground. The number of files that contained bat echolocations was tabulated for each detector and each night from those mounted on meteorological towers. Meteorological conditions 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 number of bat files recorded, tower identity, height and meteorological variables. The model that best fit the data was selected and used to estimate the precision of estimates of bat activity that could be established with more of fewer towers.

Results

Sixty-one echolocation files were recorded over 340 detector-nights of data between 25 October and 5 December 2007. The mean number of bat files recorded per night in the project area, using all detectors, was 1.69 and the median was 1 bat file per night using all detectors combined. Echolocation files were recorded at all heights on all towers and there was no clear relationship between number of detections and height of detector microphones. The top model, based on AIC, indicated that number of echolocations was best explained by air temperature, wind speed, wind direction, and detector height. However wind speed and, especially, air temperature were the most important predictors of bat activity during period of measurement. We estimated that the use 3 – 4 towers would produce relatively precise estimates of the mean number of bat files recorded at each of three heights.

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 survey effort necessary to produce precise estimates of activity. Bat activity during late-fall/early winter at the Dillon Wind site was low relative to echolocation studies elsewhere. However, echolocation activity measured during this time period does not allow us to predict bat activity at other times of the year. The methods used in this report will be used to characterize bat activity at other times of year and with respect to meteorological variables. The 4 meteorological towers we used to measure echolocation activity produced relatively precise estimates of bat activity during this time period, and additional bat monitoring towers will allow determination of whether this estimate holds in during other time periods throughout the year.

Future Steps

Echolocation monitoring at the Dillon Wind site is scheduled to continue until late-fall 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, to observe a response to construction and operation of wind turbines. Additionally, a fatality monitoring program is scheduled to begin in spring 2008 which will all linkages to be established between number of fatalities and echolocation activity measured on site.

Benefits to California

Initiation of 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 energy 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 the year 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 (CEC) and the California Department of Fish and Game (CDFG) have issued guidelines for assessing and minimizing impacts to birds and bats from wind energy development (CEC and CDFG 2007). However survey methodologies for monitoring bats are not well-developed, especially compared to those for birds, and additional information is needed. One consistent recommendation has been to monitor activity levels of bats during pre-construction with the expectation that this would help assess the relative risk that a development may pose to bats. However it remains to be demonstrated whether pre-construction 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. For pre-construction monitoring to be a broadly applied 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 wind energy production in California 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 make 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 have 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 of bat activity patterns in this area and migration routes of bats within the state, coupled with year-round temperatures typically associated with higher bat activity levels, it is unclear when the highest levels of bat activity may occur in this 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. Nevertheless there is speculation that bat fatalities may be high at wind facilities in the southwestern United States (Kunz et al. 2007b). Thus, in addition to addressing methodological concerns, there is a basic need to understand 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 use of echolocation detectors, which sense and record the ultrasonic sounds produced by bats, to characterize activity patterns by bats is well developed. 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 involved deployment of 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. Echolocation detectors were deployed at 12 separate locations at the facility and at 3 different heights in order to characterize spatial variation in use of this area by bats. Detectors were configured to record echolocations on each night over the length of the project to account for temporal variation in bat activity levels. The study was designed to exceed the number of locations we presumed would be 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 will demonstrate the methods by which the number of bat detections can be related to meteorological conditions measured on-site (e.g., wind speed, wind direction). This study will lay the foundation for future phases of work wherein bat activity levels can be related to estimated number 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/early winter by two groups of species which differ in frequencies at which they echolocate (hereafter, low and high frequency bats).
- Determine the number of spatial replicates (i.e. tower locations) necessary to adequately describe activity of low and high frequency bats in the project area.
- Assess the relative effectiveness of echolocation detectors at different heights for describing 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 area 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 and will result in the construction of 45 one MW turbines. The site is divided into 3 development areas, 2 with 20 turbines apiece and a third (not depicted in Figure 1) with 5 additional turbines. Bat activity was measured in the two largest areas of development, each of which encompasses approximately 1 square mile.

