BAT ECOLOGY RELATED TO WIND DEVELOPMENT AND LESSONS LEARNED ABOUT IMPACTS ON BATS FROM WIND DEVELOPMENT

This session shifted the focus of the workshop to the issue of wind energy development's impacts specifically on bats. The presentations discussed lessons that have been learned regarding direct and indirect impacts on bats, and strategies planned to address such issues. Presenters addressed what the existing science demonstrates about land-based wind turbine impacts on bats, including: mortality, avoidance, direct habitat impacts, species and numbers killed, per turbine rates/per MW generated, and impacts on threatened and endangered species. They discussed whether there is sufficient data for wind turbines and bat impacts for projects in the eastern US, especially on ridge tops. Finally, the subject of offshore impacts on bats was briefly addressed, including what lessons have been learned in Europe and how these can be applied in the US.

A Review of Bat Impacts at Wind Farms in the US

by
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Bat collision mortality at wind farms is a definite concern with respect to the ongoing development of wind energy facilities. It is important to note, however, that bat collision is not unique to wind farms. Bats also are known to collide with lighthouses, communication towers, tall buildings, powerlines, and fences. Nevertheless, bat collision mortality at wind plants is a widespread phenomenon, with bat mortality at wind plants often exceeding avian collision mortality. (Between mid-July and mid-September, the number of bat fatalities found at Buffalo Ridge, Minnesota averaged on the order of 175 bats compared with about 10 avian fatalities during the same period.)

Of forty-six species of bats in North America, eleven species have been identified among fatalities at wind plants, although no federally endangered or threatened bats have been found at a US wind farm. Typically, bat mortality involves solitary, tree-roosting bat species such as the silver-haired, hoary and eastern red bats. Hoary bats account for nearly half of all bat fatalities at wind plants. Other species impacted by collisions with wind turbines include the northern long-eared bat, western red bat, Brazilian free-tailed bat, long-eared myotis, and the Seminole bat.

The overall average bat fatality rate for US wind projects is 3.4 fatalities per turbine per year, or 4.6 per MW per year. The highest rates of bat mortality at wind plants have been found in the Eastern US, with one particularly large fatality event occurring at Mountaineer, West Virginia. In all other regions of the US, bat fatality rates are relatively low (see table, below). Generally, bat mortality occurs primarily in the late summer and early fall. Existing data include a summary of 1,628 fatalities, with about 90% occurring from mid-July to the end of September and over 50% of those occurring in August. It has been found that the late summer increase is *not* due to increases in the number of inexperienced juvenile bats. For example, at the Buffalo Ridge site in Minnesota 68% of the fatalities found were adults. At Stateline, Oregon/Washington, 64% of all bat carcasses found were adults.

Bat Fatality Estimates for the US, by Region

Region	# Studies	# MW	Fatalities/ Turbine/year	fatalities/ MW/year	~ Annual Fatalities
Northwest	4	397	1.2	1.7	675
Rocky Mountains	2	68	1.2	1.9	129
Upper Midwest	4	254	1.7	2.7	686
East	2	68	46.3	32	2,176
Overall	12	787	3.4	4.6	3,620

The seasonal timing of high bat fatality rates at wind plants does suggest that migrating bats are involved. For instance, hoary bats, eastern red bats, and silver-haired bats all migrate from mid-July through October. Migratory concentrations of hoary bats have been observed throughout North America in the month of August. In addition, the autumn dispersal of eastern pipistrelle, big brown and little brown bats occurs from the last week of July to mid-October. One possible reason that bat mortality at wind sites is much lower in the spring, as opposed to the fall, is that bats may follow different migration routes in each season and generally have different migration behavior (i.e., leisurely in spring vs. hurried in the fall). For example, in Florida it was observed that the fall migration of hoary bats occurred in waves, but the spring migration was more scattered and less organized.

Other evidence regarding bat mortality at wind energy facilities suggests that fatalities do not involve resident or foraging populations, which by default again points to migrating populations as the key group at risk. With respect to resident populations, research has shown that at Buffalo Ridge, Minnesota, Foote Creek Rim, Wyoming, Wisconsin, and the National Wind Technology Center in Colorado, relatively large populations of bats were documented breeding in close proximity to wind plants when no or few fatalities were documented. Moreover, only 51 of the 1,628 (3.1%) documented bat fatalities across the US have occurred during June and early July when most bats are residing at summer breeding areas.

