Relationships between Bats and Wind Turbines in Pennsylvania and West Virginia:

An Assessment of Fatality Search Protocols, Patterns of Fatality, and Behavioral Interactions with Wind Turbines

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EXECUTIVE SUMMARY

We investigated relationships between bats and wind turbines at the Mountaineer Wind Energy Center in Tucker County, near Thomas, West Virginia, and at the Meyersdale Wind Energy Center in Somerset County near Meyersdale, Pennsylvania. Our primary objectives were to compare results of daily versus weekly carcass searches, quantify bias corrections needed to more accurately estimate fatality, and recommend improved search protocols for bats. We also correlated bat fatalities detected during daily searches with the previous nights' weather and turbine conditions, observed and quantified behavior of bats encountering moving and non-moving blades at turbines with and without FAA lights, and evaluated the use of trained dogs to detect bat fatalities beneath turbines. Fatality searches were conducted at both sites between 31 July and 13 September 2004 with half of the turbines at each site searched daily and the other half weekly. Thermal imaging cameras were used to assess bat, bird, and insect activity at turbines only at Mountaineer from 2–27 August 2004.

Patterns of Bat Fatality

A total of 398 and 262 bat fatalities were found during searches at Mountaineer and Meyersdale, respectively, during the 6-week study period. Six species were killed at Mountaineer and 7 at Meyersdale: hoary bats, eastern red bats, eastern pipistrelles, little brown bats, silver-haired bats, big brown bats, and northern long-eared bats (only found at Meyersdale) were discovered(from highest to lowest number found). More adult male bats were found than juvenile males, adult females, or juvenile female bats.

Bat fatalities were highly variable and periodic throughout the study. Fatalities were distributed across all turbines, although higher than average numbers of bats generally were found at turbines located near an end or center of the string at both sites. Of the 64 turbines studied, one (turbine 11 at Mountaineer) was non-operational throughout the study period and this was the only turbine where no fatalities were found. Timing of all bat fatalities at Mountaineer and Meyersdale was highly correlated, suggesting broader landscape, perhaps regional, patterns dictated by weather and prey abundance/availability or other factors. Although we found more male than female bat fatalities, the timing by sex was similar at both sites. Additionally, fatalities of hoary and eastern red bats were distributed throughout the study period and there was a positive correlation in the timing of fatality for these two species at both sites. Bat fatalities were not different between turbines equipped with FAA lights and those that were unlit at both sites.

The majority of bats were killed on low wind nights when power production appeared insubstantial, but turbine blades were still moving, often times at or close to full operational speed (17 rpm). Fatalities tended to increase just before and after the passage of storm fronts. These relationships were consistent between the two sites.

Estimates of Total Bat Fatality

Estimates of total fatality were derived from the number of bat carcasses found, adjusting these numbers for searcher efficiency and removal of carcasses by scavengers, and amount of area searched. The overall, average searcher efficiency for bat carcasses was estimated to be 44 and 25% at Mountaineer and Meyersdale, respectively, for all trials and habitats combined. Searcher efficiency was highest on bare ground and declined rapidly as height and density of vegetation increased. The highest rates of searcher efficiency were estimated within 10 m of the turbines at both sites (64 and 63% at Mountaineer and Meyersdale, respectively) because much of this area is bare ground. Searcher efficiency was variable >10 m away from turbines, but was lower because this area contained more low visibility habitat. Searcher efficiency also was highest within 1 m of the transect line, and detection of carcasses placed further than 3.0 m from the transect line dropped significantly. Scavenger removal rates were very different between the two study sites. At Mountaineer, 24% of bats that were killed the previous night and then left where they fell for trials were removed on the same day the trial started, and 70% of these bats were removed within 24 hr. Bat carcasses placed in high visibility habitats at Mountaineer were removed at nearly twice the rate in the first 24 hr compared to those placed in low visibility habitats. In contrast, scavenger removal rates were very low at Meyersdale, with only 3% of fresh bat carcasses removed within the first 24 hr and 16% by day 7. Fresh bat carcasses were removed faster than frozen bat carcasses, and frozen bat carcasses were removed faster than frozen bird carcasses.

Estimates of total fatality were heavily influenced by the periodicity of bat kills and carcass removal by scavengers, particularly at Mountaineer where estimates from weekly searches were nearly 3 times lower compared to those from daily estimates because of high scavenging and the periodicity in fatality occurrence. Several of the weekly searches were conducted just prior to high fatality nights, yielding lower than the average rates of fatalities. Based on estimates derived from habitat visibility strata, daily searches at Mountaineer yielded an estimated 38 bats killed per turbine for the 6-week study period (90% confidence interval = 31–45) and a daily kill rate of 0.90 bats per turbine. The total number of bats estimated to have been killed by the 44 turbines just during this 6-week period was 1,364–1,980. At Meyersdale, an estimated 25 bats were killed per turbine based on daily searches during the 6-week study (90% confidence interval = 20–33), yielding a daily kill rate of 0.60 and a total of 400–660 bats killed by the 20 turbines during the 6-week study. Because of low scavenging rates, weekly searches at Meyersdale yielded similar, but slightly higher (1.2 times) results compared to daily searches; an estimated 30 bats killed per turbine during the 6-week study (90% confidence interval = 20–46) and a daily kill rate of 0.71 for a total estimated 400–920 bats killed during the 6-week study.

Thermal Imaging

For 10 nights from 8–24 August, we made a total of 2,398 observations at turbines: 998 bats (41%), 503 insects (20%), 37 birds (1%), and 860 unknown (35%) (Table 3-2). Nightly numbers of bat passes observed at a single turbine were highly variable, with as few as 9 per night and as many as 291, although we were unable to quantify the total number of bats making passes in video sequences (i.e., one bat could make several passes while foraging). Most bat activity was observed within 2 hr after sunset. There was a significant positive correlation between insect passes and bat passes observed across all nights. Although insect activity was somewhat higher at turbines with FAA lights, aviation lighting did not appear to affect the incidence of foraging bats around turbines and there was no difference between numbers of bat passes at lit and unlit turbines.

Thermal images indicated that bats are attracted to and investigate both moving and non-moving blades. Thermal images of bats attempting to land, or actually landing on stationary blades and turbine masts, suggest possible curiosity about potential roosts or use for gleaning insects. Images of bats chasing turbine blades rotating at slow speeds suggest possible attraction to movement out of curiosity. However, most of the observed collisions (7 of 8) were between bats and fast-moving (17 rpm) turbine blades. Thermal imaging observations of bat and insect activity support the conclusion that fatality occurs primarily on low wind nights, but when blades are pitched into the wind and powered to rotate, which may be at or near their maximum speeds of 17 RPM, despite modest or no power production.

Use of Trained Dogs to Recover Bat Fatalities:

Searcher efficiency trials with dog-handler teams were performed on 3 different days at 4–6 turbines each day at Mountaineer, using a total of 45 trial bats. At Meyersdale, trials were performed on 5 different days at 4–6 turbines each day, with 52 trial bats. Dogs found 71% of the bats randomly placed in searcher efficiency trials at Mountaineer and 81% of those at Meyersdale, compared to 42% and 14% for human searches, respectively. Both the dog-handler team and humans found a high proportion of trial bats within 10 m of the turbine, usually on open ground (88 and 75%, respectively). However, human search efficiency declined as vegetation height and density increased while dog-handler efficiency remained high. The dog-human team consistently found higher proportions (65-100%) of trial carcasses in high, medium, and low visibility habitats at both sites, and 40-50% in extremely low visibility habitats.

Conclusions

Our estimates of bat fatality are among the highest ever reported and support the contention that forested ridges are locations of especially high risk for bat fatality at wind facilities. This study only covered 6 weeks (31 July to September 13) in just one year and is not a measure of full season bat activity, behavior, or fatality. Estimated fatality rates from the 6-week period appeared to be as high during the first site visits in mid-July suggesting a significant number of fatalities may have occurred prior to the study, and the fatality rates likely continued at least through September and early October, as is reported by other studies.

Weekly searches at Mountaineer underestimated the fatality rate by nearly a factor of 3. A primary reason for this is that the timing of the weekly fatality searches at Mountaineer tended to occur before the larger fatality events. A better design would have been to search a portion of the turbines each day for 4 days rather than all turbines on one day, thus balancing variation in timing of fatalities. Estimates for daily and weekly searches were similar at Meyersdale primarily because scavenging was very low. Mountaineer began operation one-year earlier than Meyersdale, and we hypothesize that scavenging could change through time at the Meyersdale facility as scavengers learn of a new food source, exhibiting a temporal influence on fatality search protocols. Also, differences in scavenging rates could be a function of species composition of bird and mammal scavengers at the different sites.

There are many possible sources of attraction that may explain bat fatalities. Ultrasound emissions may attract the curiosity of bats, although this hypothesis remains untested. Light sources have been shown to attract insects and therefore bats, but our fatality searches and thermal imaging data indicated no difference in bat fatality or activity at turbines with and without FAA recommended lighting. Bats may be investigating wind turbines to evaluate their potential as roosting sites. We observed bats making several check passes at turbine masts and landing on both the mast and a non-moving blade, lending support for this cause for attraction. This curiosity and investigation behavior would likely increase the probability of a collision with a moving blade over random chance alone. If there are ephemeral, abundant food resources at wind turbine sites, an increase in bats aloft may represent an attempts by both local and transient, migrating bats to take advantage of these resources. The high variation in numbers of both bats and insects that we observed on a nightly basis seems to support this hypothesis. We could not confirm if observed bats were local or migrants, but we often saw bats feeding and foraging around and in the rotor-swept zone of the turbine blades. Additionally, modifications to the landscape to construct the wind farm, including creating open space around turbines and the access road, may create favorable foraging habitats for both local and migratory bats.

Another significant finding of this research is that the distribution of bat activity throughout the night is uneven. We found that higher bat activity occurs in the first two hours after sunset. This observation combined with our findings that weather patterns appear to be predictors of bat activity and fatality, suggests that windows of high risk for collisions may be clearly identifiable with additional longer-term studies. If so, collisions and fatality could be greatly reduced by focusing mitigation efforts on these high-risk times.

Scope and Future Research

This study is the first attempt to observe and interpret bat behavior in the rotor-sweep zone of operating turbines in an effort to shed light on why and how collisions and fatality occur. The study only covered 6 weeks (31 July to September 13) in just one year and is not a measure of full season bat activity, behavior, or fatality. Unusually cool summer temperatures and passage of 4 major hurricanes in August may have influenced bat activity on ridges. Low temperatures are known to suppress bat and insect activity, particularly at higher elevations. Until a full season of fatality searches are conducted (April-October), it should not be assumed that: 1) fatalities do not occur and/or are biologically insignificant during other periods; 2) the 6-week period we studied includes the peak of fall migration; and 3) that other species of bats, such as Indiana bats, are not being killed at wind facilities during different times of the year. Scavenging rates should not be assumed similar between sites even in close proximity and in similar habitat conditions. Scavenging could be expected to change over time as well.

This study was conducted in two areas located on forested ridges in the Appalachian Mountains and statistical inferences are limited to these sites. However, we believe that our findings reflect an emerging pattern of bat fatality associated with wind turbines located on forested ridges and suggest that similar fatality rates could be expected at sites with comparable forest composition and topography, especially in the eastern U.S.

Results from this study suggest the following research needs:

- Conduct extensive post-construction fatality searches for a "full season" of bat movement and activity (April-October) to fully elucidate temporal patterns of fatality.
- Experimentally evaluate the cost effectiveness of "feathered" (i.e., moving slowly, neither powered nor oriented to catch wind) turbine blades at low wind speeds to minimize bat fatality during high risk periods.
- Further investigate the relationship between passage of storm fronts, weather conditions (e.g., wind speed, barometric pressure), turbine blade movement, and bat fatality.
- Conduct post-construction fatality searches at existing wind facilities that encompass a broad range of habitat types and topographic features to further understand patterns of fatality in relation to surrounding landscape context. These data are essential for assessing potential risks at future developments.
- Investigate approaches for making turbines less attractive to bats or for deterring bats.
- Further test the search efficiency and efficacy of using dogs to recover bat fatalities and compare with human searchers.

CHAPTER 1. BACKGROUND and STUDY AREA LOCATION

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Wind has been used to commercially produce energy in North America since the early 1970s and is one of the most rapidly growing sectors of the power industry. Wind turbines are able to generate electricity without many of the negative environmental impacts associated with other energy sources (e.g., air and water pollution, greenhouse gas emissions associated with global warming and climate change), potentially benefiting birds, bats, and many other plant and animal species. However, fatalities of birds and bats occur at wind farms worldwide, including Australia (Hall and Richards 1972), the U.S. and Canada (Erickson et al. 2002, Johnson et al. 2002, 2003, 2005, Nicholson 2003, Fiedler 2004, Kerns and Kerlinger 2004), and northern Europe (Ahlen 2002, 2003).

More than 1,100 species of bats account for nearly a quarter of all mammals, yet they are poorly studied. Many populations have been extirpated or have declined alarmingly. They are exceptionally vulnerable because most rear only one young per year and concentrate in large colonies in caves and other vulnerable locations. Their ecological roles and survival needs often remain undocumented, leading to neglect in conservation planning (Mickleburgh et al. 1992, IUCN 1994, Racey and Entwistle 2003). Because bats are long-lived and have exceptionally low reproductive rates (Kunz 1982), population growth is slow and the ability to recover from population crashes is limited (Racey and Entwistle 2003). Habitat loss and degradation, disturbance and/or loss of roosts, and persecution have contributed greatly to the decline of many species of bats (Kunz 1982, Pierson 1998, Racey and Entwistle 2003). Fatality of bats at wind turbines has been recognized only recently as a major conservation concern. However, cumulative impacts of continued wind energy development could be a critical source of additive mortality in some areas (Tuttle 2004).

Although bats collide with other tall anthropogenic structures, the frequency and number of fatalities is much lower than those observed at wind turbines. For example, Crawford and Baker (1981) reported 54 bat collision victims at a television tower over a 25-year period, while 12 dead hoary bats were discovered at a different television tower over an 18-year period (Zinn and Baker 1979). Similarly, small numbers of bats (≤5) have been killed by colliding with communication towers (Ganier 1962, Avery and Clement 1972, Taylor and Anderson 1973), large buildings (Terres 1956, Timm 1989, Mumford and Whitaker 1982), powerlines (Dedon et al. 1989), and barbed wire fences (Denys 1972, Wisely 1978, Fenton 2001). In contrast, bats are killed by wind turbines with far greater frequency relative to other structures (e.g., Fiedler 2004, Kerns and Kerlinger 2004, Johnson et al. 2005).

Several plausible hypotheses have been proposed to explain why bats are killed by wind turbines (Table 1-1). Bat fatality appears to be higher during late summer and fall when bats begin autumn migration (Fleming and Eby 2003) and migratory species (e.g., hoary bat, red bat, and silver-haired bat) comprise the majority of fatalities at all wind farms studied to date (e.g., Erickson et al. 2002, Kerns and Kerlinger 2004, Johnson et al. 2005, this report). If migratory species use linear corridors (Humphrey and Cope 1976, Timm 1989), wind farms located on ridges, or where corridors are created in forests, then bat fatalities may increase during migration or while foraging. If migrating bats do not echolocate they could fly directly into turbines without detecting them, but there is no evidence to support this. Other logical hypotheses center on visual or acoustic attraction or failure by bats to detect turbines (Table 1-1). All of these hypotheses lack empirical data and warrant further investigation.

Although bat fatalities have been recorded either anecdotally or formally at almost every wind farm where post-construction surveys have been conducted, efforts to specifically estimate bat fatality rates are rare. Prior to 2004, only 11 monitoring efforts had attempted to estimate fatalities, and only 6 were conducted specifically to evaluate bat fatality (Greg Johnson, Western Ecosystems Technology, unpublished data). Additionally, only 4 studies have used bat carcasses in searcher efficiency and scavenger removal trials to develop bias corrections. The remaining studies either used birds as surrogates or did not conduct bias correction trials (Greg Johnson, Western Ecosystems Technology, unpublished data).

Estimates of bat fatalities vary considerably reflecting region of study, habitat conditions, sampling interval, and bias correction. Bat fatalities may be relatively low at wind energy

Table 1-1. A list and general description of hypotheses regarding possible mechanisms of bat attraction to or failure to detect wind turbines (modified from Kunz et al., in prep).

Hypothesis	Description of hypothesis
Linear corridor hypothesis	Many species of bats (especially red and hoary bats) are known to use linear corridors during migration and while foraging. Wind farms in forested regions can be developed along natural corridors such as ridge tops or corridors are created when access roads are constructed. If bats use such corridors where wind turbines are located, they may increase the chance of collision during migration or while foraging.
Acoustic failure hypothesis.	Either migrating or foraging bats may fail to acoustically detect wind turbines, particularly moving blades. If the smooth cylindrical turbine masts are not detected by echolocating bats, then bats may collide directly with and be killed by these structures during flight. The functional range of echolocation by North American bats typically varies from 3–5 m. Migrating bats flying at a velocity of 5 m/s would have less than a second to respond to a wind turbine.
Visual failure hypothesis	Rotating rotor blades are subject to motion smear, thus making them difficult for organisms to see and respond appropriately. This hypothesis relates more to birds, but bats do use vision and bats may fail to visually detect wind turbine rotor blades.
Roost attraction hypothesis	Bats may be attracted to wind turbines because the tall, white turbine masts are perceived as potential roosts. During migration in late summer and fall, bats seek shelter during the day, following night-time travel. Bats may mistake the large, white turbine masts for potential tree roosts and thus increase their susceptibility to collision at turbines.
Light attraction hypothesis	Bats may be attracted to the lights placed on wind turbines. Currently, these lights range from red lights or stroboscopic lights placed on alternative turbines, as recommended by the Federal Aviation Administration.
Acoustic attraction hypothesis	Bats may be attracted to sounds (audible and/or ultrasonic) produced by wind turbines. The uniform constant sounds made by the turbine generator and/or the variable “swishing” sounds made by rotating blades may attract bats and increase their risk of collision.

TABLE 1. Continued.

Motion attraction hypothesis	Curious bats may be attracted to the movement of rotating turbine blades. By investigating the moving blades, bats increase their risk of collision.
Insect concentration hypothesis	Flying insects rise in altitude with warm daily air masses and may become concentrated, particularly along ridge tops on certain nights. If the activity of migrating and locally foraging bats increases in response to high insect concentrations they increase their exposure to turbines and possible collision.
Insect attraction hypothesis.	Flying insects may be attracted to the white turbine masts at night and then get trapped in the downstream wake of the rotors. Bats respond to these concentrations of insects in the wake and collide with the turbine in the process of feeding.

facilities in open prairie and farmland of the upper Midwestern and western U.S. ($\leq$3 bat fatalities/turbine for the period of study; Erickson et al. 2002, Johnson et al. 2005). Recent studies conducted at two eastern U.S. wind facilities located on forested ridge and mountain tops reported large numbers of bat fatalities (Nicholson 2003, Fiedler 2004, Kerns and Kerlinger 2004). The latter findings have heightened awareness and sparked criticism relative to bat fatalities at wind farms. The estimated average of 2,092 (range = 1,398–4,032) bats killed between 4 April and 11 November 2003 at Mountaineer in West Virginia (Kerns and Kerlinger 2004) surprised government agencies, academics, researchers, and industry, leading to an immediate call for action to identify the problems and develop potential solutions.

Collaboration to Find a Solution. Following the report from the 2003 study at Mountaineer, representatives from the American Wind Energy Association (AWEA), Bat Conservation International (BCI), the U.S. Department of Energy's National Renewable Energy Laboratory (NREL), and the U.S. Fish and Wildlife Service (USFWS) met in late 2003 and agreed to embark on collaborative efforts to further understand causes of bat fatalities at wind facilities and work toward developing solutions. A two-day "Bats and Wind Power Generation Technical Workshop" was organized by BCI and the USFWS and hosted by Florida Power and Light (FPL) Energy in Juno Beach, Florida on 19–20 February 2004. The workshop brought together leading experts on bat ecology, radar and thermal imaging technology, and avian acoustical monitoring from the United States, Canada, and the United Kingdom, as well as representatives from the U.S. Department of Energy, the USFWS, the U.S. Forest Service, the U.S. Bureau of Land Management, state agencies, and private industry (proceedings available at http://www.batcon.org/wind/). Invited experts were asked to address the following questions:

- What are the problems associated with bats and wind turbines?
- What are the most significant knowledge gaps for understanding the underlying causes of the problems with bats and wind turbines?
- What tools and technologies (e.g., radar, thermal imaging, acoustic) would be most helpful in developing a better understanding of bat-turbine interactions and quantifying the magnitude of the problem?
- What actions are needed to address the problems and near term priorities?

Experts concluded that causes and solutions would be extremely difficult to identify without more reliable information about 1) bat migration; 2) bat interactions with turbines, particularly their responses to moving versus non-moving blades and how they are being killed; 3) patterns of fatality in relation to location, topography, weather, and turbine characteristics; and 4) potential deterrents and/or avoidance mechanisms. The highest immediate field research related priorities recommended by this expert panel included:

- Conducting daily fatality searches to begin elucidating patterns of fatality in relation to location, topography, weather, and turbine characteristics.
- Developing and testing post-construction carcass search protocols.
- Observing interactions and collisions with turbines.
- Measuring acoustic emissions of turbines.
- Experimentally testing shutting off turbines (i.e., feathering and free-wheeling).
- Correlating acoustic and thermal imaging data.
- Necropsy bat carcasses to determine causes of death.

AWEA, BCI, NREL, and the USFWS collaborated to form the Bats and Wind Energy Cooperative (BWEC) to conduct research needed to correlate patterns of fatality, identify possible causal mechanisms, and develop and test solutions to prevent or minimize bat fatality at wind farms (see http://www.batcon.org/wind/). Based on the recommendations of its experts, the BWEC under took field research during the summer of 2004 to improve carcass search protocols and observe bat interactions with turbines. We focused on the Mountaineer facility in West Virginia because of baseline work conducted there in 2003 (Kerns and Kerlinger 2004) and the support for research by the landowner and lessee, FPL Energy. Additionally, FPL Energy provided funding for a complimentary study at their Meyersdale Wind Energy Center in Pennsylvania. The survey protocol used at Mountaineer in 2003 was originally designed to monitor avian fatality rates and was weak in regard to estimating bat fatality. Criticism of the 2003 protocol focused primarily on field sampling biases (e.g., small sample sizes, poor accounting for carcass removal by scavengers and searcher efficiency, absence of searches in early August, and failure to account for detectability among habitats) that may bias number of fatalities reported.

This report presents findings from research sponsored by the BWEC during the 2004 field season. Our primary objectives were to 1) conduct daily and weekly carcass searches to evaluate search interval and improve quantification of bias corrections for searcher efficiency and scavenger removal of bats; 2) account for differences in bias corrections among different habitat conditions; 3) develop recommendations for improving and standardizing fatality search protocols for bats at turbines; and 4) observe and quantify behavioral interactions of bats encountering both moving and non-moving turbine blades. We also: a) correlated bat fatalities collected during daily searches with the previous nights' weather and turbine conditions; b) quantified bat and insect activity in relation to weather conditions; c) quantified insect aggregations at turbines; and d) evaluated the use of trained dogs to recover bat fatalities at turbines. Below, we describe the study areas for all aspects of this research. The chapters that follow present methods, results, and discussion for individual components of the study. The last chapter addresses the scope and limitations of the research and discusses future information needs. Appendices provide data forms used, miscellaneous photographs, and tables of raw data.

STUDY AREAS

Turbines

The wind turbines installed at both study sites are Neg Micon 72C 1.5 megawatt turbines. Each turbine has a rotor-swept diameter of 72 m. Turbines at the Mountaineer Wind Energy Center have masts that are 69.5 m (228 ft) tall from the ground to the center of the nacelle and 104.5 m (343 ft) in total height from the ground to the top of the rotor-swept area. At the Meyersdale Wind Energy Center, the turbine masts are 80 m (262 ft) tall from the ground to the center of the nacelle and 115 m (377 ft) in total height from the ground to the top of the rotor-swept area. The turbine blades can turn up to 17 revolutions per minute (RPM) achieving tip speeds >62.5 m/s (140 mph). These turbines operate at wind speeds up to 24.6 m/s (55 mph), but are programmed not to exceed this speed to avoid mechanical damage. The turbine "cut-in" speed (speed at which the turbine generator begins making electricity) is 4 m/s (~9 mph) and the blades will move at their maximum speed of 17 rpm thereafter. However, the turbine blades also can rotate up to 17 RPM at wind speed <4 m/s without generating power (Dan Mandli, FPL Energy, pers. commun.).

Approximately one-third of turbines at each site are lit with L-864 red strobes at the top of the nacelle, per Federal Aviation Administration (FAA) recommendations. Each turbine is equipped with a digital anemometer that continuously records wind and weather data.

Wind Facilities

The Mountaineer and Meyersdale Wind Energy Centers are located along the Appalachian plateau approximately 90 km from each other (Figure 1-1). The Mountaineer facility began operation on 20 December 2002, and consists of 44 turbines and 2 meteorological towers in Tucker County, near Thomas, West Virginia (Figure 1-2). The turbines are arrayed linearly along the crest of the ridge of Backbone Mountain at an average elevation of approximately 1,025 m from just south of the Maryland border to a site 8.8 km south of where Route 219 crosses Backbone Mountain (Figure 1-2). Twelve of the turbines are lit with two pairs of FAA recommended lights at this site. This facility lies within the Appalachian mixed mesophytic forests ecoregion and encompasses the moist broadleaf forests that cover the plateaus and rolling hills west of the Appalachian Mountains. Turbines at the north end of the string lie adjacent to the Monongahela National Forest.

The Meyersdale facility began operation exactly one year later than Mountaineer on 20 December 2003. The site consists of 20 turbines and 2 meteorological towers and is located in the Laurel Highlands in Somerset County approximately 2 km east of Meyersdale, Pennsylvania (Figures 1-1 and 1-3). Turbines at the Meyersdale facility are arrayed in a linear 4-km string along the crest of the ridgeline to the prominent ridge of Allegheny Mountain at 800–885 m (Figure 1-3). Six of the turbines at Meyersdale are lit with one pair of recommended FAA lights. This facility also lies within the Appalachian mixed mesophytic forests ecoregion. Turbines at both sites are located in forest clearings, and a gravel road connects the string of turbines making access relatively easy (Figure 1-4).

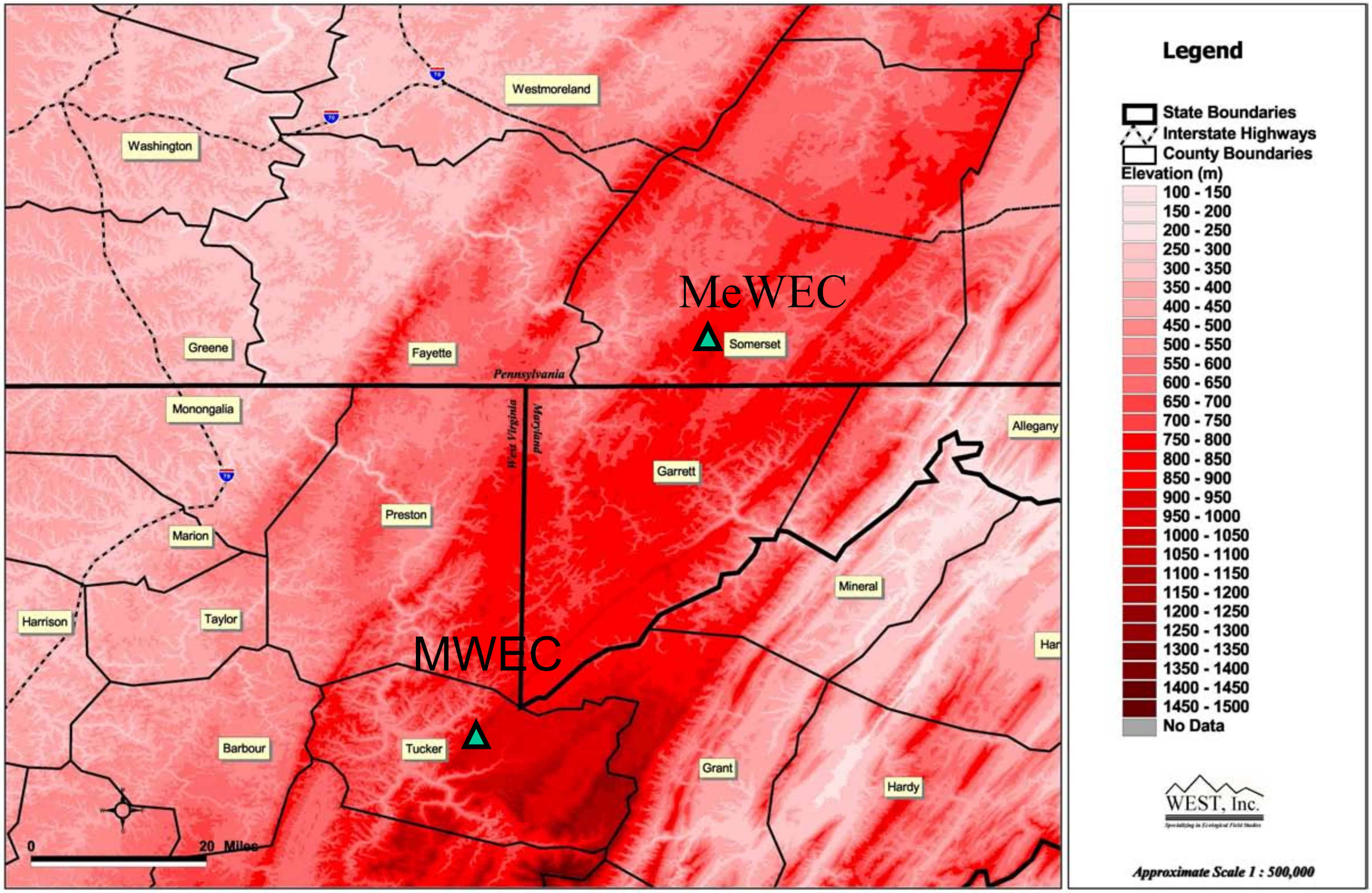

Figure 1-1. Location of the Mountaineer Wind Energy Center in Tucker County, West Virginia, and the Meyersdale Wind Energy Center located in Somerset County, Pennsylvania. Both sites are on the Appalachian Plateau.

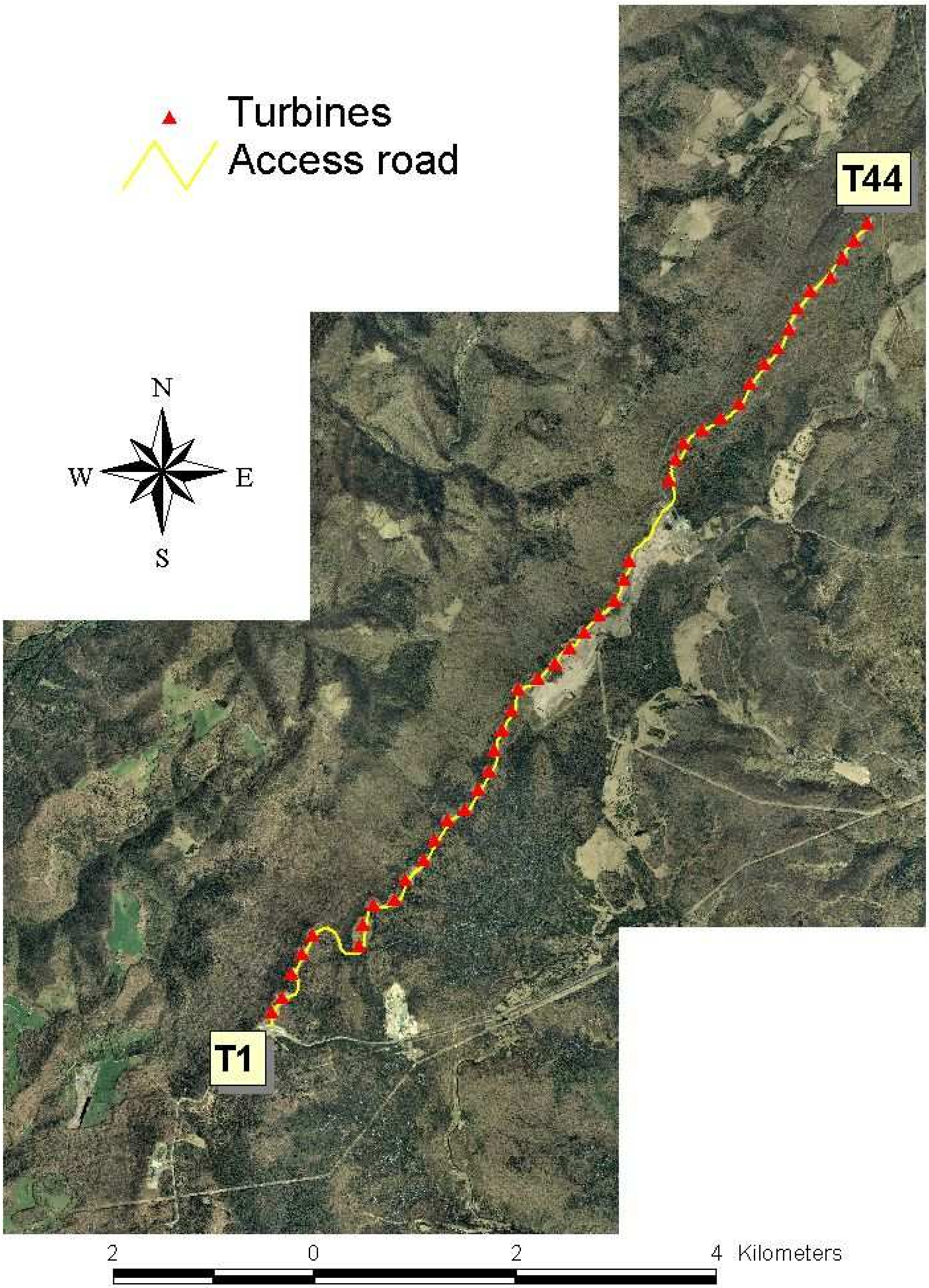

Figure 1-2. Aerial ortho-photo (scale = 1:24,000) depicting the location of turbines at the Mountaineer Wind Energy Center, Tucker County, West Virginia.

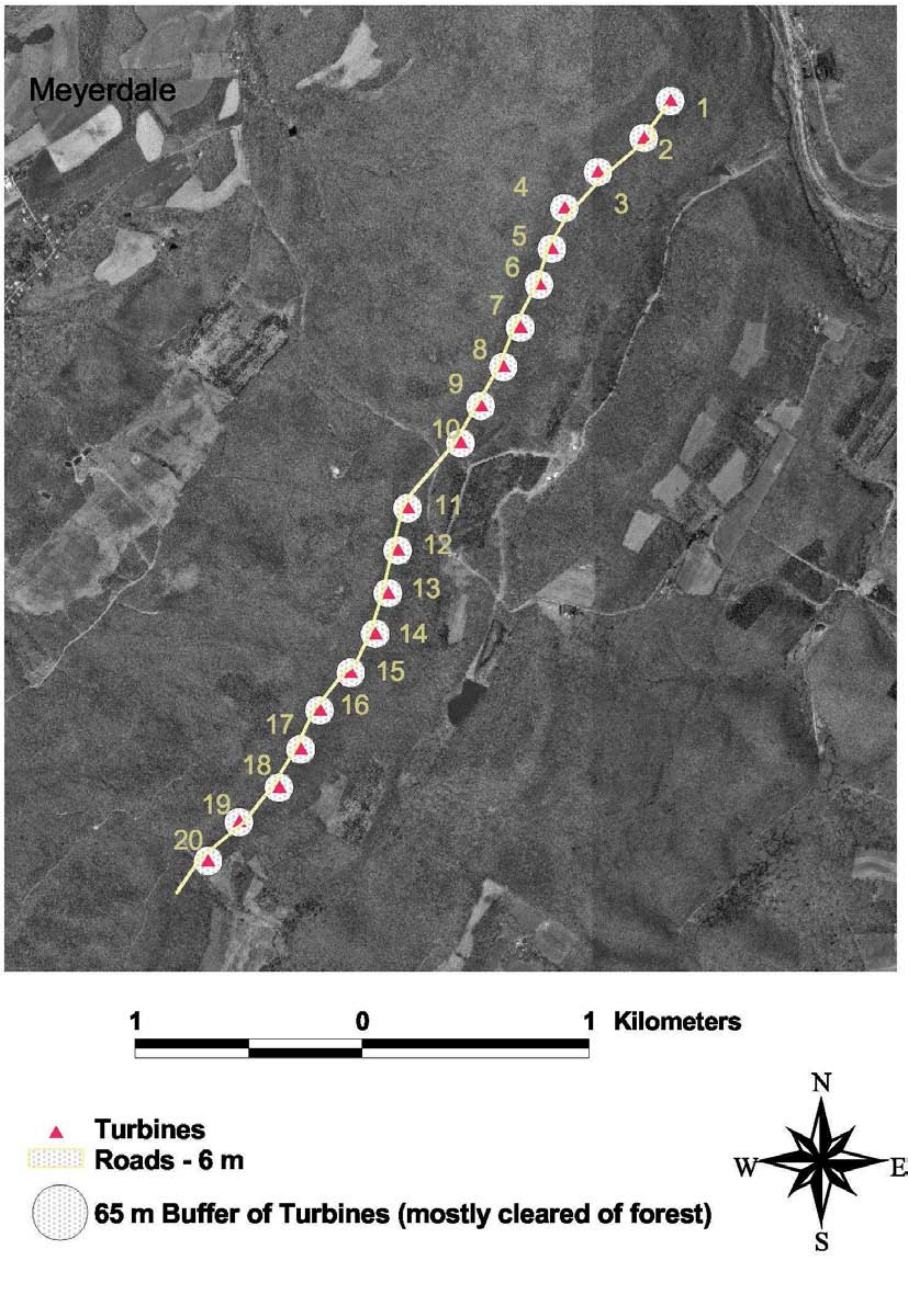

Figure 1-3. Aerial ortho-photo (scale = 1:24,000) depicting the location of turbines at the Meyersdale Wind Energy Center, Somerset County, Pennsylvania.

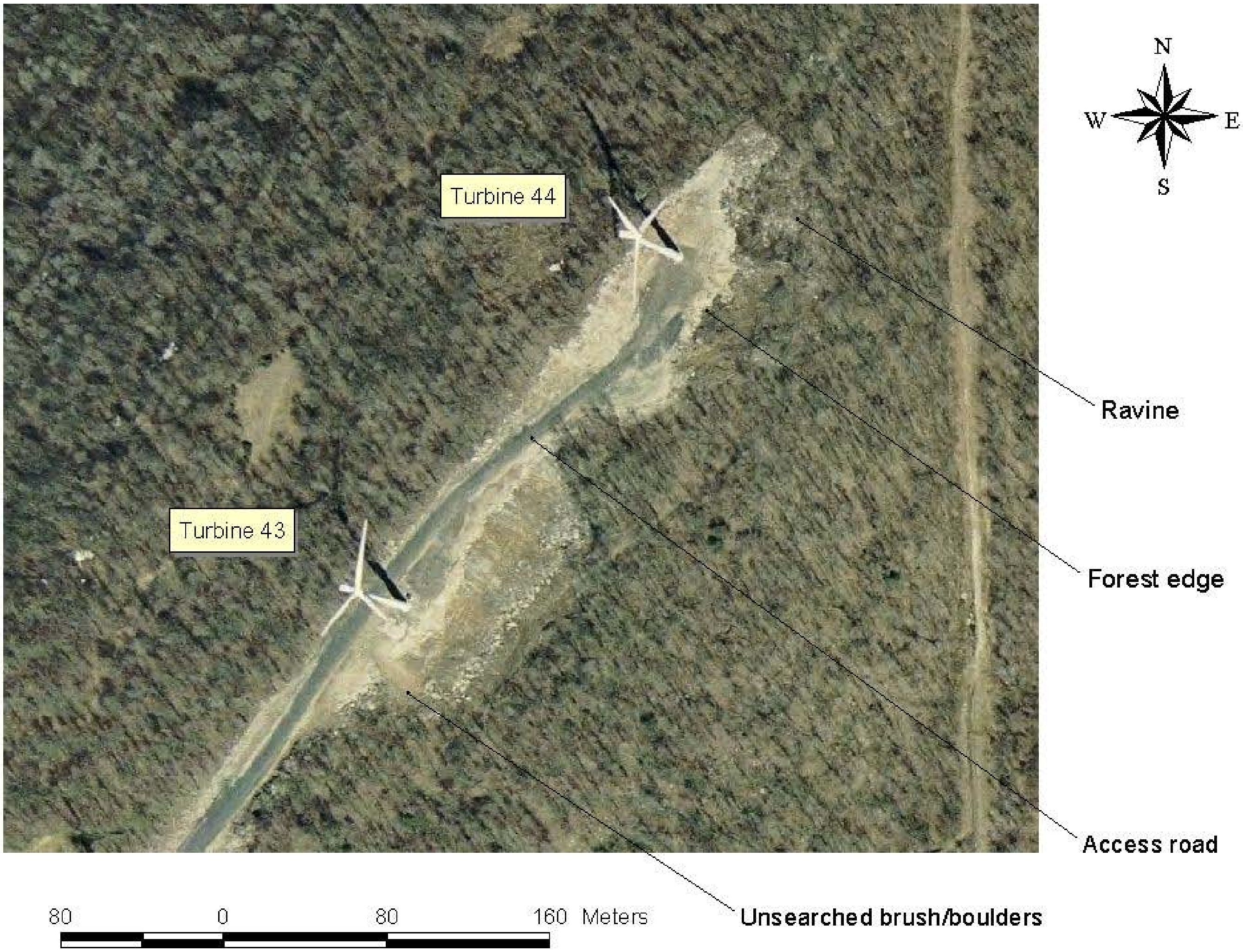

Figure 1-4. Aerial ortho-photo depicting the "footprint" surrounding turbines 43 and 44 at the Mountaineer Wind Energy Center. Contractors attempted to clear even circles around each turbine and each permanent meteorological tower at both sites, but site-specific conditions (i.e., grading requirements) sometimes altered that pattern, as depicted above.

CHAPTER 2. BAT AND BIRD FATALITY AT WIND ENERGY FACILITIES IN PENNSYLVANIA AND WEST VIRGINIA

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Post-construction monitoring studies have provided much of the available information on bat fatalities at wind farms. Originally designed to monitor annual or seasonal bird fatality rates, current post-construction fatality monitoring protocols have been criticized for several reasons. Search intervals often are infrequent (e.g., 7–30 day intervals), and there have been few bat scavenging bias trials, resulting in potentially imprecise and inaccurate estimates of fatality rates for bats. While the statistical properties for at least some common estimators have been evaluated and suggested to be unbiased or close to unbiased under the assumptions of the simulations (Barnard 2000, Schoenfeld 2004, W. P. Erickson, Western Ecosystems Technology, unpublished data), important field-sampling biases warrant further investigation. Important sources of bias include 1) fatalities that occur on a highly periodic basis; 2) carcass removal by scavengers; and 3) searcher efficiency.

In most studies, searches have been conducted on a systematic schedule of days (e.g., every 3, 7, 14, or 30 days). The estimators often used assume fatalities occur at uniformly distributed, independent random times between search days. If the fatality time distribution is instead highly clustered, then estimates may be biased, especially if carcass removal rates are high. Most estimators apply an average daily rate of carcass removal expected during the study. If most fatalities occur immediately after a search, those fatalities would have a longer time to be removed before the next search resulting in higher scavenging rates than the average rate used in the estimates, leading to an underestimate of fatalities. On the other hand, if most fatalities occur before, but close to the next search, the fatality estimate may be an overestimate.

The second source of bias in fatality estimation relates to scavenging and carcass removal. Past experiments to assess carcass removal may not have been representative of scavenging on bats in the field, since many studies used small birds to represent bats. Two studies conducted by Erickson et al. (2003a) and Johnson et al. (2003) used bat carcasses (estimated to be killed the previous night when found) and found similar or lower scavenging rates on bat carcasses compared to small bird carcasses. However, small sample sizes may have biased estimates and limited the scope of inference. Furthermore, scavenging varies from site to site and among habitats. A third source of bias is associated with searcher efficiency, the observer's ability to detect carcasses under a given set of circumstances. Searcher efficiency can vary by many factors, including habitat, observer, and lighting conditions. Estimates of searcher efficiency are required to adjust the number of carcasses found to correct for detection bias.

We present results of an intensive 6-week study at two wind energy facilities in Pennsylvania and West Virginia. Our primary objectives were to: 1) conduct daily and weekly fatality searches to evaluate the influence of search interval on fatality estimates; 2) improve quantification of bias corrections for searcher efficiency and scavenger removal of bats; 3) account for differences in bias corrections among different habitat conditions; 4) develop recommendations for improving and standardizing fatality search protocols for bats at turbines; and; 5) correlate fresh bat fatalities collected daily with weather and turbine characteristics.

FIELD METHODS

Study Sites and Sampling Interval

Carcass searches were performed from 31 July through 11 September 2004 at the Mountaineer Wind Energy Center and from 2 August through 13 September 2004 at the Meyersdale Wind Energy Center. These dates span a period when the highest numbers of bat fatalities have been recorded (e.g., Erickson et al. 2002, Johnson et al. 2003, Nicholson 2003, Kerns and Kerlinger 2004, Johnson et al. 2005). At each site, half of the turbines were sampled daily and the remaining half once each week (i.e., all turbines searched on the same day). To ensure that all turbines were sampled on both daily and weekly intervals, we randomly selected either even or odd numbered turbines to be sampled daily during the first 3 weeks and then sampled weekly during the last 3 weeks of the study. We chose to sample even or odd numbered turbines by assigning "heads" on a coin to even turbines and odd to "tails" and flipping the coin one time for each study site. Consequently, all odd-numbered turbines were searched daily and all even-numbered turbines weekly during the first three weeks of the study at both sites. By contrast, we sampled all even-numbered turbines daily and all odd-numbered turbines weekly during the last three weeks of the study. This systematic random sampling scheme provided interspersion (Hurlbert 1984) of sampling effort among habitat conditions, physical characteristics of turbine locations and characteristics (e.g., lighting). The first "sweep" search (31 July at Mountaineer, 2 August at Meyersdale) was conducted at all turbines to remove as many carcasses that may have accumulated before new searches began.

Delineation of Carcass Search Plots

We centered rectangular plots (130 m east-west by 120 m north-south) on each turbine sampled (Figure 2-1). Studies conducted at other wind energy facilities in indicate that most bat fatalities (>80%) typically are found within ½ the maximum distance from the tip height to the ground (Erickson et al. 2003a, b, Johnson et al. 2003, Young et al. 2003). The tip height for turbines in our study was either 104.5 (Mountaineer) or 115 m (Meyersdale), but the areas cleared of forest varied from approximately 35–100 m from the turbines. At Meyersdale, searches were conducted periodically at the 2-permanent meteorological towers, but were not conducted at those located at Mountaineer.