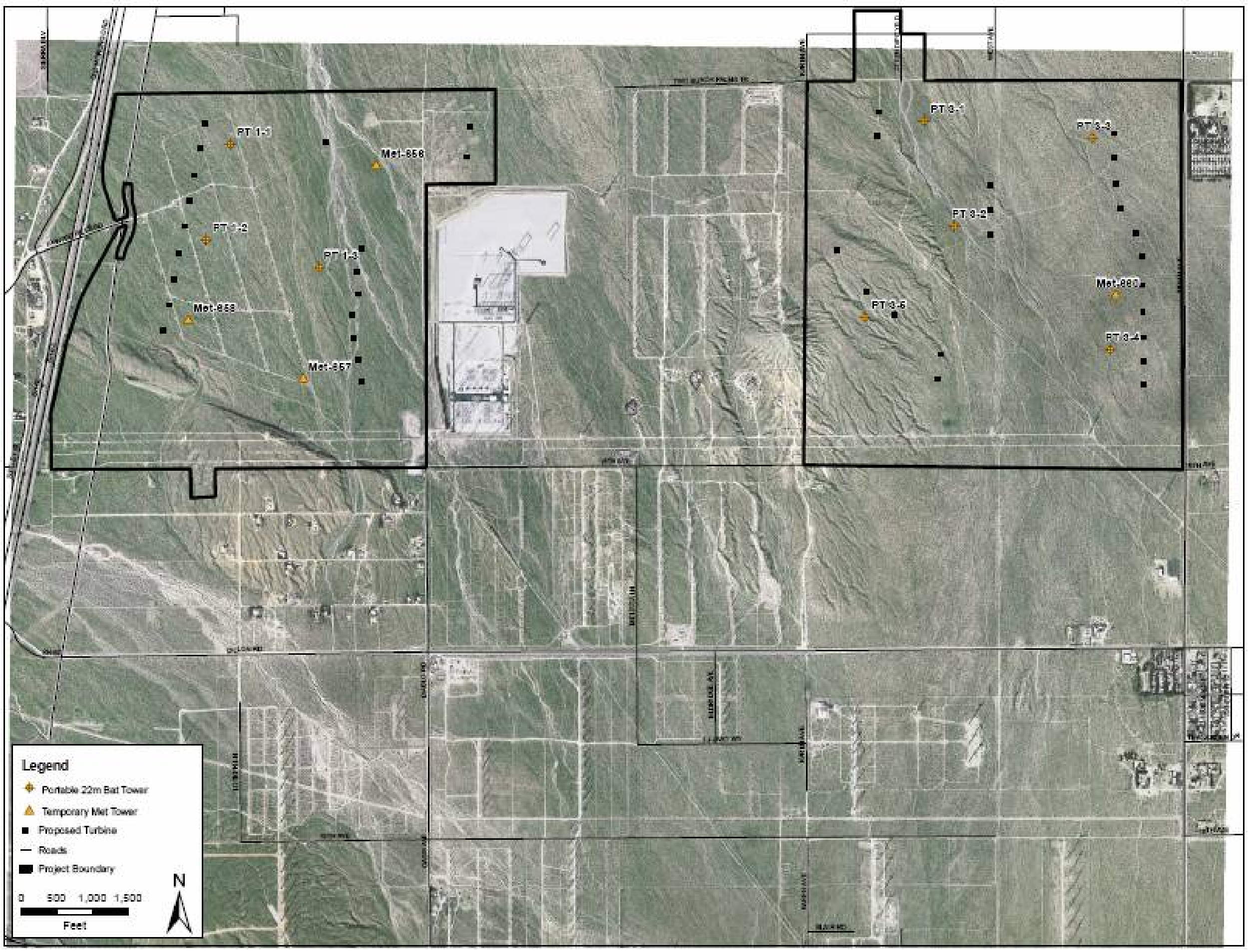


Figure 1. Aerial view of the Dillon Wind Project Area in North Palm Springs, California depicting locations of bat echolocation monitoring towers in relation to proposed locations of wind turbines at the site.

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 which had pre-existing meteorological towers that could be equipped with echolocation detection equipment. Secondly, to make the most effective and efficient use of research funds, we sought a site with high probability of construction such that pre-construction 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-to-no 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.

2.2 Monitoring Bat Activity

Bat activity was monitored using ANABAT II echolocation detectors which stored time vs. frequency displays of echolocation calls to compact flash cards (CF cards) via ANABAT storage Z-CAIMs. ANABAT detectors were calibrated relative to one another using the methods of Larsen and Hayes (2000). We randomly selected a detector and set it to a sensitivity of 6. This sensitivity level was chosen based on previous experience and on-site pilot studies which indicated that it represented an appropriate balance between maximizing the number of echolocation detections and minimizing the number of non-bat sounds (e.g., wind, cables striking tower) recorded. The sensitivity of all other detectors were set relative to that of the first randomly selected detector and ranged from 5.9 to 7.3. The only detectors that required sensitivity settings above 6.4 were older detectors (circa 1999) that were employed on the project.

Detector microphones were housed in weather proof casings (a.k.a. bat hats; EME System, 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 direction of the wind, and we assume that data gathered in this direction is representative of bat activity at each location. Microphones were connected via Canare brand electronics cable to bat detection and recording systems were housed on the ground in weather and dust proof containers (Figure 2B). Detectors and ZCAIM units were powered by a 12V battery, recharged daily by a 10W solar panel attached to the tower (Figure 2C). Detectors and ZCAIM were configured to begin monitoring ~ 30 minutes before sunset and continue until ~ 30 minutes after sunrise. Detector systems are capable of cycling on and off and collecting data over this period of time for multiple days unattended. Detector systems were visited approximately weekly to ensure that the systems were operating properly and to download data from CF cards.

