FINAL REPORT:

WIND-TURBINE RELATED BAT MORTALITY IN SOUTHWESTERN MINNESOTA

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Introduction

Mortality of animals that fly into man-made structures has been studied for buildings, communication towers, and more recently, for large turbines that convert wind energy into electrical power (Johnson et al., 2000; Osborn et al., 1996). The development of wind energy at Buffalo Ridge, Lincoln and Pipestone Counties, Minnesota, was initiatated in 1994. Three phases of development, identified by discrete locations, time of construction, and different developers, include phase II (P2; 143 turbines) and phase III (P3; 138 turbines). A state-ordered study of bird mortality at Buffalo Ridge (Johnson et al., 2000) incidentally found about three-fold more bats than birds in 1998 and 1999, but that monitoring project ended in 1999. Our purpose in this research was to extend the monitoring of P2 and P3 into 2000 using identical methods, and to analyze the data from all three years to test the following hypotheses:

> **Overview**
>
> 1) Estimated total bat kill is 528 bats at Phase II and Phase III, based on finding 71 carcasses in 2000.
>
> 2) No change in mortality rate from prior years.
>
> 3) No statistically significant change in species composition of the kill in 2000 from prior years
>
> 4) No carcasses of state-endangered or threatened species were observed.
>
> 5) The greatest mortality occurred during July and August.
>
> 6) No effect of crop type on mortality rate per turbine.
>
> 7) The mortality rate per turbine is greater in Phase III than in Phase II in 2000.

H1: No differences exist among years in the species composition of bats killed.

H2: No differences exist among years in the relative mortality rate per turbine.

H3: No significant correlation exists between mortality rate and adjacent land-use type.

H4: Mortality is random with respect to time-of-year.

Herein we provide brief methods, results, interpretation, and all data collected (see Appendix 1). In addition to the final report, we have included a copy of our manuscript in preparation for submission to *American Midland Naturalist*. Because this manuscript is only a draft, we provide it to you as a courtesy and ask that it not be reproduced or published. As soon as they are available, you will be provided with a copy of the manuscript submitted for publication and a copy of the published version to be included into the final report on this grant. For a full introduction to the project and statement of hypotheses, see the attachment (Krenz et al., unpublished manuscript).

Methods

Our overall goal was to observe mortality as was done in previous years so as to collect comparable data for the purpose of temporal monitoring. We searched for bat carcasses beneath the same set of 68 turbines used by Johnson et al. (2000) in their searches in 1998 and 1999 in P2 and P3. We used the search protocol at each turbine site from Johnson et al. (2000) with the exception that we used a 30-m quadrat instead of a 60-m quadrat because 97% of the bat carcasses found by Johnson et al. (2000) were within 30 m of a tower. We used their length-of-stay estimates in our calculation of the chance of finding a bat carcass. For the same calculation, we generated new field estimates of searcher efficiency within each habitat type (the probability of detecting bat carcasses that existed at the time of the search). We restricted our search period to the months of July through October because a large majority of the mortality occurs during this period (Johnson et al., 2000).

At each turbine, we noted the crop type. For each carcass, we recorded the turbine number, the date, the distance of the carcass from the center of the tower, and if possible, the sex, age, and cause of death. We used the number of fatalities found during searches to estimate total fatalities in P2 and P3. We also estimated mortality rates by habitat type using the protocol described by Johnson et al. (2000).

An important distinction between our protocol and the Johnson et al. (2000) protocol is that in estimating absolute mortality (an extrapolation from the relative mortality data using estimates of areas searched and habitat-specific searcher efficiencies among other factors) we will be using a mapping approach to account for the exact size and shape of the graveled area under each turbine (known as the gravel pad). We expect this to have an effect on mortality estimates because of the turbine-to-turbine variation in pad area and shape and because the vast majority of carcasses are found on the pads. Note that searcher efficiencies are very high in graveled habitats and low in all other habitats.

We compared mortality means by habitat, phase, and date within year to test for significant differences (LSD; Zar, 1986). We compared species composition among years using a contingency table analysis (G-test; Zar, 1986).

A full description of our methods is contained in the attachment (Krenz et al., unpublished manuscript).

Results

We found 72 carcasses of six species beneath 68 turbines in 2000 (Appendix 1). Most carcasses were found well within the 30-m quadrats; only 3 carcasses (4%) were found more than 25 m from the center of the turbine tower (Figure 1). Searcher efficiency was 95% on the gravel pads and lower in vegetated areas (Table 1).

We did not find any individuals of any species in 2000 that were not discovered in 1998 or 1999 except for the big brown bat.

Two species previously found (eastern pipistrelle and little brown bat) were not found in 2000 (Table 3). Most (66%) of the 2000 carcasses were hoary bats. One of the 72 carcasses was not identified to species. There was no significant difference among years in the species composition of the killed bats (Table 3).