Habitat Mapping

At both sites, the number of transect lines and length of each line was recorded for each plot, and habitat along each transect line was mapped. For each meter of transect line, we recorded the percent ground cover, height of ground cover (low [<10 cm], medium [11–50 cm], high [>50 cm]), type of habitat (vegetation, brush pile, boulder, etc), and the presence of extreme slope. We collapsed these habitat characteristics into visibility classes that reflected their combined influence on carcass detectability (Table 2-1). We defined visibility classes as high, medium, low, and extremely low at Mountaineer, and high, medium, and low at Meyersdale. Visibility classes were adjusted if the addition of an additional habitat feature altered visibility (e.g., a section of transect line with 11–25% vegetative cover and low height (<10 cm tall) would change from low to medium visibility if a brush pile or slope >25% were added; Table 2-1). Photographs in Appendix I illustrate examples of different habitats and visibility classes.

Transect Searches

Transects at both sites were 10 m apart, yielding a search width of 5 m on each side of the transect line. Searchers walked approximately 13–25 m/min along each transect searching both

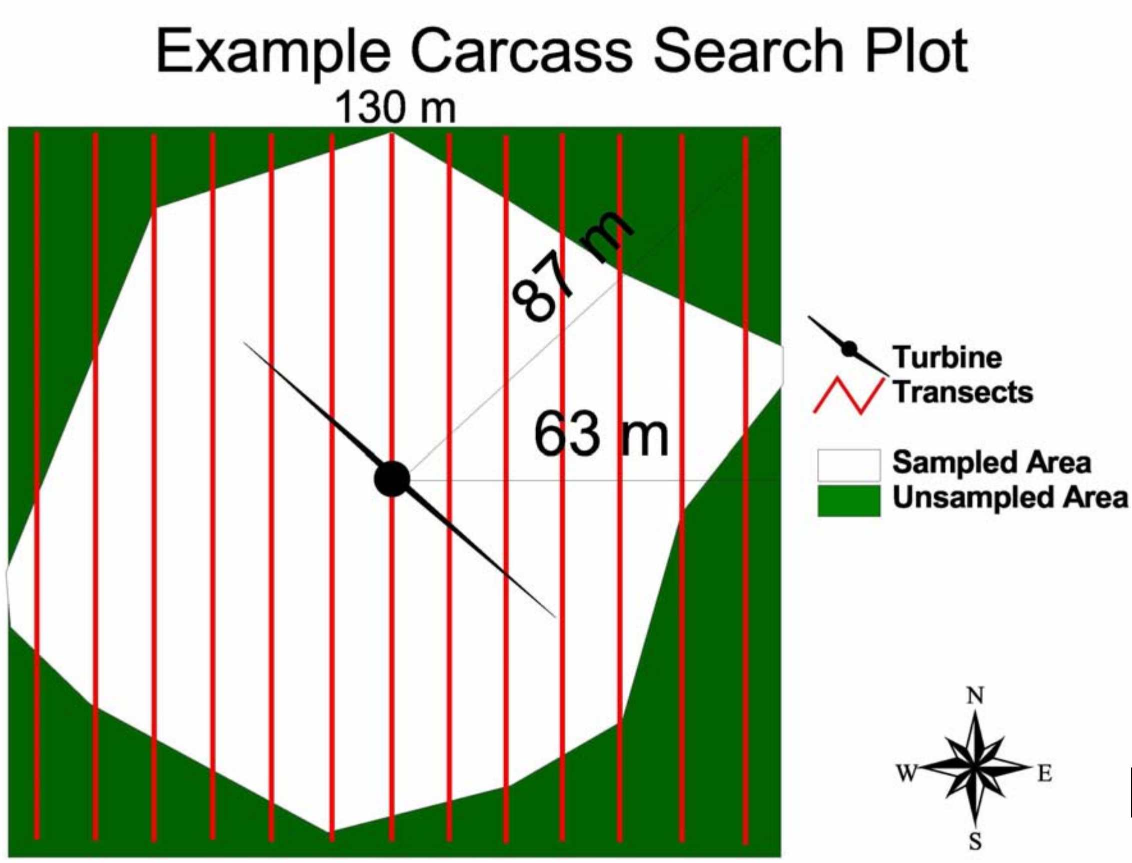


Figure 2-1. Hypothetical carcass search plot at a wind turbine illustrating the maximum plot size (130 m east-west and 120 m north-south) and an example of variable area sampled.

% Vegetative Cover	Vegetation Height	Visibility Class	Visibility Class Change with Addition of Feature (i.e., brush pile, slope >25%)
0, bare ground	-	High	Medium
1-10	L	High	Medium
	M	High	Medium
	H	High	Medium
11-25	L	High	Medium
	M	High	Medium
	H	High	Medium
26-50	L	High	Medium
	M	Medium	Low
	H	Medium	Low
51-75	L	Medium	Low
	M	Low	Extremely Low
	H	Low	Extremely Low
76-99	L	Medium	Low
	M	Extremely Low	Extremely Low
	H	Extremely Low	Extremely Low
100	L	Medium	Low
	M	Extremely Low	Extremely Low
	H	Extremely Low	Extremely Low

Table 2-1. Habitat visibility classification scheme used during this study. Visibility classes were adjusted to the next lower class if slope>25% or brush piles were present within the search area along the transect line being classified.

sides out to 5 m for fatalities. This range of searcher pace was calculated by dividing the total number of meters searched at a given turbine by the average time it took to search the turbine plot. Search speed varied by habitat type and terrain. At Mountaineer, large boulders and extreme slope occasionally prevented searchers from following delineated transect lines. In these cases, searchers took the safest route nearest the transect line and afterwards scanned the impassable area for carcasses. All searches at both sites began at approximately 0630 hr and were completed by 1730 hr. On days when inclement weather forced search crews to halt survey efforts, searches resumed within a few hours or less when weather conditions permitted. Search time per turbine varied from 30–90 min depending on searchable area, habitat type, and terrain. Fatalities found during the search period were flagged and recorded after searching all transects within the plot. All scheduled searches were completed except during the last day of study at Meyersdale (the final survey of all 20 turbines) when, due to an unforeseen safety incident, searches were not completed for turbines 15–20.

While search effort per turbine at both sites was similar, Mountaineer had over twice as many turbines as Meyersdale. Consequently, the number of searchers employed and number of turbines searched per day differed between sites. At Mountaineer, 3 technicians searched the daily sample set of turbines (n = 22, 6–8 turbines/day/person), while at Meyersdale 2 technicians searched the daily set of turbines (n = 10, 5 turbines/day/person). For weekly searches, 6 and 4 technicians were required to complete searches at all turbines one day per week at Mountaineer and Meyersdale, respectively (n = 44 and 20 turbines, respectively). Each searcher recorded date, start time, end time, observer name, wind direction, and turbine operation (operational, stopped, removed for repairs), and any additional observations made at each turbine that he/she searched (see Appendix II).

When a dead bat was encountered, the searcher first recorded the distance from the carcass to the point on the transect line at which the carcass was first observed. The carcass was then flagged with a note card or data sheet and the search was continued. Following the search, we returned to each carcass to record information on a fatality data sheet (Appendix II) including date, time found, species, sex and age (where possible), observer name, identification number of carcass, turbine number, perpendicular distance from the transect line to the carcass, distance from turbine, azimuth from turbine, habitat surrounding carcass, detection type surrounding carcass, condition of carcass (entire, partial, scavenged), probable scavenger of carcass (if scavenged), cause of death/visible injuries (where possible), and estimated time of death (e.g., <1 day, <2 days). Rubber gloves or an inverted plastic bag were used to handle carcasses to reduce possible human scent bias for carcasses later used in scavenger removal trials. Carcasses were placed in a plastic bag and labeled. Most fresh carcasses were redistributed on the same day for scavenging trials; others were frozen for future use in searcher efficiency trials. In some cases, fresh fatalities were left in place for scavenging trials. All species of *Myotis* were retained and frozen for later identification to eliminate the possibility of misidentifying an Indiana bat (*Myotis sodalis*), a species listed as endangered under the U.S. Endangered Species Act.

All maintenance personnel and others working at both sites were instructed not to move or otherwise disturb any bat or bird fatality they discovered. Additionally, they were instructed only to disclose the location of such fatalities to the senior researcher on site so as not to bias formal searches by technicians. Fatalities discovered by maintenance personnel and others not conducting formal searches were recorded as incidentals and the carcasses were not collected or removed from the site unless they were later discovered as part of a scheduled search, after which they were removed from the list of incidentals. Bat fatalities also defined as incidentals included those carcasses 1) found after a search, 2) found at a turbine not scheduled to be searched, 3) known by the senior researcher to have been scavenged prior to the search, and 4) individuals found alive and later released. Incidental observations were not included in any statistical analyses.

Searcher Efficiency

Searcher efficiency was quantified to adjust the estimate of total fatalities for observer detection bias. We estimated searcher efficiency rates at both sites by randomly testing searchers throughout the study. We used a random numbers table to generate a list of random turbine numbers and random azimuths and distances (m) from turbine for each bat used in searcher efficiency trials. We used a sample of carcasses among different species of bats and in various stages of decay that were found during searches for searcher efficiency trials. All carcasses were placed within the area to be searched for a given turbine. Each trial carcass was discreetly marked (tape on back or abdomen) with a unique identification number so that it could be identified as a study carcass after it was found. For each turbine selected for sampling on a given day, we randomly chose 0–4 carcasses and dropped them from waist height, rather than physically placing them, at the pre-determined random directions and distances prior to the searcher's arrival. After dropping the carcass, if we felt the tape on a trial bat was exposed, making it more likely to be seen by a searcher, the bat was flipped over to hide the marking. We attempted to use carcasses in different physical conditions (e.g., fresh, decomposed, partial) to account for this source of variation in searcher detectability. Searcher efficiency trials were conducted throughout the study period in various weather conditions and, although we did not stratify effort by habitat type, searcher efficiency carcasses were distributed among the 4 different visibility categories used in this study.

Searchers were unaware which turbines were used or the number of carcasses placed beneath those turbines during each trial; they only knew that a turbine was being sampled after finding the first trial carcass. When a test carcass was found, the searcher recorded the identification number, distance from carcass when first observed, transect line, perpendicular distance to transect line, and habitat/detection type surrounding the carcass. Carcasses found were either collected for use in future trials or left on the ground for use in scavenging trials. The senior researcher at both sites was present during all trials, recorded test carcasses recovered by searchers, and returned to the location of carcasses not discovered by searchers to ensure that each was still present and available for detection and not scavenged prior to the search.

Scavenging and Carcass Removal

Scavenging, herein referred to as carcass removal trials, was evaluated from 31 July to 11 September at Mountaineer and 2 August to 13 September at Meyersdale. We assessed bat carcass removal by scavengers using fresh and frozen and thawed bat carcasses found at each study site. We also evaluated removal of bird carcasses by using frozen specimens representing small (e.g., house sparrows) and medium sized (e.g., rock dove) birds thawed before use. All carcasses were marked discreetly using a piece of tape on the back or abdomen with a unique identification number so that it could be identified by personnel if found during a plot search. Fresh bat carcasses found each day by searchers were uniquely marked and either left in the field where found and or redistributed to predetermined random locations. When redistributing trial carcasses, we used a random numbers table to generate a list of random turbine numbers and random azimuths and distances from turbine for each bat or bird carcass to be used in removal trials. Carcasses were dropped from waist height, rather than physically placing them, at the pre-determined random locations. Carcass removal trials were conducted throughout the study period in various weather conditions and, although we did not stratify effort by habitat type, trial carcasses were distributed among the 4 different visibility categories used in this study. All carcasses were placed within the maximum plot area (130 m x 120 m) to be searched for each turbine.

Data recorded for each trial carcass prior to placement included date of placement, species, turbine number, distance and direction from turbine, habitat surrounding the carcass, and detection type surrounding carcass. During subsequent visits to each trial carcass, the senior researcher noted the presence/absence of the carcass, the degree of scavenging (none, light, medium, heavy), the location of scavenging on the body, probable scavenger, and any additional comments observations. Carcasses were checked daily until they were removed or until the end of the trial (21 days). At Mountaineer, remote cameras were employed during the final two weeks of the study period to film scavengers feeding on bat carcasses found in the road and bare ground areas.

Weather

Each turbine and meteorological tower was equipped with a digital anemometer that recorded weather and turbine variables every 10 min; the anemometers provided a mean, median, minimum, and maximum value for all variables for each 10 min interval every 24 hr period for which they are operational. These data were downloaded regularly to a computer located at the main office at each site. Additionally, weather data for each day searched was obtained from the National Weather Service Station located in Morgantown, WV, approximately 100 and 125 km from Meyersdale and Mountaineer, respectively, as a measure of regional weather patterns. We calculated mean, median, maximum, and minimum from 2000 to 0600 hr for temperature, pressure, dew point, wind speed, humidity, and visibility. We also calculated the percent of the 10 hr period that rain was recorded as an index to presence of storm fronts.

Turbine Lighting and Anemometers

At both sites we compared mean number of bat fatalities found during the study period at turbines lit with FAA recommended strobe lights to those from unlit turbines at both sites to assess whether bats might be attracted to the light itself or perhaps insects attracted to these lights.

During the last three weeks of the study, we conducted an experiment to determine if bats might be attracted to ultrasonic sounds emitted by digital anemometers located on top of each turbine's hub. We disabled anemometers at half of the even-numbered turbines that were searched daily during that period at both sites (n = 11 and 5 at Mountaineer and Meyersdale, respectively). We randomly chose an even-numbered turbine as a starting point and then selected every forth turbine in each direction from the starting turbine to ensure interspersion of treatments (Hurlbert 1984). At Mountaineer, we disabled anemometers at turbines 2, 6, 10, 14, 18, 22, 26, 30, 34, 38, and 42. At Meyersdale, anemometers were disabled at turbines 4, 8, 12, 16, and 20.

STATISTICAL METHODS

The primary analyses focused on comparing fatality rate estimates from weekly and daily searches. We describe in detail fatality rate estimation, including discussion of each component of the estimation process. The following variables are used in the equations below:

i — Stratum index. Two stratification approaches were used. In one analysis, we defined 2 stratum, i=1 for the area within 10 m of the turbine, i=2 for the area >10 m from the turbine. In the second analysis, we defined 3 stratum, i=1 for high visibility areas, i=2 for moderate visibility areas, and i=3 for low visibility areas.

j — Search frequency index. i=1, for daily searches, i=2 for weekly searches.

k — Turbine or search plot index. k=1, 20 for Meyersdale, and k=1, 44 for Mountaineer.

c_{ijk} — Number of carcasses detected at plot *k* during daily searches (j=1) and from weekly searches (j=2) with the ith stratum for the sampling period (3 weeks) for which the cause of death is either unknown or is attributed to the facility.

n — Number of search plots.

$\overline{c}_{ij}$ — Average number of carcasses observed per turbine per sampling period (3 weeks) for daily searches (j=1) and for weekly searches (j=2) for the ith stratum.

t_l — Time (days) the lth carcass remains in the study area before it is removed.

d — Total number of carcasses placed in searcher efficiency trials.

p_i — Estimated average probability an available carcass is found by searchers in the ith stratum.

$\hat{\pi}_{ij}$ — Estimated probability that a carcass is both available to be found during a search and is found for daily searches (j=1) and weekly searches (j=2) in the ith stratum.

m_{ij} Estimated average number of fatalities per turbine per search period for daily searches (j=1) and weekly searches (j=2), in the ith stratum, adjusted for removal and observer detection bias.

Observed Number of Carcasses

The estimated average number of carcasses ($\bar{c}_{ij}$) observed per turbine per search period (6 weeks) from daily (j=1) and from weekly searches (j=2) within the ith stratum is:

$$\bar{c}_{ij} = 2 \cdot \frac{\sum_{k=1}^{n} c_{ijk}}{n}.$$

where n is the number of turbines searched, c_{ijk} is the number of fatalities found during daily searches (j=1) or weekly searches (j=2) in the ith stratum at the kth turbine. The multiplier of 2 adjusts the observed fatality rates for the fact only half the turbines were sampled daily or weekly each 3-week period.

Estimation of Carcass Removal

Estimates of carcass removal were used to adjust carcass counts for removal bias. Carcass removal rates are expressed as the estimated cumulative probability distribution function $F_i(X<x)$ for the ith stratum, where x is the day since placement. $F_i(X<x)$ is the estimated probability a carcass remains at least x days prior to removal.

Estimation of Searcher Efficiency

Searcher efficiency rates were expressed as *p,* the average probability a carcass is detected by searchers. Observer detection rates and associated 90% confidence intervals were calculated and compared based on searcher efficiency trial data and from distance sampling analysis. For the trial data, searcher efficiency rates were calculated by dividing the number of trial carcasses observers found by the total placed.

Program DISTANCE was used to model detection probabilities (f(x)) as a function of distance (x) from transect line. Candidate models considered included: 1) uniform with a cosine adjustment; 2) uniform with a simple polynomial adjustment, and; 3) half normal with hermite polynomial adjustment:

Key function	Series expansion
Uniform, $1/w$	Cosine, $\sum_{j=1}^{m} a_j \cos(j\pi y/w)$
Uniform, $1/w$	Simple polynomial, $\sum_{j=1}^{m} a_j (y/w)^{2j}$
Half-normal, $\exp(-y^2/2\sigma^2)$	Hermite polynomial, $\sum_{j=2}^{m} a_j H_{2j}(y_s)$, where $y_s = y/\sigma$

where w is the width of the transect y is the distance for the observation.

However, detection rates immediately on the transect line were not 100%; therefore, adjustments to the detection probabilities assuming less than 100% detection on the transect line (g(0)) were applied (Buckland et al. 2001). At Mountaineer, the approximate perpendicular distance to the experimental trial carcasses were measured, allowing some measure of g(0). However, the exact position of the searchers when conducting the searches may have differed slightly from the position of the researcher placing carcasses.

Estimation of Bat Fatalities

Bat fatality estimates were calculated using a modified form of the estimator proposed by Erickson et al. (2003b). Estimates were calculated separately for daily and weekly searches.

Within the different search intervals, separate estimates were calculated using two stratification approaches. In the first approach, two stratum were identified: areas of plots within 10 m of turbines and areas of plots >10 m from turbines. This simple stratification generally accounts for the differences in search detection and scavenging rates, and allows for more direct adjustments for the differential likelihood of fatality occurrence as a function of distance from turbines. For the second approach, three stratum were identified, corresponding to high visibility habitats, moderate visibility habitats, and low to extremely low visibility habitats (see Table 2-1).

The estimated mean number of fatalities/turbine/search period (m_{ij}) was calculated for daily and weekly searches (j=1 and 2) and the ith stratum by dividing the observed mean fatality rate (#/turbine/6-week period) ($\bar{c}_{ij}$) divided by $\hat{\pi}_{ij}$, an estimate of the probability a carcass is not removed by a scavenger (or other means and is detected, and multiplied by A, an adjustment for the area within the 130 m x 120 m plot that was not searched:

$$m_{ij} = A\frac{\bar{c}_{ij}}{\hat{\pi}_{ij}}$$

The overall estimate m_j for daily (j=1) or weekly (j=2) surveys is calculated by summing the individual stratum estimates. Estimated daily per turbine fatality rates (d_j) are calculated by dividing m_j by 42, the number of study days. The value for A was approximated using the following formula:

$$A = \frac{\sum_{k'=1}^{7} \frac{c_{k'}}{p_{k'} s_{k'}}}{\sum_{k'=1}^{7} \frac{c_{k'}}{p_{k'}}}$$

where $c_{k'}$ is the observed number of fatalities found in the k'th 10 m distance band from the turbine, $p_{k'}$ is the estimated observer detection probability in the k'th 10 m distance band from the turbine, and $s_{k'}$ is the proportion of the k'th 10 m distance bands that was sampled across all turbines. The same value of A was used in both stratification approaches.

Estimates of the average probability a bat that dies on a turbine searched daily and is found ($\hat{\pi}_{i1}$) in the ith stratum was calculated by the formula:

$$\hat{\pi}_{i1} = \left(\frac{1}{21}\right) \sum_{x=1}^{21} \sum_{t=1}^{x} (1 - F_i(T < t)) \cdot p_i \cdot (1 - p_i)^{(t-1)}$$

where p_i is the estimated observer detection probability in the ith stratum and $F_i(T<t)$ is the cumulative probability distribution function for carcass removal in the ith stratum. Estimates of the average probability a bat that dies on a turbine searched daily and is found for the ith stratum ($\hat{\pi}_{i2}$) was calculated by the formulae:

$$\hat{\pi}_{i2a} = \left(\frac{1}{7}\right) \sum_{t=1}^{7} (1 - F_i(T < t)) \cdot p_i$$

$$\hat{\pi}_{i2b} = \hat{\pi}_{i2a} + \left(\frac{1}{7}\right) \sum_{t=8}^{14} (1 - F_i(T < t)) \cdot p_i \cdot (1 - p_i)$$

$$\hat{\pi}_{i2c} = \hat{\pi}_{i2b} + \left(\frac{1}{7}\right) \sum_{t=15}^{21} (1 - F_i(T < t)) \cdot p_i \cdot (1 - p_i)^2$$

$$\hat{\pi}_{i2} = (\hat{\pi}_{i2a} + \hat{\pi}_{i2b} + + \hat{\pi}_{i2c}) / 3$$

Variance and 90% confidence intervals were calculated using Monte Carlo/bootstrapping methods (Erickson et al. 2003b, Manly 1997). Comparisons of point estimates and variance for each fatality estimate (daily, weekly) were used to evaluate accuracy and precision of the methods.

Methods for Associations between Turbine and Weather Characteristics and Bat Fatalities

Univariate Analyses. Associations between turbine and weather characteristics (Table 2-2) and fresh bat fatalities were investigated using graphical methods (least squares regression lines, interaction plots), univariate association analyses (Pearson's correlations, simple linear regression), multiple regression (Neder et al. 1996) and logistic regression (Ramsey and Schafer 1997). The linear regression dependent variable was the average number of fresh bat fatalities/turbine/night. For logistic regression analysis, the dependent variable was a 1 for nights where fatalities were >0.3 bats/turbine/night (>6 and 13 total fresh bats found at all turbines at Meyersdale and Mountaineer, respectively) and 0 otherwise. These values were arbitrarily determined based on the distribution of the fatality data and gave us a reasonable sample size for the dichotomous response variable for this analysis. Independent variables used in our analyses (Table 2-2) were quantified from data gathered at anemometers located on turbines and meteorological towers and from regional weather data collected by the National Weather Service.

Multivariate Analyses. We fit several regression models to predict the number of fresh bat fatalities found at a site. The multiple linear regression models were all of the form:

$$y = \beta_0 + \beta_1 x_1 + \ldots + \beta_p x_p + \varepsilon,$$

which related the behavior of y, and index of the number of fresh bat mortalities, to a linear function of the set of predictor variables $x_1, \ldots, x_p$. The β_j's are the parameters that specify the nature of the relationship and ε is a random error term $\sim N(0, \sigma^2)$. We used the SAS Proc GLM (SAS Institute 2000) procedure to fit several alternative models for each site using least squares regression (Neter et al. 1996). Each model contained two predictor variables and possibly their interaction (i.e., one model was fit with the interaction term and another model without). To investigate the overall goodness of fit of each model we calculated the coefficient of multiple determination (R^2), which measures the proportionate reduction of total variation in fresh bat mortalities associated with the use of the model's predictor variables (Neter et al. 1996). For

Abbreviation	Description
tet_avg	Mean nightly temperature; measured at turbines and averaged across all turbines at a site.
hum_avg	Mean nightly relative humidity; measured at met towers and averaged for all towers at a site.
pre_avg	Mean nightly barometric pressure; measured at met towers and averaged for all towers at a site.
wst_med, wst_avg	Median or Average nightly wind speed; measured at turbines and averaged across all turbines at a site.
wsm_med, wsm_avg	Median or Average nightly wind speed; measured at met towers and averaged across all turbines at a site.
pc2	Proportion of night (10 min intervals) from 2000 to 0600 hr with wind speed of 0–4 m/s; measured at turbines and averaged across all turbines at a site.
pc4	Proportion of night (10 min intervals) from 2000 to 0600 hr with wind speed of 4–6 m/s; measured at turbines and averaged across all turbines at a site.
pc6	Proportion of night (10 min intervals) from 2000 to 0600 hr with wind speed of >6 m/s; measured at turbines and averaged across all turbines at a site.
rpm	Mean nightly turbine blade speed (rpm); measured at turbines and averaged across all turbines at a site.
r_s	Proportion of night when rain was recorded; categorical variable classed as <10% or >10% of night; data measured by National Weather Service in Morgantown, WV.
wst_med^2, wst_avg^2	Quadratic term for median or average mean nightly temperature; measured at turbines and averaged across all turbines at a site.
bp_mean*2	Quadratic term for mean nightly barometric pressure; measured at met towers and averaged for all towers at a site.

Table 2-2. Abbreviations and descriptions of weather and turbine variables used for analyses during this study.

inferences about each parameter in every model fit, we calculated the student's *t* statistic and p-value using standard statistical procedures for least squares regression models (Neter et al. 1996).

A total of 43 observations (i.e., nights) from both Meyersdale and Mountaineer were used in this analysis. We fit all possible two variable models with the Meyersdale data using the predictor variables from Table 2-2, but no model contained both (1) proportion of night with a wind speed of <4 m/s and median wind speed at turbines or mean rpm of turbines, (2) proportion of night with a wind speed ≥ 6 m/s and median wind speed at turbines or average rpm of the turbines; and (3) proportion of night with a wind speed <4 m/s and proportion of night with wind speed ≥ 6 m/s. For the Mountaineer site, we fit all possible two variable models to the data except models containing both (1) proportion of night with a wind speed of <4 m/s and mean wind speed at met towers or median wind speed at turbines or mean rpm of the turbines, (2) proportion of night with a wind speed ≥ 6 and mean wind speed at met towers or median wind speed at turbines or mean rpm of the turbines; (3) proportion of night with a wind speed <4 m/s and proportion of turbines with a wind speed ≥ 6 m/s; and (4) the mean and median values of the same measure. These exceptions were due to perceived high correlations between the pairs of variables that could have resulted in severe multicollinearity problems (Neter et al. 1996). This resulted in a total of 34 and 68 models fit to the Meyersdale and Mountaineer bat fatality data, respectively.

To determine the "best" model for each site, we used the second order variant of Akaike's Information Criterion (AICc) (Burnham and Anderson 2002). The AICc value for each model was calculated as:

$$AICc = n\ln(\hat{\sigma}^2) + 2K + \frac{2K(K+1)}{n-K-1},$$

where *n* was the number of observations, *ln* was the natural logarithm, *K* was the number of parameters in the model + 1 (for $\hat{\sigma}^2$), and $\hat{\sigma}^2$ was the maximum likelihood estimate of σ^2, estimated by:

$$\hat{\sigma}^2 = \frac{\sum \varepsilon_i^2}{n}.$$

The model with the lowest AICc value within the set of models for a site was chosen as the best model, given the data and set of models fit.

Using weather and turbine characteristics (Table 2-2) from Meyersdale and Mountaineer, we fit several multiple logistic regression models (Ramsey and Schafer 1997) to predict relatively high bat fatalities versus low fatalities found at a site. The total number of observations (i.e., nights), predictor variables, and the models analyzed were the same as those discussed above for multiple regression analyses for both Meyersdale and Mountaineer.

The logistic regression models were all of the form:

$$\pi = \frac{\exp\left(\beta_0 + \beta_1 x_1 + \beta_2 x_2 + ... + \beta_k x_k\right)}{1 + \exp\left(\beta_0 + \beta_1 x_1 + \beta_2 x_2 + ... + \beta_k x_k\right)}$$

where π was where or not the index of the number of fresh bat mortalities was high (> 0.30) or low ($\leq$ 0.30), $x_1,...,x_p$ were a set of predictor variables, and $\beta_0,\ldots,\beta_p$ were parameters to be estimated. A "best" set of predictor variables to include in the logistic model was selected by fitting all possible two predictor variables, and their interaction of predictor variables (i.e., one model was fit with the interaction term, and another model without) and ranking the resulting models by corrected Akaike's Information Criterion (Burnham and Anderson 2002). AIC_C for the logistic models was defined as:

$$AIC_C = -2\ln\left(L_M\right) + 2K * \left(n/n - K - 1\right)$$

where K was the number of parameters in the model, n is the total number of observations, and L_M was the value of the likelihood function for the fitted model. The model with minimum AIC_C among those fit was chosen as our "best" model given the data and the set of models fit (Burnham and Anderson 2002).

In standard logistic regression analysis, individual "successes" (here, a high index of the number of fresh bat mortalities) and "failures" (here, a low index of the number of fresh bat mortalities) are assumed to be independent of one another and follow a binomial distribution. For inferences about each parameter in every model fit, we calculated the Wald's χ^2 statistic and p-value using standard statistical procedures for logistic regression models (Ramsey and Schafer 1997). All calculations were carried out using SAS Proc LOGISTIC (SAS Institute 2000).

RESULTS

Characteristics of Bat Fatalities

We found 398 and 262 bat carcasses during scheduled searches of approximately 880 and 500 search hours at the Mountaineer and Meyersdale, respectively, and recorded an additional 68 and 37 incidental bat fatalities at the two sites (Tables 2-3 and 2-4). Six bat species were found at the Mountaineer, and 7 species at Meyersdale. The species composition of bat fatalities was similar between those encountered during standard searches and those encountered at all other times (Tables 2-3 and 2-4). At Mountaineer and Meyersdale, hoary bats were most commonly found, accounting for 33.7 and 46.2%, respectively, of all carcasses found; Eastern red bats (24% and 27.2%, respectively), and the Eastern pipistrelle (24% and 7.7%, respectively) also contributed to the majority of total observed fatalities at the two sites. At Mountaineer, little brown (10.1%), silver-haired (5.2%), big brown (2.8%), and unidentified (0.4%) bats accounted for the remainder of the carcasses. Big brown and silver-haired (6.0% each), little brown (3.0%), unidentified (2.9%), northern long-eared (0.7%), and unidentified *Myotis* (0.3%) accounted for the remainder of fatalities at Meyersdale.

At both sites, searchers found considerably more fresh bats, those killed the night before, than older carcasses and especially those in advanced stages of decay (Figure 2-2). Of the carcasses for which sex and age could be determined, we found more dead adults than juveniles (binomial test, $p < 0.0001$, both sites) and more males than females ($p < 0.0001$, both sites) at both sites (Figure 2-3).

Of the bat fatalities for which we could visibly determine the type of injury, the highest percentage was wing injury (25% at Mountaineer and 14.4% at Meyersdale). A smaller percentage of fatalities at both sites were found with lacerations, head injuries, or back injuries. Eight percent of fatalities found at Mountaineer had more than one injury and in all cases involved a wing injury and one or more other injuries (head, laceration, etc.). Thirty-five percent of the fatalities found at Mountaineer and 48.2% of those found at Meyersdale had no externally visible sign of injuries.

At Mountaineer, we found 9 bats alive and released them later in the day. Most were hoary bats (56%). Three bats were found live and released during the study period at Meyersdale, 2 eastern red bats and a hoary bat.

	Fatalities found during scheduled searches		All Fatalities	
Species	**Total**	**% Comp.**	**Total**	**% Comp.**
Hoary bat	134	33.7	156	33.5
Red bat	96	24.1	112	24.0
Eastern pipistrelle	98	24.6	112	24.0
Little brown bat	39	9.8	47	10.1
Silver-haired bat	19	4.8	24	5.2
Big brown bat	10	2.5	13	2.8
Unidentified bat	2	0.5	2	0.4
Total	**398**		**466**	

Table 2-3. Total number bats and composition of bat species fatalities discovered at the Mountaineer Wind Energy Center from scheduled searches and all fatalities (searches plus incidentals) combined from 31 July through 11 September 2004.

	Fatalities found during scheduled searches		*All Fatalities*	
Species	**Total**	**% Comp.**	**Total**	**% Comp.**
Hoary bat	119	45.4	138	46.2
Red bat	72	27.5	82	27.4
Eastern pipistrelle	21	8.0	23	7.7
Big brown bat	18	6.9	18	6.0
Silver-haired bat	15	5.7	18	6.0
Little brown bat	7	2.7	9	3.0
Unidentified bat	7	2.7	8	2.7
Northern long-eared bat	2	0.7	2	0.7
Unidentified *Myotis*	1	0.5	1	0.3
Total	**262**		**299**	

Table 2-4. Total number bats and composition of bat species fatalities discovered at the Meyersdale Wind Energy Center from scheduled searches and all fatalities (searches plus incidentals) combined from 2 August through 13 September 2004.

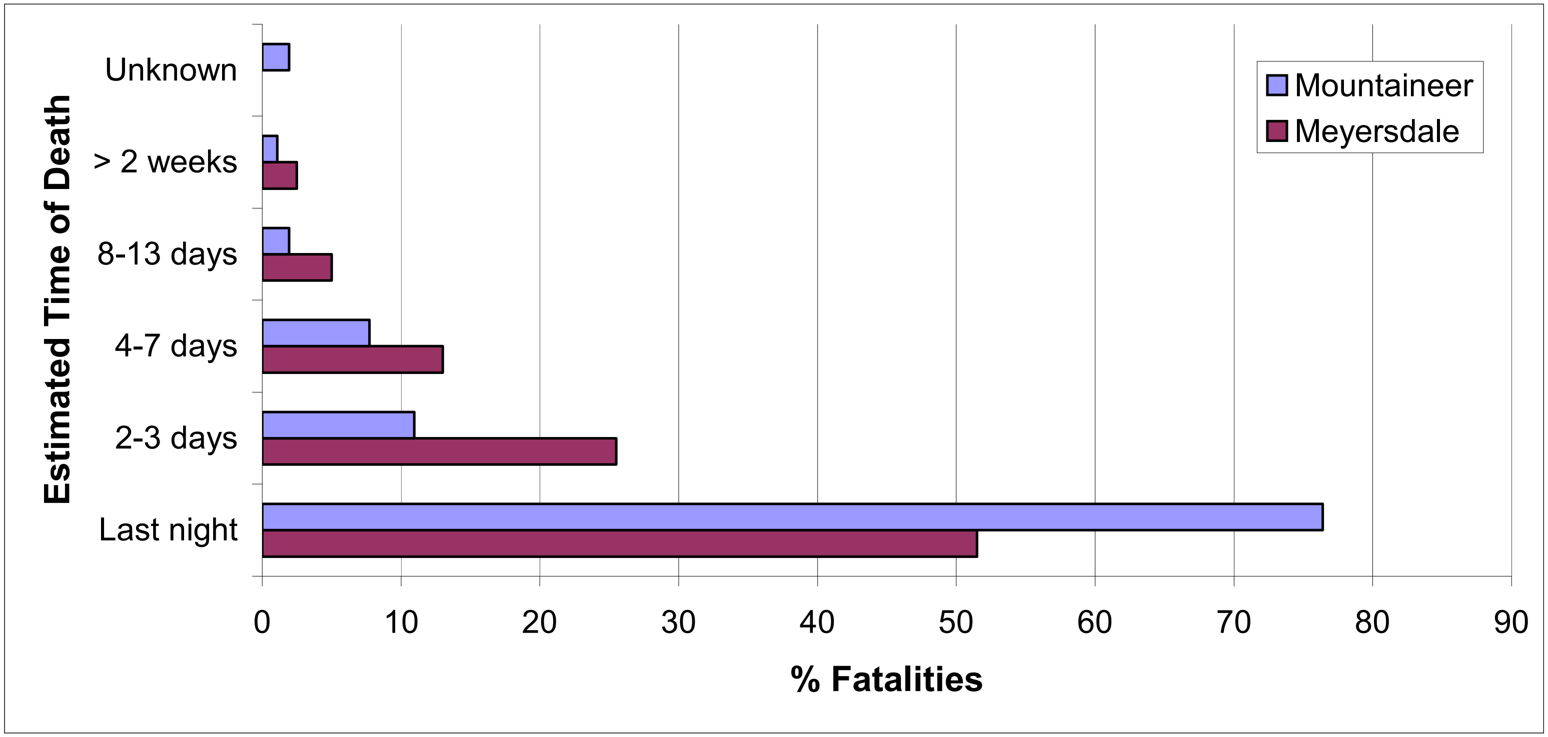
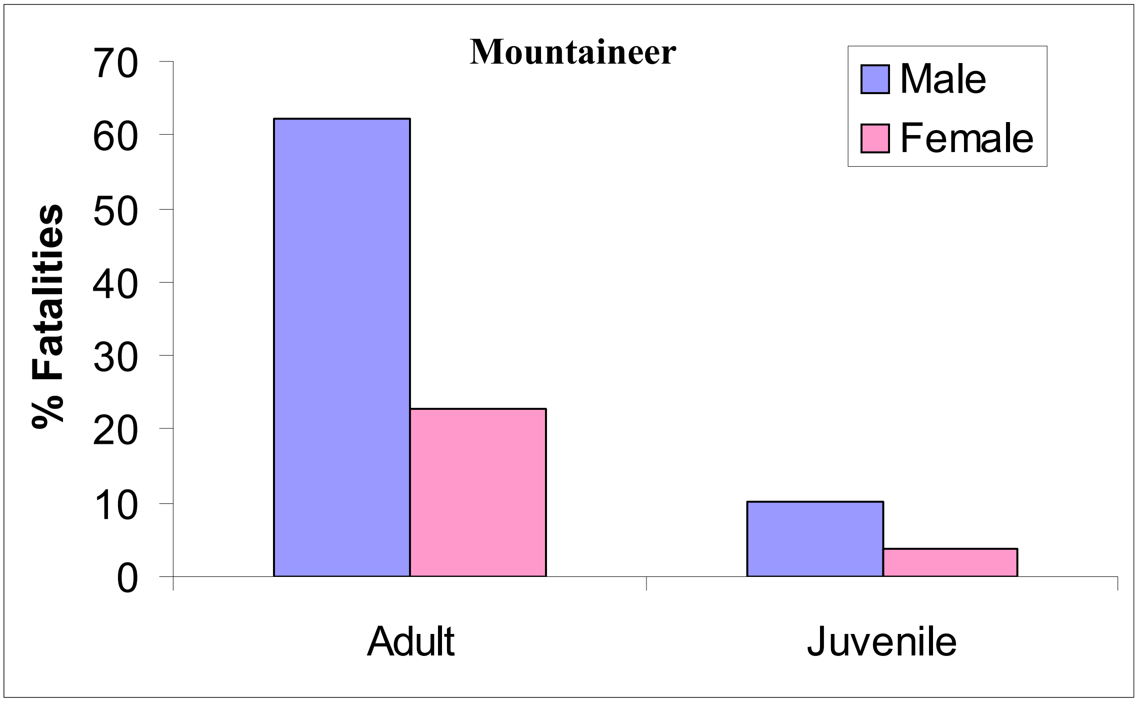


Figure 2-2. Percent of total fatalities found at the Meyersdale and Mountaineer Wind Energy Centers by condition of carcass at time of recovery.



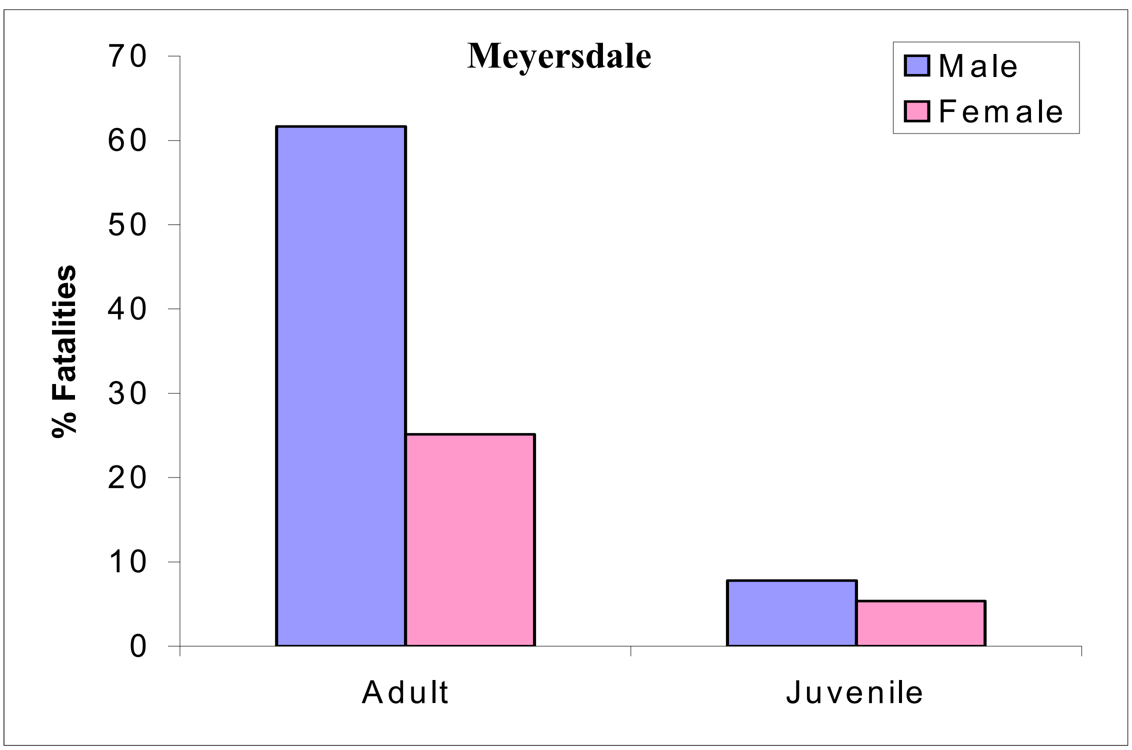


Figure 2-3. Percent of total fatalities representing adult and juveniles and male and female bats at the Mountaineer Wind Energy Center.

Bat Fatalities across Turbines

At both sites, actual number of bat fatalities varied across turbines within turbine string (Figure 2-4). At Mountaineer, bat fatalities per turbine ranged from zero (Turbine 11) to 22 (Turbine 1), with an average of 10.6 bats found per turbine (Figure 2-4). At Meyersdale, number of fatalities per turbine ranged from 3 (Turbine 9) to 22 (Turbine 20), with an average of 13.1 bats found per turbine (Figure 2-4). The only turbine where no fatalities were discovered (Turbine 11 at Mountaineer) had been non-operational. This turbine was in a "feathered" mode (blades parallel with the wind) and "free-wheeling" (blades allowed to move freely), but the blades rarely moved while in this position unless winds exceeded 15 m/s (D. Mandli, FPL Energy, pers. commun.).

Search Area and Habitat

Total area searched (m^2), percent area searched as a function of the maximum search area (130 x 120 m plots or 15,600 m^2), and proportion of detection types within each search plot were calculated for each plot at both sites. Search plots at Mountaineer averaged 52.9% of maximum search area. The largest plot at Mountaineer (Turbine 2) had a search area of approximately 86% of the maximum possible search area (130 m x 120 m, 15,600 m^2), while the search area for the smallest plot (Turbine 44) was only 27.5% of the maximum search area. Search plots at Mountaineer often were irregularly shaped and distances from each turbine to its search plot boundary varied in all directions. For example, at many northern turbines in the string, search plots could not extend further than 30 m northwest or southeast because of the proximity of forest edge. Approximately 79% of possible search area between 30–40 m from the turbines was searched for fatalities, and only 41% of the area between 50–60 m from turbines was searched (Table 2-5, Figure 2-5).

At Meyersdale, larger, more uniform turbine clearings allowed greater search plot areas. Approximately 74.3% (12,560 m^2) of maximum search area (130 x 120 m plot or 15,600 m^2) was searched there, with the remaining area not searched because of forested areas, areas with extremely low likelihood of finding fatalities, or areas where safety was a concern (e.g., large, dense brush piles). The smallest plot sizes at Meyersdale were located at the two ends of the turbine string (Turbines 1 and 20), with an area of approximately 10,600 m^2 (62.7% of maximum search area) and 11,000 m^2 (65.1% of maximum search area) searched, respectively. At Meyersdale, 99% of the area from 30–40 m from the turbines was searched, and a relatively high

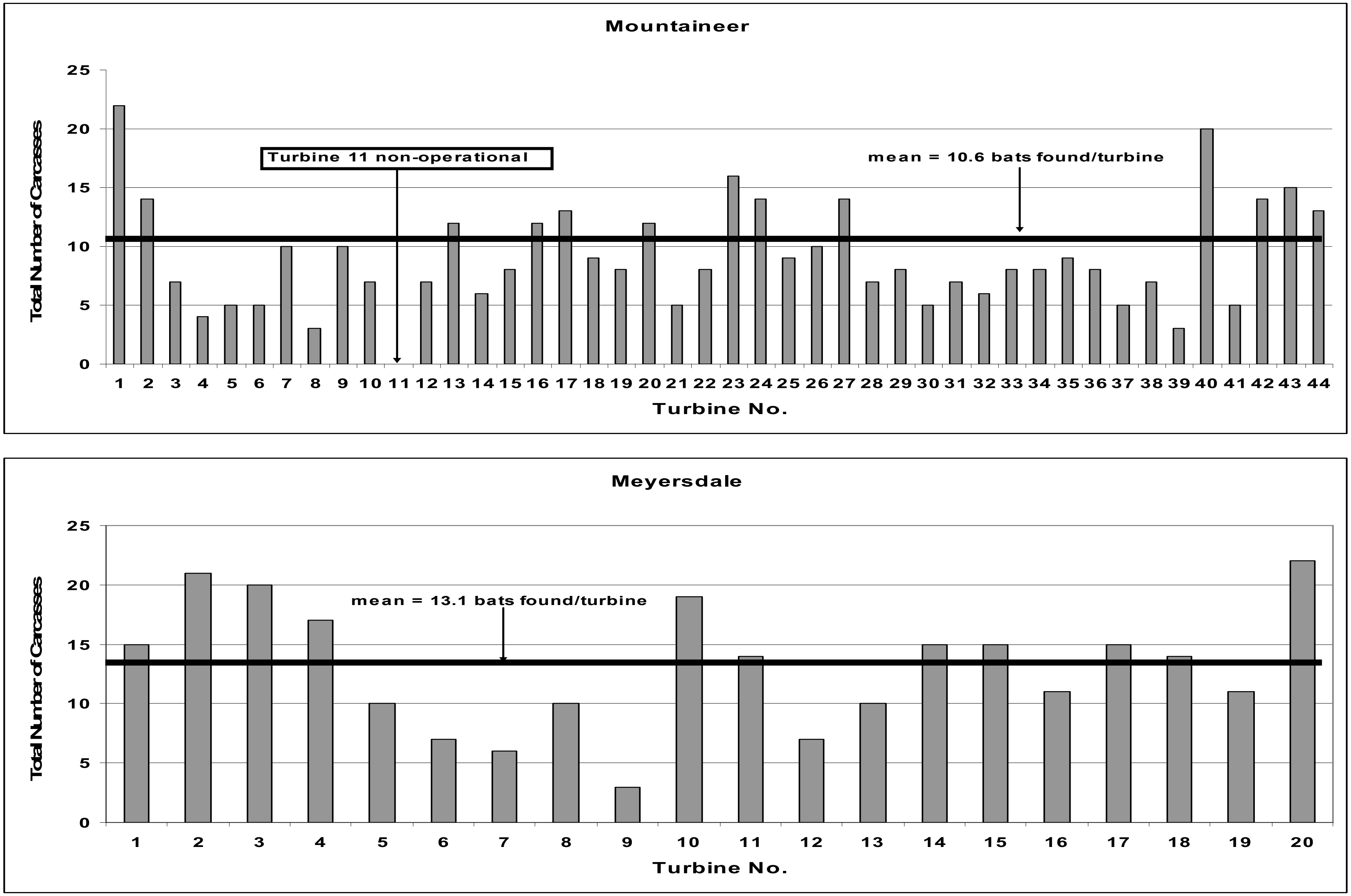


Figure 2-4. Number of bat fatalities found at each turbine during the study period at the Mountaineer and Meyersdale Wind Energy Centers during the study period in 2004.