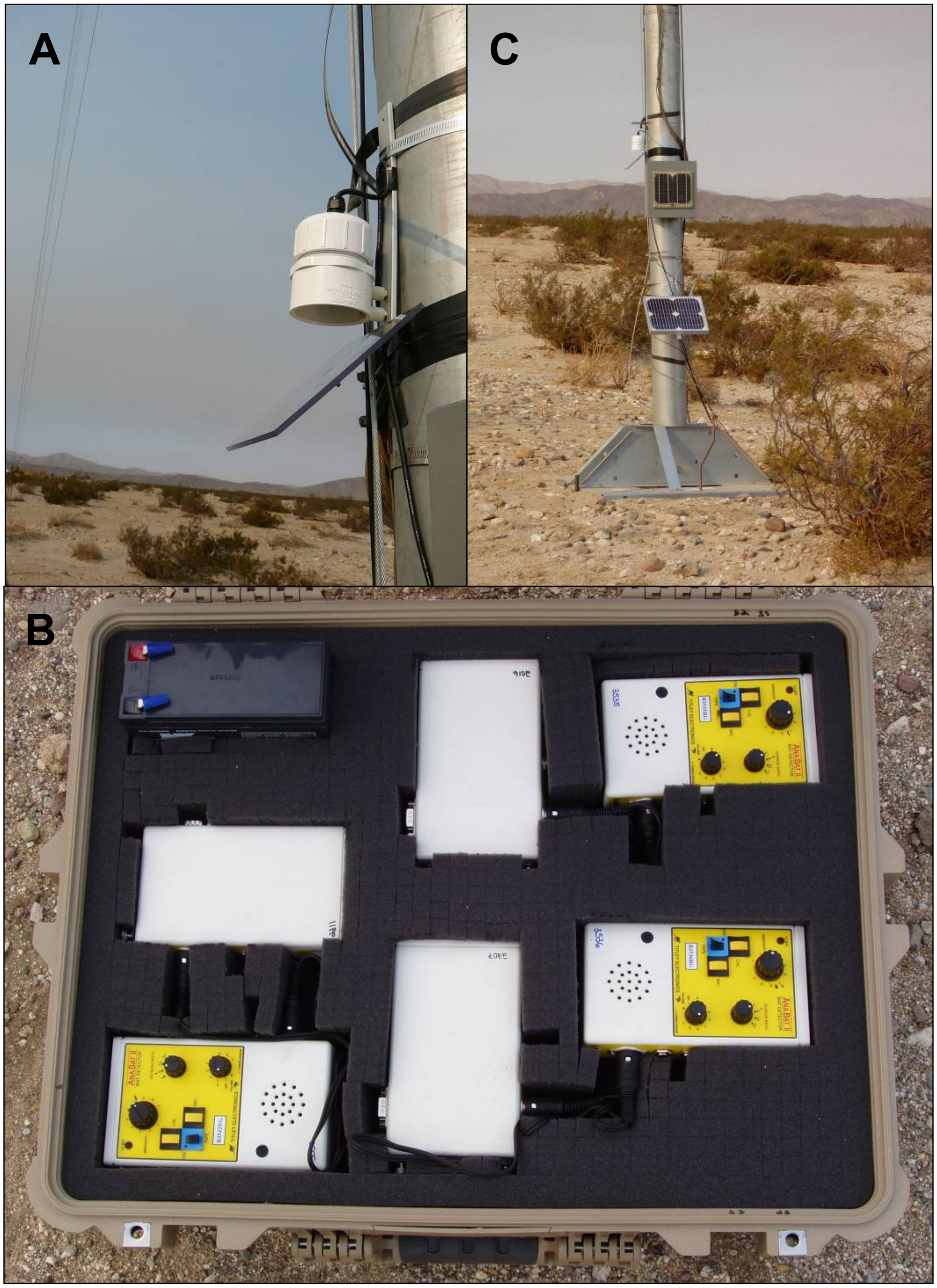


Figure 2. Echolocation detection systems as deployed on meteorological towers at Dillon Wind site in North Palm Springs, California. A) Bat hat attached at 2m, B) ANABAT detectors and Storage Z-CAIMs in element proof container, C) 10 W solar panel used to power system.

2.2.1 Detector Heights

Detector microphones in bat hats were mounted on 4 meteorological towers (MET towers) and 8 portable bat monitoring towers (Figure 1). Locations of 60m 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 m above ground on MET Towers (Figure 3A) during Phase I of this project on October 25-26, 2007. Bat hats were attached to MET towers via the use of a pulley box 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 MET tower.

Bat hats were attached at 2m and 22m above ground on portable bat monitoring towers (Figure 3C; Force12 Inc. Paso Robles, California) during Phase II of this project on December 13-15, 2007. We selected locations for the portable towers 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). We chose the size of the portable towers based on trade-offs between maximum height, cost, and ease of installation on-site. 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).