Studies of bat activity also suggest that fatalities at US wind facilities do not involve foraging bats. For example, a bat activity study conducted in Minnesota found 2 passes per night at turbines compared to 48 passes per night in more suitable habitats such as woodlands and wetlands. Also, no “feeding buzzes” typically made by foraging bats were documented at turbines in Minnesota or Wyoming; however, bats foraging at the top of the turbine hub or higher would not have been detected. Generally, the turbines in the West and Midwest with the highest bat mortality are situated in crop fields, pastures, or short-grass prairies – all of which are habitats not typically used by foraging bats. One study from Sweden did, however, find that bats were foraging near turbines.

Given their finely-tuned echolocation capabilities, it is somewhat of a mystery as to why bats cannot detect wind turbines. For example, bats can navigate through constructed clutter zones made of staggered vertical strands of fine wire, spaced 1 m apart. It has also been demonstrated that captive bats can avoid colliding with moving objects more successfully than stationary ones, presumably because their foraging habits program them to detect moving objects.

So the question remains, why do bats collide with turbines? Several researchers believe that migrating bats may navigate without the use of echolocation. For example, a study conducted in Wyoming suggests that migrating hoary bats do not echolocate (Gruver 2002). Of 20 echolocation calls recorded at turbines and attributed by species, only one was a hoary bat even though this species comprised 88% of the fatalities. (Again, however, migrating hoary bats flying at or above the turbine hub height would not have been detected by the instruments being used in this study.) A study from Minnesota offers contradictory evidence that migrating bats possibly do echolocate, as echolocation activity was found to peak in late July and August, around the beginning of the migration period (Johnson et al. 2003). Generally, evidence suggests that bats depend on vision rather than echolocation for long-distance orientation. Thus, if bats are flying through wind farms by sight only, then causes of bat mortality could be similar to causes of nocturnal avian collision mortality at wind plants.

Another key question regarding bat mortality at wind plants is whether turbines attract bats. Several studies have shown high foraging activity by bats around artificial lights. Lights on turbines may attract moths and other nocturnal insects, thus increasing the probability of bat collisions since bats feed on insects at night. However, several data sets have been examined to date and there has been no correlation between turbine lighting and bat activity or mortality at turbines. For example, at Buffalo Ridge, Minnesota there are 138 turbines and every other one is lit. There have been 171 fatalities found at the site, of which 52% were found at lit turbines and 48% at unlit turbines. Findings at another Minnesota site as well as at Foote Creek Rim, Wyoming, Klondike, Oregon, and Stateline, Oregon/Washington sites similarly seem to indicate that bats are not attracted specifically to lit turbines.

Other possible reasons why bats could be attracted to wind turbines include roosting behavior and noise effects. An older study (Dalquest 1943) reported that migrating hoary bats look for the nearest available tree when daylight approaches, so it may be possible that bats mistake turbines for trees. There have been questions raised regarding whether turbines emit ultrasonic noises that attract bats or “jam” their echolocation frequencies. Bat echolocation devices placed at turbines have not detected any ultrasonic noises, but it should be noted that the detectors used are not capable of picking up ultrasonic noises from the nacelle or higher portions of the turbine. Other bat activity studies from Iowa (Koford 2004) and Sweden (Ahlen 2003) also found that bats were not attracted to turbines. An interesting aspect of this problem is that if bats were simply colliding with a random obstacle (that happened to be a wind turbine), higher mortality would be expected at meteorological towers supported by guy wires. However, searches conducted at six Foote Creek Rim meteorological towers did not bear this out. (None of the 128 bat carcasses, found at Foote Creek Rim, were found near the met towers. Searches conducted at Buffalo

Mountain, Tennessee (Nicholson 2003) and Buffalo Ridge, Minnesota (Johnson et al.2003) also found no dead bats at met towers.

Given the uncertainty that exists regarding wind turbine-bat interaction, there are a number of research questions still to be addressed with respect to the issue. Some of the key research questions to be answered at this point include:

- Are the bat species involved more susceptible than others or is the fatality composition proportional to the abundance of migrating bats?
- At what altitude do migrating bats fly?
- To what extent do migrating bats echolocate?
- Do bats follow linear features such as ridgelines while migrating?
- How can bat migration corridors be identified pre-construction?
- What factors may be related to collisions – weather, fronts, turbine operation?
- What affect does collision mortality have on populations?
- Is there any way to repel bats from wind turbines?
- What can be done to mitigate bat mortality at wind energy facilities?