	Proportion of Area Searched	
Distance (m)	**Mountaineer**	**Meyersdale**
0-10	1.00	1.00
10-20	1.00	1.00
20-30	0.97	1.00
30-40	0.79	0.99
40-50	0.65	0.91
50-60	0.41	0.79
>60	0.20	0.60

Table 2-5. Proportion of the area searched in 10 m distance bands at the Mountaineer and Meyersdale Wind Energy Centers.

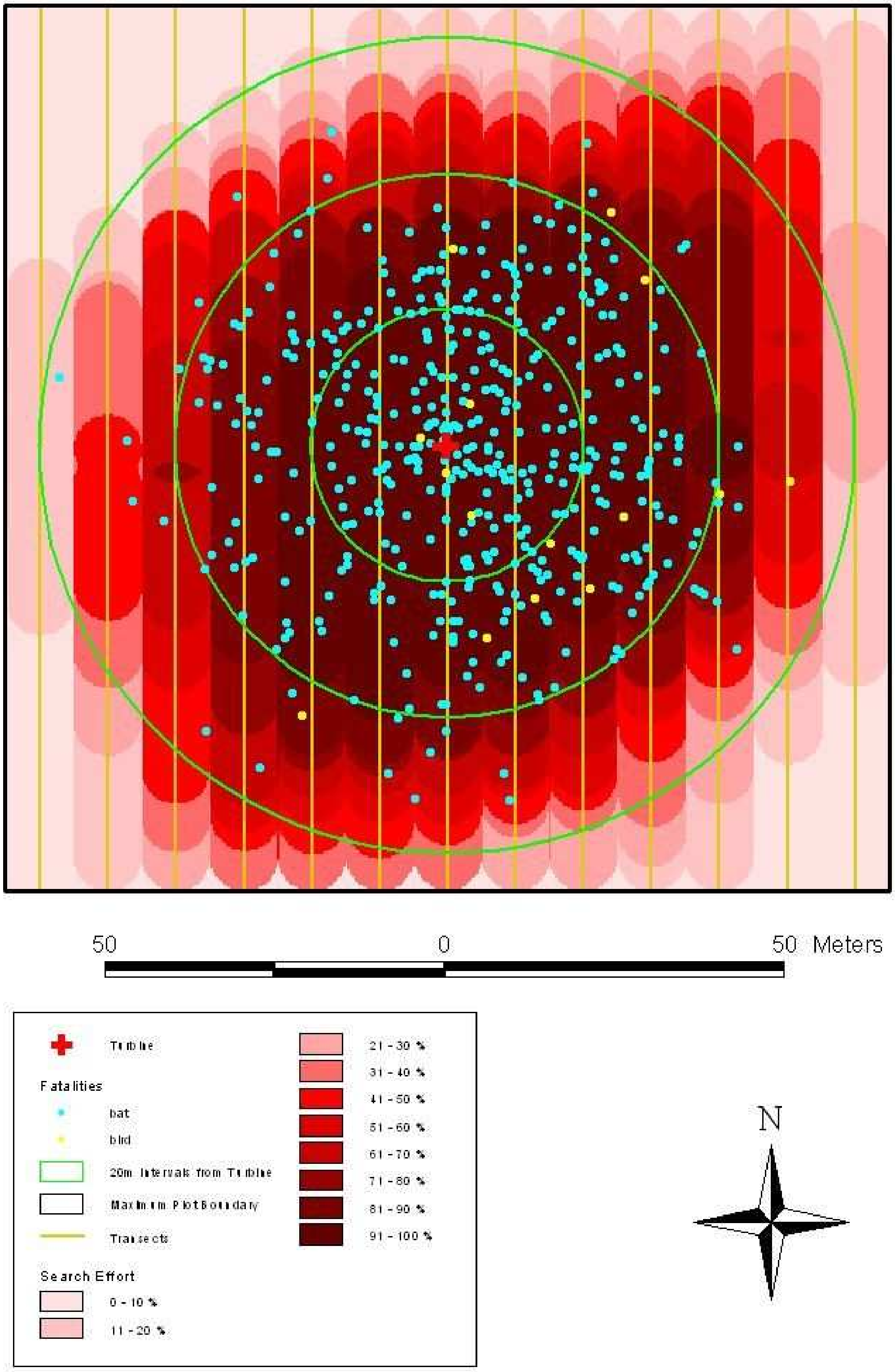


Figure 2-5. Proportion of maximum plot area sampled overlaid with location of bat and bird fatalities for all turbines combined at the Mountaineer Wind Energy Center in West Virginia, 31 July to 11 September 2004.

percentage of the possible search area between 40–50 m and >50 m was searched (91% and 79% respectively), considerably higher than that at Mountaineer (Table 2-5, Figure 2-6).

Proportions of each visibility class were calculated for every turbine search plot and varied greatly within and among turbines at each site. On average at Mountaineer, 42% of plots were in high visibility, 20% medium visibility, 16% low visibility, and 22% extremely low visibility classes. The turbine access road at Mountaineer, which cuts through all search plots, contributed greatly to the proportion of high visibility areas within the plots (10–40% of the area for all turbines). Brush piles and boulders, typically categorized as low or extremely low visibility, comprised 5.6% and 10.4% respectively of total searched area at Mountaineer. Additionally, 4% of transect lines of all search plots were characterized by extreme slope, which was often impassable and required leaving the transect line while searching. Approximately 36% of the each search plot at Meyersdale was considered high visibility, while 28% was moderate visibility, and 36% low visibility. Plots at Meyersdale had few steep slopes and fewer boulders and brush piles (3.3% and 4.3% respectively) compared to plots at Mountaineer. Detectability at Meyersdale was affected by thick grassy vegetation (68.2% of search plots) rather than extreme topographic features.

Distribution of Fatalities Relative Distance and Direction from Turbine

At Mountaineer, 93% of all fatalities were found ≤40 m from the turbine (Table 2-6; Figure 2-5). At Meyersdale, nearly 84% of all fatalities were found ≤40 m from the turbine (Table 2-6; Figure 2-6). At both sites, ≤3% of fatalities were found >50 m from the turbines (Table 2-6; Figures 2-5 and 2-6). When these percentages are adjusted by amount of search effort and average searcher efficiency rate within each of these distance bands, it is estimated that 80% of the fatalities occurred within 40 m of the turbine and <1% outside 60 m (Figure 2-7). At Meyersdale, whereas 14% of all bat carcasses found were within 10 m of the turbine base, the detection rate was approximately 3–4 times higher (see the results of Searcher Efficiency below) in this area and the adjusted estimates indicate that only 5% of the bats were located with 10 m of the turbines (Figure 2-7). At Mountaineer, after adjusting for search effort and average searcher efficiency rate, it is estimated that approximately 9% of the fatalities occurred within 10 m of the turbines. At Mountaineer, it is estimated that 9% of the actual fatalities occurred in areas not searched within the 130 m x 120 m plots (A=1.09). At Meyersdale, it is estimated that

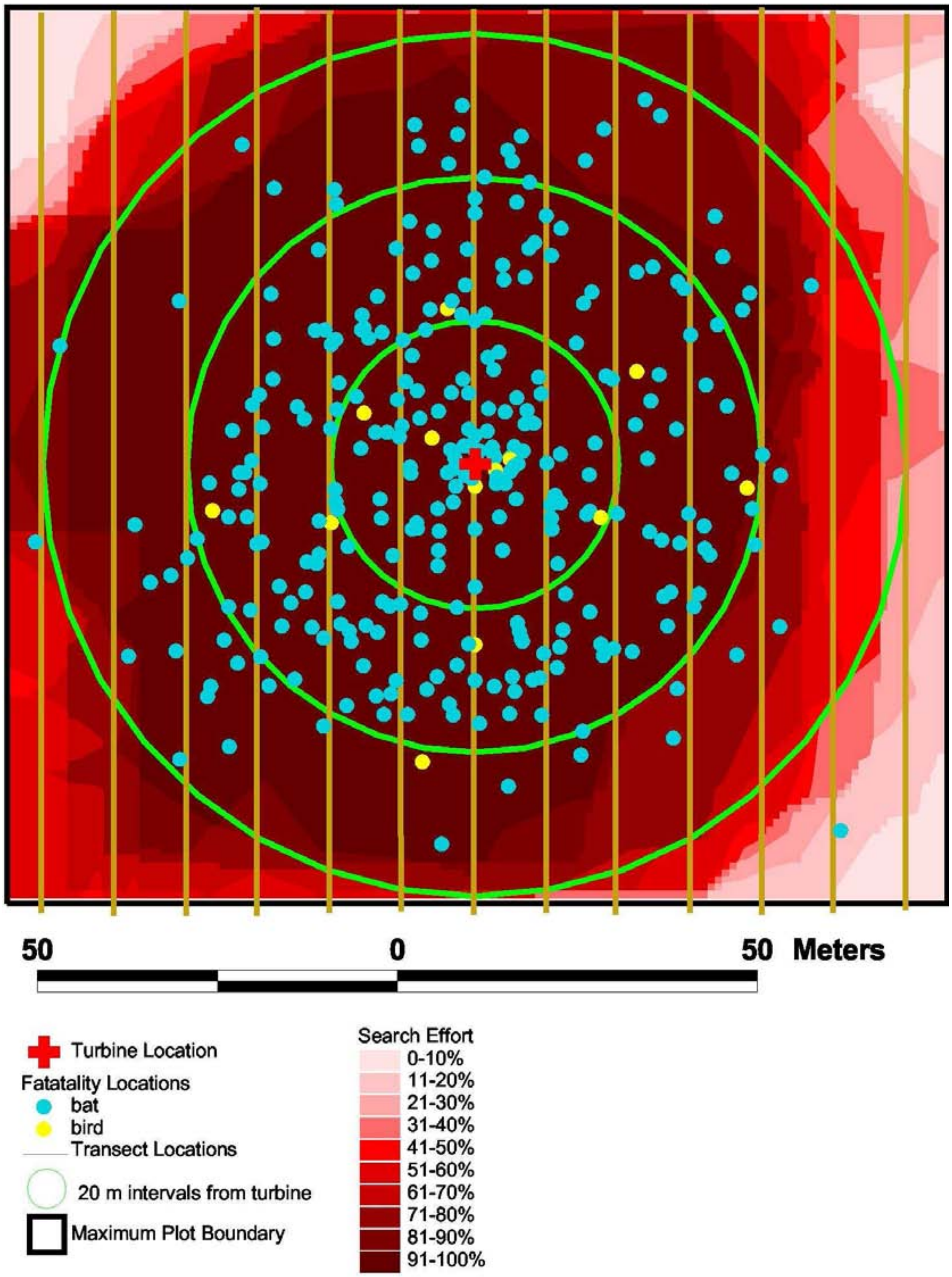
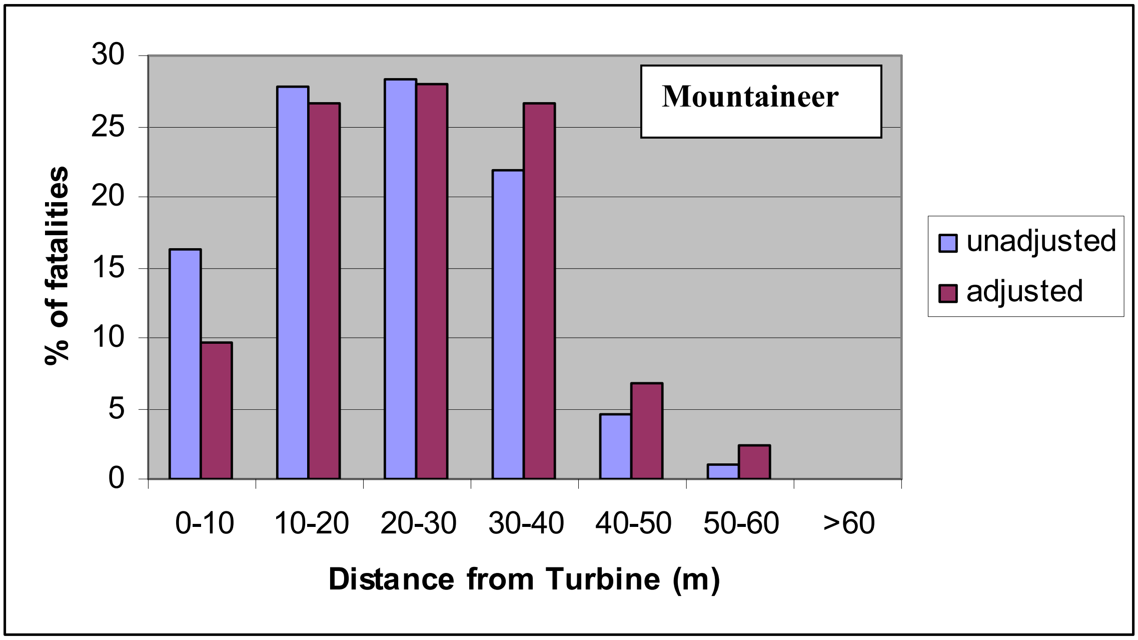


Figure 2-6. Proportion of maximum plot area sampled overlaid with location of bat and bird fatalities for all turbines combined at the Meyersdale Wind Energy Center in Pennsylvania, 2 August to 13 September 2004.

	Mountaineer	Meyersdale
	% Bat Fatalities	**% Bat Fatalities**
Quadrant		
NE	26.6%	23.4%
SE	32.6%	22.7%
SW	18.9%	30.1%
NW	21.9%	23.7%
Distance to Turbine (m)		
0 – 10	15%	14.0%
11 – 20	25.7%	16.7%
21 – 30	30.3%	25.1%
31 - 40	22.1%	28.1%
41 – 50	5.4%	12.4%
> 50	1.5%	3%

Table 2-6. Distribution of bat fatalities among directional quadrants and distance from turbines at Mountaineer and Meyersdale Wind Energy Centers.



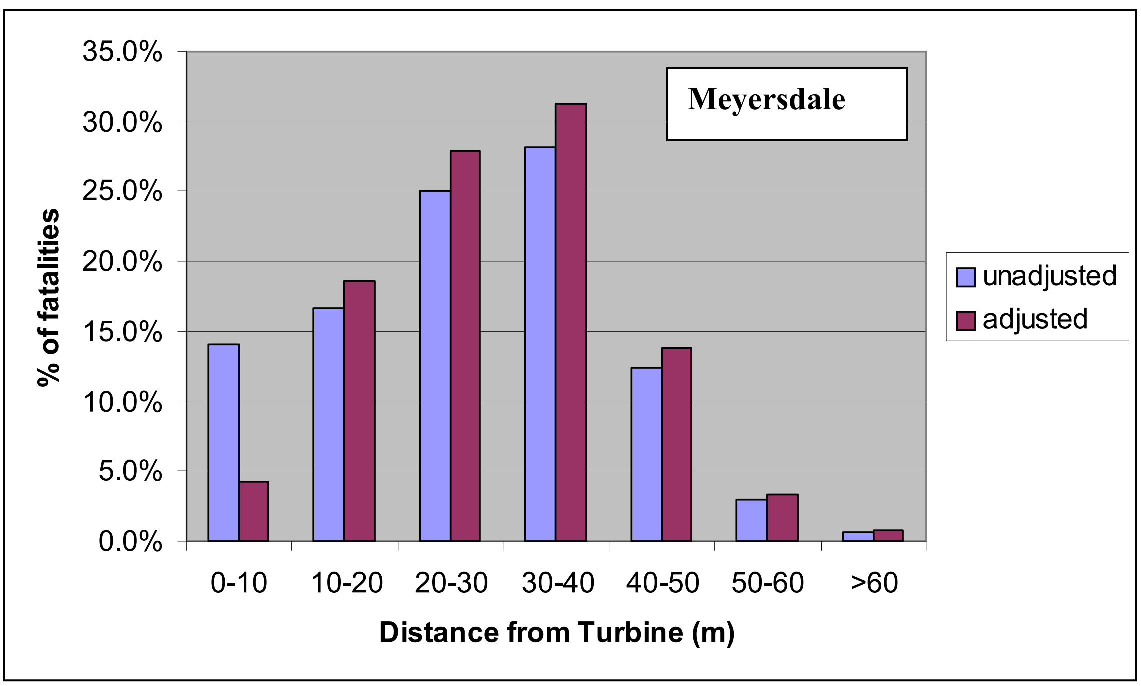


Figure 2-7. Distribution of fatalities as a function of distance from turbine for the Mountaineer and Meyersdale sites based on unadjusted counts, and counts adjusted for search detect and sampling effort.

3.5% of the actual fatalities that occur were located in areas not searched within the 130 m x 120 m plots (A=1.035).

At Mountaineer, the distribution of carcasses around turbines did not differ among the four most commonly found species (hoary bat, eastern red bat, eastern pipistrelle, little brown), though the species vary greatly in size ($F = 1.57$, $p = 0.16$). At Meyersdale, a similar result was shown using the five most commonly discovered species (four listed above and silver-haired bat; $F = 1.54$, $p = 0.19$). These five most commonly found bat species range from 19–28 g for the hoary bat to ≤6 g for the Eastern pipistrelle. At both sites, a large majority of the carcasses were found from 10–40 m (79% Mountaineer, 70% Meyersdale), with the 21–30 m distance band from turbines having the highest percentage at Mountaineer (30.3%) and the 30–40 m distance band from turbines having the highest percentage at Meyersdale (28.1). However, these percentages do not account for detection and scavenging bias, or searched area which may vary as a function of distance from turbine.

At both sites, bat fatalities were fairly evenly distributed within each cardinal direction around the turbines for all days and turbines combined (Table 2-6, Figures 2-5 and 2-6). At Mountaineer, the majority of fatalities were found in the SE quadrant (32.6%), whereas a slightly higher percentage of fatalities were found in the SW quadrant at Meyersdale (30.1%). At both sites, these quadrants generally correspond with location of the access road which had high searcher detectability.

Unadjusted Fatality Rate Comparisons by Search Interval

At Mountaineer, we found 6.1 times more fatalities during daily searches (15.3 bats/turbine) compared to weekly searches (2.4 bats/turbine) with approximately 7 times the search effort. At Meyersdale, daily searches yielded approximately 2.1 times the number of fatalities (16.4/turbine) during the weekly searches (7.7 bats/turbine) with approximately 7 times the search effort.

Searcher Detection Probability

At Mountaineer, a total of 215 bat carcasses were used in searcher efficiency trials (Table 2-7). Four searcher efficiency carcasses were scavenged prior to completion of the trials. Overall searcher efficiency for bat carcasses was estimated to be 43.6% for all trials. The highest rates of searcher efficiency were estimated within 10 m of the turbines (63.9%), with rates dropping as distance from turbine increased (Table 2-7). Similarly, observer detection rates were

	No. Placed	No. Scavenged Prior to Search	No. Found	% Found
Overall	215	4	92	43.6%
Distance from Turbine (m)				
0 – 10	36	0	23	63.9%
11 – 20	39	1	19	50.0%
21 – 30	52	1	21	41.2%
31 – 40	42	0	16	38.1%
41 – 50	25	0	5	20.0%
51 – 60	18	2	7	43.8%
> 60	3	0	1	33.3%
Observer Detection Type				
High	85	4	55	64.7%
Medium	55	0	25	45.5%
Low	31	0	9	29.0%
Extremely Low	40	0	3	7.5%
Distance to Transect Line (m)				
0 – 1	89	1	43	48.3%
1.1 – 2.0	37	0	22	59.5%
2.1 – 3.0	27	2	14	51.9%
3.1 – 4.0	23	1	6	26.1%
4.1 – 5.0	39	0	7	17.9%

Table 2-7. Searcher efficiency at the Mountaineer Wind Energy Center as a function of distance to turbine, visibility type, and distance to transect line.

high in areas with high visibility (64.7%), with rates dropping as visibility decreased (Table 2-7). Searcher efficiency was 48.3% within 1 m of the transect line, but was slightly higher when carcasses were placed within 3 m of the transect line (1.1–2.0 m = 59.5%, 2.1–3.0 m = 51.9%). Detection of carcasses placed further than 3.0 m from the transect line dropped significantly, with only 17.9% of carcasses found at distances >4 m from the transect line (Table 2-7).

At Meyersdale, a total of 161 bat and 27 bird carcasses were used in searcher efficiency trials (Table 2-8). Overall searcher efficiency for bat carcasses was estimated at 25% for the entire time period, with highest rates estimated with 10 m of the turbines (63%), and low rates estimated at other distances from turbines (10–25%); Table 2-8). High visibility areas had an observer detection probability at 48.1%, moderate at 18%, and low visibility habitats estimated at 10% (Table 2-8).

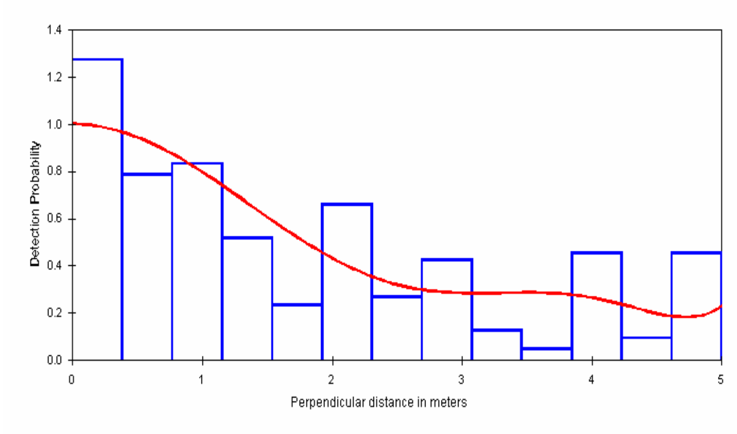
DISTANCE Sampling

For fatalities found during searches at Mountaineer and Meyersdale, the relationship between the number of fatalities found and perpendicular distance from transect are illustrated in Figures 2-8 and 2-9, respectively. In general, a strong negative relationship exists between the distance from the transect line and the detection probability, as was expected.

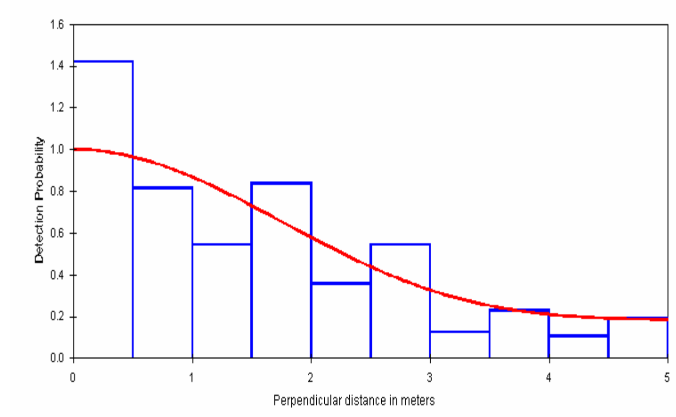
Models fit for data collected within 10 m of the turbines suggested a small (Mountaineer) or no decline (Meyersdale) in detection as a function of distance from transect, likely due to the good visibility in this area. A much steeper detection function was estimated for areas greater than 10 m from turbines. The estimated detection probability was estimated to be approximately 3 times higher within 1 m of the transect line compared to all areas farther than 2.5 m from transects at Mountaineer. At Meyersdale, the detection probabilities were estimated to be approximately 5 times higher near the transect line compared to areas greater than 3 m from the transect line. Search widths of 3 m, which have commonly been used at other sites (Erickson et al. 2003b, Johnson et al. 2003) may have increased the detection probabilities significantly over the 5 m intervals, and lead to more precise estimates. In more open habitats, such as the area within 10 m of turbines at these two sites, a 5 m search interval appears adequate. The detection functions were also estimated by low, moderate and high visibility categories. The detection functions at Mountaineer in the low detection category dropped off quickly with low estimated detection from 2–3 m. At Meyersdale, most of the carcasses were observed within 0.5 m from the transect line, and no fatalities were documented at distances >3.5 m. A reasonably similar

	No. Placed	No. Scavenged Prior to Search	No. Found	% Found
Overall	161	0	41	25.5%
Distance from Turbine (m)				
0 – 10	32	0	20	62.5%
11 – 20	23	0	3	13.0%
21 – 30	32	0	4	12.5%
31 – 40	24	0	6	25.0%
41 - 50	34	0	6	17.6%
>51	16	0	2	12.5%
Observer Detection Type				
High	52	0	25	48.1%
Medium	68	0	12	17.6%
Low	40	0	4	10.0%

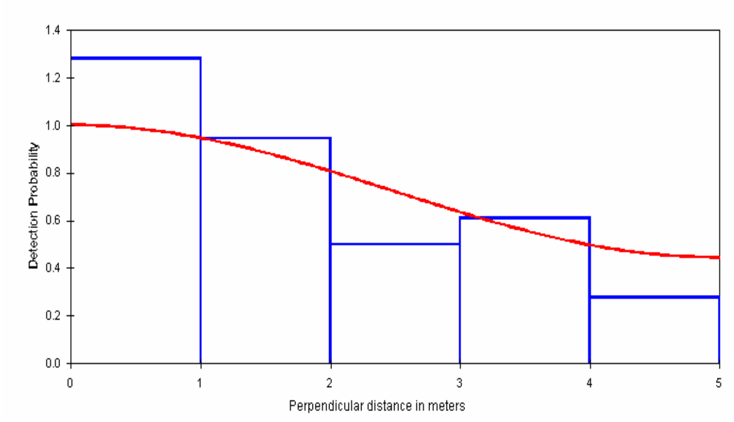
Table 2-8. Searcher efficiency at the Meyersdale Wind Energy Center as a function of distance to turbine, visibility type, and distance to transect line. There was missing visibility data for one bat specimen.



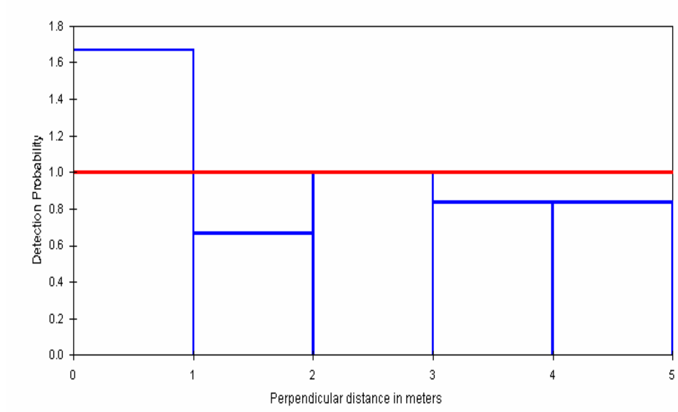
Mountaineer – all bats



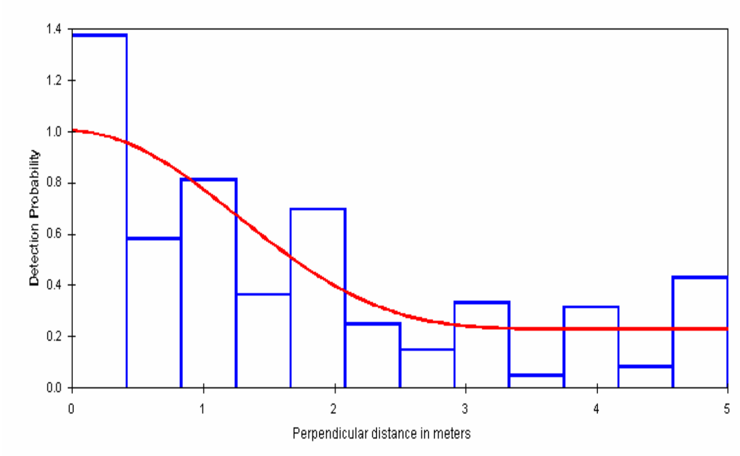
Meyersdale – all bats



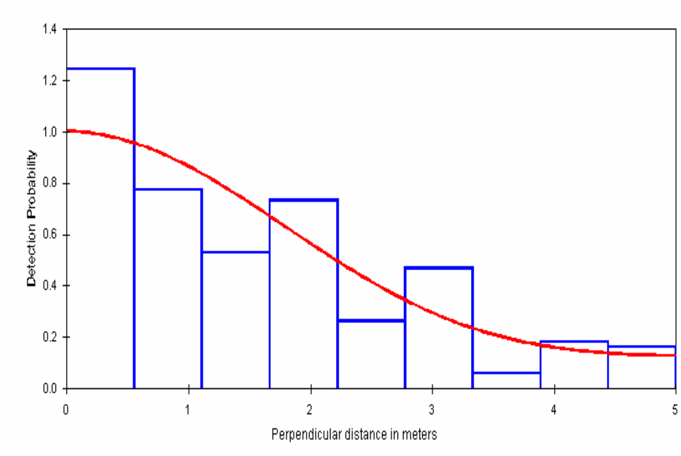
Mountaineer – within 10 m of turbines



Meyersdale – within 10 m of turbines

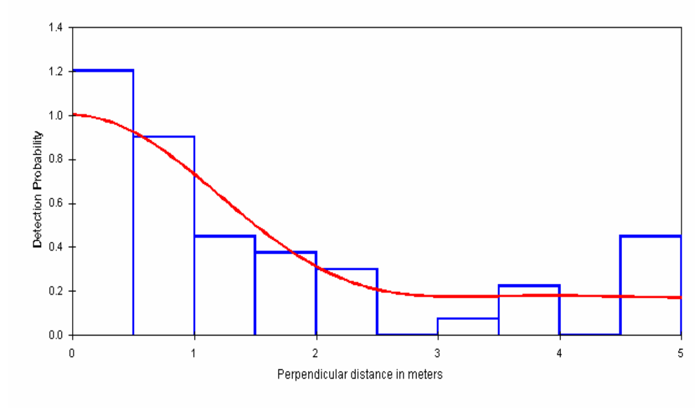


Mountaineer - >10 m from turbines

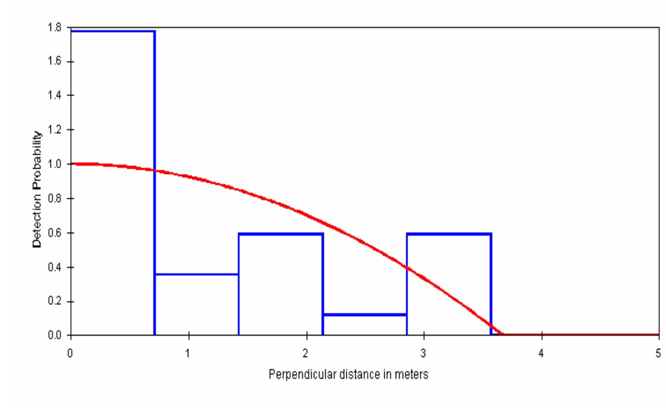


Meyersdale - > 10 m from turbines

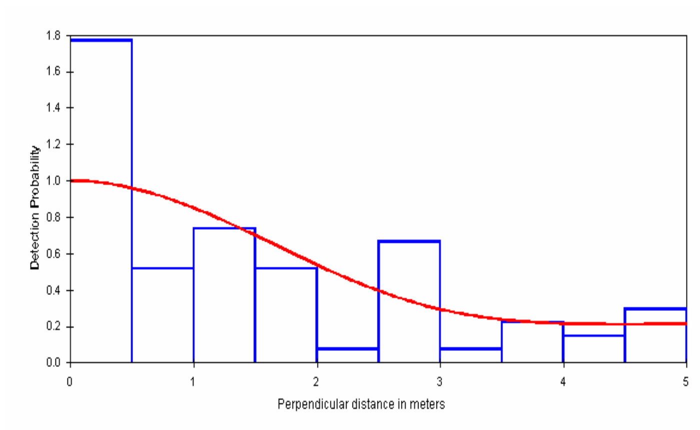
Figure 2-8. Estimated detection functions for all bats and for those within 10 m of turbines and those greater than 10 m from turbines at the Mountaineer and Meyersdale Wind Energy Centers.



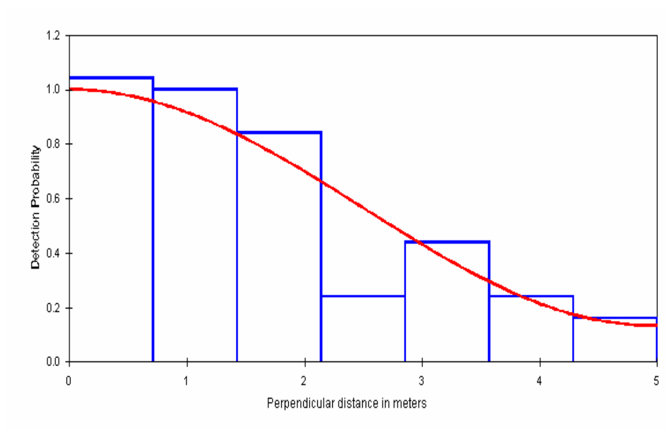
Mountaineer – low detection



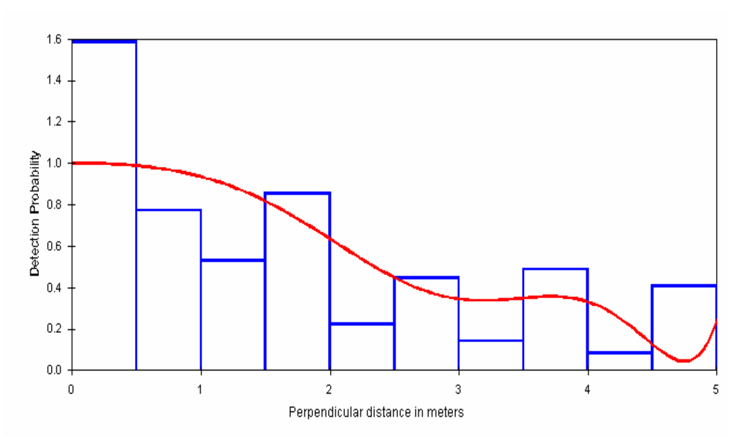
Meyersdale – low detection



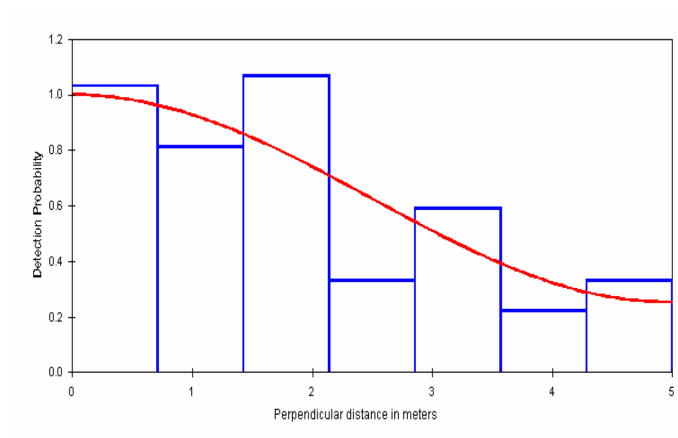
Mountaineer – moderate detection



Meyersdale – moderate detection



Mountaineer – High detection



Meyersdale – High detection

Figure 2-9. Estimated detection functions for low, moderate, and high visibility habitats at the Mountaineer and Meyersdale Wind Energy Centers.

form of the detection functions existed at both study sites in the moderate and high visibility categories.

The average detection probability within 5 m of the transect line was estimated for different assumptions of g(0), the detection probability on the transect line (Table 2-9). The perpendicular distance from the transect line to the experimentally placed carcasses was measured at the Mountaineer site, allowing for an approximation to the detection probability on the transect line. Using an overall estimate of g(0) of 0.50–0.60 at Mountaineer, the estimated detection probability generated by Program DISTANCE was 0.285 (95% C.I.: 0.25, 0.32). This is significantly lower than what was observed from the searcher efficiency experimental trials (approximately 40%). For areas within 10 m of turbines, and assuming g(0) was approximately 0.8, the estimated detection probability was 0.578 (95% CI: 0.448, 0.708), similar to the estimate from the experimental bias searcher efficiency trials (0.639).

The approximate distance from the trial carcass to the transect line was not recorded during searcher efficiency trials at Meyersdale, so we cannot estimate g(0) the same way as was done for Mountaineer. However, overall detection rates at Mountaineer were approximately 10–20% high than Mountaineer. So a reasonable estimate of g(0) would be 10–20% less than the estimate at Mountaineer or 0.40–0.50. With this assumption, the estimated average detection probability for all bats was 0.258 (95% CI: 0.224, 0.292), which is very similar to the overall detection probability estimated from the experimental trials (0.255). For areas with 10 m of turbines, the estimated detection function was flat, suggesting no relationship between distance and detection probability in this high visibility area. For areas greater than 10 m from turbines, the detection function suggests that detection rates were approximately 5 times higher on the line compared to areas greater than 3.5 m from the transect line.

These results suggest that distance sampling may be useful for estimating searcher efficiency probabilities; however, experimental trials will be necessary to estimate the detection probabilities near the transect line.

data	g(0)[a]	p[b]	95% LCL	95% UCL
Meyersdale				
all bats				
	1.0	0.516	0.448	0.584
	0.8	0.413	0.358	0.467
	0.7	0.361	0.313	0.409
	0.6	0.310	0.269	0.350
	0.5	0.258	0.224	0.292
≤ 10m from turbine				
	1.0	1.000		
	0.8	0.800		
	0.7	0.700		
	0.6	0.600		
	0.5	0.500		
> 10m from turbine				
	1.0	0.491	0.425	0.557
	0.8	0.393	0.340	0.446
	0.7	0.344	0.298	0.390
	0.6	0.295	0.255	0.334
	0.5	0.246	0.213	0.278
Mountaineer				
data	g(0)	p	95% LCL	95% UCL
all bats				
	1.0	0.474	0.416	0.533
	0.8	0.380	0.333	0.426
	0.7	0.332	0.291	0.373
	0.6	0.285	0.250	0.320
	0.5	0.237	0.208	0.267
≤ 10m from turbine				
	1.0	0.723	0.560	0.885
	0.8	0.578	0.448	0.708
	0.7	0.506	0.392	0.620
	0.6	0.434	0.336	0.531
	0.5	0.361	0.280	0.443
> 10m from turbine				
	1.0	0.452	0.393	0.511
	0.8	0.362	0.315	0.409
	0.7	0.317	0.275	0.358
	0.6	0.271	0.236	0.307
	0.5	0.226	0.197	0.255

[a] estimated detection probability on the transect line

[b] estimated detection probability, accounting for the detection on the line (g(0)) and the estimated detection probabilities as a function of distance from turbine in

Table 2-9. Detection probabilities calculated in program DISTANCE for search plot transects at the Mountaineer and Meyersdale Wind Energy Centers.

Carcass Removal Rate

Carcass removal rates were very different between the two study sites. At Mountaineer, carcass removal was high for both fresh and frozen bat carcasses (Figure 2-10) and fresh bats left in place or randomly distributed (Figure 2-11). Fresh bat carcasses were removed at a higher rate than those specimens that had been frozen for 1 day to several months, but the removal trend was similar (Figure 2-10). On average, fresh bats were removed significantly faster (mean = 2.88 days) as frozen bats (mean = 5.47 days) at Mountaineer ($t = 3.46$, $p = 0.0007$). Twenty-four percent of bats left where they fell were removed on the same day the trial started (Figure 2-11). Thirty-five percent of the randomly placed bats were removed within the first 24 hr, whereas 70% of those that were left where they fell were removed within the same time period (Figure 2-11). Forty-eight percent of the carcasses placed at random were removed within 48 hr of placement, and by day 18 over 90% of these carcasses were removed by scavengers. Bat carcasses placed in high visibility habitats at Mountaineer were removed at approximately twice the rate (47.7% removed with the first 24 hr) of those placed in low to extremely low visibility habitats (12.5% and 29% respectively within the first 24 hours; Figure 2-12). Carcasses that were placed or left where they fell in the road ($n = 39$) exhibited an even higher rate of removal than those found in bare ground areas. Eighty-seven percent of carcasses in the road were removed within the first 24 hr. With the exception of one carcass that was run over by a vehicle in the road, all carcasses were removed with 48 hr of placement.

In contrast, carcass removal rates were very low for the Meyersdale (Figure 2-13). Only 3% of the fresh bat carcasses were removed within the first 24 hr, 16% by day 7, and only 21% were removed by day 16 (Figure 2-13).

Detection Probability and Fatality Estimation

Mountaineer – Distance from Turbine Stratification. At Mountaineer, the estimated probability that a bat fatality occurred during the study in the searched area and was found during daily searches was 0.58 for the area within 10 m of turbines and 0.42 in searched areas farther than 10 m from turbines (Table 2-10). From daily searches, we estimated that 15.3 bats/turbine/6-week study period were observed and that 9% of the actual fatalities occurred in areas not searched within the 130 m x 120 m plots (A=1.09). The resulting adjusted fatality rate estimate is 38 bats/turbine/6-week study period (90% CI: 32, 46), and a daily fatality rate of 0.91 per turbine (90% CI: 0.75, 1.09). The estimated probability a bat fatality that occurred during the

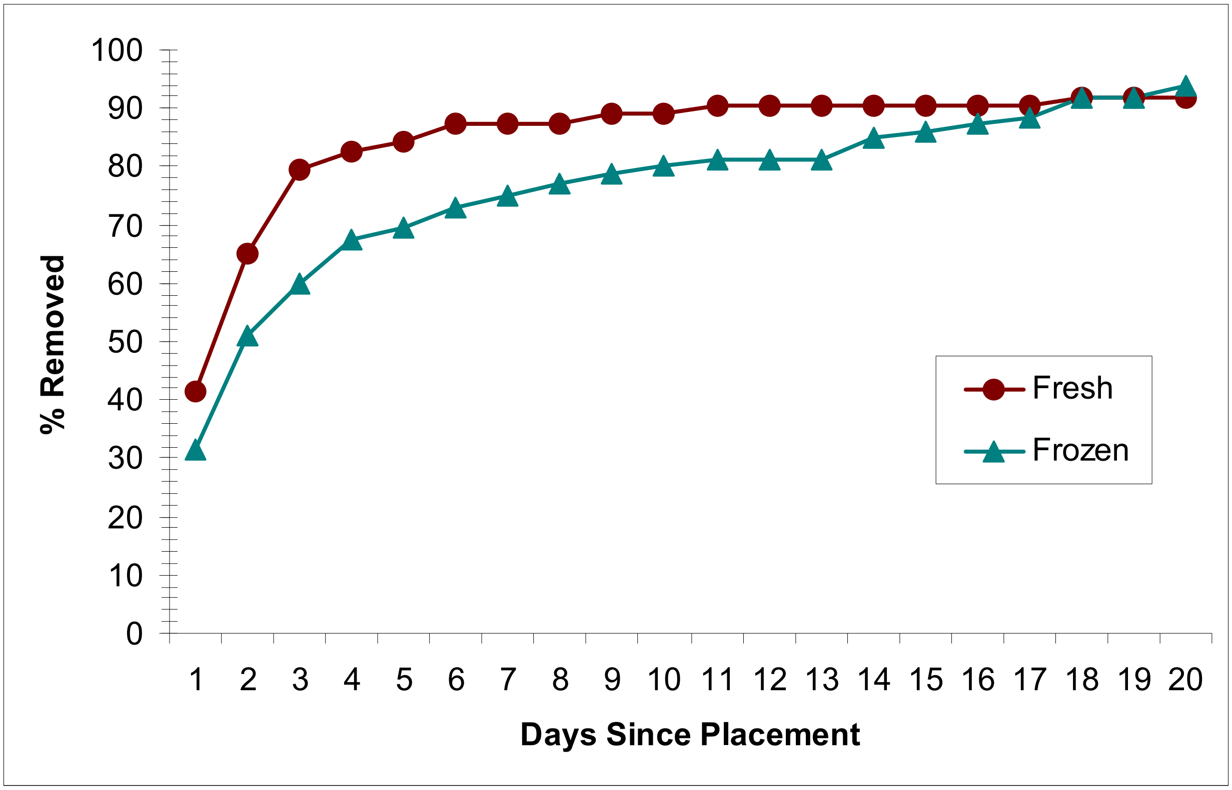


Figure 2-10. Removal by scavengers of fresh and frozen bat carcasses during carcass removal trials at the Mountaineer Wind Energy Center.

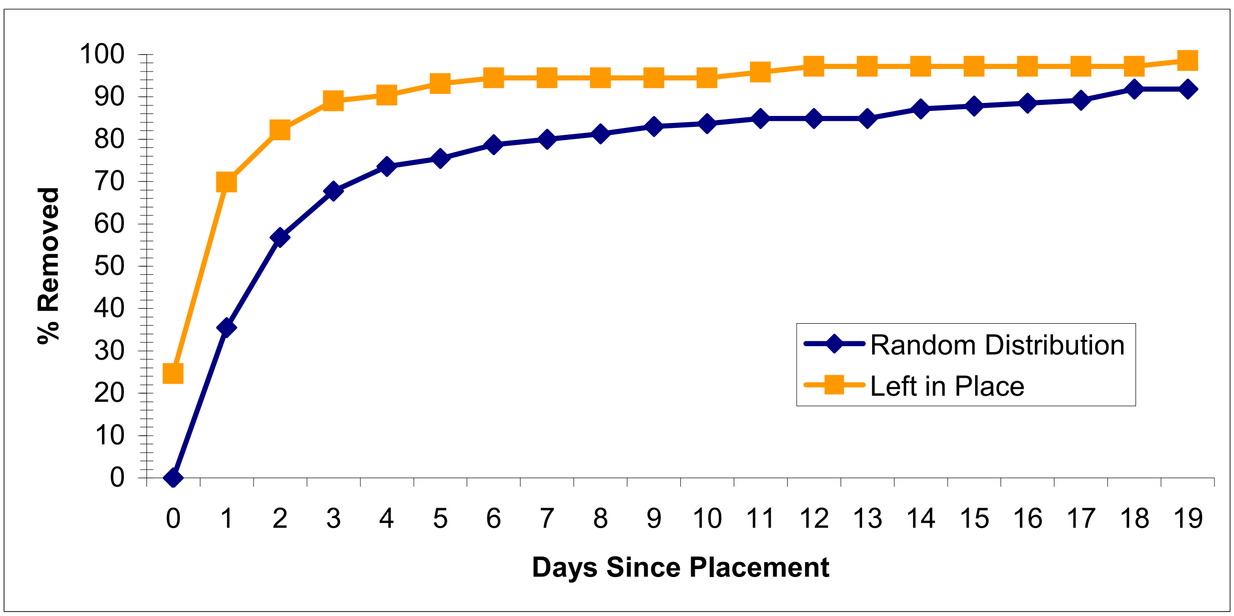


Figure 2-11. Removal by scavengers of randomly distributed carcasses and carcasses that were left where they fell during carcass removal trials at the Mountaineer Wind Energy Center.