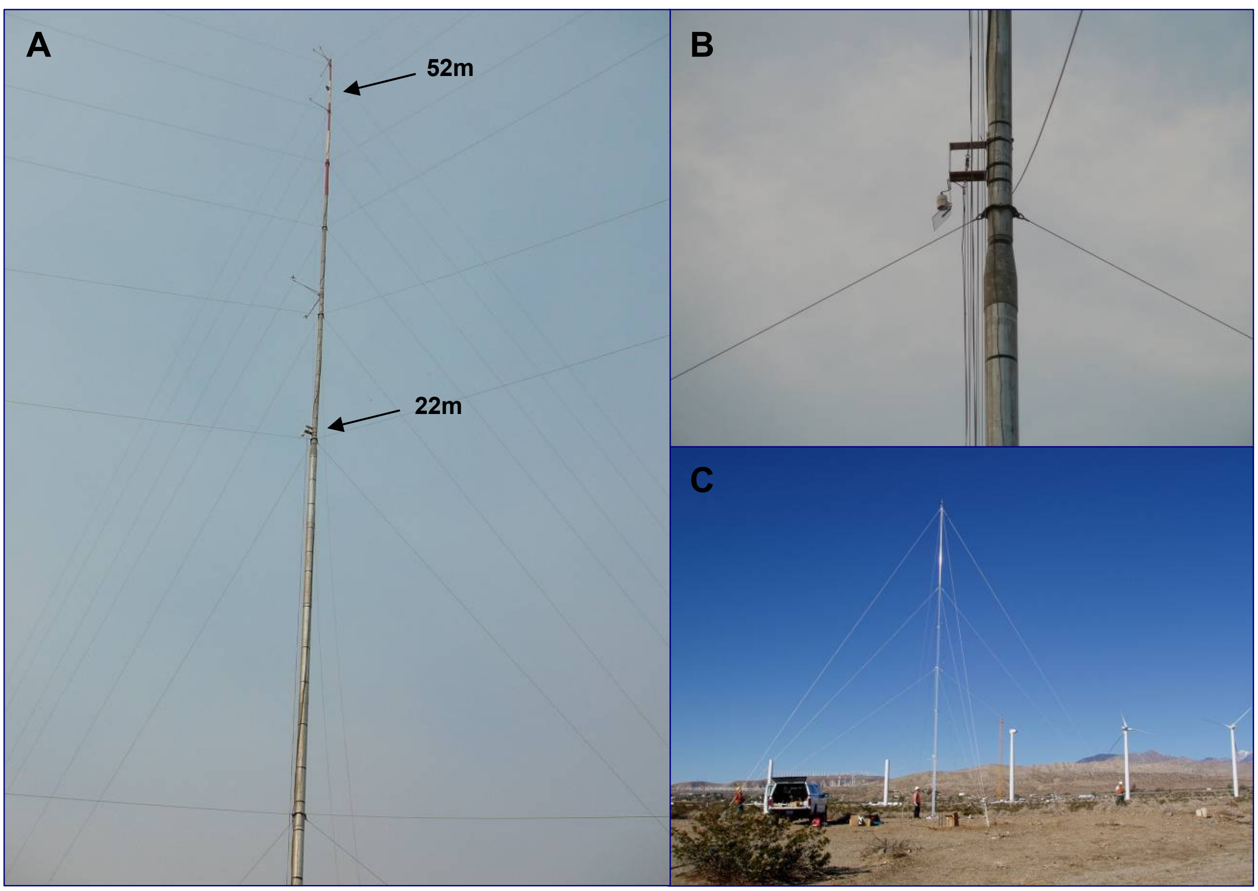


Figure 3. Echolocation detection towers. A) Detector microphones mounted at 22m and 52m on MET tower, B) Detail of pulley system used to position microphones on MET towers, C) Portable bat monitoring tower.

2.2.1 Meteorological Data

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

2.3 Processing Echolocation Data

We defined a bat pass as a series of ≥ 2 echolocation calls each with a duration ≥ 2 ms (Hayes 1997, Weller et al. 2007). We defined bat passes based on tradeoffs between excluding non-bat sounds, which were prevalent on windy nights, and minimizing the number of bat detections that were excluded. We separated potential echolocations by bats 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 at bat/wind energy studies in other regions of the U. S. (Arnett et al. 2006). This filter specifies the minimum length of the body of calls, Bodyover, to be at least 80 μs, minimum frequency ≥18kHz, and Smoothness value of 25. Smoothness refers to distance between successive points before they are considered part of the same call. Because this filter excluded echolocation calls with minimum frequencies <18kHz it may exclude calls from some species in the deserts of Southern California. Therefore we designed a custom filter 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 ≥7kHz, and duration of at least 4 ms. Although this duration exceeded our basic definition for a bat echolocation 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. Each ANABAT file that passed these filters was visually inspected to determine whether it was a bat pass. Bat passes were then further identified as to whether they were produced by high (≥35kHz) or low (<35kHz) echolocating bats, based on their minimum frequency.

2.4 Data Analyses

Data analyses were conducted using echolocation and meteorological data collected from October 25 – December 5, 2007. We used the number of bat files recorded at each height on each met tower as the dependent variable in all analyses.

2.4.1 Modeling Approach

We used Generalized Additive Models (GAMs) to suggest an appropriate form of the relationship between number of bat files 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 PROGRAM R.

We used Generalized Linear Mixed Models (PROC GLIMIXED in SAS) to model patterns of bat files detected with respect to independent variables including Dillon Wind sub-area, MET tower, detector height and meteorological variable. Owing to 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. Meteorological variables included: Mean_Temp - mean air temperature (°C), Mean_Speed_30 - mean wind speed (m/s) measured at 30m and Sin_mean and Cos_mean - two variables to characterize mean nightly wind direction. We selected 9 likely models to explain observed patterns of bat activity based on 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.

We used an information-theoretic approach (Burnham and Anderson 2002) 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. 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 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

We used estimates of means and standard errors from our top-ranked model to predict the means and standard errors for expected number of bat files per night for each height and with the same amount of effort as in the original dataset (*i.e.,* the same number of visits as in the original data set and at the mean values of all of the covariates). That standard error corresponds to what is expected with 4 towers and it is labeled se_4.

From statistical theory, the standard error will change as the reciprocal of the square root of the number of towers, at least for those numbers of towers not too far away from the 4 towers used in this study. Specifically if the standard error expected with a single tower is labeled se_1, then we should have $se_n = \frac{se_1}{\sqrt{n}}$ where *n* is the number of towers. Because we know se_4, 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 $se_n = \frac{2se_4}{\sqrt{n}}$. We used data collected at 4 MET towers from 25 October – 5 December 2007 to estimate the standard error and coefficient of variation that would be achieved with 1 – 12 towers, the 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 between 25 October and 5 December 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 of those nights and on all but one night the number of active echolocation detectors on MET towers exceeded the number of bat files recorded (Figure 4). The mean number of bat files recorded per night in the project area, using all detectors, was 1.69 and the median was 1 bat file per night using all detectors combined. On a per tower basis, the mean number of detections per night ranged from 0.18 – 0.5 and the number of nights with zero detections exceeded the number of nights when bats were detected on every tower (median = 0 for all towers). The maximum number of detections at a single detector location was 4 at the 52m detector on DIL651 on 26 October, 2007.

At most towers there was no clear pattern to heights at which bat echolocations were detected, however at DIL651 there is an indication that more bat detections were recorded at the 52m height (Figure 5).