To address any of these questions thoroughly will require methods and tools (night vision devices, infrared cameras, radar) for documenting bat behavior and collisions — and for helping formulate solutions.

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Wind Power: Bats and Wind Turbines

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PART I: WHAT IS CURRENTLY KNOWN

There are some things we know regarding the interaction between bats and wind turbines, and also a variety of things that are unknown (Johnson et al. 2003; Ahlen 2003). Wind energy is the fastest growing sector of the power industry, with over half of the states in the US possessing developed on-shore wind resource areas and wind power prevalent throughout Europe (Elliott, Schwartz and Scott 2004). Europe has also pioneered offshore wind developments (Pasqualetti, Righter and Gip 2004), with the US currently exploring offshore options.

It is known that bats are being killed by wind turbines and that about 90% of the fatalities are migratory species, with most bat fatalities occurring in late summer and fall (Pasqualetti, Righter and Gip 2004). It is also known that wind turbine sites are concentrated along expected migratory corridors, such as along ridge tops and in open plains (on-shore) and along coastal regions (offshore). Turbines are tall and mostly white, with pronounced blade tip and wake vortices (Petersen and Madsen 2004; Morrison and Sinclair 2004). Rotating turbine blades create motion smear and turbulence (Pasqualetti 2004; Petersen 2004), while rotors and turbine blades produce audible (and possibly ultrasonic) sounds (Morrison and Sinclair 2004).

At present, the short- and long-term quantitative environmental effects of existing turbines have not been adequately assessed (although there are more data on birds than bats) (Ahlen 2003; Morrison 2004). It can be further argued that re-powering of existing turbine sites with larger and more efficient turbines poses an unknown risk on bats (and birds) at sites that have shown little adverse impact to date. There are several outstanding questions regarding the characteristics of wind turbines that should be addressed. Some of the key questions are noted as follows:

- Do wind turbines attract bats? If so, how and when?
- Do wind turbines attract flying insects? If so, how and when?

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- Can wind turbines be locked or shut down during bat migration?
- If wind turbines attract bats, can they be modified to reduce impact?
- Can wind turbines be structurally modified to mitigate impacts on bats?

There are also a number of outstanding questions with respect to bats and their behavior that also need be answered, including:

- What are the migratory corridors of bats?
- What sensory cues do insectivorous bats use at night, especially migratory species?
- What time of night or day are bats being killed by wind turbines?
- Do bats collide with turbine blades or with the tower poles?
- How many bats are actually killed by wind turbines?
- What is the feeding behavior of bats in the vicinity of turbines?
- What are the ages of bats killed by wind turbines?
- Is mortality linked to age, sex, or reproductive condition?

I have listed nine hypotheses for testing in an attempt to determine how and why insectivorous bats are being killed by wind turbines: sensory failure, roost attraction, acoustic attraction, insect concentration, food resources, reduced maneuverability, decompression, and light attraction.

- The ***sensory failure hypothesis*** postulates that migrating and feeding bats fail to visually or acoustically detect wind turbines (Ahlen 2003). The smooth cylindrical turbine masts may not be detected by during night migration and it is possible that motion smear associated with rotating turbines (Morrison and Sinclair 2004) also makes it difficult for bats to see turbine blades, if vision is used by bats flying at relatively high altitudes

- The ***roost attraction hypothesis*** asks whether bats are attracted to wind turbines during migration because they are perceived as roost trees (Ahlen 2003). If bats approach a wind turbine tower, as if was a roost place, fatalities may result. This hypothesis is provisionally supported by observations that the greatest number of bats killed at the Mountaineer site in West Virginia was located relatively near the towers (J. Kearn, pers. comm.).

- The ***acoustic attraction hypothesis*** states that blades from some wind turbines emit low frequency sounds that attract bats (Ahlen 2003). If bats are attracted to the sound, and encounter turbine rotors, fatalities may occur.

- The ***insect concentration hypothesis*** employs the following logic. Many flying insects rise in altitude with warm daily air masses; insects become concentrated along high points in the landscape, known as “hill-topping” at night; migrating and foraging bats may use corridors with high insect concentrations and therefore collide with turbines on ridge tops where insects often concentrate (Ahlen 2003).