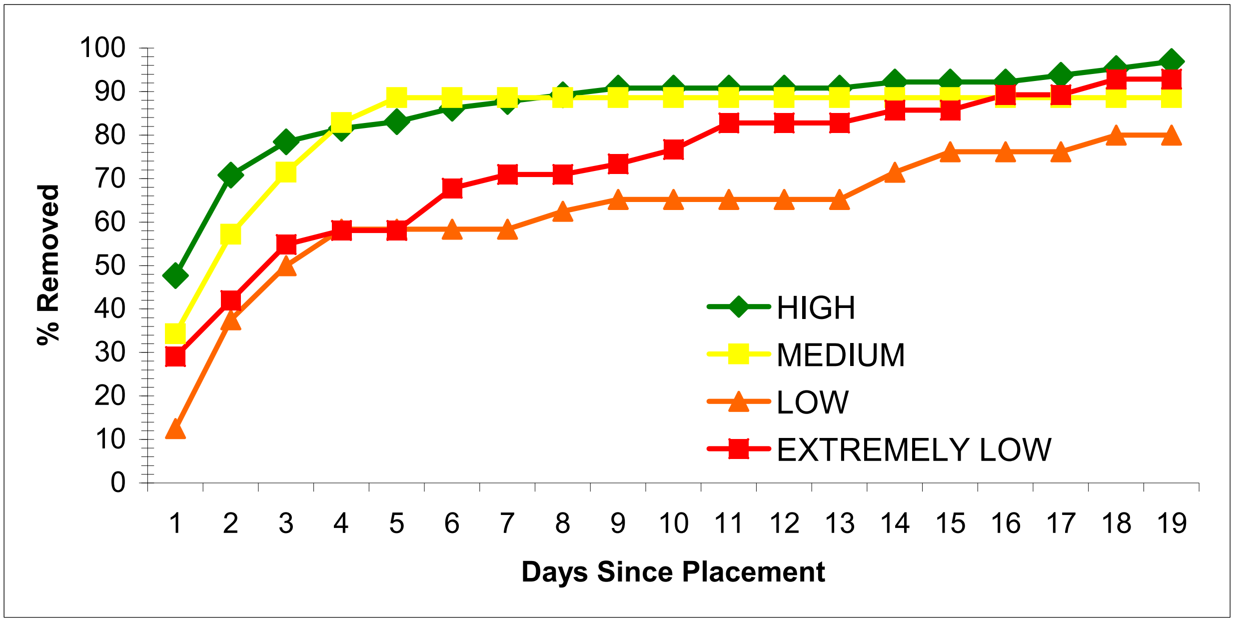


Figure 2-12. Removal by scavengers of bat carcasses by visibility types during carcass removal trials at the Mountaineer Wind Energy Center.

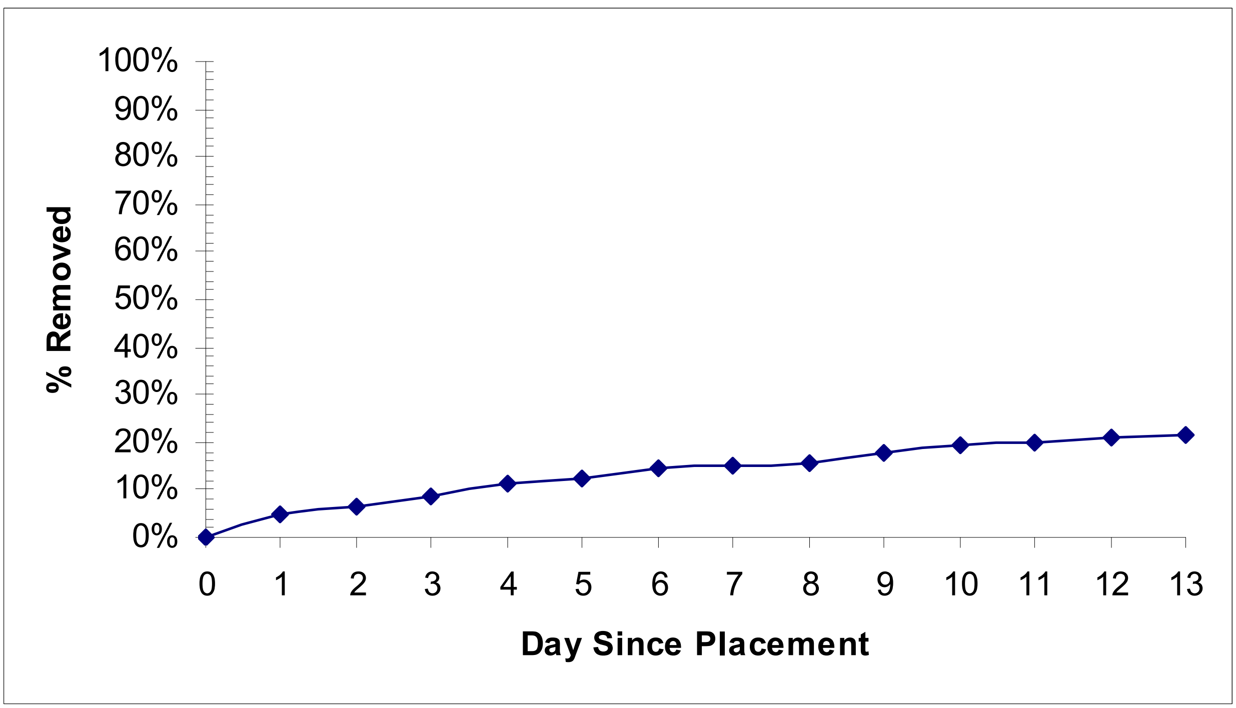


Figure 2-13. Removal by scavengers of fresh bat carcasses during carcass removal trials at the Meyersdale Wind Energy Center.

	Daily Searches				Weekly Searches			
			90% C.I.				90% C.I.	
Parameter	mean	se	ll	ul	mean	se	ll	ul
Search Area Adjustment								
A	1.09				1.09			
Observer Detection								
p_1	0.64	0.08	0.50	0.78	0.64	0.08	0.50	0.78
p_2	0.39	0.04	0.33	0.45	0.39	0.04	0.33	0.45
Observed Fatality Rates (Fatalities/turbine/6-weeks)								
$\bar{c}_{1j}$	2.51	0.45	1.82	3.32	0.36	0.12	0.18	0.55
$\bar{c}_{2j}$	12.79	1.09	11.00	14.64	1.99	0.35	1.45	2.57
$\bar{c}_1$	15.30	1.30	13.23	17.50	2.35	0.39	1.73	3.00
Average Probability of Carcass Availability and Detected								
$\hat{\pi}_{1i}$	0.58	0.07	0.47	0.70	0.25	0.05	0.17	0.34
$\hat{\pi}_{2i}$	0.42	0.03	0.37	0.47	0.18	0.02	0.14	0.22
Adjusted Fatality Estimates (Fatalities/turbine/6-week period)								
m_{1j}	4.37	0.96	2.96	6.07	1.52	0.61	0.66	2.62
m_{2j}	30.72	3.64	25.15	36.86	11.39	2.49	7.63	15.80
m_j	38.24	4.30	31.69	45.71	14.07	2.89	9.74	19.19
Daily Fatality Rates (Fatalities/turbine/day)								
d_{1j}	0.10	0.02	0.07	0.14	0.04	0.01	0.02	0.06
d_{2j}	0.73	0.09	0.60	0.88	0.27	0.06	0.18	0.38
d_j	0.91	0.10	0.75	1.09	0.33	0.07	0.23	0.46

Table 2-10. Bootstrap point estimates (mean) standard errors (se) and lower (ll) and upper (ul) of 90% confidence intervals for daily and weekly bat fatality rate estimation at the Mountaineer Wind Energy Center using two stratum (i=1 corresponds to area within 10 m of turbine, i=2 corresponds to area >10 m from turbine).

study in the searched area and was found during weekly searches at Mountaineer was 0.25 for areas within 10 m of turbines and 0.17 in searched areas farther than 10 m from turbines (Table 2-10). From weekly searches, 2.4 bat fatalities/turbine/6-week study period were observed and 9% of the actual fatalities occur in areas not searched within the 130 m x 120 m plots (A=1.09). The resulting fatality rate estimate is 14 bats/turbine/6-week study period (90% CI: 10, 19) at Mountaineer. The daily per turbine fatality rate was 0.33 bats/turbine/day (90% CI: 0.23, 0.46).

Mountaineer – Habitat Visibility Stratification. At Mountaineer, the estimated probability a bat fatality occurred during the study in the searched area and was found during daily searches was 0.51 for the high visibility areas, 0.45 in moderate visibility areas, and 0.29 in low visibility areas (Table 2-11). The resulting adjusted fatality rate estimate was 37.8 bats/turbine/6-week study period (90% CI: 31, 45). The daily fatality rate was 0.90 per turbine (90% CI: 0.74, 1.07). For weekly searches, the estimated probability a bat fatality occurred during the study in the searched area and was found was 0.26 for high visibility areas, 0.20 for moderate visibility areas and 0.08 for low visibility areas. The resulting fatality rate estimate was 16.5 bats/turbine/6-week study period (90% CI: 10.6, 24.1) and the daily per turbine fatality rate was 0.39 bats/turbine/day (90% CI: 0.25, 0.57).

Meyersdale – Distance from Turbine Stratification. At Meyersdale, the estimated probability a bat fatality occurred during the study in the searched area and was found during daily searches was 0.93 for the area within 10 m of turbines and 0.71 in searched areas farther than 10 m from turbines (Table 2-12). From daily searches, we estimated that 16.4 bats/turbine/6-week study period were observed and that 3.5% of fatalities occurred in areas not searched within the 130 m x 120 m plots (A=1.035). The resulting adjusted fatality rate estimate was 23 bats/turbine/6-week study period (90% CI: 19, 28). The daily fatality rate was 0.56 per turbine (90% CI: 0.46, 0.67). For weekly searches, the estimated probability a bat fatality occurred during the study in the searched area and was found was 0.71 for the areas within 10 m of turbines and 0.27 in searched areas farther than 10 m from turbines (Table 2-12). From weekly searches, 24 bat fatalities/turbine/6-week study period were observed and that 3.5% of

	Daily Searches				Weekly Searches			
			90% C.I.				90% C.I.	
Parameter	mean	se	ll	ul	mean	se	ll	ul
Search Area Adjustment								
A	1.09				1.09			
Observer Detection								
p_1	0.65	0.05	0.56	0.74	0.65	0.05	0.56	0.74
p_2	0.46	0.07	0.35	0.56	0.46	0.07	0.35	0.56
p_3	0.17	0.04	0.10	0.25	0.17	0.04	0.10	0.25
Observed Fatality Rates (Fatalities/turbine/6-weeks)								
$\overline{c}_{1j}$	5.40	0.48	4.61	6.18	0.86	0.16	0.61	1.14
$\overline{c}_{2j}$	1.50	0.21	1.18	1.84	0.16	0.07	0.05	0.30
$\overline{c}_{3j}$	0.91	0.19	0.61	1.23	0.25	0.08	0.14	0.39
$\overline{c}_{1}$	7.81	0.63	6.80	8.89	1.27	0.21	0.93	1.61
Probability of Carcass Availability and Detected								
$\hat{\pi}_{1i}$	0.51	0.04	0.45	0.57	0.26	0.03	0.21	0.31
$\hat{\pi}_{2i}$	0.45	0.04	0.38	0.51	0.20	0.03	0.15	0.25
$\hat{\pi}_{3i}$	0.29	0.06	0.19	0.40	0.08	0.03	0.04	0.13
Adjusted Fatality Estimates (Fatalities/turbine/6-week period)								
m_{1j}	21.27	2.42	17.51	25.47	6.70	1.45	4.52	9.22
m_{2j}	6.79	1.13	5.07	8.71	1.62	0.78	0.51	3.06
m_{3j}	6.58	2.24	3.78	10.55	6.82	3.41	2.74	13.09
m_j	37.76	4.33	31.20	45.09	16.50	4.32	10.55	24.07
Daily Fall Fatality Rates (Fatalities/turbine/day)								
d_{1j}	0.51	0.06	0.42	0.61	0.16	0.03	0.11	0.22
d_{2j}	0.16	0.03	0.12	0.21	0.04	0.02	0.01	0.07
d_{3j}	0.16	0.05	0.09	0.25	0.16	0.08	0.07	0.31
d_j	0.90	0.10	0.74	1.07	0.39	0.10	0.25	0.57

Table 2-11. Bootstrap point estimates (mean) standard errors (se) and lower (ll) and upper (ul) of 90% confidence intervals for daily and weekly bat fatality rate estimation at the Mountaineer Wind Energy Center using three habitat stratum (i=1 corresponds to areas with high visibility, i=2 corresponds to areas with moderate visibility, and i=3 corresponds to areas with low visibilty).

	Daily Searches				Weekly Searches			
			90% C.I.				90% C.I.	
Parameter	mean	se	ll	ul	mean	se	ll	ul
Search Area Adjustment								
A	1.04				1.04			
Observer Detection								
p_1	0.63	0.09	0.47	0.75	0.63	0.09	0.47	0.75
p_2	0.18	0.03	0.12	0.24	0.18	0.03	0.12	0.24
Observed Fatality Rates (Fatalities/turbine/6-weeks)								
$\bar{c}_{1j}$	1.81	0.52	1.00	2.70	1.11	0.36	0.60	1.70
$\bar{c}_{2j}$	14.60	1.26	12.50	16.60	6.39	1.04	4.80	8.20
$\bar{c}_{1}$	16.40	1.47	14.00	18.80	7.50	1.20	5.60	9.50
Average Probability of Carcass Availability and Detected								
$\hat{\pi}_{1i}$	0.93	0.02	0.89	0.96	0.71	0.06	0.60	0.81
$\hat{\pi}_{2i}$	0.71	0.05	0.62	0.78	0.27	0.05	0.20	0.35
Adjusted Fatality Estimates (Fatalities/turbine/6-week period)								
m_{1j}	1.95	0.56	1.07	2.90	1.57	0.54	0.77	2.53
m_{2j}	20.74	2.43	17.02	25.02	24.17	6.00	15.90	35.03
m_j	23.48	2.69	19.35	28.23	26.64	6.35	17.85	37.99
Daily Fall Fatality Rates (Fatalities/turbine/day)								
d_{1j}	0.05	0.01	0.03	0.07	0.04	0.01	0.02	0.06
d_{2j}	0.49	0.06	0.41	0.60	0.58	0.14	0.38	0.83
d_j	0.56	0.06	0.46	0.67	0.63	0.15	0.42	0.90

Table 2-12. Bootstrap point estimates (mean) standard errors (se) and lower (ll) and upper (ul) of 90% confidence intervals for daily and weekly bat fatality rate estimation at the Meyersdale Wind Energy Center using two stratum (i=1 corresponds to area within 10 m of turbine, i=2 corresponds to area >10 m from turbine).

fatalities occurred in areas not searched within the 130 m x 120 m plots (A=1.035). The resulting fatality rate estimate was 27 bats/turbine/6-week study period (90% CI: 18, 38) and the daily per turbine fatality rate was 0.63 bats/turbine/day (90% CI: 0.42, 0.92).

Meyersdale – Visibility Stratification. At Meyersdale, the estimated probability a bat fatality occurred during the study in the searched area and was found during daily searches was 0.90 for the high visibility areas, 0.70 in moderate visibility areas, and 0.51 in low visibility areas (Table 2-11). The resulting adjusted fatality rate estimate was 25.1 bats/turbine/6-week study period (90% CI: 20, 33). The daily fatality rate was 0.60 per turbine (90% CI: 0.48, 0.78). For weekly searches, the estimated probability a bat fatality occurred during the study in the searched area and was found was 0.60 high visibility areas, 0.27 for moderate visibility areas and 0.16 for low visibility areas. The resulting fatality rate estimate was 29.8 bats/turbine/6-week study period (90% CI: 19.8, 45.5) and the daily per turbine fatality rate was 0.71 bats/turbine/day (90% CI: 0.47, 1.08).

DISTANCE Sampling. The estimated detection probabilities from distance sampling in areas greater than 10 m from turbines using distance sampling were significantly lower than the corresponding estimates from the searcher efficiency trials at Mountaineer. Using the distance sampling estimates, the fatality rates would increase by approximately 30%, yielding approximately 45 bat fatalities/turbine/6-week period at Mountaineer, and 30 bat fatalities/turbine/6-week period at the Meyersdale. Both methods of analysis rely on several different assumptions such as the form of the distance function in the distance sampling approach, and the assumed representative nature of carcasses using the searcher efficiency approach.

Bat Fatalities Relative to FAA Lighting and Anemometers

Bat fatalities were similar between turbines equipped with FAA lights and those that were unlit. At Mountaineer, an average of 9.3 (± 0.5 SE) bat fatalities/turbine were found at lit turbines compared to an average of 9.7 (± 0.3 SE) fatalities/turbine at unlit turbines (Table 2-14). Similarly, at Meyersdale an average of 11.9 bats/turbine (± 1.7 SE) were found at lit turbines compared to 13.2 bats/turbine (± 1.2 SE) at unlit turbines (Table 2-14). These data suggest that observed variations in fatality per turbine were not attributable to the FAA L-864 red strobe lighting mounted on certain turbines within the string.

	Daily Searches				Weekly Searches			
			90% C.I.				90% C.I.	
Parameter	mean	se	ll	ul	mean	se	ll	ul
Search Area Adjustment								
A	1.04				1.04			
Observer Detection								
p_1	0.48	0.07	0.37	0.60	0.48	0.07	0.37	0.60
p_2	0.18	0.05	0.10	0.25	0.18	0.05	0.10	0.25
p_3	0.10	0.05	0.03	0.18	0.10	0.05	0.03	0.18
Observed Fatality Rates (Fatalities/turbine/6-weeks)								
$\bar{c}_{1j}$	4.00	0.48	3.25	4.80	4.00	0.48	3.25	4.80
$\bar{c}_{2j}$	3.31	0.38	2.70	3.95	3.31	0.38	2.70	3.95
$\bar{c}_{3j}$	1.25	0.29	0.80	1.75	1.25	0.29	0.80	1.75
$\bar{c}_1$	8.55	0.71	7.40	9.70				
Probability of Carcass Availability and Detected								
$\hat{\pi}_{1i}$	0.90	0.03	0.85	0.93	0.60	0.06	0.50	0.70
$\hat{\pi}_{2i}$	0.70	0.08	0.55	0.80	0.27	0.06	0.16	0.37
$\hat{\pi}_{3i}$	0.51	0.15	0.20	0.72	0.16	0.07	0.04	0.27
Adjusted Fatality Estimates (Fatalities/turbine/6-week period)								
m_{1j}	8.92	1.11	7.17	10.85	7.76	1.77	5.16	10.89
m_{2j}	9.65	1.74	7.38	12.61	15.71	5.97	8.83	26.44
m_{3j}	5.69	3.75	2.71	12.05	5.33	6.21	0.83	14.84
m_j	25.11	4.58	20.12	32.67	29.81	9.06	19.78	45.51
Daily Fall Fatality Rates (Fatalities/turbine/day)								
d_{1j}	0.21	0.03	0.17	0.26	0.18	0.04	0.12	0.26
d_{2j}	0.23	0.04	0.18	0.30	0.37	0.14	0.21	0.63
d_{3j}	0.14	0.09	0.06	0.29	0.13	0.15	0.02	0.35
d_j	0.60	0.11	0.48	0.78	0.71	0.22	0.47	1.08

Table 2-13. Bootstrap point estimates (mean) standard errors (se) and lower (ll) and upper (ul) of 90% confidence intervals for daily and weekly bat fatality rate estimation at the Meyersdale Wind Energy Center using three habitat stratum (i=1 corresponds to areas with high visibility, i=2 corresponds to areas with moderate visibility, and i=3 corresponds to areas with low visibilty).

	Mountaineer		Meyersdale	
	Lit	Unlit	Lit	Unlit
No. of Turbines	12	32	6	14
Total No. of Fatalities Found	112	311	71	185
Mean No. of Fatalities/Turbine (SE)	9.3 (0.5)	9.7 (0.3)	11.9 (1.7)	13.2 (1.2)

Table 2-14. Average number of bat carcasses found at turbines lit with FAA aviation strobe lights compared to those at unit turbines at the Mountaineer at Meyersdale Wind Energy Centers.

Bat fatalities continued to occur at turbines with disabled anemometers at both sites. Observed fatality rates were slightly less at turbines with the anemometers turned off than at turbines with operating anemometers, however the differences were not statistically significant (Mountaineer: $p = 0.18$, Meyersdale: $p = 0.53$). At Mountaineer, the average number of bat fatalities/turbine during the period when the anemometers were shut off was 3.91 ($\pm$ 0.61) and during the same period the average was 5.73 ($\pm$ 1.15) at the remaining turbines searched using the same search interval. At Meyersdale, the average number of bat fatalities/turbine during the period when the anemometers were shut off was 8.8 ($\pm$ 0.97), and during the same period the average was 10.2 ($\pm$ 1.88) at the remaining turbines searched using the same search interval.

Temporal Pattern of Bat Fatalities

We used the number of fresh bat fatalities found on a given day divided by the total number of turbines searched on the same day (pooled across all turbines searched that day) as an index for assessing the temporal pattern of bat fatalities. Bat fatality varied greatly by date during the 6-week study period and the timing of bat fatality was highly correlated ($r = 0.80$) between the two sites (Figure 2-14). At both sites, the highest fatalities were found on 2 August 2004 and 1 September 2004, with a smaller peak of fatality occurring on 22 August 2004. Although we found more male bat fatalities compared to females, the timing of bat fatalities by sex was similar throughout the study period (Figure 2-15). At both sites, the most common bat species fatalities found (hoary bats and red bats) were distributed throughout the study period, and there was a positive correlation in the timing of fatality for these two species at both sites (Figure 2-16). At Mountaineer, eastern pipistrelles were found on most search days, with large numbers of this species found on 22 August (Figure 2-17). Other less common species appeared more sporadic in the timing of fatality at Mountaineer. At both sites, only two occurrences of silver-haired bats were recorded prior to 30 August 2004. At Mountaineer, silver-haired bats were then found every day from 30 August to 5 September and again on 10 and 11 September. At Meyersdale, silver-haired bats, all females, were found from 3–13 September and no little brown bats were observed in September. Conversely, big brown bats were seldom found at either site in September (1 at Mountaineer, 2 at Meyersdale).

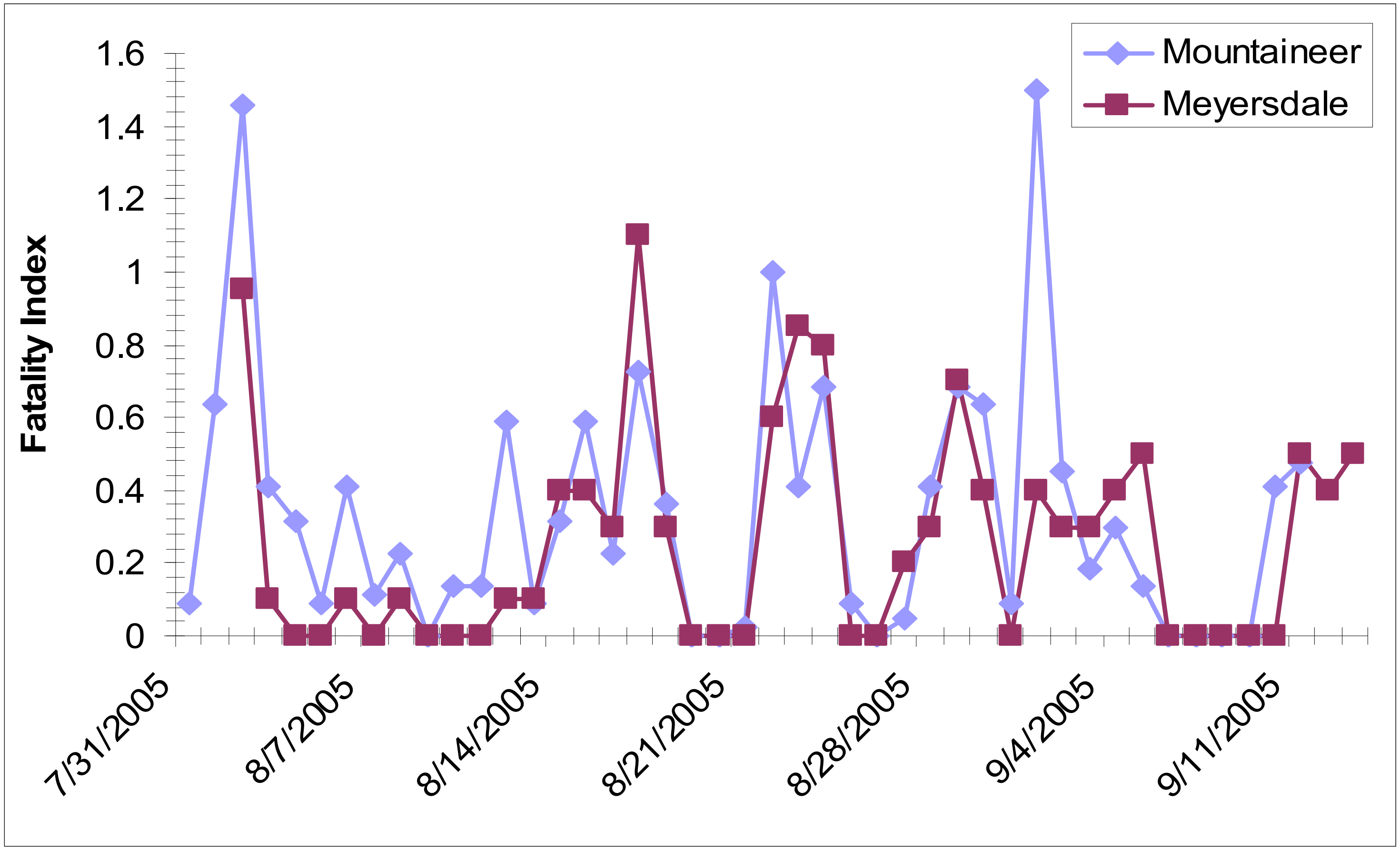


Figure 2-14. Fatality index (number of fresh bat fatalities/number of turbines searched) depicting the timing of fresh bat fatalities by date at the Mountaineer and Meyersdale Wind Energy Centers.

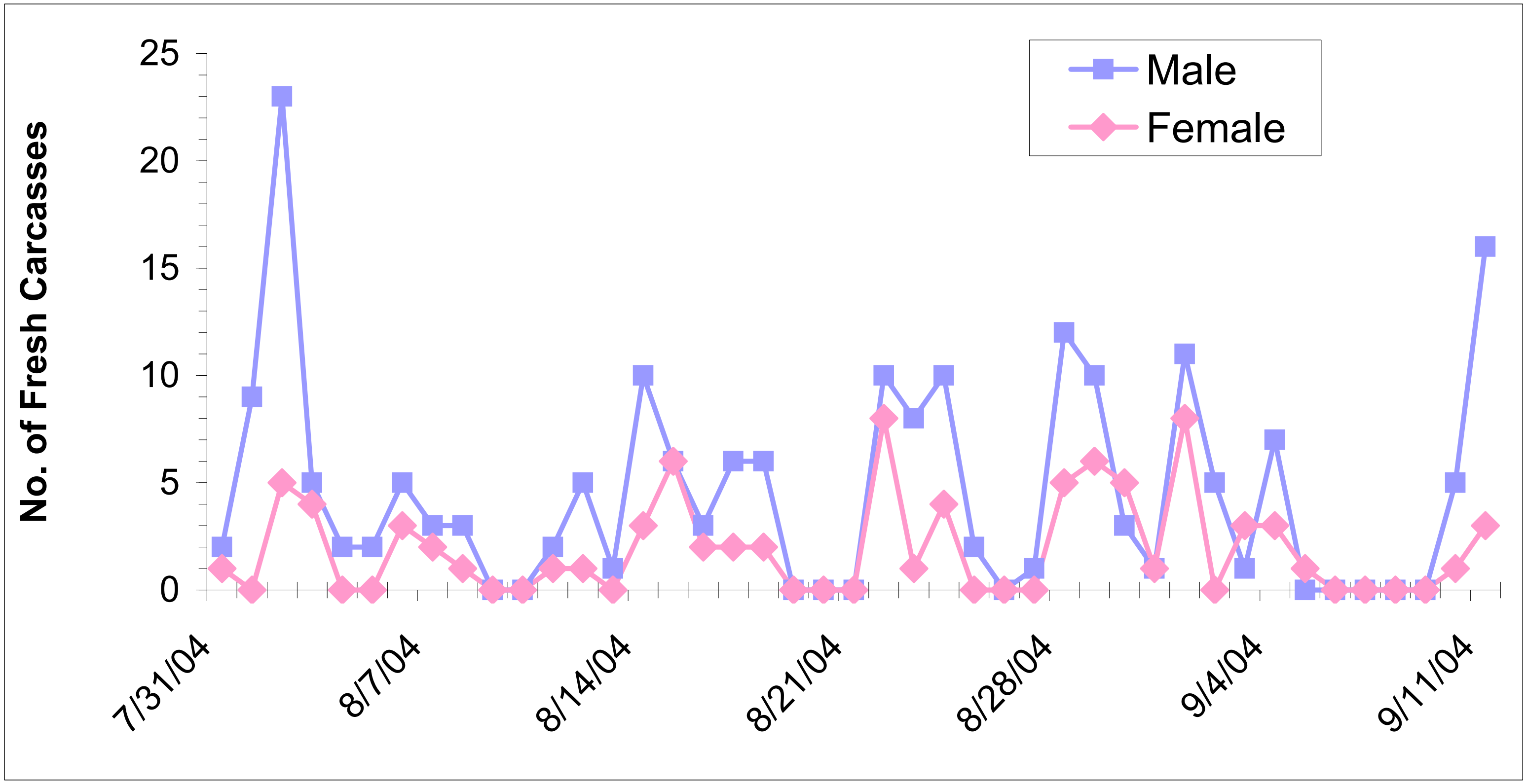


Figure 2-15. Number of fresh bat fatalities by sex for each day of the study at the Mountaineer and Meyersdale Wind Energy Centers.

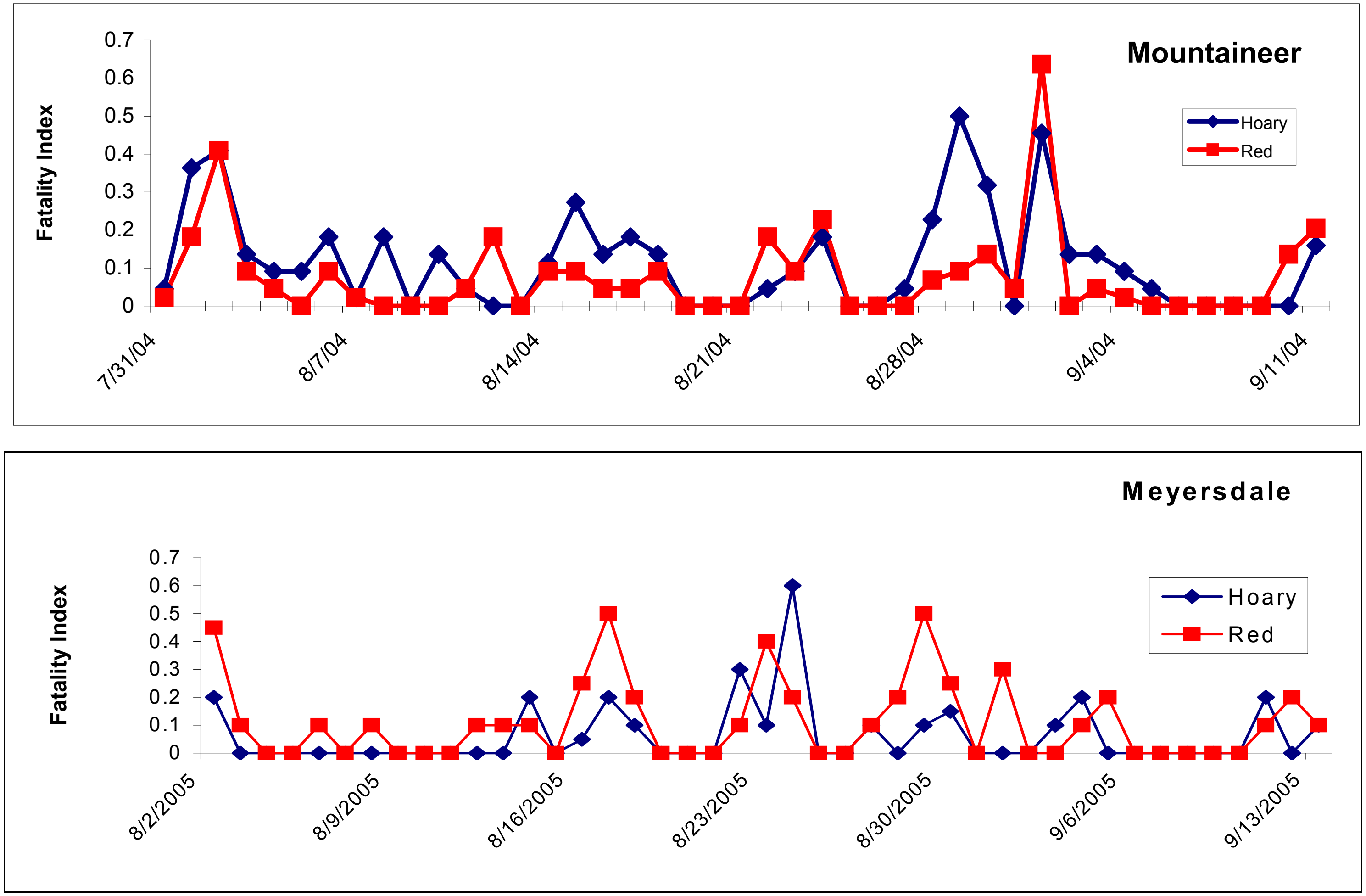
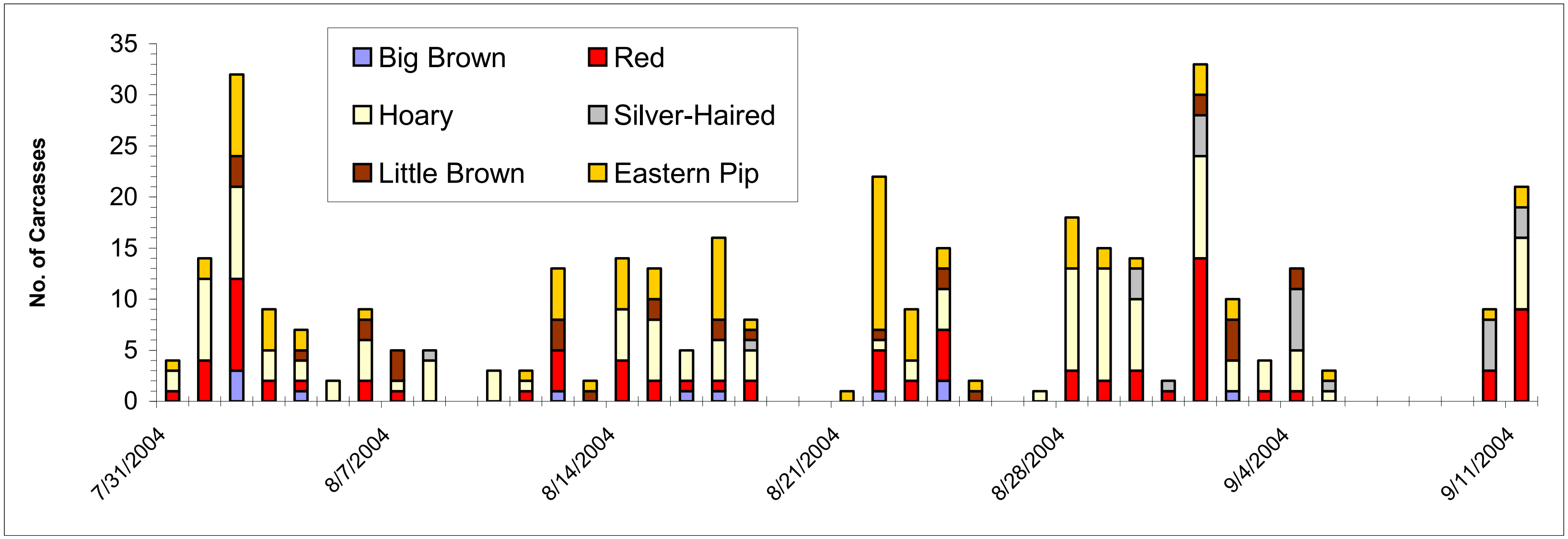


Figure 2-16. Fatality index (number of fresh bat fatalities/number of turbines searched) depicting the timing of fresh hoary and red bat fatalities by date at the Mountaineer and Meyersdale Wind Energy Centers.



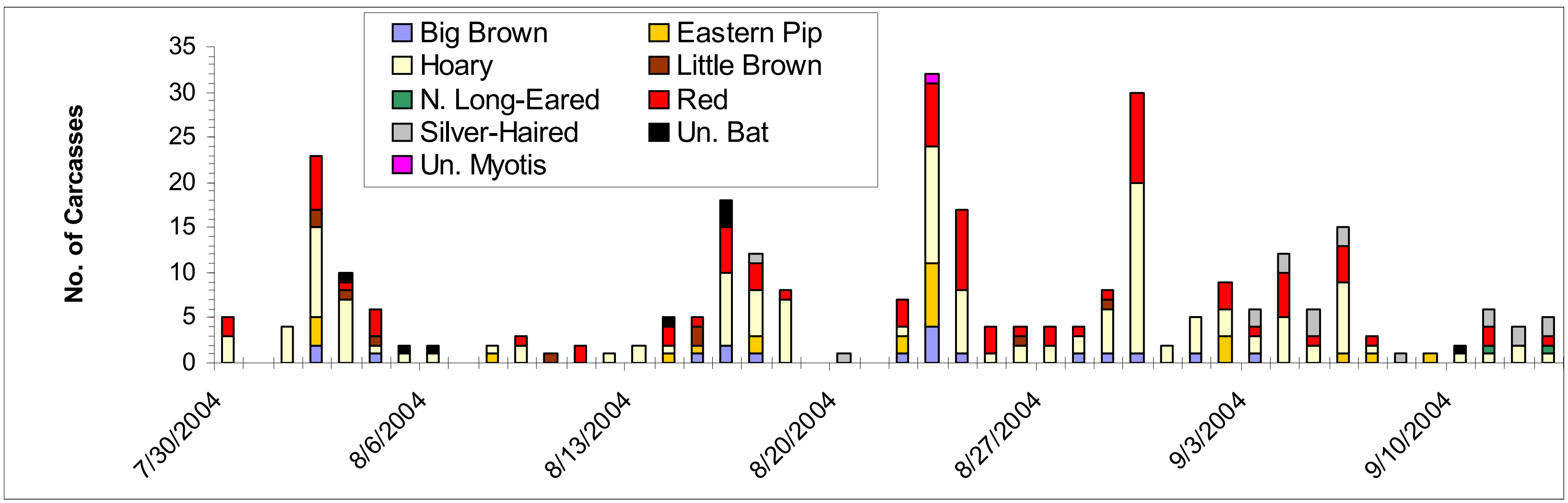


Figure 2-17. Number of fresh bat fatalities by species for each day of the study at the Mountaineer and Meyersdale Wind Energy Centers.

Associations between Turbine and Weather Characteristics and Bat Fatalities

Univariate Analyses. Many of the nightly weather and turbine characteristics showed an association with fresh bat fatalities found the next day and relationships were consistent between the two sites (Table 2-15). Factors relating to wind speed were significantly related to bat fatality and all values indicated that higher wind speeds were associated with lower fatality rates. Median nightly wind speed at turbines was negatively related to bat fatality ($r = -0.586$, $p < 0.001$ at Mountaineer; $r = -0.64$, $p < 0.001$ at Meyersdale, Figure 2-18). The proportion of 10 min intervals from 2000–0600 hr when wind speed was <4 m/sec was positively related to bat fatalities ($r = 0.561$, $p < 0.001$ at Mountaineer; $r = 0.624$, $p < 0.001$ at Meyersdale), whereas the reverse was true for proportion of the night when winds were >6 m/sec ($r = -0.634$, $p < 0.001$ at Mountaineer; $r = -0.66$, $p < 0.001$ at Meyersdale, Figure 2-19). Average nightly turbine blade speed (RPM) was negatively related to observed fatality rates ($r = -0.439$, $p = 0.003$ at Mountaineer; $r = -0.537$, $p < 0.001$ at Meyersdale). Higher barometric pressure was associated with higher bat fatality rates at both sites, but more so at Meyersdale ($r = 0.313$, $p = 0.09$). Relative humidity, which was only collected at the Meyersdale, was negatively related to bat fatality rates ($r = -0.302$, $p = 0.11$). Temperature did not show an association with fatality rates at Mountaineer ($r = 0.063$, $p = 0.68$), but there was a positive association between temperature and fatality at Meyersdale ($r = 0.244$, $p = 0.11$). Lower relative humidity and higher barometric pressure were typically associated with conditions after weather fronts passed through the area.

We also found a relationship between bat fatalities and presence of percent of the night raining (an index to presence of storm fronts). Few bat fatalities were discovered during the storms while the highest number of fatalities occurred in the few days after the storm, especially on low wind nights (Figure 2-20).

Turbine blades can rotate at a maximum speed of 17 RPM at wind speeds from 3–4 m/s (Dan Mandli, FPL Energy, pers. commun.). During 8 nights when no bats were found the following day at Mountaineer, median wind speeds averaged more than twice that for the 5 nights when the most bats were killed at this site (Table 2-16). However, turbine RPM averaged 15.6 and 12.4 for the nights of lowest and highest kills, respectively, indicating that blades were moving at rapid speeds even on low wind nights. One of the 8 nights when no bats were found the following day was a disproportionately low wind night relative to the remaining 7 nights that had consistently high winds; this low wind night accounted for the large variation for all

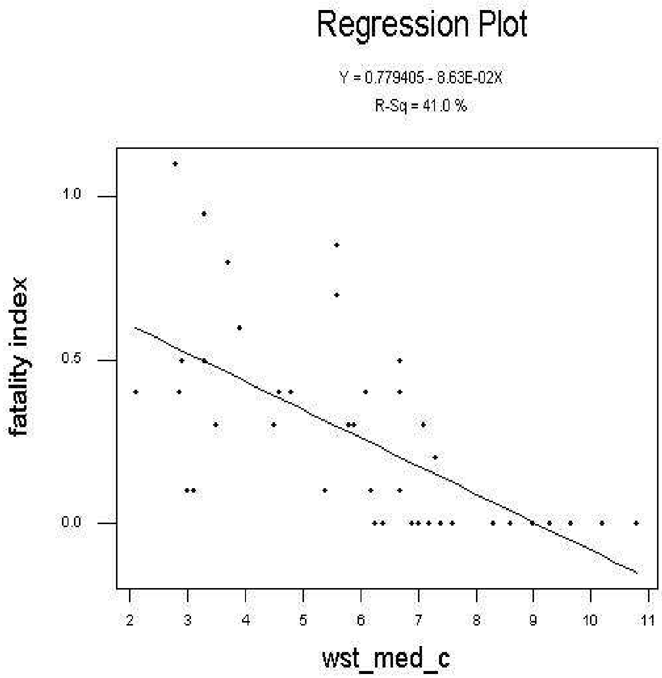
Mountaineer						
Variable	B_o	B_1	se	p	R^2	r
temperature (avg. nightly)	0.155	0.007	0.017	0.682	0.004	0.063
humidity (avg. nightly)	No	data				
pressure (avg. nightly)	-14.895	0.017	0.012	0.174	0.043	0.207
wind speed (median nightly)	0.729	-0.074	0.016	<0.001	0.344	-0.586
variation in wind speed	0.406	-0.193	0.062	0.003	0.183	-0.428
proportion of w.s.<4 m/sec	0.127	0.006	0.001	<0.001	0.315	0.561
proportion of w.s.4-6 m/sec	0.103	0.007	0.002	0.003	0.187	0.432
proportion of w.s.>6 m/sec	0.505	-0.005	0.001	<0.001	0.406	-0.637
turbine blade rpm	0.902	-0.044	0.014	0.003	0.192	-0.439
rain or a storm during >10% of the night (categorical var.)	0.324	-0.179	0.116	0.130	0.055	-0.235
temperature (squared)	0.204	0.0002	0.0005	0.621	0.006	0.078
wind speed (squared)	0.501	-0.005	0.001	<0.001	0.314	-0.560
pressure (squared)	-7.305	$9.59e^{-6}$	$7.11e^{-6}$	0.185	0.043	0.206

Meyersdale						
Variable	B_o	B_1	se	p	R^2	r
temperature (avg. nightly)	-0.266	0.027	0.016	0.107	0.059	0.244
humidity (avg. nightly)	1.202	-0.012	0.007	0.106	0.091	-0.302
pressure (avg. nightly)	-26.811	0.030	0.017	0.093	0.098	0.313
wind speed (median nightly)	0.779	-0.086	0.016	<0.001	0.410	-0.640
variation in wind speed	0.314	-0.132	0.138	0.349	0.031	-0.177
proportion of w.s.<4 m/sec	0.110	0.006	0.001	<0.001	0.389	0.624
proportion of w.s.4-6 m/sec	0.183	0.003	0.002	0.201	0.038	0.194
proportion of w.s.>6 m/sec	0.536	-0.006	0.001	<0.001	0.436	-0.660
turbine blade rpm	0.907	-0.045	0.011	<0.001	0.289	-0.537
rain or a storm during >10% of the night (categorical var.)	0.300	-0.225	0.113	0.052	0.089	-0.298
temperature (squared)	-0.014	0.0007	0.0004	0.111	0.061	0.247
wind speed (squared)	0.533	-0.007	0.001	<0.001	0.383	-0.619

B_o = constant or intercept
B_1 = slope coefficient
se = standard error for slope coefficient
p = p-value for test of B_1=0
R^2 = R-squared for regression
r = Pearson's correlation coefficient

Table 2-15. Univariate regressions and correlations between nightly weather and turbine characteristics and nightly fresh bat fatality rates at the Mountaineer and Meyersdale Wind Energy Centers.