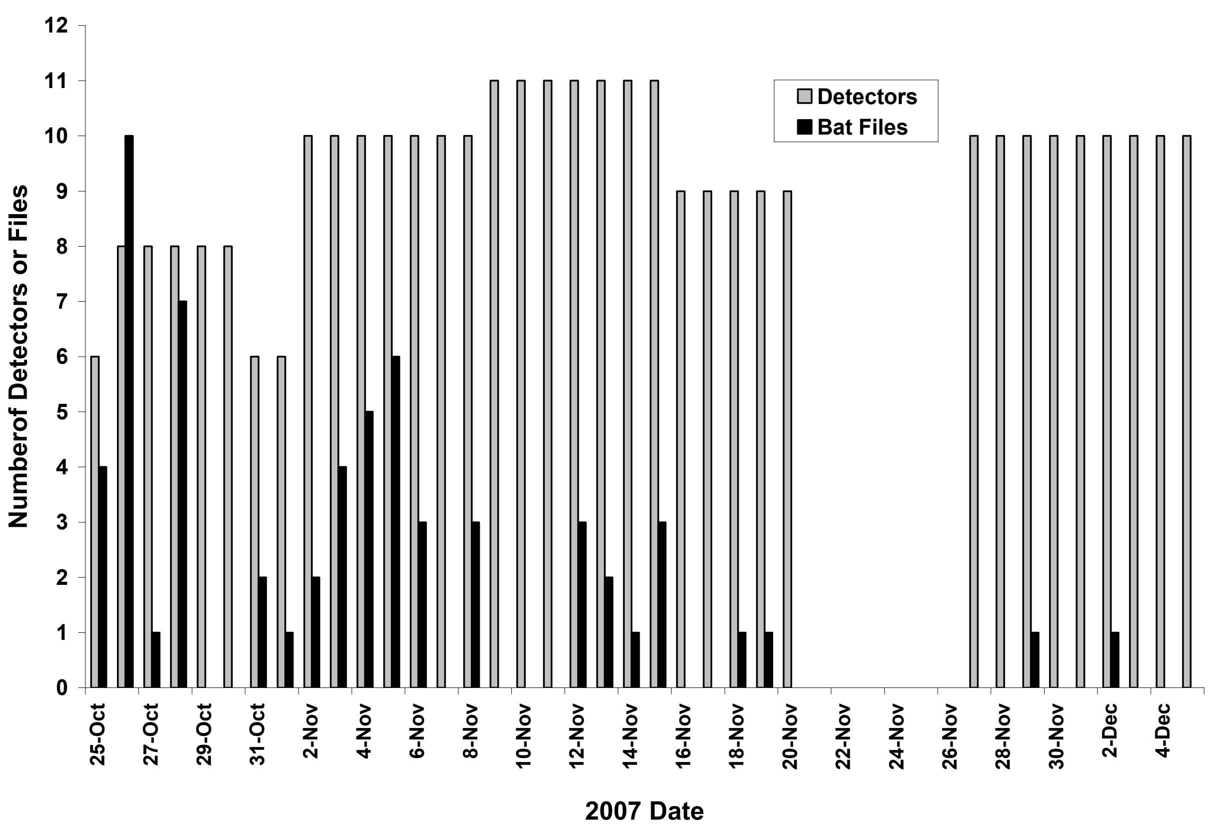


Figure 4. Number of echolocation detectors deployed and total number of bat files recorded from 25 October – 5 December 2007 at the Dillon Wind site, North Palm Springs, California.

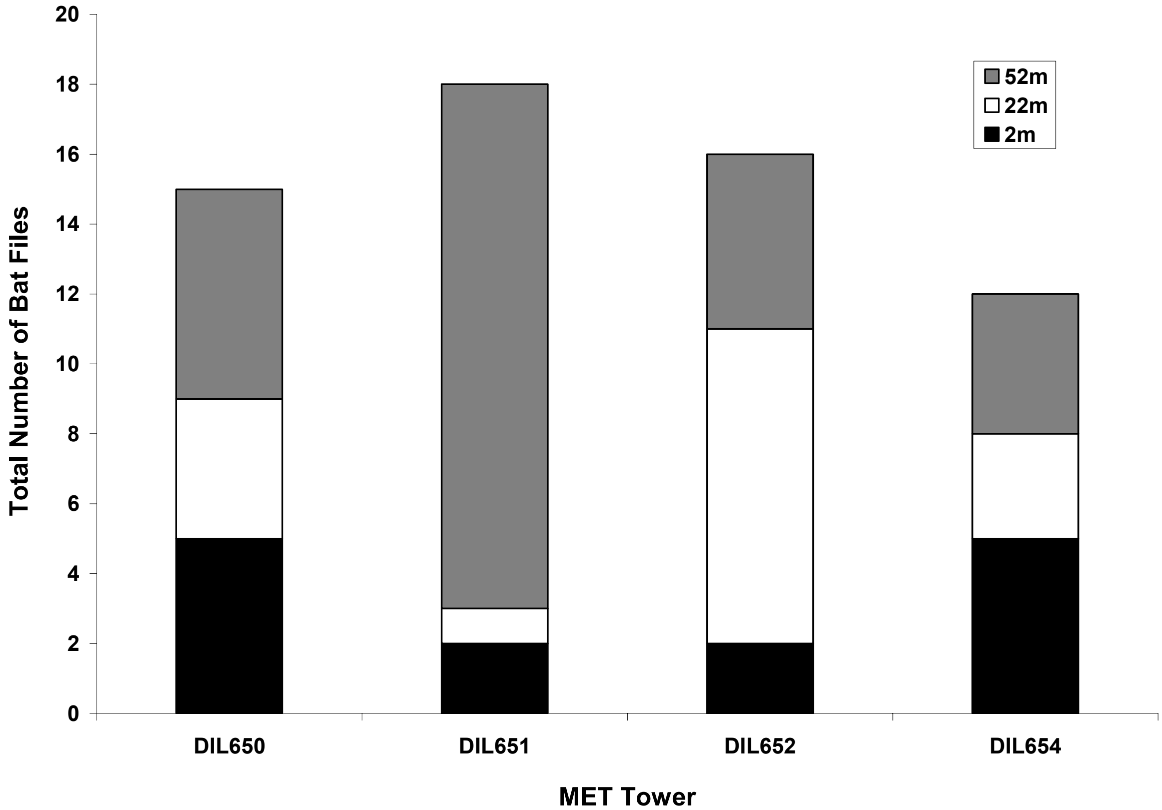
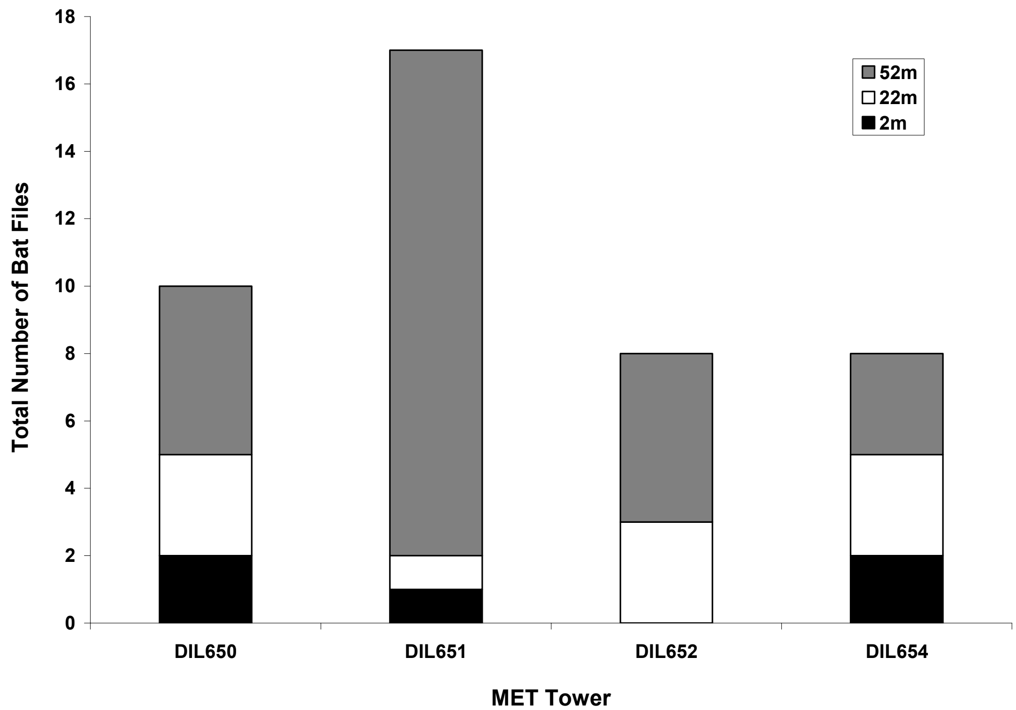