- The ***insect entrapment hypothesis*** postulates that flying insects are attracted to the white turbine masts at night and then get trapped in the wake of the downstream vortex. Bats are in turn attracted to the concentrations of insects in the wake and collide with the turbine in the process of trying to feed on the insects. This hypothesis may be most relevant to locally feeding, non-migratory species, rather than migratory species.

- The ***linear corridor hypothesis*** states that many bats follow linear corridors while foraging and during migration, and thus they tend to concentrate in areas where forests have been cut down to create right-of-ways for wind turbine construction and maintenance.

- The ***reduced maneuverability hypothesis*** states that the body mass and wind loading of migrating and prehibernating bats increase during the summer and autumn (Kunz, Wrazen, and Burnett 1998), thus reducing their ability to maneuver in the air and making them less able to avoid wind turbines.

- The ***decompression hypothesis*** states that flying bats are killed by rapid decompression as they encounter the turbulence associated with rotating wind turbines.

- The ***light attraction hypothesis*** states that flying bats are attracted to the flashing lights placed on wind turbines to warn low flying aircraft. Recent evidence suggest that there is no difference in fatality rates at lighted and unlighted wind turbines (Johnson et al. 2003), although additional evaluation is needed using different colors, positions, and flash frequencies.

In addition to testing the above hypotheses, monitoring programs should be conducted both pre- and post-construction, with a focus on identifying species, estimating population trends and demographic variables, and on identifying habitat and environmental variables (Morrison and Sinclair 2004). There are several types of studies that should be thoroughly executed to fully assess the impacts of wind turbines on bats. The siting of turbines and their design characteristics need to be examined. Assessment of insect activity should be carried out and test (wind turbine) and control (no wind turbine) sites. Comprehensive bat fatality assessments need to be conducted at all sites with the use of cutting novel methods (e.g., bat sniffing dogs) and standardized sampling and survey methods (daily and seasonal surveys). Key environmental variables (e.g., moon phase, moon light intensity, cloud cover, air temperature, wind speed and wind direction) should be collected at the altitudes above the ground where flying bats are expected to encounter wind turbines. In turn, these data should be used to develop models of bat fatalities at wind turbine sites.

Monitoring methods should minimally include: ground surveys, acoustic (ultrasound) recordings, spotlighting, night vision imaging, infrared thermal imaging, and radar imaging. Pre-construction assessments should focus on acoustic and radar monitoring, infrared thermal imaging, and insect sampling. Use of mist nets set at ground level is highly questionable for assessing the presence of migrating and feeding bats in the vicinity of wind turbines. In addition to the above mentioned detection devices, post-construction assessments should incorporate fatality searches and scavenger/decomposition assessment. Proposed protocol criteria and data required for assessing and modeling bat fatalities are outlined below.

Proposed (Post-Construction) Protocols for Assessing Bat Fatalities at On-Shore Sites

Minimum Search Area	Span of wind turbine rotor
Frequency of Search	Daily at 1/3 of the sites Weekly at 1/3 of sites None at 1/3 of sites
Time of Search	Daytime
Consistent Search Effort	One hour per wind turbine
Search Path	Circular
Search Period	March-November
Human Observers	x 2
Use of Trained Dog "Sniffers"	To test human searcher efficiency

Data Needed for Assessing and Modeling Bat Fatalities at Wind Turbines

Date	Day, month, year
Environmental Conditions	e.g., temperature, precipitation, light, etc.
Relationship of bat position from turbine	Bearing and distance
Species Identification	e.g., forearm length of bats
Further specification	Sex, age (juvenile v. adult, based on fused epiphyses)
Reproductive condition	e.g., pregnant, lactating, post-lactation, non-reproductive
Physical condition	e.g., broken bones, abrasions, decomposition, damage from scavengers

When assessing bat fatalities, results should be corrected for searcher bias, scavenging/removal bias, crippling/injury bias, and habitat bias.