MOUNTAINEER



MEYERSDALE

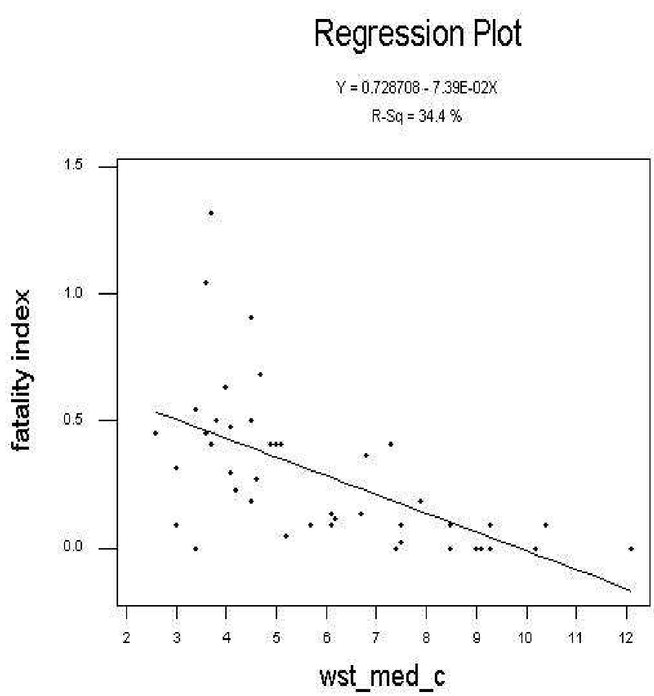
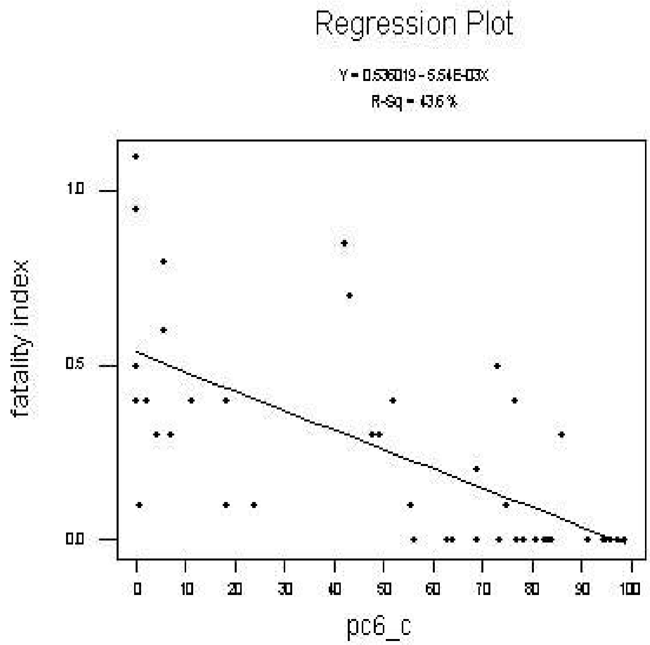


Figure 2-18. Plots and regression analysis of the fresh bat fatalities/turbine/night against the median wind speeds (m/sec, wst_med_c) measured at the turbines.

MOUNTAINEER



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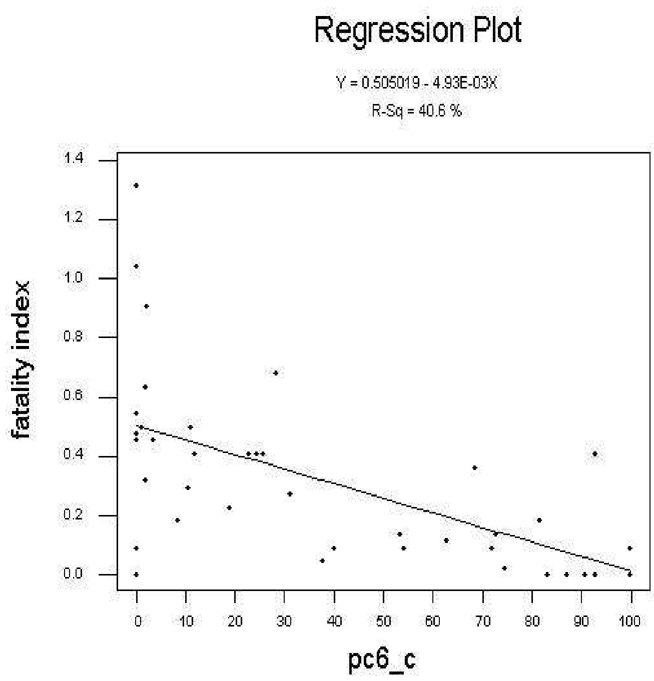


Figure 2-19. Plots and regression analysis of the fresh bat fatalities/turbine/night against the average percentage of the night where wind speeds are greater than 6 m/sec (%, pc6_c) measured at the turbines.

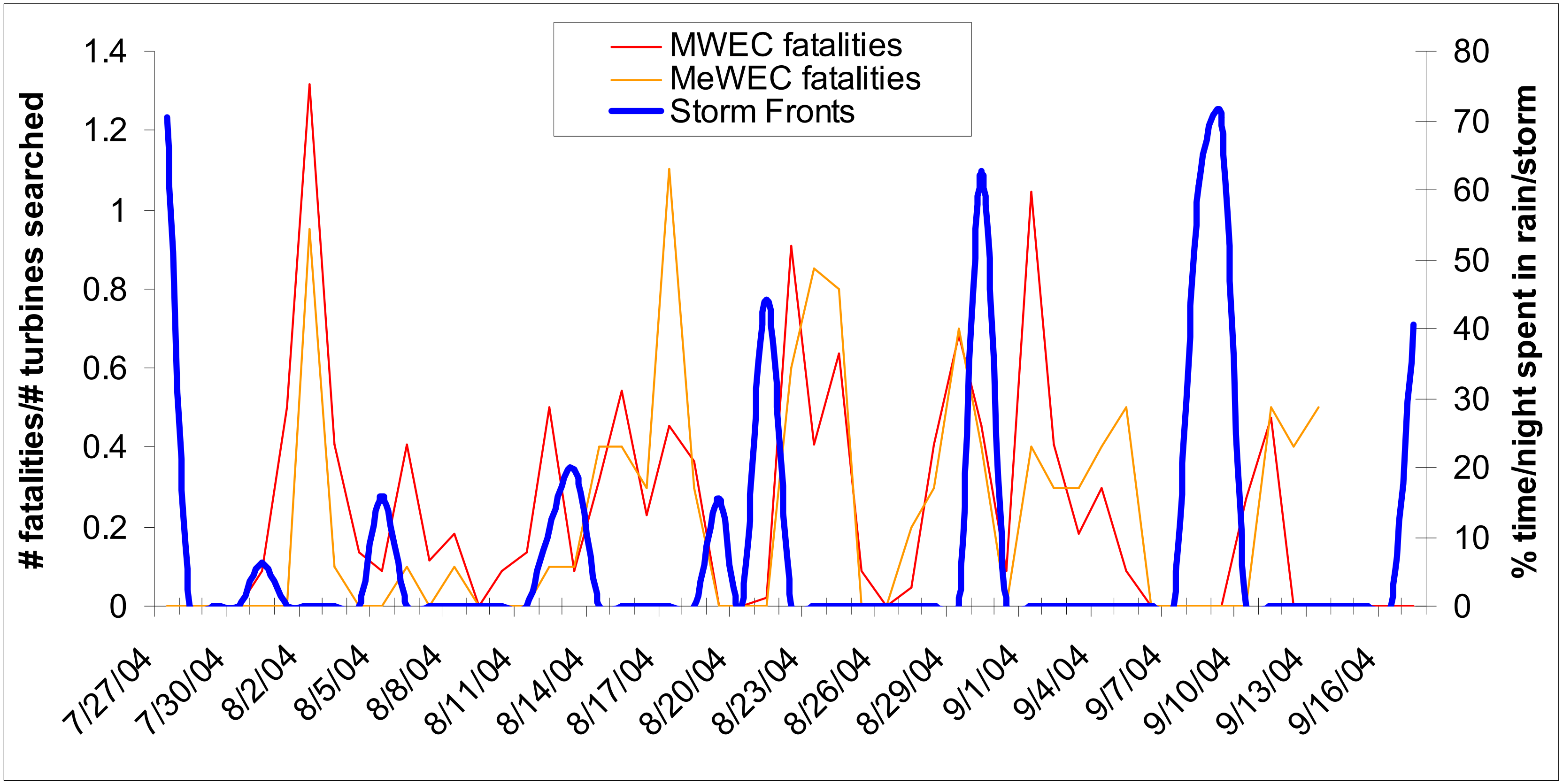


Figure 2-20. Number of fresh bat fatalities in relation to the percent of the night raining by study day at the Mountaineer and Meyersdale Wind Energy Centers.

	Lowest # Found (n=8*)			Highest # Found (n=5)		
	Mean	SD	Range	Mean	SD	Range
wind speed (median nightly; m/s)	8.6	2.5	3.4–12.1	4.1	0.5	3.6–4.7
proportion of wind <4 m/sec	10.1	25.9	0–74.2	49.4	21.2	28.7–77.1
proportion of wind 4–6 m/sec	8.1	8.6	0–25.8	44.1	17.1	22.9–69
proportion of wind >6 m/sec	81.7	33.6	0–100	6.5	12.2	0–28.3
turbine blade speed (mean rpm)	15.9	1.7	11.5–16.8	12.4	1.8	11.4–15.1

Table 2-16. Mean, standard deviation, and range for median nightly wind speed at turbines, the proportion of 10 minute intervals from 2000–0600 hr when wind speed was <4 m/s, 4–6 m/s, and >6 m/s, and blade rotation speed for 8 nights when no bats were found the following day and 5 nights with the highest number of bats were found at the Mountaineer Wind Energy Facility.

	Lowest # Found (n=17)			Highest # Found (n=5)		
	Mean	SD	Range	Mean	SD	Range
wind speed (median nightly; m/s)	8.0	1.4	6.3–10.8	4.2	1.3	2.8–5.6
proportion of wind <4 m/sec	3.5	2.4	0.1–7.5	54.6	29.1	20.9–88.3
proportion of wind 4–6 m/sec	15.9	13.0	0–38.9	27.2	11.1	11.7–38.6
proportion of wind >6 m/sec	81.6	13.1	56.5–99	18.2	22.5	0–43.3
turbine blade speed (mean rpm)	16.6	0.6	14.9–17.1	11.5	2.9	8.5–15.8

Table 2-17. Mean, standard deviation, and range for median nightly wind speed, the proportion of 10 minute intervals from 2000–0600 hr when wind speed was <4 m/s, 4–6 m/s, and >6 m/s, and blade rotation speed for 17 nights when no bats were found the following day and 5 nights with the highest number of bats were found at the Meyersdale Wind Energy Facility.

variables at Mountaineer (Table 2-16). Similar patterns were found at Meyersdale; for the 17 nights when no bats were found the following day, median wind speeds averaged twice those of the 5 nights when most bats were found (Table 2-17), while turbine RPM averaged 16.6 and 11.4 for the nights of lowest and highest kills, respectively.

We also investigated associations between the nightly weather and turbine characteristics and the dichotomous dependent variable indicating high observed fatality rates (>0.30/turbine/night) or low ($\leq$0.30/turbine/night). Patterns were similar to that observed using univariate linear regressions (Table 15). Factors relating to wind speed and presence of storms/rain were significantly related to predicting a high or low bat fatality night with values indicating higher wind speeds were associated with low fatality (Table 18).

Multivariate Analyses. Assessments of the interaction between presence of storms and wind speed indicate that rainy nights with higher wind speeds were associated with extremely low observed bat fatalities (Figures 2-21, 2-22).

We fit multiple linear and multiple logistic regression models focusing on all possible two variable models and interactions. The best 8 linear regression models using AICc out of the possible models considered are reported in Table 2-19. The best multiple linear regression model selected at both sites included the storm/rain indicator variable and the proportion of the night with wind speeds >6 m/sec. Coefficients for these variables were similar among the two sites suggested the presence of regional storm fronts and high winds were associated with lower fatality rates at both sites. Other variables that occasionally showed up in the top 8 models of both sites included other wind speed variables (median and mean nightly wind speeds, proportion of night with wind speeds <4 m/sec, temperature, barometric pressure). The R^2 values for the top 8 models ranged from 0.41–0.52, indicating a moderate fit to the variation in the data.

The best 8 multiple logistic regression models using AICc out of the models considered are reported in Table 2-20. Again, similar variables associated with predicting the magnitude of bat fatalities also were associated with predicting the probability of a low or high bat fatality night. Nightly wind speeds (mean and median) were consistently in the top models for both sites, while the presence/absence of storms was occasional observed in the top models for both sites.

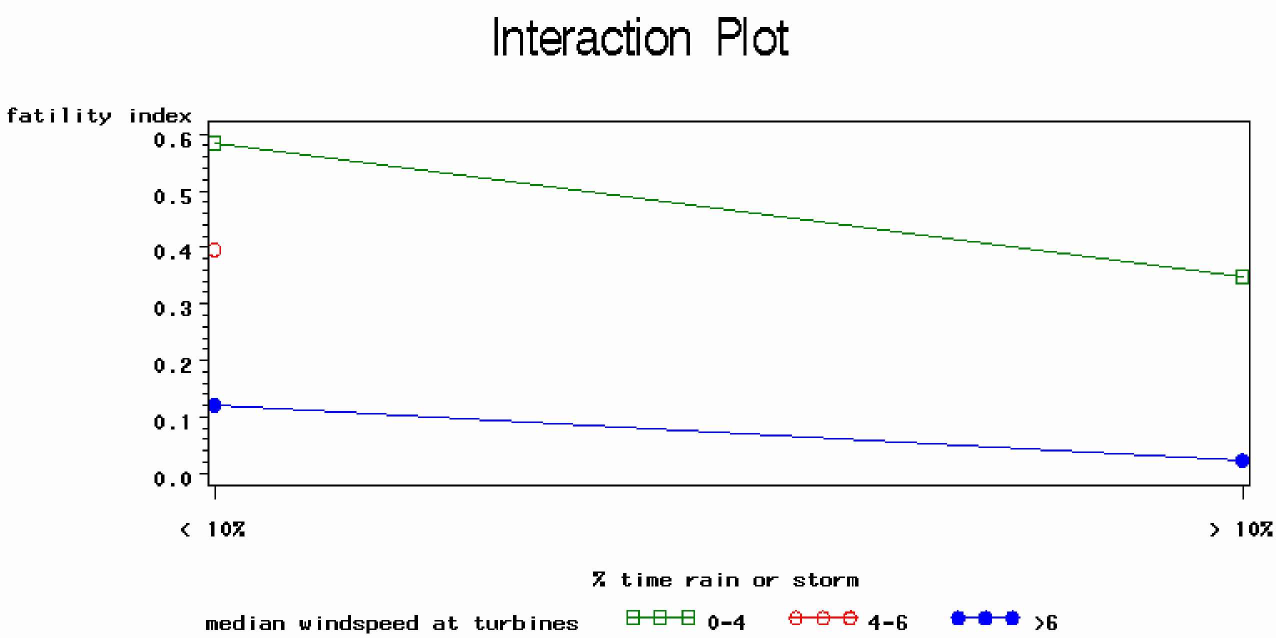
Mountaineer					
Variable	B_o	B_1	se	p	AICc
wind speed (squared)	1.932	-0.071	0.025	0.004	44.95
proportion of w.s.>6 m/sec	1.236	-0.043	0.013	<0.001	45.14
wind speed (median nightly)	3.947	-0.786	0.254	0.002	45.32
proportion of w.s.<4 m/sec	-1.770	0.050	0.016	0.001	47.60
turbine blade rpm	6.588	-0.492	0.172	0.004	49.63
proportion of w.s.4-6 m/sec	-1.488	0.039	0.018	0.031	57.43
rain or a storm during >10% of the night (categorical var.)	-0.172	-0.927	0.884	0.295	61.56
pressure (avg. nightly)	-77.840	0.087	0.092	0.343	61.81
pressure (squared)	-39.025	$4.9\ e^{-5}$	$5.2\ e^{-5}$	0.344	61.82
temperature (squared)	-0.851	0.001	0.003	0.656	62.57
temperature (avg. nightly)	-1.073	0.039	0.120	0.743	62.66

Meyersdale					
Variable	B_o	B_1	se	p	AICc
wind speed (squared)	2.005	-0.078	0.025	0.002	42.19
wind speed (median nightly)	3.778	-0.786	0.241	0.001	43.10
proportion of w.s.>6 m/sec	1.232	-0.043	0.013	<0.001	43.85
proportion of w.s.<4 m/sec	-1.894	0.047	0.014	0.001	44.06
turbine blade rpm	4.923	-0.388	0.128	0.002	46.34
rain or a storm during >10% of the night (categorical var.)	-0.406	-1.540	1.123	0.170	57.44
temperature (avg. nightly)	-2.541	0.098	0.123	0.428	59.27
temperature (squared)	-1.614	0.003	0.003	0.420	59.26
proportion of w.s.4-6 m/sec	-0.909	0.011	0.017	0.506	59.48

B_o = constant or intercept
B_1 = slope coefficient
se = standard error for slope coefficient
p = p-value for test of B_1=0
AICc = second order variant of Akaike's Information Criterion

Table 2-18. Univariate logistic regressions, ranked by AICc value, for nightly weather and turbine characteristics and nightly fresh bat fatality rates at the Mountaineer and Meyersdale Wind Energy Centers.

MOUNTAINEER



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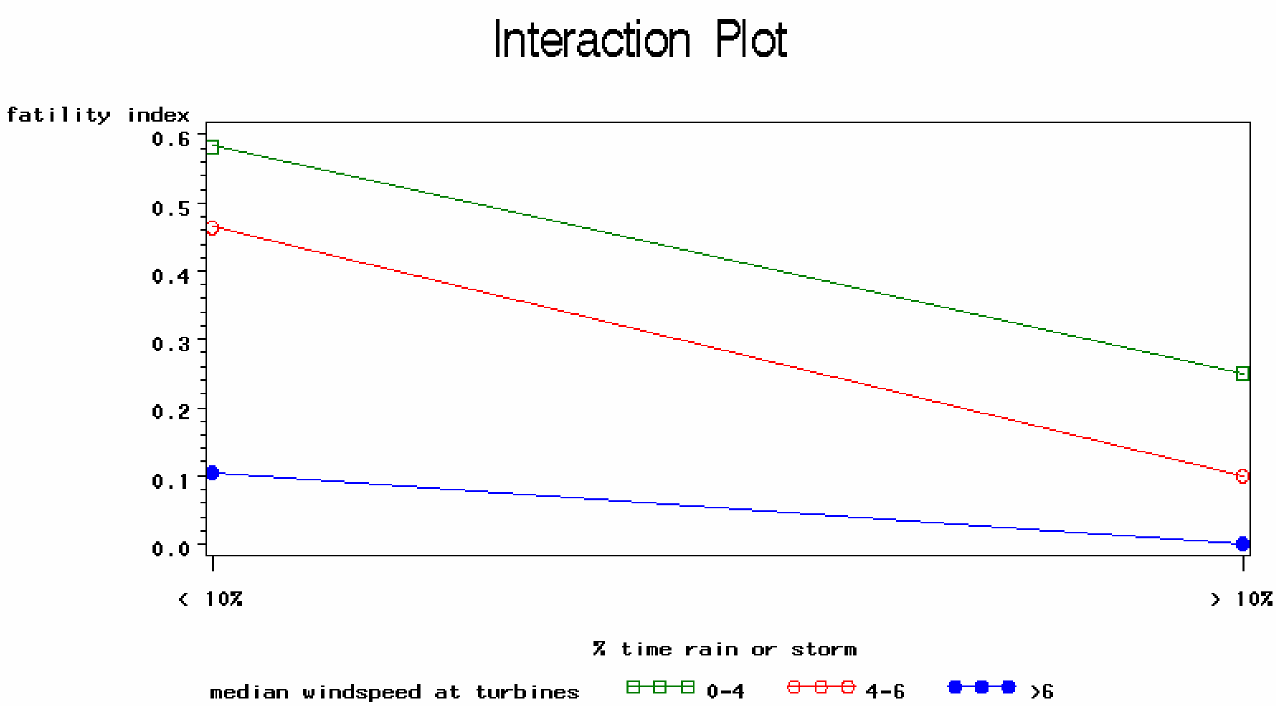
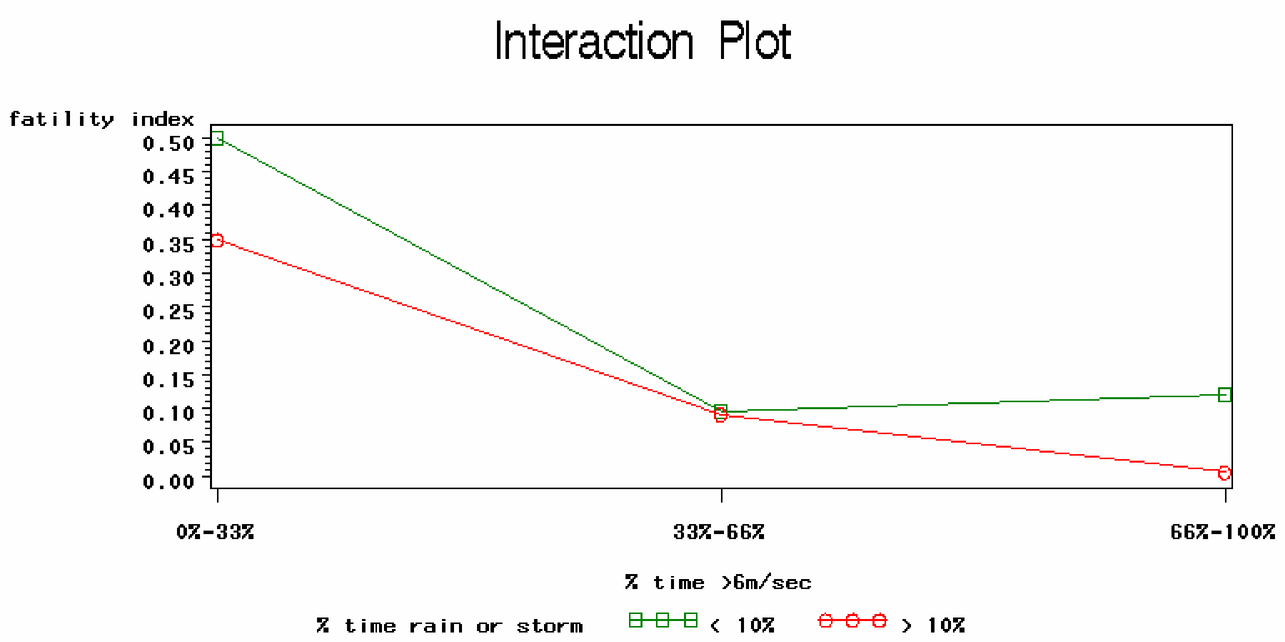


Figure 2-21. Plot of the average number of fresh bat fatalities per turbine per night ("fatality index") for levels of median nightly wind speed levels and for levels of the rain storm indicator variable.

MOUNTAINEER



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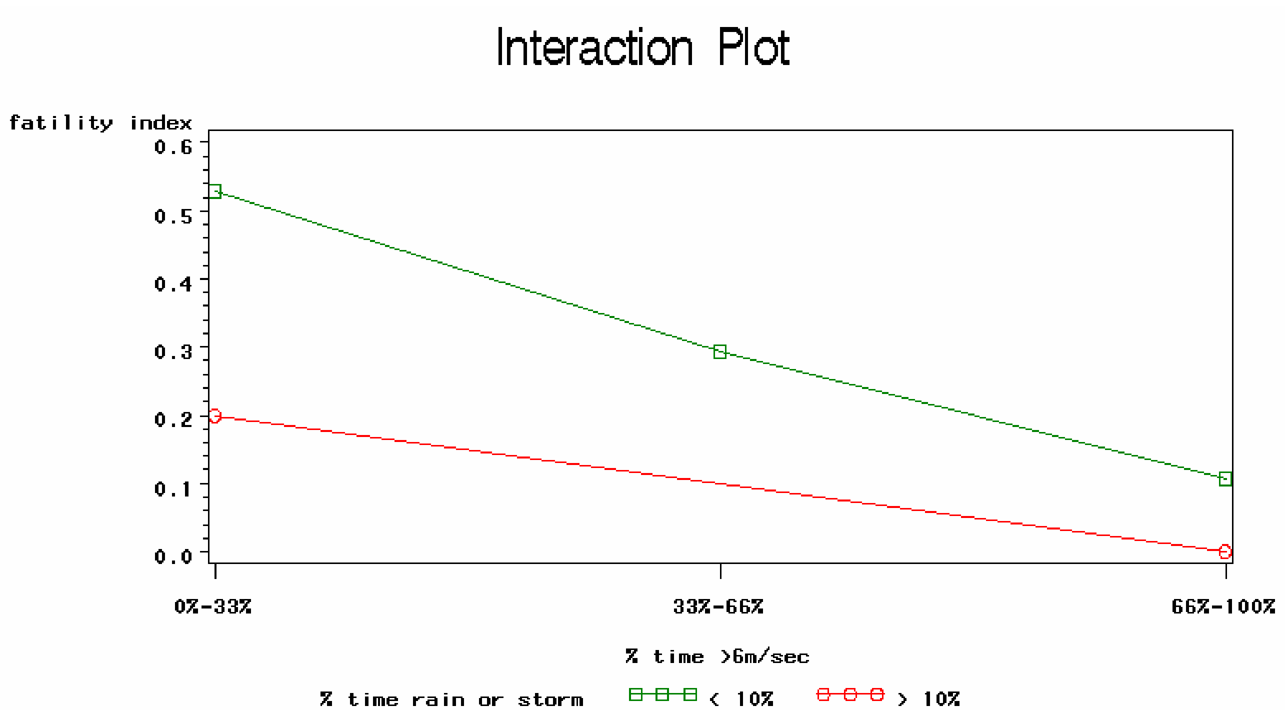

Figure 2-22. Plot of the average number of fresh bat fatalities per turbine per night ("fatality index") for levels of median nightly wind speed levels and for levels of the rain storm indicator variable.

	Mountaineer					Meyersdale			
Variable	Coeff	SE	P		Variable	Coeffic	SE	P	
Model 1	**AICc=**	**-125.040**	**R2=**	**0.44**	**Model 1**	**AICc=**	**-130.73**	**R2=**	**0.50**
Intercept	0.526	0.055	<.0001		Intercept	0.564	0.06	<.00	
pc6	-0.005	0.001	<.0001		pc6	-0.005	0.00	<.00	
r_s	-0.140	0.091	0.1297		r_s	-0.190	0.08	0.03	
Model 2	**AICc=**	**-124.197**	**R2=**	**0.43**	**Model 2**	**AICc=**	**-130.62**	**R2=**	**0.52**
Intercept	0.185	0.261	0.4829		Intercept	0.597	0.06	<.00	
pc6	-0.005	0.001	<.0001		pc6	-0.006	0.00	<.00	
tet_avg	0.017	0.014	0.2173		r_s	-0.368	0.15	0.02	
					pc6*r_s	0.003	0.00	0.16	
Model 3	**AICc=**	**-124.081**	**R2=**	**0.43**	**Model 3**	**AICc=**	**-128.59**	**R2=**	**0.47**
Intercept	-10.178	8.845	0.2567		Intercept	0.114	0.26	0.66	
pc6	-0.005	0.001	<.0001		pc6	-0.005	0.00	<.00	
pre_avg	0.012	0.010	0.2342		tet_avg	0.021	0.01	0.10	
Model 4	**AICc=**	**-124.038**	**R2=**	**0.46**	**Model 4**	**AICc=**	**-127.85**	**R2=**	**0.46**
Intercept	-0.201	0.375	0.5953		Intercept	0.151	0.05	0.00	
pc6	0.007	0.009	0.4162		pc2	0.006	0.00	<.00	
tet_avg	0.038	0.020	0.0647		r_s	-0.206	0.09	0.02	
pc6*tet_avg	-0.001	0.000	0.1647						
Model 5	**AICc=**	**-123.479**	**R2=**	**0.45**	**Model 5**	**AICc=**	**-127.84**	**R2=**	**0.46**
Intercept	0.059	0.071	0.4126		Intercept	0.792	0.10	<.00	
pc2	0.002	0.002	0.3684		r_s	-0.176	0.09	0.05	
pc4	0.001	0.003	0.7056		wst_med	-0.083	0.02	<.00	
pc2*pc4	0.000	0.000	0.0884						
Model 6	**AICc=**	**-123.456**	**R2=**	**0.45**	**Model 6**	**AICc=**	**-127.47**	**R2=**	**0.49**
Intercept	0.422	0.134	0.003		Intercept	0.858	0.11	<.00	
pc4	0.003	0.003	0.3219		r_s	-0.499	0.26	0.06	
pc6	-0.003	0.002	0.0477		wst_med	-0.094	0.02	<.00	
pc4*pc6	0.000	0.000	0.0895		r_s*wst_m	0.051	0.04	0.19	
Model 7	**AICc=**	**-122.927**	**R2=**	**0.44**	**Model 7**	**AICc=**	**-127.29**	**R2=**	**0.49**
Intercept	0.534	0.059	<.0001		Intercept	-0.214	0.43	0.62	
pc6	-0.005	0.001	<.0001		pc6	0.002	0.01	0.79	
r_s	-0.189	0.146	0.2026		tet_avg	0.038	0.02	0.08	
pc6*r_s	0.001	0.002	0.67		pc6*tet_av	0.000	0.00	0.34	
Model 8	**AICc=**	**-122.722**	**R2=**	**0.41**	**Model 8**	**AICc=**	**-127.25**	**R2=**	**0.48**
Intercept	0.420	0.214	0.057		Intercept	-0.247	0.49	0.61	
pc6	-0.005	0.001	0.0004		rpm_avg	0.057	0.03	0.08	
rpm_avg	0.007	0.018	0.683		wst_med	0.284	0.16	0.08	
					rpm_avg* wst_med	-0.022	0.01	0.03	

Table 2-19. The best 2-variable and possible interaction multiple regression models between nightly weather and turbine characteristics and nightly fresh bat fatality rates at the Mountaineer Wind Energy Center.

	Mountaineer				Meyersdale		
Variable	Coefficient	SE	P	Variable	Coefficient	SE	P
Model 1	**AICc=**	**42.9**		**Model 1**	**AICc=**	**42.2**	
Intercept	1.923	0.7171	0.0073	Intercept	2.005	0.8344	0.0163
wsm_avg^2	-0.071	0.0243	0.0034	wst_med^2	-0.0781	0.0249	0.0017
Model 2	**AICc=**	**43.7**		**Model 2**	**AICc=**	**42.6**	
Intercept	3.7383	1.2295	0.0024	Intercept	4.5149	1.6032	0.0049
wsm_avg	-0.7556	0.2365	0.0014	r_s	-2.1967	1.4409	0.1274
				wst_med	-0.873	0.279	0.0018
Model 3	**AICc=**	**43.9**		**Model 3**	**AICc=**	**42.7**	
Intercept	1.7566	0.6764	0.0094	Intercept	-1.7623	0.5691	0.0020
wsm_med^2	-0.0638	0.0219	0.0036	pc2	0.0548	0.0178	0.0022
				r_s	-2.6273	1.5972	0.1000
Model 4	**AICc=**	**44.7**		**Model 4**	**AICc=**	**43.1**	
Intercept	0.8135	2.8027	0.7716	Intercept	3.7777	1.3493	0.0051
tet_avg	0.1656	0.1478	0.2624	wst_med	-0.7863	0.2413	0.0011
wsm_avg	-0.7925	0.2391	0.0009				
Model 5	**AICc=**	**44.8**		**Model 5**	**AICc=**	**43.2**	
Intercept	3.4132	1.1445	0.0029	Intercept	1.6836	0.7417	0.0232
wsm_med	-0.6888	0.2172	0.0015	pc6	-0.0466	0.0141	0.0009
				r_s	-2.1104	1.3489	0.1177
Model 6	**AICc=**	**45.0**		**Model 6**	**AICc=**	**43.8**	
Intercept	1.9323	0.7424	0.0092	Intercept	1.2315	0.6222	0.0478
wst_med^2	-0.0705	0.0247	0.0042	pc6	-0.0426	0.0125	0.0007
Model 7	**AICc=**	**45.1**		**Model 7**	**AICc=**	**44.1**	
Intercept	1.2355	0.5384	0.0217	Intercept	-1.8937	0.5371	0.0004
pc6	-0.0426	0.0128	0.0008	pc2	0.0467	0.0143	0.0011
Model 8	**AICc=**	**45.2**		**Model 8**	**AICc=**	**45.0**	
Intercept	3.9696	1.3131	0.0025	Intercept	6.081	7.0919	0.0077
r_s	-1.0646	1.1886	0.3704	rpm_avg	-0.4453	8.9211	0.0028
wsm_avg	-0.7741	0.2494	0.0019	r_s	-2.4683	2.5551	0.1099

Table 2-20. The best 2-variable and possible interaction logistic regression models between nightly weather and turbine characteristics and nightly fresh bat fatality rates at the Mountaineer and Meyersdale Wind Energy Centers.

DISCUSSION

The species composition of bats killed during this study was similar between the two study areas and dominated by hoary and red bats (34 and 24% at Mountaineer, respectively, and 45 and 28%, respectively at Meyersdale). The dominance of Lasiurine species in our study is consistent with results from the study at Mountaineer in 2003 (Kerns and Kerlinger 2004; 42 and 19% red and hoary bats, respectively) and with other studies (e.g., Erickson et al. 2003a, 2003b, Young et al. 2003, Johnson et al. 2005). Hoary bats are fast, less maneuverable, and feed primarily in open habitats (Barclay 1985). Additionally, they are known to detect insect prey and begin pursuit at farther distances relative to other species, presumably because prey detected at short distances are less available because of insufficient time for them to react and maneuver for the capture (Barclay 1985). If hoary bats detect movement at a distance and misconstrue the motion of turbine blades for insect prey, they may not be able to maneuver away from the blades before being struck. This could explain the apparent susceptibility of hoary bats to turbines as evidenced by their repeated dominance in fatalities currently reported.

Johnson (2004) summarized data available for 1,628 bat collision fatalities in the U.S. and found that approximately 90% of fatalities occurred from mid-July through the end of September, with over 50% occurring in August. The reported peak of turbine collision fatality in mid-July through August appears to correspond with post-breeding southward migration of Lasiurine species (Findley and Jones 1964, Bogan et al. 1996, Fleming and Eby 2003, Cryan 2003). Some species are known to engage in sex-specific migrations (Findley and Jones 1964, Shump and Shump 1982, Barclay 1985, Cryan 2003, Fleming and Eby 2003), which may explain why we discovered pulses of bat species of specific genders during this study. For example, at Meyersdale we encountered an immediate pulse of female silver-haired bat fatalities during the last week of the study in September.

Johnson (2004) reported that, in open prairie and farmland, bat fatality appears to be low during the breeding season; only 66 of the 1,628 reported fatalities (4.1%) occurred between May 15 and July 15. At several wind farms studied, low mortality has been documented during the breeding season even though relatively large numbers of bats were present in the area (Fiedler 2004; Gruver 2002; Howe et al. 2002; Johnson et al. 2003). Most of these wind farms were in open areas such as crop fields, grasslands, and shrub steppe, and breeding bats may be more prone to collision at wind farms constructed in bat foraging habitats, such as those constructed in forested areas. More data on bat fatality risks for an entire "season" (i.e., April through October) representing a variety of habitat and topographic conditions are needed to further evaluate temporal patterns of fatality.

Johnson et al. (2005) contended that it was unlikely resident bats would spend significant amounts of time foraging near turbines in crop fields or pastures. We agree with this postulation, but our study area is in a forested system where local as well as transient populations reside. The big brown bat, little brown bat, and eastern pipistrelle spend the winter in caves and may migrate several hundred kilometers to hibernate (Davis and Hitchcock 1965, Griffin 1970, Humphrey and Cope 1976). Dispersal of summer colonies occurs as early as August, peaking in September or October (Barbour and Davis 1969, Johnson et al. 2005), which corresponds with high fatalities documented at wind farms studied to date.

We believe that, in addition to migratory individuals, year-round resident bats may be killed by wind turbines at our study sites. Field crews readily observed bats emerging at dusk and feeding in the clearings around turbines, supporting the fact that at least some bats occupying forests near the turbines might be local residents. Bats can travel long distances between roost sites and preferred foraging areas (e.g., Hutchinson and Lacki 1999, Broders 2003, Sybil Amelon, U.S. Forest Service, unpublished data) and local bats may engage in either seasonal or weather-related movements to forested ridges to forage, thereby increasing their exposure to turbines.

In addition to moving through the Appalachian region or stopping over during migration, some migratory species may use the areas we studied as summer range. Concentrations of hoary bats have been recorded in various regions of North America during July and August (Cryan 2003), a time when fatality appears to peak at wind turbines. Similarly, concentrations of Eastern red bats appear highest in the eastern U.S. during these same months (Cryan 2003). Higher concentrations at this time could reflect local bats summering near our study areas, migrants moving through or stopping over in the area, or, most likely, a combination of both. Migratory flights by some species may be interspersed with short stopovers when individuals or groups pause to rest, feed, and drink (Fleming and Eby, 2003). Migrating bats, particularly males, may concentrate at higher elevations and ridges where turbines were located and may be attracted to turbines by mistaking them for suitable roosting or feeding sites.

It has been postulated that juvenile bats may be more susceptible to fatality at turbines during fall dispersal because of their inexperience with flight and their surrounding environment. However, we found considerably more adult male than adult females or both sexes of juveniles. This finding may result from differential distribution among males and females, both with and without juveniles, within landscapes. It is thought that males and females of the Lasiurine species, as well as others, occupy different landscapes, sometimes even regions, at least during summer (Findley and Jones 1964, Barclay 1991, Cryan 2003). Additionally, there appears to be a negative relationship between capture of female bats and rise in elevation (Cryan et al. 2000, E. B. Arnett, Oregon State University, unpublished data). This likely reflects different physiological and energetic demands between males and females, which appears to influence their use of habitat (Barclay 1991, Cryan and Wolf 2003, Willis and Brigham 2005).

The number of bats killed at wind energy facilities depends on several factors. Some likely relate to the facility itself, such as configuration of the turbines (e.g., linear, nonlinear, single row, double row), orientation of a ridge where turbines might be located (e.g., N-S, E-W, NE-SW, etc), dominant ecotype (e.g., open prairie, deciduous forest, cropland), abundance of bats in the area, landscape configuration, and proximity to key features such as maternity roosts or hibernacula. Other variables associated with fatality likely depend on features of the individual turbine, such as the model of turbine used and proximity of a turbine to habitat features (e.g., open water, forest edge). Some empirical data exist that show a relationship between large scale regional/habitat differences and bat mortality (e.g., forested versus non-forested sites). However, few empirical data exist to help us understand the smaller scale factors affecting mortality levels.

Fatality was distributed across all turbines at both sites, although higher than average numbers of bats generally were found at turbines located near the end or center of the string at both locations. To further investigate whether fatality rates are independent of turbine location, we tested for a correlation between the number of bat fatalities observed at each turbine in the 2003 and 2004 studies at Mountaineer. A weak positive, but statistically insignificant correlation was observed ($r = 0.25$, $p = 0.1031$). The correlation was driven mostly by the high number of fatalities observed in both years at turbine 1 (an end row turbine with a large, logistically easy search area and with a relatively large proportion of high visibility habitat). If this turbine is removed from the analysis, the correlation is near zero ($r = -0.08$, $p = 0.61$). The distribution of fatalities across turbines could arise from a common source or sources of attraction to turbines that vary little across the string at both sites we studied. However, factors such as differences in detection at turbines could mask clustering of fatalities or indicate clustering of fatalities when they do not exist. A safe conclusion is that, based on limited information, a high degree of clustering of fatalities at turbines was not observed.

Interestingly, the only turbine where no bat fatalities were found, for both sites, occurred at Turbine 11 at Mountaineer. This turbine was in a "feathered" (blades parallel with the wind) and "free-wheeling" (blades allowed to move freely) mode, but the blades essentially did not move while in this position unless winds were exceedingly high (generally >15 m/s; D. Mandli, FPL Energy, pers. commun.). In addition to the routine searches, this turbine was searched on 3 different days with trained dogs (Chapter 4) and no fatalities were found. This suggests that bats are not running into stationary blades or turbine masts. Thermal imaging observations work (Chapter 3) indicated that bats easily avoided stationary or slowly moving blades and wind speed and turbine RPM data from low wind nights support the contention that blades are often moving at maximum rotational speed (17 RPM) even during low wind nights.

Bats are known to aggregate near lights (e.g., street lights) to forage on insect concentrations (Furlonger et al. 1987, Fenton 1997). FAA regulation requires that approximately one-third of the turbines be equipped with L-864 red strobes on the nacelle. They are distributed throughout the string at approximately every 3–4 turbines. It has been hypothesized that lights on turbines may attract insects that bats may feed on, thereby increasing the probability of collision. While some birds have been shown to be attracted to certain types of lit structures at Mountaineer, such as sodium vapor lighting (Kerns and Kerlinger 2004), we do not believe that lighting is a significant source attraction to the turbines, as our data did not indicate a difference in the number of bat fatalities found at lit compared to unlit turbines.

Ultrasounds emitted from turbines may be another source of attraction to bats that warrants further investigation. Early during the study, we discovered that the digital anemometers atop each turbine emit ultrasound (approximately 38 kHz) well within the frequency range used by bats occupying the study area. However, after disabling these anemometers at half of the turbines being searched daily for the last 3 weeks of study, we saw no measurable difference in fatality and are confident that this device is not a significant source of attraction to turbines. Ultrasonic emissions from these anemometers likely were far too weak

(<0.05 watts) and dissipated too quickly for bats to detect them. However, there are other sources of ultrasonic emission from the turbines that may attract bats and should be investigated further.

The approach used for calculating adjusted fatality estimates is consistent with the approach outlined by Shoenfeld (2004) and Erickson et al. (2003b), although some differences exist. The methods for estimation we used utilized the empirical cumulative probability distribution function for adjusting the fatality rates for carcass removal bias. While the formulas are more complex, previous methods assumed that carcass removal follows an exponential distribution, which simplifies the formulas for estimation and is not always appropriate. The exponential model fit reasonably well for Meyersdale, but did not fit for Mountaineer. The approach we used does not assume a parametric form for the carcass removal distribution.

Carcass removal rates were markedly different between Mountaineer and Meyersdale. The Mountaineer facility began operation one-year earlier than Meyersdale and it is possible that scavengers had more time to learn of a new food source beneath turbines at Mountaineer. Also, differences could be a function of species composition of avian and mammalian scavengers at the different sites. For example, at Mountaineer, but never at Meyersdale, we observed corvids (ravens and crows) removing carcasses from the access road and bare ground near turbines. We hypothesize that scavenging could change through time at a given site and must be accounted for when attempting to estimate fatality rates.

Fresh bat carcasses often are not readily available for mortality studies. In lieu of fresh bat carcasses, researchers typically use frozen and then thawed bird and bat specimens as surrogates for trials. At Mountaineer, both fresh and frozen bat specimens were placed in the field under similar environmental conditions and within similar habitat visibility classes. Fresh bat specimens were removed more rapidly than those that had been previously frozen, and frozen bat carcasses were removed at a faster rate than frozen bird carcasses. Therefore, carcass removal studies conducted with fresh specimens should more accurately reflect realistic rates of scavenging. When frozen bat or bird carcasses must be used, adjustments to carcass removal rates should be conducted to account for this important bias when correcting fatality rates.

Turbines with high amounts of searchable area did not necessarily yield higher numbers of carcasses. Prior to this study, we hypothesized that turbines with high percentages of high detection areas (e.g., roads, bare ground) would yield higher numbers of carcasses at

Mountaineer. However, there is a weak negative correlation between the percentage of detection area per turbine and the number of carcasses found (r = -0.2). We believe that while it may be easier for searchers to detect a carcass if it were present at those turbines, it is also easy for scavengers to visually detect and remove the same "high detection" carcass prior to a searcher's arrival at the turbine. In addition, most turbines were sampled out to at least 40 m and the distribution of fatalities as a function of distance to turbines and adjusted for sampled areas suggest that a high percentage of the fatalities (>80%) occur within 40 m of the turbine. Therefore, although plot sizes varied, the unsampled areas at most turbines are areas where fatalities are not likely to occur frequently.

We used two approaches to stratifying the data to account for variability in searcher efficiency and scavenging as a function of habitat. The first simple approach was to calculate separate corrections for these biases on two stratum, the areas within 10 m of turbines, associated with higher detection rates, and the areas outside 10 m of the turbines, generally associated with lower detection rates. In general, higher searcher efficiency rates are observed within the 10 m area due to the turbine pad and road, and this approach does not rely so much on the relatively subjective and time consuming mapping of habitat and visibility. The second approach was to stratify the data by three fatality visibility categories (high, moderate and low), and resulted in similar estimates to the first approach.

The estimation approach did assume the searcher efficiency rate was constant during the period of study, and that searcher efficiency was not dependent on the time a carcass was in the field. The study was not designed to test this hypothesis. However, based on observing the condition of trial carcasses over time, this assumption may have been violated. In some cases, detection probabilities may increase in the first few days because of both visual (e.g., presence of insects on carcasses) and olfactory (smell) cues. Over time the detection probabilities may decrease significantly, due to the weathering of carcasses. This phenomenon may especially be true in these wet conditions at these sites. Fatality search efforts should attempt to account for this bias by using relatively equal proportions of different carcass conditions among different habitat visibility classes.