Figure 5. Total number of bat echolocation files, by detector height, recorded at each of 4 MET towers at the Dillon Wind site in North Palm Springs California from 25 October – 5 December, 2007.

Low-frequency bats composed 43 of the 61 echolocation detections recorded. Low frequency bats tended to be recorded more frequently at detectors at 52m than at 2 or 22m (Figure 6A). No MET tower had more than 2 detections of a low frequency bat at the 2m detector over the entire period of operation. Conversely, high frequency bats were infrequently recorded at the 52m detectors, with a single detection of a high frequency bat at 3 of the towers (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 non-linear relationships between any of the meteorological and number of bat files recorded nightly (Figure 8); this is evidenced by mean values of relationships fitting symmetrically between the confidence intervals (Figure 8).



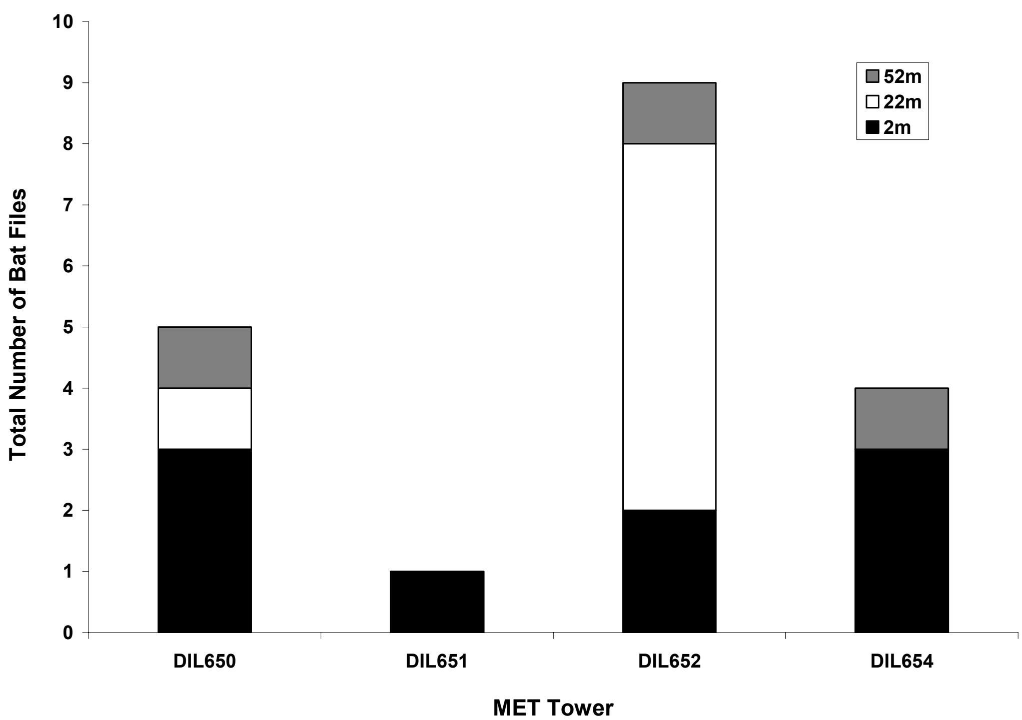


Figure 6. Total number of detections of A) Low-frequency (min. freq. <35kKz) and B) High-frequency (≥35kHz) bats in Dillon Wind project area, 25 October – 5 December 2007.