PART II: IDEAS FURTHER RESEARCH

In February 2004, Bat Conservation International (BCI), US Fish & Wildlife Service) (USFWS), American Wind Energy Association (AWEA), and National Renewable Energy Laboratory (NREL) sponsored a two-day workshop in Juno Beach, Florida. Hosted by FPL Energy, the Bats and Wind Power Generation Technical Workshop grew out of concern about bats at the Mountaineer, West Virginia site. The workshop brought together bat ecologists and ornithologists, Federal and state government agencies, and people from the wind industry to share information about how wind power affects bats and to identify ideas for better understanding and resolving bat-related issues in wind energy development. In particular, we wanted to learn what had occurred at Mountaineer, what were the significant knowledge gaps, and what are the most helpful tools, technologies, and information-gathering techniques to better understand bat-turbine interactions and quantify the magnitude of problem. We wanted to figure out what actions to take – both immediate next steps to address problems, near-term priorities. For top ten priorities, we came up with a table with "soundbite" descriptions of what needs to be done, tasks, performers, schedule, costs, and immediate next steps. We tried to develop a seasonal understanding of what needed to be done.

A peer-reviewed paper that raises a variety of wind power-related issues such as bat issues, technology and research protocols is being developed. It is hoped this paper will provide information to researchers, Federal and state agencies, and people in the wind industry – most of whom are expected to contribute to this paper. (It is quite rare to have input from this wide of a range of stakeholders in a peer-reviewed paper.)[17]

There are a variety of points to consider for future work/research on bat monitoring protocols. The importance of temporal and spatial considerations in fatality assessment is of high importance. While night vision devices, including infrared reflectance imaging, requires some light source (for bright moon light or an infrared light source), infrared thermal imaging (which detects heat) can be used independent of ambient light (Frank et al. 2003). This technology can be used to successfully to monitor and census flying bats (Ahlen 2003; Frank et al. 2003). Infrared thermal imaging has the advantage of making it possible to distinguish between birds and bats (Kunz, pers. obs.). Visible spotlighting may be the most cost effective way to do make visual spot checks for activity of bats and insects in the vicinity of wind turbines. Spotlighting should be relatively brief (<30 seconds) to avoid attract insects (and bats) in the beam of light.

Monitoring studies should employ ultrasonic detectors to record sounds produced bats (typically in the range 20 to 100 kHz. However, most ultrasonic detectors have a relatively short range of detection (<30 m) (Pettersson 2004), thus they should be positioned high enough above the ground to detect bats that are likely to encounter turbine towers and rotors. Most small, frequency modulating (FM), echolocating bats have a fairly short range of effectiveness for detecting objects while in flight (typically < 5 m) (Fenton 2004; Pettersson 2004). Marine surveillance radars may be effective at detecting flying targets, but they cannot distinguish birds from bats. Using infrared thermal imaging in conjunction with marine surveillance radar may prove useful in distinguishing bats from birds in radar images. Sticky traps may prove useful for assessing insect activity in the vicinity of wind turbines (Pettersson 2004).

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Discussion, Questions and Answers

Comment: FPL Energy first met to discuss bat-wind turbine interactions in December 2003; the Juno Beach workshop was held in February, and now (in May) is gearing up to do a study of fall bat migration at Mountaineer. The $300,000 effort (including funding a full-time bat-wind turbine interactions staff position and bringing technology up to Mountaineer to do study). In terms of birds, it's been very difficult to actually observe the interaction, but hoping to be able to accomplish that at Mountaineer with respect to bats.

Does the wind industry periodically clean turbine blades, in which case they could be examined for insect remains, which may help inform the insect concentration hypothesis? *Response:* Turbines are designed to prevent the collection of dust and insects as much as possible. Rotor blades in the West require more regular cleaning because there is less rainfall.

Has the airspeed of bats relative to the wind speed in the rotor vortex been examined? The participant also asked whether insect updraft along ridgelines had been investigated, noting that some of those types of wind currents reverse at night.

Response: Existing evidence suggests that insects are drawn up during the day and concentrate on ridges at night.

Comment: There have been inconsistent statements made about the range of bats' echolocation abilities.

Response: Bat echolocation has been detected as far out as 30 m, but most insectivorous bats that produce frequency modulated (FM) calls typically can only detect small insects within the range of 2-5 m. There is no empirical evidence that bat echolocation has been recorded at distances of 100 m or more.

Comment: Research protocols between birds and bats may need to be coordinated. *Response:* This may be difficult. Bird carcasses are easier to spot than bat carcasses. When a bat dies, it folds up, so that the carcass looks like a small brown blob about the size of man's thumb.