Weekly searches at Mountaineer appeared to underestimate the fatality rate by a factor of 3 during this study period. We believe this is attributed to the fact that timing of fatality searches at Mountaineer often occurred before periodic, large fatality events and that carcass removal rates were high. The highest fatality rates at Mountaineer typically occurred within a day or two after the weekly search and, given the high carcass removal rates, led to the low number of fatalities found during weekly searches. A better weekly design would be to search 10 turbines each day for 4 days rather than all turbines on one day. This would provide better interspersion of searches among days of the study, and likely would have resulted in more similar estimates from daily and weekly searches. This interspersion of searches among possible search days is the approach that has been used at most studies where searches are conducted on weekly or less frequent intervals. The fatality rates from weekly and daily searches at Meyersdale were similar (+/- 17%), suggesting that in cases when carcass removal rates are relatively low, infrequent searches can yield relatively accurate fatality estimates. As expected, widths of the confidence intervals for the point estimates were larger for the weekly searches. At Meyersdale, the average half-width of the confidence intervals was 10 bats/turbine/6-week period) for weekly searches and 4.4 or daily searches. The coefficient of variation of the mean (standard error/mean) was 23% from weekly searches and 11% from the daily searches. Design recommendations for studies with cost constraints would include estimating carcass removal near initiation and during the study, including a mixture of frequent searches at some turbines and less frequent searches at others, and possibly subsampling the area at each turbine.

Bat fatality rates appeared relatively periodic and related to weather conditions and related events (e.g., passage of storm fronts). The strong, positive correlation in timing of fatalities between the two study areas support broader landscape, perhaps regional, patterns dictated by weather and insect abundance. Erickson and West (2002) reported that both regional patterns of climatic conditions as well as local weather conditions can predict activity of bats. In our study, nights of high wind speeds were associated with extremely low observed bat fatalities, regardless of the level of the other variables measured, and the highest fatality rates generally were associated with indicators of low wind speed, low relative humidity, higher temperature and higher barometric pressure. Lower relative humidity and higher barometric pressure were typically associated with conditions after weather fronts passed through the area. Strong winds can influence insect abundance and activity, which in turn influences bat activity. Bats are known to suppress their activity during periods of rain, low temperatures, and strong winds (Erkert 1982, Erickson et al. 2002). Sporadic hatches of insects that are likely associated with favorable weather and flight conditions may periodically increase local bat activity (Erickson and West 2002).

Wing morphology of bats and vegetative structure of their environment has strong influence on the partitioning of different habitats among species (Crome and Richards 1988). The small gaps and numerous edges created for turbines and access roads may have created suitable foraging habitat for bats occupying these forested ridges. Grindal and Brigham (1998) reported higher bat activity in small forest openings. These clearings may be favorable for some insect prey and are most certainly conducive to the foraging strategies of some species of bats. As previously mentioned, hoary bats are fast, less maneuverable fliers and prefer to feed in open habitats (Barclay 1985).

Some species of bats are known to night-roost and many species “hawk” for insect prey (Kunz 1982, 2004, J Szewczak, Humboldt State University, pers. communn.), although this is not the case for the Lasiurines. Turbines appear to be optimally located within forested openings and near edges and bats may misconstrue turbines as favorable roost sites where they could rest between foraging bouts, digest food, and conduct foraging sorties. We observed bats landing on the mast of a turbine and on a stationary turbine blade (Chapter 3), thus supporting this hypothesis.

CHAPTER 3. TIMING OF NIGHTLY BAT ACTIVITY AND INTERACTION WITH WIND TURBINE BLADES

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To date only a few published studies have attempted to evaluate the impact of installed wind turbines on local and migrating bat populations (e.g., Johnson et al. 2003, 2005, Erickson et al. 2003a, b). These studies focused primarily on quantifying the impact of turbines on local and migrating populations by enumerating injured and killed animals beneath and adjacent to operating turbines. While these studies establish that bat mortality occurs at wind turbine sites, they did not attempt to quantify the causal factors, integrate the behavioral ecology of the species affected, or experimentally test factors that might contribute to the mortality observed. This underscores a conspicuous gap in our understanding of why bats are killed at wind turbines, what circumstances might predict these events, and what approaches might be used to mitigate their effects. Prior to this study, there had been no direct observations of bats being struck by moving turbine blades. This gap in our understanding is an important one to close, as it leaves potential mitigation strategies uncovered.

There are several possible explanations for the occurrence of injured and dead bats on the ground beneath and near turbines. Broadly, there are two basic hypotheses. First, bats aloft may simply come into contact with rotating blades by random chance alone. The bats at risk are thought to be a mix of local forest-dwelling species and migrants traveling through the area. Many of the small insectivorous species collected during the study are high-frequency echolocators. Because high frequencies attenuate quickly in air, these bats may either fail to detect moving blades or they may detect them but may not have time to react before being struck.

Secondly, there may be a variety of factors that contribute to an attraction phenomenon that results in a higher than expected density of bats flying near operating turbines, and therefore higher mortality. Although the population density of the species we collected is unknown in the study area, they are not thought to be as abundant as the number of observed fatalities would suggest. Forest edge effects created by the construction of the access road to the turbines may create favorable foraging grounds where bats can more easily capture moths, beetles and other flying insect prey, creating hotspots of bat activity. These prey patches are likely ephemeral, and therefore bat activity and the likelihood of being struck by rotating turbine blades may be predicted by insect phenology and weather patterns. Alternatively, migratory patterns may explain increases in bat mortality near the end of the warm season. Migratory flights by some species may be punctuated with short stopovers when individuals or groups pause to feed, drink and roost in trees (Fleming and Eby 2003). As with local populations, migrants or groups of bats making stopovers may be similarly attracted to these areas. In addition, there may be physical parameters of the operation of the turbines that increases the probability collisions. One such possibility is the production of ultrasound by rotating blades, generator operation, or other moving components of the turbines that may interfere with, interest, or otherwise alter the behavior of flying bats. Finally, weather patterns are likely to influence the density of bats aloft on this mountain ridge, as they do in other bat habitat.

Supporting or validating any of these hypotheses requires clear observation and quantification of foraging and flight behavior near turbines. There are several established methods for monitoring flight activity of bats during dark hours, including night-vision, phosphorescent tags, strobe photography and reflective infrared video cameras. Each of these techniques, while effective, has limitations for monitoring activity around wind turbines. The primary problem is one of scale. The increasing size of turbine towers, blades and the area swept by the blades means that larger volumes of airspace must be monitored. Imaging techniques that require illumination sources such as night-vision, strobes and reflective IR cameras are largely inadequate as it is difficult if not impossible to equally and evenly illuminate the entire turbine tower and blades. The ability to detect bats with these techniques decreases markedly with distance. In addition photo-multipliers (night-vision) contain inherent noise in the images they produce, making discrimination of small objects at a distance difficult. Marking sufficient numbers of bats with chemiluminescent tags to detect their presence around turbines would be difficult, especially considering that the populations are likely transient. Thus, we deployed a novel technique for monitoring wildlife activity: thermal infrared imaging.

Thermal IR cameras detect heat emitted from, and reflected off of all objects. No illumination is required, and any scene can be captured in complete darkness. The distance at which objects can be imaged is limited only by the optics chosen, and the size of the imaging sensor. Wherever there is sufficient contrast in temperatures, objects can be resolved.

Temperature differences can also be detected at long distances. In addition, infrared light is less scattered than visual wavelengths by water vapor and fine particles in air. This means that we are able, to a certain extent, to see through fog - a frequent occurrence at the Mountaineer facility.

We designed this portion of the study to use thermal infrared imaging to allow us to observe the basic types of flight behaviors around the rotor-swept zone of turbines in operation. Because there was, to date, no direct evidence in the literature that bats in flight are being struck by rotating blades, our first objective was to observe and document how bats behave while flying throughout the sweep zone where there is the potential for contact. Second, we conducted multiple full-night observation periods from which we enumerated and classified bats and insects aloft, scored behavior types, and collected variables that might be predictors of collisions. Finally we designed experiments to test the effects of blade rotation and aviation lighting on bat activity and the number of collisions. The hypotheses these experiments were designed to test were as follows:

- H_{a1}: There is significant difference between the level of bat activity and/or collisions at rotating turbines and that of feathered or otherwise non-moving, turbines.
- H_{a2}: There is significant difference between the level of bat activity and/or collisions at lit turbines compared to unlit turbines.
- H_{a3}: Bat activity is not evenly temporally distributed throughout the nightly foraging period.

METHODS

This study was conducted from 2–27 August 2004 at the Mountaineer Wind Energy Center (see Chapter 1). To observe bat and turbine blade interactions and establish the timing of nightly flight activity around operating turbines, we employed three FLIR Systems S60 uncooled microbolometer video cameras with matched and calibrated lenses. Each camera was mounted on a tripod and all three cameras were grouped together (0.5m apart) at a single observation station beneath a turbine (Figure 3-1). Three portable computer systems were used to capture real-time radiometric data streams from each of the cameras using FLIR Thermacam Researcher software. Data were captured at a rate of 30 frames per second and each frame of data was

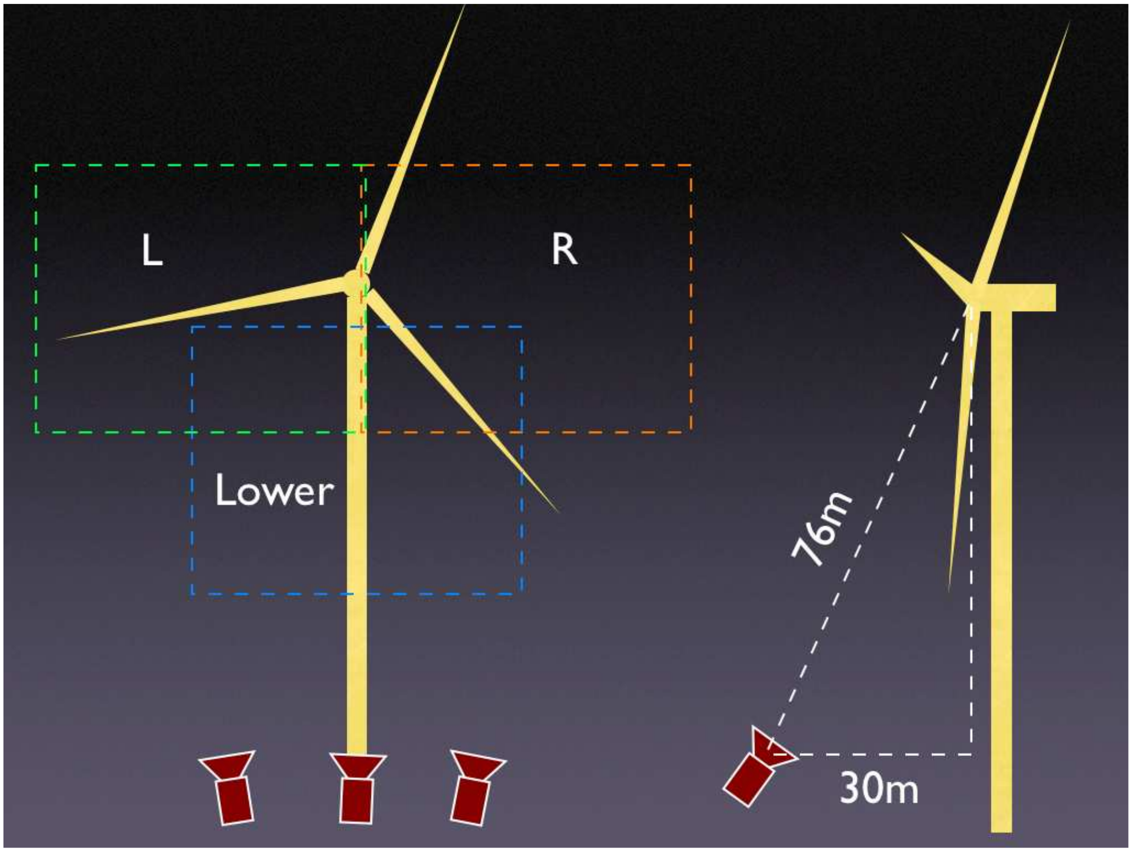

Figure 3-1. Hypothetical setup for nightly observations using three thermal IR cameras positioned 30 m from the turbine base and pointed directly upwind and perpendicular to the plane of blade rotation.

stamped with the time accurate to 0.001 seconds. While the cameras are capable of recording at 60 fps, this would have doubled our hard drive storage needs, and was not logistically or economically feasible. In order to test the effect of turbine lighting (H_{a2}), we placed our cameras at randomly chosen lit and unlit turbines for 5 non-consecutive nights.

To observe bat flight behavior and to test our hypotheses, we positioned the observation station with the three IR cameras near the base of wind turbines at dusk. Terrain permitting, we placed the observation station 30 m from the base of the turbine tower (Figure 3-1). Mean wind heading was assessed when positioning the station and we attempted to locate the camera station, on average, directly upwind and perpendicular to the plane of rotation. In most cases the station was at an equal elevation to the base of the tower, so that the straight-line distance from the camera to the hub was 76 m. We pointed and focused each camera on a different part of the rotor-swept area; camera A on the left, upswing portion of the rotor-swept area, camera B on the right, downswing side, and camera C on the lower portion of the rotor-swept area (Figure 3-1). We used a 24° field-of-view lens, which, at a distance of 76 m images an area that is 34 m wide by 24 m high. We recorded continuously for 9 hr beginning at 2030 hr and continuing until 0530 hr the following morning. All cameras were started simultaneously, and recordings were synchronized. In order to test H_{a2}, we placed our cameras alternatively at lit turbines for 5 nights and at unlit turbines for 5 nights.

We analyzed the data by manually observing playback of all video sequences in real-time or near to real-time and by recording in a log the appearance and timing of flying objects. Each object observed was recorded with a time stamp and classified according to a set of qualitative criteria. Object types included bats, insects, birds, aircraft, and unknown (unidentifiable). Criteria included object size, object morphology, estimations of inertia and velocity, evaluation of flight maneuvers and behaviors, wing beat frequency, and interaction with the rotating turbine. In an effort to reduce false positives and observer biases, we were highly conservative when classifying objects, identifying many as unknown. Every effort was made to correctly identify and reduce false positives, including identifying multiple passes belonging to a single individual. We also classified behavior types along with each object observation. Objects flying through the field of view without incident were labeled as “fly”. Those making sharp or sudden course corrections synchronous with a nearby moving blade were labeled “avoid”. To distinguish these behaviors from normal foraging and pursuit maneuvers, we were careful to label behaviors as “avoid” only when they occurred at the same time that a blade was moving through nearby air space. Any obvious collisions or contact with any part of the turbine structure were labeled “contact”.

Along with the classification, each observation included an estimation of flight elevation. Elevation was classified as low, medium, or high. Low corresponded to flying objects occurring below the sweep zone (approximately 0–40 m above ground), medium to those in the range of heights of the sweep zone (41–110 m), and high to those above the sweep zone (above 110 m). We also noted the entry and exit points from the field of view as an estimate of flight heading by an object (bat, bird, or insect).

RESULTS

Manual observation of video sequences (a.k.a. data sets; one data set = one video sequence [7–9 hr of imaging] for one camera on one night) from all nights and cameras proved more time consuming than we had originally expected, in part because we observed far more bats, insects and birds that we had originally anticipated. We were able to analyze 17 nightly datasets, representing approximately 530 man-hours of video observation, wherein we observed a total of 4,572 objects aloft that included 1,808 bats (39%), 872 insects (19%), 44 birds (.9%), 5 aircraft (0.1%), and 1,843 unknown (40%).

We chose to further analyze only data for complete 9-hr datasets from all three cameras on 10 nights from 8–24 August. Time constraints dictated that we select datasets collected by one camera for these 10 sample nights for the final analysis. To obtain a representative sample of all 30 possible datasets, we analyzed a subset of 3 nights from all cameras (A, B, and C) and compared the number of bats observed with each camera (left (a), right (b), and lower (c) for three nights of observations (Table 3-1). In general, more bats were observed from camera C than from other cameras, likely due to the slightly lower elevation angle of this camera allowing it to capture objects that were closer to the lens and, therefore, more easily identified as bats. However, total numbers of bats observed were variable from camera to camera and we found no significant difference between the mean numbers of bats observed from any one camera. We also found no significant difference between the mean numbers of bats observed with one camera and the mean number of bats for all cameras combined. Given these results, we chose to

Date	Turbine	Cam A	Cam B	Cam C	Mean all Cameras (SE)
8/14/04	37	129	105	239	158 (41.3)
8/22/04	20	221	94	256	190 (49.3)
8/24/04	16	39	43	50	44 (3.2)

Table 3-1. Number of bats observed with each of the three IR cameras (A, B, and C). No significant differences exist between the mean numbers of bats from camera to camera.

analyze the data from camera A (left, upswing portion of the rotor-swept area; Figure 3-1) for 10 nights, and are confident this camera is representative of bat activity at a given turbine.

For the A-camera data set, we made a total of 2,398 observations across 10 nights from 8–24 August: 998 bats (41%), 503 insects (20%), 37 birds (1%), and 860 unknown (35%) (Table 3-2). Bats were usually distinguishable from other objects with the orientation of the body and wings aiding in their identification. The majority of bats we observed were flying at the height of the sweep zone, or below (medium and low categories). Most bats appeared to be foraging. We observed pursuit and terminal-phase capture maneuvers, with individuals looping and persisting in the field of view for durations of 5–120 seconds. Forty percent of all observations were classified as unknown, reflecting both our effort to be precise and the difficulty of discriminating bats from birds and insects in fog and inclement weather conditions. Many of the unknown objects recorded were likely unresolvable bats. Among flying bats, elevation was highly variable, with some individuals flying within 10 m of the camera lens, and others forging at or above the height of the turbine nacelle. We observed few birds, mostly as individuals, but also occasional flock formations. Insects were abundant within the low altitude band, often appearing as cooler and less well defined objects as they were out of the camera's depth of field (Figure 3-2, d).

Most bats we observed were flying at the medium altitude band (within the upper and lower bounds of the blade swept area), more than three times the number observed flying at 'low' or 'high' altitudes (Figure 3-3). Although camera resolution and cloud cover may bias

Date	Turbine #	Total Objects	Bats	Birds	Insects	Unknown	Bat Avoid or Contact
2004-08-08	18	72	17	2	37	16	2
2004-08-10	27	27	9	0	12	6	0
2004-08-11	25	251	124	5	47	75	6
2004-08-13	26	52	42	0	5	5	5
2004-08-14	37	362	129	2	63	168	3
2004-08-16	41	786	291	1	133	361	14
2004-08-17	31	233	74	0	117	42	0
2004-08-21	10	82	52	10	7	13	0
2004-08-22	20	354	221	17	60	56	15
2004-08-24	16	179	39	0	22	118	2
		2,398	998	37	503	860	47

Table 3-2. Summary all observations for 9-hr datasets from camera A (left half of the rotor-swept area) from 8–24 August 2004. The column "avoid or contact" indicates cases when a bat either changed flight path to avoid colliding with a moving blade, or did collide with it.

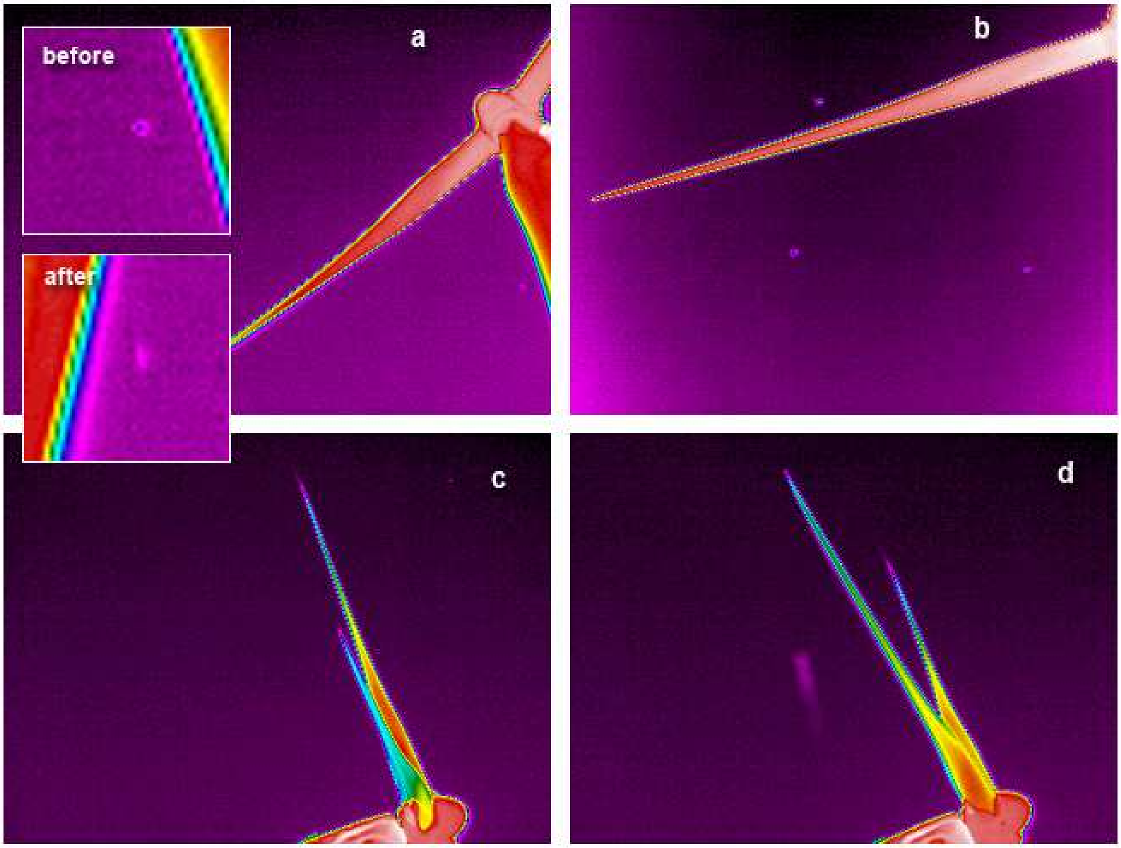

Figure 3-2. Single frames taken from IR data to illustrate common of observations. (a) a medium-height bat just before and after collision with a moving blade (inset); (b) three low-medium flying bats at one time in the camera field of view; (c) a typical 'high' bat flying above the reach of the turbine blades; and (d) a typical low-flying insect, characterized by the blurry streak, an artifact caused by the camera's integration time, indicating fast motion close to the camera.

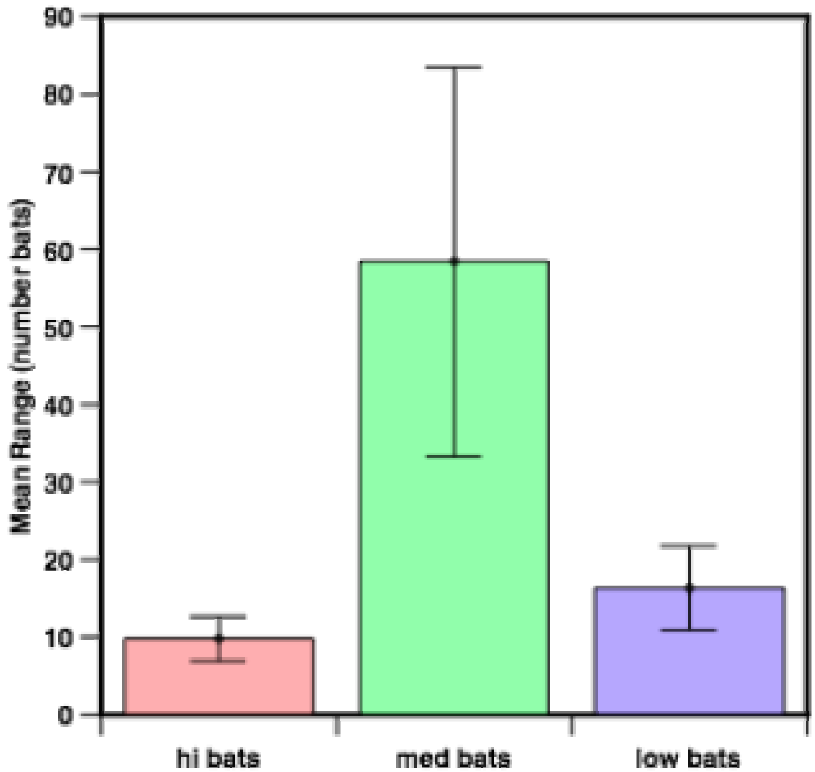

Figure 3-3. Mean number bats (+ SE) observed flying at low, medium, and high elevations in camera A from 8–24 August 2004 at turbines at the Mountaineer Wind Energy Center.

downward the number of high-flying bats observed, medium-flying bats still greatly outnumbered low-flying bats by a factor of 2:1. Bats appeared to spend much of their time foraging and flying at the range of heights at which the turbine blades were operating. Examples of behavior type are illustrated in Figure 3-2.

The number of bats we observed on a nightly basis was highly variable, with as few as 9 per night and as many as 291 (std dev_{bats} = 92, Figure 3-4). There was a significant correlation between insect passes and bat passes observed across all nights ($r = 0.71$, $F_{.05(2), 9, 9} = 4.025$, $p = 0.04$). Nightly insect abundance was also a significant predictor of bat passes ($R^2 = 0.50$, $F = 8.1422$, $p = 0.02$, Figure 3-5).

We also examined the temporal distribution of bat activity throughout the night. Bat activity is conspicuously higher in the first two hours after sunset, and then tapers off (Figure 3-6). We often noticed a lull in activity close to midnight, which was expected as many forest bat species are thought to seek out night-roosts after an initial bout of foraging (Kunz 1982, Kunz and Lumsden 2003, Kunz 2004). These same species often re-emerge for additional foraging periods in the early morning hours (Erkert 1982). We did observe higher numbers of bat passes after a midnight lull in some data sets, but the overall trend was a gradual decrease. Insects appeared to be most active in the hours immediately after sunset, and their numbers decline steadily throughout the night (Figure 3-6).

Aviation lighting did not appear to affect the incidence of foraging bats around turbines. There was no significant difference between numbers of bat passes (camera A) at lit and unlit turbines ($t = 0.42$, $p = 0.68$), rejecting H_{a2}. Interestingly, insect activity was higher at lit turbines than at unlit turbines ($t = 1.62$, $p = 0.14$, Figure 3-7). This suggests that aviation lights may attract insects, although we were unable to detect any subsequent effect on bat behavior.

We tested a number of environmental conditions for their affects on bat activity (Figure 3-7). Although average nightly ambient temperature did not predict bat passes, blade RPM was a significant negative predictor of bat passes ($R^2 = 0.42$, $F = 5.91$, $p = 0.04$), and insect activity was a significant positive predictor ($R^2 = 0.22$, $F = 2.3134$, $p = 0.17$). Bat activity may be a function of wind heading, which is an indication that larger meteorological patterns may be involved with bats activity and subsequent mortality.

While most bats were observed simply foraging or flying around the turbines, we also recorded clear instances of avoidance of blades and bats being struck by blades. Of the total

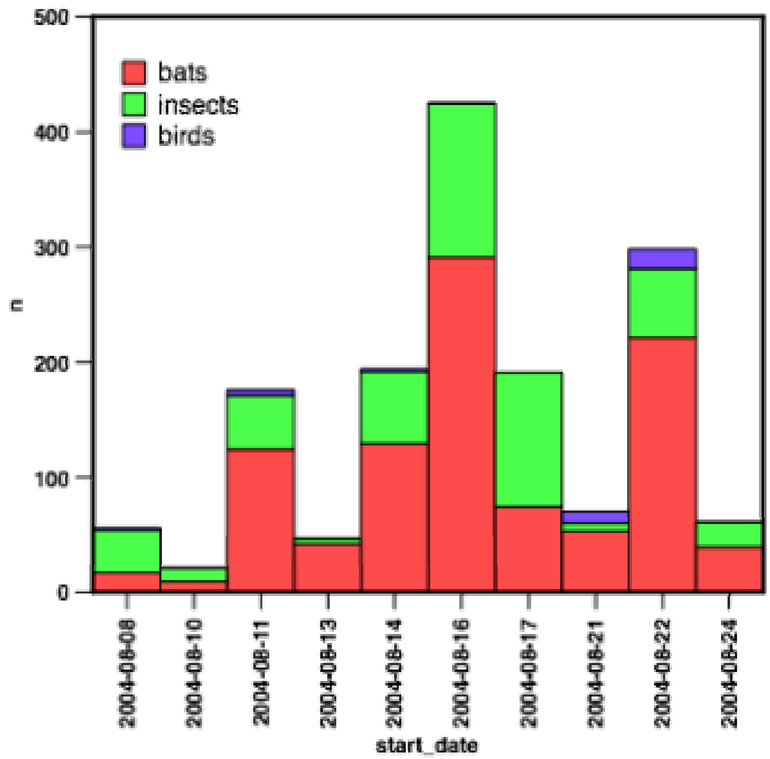

Figure 3-4. Total number of bat, bird, and insects passes per night for 10 nights from 8–24 August 2004 at the Mountaineer Wind Energy Center.

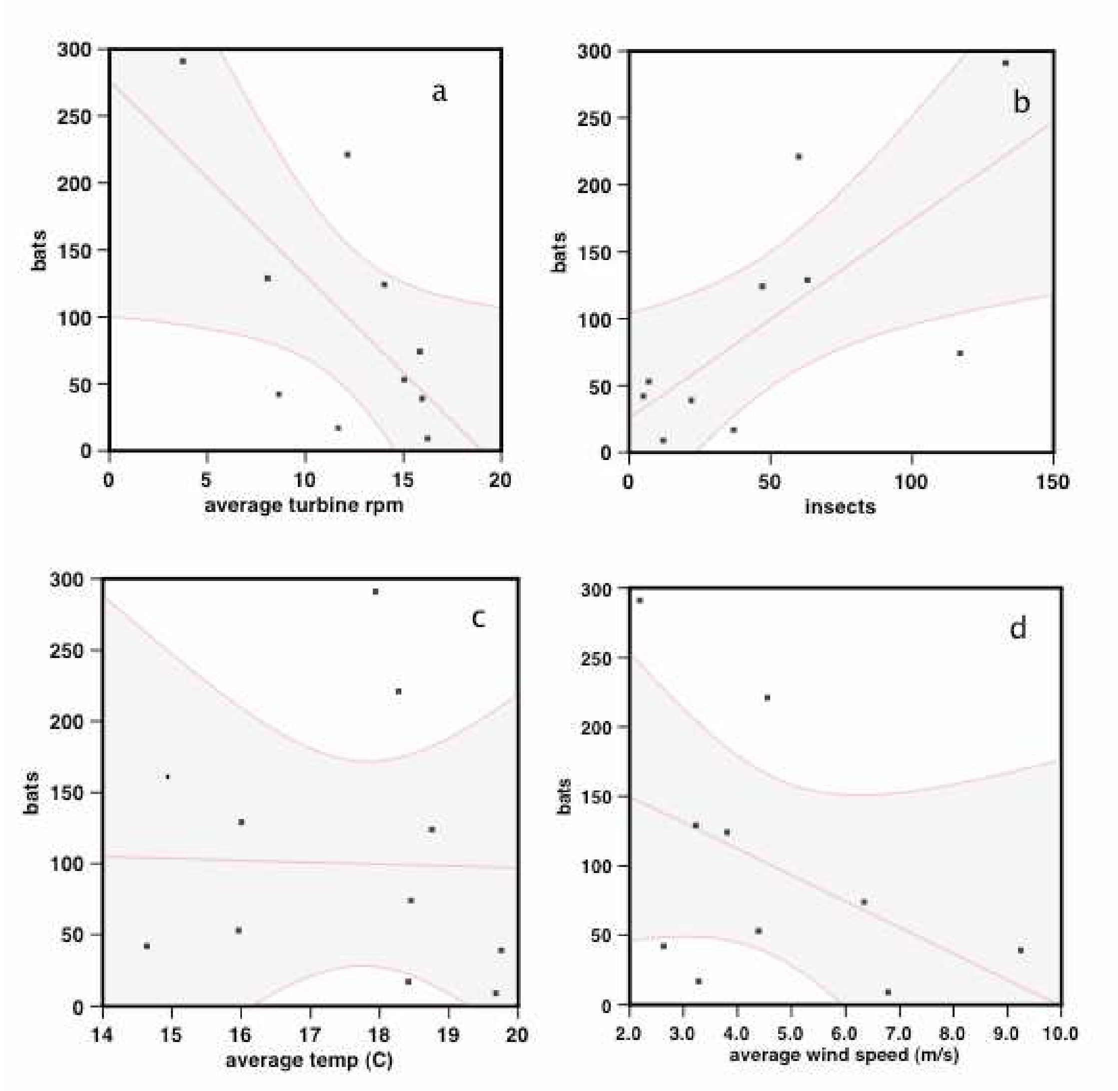

Figure 3-5. Relationship between number of bat passes and (a) average turbine blade rotations per minute (RPM); (b) insect passes, (c), average nightly temperature, and (d) average nightly wind speed at the Mountaineer Wind Energy Center.

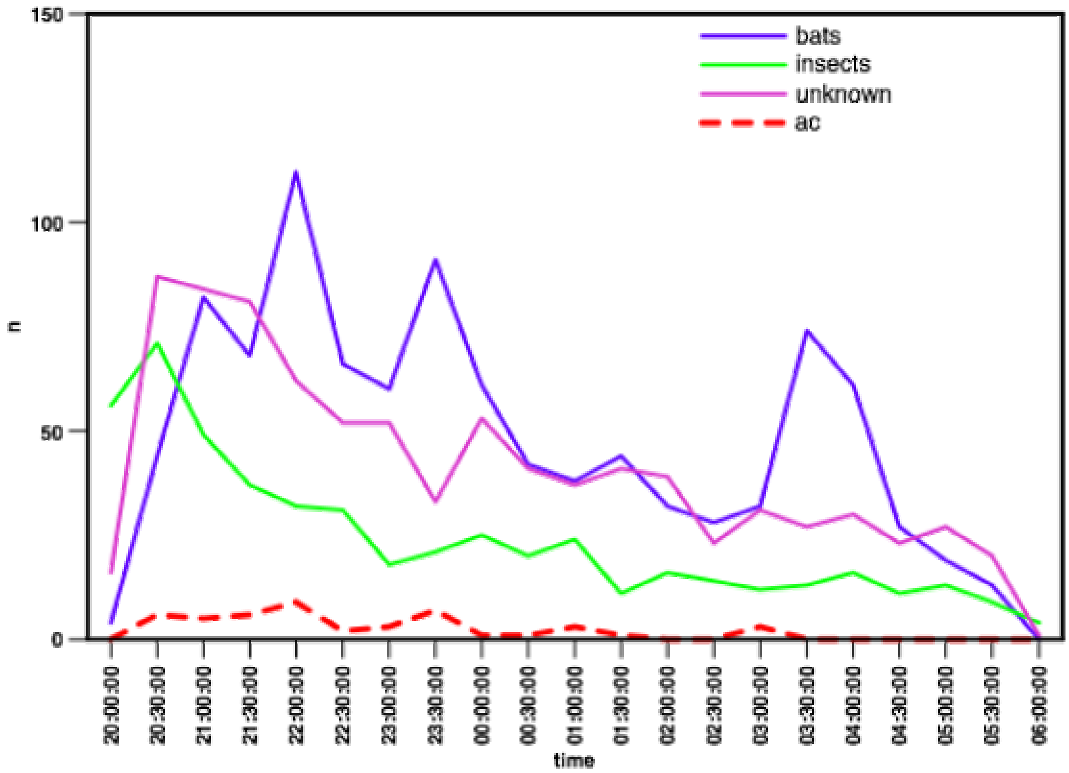

Figure 3-6. The distribution of activity exhibited during the night, averaged across 10 nights from 8–24 August 2004, for bats, insects, and unknown objects from 2030 hr to 0530 hr at the Mountaineer Wind Energy Center (ac = aircraft).

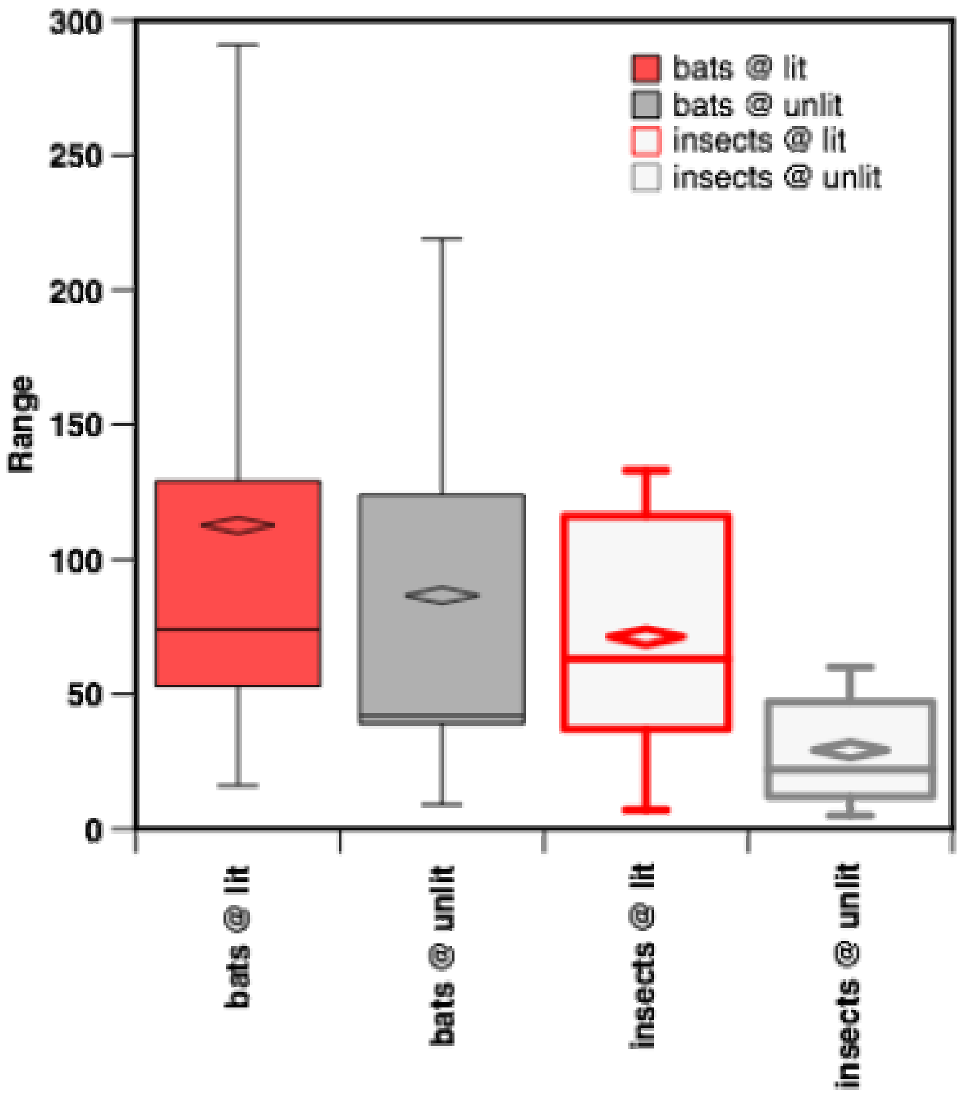

Figure 3-7. Box and whisker plots of bat and insect passes in relation to turbines that were lit with FAA lighting and those that were unlit for 10 nights from 8–24 August 2004 at the Mountaineer Wind Energy Center.

Observations of bats, we observed this avoidance behavior 66 times (7%). Avoidance involved sharp, evasive flight maneuvers that were coincident with a moving blade. Notably, many of the instances of avoidance behavior involved multiple passes. It is well documented that bats often make check passes when investigating a structure or potential roost. Bats often appeared to continue to investigate the turbine blades after a near miss, rather than fly off quickly. This often resulted in several near misses in a row, with the bat appearing to be repeatedly buffeted by turbulence close to the blade surface. We estimate that such interactions occurred within 5 m of some part of the blade.

We observed bats colliding with moving blades on 8 occasions (<1% of all observations). In no cases did we observe a bat striking the turbine tower, nacelle, or still blades. Collisions were marked by an abrupt, angular change in heading and velocity, and were generally of two types: glancing blows and direct hits. Most of the collisions were glancing blows, where a sudden deceleration or change of heading occurs. We also witnessed direct hits when bats appeared to be struck closer to the centerline of a moving blade, and were greatly accelerated. We could not confirm that bats struck by the blades landed beneath the turbine as our camera's field of view did not include the ground. Bat passes in general and contact and avoidance behavior specifically, tended to occur at lower wind speeds. Table 3-3 summarizes the 8 instances of contact that we observed, and turbine RPM and wind speed when they occurred. In each case, the wind speed was similar to the nightly average and occurred during relatively low-wind times. Seven of the 8 observed strikes occurred when turbine blades were rotating at their maximum speed of 17 RPM (Table 3-3).

We also observed a wide variety of investigative behavior by bats. Bats often make several check passes before alighting on and entering roost structures such as trees and buildings. We often observed bats making check passes or flying repeated loops near moving blades. In 4 separate instances, we also observed bats executing check passes and briefly alighting on the monopole itself. This usually occurred at approximately one-half to two-thirds of the height of the hub. This behavior was particularly well illustrated in one instance when an individual bat, while investigating the length of a still turbine blade, completed several check passes before briefly alighting on the blade surface, approximately 2/3 down the length of the blade toward its

Date	Time	Turbine #	Wind speed at collision time (m/s)	Mean windspeed, all turbines (m/s)	RPM at turbine at collision	Mean RPM (all turbines)
08-16-2004	21:46:17	41	0	1.1	3.1	2.1
08-22-2004	22:49:19	20	4.3	3.3	16.9	9.1
08-23-2004	01:15:56	20	7.1	6.1	17.1	15.8
08-23-2004	02:02:36	20	7.5	6.5	17.1	15.9
08-23-2004	03:03:29	20	7.3	6.9	17.1	15.9
08-24-2004	21:11:12	16	8.4	9.0	17.1	15.9
08-25-2004	00:31:45	16	9.4	10.2	17.1	16.0
08-25-2004	03:20:20	16	8.6	9.6	17.1	15.9

Table 3-3. Summary of date, time, wind speed, and turbine blade RPM for 8 observed bat collisions with moving turbine blades at the Mountaineer Wind Energy Center.

distal end. We also observed remarkable instances of bats chasing the tips of slow-moving blades during low wind conditions and when turbine blades were moving slowly.

DISCUSSION

In the absence of any real understanding of why bats are injured and killed at wind farms, there have been many hypotheses advanced about how and why this happens. Many of these focus on the idea that bats are in some way attracted to wind turbine areas and the result is a greater than normal probability of being struck by a moving blade. Indeed, the number of carcasses for species like hoary and red bats collected at turbines is quite different from that obtained from mist net surveys in this region (C. Stihler, West Virginia Department of Fish and Wildlife, unpublished data), and yields a different inference regarding populations for these species in Appalachia. This suggests two distinct possibilities: either the population density of these species fluctuates markedly over the course of the season (possibly as a result of transient or migrating individuals), or wind farms attract bats aloft. Both have clear implications for mitigating bat mortality at these sites and how we continue to study this problem.

In the case of transient populations and migration, collision events and mortality may not be evenly distributed throughout the active season for bats. Transient population fluctuations are most likely to occur around the time of both spring and fall migration. An increase in the density of foraging bats near turbines may represent an attempt by transient or migrating individuals to take advantage of these resources. The high variation in numbers of both bats and insects that we observed on a nightly basis seems to support this hypothesis. Weather patterns may simply amplify this seasonal relationship.

Unfortunately, it is difficult if not impossible to distinguish individuals foraging near turbines as local, transient, or migrant. This is true, in part, because we still know very little about the specifics of migration behavior, such as the duration, number and altitude of flights, how timing, routing and directionality are affected by weather events, and how often bats stop to rest, forage, or drink. Migration flights by some species may proceed as series of short stopovers when individuals or groups pause to feed, drink and roost in trees (Fleming and Eby 2003). Other species may proceed by a series of longer duration or higher altitude flights. Continuous flights well above the tree canopy have been observed in late summer in forested northeast mountain areas (Horn 2004). For these species, our results do not support the hypothesis that wind turbines are randomly killing bats simply because they stand in the direct path of migration routes. We observed bats primarily feeding and foraging around and in the sweep zone of the turbine blades. To understand the population dynamics of these bats, future studies will have to monitor fluctuations in bat abundance aloft throughout the entire season both in areas with and areas without operating turbines.

Alternatively, there are many possible attraction phenomena that explain bat fatalities. Ultrasound emissions may attract the curiosity of bats although this hypothesis remains untested. Although we detected no significant differences between the levels of bat activity at lighted versus non-lighted turbines at the Mountaineer facility, light sources have been shown to attract insects and thereby bats as well to wind turbine sites. What is more likely is that the modifications to the landscape and forest structure necessary to construct the wind farm, including the open space around turbines and the linear landscape along the access road, have created favorable foraging grounds for bats. The forest edge effects created by clearing are favorable to insect congregations and to bats' ability to capture them in flight. As with local populations, migrants or groups of bats making stopovers may be similarly attracted to these areas.

That bat activity was so highly variable on a nightly basis suggests that it may be dynamic variables such as weather conditions that affect their abundance, rather than some fixed property of the turbines themselves. Insect abundance is ephemeral and dependent on weather patterns as well; therefore bat activity and the likelihood of being struck by rotating turbine blades may be predicted by insect phenology and weather patterns. The lack of statistically significant effect from temperature, barometric pressure, and wind are likely due to our small sample size ($n = 10$). The number of bat passes we observed generally was higher at lower wind speeds and daily carcass searches (Chapter 2) suggest that fatality increases on low wind nights; periods when insects are likely most active. Average nightly wind speed for the month of August at the study area was 5.19 m/s. We unable to compare the number of bats observed on a nightly basis with the number of fatalities for that night at that turbine because of small sample size (usually just one or two carcasses found at any given turbine).

Perhaps the most significant observations of our study were those of bats actively investigating both moving and still turbine blades and masts. Bats alighting on and investigating blades and towers seems to suggest that bats are indeed attracted to wind turbines. One possible explanation for this behavior is that bats view these tall structures, standing in open space, as roost trees. Forest bats often seek out large trees and snags as desirable roosting habitat (e.g., Kunz 1982, Vonhoff and Barclay 1996, Ormsbee and McComb 1998). Turbines are located within forested openings and near forest edges which may make them appear to be a favorable roost to a foraging or even migrating bat. Bats may be investigating wind turbine structures in an attempt to evaluate their potential as roosting sites. This curiosity and investigation behavior would likely increase the probability of a collision with a moving blade over random chance alone. This may explain why the rate of injury and mortality at this site is greater than population estimates and random chance alone would suggest.

A significant finding of this research is that the distribution of bats activity throughout the night is also uneven. We found that that the bulk of bat activity occurs in the first two hours after sunset. This observation, combined with our findings that weather patterns and seasonal fluctuations are also predictors of bat abundance, suggests that windows of high risk for collisions may be clearly identifiable with additional longer-term studies. If so, collisions and mortality could be greatly reduced by focusing mitigation efforts on these high-risk times.