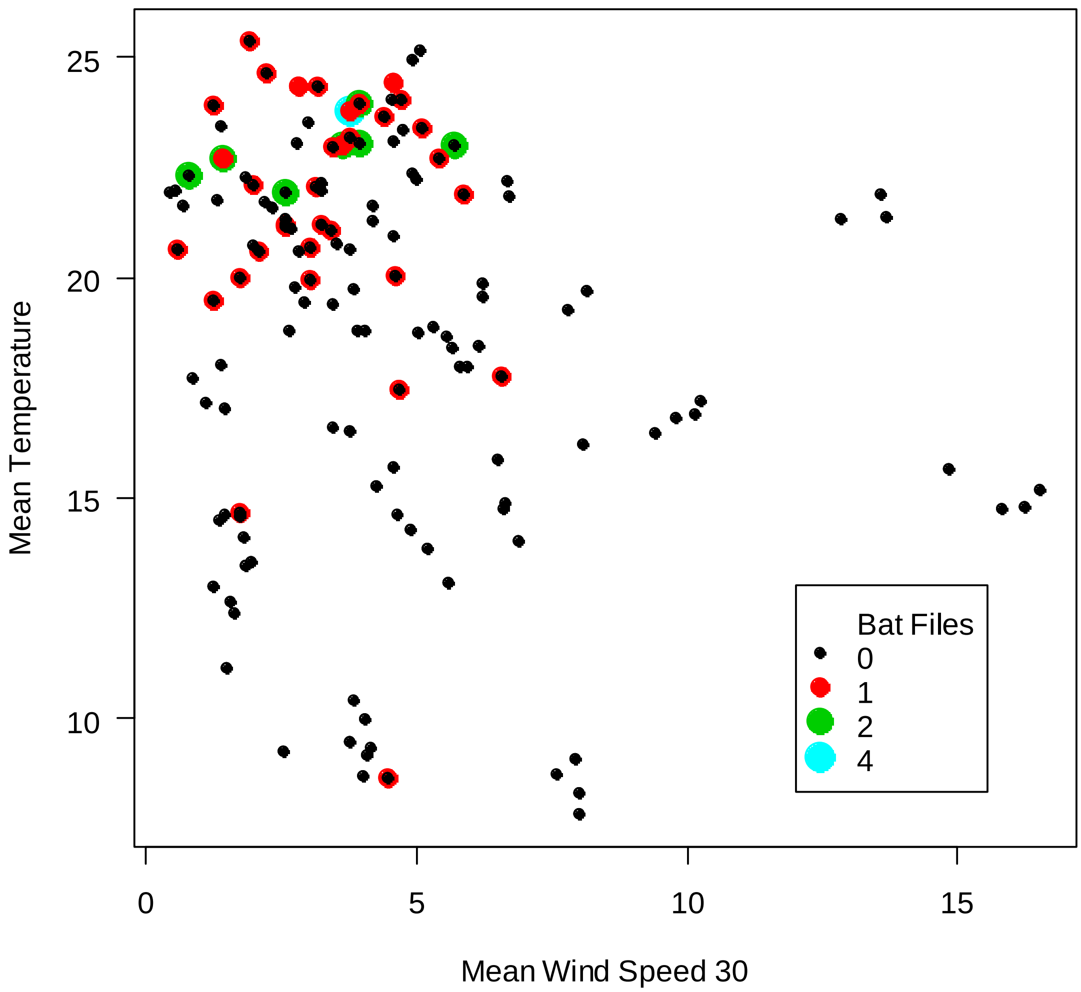


Figure 7. Relationship between mean air temperature, mean wind speed at 30m, and number of echolocation detections at each height on each MET tower at the Dillon Wind site 25 October – 5 December 2007.

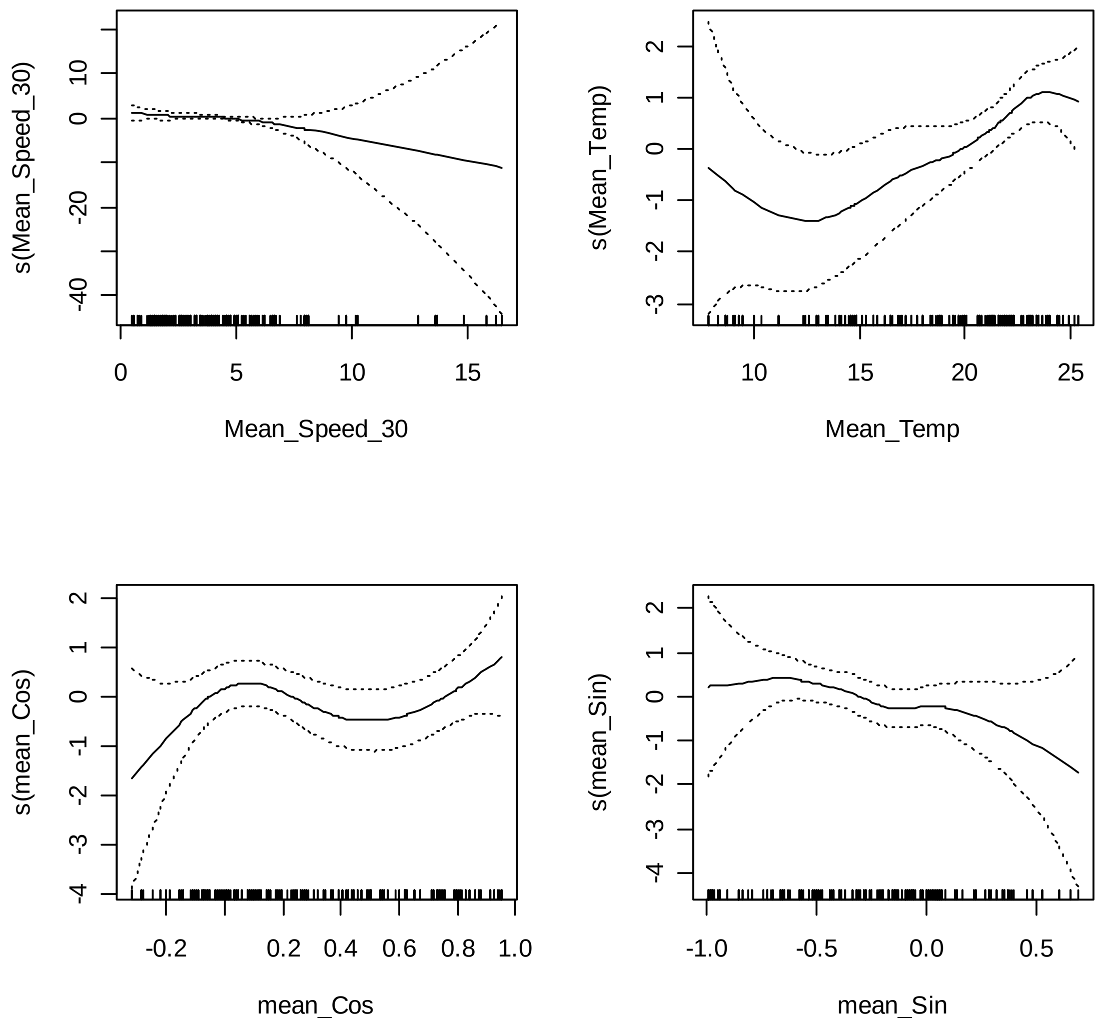


Figure 8. Form of relationships between number of bat files and mean meteorological variables on a nightly basis, as determined from Generalized Additive Models. Dotted lines represent 2 standard deviations around the mean. Mean Speed 30 is wind speed (m/s) at 30 m height, Mean_Temp is air temperature (°C), and mean_Cos and mean_Sin are components describing wind direction.

The top-ranked model for explaining the number of bat files recorded 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 our data and use of wind speed alone has an infinitesimally small chance of being the best model.

We used results from our best model to estimate the number of towers that would be necessary to achieve similarly precise estimates for the mean number of bat files recorded at each height (Table 2). These results show that only small improvements in precision, ≤ 3% as measured using coefficient of variation, would be achieved via the use of more than 4 towers at this site, during this time period. In fact, similarly precise estimates for the mean number of bat files (within 6%) could have been achieved for this dataset using only 3 MET towers. Use of 1-2 towers to measure bat echolocation activity at the site during this time period would produce relatively imprecise estimates (Table 2).

Table 1. Results of model selection procedure to explain number of bat files recorded at each echolocation detector position on a nightly basis. 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; and AIC_c weight Akaike weight of the model

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	- - -

Table 2. Mean number of bat files recorded at each height as estimated from the top-ranked model using data collected from 25 October – 5 December 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%

4.0 Conclusions

The most important result of this project was to demonstrate the methods and analytical methods useful for estimating the amount of bat activity using automated echolocation detectors, linking that data to on-site meteorological conditions, and estimating survey effort necessary to produce precise estimates of activity. Such methods are valuable for evaluating these relationships using larger datasets in additional time periods, including during potential spring and fall migration periods and in other study areas. An array of 26 echolocation detectors has been deployed on 12 towers at 3 heights in the project area. An efficient system for processing large volumes of echolocation and meteorological data is in place which will allow us to efficiently add to the dataset as these units continue to collect data on a daily basis. Finally, this project demonstrated a set of statistical and analytical procedures useful for evaluating relationships between bat echolocation data, detector height, and meteorological data collected. 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 report is based on a sample of data from the Dillon Wind project area during late-fall and early-winter 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 may have altered preliminary conclusions significantly. 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/early winter 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 demonstrates that bat activity is linked to temperature and was collected during the coolest portion of the year; thus bat activity may increase during warmer periods of the year. 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 In Press), though demonstration of such an effect would be difficult at this site because of the limited period of pre-construction echolocation monitoring.

Our models clearly indicated that both mean air temperature (positive) and mean wind speed at 30m (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. Examination of the 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 on bat activity of maximum and minimum values of meteorological variables.

We used the total number of bat files recorded as the dependent variable in all analyses due to the low overall number of files recorded. Future analyses will consider low frequency and high frequency bats separately in terms of the amount and configuration of detectors necessary to precisely estimate activity levels and the meteorological variables that best explain activity patterns. Nevertheless, examination of our raw data indicated that low frequency bats made up the majority of our detections and were detected more frequently at the 52m 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., large number of detections in a single night were not observed) but it is noteworthy that low frequency bats tended to be detected at the highest detector locations even outside migratory periods (Arnett et al. 2006, Redell et al. 2006, Reynolds 2006).

Our analyses indicated that measuring bat activity at 4 MET towers produced reasonably precise estimates for the mean number of bat files recorded at each height in the Dillon Wind project area during late-fall/early winter 2007. The addition of extra towers would have provided little improvement on precision of estimates during this time period. Nevertheless, as specified in our study plan to the Energy Commission, we added an additional 8 towers with detectors at 2 and 22m above ground on December 13 – 15, 2007. Data from these detectors will be used to confirm or refine our precision estimates using data collected beginning 15 December, 2007. If bat activity patterns at other times of the year differ greatly from those observed during late-fall/early winter 2007, this may alter the number of spatial replicates, in the form of towers, needed to produce precise estimates of bat activity.

4.1 Future Steps

This project is scheduled for continuous collection of echolocation and meteorological data at the Dillon Wind site until at least 31 October 2007 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 time period (e.g., month, season) will be included as a covariate in analyses. This will not only allow us to place the amount of bat activity measured during late-fall/early-winter 2007 into an annual context but will also allow re-evaluation of requirements for sample size and detector configuration at other times of the year, as well as a re-evaluation 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 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 work 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.

Similar studies to this one need to be conducted in other areas and habitats throughout the state 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 proposed wind energy developments in California. A review of the methods used to conduct this study will provide a good starting point for design of 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 risk to bats (and birds) in California and throughout the world.

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