There are some important limitations to the interpretation of our data. Based on our highly conservative classification scheme, we consider our measures of abundance to be accurate and to have a low rate of error or false positives. However, there are several factors that may bias the number and types of objects we observed. Clear observations were a challenge given the varying weather conditions and the geometrical problem of maximizing our field of view without reducing or ability to resolve flying bats, particularly those at middle to high elevations. Low fog and cloud cover are common at the Mountaineer facility, and although infrared light is less scattered by water vapor than visual wavelengths, fog nevertheless reduces visibility and clarity in the images. Thus, to a certain extent, the number of objects observed may tend to be auto correlated with low fog and cloud cover. This is partly due to the limitation of the camera's ability to clearly resolve bat-sized objects at distances above the reach of the turbine's blades, where bats are most difficult to detect.

Our study represents the first attempt to observe and interpret bat behavior in the rotor-sweep zone of operating turbines in an effort to understand why and how collisions and mortality occurs. There are some important hypotheses that we did not address due to time, economic and logistical constraints (H_{a1}). Future research must focus on three key areas. Seven of the 8 observations of bats colliding with moving blades were at the maximum speed of 17 RPM. To address the hypothesis that the action and speed of rotating turbine blades results in mortality, experimentally testing the effect of halting (feathering) blade rotation on mortality and bat activity around turbines is needed. Given the small windows of high activity and risk that our study has uncovered, executing such a study would likely require only small amount of turbine down-time, on the order of 2-3 hours for single turbine for a handful of nights. Secondly, future research must extend the full length of the season in which bats are active. In order to address the effect of transient populations and migration, we must monitor activity trends from early spring through late fall. Finally, to better understand the factors that may contribute to mortality, we must look more closely at what actually happens in the moments before a bat is struck by a rotating turbine blade.

Our results indicate that bats are in many cases successfully avoiding moving blades. However, the infrared images we collected were limited in resolution and detail. Existing, more sensitive cameras are currently available and should be used in future research. To capture the interaction in finer spatio-temporal detail, two high-resolution cameras should be used in conjunction to capture synchronized stereo image pairs, from which 3D spatial models can be constructed. Such visualization could show us, in each example, how close bats and blades are, how bats successfully avoid blades, and what factors contribute to collisions. Such information would likely suggest new mitigation strategies.

CHAPTER 4. USE OF DOGS TO RECOVER BAT AND BIRD FATALITIES AT WIND FARMS

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Post-construction carcass searches have been used to estimate fatality of birds and bats at wind farms (e.g., Erickson et al. 2002, Johnson et al. 2003, 2005, this report). Originally designed to monitor annual or seasonal avian fatality rates, current post-construction fatality monitoring protocols have been criticized because search intervals are infrequent (e.g., 7–14 day intervals) and searcher efficiency and carcass removal by scavengers may not be adequately quantified to provide accurate and precise estimates of fatality rates of bats. Additionally, searcher efficiency and scavenger removal vary by habitat type because different vegetative cover conditions influence observer detectability and scavenging rate. Several studies have reported that fewer bird carcasses are found in densely vegetated habitats, which leads to lower fatality estimates in these conditions (e.g., Wobeser and Wobeser 1992, Philbert et al. 1993).

Wildlife biologists increasingly have used dogs in their investigations (Gutzwiller 1990, Shivik 2002). The olfactory capabilities of dogs could greatly improve the efficiency of carcass searches, particularly in dense vegetation (Homan et al. 2001). Dogs generally have been used in research on waterfowl and upland game birds (Zwickel 1980, Gutzwiller 1990), but more recently to recover passerine fatalities during carcass searches. However, use of dogs present unique challenges that warrant consideration. Gutzwiller (1990) noted that the use of dogs can alter established protocols and introduce unknown biases relative to traditional human searches. Additionally, Gutzwiller (1990) pointed out that inconsistent performance by individuals or among different dogs may be attributable to different habitats, weather, and changing physical or physiological conditions for the dog, or any combination of these factors. Clearly, use of trained dogs in wildlife research is important, but limitations and biases warrant further investigation. While biases cannot be totally avoided during field research, careful study design and analyses are important for limiting bias (Gutzwiller 1990).

To my knowledge, dogs have not been trained to find bat carcasses during searches to evaluate fatality at wind farms. Here-in, I present results of a baseline effort to assess the efficiency of dog-handler teams to recover bat fatalities during searches at the Mountaineer and

Meyersdale Wind Energy Centers. My objective was to train dogs to find bat carcasses and conduct pilot studies to determine the search efficiency of dog-handler teams under different environmental and vegetative conditions encountered at these two wind facilities. This effort was not intended to account for all potential sources of bias when using dogs for carcass searches (Gutzwiller 1990, Homan et al. 2001, Shivik 2002), but I provide recommendations for future research needed to better elucidate patterns and evaluate the biases and efficiency when using dogs for bat fatality searches.

METHODS

I tested the search efficiency of dog-human teams during scheduled human searcher efficiency trials (see Chapter 2) conducted at the Mountaineer Wind Energy Center and the Meyersdale Wind Energy Center from 9 August through 6 September 2004.

Training Dogs to Find Bats

Two chocolate Labrador retrievers (one 2-year-old male and one 3-year-old female) were trained for one-week prior to initiating formal field testing. I trained these dogs using fundamental principles employed to teach basic obedience, upland game bird hunting techniques (i.e., "quartering"), and blind retrieve handlings skills (Dobbs et al. 1993). Dogs were trained to quarter within a 10 m wide area using hand signals and whistle commands and to locate bat carcasses of different species and in different stages of decay. When a test bat was found by a dog, an immediate "sit" whistle was given by the handler to establish the behavior of stopping and sitting when a bat was found. The dog was then rewarded with a food treat if it performed the task of finding a trial bat and then sitting, or at least stopping movement, without disturbing the bat. The male retriever occasionally would pick up fresh bat carcasses before I could command "sit;" if he did so, I commanded "hold" which is a common command used when force-fetching retrievers and indicates to the dog that it should hold the object in its mouth still until removed by the handler (Dobbs et al. 1993). This prevented the dog from swallowing or otherwise damaging carcasses. By following this procedure regularly, dogs quickly learned: 1) to quarter within a very small area (10 m transect width); 2) that it was acceptable and rewarding to find bat carcasses; and 3) in order to receive their reward, they were required to not only find bat carcasses, but to either leave them undisturbed or hold them still in their mouth.

Fatality Searches

I tested dogs simultaneously with humans during a sample of searcher efficiency trials that were conducted regularly throughout the study at both sites. Methods used for searching transects and evaluating searcher efficiency are described in Chapter 2. On the day of a searcher efficiency trial at either Mountaineer or Meyersdale, I coordinated with the senior researcher regarding which turbines had been randomly selected for trials, but was not told how many bats were randomly placed at each. Dog-handler searches were conducted both before and after humans had searched the plot. Since humans were instructed to always leave trial carcasses they found in place for the senior researcher to gather at the end of the day, trial carcasses were available after a human search for the dog-handler team. If the dog-handler team searched before the human, any trial or previously undiscovered carcasses were left in place.

For each trial, I searched the first plot with the male retriever and then alternated plots with the female. By alternating dogs within and among trials, I was able to: 1) balance the use of the two dogs in time and space to reduce "observer" bias; 2) evaluate differences in search efficiency between dogs; and 3) provide adequate rest for each dog between searches to reduce fatigue, which could significantly alter individual performance and induce bias. At each plot, I walked transect lines at a rate similar to that of human searchers (approximately 13–25 m/min), while the dog was allowed to quarter the entire width of the transect (5 m on each side) scenting and looking for bats. Similar to human searches, search speed varied by habitat type and terrain and at Mountaineer, large boulders and extreme slope occasionally prevented the dog-handler team from following delineated transect lines. In these cases, the safest route nearest the transect line was taken and the human scanned the impassable area for carcasses. The dog-handler team attempted to search for the same amount of time as humans at each plot, which varied from 30–90 min depending on searchable area, habitat type, and terrain.

Although I searched for carcasses like other human searchers, my primary focus was on the visual cues of each dog indicating that it had found a bat carcass. Once a dog or I found a carcass, we marked it with a piece of flagging and continued, recording all data after completing the search plot. We recorded all searcher efficiency trial carcasses and their numbers on a data sheet and confirmed the results of dog-human teams and humans with the senior researcher at the end of the day. Any bat fatalities discovered by dogs that had not yet been found by human searchers were recorded on separate data sheets and given to the senior researcher to be recorded as incidentals if never found during regularly scheduled searches.

I present proportions of: 1) all bats found; 2) bats found at different distance intervals from turbines; and 3) bats found among different visibility classes (see Chapter 2) for both dog-handler teams and humans that searched the same transects for a relative comparison of findings. This study was not designed to be a direct comparison between dogs and humans because humans were restricted to walking and observing from the transect line, whereas dogs were allowed to quarter the entire 10 m wide search area for each transect, although the handler walked on and searched from the transect line similar to human searches. Data were pooled for all trial carcasses used in this study.

RESULTS

I completed dog-handler team searcher efficiency trials on 3 different days at 4–6 turbines each day (n = 45 bats) at Mountaineer, and 5 different days of trials at 4–6 turbines each day (n = 52 bats) at Meyersdale. Results varied between the male and female dogs at Mountaineer (20 of 25 [80%] trial carcasses found by the male compared to 12 of 20 [60%] by the female), but were similar between dogs at Meyersdale (80 and 82% for the male and female, respectively; Tables 4-1 and 4-2).

Dog-handler and human searcher efficiency varied considerably between the two study sites. Overall dog-handler efficiency for all trials and bats combined, and using combined findings from both dogs, was 71% at Mountaineer and 81% at Meyersdale, compared to 42 and 14% for human searchers, respectively (Tables 4-1 and 4-2).

Dog-handler and human searcher efficiency also varied considerably by distance from the turbine. At Mountaineer, both the dog-handler team and humans found a high proportion of trial bats within 10 m of the turbine (88 and 75%, respectively). Human search efficiency generally declined beyond 10 m from the turbine and ranged from 20–60% for 10 m distance intervals out to 60 m from the turbine, whereas dog-handler efficiency ranged from 50–80% for the same intervals from turbines at Mountaineer (Table 4-1). At Meyersdale, human searcher efficiency was poor regardless of distance from turbine, but was the highest (25%) within 10 m of the turbine, compared to 83% for the dog-handler team (Table 4-2). Efficiency for the dog-handler team was relatively consistent across distance intervals beyond 10 m from the turbine at Meyersdale, ranging from 67–88%, compared to 0–20% for humans.

Searcher efficiency varied for the dog-handler team and humans among habitat visibility classes at both sites as well. At Mountaineer, both the dog-handler team and humans found fairly similar proportions of trial bats within high visibility habitats (65 and 59%, respectively; Table 4-1). Human search efficiency declined considerably as visibility decreased (50, 38, and 10% for medium, low, and extremely low visibility categories, respectively) at this site. The dog-handler team found more trial carcasses in medium (100%), low (75%), and extremely low (50%) visibility habitats at Mountaineer (Table 4-1). At Meyersdale, human searcher efficiency generally was poor regardless of habitat visibility; humans found none of the trial carcasses in extremely low visibility habitats and only 14% in high visibility habitats (Table 4-2). Eleven and 23% of trial carcasses were found by humans in medium and low visibility habitats, respectively at Meyersdale. The dog-human team consistently found high proportions of trial carcasses in high, medium, and low visibility habitats (86, 89, and 85%, respectively), but found only 2 of 5 (40%) in extremely low visibility habitats (Table 4-2).

DISCUSSION

Both dogs quickly learned search protocols and were very efficient at recovering bat fatalities at both sites. There were considerable differences in both dog-handler team and human searcher efficiency between the two study sites. Similar to the results and discussion offered in Chapter 2, I believe this reflects the differences in vegetative cover, terrain, and amount of high visibility habitat found at the two sites. Plots at the Mountaineer are highly variable, but often have considerably more open, high visibility habitat (mostly non-vegetated bare ground) interspersed throughout the plot, but also have steeper, rockier slopes that are difficult to search. At Meyersdale, plots are predominantly flat or gently rolling with very few steep grades within search plots and much easier for dogs and humans to search than those at Mountaineer. However, plots at Meyersdale are dominated by moderate to heavy grass cover in all 20 search plots, with highly visible habitat only occurring on the access road and near the turbine (generally <10 m). Human search efficiency was very low in these habitat visibility conditions, but dog-handler teams had consistently high efficiency, perhaps due to more favorable terrain which made searching easier for the dogs and because the heavy grass cover offered more consistent and favorable scenting conditions. Steeper slopes at Mountaineer appeared to fatigue dogs more rapidly, which likely negatively influenced their performance, especially on warmer days.

While findings from this pilot effort on the use of dogs to recover bat fatalities are promising, more research is required to better elucidate patterns and account for the limitations and biases that influence the efficiency of dog-handler teams. The results of this pilot study are not a fair comparison between humans and dogs because humans were restricted to walking and observing from the transect line, whereas dogs were allowed to quarter the entire 10 m-wide search area for each transect. Future work should incorporate experiments that allow for human searchers and dog-handlers teams to search transects in the same way. The following suggestions, modified from Gutzwiller (1990), Homan et al. (2001), and Shivik (2002), seem prudent regarding future studies on the use of dogs for carcass searches.

1. If dogs are to be considered sampling tools, future research should focus on factors that will help to further develop standards for the use of dogs in this type of sampling.
2. The influence of weather conditions on dog-handler search efficiency among different habitats should be further evaluated to assess bias associated with these factors.
3. The effects of search time, species of bat, and density of trial carcasses on dog-handler search efficiency should be further investigated.

Until more information is gathered to further evaluate the use of dogs to recover bat fatalities, the following points (from Gutzwiller 1990) should be considered and explicitly stated to improve accuracy, precision, and interpretation of results when using dogs to recover bat fatalities:

1. Use either the same dog throughout a study or balance the use of different dogs in time and space to reduce "observer" bias.
2. If possible, restrict searches to certain periods of the day to avoid fluctuations in temperature, humidity, and other weather-related factors that could influence scenting conditions.
3. Randomize the spatial and temporal order of search plots to balance the space and time-related effects, as well as weather factors mentioned above.
4. Ensure that dogs are fit and well trained and, if using more than one, that they are as equal as possible relative to fitness and training.

	N	No. Found by Dogs	%	No. Found by Humans	%
Overall	45	32	71	19	42
Distance from Turbine (m)					
0 – 10	8	7	88	6	75
11 – 20	8	4	50	3	38
21 – 30	8	5	63	3	38
31 – 40	10	8	80	2	20
41 - 50	6	4	67	2	33
>50	5	4	80	3	60
Visibility					
High	17	11	65	10	59
Medium	10	10	100	5	50
Low	8	6	75	3	38
Extremely Low	10	5	50	1	10
Dogs (all bats combined)					
Male	25	20	80		
Female	20	12	60		

Table 4-1. Percent of searcher efficiency trial bats found by dogs and humans for all trial carcasses, within distance categories from the turbine, and among visibility classes for 3 trials conducted on 11, 23, and 25 August 2005 at the Mountaineer Wind Energy Center.

	N	No. Found by Dogs	%	No. Found by Humans	%
Overall	52	42	81	7	14
Distance from Turbine (m)					
0 – 10	12	10	83	3	25
11 – 20	8	7	88	0	0
21 – 30	8	7	88	1	13
31 – 40	10	8	80	2	20
41 - 50	11	8	73	0	0
>50	3	2	67	0	0
Visibility					
High	14	12	86	2	14
Medium	19	17	89	2	11
Low	13	11	85	3	23
Extremely Low	5	2	40	0	0
Dogs (all bats combined)					
Male	25	20	80		
Female	27	22	82		

Table 4-2. Percent of searcher efficiency trial bats found by dogs and humans for all trial carcasses, within distance categories from the turbine, and among visibility classes for 3 trials conducted on 9, 15, and 16 August and 5 and 6 September 2005 at the Meyersdale Wind Energy Center.

CHAPTER 5. SYNTHESIS, SCOPE, LIMITATIONS, AND FUTURE RESEARCH NEEDS

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SYNTHESIS

Our primary goals were to evaluate and improve fatality search protocols and observe behavioral interactions of bats encountering turbines in an effort to understand why and how collisions and fatalities occur. This is the first attempt to observe and interpret bat behavior in the rotor-swept zone of operating turbines.

Only recently have bats become an important consideration at wind facilities during pre- and post-construction monitoring efforts. Consequently, very few efforts have been conducted to assess bat fatalities at wind facilities. Bat fatalities have been recorded either anecdotally or formally at almost every wind farm worldwide where post-construction surveys have been conducted, but efforts to specifically estimate bat fatality are rare. Additionally, only 4 studies prior to our work used bat carcasses in searcher efficiency and scavenger removal trials to develop bias corrections. Studies using birds as surrogates, or not conducting bias correction trials at all, clearly are biased and should be interpreted with caution. Fatality rate estimates for this study were heavily influenced by the periodicity of bat fatalities, the weekly search interval we employed, and high scavenger removal at Mountaineer. Weekly searches at this facility underestimated the fatality rate by a factor of nearly three. Researchers should consider and adequately address these issues when designing post-construction monitoring studies. We highly recommend pilot efforts to address the extent to which the aforementioned factors influence estimates of fatality so as to achieve reliable estimates. Line transect sampling and analysis using program DISTANCE may offer an alternative sampling and analysis procedure that previously has not been used for post-construction fatality monitoring.

Our estimates of bat fatality are among the highest ever reported and support the contention that forested mountains and ridges, especially in the eastern U.S., are the highest risk sites currently known for bats at wind facilities. When daily searches were corrected for searcher efficiency, scavenging, and search area, we estimated an average of 38 and 25 bats per turbine were killed at Mountaineer and Meyersdale, respectively, during just the 6-week period we investigated. We believe that the estimated fatality rates from the 6-week period likely were as high in mid-July when we first visited the sites and noted fatality prior to sampling and probably continued at least through September, corresponding with reports from other studies (e.g., Kerns and Kerlinger 2004).

Although no fatalities of threatened or endangered species (e.g., Indiana bat) have been found to date at wind farms, the continued development of wind power generation may pose risk to these species at other locations. Continued high fatality rates of other species (e.g., eastern red bats and hoary bats) warrant greater attention and consideration, as many species of bats are believed to be in decline (Pierson 1998). Because bats are long-lived and have exceptionally low reproductive rates (Kunz 1982), population growth is relatively slow and ability to recover from population crashes limited, thereby increasing the risk of local extinctions (Barclay and Harder 2003, Racey and Entwistle 2000, 2003). Given the projected development of wind power generation, particularly in the region we studied, biologically significant impacts could be anticipated for some species when cumulative impacts are considered.

Our results appear to corroborate the few studies conducted in regard to species composition of bat fatalities at wind facilities. The dominance of tree roosting, migratory species (e.g., eastern red bat and hoary bat) fatalities appears to be a unifying theme among studies conducted in the western, upper Mid-western, and the eastern U.S. However, no studies have been reported from wooded ridges in the western U.S., or anywhere in the southwest (e.g., Arizona, Oklahoma, Texas), and different species of bats may be more susceptible in some areas (e.g., Mexican free-tailed bats).

Patterns of bat fatality, relationships between weather and turbine variables, and observations with thermal imaging all corroborate and suggest bat fatalities at the two sites occur primarily on low wind nights, but mostly when turbine blades are rotating at or near their maximum speed of 17 RPMs. Kerns and Kerlinger (2004) noted a similar pattern for bat fatalities in 2003. This observed pattern offers promise toward predicting periods of high fatality and warrants further investigation at wind facilities in this region to assess whether our findings represent a predictable, annual pattern.

Our observations with thermal imaging lead us to conclude that bat attraction to turbines is influenced by a number of ultimate and proximate factors that likely interact with one another. For example, our thermal images of bats attempting to land or actually landing on stationary blades and the turbine mast generally support the roost attraction hypothesis, but the ultimate attraction to the site where a turbine is located might be available prey. Once in proximity, bats may misconstrue turbines as suitable day or night roosts or as perches to facilitate feeding. Alternatively, the initial attraction for migrating bats moving across a landscape might be the prominence of turbines and the possibility of a suitable roost worth investigating. Video images of bats chasing turbine blades rotating at slow speeds offer further insight to possible attraction. Bats may investigate moving blades simply out of curiosity, because movement is mistaken as evidence of prey, or because of attractive sounds. Regardless of the proximate and ultimate sources of attraction, our observations do not indicate that bat fatality at turbines is a random event.

SCOPE AND LIMITATIONS

There are several limitations to our study that warrant discussion to provide the appropriate context for interpreting results. Our study was conducted in two areas located on forested ridges in the Appalachian Mountains and statistical inferences are limited to these sites. However, we believe that our findings reflect an emerging pattern of bat fatality associated with wind turbines located on forested mountains or ridges in this region, and suggest that similar findings at other wind facilities with comparable forest composition and topography could be expected.

Our study encompassed only a 6-week period which typically might be expected to include the peak period of bat fatality. However, unseasonably low temperatures and record weather events may have reduced or delayed bat activity on ridges, and our observations do not reflect a full season of bat movement and activity. Our fatality estimates cannot be directly compared to other studies, including the 2003 work at Mountaineer (Kerns and Kerlinger 2004), because of different sampling protocols employed (i.e., a different approach and level of intensity employed when quantifying searcher efficiency and carcass removal for adjusting estimates). However, it is clear that numerous bats were killed at the two sites we investigated. Until a full season of carcass searches and bias quantification are gathered (i.e., April through at least October), it should not be assumed that: 1) fatalities are not occurring and/or are otherwise biologically insignificant during other periods; 2) the 6-week period we studied includes the suspected peak of fall migration; and 3) that other species of bats, particularly threatened or endangered species (e.g., Indiana bats) are not being killed at wind facilities during different times of the year or that theses species will not be at risk as other locations are developed in the future.

Differences in scavenging rates between the two sites suggest that scavenging must be determined on a site-specific basis and should not be assumed similar between sites even in close proximity and in similar habitat conditions. A single year of data is inadequate to accurately predict the search interval or assess bias corrections appropriately and future surveys should account for temporal patterns of scavenging among different vegetation types.

FUTURE RESEARCH NEEDS

Numerous questions require further and immediate investigation to advance our understanding of bat fatality at wind turbines, develop solutions for existing facilities, and aid with assessing risk at future wind facilities.

First and foremost, it is clear that a large proportion of bat fatalities occur on nights with low winds and relatively low levels of power production. Should this pattern prove to be persistent, curtailment of operations during predictable nights or periods of high bat kills could reduce fatalities considerably, potentially with modest reduction in power production and associated economic impact on project operations. Based on our discussions with engineers, maintenance personnel, and manufacturers, there are options that warrant immediate investigation and discussion so as to develop appropriate experiments. Options to consider for experimentation include, but are not limited to: 1) full curtailment on low wind nights when winds are <6 m/s; 2) partial curtailment from sunset to midnight (when bats and insects are most active) on nights when winds are <6 m/s; 3) changing the “cut-in” speed (speed at which the generator begins producing power; blades are at full speed of 17 RPM) on turbines from 4 m/s to 6 m/s; 4) changing computer settings and requiring turbines to remain fully feathered, but free-wheeling, until the experimental cut-in speed is detected by the anemometers, at which time the turbine would then "pitch" into the wind and "cut-in" at the pre-set, desired speed. These turbine treatments, or combinations of treatments, require rigorous experimentation at multiple sites to evaluate the effect on bat fatality and the associated economic costs.

Bats appear to be attracted to turbines, at least at a small scale, perhaps for a number of reasons, but food availability in openings on ridges, acoustic and/or visual attraction to blade movement, sound attraction, and possible attraction as roosts seem plausible given our findings and current state of knowledge. As such, further investigations are needed to determine regarding the sources of attraction and how to best mitigate or eliminate sources of attraction.

Based on our results and current state of knowledge, we recommend the following research needs:

1) Conduct extensive post-construction fatality searches for a "full season" of bat movement and activity (April-October) to fully elucidate temporal patterns of fatality.
2) Further investigate the relationships between passage of storm fronts, weather conditions (e.g., wind speed, temperature), turbine blade movement, and bat fatality.
3) Experimentally test and compare moving and non-moving turbine blades ("treatments" discussed above) at multiple sites to quantify reductions in bat fatality relative to economic costs of curtailment.
4) Conduct extensive post-construction fatality searches at existing wind facilities that encompass a broad range of habitat types and topographic features to further understand patterns of fatality in relation to surrounding landscape context. These data would be useful for assessing potential risk at future developments.
5) Evaluate sources of attraction to turbines (e.g., ultrasonic emission, prey availability).
6) Investigate approaches for developing possible deterrents; testing any such deterrents should be performed under controlled conditions first, and then under varying environmental and turbine conditions at multiple sites.
7) Further test the search efficiency and efficacy of using dogs to recover bat fatalities versus humans under different search conditions and quantify biases associated with using dogs.
8) Compare different methods and tools (radar, thermal imaging, and acoustic detectors) simultaneously to better understand bat activity, migration, proportions of bats active in the area of risk, and their interactions with turbines.

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APPENDIX I
Photos of Habitat Visibility Classes

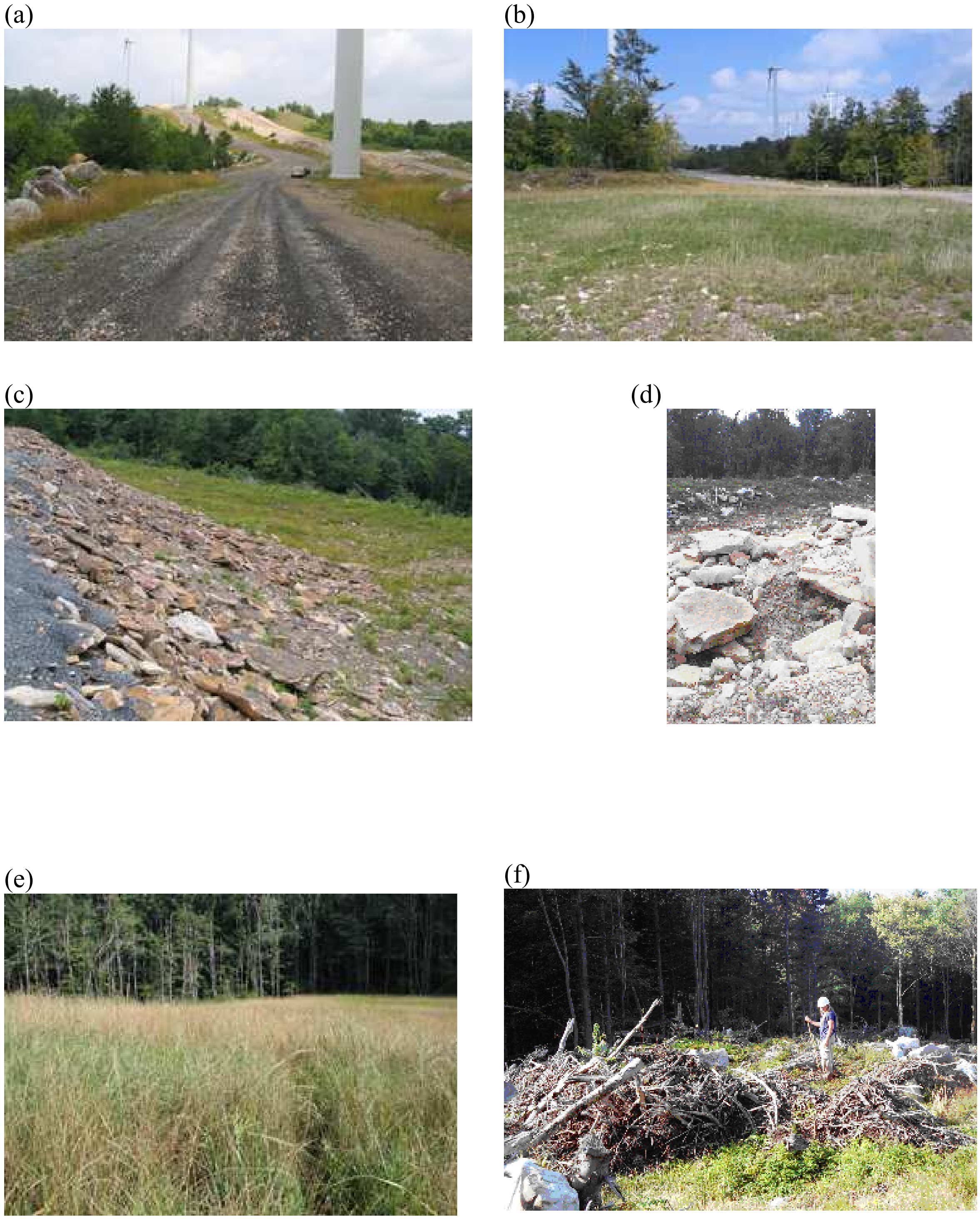


Figure 2-2. Examples of habitat visibility classes at the Mountaineer and Meyersdale Wind Energy Centers, including a) high detection road, b) medium detection vegetation, c) medium detection slope, d) low detection boulders, e) extremely low detection tall grass, and f) extremely low detection brush pile.

APPENDIX II
Data Forms

MWEC WIND ENERGY CENTER, WV
Searched Turbines Fall 2004

Searcher: ____________________________ **Date:** _________________________

Turbine #	Start Time	End Time	Wind Dir	Operation	# Carcasses
				Working Stopped Removed	______Bat ______Bird
				Working Stopped Removed	______Bat ______Bird
				Working Stopped Removed	______Bat ______Bird
				Working Stopped Removed	______Bat ______Bird
				Working Stopped Removed	______Bat ______Bird
				Working Stopped Removed	______Bat ______Bird
				Working Stopped Removed	______Bat ______Bird
				Working Stopped Removed	______Bat ______Bird

Figure I-1. Turbine datasheet completed by each searcher/day.

MWEC WIND ENERGY CENTER, WV
Fatality Report **Fall 2004**

ID #: ____________________________ **Searcher:** ____________________________

Recovery Date: ___________________ **Time Found:** _________________________

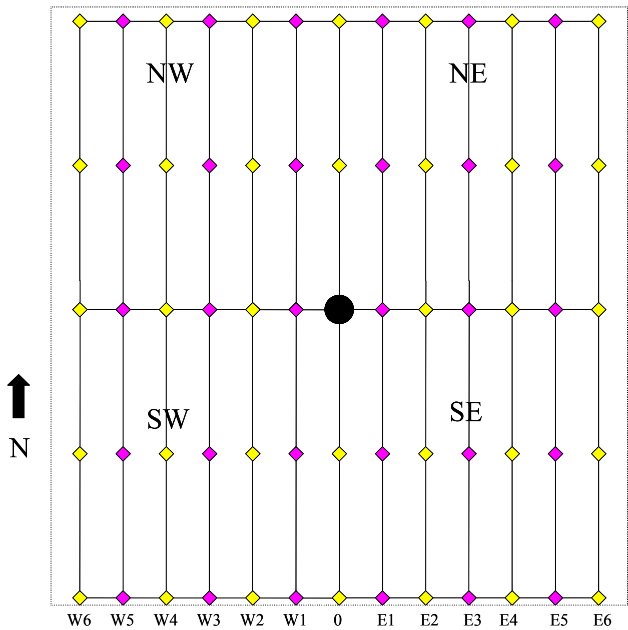
When Found: Before Search During Search After Search

THE TURBINE

Turbine #: _______________________ **Operating at recovery time?** Yes No

Quadrant: NE SE NW SW **Degree:** _________ **Distance:** ______________

Note: Degrees should match quadrant. NE: 0 –90 SE: 90 – 180 SW: 181 – 270 NW: 271 – 359



THE TRANSECT

Observer distance from carcass when first detected:

____

Transect #:

____

Perp. Distance to Transect:

____

Found Outside of plot?
Yes No

THE VEGETATION (w/in 1 m radius of carcass)

Dominant Cover (choose only one):

_______ Bare Ground (0% vegetation; e.g., road, gravel, dirt)
_______ Vegetation (clover, grass, blackberry)
 ______ Short (below ankle)
 ______ Medium (ankle to knee)
 ______ Tall (above knee)
_______ Large Rock/Boulders
_______ Brush Pile

Other: _____________________________

% Veg: <10 11-25 26-50 50-75 75-99 100

Visibility Index

_______ Extremely Low (e.g., dense tall grass)
_______ Low (e.g., brush pile with >50% veg)
_______ Moderate (e.g., 25% tall veg)
_______ High (e.g. bare ground, 10% med veg)

Slope >25% Yes No

Notes:

____

____

Figure I-2. Fatality datasheet (page 1); one datasheet was completed for each carcass found.

THE CARCASS

Bird / Bat **Live / Fatality** **If Live:** Euthanized Released

Left for Carcass Removal: Yes No **Carcass Removal ID**: _______________

Species: ________________________ **Age:** A J U **Sex:** M F U

Position: Face Up Face Down

Physical Condition at time of find: Complete Partial Feather Spot

Describe injuries:

____

____

Scavenging: Yes No **Possible Scavengers:** unknown insects rodents small carnivores corvids other: ________________

Scavenging Notes:

____

____

Carcass Condition:

_____ Fresh

_____ Decomposing – early

_____ Decomposing – late

_____ Desiccated

Infestation:

______ None ______ Flies

______ Ants ______ Maggots

______ Bees/Wasps ______ Beetles

______ Grasshoppers ______ Other

Eyes:

_____ Round/fluid filled

_____ Dehydrated

_____ Sunken

_____ Empty

Estimated time of death:

______ Last night ______ > 2 weeks

______ 2 – 3 days ______ > month

______ 4 – 7 days ______ Unknown

______ 7 – 14 days

Photo Number if taken: ___________

Additional Notes:

____

____

____

Figure I-2, continued. Fatality datasheet (page 2).

APPENDIX III
Summary of Bat Fatality Data

Table III-1. List of bat fatalities found at Mountaineer during standardized search from August 2 through September 13, 2004.			
Date	**Species**	**Nearest Turbine**	**Distance to Nearest Turbine (m)**
07/31/04	little brown bat	1	32
07/31/04	little brown bat	3	27
07/31/04	hoary bat	6	2
07/31/04	little brown bat	12	4
07/31/04	red bat	13	18
07/31/04	eastern pipistrel	16	34
07/31/04	red bat	18	39
07/31/04	hoary bat	18	28
07/31/04	hoary bat	27	21
07/31/04	little brown bat	34	30
07/31/04	red bat	42	47
08/01/04	eastern pipistrel	1	19
08/01/04	hoary bat	1	24
08/01/04	hoary bat	1	30
08/01/04	hoary bat	3	3
08/01/04	eastern pipistrel	7	21
08/01/04	little brown bat	13	28
08/01/04	hoary bat	15	11
08/01/04	hoary bat	15	10
08/01/04	red bat	15	35
08/01/04	red bat	19	21
08/01/04	hoary bat	25	18
08/01/04	hoary bat	29	17
08/01/04	hoary bat	35	23
08/01/04	red bat	43	18
08/02/04	red bat	1	3
08/02/04	red bat	1	5
08/02/04	hoary bat	1	11
08/02/04	red bat	1	12
08/02/04	little brown bat	1	34
08/02/04	eastern pipistrel	3	13
08/02/04	red bat	5	11
08/02/04	red bat	7	8
08/02/04	eastern pipistrel	7	32
08/02/04	big brown bat	7	22
08/02/04	little brown bat	9	44
08/02/04	eastern pipistrel	9	4
08/02/04	eastern pipistrel	9	2
08/02/04	red bat	9	7
08/02/04	red bat	9	7
08/02/04	eastern pipistrel	15	28

08/02/04	eastern pipistrel	17	12
08/02/04	hoary bat	17	21
08/02/04	big brown bat	17	27
08/02/04	big brown bat	17	23
08/02/04	hoary bat	17	25
08/02/04	red bat	21	6
08/02/04	hoary bat	29	35
08/02/04	hoary bat	29	3
08/02/04	hoary bat	29	36
08/02/04	eastern pipistrel	33	11
08/02/04	little brown bat	33	23
08/02/04	eastern pipistrel	35	12
08/02/04	red bat	41	18
08/02/04	hoary bat	8	26
08/02/04	hoary bat	38	34
08/03/04	eastern pipistrel	1	2
08/03/04	unknown	1	5
08/03/04	eastern pipistrel	1	40
08/03/04	eastern pipistrel	5	15
08/03/04	eastern pipistrel	13	4
08/03/04	hoary bat	15	15
08/03/04	eastern pipistrel	15	32
08/03/04	eastern pipistrel	15	20
08/03/04	little brown bat	17	24
08/03/04	eastern pipistrel	19	15
08/03/04	big brown bat	25	55
08/03/04	red bat	27	28
08/03/04	eastern pipistrel	31	26
08/03/04	red bat	35	41
08/03/04	hoary bat	43	10
08/04/04	eastern pipistrel	3	6
08/04/04	hoary bat	5	25
08/04/04	red bat	5	31
08/04/04	hoary bat	7	40
08/04/04	eastern pipistrel	15	26
08/04/04	red bat	43	28
08/04/04	red bat	43	32
08/04/04	eastern pipistrel	43	17
08/05/04	hoary bat	33	22
08/05/04	hoary bat	33	31
08/06/04	little brown bat	1	7
08/06/04	little brown bat	1	4
08/06/04	hoary bat	19	29
08/06/04	eastern pipistrel	23	36
08/06/04	red bat	23	27

08/06/04	hoary bat	23	28
08/06/04	red bat	27	20
08/06/04	hoary bat	43	33
08/06/04	hoary bat	43	37
08/07/04	red bat	7	28
08/07/04	eastern pipistrel	7	31
08/07/04	hoary bat	9	49
08/07/04	hoary bat	25	51
08/07/04	eastern pipistrel	39	3
08/07/04	hoary bat	4	36
08/07/04	little brown bat	16	14
08/07/04	little brown bat	26	18
08/07/04	hoary bat	36	14
08/07/04	little brown bat	40	37
08/07/04	little brown bat	44	39
08/08/04	hoary bat	5	29
08/08/04	hoary bat	9	22
08/08/04	silver-haired bat	9	9
08/08/04	hoary bat	13	34
08/09/04	hoary bat	13	35
08/09/04	eastern pipistrel	25	21
08/10/04	hoary bat	5	15
08/10/04	hoary bat	13	40
08/10/04	eastern pipistrel	29	17
08/10/04	eastern pipistrel	31	12
08/11/04	red bat	19	31
08/11/04	hoary bat	21	34
08/11/04	eastern pipistrel	27	44
08/12/04	little brown bat	1	24
08/12/04	eastern pipistrel	1	22
08/12/04	big brown bat	3	42
08/12/04	big brown bat	3	25
08/12/04	red bat	13	30
08/12/04	eastern pipistrel	17	32
08/12/04	eastern pipistrel	19	24
08/12/04	little brown bat	21	33
08/12/04	red bat	23	43
08/12/04	little brown bat	23	30
08/12/04	eastern pipistrel	31	10
08/12/04	little brown bat	35	18
08/12/04	red bat	43	12
08/13/04	little brown bat	9	12
08/13/04	eastern pipistrel	9	50
08/13/04	eastern pipistrel	21	31
08/14/04	hoary bat	1	0.3

08/14/04	hoary bat	13	24
08/14/04	eastern pipistrel	13	12
08/14/04	hoary bat	13	32
08/14/04	eastern pipistrel	23	31
08/14/04	eastern pipistrel	23	20
08/14/04	hoary bat	29	18
08/14/04	red bat	37	3
08/14/04	eastern pipistrel	37	29
08/14/04	red bat	43	22
08/14/04	eastern pipistrel	4	23
08/14/04	eastern pipistrel	6	19
08/14/04	hoary bat	6	17
08/14/04	eastern pipistrel	8	10
08/14/04	hoary bat	10	32
08/14/04	red bat	28	23
08/14/04	eastern pipistrel	28	11
08/14/04	red bat	34	34
08/14/04	eastern pipistrel	40	2
08/14/04	hoary bat	40	43
08/14/04	eastern pipistrel	42	24
08/14/04	red bat	42	28
08/15/04	little brown bat	1	28
08/15/04	little brown bat	1	26
08/15/04	hoary bat	1	36
08/15/04	eastern pipistrel	13	20
08/15/04	hoary bat	17	8
08/15/04	eastern pipistrel	19	17
08/15/04	hoary bat	23	30
08/15/04	hoary bat	23	23
08/15/04	hoary bat	23	8
08/15/04	hoary bat	27	23
08/15/04	eastern pipistrel	33	3.5
08/15/04	red bat	35	31
08/15/04	eastern pipistrel	37	31
08/15/04	red bat	43	11
08/16/04	hoary bat	7	20
08/16/04	hoary bat	17	5
08/16/04	hoary bat	23	35
08/16/04	big brown bat	25	12
08/16/04	red bat	25	31
08/16/04	little brown bat	25	31
08/16/04	eastern pipistrel	27	38
08/17/04	eastern pipistrel	17	0.5
08/17/04	eastern pipistrel	17	18
08/17/04	eastern pipistrel	21	38

08/17/04	little brown bat	25	23
08/17/04	red bat	27	36
08/17/04	eastern pipistrel	27	22
08/17/04	hoary bat	27	30
08/17/04	red bat	31	20
08/17/04	eastern pipistrel	33	10.5
08/17/04	hoary bat	35	41
08/17/04	hoary bat	39	28
08/17/04	hoary bat	43	10
08/17/04	red bat	43	3
08/18/04	red bat	1	31
08/18/04	hoary bat	7	27
08/18/04	eastern pipistrel	7	1.4
08/18/04	little brown bat	13	5.2
08/18/04	red bat	17	19
08/18/04	silver-haired bat	27	40
08/18/04	hoary bat	27	37
08/18/04	hoary bat	29	15
08/21/04	unknown	1	15
08/21/04	eastern pipistrel	4	99
08/21/04	hoary bat	14	38
08/22/04	eastern pipistrel	2	20
08/22/04	eastern pipistrel	2	17
08/22/04	eastern pipistrel	2	23
08/22/04	eastern pipistrel	2	27
08/22/04	hoary bat	2	40
08/22/04	eastern pipistrel	10	21
08/22/04	red bat	10	22
08/22/04	eastern pipistrel	12	10
08/22/04	little brown bat	14	16
08/22/04	eastern pipistrel	16	24
08/22/04	eastern pipistrel	20	17
08/22/04	red bat	20	27
08/22/04	eastern pipistrel	22	16
08/22/04	big brown bat	24	40
08/22/04	eastern pipistrel	24	36
08/22/04	eastern pipistrel	26	12
08/22/04	red bat	28	8
08/22/04	eastern pipistrel	32	19
08/22/04	eastern pipistrel	34	37
08/23/04	eastern pipistrel	8	10
08/23/04	hoary bat	18	4
08/23/04	eastern pipistrel	18	26
08/23/04	eastern pipistrel	20	20
08/23/04	eastern pipistrel	20	32

08/23/04	red bat	22	3
08/23/04	red bat	24	32
08/23/04	eastern pipistrel	34	15
08/23/04	eastern pipistrel	38	4
08/23/04	hoary bat	40	7
08/24/04	big brown bat	2	10
08/24/04	hoary bat	2	28
08/24/04	red bat	18	16
08/24/04	red bat	20	32
08/24/04	eastern pipistrel	22	20
08/24/04	eastern pipistrel	24	20
08/24/04	little brown bat	24	26
08/24/04	red bat	28	22
08/24/04	red bat	30	17
08/24/04	red bat	30	15
08/24/04	eastern pipistrel	32	16
08/24/04	red bat	34	37
08/24/04	red bat	38	31
08/24/04	hoary bat	40	15
08/24/04	little brown bat	40	23
08/24/04	hoary bat	42	12
08/25/04	eastern pipistrel	14	20
08/25/04	eastern pipistrel	14	25
08/25/04	red bat	24	22
08/25/04	little brown bat	32	46
08/25/04	hoary bat	40	29
08/25/04	eastern pipistrel	44	20
08/26/04	eastern pipistrel	2	28
08/26/04	little brown bat	20	22
08/27/04	hoary bat	16	12
08/28/04	eastern pipistrel	12	9
08/28/04	red bat	18	12
08/28/04	hoary bat	24	34
08/28/04	red bat	26	43
08/28/04	hoary bat	26	15
08/28/04	red bat	30	24
08/28/04	hoary bat	40	4
08/28/04	eastern pipistrel	40	12
08/28/04	eastern pipistrel	40	8
08/28/04	red bat	42	7
08/28/04	hoary bat	42	30
08/28/04	hoary bat	42	19
08/28/04	eastern pipistrel	44	9
08/28/04	hoary bat	3	23
08/28/04	red bat	17	4

08/28/04	red bat	19	29
08/28/04	eastern pipistrel	23	24
08/28/04	red bat	23	15
08/28/04	eastern pipistrel	23	24
08/28/04	hoary bat	27	32
08/28/04	red bat	27	34
08/28/04	hoary bat	31	15
08/28/04	hoary bat	31	22
08/28/04	red bat	33	5
08/28/04	hoary bat	33	24
08/28/04	eastern pipistrel	35	9
08/28/04	hoary bat	41	20
08/28/04	red bat	41	9
08/29/04	eastern pipistrel	2	25
08/29/04	hoary bat	10	23
08/29/04	hoary bat	10	30
08/29/04	hoary bat	16	24
08/29/04	hoary bat	16	20
08/29/04	hoary bat	16	25
08/29/04	hoary bat	16	23
08/29/04	hoary bat	18	37
08/29/04	red bat	20	28
08/29/04	eastern pipistrel	26	33
08/29/04	hoary bat	26	30
08/29/04	hoary bat	34	11
08/29/04	eastern pipistrel	34	20
08/29/04	hoary bat	40	29
08/29/04	hoary bat	40	37
08/29/04	hoary bat	40	39
08/29/04	red bat	40	24
08/29/04	hoary bat	42	3
08/30/04	eastern pipistrel	10	32
08/30/04	hoary bat	16	2
08/30/04	red bat	20	21
08/30/04	hoary bat	24	24
08/30/04	eastern pipistrel	28	14
08/30/04	hoary bat	30	25
08/30/04	hoary bat	36	35
08/30/04	silver-haired bat	36	34
08/30/04	hoary bat	42	24
08/30/04	red bat	42	5
08/30/04	hoary bat	44	29
08/31/04	red bat	12	7
08/31/04	red bat	42	18
08/31/04	hoary bat	44	3

09/01/04	red bat	4	13
09/01/04	red bat	12	11
09/01/04	hoary bat	12	52
09/01/04	little brown bat	12	33
09/01/04	eastern pipistrel	16	25
09/01/04	hoary bat	18	16
09/01/04	red bat	18	43
09/01/04	red bat	20	28
09/01/04	silver-haired bat	22	31
09/01/04	red bat	24	42
09/01/04	hoary bat	34	19
09/01/04	hoary bat	36	20
09/01/04	red bat	36	26
09/01/04	red bat	36	36
09/01/04	red bat	36	2
09/01/04	hoary bat	40	21
09/01/04	red bat	40	17
09/01/04	hoary bat	40	18
09/01/04	hoary bat	42	17
09/01/04	red bat	44	4
09/01/04	little brown bat	44	17
09/01/04	hoary bat	24	39
09/02/04	big brown bat	8	39
09/02/04	eastern pipistrel	12	27
09/02/04	little brown bat	12	24
09/02/04	hoary bat	22	37
09/02/04	little brown bat	24	19
09/02/04	eastern pipistrel	38	36
09/02/04	hoary bat	40	37
09/02/04	little brown bat	42	33
09/02/04	hoary bat	44	1
09/03/04	hoary bat	20	21
09/03/04	hoary bat	24	19
09/03/04	little brown bat	36	18
09/03/04	hoary bat	38	33
09/03/04	red bat	42	45
09/04/04	little brown bat	2	56
09/04/04	hoary bat	14	23
09/04/04	red bat	20	53
09/04/04	hoary bat	20	15
09/04/04	silver-haired bat	22	22
09/04/04	red bat	28	18
09/04/04	little brown bat	32	38
09/04/04	little brown bat	34	10
09/04/04	hoary bat	38	33

09/04/04	silver-haired bat	38	10
09/04/04	red bat	44	26
09/04/04	silver-haired bat	19	38
09/04/04	hoary bat	23	2
09/04/04	hoary bat	23	30
09/04/04	silver-haired bat	25	12
09/04/04	silver-haired bat	31	12
09/04/04	silver-haired bat	35	27
09/04/04	little brown bat	35	27.2
09/04/04	silver-haired bat	37	19
09/04/04	hoary bat	39	3.5
09/04/04	hoary bat	41	23
09/04/04	hoary bat	43	11
09/04/04	hoary bat	43	19
09/04/04	red bat	43	36
09/05/04	silver-haired bat	2	28
09/05/04	hoary bat	24	26
09/06/04	red bat	6	10
09/06/04	hoary bat	22	18
09/06/04	silver-haired bat	26	34
09/07/04	red bat	16	20
09/07/04	hoary bat	40	19
09/07/04	red bat	44	12
09/08/04	hoary bat	22	26
09/09/04	hoary bat	30	24
09/09/04	hoary bat	32	45
09/10/04	silver-haired bat	2	41
09/10/04	eastern pipistrel	4	20
09/10/04	red bat	6	20
09/10/04	red bat	10	24
09/10/04	silver-haired bat	40	33
09/10/04	silver-haired bat	44	5
09/11/04	hoary bat	2	12
09/11/04	red bat	2	28
09/11/04	red bat	4	9
09/11/04	red bat	14	13
09/11/04	red bat	24	39
09/11/04	red bat	26	26
09/11/04	silver-haired bat	26	40
09/11/04	red bat	26	31
09/11/04	eastern pipistrel	28	15
09/11/04	silver-haired bat	28	17
09/11/04	hoary bat	32	37
09/11/04	eastern pipistrel	36	19
09/11/04	hoary bat	38	47

09/11/04	hoary bat	44	12
09/11/04	hoary bat	44	25
09/11/04	red bat	44	14
09/11/04	red bat	9	34
09/11/04	red bat	9	15
09/11/04	hoary bat	16	27
09/11/04	red bat	27	39
09/11/04	red bat	27	40
09/11/04	hoary bat	37	41
09/11/04	silver-haired bat	41	35
09/11/04	hoary bat	41	38

Table III-2. List of bat fatalities not observed on standardized searches at Mountaineer from July 31 through September 11, 2004.

Date	**Species**	**Nearest Turbine**	**Distance to Nearest Turbine (m)**
07/31/04	little brown bat	1	32
07/31/04	little brown bat	1	10
07/31/04	little brown bat	1	10
07/31/04	eastern pipistrel	2	35
07/31/04	little brown bat	3	27
07/31/04	hoary bat	6	2
07/31/04	little brown bat	12	4
07/31/04	red bat	13	18
07/31/04	eastern pipistrel	16	34
07/31/04	red bat	18	39
07/31/04	hoary bat	18	28
07/31/04	hoary bat	27	21
07/31/04	little brown bat	34	30
07/31/04	red bat	42	47
08/01/04	red bat	10	34
08/01/04	hoary bat	16	20
08/01/04	hoary bat	16	27
08/02/04	hoary bat	14	35
08/04/04	big brown bat	2	20
08/04/04	eastern pipistrel	10	16
08/04/04	little brown bat	10	1
08/04/04	red bat	30	18
08/08/04	hoary bat	4	21
08/09/04	little brown bat	27	47
08/10/04	hoary bat	32	18
08/12/04	red bat	18	39
08/12/04	eastern pipistrel	18	29
08/15/04	red bat	28	2

08/17/04	big brown bat	16	17
08/17/04	eastern pipistrel	24	26
08/17/04	hoary bat	26	14
08/17/04	eastern pipistrel	28	16
08/17/04	eastern pipistrel	30	6
08/17/04	little brown bat	36	15
08/22/04	red bat	31	13
08/22/04	eastern pipistrel	31	8
08/24/04	hoary bat	37	13
08/30/04	hoary bat	31	6
08/30/04	hoary bat	33	19
08/30/04	red bat	33	23
08/30/04	silver-haired bat	43	20
09/01/04	hoary bat	13	16
09/01/04	eastern pipistrel	19	10
09/01/04	silver-haired bat	19	18
09/01/04	red bat	25	9
09/01/04	silver-haired bat	25	5
09/01/04	red bat	31	25
09/01/04	eastern pipistrel	31	30
09/01/04	red bat	31	35
09/01/04	red bat	35	25
09/01/04	hoary bat	43	12
09/02/04	little brown bat	33	28
09/05/04	eastern pipistrel	27	20
09/10/04	silver-haired bat	33	44
09/10/04	silver-haired bat	33	26
09/10/04	red bat	35	9

Table III-3 - List of bat fatalities found at Meyersdale during standardized search from August 2 through September 13, 2004.

Date	Species	Nearest Turbine	Distance to Nearest Turbine(m)
08/02/2004	eastern pipistrel	1	21
08/02/2004	eastern pipistrel	1	20
08/02/2004	red bat	2	40
08/02/2004	hoary bat	3	8
08/02/2004	little brown bat	4	28
08/02/2004	big brown bat	4	5
08/02/2004	red bat	4	22
08/02/2004	hoary bat	6	28
08/02/2004	red bat	7	29
08/02/2004	hoary bat	10	12
08/02/2004	hoary bat	10	13
08/02/2004	hoary bat	10	30
08/02/2004	hoary bat[a]	14	32
08/02/2004	eastern pipistrel[a]	14	26
08/02/2004	hoary bat	14	26
08/02/2004	red bat[a]	14	28
08/02/2004	little brown bat	16	25
08/02/2004	hoary bat	17	32
08/02/2004	red bat	17	29
08/02/2004	hoary bat	17	35
08/02/2004	big brown bat	18	17
08/02/2004	hoary bat[a]	18	32
08/02/2004	red bat	18	23
08/03/2004	hoary bat	1	40.5
08/03/2004	red bat	5	45
08/03/2004	little brown bat[a]	11	15
08/03/2004	hoary bat	11	35
08/03/2004	hoary bat	11	25
08/03/2004	hoary bat	15	27
08/03/2004	hoary bat	15	32
08/03/2004	hoary bat	15	27
08/03/2004	hoary bat	19	62
08/04/2004	big brown bat	1	25
08/04/2004	hoary bat[a]	1	31.5
08/04/2004	red bat	3	72
08/04/2004	red bat	11	32
08/05/2004	unidentified bat	3	22
08/05/2004	hoary bat	11	56
08/06/2004	unidentified bat	9	
08/06/2004	hoary bat	15	32.25
08/08/2004	eastern pipistrel	11	14
08/08/2004	hoary bat	13	48

Table III-3 - List of bat fatalities found at Meyersdale during standardized search from August 2 through September 13, 2004.

Date	Species	Nearest Turbine	Distance to Nearest Turbine(m)
08/09/2004	red bat	12	27
08/09/2004	hoary bat	14	42
08/09/2004	hoary bat	20	9
08/10/2004	little brown bat	1	13
08/11/2004	red bat	5	40
08/12/2004	hoary bat	15	43
08/13/2004	hoary bat	1	18
08/14/2004	eastern pipistrel	3	31
08/14/2004	red bat	5	38
08/14/2004	red bat	11	8
08/14/2004	unidentified bat	13	35
08/14/2004	hoary bat[a]	15	15
08/15/2004	eastern pipistrel[a]	7	22.5
08/15/2004	big brown bat	9	35
08/15/2004	little brown bat	17	22
08/15/2004	little brown bat	17	21.5
08/16/2004	big brown bat	2	28
08/16/2004	unidentified bat	4	4
08/16/2004	red bat[a]	4	7.5
08/16/2004	hoary bat	4	3
08/16/2004	hoary bat	4	14
08/16/2004	red bat	5	2
08/16/2004	hoary bat[a]	5	39.5
08/16/2004	hoary bat[a]	5	26
08/16/2004	big brown bat	8	30.5
08/16/2004	hoary bat	10	35.75
08/16/2004	unidentified bat[a]	14	55
08/16/2004	hoary bat	16	20
08/16/2004	red bat	18	31
08/16/2004	red bat[a]	19	53
08/16/2004	red bat[a]	19	42
08/16/2004	unidentified bat	20	34
08/16/2004	hoary bat	20	48
08/16/2004	hoary bat	20	45
08/17/2004	red bat	1	12.5
08/17/2004	eastern pipistrel	1	10.5
08/17/2004	hoary bat	3	4
08/17/2004	hoary bat	3	42.5
08/17/2004	big brown bat	3	20
08/17/2004	red bat	5	52
08/17/2004	hoary bat	9	26
08/17/2004	hoary bat	11	33

Table III-3 - List of bat fatalities found at Meyersdale during standardized search from August 2 through September 13, 2004.			
Date	**Species**	**Nearest Turbine**	**Distance to Nearest Turbine(m)**
08/17/2004	hoary bat	11	10
08/17/2004	red bat	13	32.5
08/17/2004	silver-haired bat	13	32
08/17/2004	eastern pipistrel	15	11.5
08/18/2004	hoary bat	1	5.5
08/18/2004	hoary bat	3	21
08/18/2004	hoary bat[a]	13	3.5
08/18/2004	red bat	17	48
08/22/2004	eastern pipistrel	1	17
08/22/2004	hoary bat	3	13
08/22/2004	red bat	3	30.5
08/22/2004	red bat	3	26
08/22/2004	big brown bat	11	2
08/22/2004	red bat	13	3
08/23/2004	hoary bat	1	24
08/23/2004	big brown bat	2	27
08/23/2004	eastern pipistrel	2	27
08/23/2004	eastern pipistrel	2	35
08/23/2004	big brown bat	3	50
08/23/2004	hoary bat	3	4
08/23/2004	red bat	4	35
08/23/2004	big brown bat	5	29
08/23/2004	hoary bat	5	37
08/23/2004	hoary bat	8	33.5
08/23/2004	big brown bat	10	37
08/23/2004	hoary bat[a]	10	6
08/23/2004	hoary bat	10	23
08/23/2004	red bat	13	23
08/23/2004	eastern pipistrel	15	105
08/23/2004	unidentified myotis	15	32
08/23/2004	eastern pipistrel	16	28.5
08/23/2004	eastern pipistrel	17	30
08/23/2004	red bat	18	45
08/23/2004	hoary bat	18	53
08/23/2004	red bat	18	6
08/23/2004	eastern pipistrel[a]	19	32
08/23/2004	hoary bat	19	32
08/23/2004	hoary bat	19	48
08/23/2004	hoary bat	19	16
08/23/2004	red bat	20	39
08/23/2004	red bat	20	43
08/23/2004	hoary bat	20	28

Table III-3 - List of bat fatalities found at Meyersdale during standardized search from August 2 through September 13, 2004.			
Date	**Species**	**Nearest Turbine**	**Distance to Nearest Turbine(m)**
08/23/2004	hoary bat	20	15
08/23/2004	hoary bat	20	3
08/23/2004	eastern pipistrel[a]	20	15
08/23/2004	red bat	20	22.5
08/24/2004	hoary bat	2	3
08/24/2004	hoary bat	4	47
08/24/2004	big brown bat	8	
08/24/2004	red bat	8	36
08/24/2004	red bat	10	31
08/24/2004	red bat	10	30
08/24/2004	red bat	12	49.25
08/24/2004	hoary bat	14	20
08/24/2004	red bat	14	40
08/24/2004	hoary bat	16	32
08/24/2004	hoary bat	18	45
08/24/2004	red bat	18	34
08/24/2004	hoary bat	18	37
08/24/2004	hoary bat	18	37
08/24/2004	red bat	20	17.25
08/25/2004	red bat	2	23
08/25/2004	hoary bat	4	25.5
08/25/2004	red bat[a]	4	36.25
08/26/2004	red bat	2	30.5
08/26/2004	little brown bat	2	13.5
08/26/2004	hoary bat	6	32
08/27/2004	hoary bat	2	2
08/27/2004	red bat	18	31
08/28/2004	red bat	6	17
08/28/2004	big brown bat	8	22.5
08/28/2004	hoary bat	16	40
08/28/2004	hoary bat	20	30.5
08/29/2004	hoary bat	4	40
08/29/2004	hoary bat	10	26
08/29/2004	hoary bat	12	37
08/29/2004	red bat	12	9
08/29/2004	hoary bat	14	60
08/29/2004	big brown bat	18	27
08/29/2004	hoary bat	20	30
08/30/2004	hoary bat	2	9
08/30/2004	hoary bat	3	26
08/30/2004	red bat	3	37
08/30/2004	red bat	3	22

Table III-3 - List of bat fatalities found at Meyersdale during standardized search from August 2 through September 13, 2004.

Date	Species	Nearest Turbine	Distance to Nearest Turbine(m)
08/30/2004	red bat	3	5
08/30/2004	hoary bat	3	21
08/30/2004	hoary bat	3	20
08/30/2004	red bat	3	44
08/30/2004	red bat	4	27
08/30/2004	hoary bat	4	15
08/30/2004	hoary bat	5	35
08/30/2004	hoary bat	6	3
08/30/2004	hoary bat	7	17.5
08/30/2004	hoary bat	11	42
08/30/2004	big brown bat	11	38
08/30/2004	hoary bat	12	11.5
08/30/2004	hoary bat	13	31.5
08/30/2004	hoary bat	13	8
08/30/2004	hoary bat	15	35
08/30/2004	red bat	15	39
08/30/2004	hoary bat	15	40
08/30/2004	hoary bat	17	32
08/30/2004	red bat	17	19
08/30/2004	hoary bat	17	26
08/30/2004	hoary bat	17	24.5
08/30/2004	red bat	19	36
08/30/2004	red bat	19	26
08/30/2004	red bat	19	21
08/30/2004	hoary bat	19	48
08/30/2004	hoary bat	20	36
08/31/2004	hoary bat	10	22.75
09/01/2004	hoary bat	2	32
09/01/2004	hoary bat	8	45
09/01/2004	hoary bat	14	25.5
09/01/2004	big brown bat	14	27
09/01/2004	hoary bat	18	28.5
09/02/2004	hoary bat	2	45
09/02/2004	red bat	2	20
09/02/2004	red bat	2	38
09/02/2004	hoary bat	2	43
09/02/2004	eastern pipistrel	14	25
09/02/2004	eastern pipistrel	16	12
09/02/2004	eastern pipistrel	20	30
09/03/2004	red bat	10	30.5
09/03/2004	big brown bat	12	20
09/03/2004	hoary bat	14	55

Table III-3 - List of bat fatalities found at Meyersdale during standardized search from August 2 through September 13, 2004.

Date	Species	Nearest Turbine	Distance to Nearest Turbine(m)
09/03/2004	silver-haired bat	16	35
09/04/2004	silver-haired bat	2	33
09/04/2004	red bat	2	42
09/04/2004	red bat	4	31
09/04/2004	hoary bat	4	58
09/04/2004	hoary bat	10	34
09/04/2004	red bat	12	22
09/04/2004	red bat	14	35
09/04/2004	hoary bat	16	34
09/04/2004	hoary bat	16	10.5
09/04/2004	silver-haired bat	16	10.5
09/04/2004	red bat	20	55
09/05/2004	red bat	2	47.5
09/05/2004	hoary bat	6	35
09/05/2004	hoary bat	6	32.75
09/05/2004	silver-haired bat	16	26
09/05/2004	silver-haired bat	20	47
09/05/2004	silver-haired bat	20	43
09/06/2004	eastern pipistrel	1	19.75
09/06/2004	hoary bat	1	16
09/06/2004	hoary bat	7	14.5
09/06/2004	silver-haired bat	7	
09/06/2004	hoary bat	8	29
09/06/2004	red bat	11	49
09/06/2004	hoary bat	11	37
09/06/2004	hoary bat	13	50
09/06/2004	red bat	15	13
09/06/2004	hoary bat	15	41
09/06/2004	hoary bat	15	3.5
09/06/2004	silver-haired bat	17	29
09/06/2004	red bat	17	23
09/06/2004	red bat	17	14
09/06/2004	hoary bat	17	24.5
09/07/2004	red bat[a]	2	25
09/08/2004	silver-haired bat	20	33
09/09/2004	eastern pipistrel	10	12
09/10/2004	hoary bat	8	22
09/10/2004	unidentified bat	20	30
09/11/2004	hoary bat	8	
09/11/2004	northern long-eared bat	8	5
09/11/2004	red bat	10	24.5
09/11/2004	red bat	10	42

Table III-3 - List of bat fatalities found at Meyersdale during standardized search from August 2 through September 13, 2004.

Date	Species	Nearest Turbine	Distance to Nearest Turbine(m)
09/11/2004	silver-haired bat[a]	10	33
09/12/2004	silver-haired bat	6	8.5
09/12/2004	hoary bat	10	28
09/12/2004	silver-haired bat	14	28
09/12/2004	hoary bat	20	24
09/13/2004	silver-haired bat	1	12
09/13/2004	red bat	2	4
09/13/2004	hoary bat	4	39
09/13/2004	silver-haired bat	7	10
09/13/2004	northern long-eared bat	10	2

Table III-4 - List of bat fatalities not observed on standardized searches at Meyersdale from July 30 through September 13, 2004.			
Date	**Species**	**Nearest Turbine**	**Distance to Nearest Turbine(m)**
07/30/2004	hoary bat	1	6
07/30/2004	hoary bat	1	34
07/30/2004	red bat	3	36
07/30/2004	red bat	3	7
07/30/2004	hoary bat	9	46
08/01/2004	hoary bat	13	9
08/01/2004	hoary bat	13	31
08/01/2004	hoary bat	14	5
08/01/2004	hoary bat	17	5
08/03/2004	unidentified bat	2	13
08/04/2004	red bat	2	42.5
08/04/2004	little brown bat	4	
08/11/2004	red bat	6	31
08/13/2004	hoary bat	6	36
08/15/2004	red bat	12	45
08/18/2004	hoary bat	2	16
08/18/2004	hoary bat	4	35
08/18/2004	hoary bat	10	42.5
08/18/2004	hoary bat	20	12
08/20/2004	silverhaired bat	2	10
08/22/2004	eastern pipistrel	4	32.5
08/24/2004	red bat	3	30
08/24/2004	red bat	9	17
08/25/2004	red bat	15	32
08/26/2004	hoary bat	15	4
08/27/2004	hoary bat	17	10
08/27/2004	red bat	17	4
08/29/2004	little brown bat	3	12.5
08/31/2004	hoary bat	11	2
09/02/2004	red bat	3	13.5
09/02/2004	hoary bat	11	
09/03/2004	hoary bat	5	48
09/03/2004	silverhaired bat	17	29.5
09/04/2004	hoary bat	5	32
09/07/2004	eastern pipistrel	13	23
09/07/2004	hoary bat	15	12
09/11/2004	silverhaired bat	1	9

APPENDIX IV
Summary of Bird Fatality Data

Summary of Bird Fatalities

At the Mountaineer Wind Energy Center (MWEC), a total of 15 avian carcasses were found during the 6-week period (Table 7), with 13 of those individuals represented by songbird or songbird-like species (cuckoos and hummingbirds). At the Meyersdale Wind Energy Center (MeWEC), a total of 13 avian carcasses were found, representing 6 known species (Table 8). Of those 13 individuals, 7 carcasses were passerines (true songbird species) and songbird-like species (cuckoos and hummingbirds). At MWEC, 8 songbird carcasses were found on 10 and 11 September, the last two days of the study period. Bat carcasses were also found in higher numbers on these two days, which were characterized by thick morning fogs and low cloud ceilings.

Table IV-1. Summary of avian fatality composition at Mountaineer based on fatalities observed in standardized search plots from 31 July – 11 September 2004.

	Fatalities found during Standardized Search Plots		All Fatalities	
Species	**Total**	**% Comp.**	**Total**	**% Comp.**
Unidentified passerine	1	8.3	1	6.7
Unidentified thrush	1	8.3	1	6.7
Unidentified warbler	1	8.3	1	6.7
Sharp-shinned Hawk	1	8.3	1	6.7
Turkey Vulture	1	8.3	1	6.7
Ruby-throated Hummingbird	1	8.3	1	6.7
Red-eyed Vireo	1	8.3	2	13.3
Black-billed Cuckoo	2	16.7	2	13.3
Yellow-billed Cuckoo	1	8.3	1	6.7
Gray Catbird	0	0.0	1	6.7
Blackburnian Warbler	1	8.3	1	6.7
Black-throated Green Warbler	0	0.0	1	6.7
Veery	1	8.3	1	6.7
Total (10 identified species)	**12**		**15**	

Table IV-2. Summary of avian fatality composition at Meyersdale based on fatalities observed in standardized search plots from 30 July – 13 September 2004.

	Fatalities found during Standardized Search Plots		All Fatalities	
Species	**Total**	**% Comp.**	**Total**	**% Comp.**
Unidentified flycatcher	3	33.33	3	23.08
Unidentified bird	3	33.33	3	23.08
Chimney Swift	2	22.22	2	15.38
Red-eyed Vireo	0	0.00	2	15.38
American Goldfinch	0	0.00	1	7.69
Black-billed Cuckoo	1	11.11	1	7.69
Ruby-throated Hummingbird	0	0.00	1	7.69
Total (6 identified species)	**9**		**13**	

Table IV-3 - List of avian fatalities observed during standardized searches at Meyersdale from August 2 through September 13, 2004.

Date	Species	Nearest Turbine	Distance to Nearest Turbine(m)
08/16/2004	chimney swift	15	25
08/17/2004	unidentified bird	7	21.5
08/18/2004	unidentified bird	1	17
08/23/2004	unidentified flycatcher	16	7
08/23/2004	black-billed cuckoo	20	26
09/02/2004	chimney swift	6	19
09/08/2004	unidentified flycatcher	12	37
09/08/2004	unidentified flycatcher	18	22
09/08/2004	unidentified bird	20	38

Table IV-4 - List of avian fatalities not observed on standardized searches at Meyersdale from July 30 through September 13, 2004.

Date	Species	Nearest Turbine	Distance to Nearest Turbine(m)
08/07/2004	American goldfinch	2	42
08/18/2004	red-eyed vireo	20	5
08/28/2004	red-eyed vireo	7	3
09/05/2004	ruby-throated hummingbird	1	3

APPENDIX V
2004 Peer-Reviewed Study Proposal

Bat Mortality at Wind Energy Facilities during Fall Migration:
A Proposal for Intensive Mortality Searches

RESEARCH PROPOSAL

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1.0 INTRODUCTION

Bat collisions and mortality associated with tall, anthropogenic structures have been documented at communication towers, lighthouses, skyscrapers, and power lines around the world. Bat collisions at wind energy facilities were first reported in Australia (Hall and Richards 1972), with subsequent fatalities documented in Europe, Canada, and the U.S. (e.g., Erickson et al. 2000, Puzen 2002, Ahlen 2003, Johnson et al. 2003a, Nicholson 2003). In the U.S., bat collision fatalities often are reported in conjunction with avian monitoring studies at wind energy facilities.

Estimates of bat fatalities appear to be low at many wind energy facilities. For example, mortality studies conducted at facilities in the western and Midwestern U.S. have resulted in estimates of less than 2 bat fatalities/turbine/year. However, two eastern U.S. wind facilities (Nicholson 2003, Kerns and Kerlinger 2004) estimated fatality rates between 25–50 bats/turbine/year.

Significance of estimated bat fatalities on population dynamics at wind energy facilities is not well understood, since little is known about either population size or trends, or migration for most species of bats (O'Shea et al. 2003). The growing number of wind facilities being constructed in the U.S. coupled with potential for high facility-related mortality has lead to concern over the potential negative impacts on bat populations.

Current information suggests that the majority of bat collision fatalities at wind turbines occur during the autumn migration period (generally late July through early September) and that species known to undergo long-distance migration (e.g., hoary bat, eastern red bat) constitute the majority of known mortality (e.g., Erickson et al. 2002, Johnson et al. 2003a, Kerns and Kerlinger 2004). Larger concentrations of bats migrating over an area at one time may increase the likelihood of collision with wind turbines.

Post-construction monitoring studies have provided much of the available information on bat migration at wind facilities and bat collisions with wind turbines. Originally designed to monitor annual or seasonal avian fatality rates, current post-construction mortality monitoring protocols have been criticized because search intervals are infrequent (e.g., 7–14 day intervals) and may not provide accurate and precise estimates of fatality rates of bats. While the statistical properties for at least some of the estimators have been evaluated and determined to be unbiased or close to unbiased under the assumptions of the simulations, (Schoenfeld 2004, Erickson unpublished data), important field sampling biases that may lead to biased estimates warrant further investigation. Important sources of bias include 1) fatalities that occur on a highly periodic basis (e.g., mass fatalities associated with peak event); 2) removal/scavenging by predators; and 3) searcher efficiency.

In most sampling designs using for monitoring bird and bat fatality rates at wind energy facilities, searches are conducted systematically over time. The estimators most often used assume fatalities occur at random times between search days. If the fatalities are distributed in a highly periodic fashion, then estimates may be biased. Most estimators that have been used apply an average rate of carcass removal expected during the study. If the majority of fatalities occur immediately after a search, those fatalities would have a longer time to be removed before the next search resulting in higher scavenging rates than the average rate used in the estimates. This would lead to an underestimate of fatalities. On the other hand, if most fatalities occur before, but close to the next search, the fatality estimate may be an overestimate.

The second potential source of bias relates to the conduct of the scavenging and carcass removal trials. Past experiments that assessed carcass removal may not be representative of scavenging that actually occurs in the field, as many studies used small birds to represent bats for carcass removal trials. In a few studies, very fresh bat carcasses (estimated to be killed the previous night) have been used in some trials (see Erickson et al. 2003, Johnson et al. 2003a). These two studies suggest similar to lower scavenging rates on bat carcasses compared to small bird carcasses. While these studies have suggested bats are scavenged at rates similar to small birds at these two sites, small sample sizes also may yield biased estimates and limit the scope of inference.

The third potential source of bias relates to how representative searcher efficiency trials and subsequent rates are to actual rates for wind turbine caused bat collisions. For example, past experiments that assessed searcher efficiency rates typically used small birds to represent bats. Additionally, past searcher efficiency trials have often utilized frozen specimens. Visual triggers for finding carcasses in the field, such as blowing feathers, contrasting colors, and flying insects around a carcass, are therefore not often present in these staged efficiency trials.

To address bat mortality issues at wind facilities, a collaborative research initiative was developed among Bat Conservation International (BCI), the United States Fish and Wildlife Service (USFWS), the American Wind Energy Association (AWEA), and the U.S. Department of Energy's National Renewable Energy Laboratory (NREL). A workshop held in February 2004 served to gather several of the world's leading bat scientists and experts from other relevant fields as well as the wind industry and federal and state agencies to discuss what is needed to understand and resolve issues involving bat mortality at wind turbines. This workshop revealed that several gaps in knowledge still exist concerning bat migration and ecology, bat behavior and bat use near wind turbines, and bat interactions and collisions with turbines. Additionally, two key research needs identified by experts from the aforementioned workshop were: (1) to conduct daily mortality searches to develop a dataset required to evaluate search effort needed to meet a desired level of precision and accuracy for fatality estimates, and 2) to evaluate the effects of carcass removal and searcher efficiency bias corrections to fatality estimators. The goal of this proposed research is to address these two research questions. To meet this goal, daily searches will be implemented during fall migration at two wind facilities, one with a previously demonstrated high number of bat fatalities. This data set will be invaluable in answering questions regarding adequacy of fatality monitoring protocols and in making recommendations for future monitoring efforts. This proposal describes the design, methodology, and data required to achieve this goal.

2.0 STUDY OBJECTIVES

As previously stated, the goal of this proposed research is to determine levels of effort and design criteria needed to obtain accurate and precise estimates of bat fatality levels at wind projects. Specific objectives for this study include (1) conduct of both daily and weekly searches for bat fatalities at wind turbines; (2) compare the precision and accuracy of intensive searches (daily) to precision and accuracy of other intervals (e.g., 7 day intervals); and (3) develop recommendations for improving and standardizing fatality search protocols for bats at turbines. A secondary outcome of this study will be a data set that can be used to associate fatality location and timing to turbine lighting, weather and other characteristics.

3.0 STUDY AREA

For this proposal, we have chosen the Mountaineer Wind Energy Center, with 44-1.5 MW turbines arrayed along an 8.8 km portion of the crest of Backbone Mountain in West Virginia, as the featured study area for this research, and we tailor the methodologies to this specific site. In addition, a similar fatality monitoring protocol will be implemented at the 20-turbine Meyersdale Facility located in southwestern PA.

4.0 FIELD METHODS

The following sections describe the field methods for the conduct of carcass searches, and experimental trials for estimating searcher efficiency and carcass removal.

4.1 Carcass Searches

The following section describes the sampling design and field methods for the conduct of the carcass search component of the study.

4.1.1 Delineation of Carcass Search Plots

Rectangular plots that are 130 m by 120 m will be centered on each sample turbine. Studies at the Vansycle wind plant (Erickson et al. 2000), the Buffalo Ridge wind plant (Johnson et al. 2003b), the Foote Creek Rim wind plant (Young et al. 2003), and the Nine Canyon Wind Project (Erickson et al. 2003a) and the Stateline Wind Project (Erickson et al. 2003b) indicate most bat fatalities (>80%) are typically found within ½ the maximum distance from the tip height to the ground. Tip height at this site is approximately 95 m, but areas out to approximately only 60 m from the turbines have been cleared of trees and shrubs at Mountaineer (Kerns and Kerlinger 2004). Adjustments to the fatality estimates will be made to account for the unsampled areas using existing information regarding distribution of fatalities within search plots (e.g., Erickson et al. 2003a, Kerns and Kerlinger 2004).

4.1.2 Vegetation Mapping and Visibility Classifications

The vegetation along each transect line with a search plot will be mapped according to predetermined habitat types, vegetation cover, and height of the vegetation. Changes in vegetation type at 3 – 5 m intervals along a transect line with be noted. Habitat types will include road, bare ground, brush pile, large rocks/boulders, and vegetative cover. Cover of vegetation (grass, blackberry, clover, etc.) will be quantified (i.e., <10%, 10–25%, 26–50%, etc.) and the height of the vegetation will be categorized as low (below ankle; <10 cm), medium (11–50 cm; about ankle to knee), or tall (>50 cm; above knee). In addition, it will noted if the transect line is extremely sloped to the point that searchers must climb or leave the transect line to find a safer alternate route.

The visibility of a carcass is inherent in its detection by a searcher; therefore, we will also map the visibility of a carcass along each transect line as it is defined by the habitat type. Visibility classifications will be defined as extremely high (i.e.: road, no vegetation), high (i.e.: <10% tall vegetation, 50% low vegetation), medium (i.e.: 50% medium vegetation, 25% vegetation within large boulders), low (i.e.: 50% medium vegetation in a brush pile, 75% tall vegetation, and extremely low (i.e.: 75% tall vegetation on an extreme slope, 100% medium vegetation). Though subjective, these visibility estimations will allow us to compare numbers of carcasses found within each visibility class and to determine mortality estimates by habitat type/visibility classification.

4.1.3 Sample Site and Sampling Interval Selection

During each of the six sampling weeks, half the turbines will be sampled 7 times/weekly, and the remaining half once/weekly. Turbines sampled daily the first three sampling weeks will include turbines 1, 3, 5, 7, ..., 43 (set 1) and turbines sampled daily the last three sampling weeks will include 2, 4, 6, 8, ..., 44 (set 2, Table 1). Set 2 will be sampled weekly the first three sampling weeks, and Set 1 will be sampled weekly the 2nd three sampling weeks. The first search will be conducted at all turbines to remove most carcasses that may have accumulated over time.

The systematic random sampling scheme will provide interspersion (Hurlbert 1984) of the search intervals among habitat conditions, physical characteristics of turbine locations and turbine characteristics (e.g., lighting). Carcass searches will be performed from 1 August through 11 September, a period where the highest number of fatalities has been recorded for several studies (Erickson et al. 2002, Johnson et al. 2003a, Nicholson 2003).

4.1.4 Transect Searches

Personnel trained in proper search techniques will conduct the carcass searches. Transects will be set approximately 10 meters apart in each plot, yielding a search width of 5 m on either side of the transect line. Transect lines will terminate at forest edges or landscape features such as ravines that are not safe to traverse. A searcher will walk at a rate of approximately 20-30 meters/minute along each transect line yielding an average search time of 5 minutes/transect line or approximately one hour/120 m^2 plot. Search speed will likely vary by turbine plot size, terrain, and habitat type within those plots (eg., searcher speed may increase in high visibility areas such as roads and decrease in low visibility areas or difficult terrain such as large boulders). Searches will be abandoned if severe weather (heavy rain, lightning, etc) is present; however searches will resume that day if weather conditions clear. Searches will commence at or near sunrise. We anticipate that it should take approximately 0.5–1.5 hours to survey the search area around each turbine depending on topography, vegetative conditions, and length of transect line. Fatalities will be recorded after the search of the entire turbine has been conducted unless prohibited by weather conditions.

4.1.5 Field Data Recording

Data recorded for each search of a turbine will include the date, start time, end time, observer, wind direction, and turbine operation (operational, stopped, removed for repairs). Data on operating time for each turbine will be obtained from the wind facility site manager. Daily weather data recorded by the senior researcher (temperature, wind direction, wind speed, incidences of inclement weather, precipitation, fog, frost/snow, and weather during previous night) will be combined with daily weather data (temperature, wind direction, and wind speed) collected from meteorological towers and wind turbines at the site. Weather data gathered every 10 min by met towers and wind turbines will be averaged for daily and hourly weather analyses. Changes in wind direction and wind speed will be noted, particularly during the evening/night.

Once a bat carcass is found, the searcher will note the distance to the carcass when first detected and will temporarily flag the carcass for ease in relocation following the search. After the search of the turbine is completed, searchers will record data for each individual carcass found. Searchers will record the perpendicular distance to the carcass from the transect line that was being searched, as well as the perpendicular distance to the closest transect line (if they differ). These recorded distances will allow us to model detection probability functions using the program DISTANCE (Laake et al. 1994, Buckland et al. 2001).

In addition to distance measurements, searchers will record the date, time found, species, sex and age (if able to be determined), observer name, identification number of carcass, turbine number, distance from turbine, cardinal direction from turbine, compass bearing from turbine, habitat beneath carcass, condition of carcass (entire, partial, scavenged), probable scavenger of carcass (if scavenged), cause of death/visible injuries (if able to be determined), and estimated time of death (e.g., <1 day, <2 days). Some carcasses will likely need to be identified to species, age, or sex in the laboratory. All *Myotis* species found will be labeled with a unique number, bagged, and frozen for future reference and possible necropsy; easily identifiable species such as the Hoary Bat or Eastern Red Bat will be bagged and either frozen or redistributed for carcass removal or searcher efficiency trials.

Casualties or fatalities found by maintenance personnel and others not conducting the formal searches within 100 m of a wind turbine, meteorological tower, substation or road will be documented using a wildlife incident reporting system (see WRRS section below). These fatalities will not be collected. Collection of state or federal endangered, threatened, or protected species will be coordinated with the USFWS and State Agencies.

4.2 Searcher Efficiency

Estimates of searcher efficiency will be used to adjust the number of carcasses found, correcting for detection bias. Searcher efficiency rates will be estimated using two techniques. The first technique involves weekly searcher efficiency trials conducted during the proposed 6 weeks of daily autumn searches. A random number of carcasses (n = 0–4/turbine) of various conditions (fresh, decomposed/desiccated, and partial due to scavenging) will be placed at randomly determined locations beneath the wind turbines within the facility during each sampling week. All carcasses will be placed at random locations within areas being searched prior to the carcass search on the same day in an attempt to avoid scavenging of the carcass by predators prior to the search.

Direction and distance from the turbine will be randomly determined for each carcass prior to the efficiency study. Carcasses will be dropped from waist height. Each trial carcass will be discreetly marked (tape on leg or underside of body) with a unique identification number so that it can be identified as a study carcass after it is found. Searching will be conducted as normally scheduled and searchers will not be aware of the testing until the first test carcass is found. The number of carcasses used on a given search day or at any given turbine will not be known by searchers.

Bat carcasses of a similar species composition to those species previously found (or likely to be found) at the wind facility for the searcher efficiency study will be used. In the absence of freshly killed bat carcasses, previously recovered and identified frozen carcasses may be used. The senior researcher will be present during searcher efficiency testing and will record those individual test carcasses that are recovered by searchers. Once a carcass is found, searchers will record distance to carcass when detected, closest transect line to carcass, and distance to that transect line. The senior researcher will record this information for each carcass not found as well as the habitat type within a 1 m radius of the test carcass. Carcasses used in searcher efficiency trials will either be removed following the trial or will be remarked and used for carcass removal (see section 4.3).

The 2nd technique for estimating searcher efficiency will be based on Distance Sampling Techniques (Buckland et al. 2001). Perpendicular distances from transect line to fatalities will be recorded and used to estimate a searcher detection probability.

4.3 Carcass Removal

Carcass removal studies will be conducted between August 1 and 11 September 2004, and will be ongoing during this time. During the research period of 6 weeks, bat and bird carcasses will be placed at random locations within the search plots. The number of carcasses used will depend on carcass availability, but is likely to exceed 150 bats and 50 birds. To avoid over-saturating the site with carcasses, we will either redistribute those carcasses found during that day or freeze recently found carcasses for redistribution the following day. These methods will also allow us to compare the scavenging rates between fresh and frozen carcasses.

Experimental carcasses will be marked discreetly using, for example, a piece of tape on one leg or underside of body with a unique identification number for recognition by searchers and other personnel. Carcass locations will also be discreetly marked with flagging or rock cairns to facilitate ease in relocation. Direction and distance from the turbine will be randomly determined for each placed bat carcass and bird carcass prior to placement in the field.

In addition to these planted carcasses, fresh bat carcasses found, particularly those seen at turbines not searched during that day, will be left in the field and monitored for scavenging. Only fresh carcasses that were identified to species in the field will be used. Experimental carcasses left beneath the turbines will be marked discreetly using, for example, a piece of tape on one leg with a unique identification number for recognition by searchers and other personnel. Locations of all carcasses used in the carcass removal study will be plotted on the map of the study area.

Initial data recorded for each trial carcass prior to placement will include date and time of placement, species, turbine/plot id, and vegetation within a 1 m radius of the carcass. During subsequent visits to each trial carcass, searchers will note the presence/absence of the carcass, the degree of scavenging (none, light, medium, heavy), location of scavenging on the body, probable scavenger, and comments. Carcasses will be checked daily until the carcass has been removed or until the carcass is recorded as desiccated (i.e., skeletonized and absent of meat) for 7 consecutive days.

5.0 STATISTICAL METHODS

The primary analyses will focus on comparison of fatality rate estimates from weekly and daily searches. Secondary analyses will investigate (1) differences in searcher efficiency estimates from searcher efficiency trials and from distance sampling, (2) differences in carcass removal rates of birds versus bats, (3) differences in carcass removal rates at turbines and away from turbines, (4) differences in observed fatality rates at lit and unlit turbines. For all analyses, mean values and confidence intervals will be calculated using bootstrapping and compared graphically. The secondary analyses that rely on hypothesis testing will be conducted using t-tests, Analysis of variance (ANOVA) or randomization tests (Manly 1997). Additional detail below is provided for fatality rate estimation, including discussion of each component of the estimation process.

5.1 Fatality Rate Estimation

The following variables are used in the equations below:

c_{ij}	the number of carcasses detected at plot *i* during daily searches (j=1) and from weekly searches (j=2) for the sampling period (3 weeks) for which the cause of death is either unknown or is attributed to the facility
n	the number of search plots
$\bar{c}_j$	the average number of carcasses observed per turbine per sampling period (3 weeks) for daily searches (j=1) and for weekly searches (j=2)
s	the number of carcasses used in removal trials
s_c	the number of carcasses in removal trials that remain in the study area after the end of the trial
t_i	the time (days) a carcass remains in the study area before it is removed
$\bar{t}$	the average time (days) a carcass remains in the study area before it is removed
d	the total number of carcasses placed in searcher efficiency trials
p	the estimated average probability an available carcass is found by searchers. Two methods will be used for estimating p.
I	the interval between searches in days
$\hat{\pi}_j$	the estimated probability that a carcass is both available to be found during a search and is found for daily searches (j=1) and weekly searches (j=2). Multiple estimates will be made, based on the different search intervals and different estimates of detection probabilities
m_j	the estimated average number of fatalities per turbine per search period for daily searches (j=1) and weekly searches (j=2), adjusted for removal and

observer detection bias. Multiple estimates will be made for each search interval, based on different estimates of $\hat{\pi}_j$.

5.1.1 Observed Number of Carcasses

The estimated average number of carcasses ($\bar{c}_j$) observed per turbine per search period (6 weeks) from daily (j=1) and from weekly searches (j=2) is:

$$\bar{c}_j = 2 \cdot \frac{\sum_{i=1}^{n} c_{ij}}{n}.$$

where n is the number of turbines (n=44), c_{ij} is the number of fatalities found during daily searches (j=1) or weekly searches (j=2) at turbine i.

5.1.2 Estimation of Carcass Removal

Estimates of carcass removal are used to adjust carcass counts for removal bias. Mean carcass removal time ($\bar{t}$) is the average length of time a carcass remains at the site before it is removed:

$$\bar{t} = \frac{\sum_{i=1}^{s} t_i}{s - s_c}.$$

This estimator is the maximum likelihood estimator assuming the removal times follow an exponential distribution and there is right-censoring of data (Lawless 1982, Barnard 2000). In our application, any trial carcasses still remaining at the end of the trial are collected, yielding censored observations. If all trial carcasses are removed before the end of the trial, then s_c is 0, and $\bar{t}$ is just the arithmetic average of the removal times. Mean removal times and associated 95% confidence intervals will be calculated. In addition, two-factor Analysis of Variance (ANOVA) will be used to compare mean removal times among the factors Carcass type (bird versus bat) and Location (near turbines versus away from turbines) if assumptions can be met. Randomization tests (Manly 1997) may be used if more than 10% of the trial carcasses remain at the end of the trial period (i.e. right censored data) and if ANOVA assumptions cannot be met. If statistically significant differences are not apparent, data may be pooled among factors for fatality estimates described below.

5.1.3 Estimation of Searcher Efficiency

Searcher efficiency rates are expressed as *p,* the average probability a carcass is detected by searchers. Observer detection rates and associated 95% confidence intervals will be calculated and compared based on the placed trial carcasses, and from the distance sampling analysis. Program Distance will be used to model the detection probabilities as a function of distance from transect line.

5.1.4 Estimation of Bat Fatalities During Fall Migration

Bat fatality estimates will be calculated using the form of the estimator proposed by Erickson et al. (2003b) and Schoenfeld (2004). The estimated mean number of facility-related fatalities/turbine/search period (m_j) is calculated for daily (j=1) and for weekly searches (j=2) by dividing the observed mean fatality rate ($\bar{c}_j$) divided by $\hat{\pi}_j$, an estimate of the probability a casualty is not removed by a scavenger (or other means), and is detected:

$$m_j = \frac{\bar{c}_j}{\hat{\pi}_j}$$

Initial estimates of $\hat{\pi}_j$ for daily (j=1) and weekly (j=2) will be calculated using the formula:

$$\hat{\pi}_j = \frac{\bar{t} \cdot p}{I}\left(\frac{e^{I/t} - 1}{e^{I/t} - 1 + p}\right)$$

where p is the estimated observer detection probability, I is the interval (days) between searches (I=1 or 7), and $\bar{t}$ is the mean carcass removal time (days). This estimator is based on the assumption the carcass removal times follow an exponential distribution (Schoenfeld 2004). Alternative models (e.g., log-normal) will be fit to the carcass removal data, and alternative estimators will be evaluated if the exponential distribution is not the best fitting model.

Separate estimates of m_j will be calculated using detection probability estimates derived from (1) distance sampling and (2) searcher efficiency trials. Variance and 95% confidence intervals will be calculated using Monte Carlo/bootstrapping methods (Erickson et al. 2003b, Manly 1997). Comparisons of point estimates and variance for each fatality estimate (daily, weekly) will be used to evaluate accuracy and precision of the methods.

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Table 1. Tentative carcass search schedule for Mountaineer

			Week 1								Week 2								Week 3								Week 4						Week 5								Week
	August																																September								
Turbine No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	1	2	3	4	5	6	7	8	9	10
1`	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1							1							1					
2	1							1							1							1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1							1							1					
4	1							1							1							1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
5[1]	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1							1							1					
6	1							1							1							1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
7	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1							1							1					
8	1							1							1							1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
9	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1							1							1					
10[1]	1							1							1							1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
11	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1							1							1					
12	1							1							1							1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
13	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1							1							1					
14[1]	1							1							1							1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
15	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1							1							1					
16	1							1							1							1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
17	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1							1							1					
18[1]	1							1							1							1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
19	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1							1							1					
20	1							1							1							1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
21	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1							1							1					
22[1]	1							1							1							1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
23	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1							1							1					
24	1							1							1							1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
25	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1							1							1					
26[1]	1							1							1							1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
27	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1							1							1					
28	1							1							1							1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
29	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1							1							1					
30[1]	1							1							1							1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
31	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1							1							1					
32	1							1							1							1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
33[1]	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1							1							1					
34	1							1							1							1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
35	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1							1							1					
36	1							1							1							1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
37[1]	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1							1							1					
38	1							1							1							1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
39	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1							1							1					
40	1							1							1							1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
41[1]	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1							1							1					
42	1							1							1							1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
43	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1							1							1					
44[1]	1							1							1							1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

[1] turbines that are lit