There were no significant differences in mortality by habitat type.

Mortality was distributed significantly non-randomly through the year (see Figure 2 and Appendix 1) with the greatest mortality occurring during the months of July and August in 2000. There were no significant differences among years in this pattern. The only species that contributed significantly to this pattern in 2000 was the hoary bat; there was no evidence that mortality of the other species was temporally non-random.

The total estimated mortality is 189 bats in P2 and 339 bats in P3. The mean (SE) mortality rate per turbine in 2000 was 1.32 bats (0.21) in P2 and 2.46 (0.30) in P3 and the difference between sites was significant. In 1999, there was no significant difference between P2 and P3 in mortality rate. There was no significant difference in overall numbers killed among years (Table 3); the total estimated mortality (P2 and P3) was 559 bats in 1999 and 528 bats in 2000.

Discussion

In general, we documented a continuation of the 1998 and 1999 patterns in terms of timing, location, and extent of mortality, and in terms of identifying species affected. With regard to our specific hypotheses, we accept each of our null hypotheses except the fourth, having strong evidence of increased mortality in late summer.

Although unanswered to this point, a key question is whether the heightened mortality in late summer is suffered by migrating or resident bats. If resident bats were the victims, then one might predict a local population effect, though it is unclear whether that would be detected simply by searching for bat carcasses. For example, if local residents were being killed, one would predict a gradual decline in bat numbers. But for such a decline to extend between years, bats would have to be philopatric to their summering grounds between years. It is also possible that Buffalo Ridge could be a "population sink" area, one that simply continually attracts bats from other areas during periods of summer mortality, preventing the observation of a local decline in bat numbers. If primarily migrant bats are being killed, then the "population" of interest becomes a continental one and one could only assume that the effect on such a population would be trivial. The three years of carcass data examined here provide no evidence of a decline in mortality.

The annual pattern of mortality, with increases in late summer, but with a conspicuous lack of increased mortality in the spring, suggests that either (1) non-migrant bats account for the mortality, or (2) migrant bats behave differently on the spring migration than they do on the fall migration. Perhaps further research could elucidate this puzzle.

Literature Cited

Johnson, G.D., W.P. Erickson, M.D. Strickland, M.F. Shephard, and D.A. Shephard. 2000. Avian monitoring studies at the Buffalo Ridge, Minnesota wind resource area. Final Report. Submitted to Northern States Power Company by Western EcoSystems Technology Inc.

Krenz, J.D., B.R. McMillan, and R. Rosendahl. Temporal and spatial patterns of bat mortality caused by wind-energy turbines in southwestern Minnesota. For submission to Amer. Midl. Nat.

Osborn, R.G., K.F. Higgins, C.D. Dieter, and R.E. Usgaard. 1996. Bat collisions with wind turbines in Southwestern Minnesota. Bat Research News 37:105-108.

Table 1. Mean vegetation height (±SD) and searcher efficiency (±SD) determined from searcher efficiency trials in five habitat types including corn, CRP (Conservation Reserve Program), beans, grazed pasture, and gravel pad.

	Corn	CRP	Beans	Grazed Pasture	Gravel Pad
Vegetation Height (m)	2.4 ± 0.1	0.88 ± 0.1	0.78 ± 0.02	0.1 ± 0.02	0.0 ± 0.0
Searcher Efficiency (%)	10 ± 9	0 ± 0	30 ± 9	50 ± 9	95 + 9

Table 2. Estimated number of bat fatalities at two wind-energy development sites at Bufflao Ridge, Minnesota during 1998-2000. These estimates were calculated using scavanger removal data (see Johnson et al., 2000) and searcher efficiency values determined from searcher efficiency trials.

Year		Phase II	Phase III
1998	Total	231	na
	Per turbine	1.62	na
1999	Total	277	282
	Per turbine	1.94	2.04
2000	Total	189	339
	Per turbine	1.32	2.46
Annual mean	Total	232	311
	Per turbine	1.63	2.25

Table 3. Number of bats (that could be identified) collected during regular fatality searches during 1998-2000. Proportion of the total bat community comprised by the indicated species is in parentheses. There was no significant difference ($P > 0.05$) in species composition (proportions) of the bat community among years.

	1998	1999	2000
Hoary bat	11 (0.48)	40 (0.59)	47 (0.66)
Eastern red bat	6 (0.26)	19 (0.28)	13 (0.18)
Silver-haired bat	3 (0.13)	1 (0.01)	6 (0.08)
Big brown bat	0 (0.0)	0 (0.0)	5 (0.07)
Little Brown bat	1 (0.04)	5 (0.07)	0 (0.0)
Eastern pipistrelle	2 (0.09)	3 (0.04)	0 (0.0)

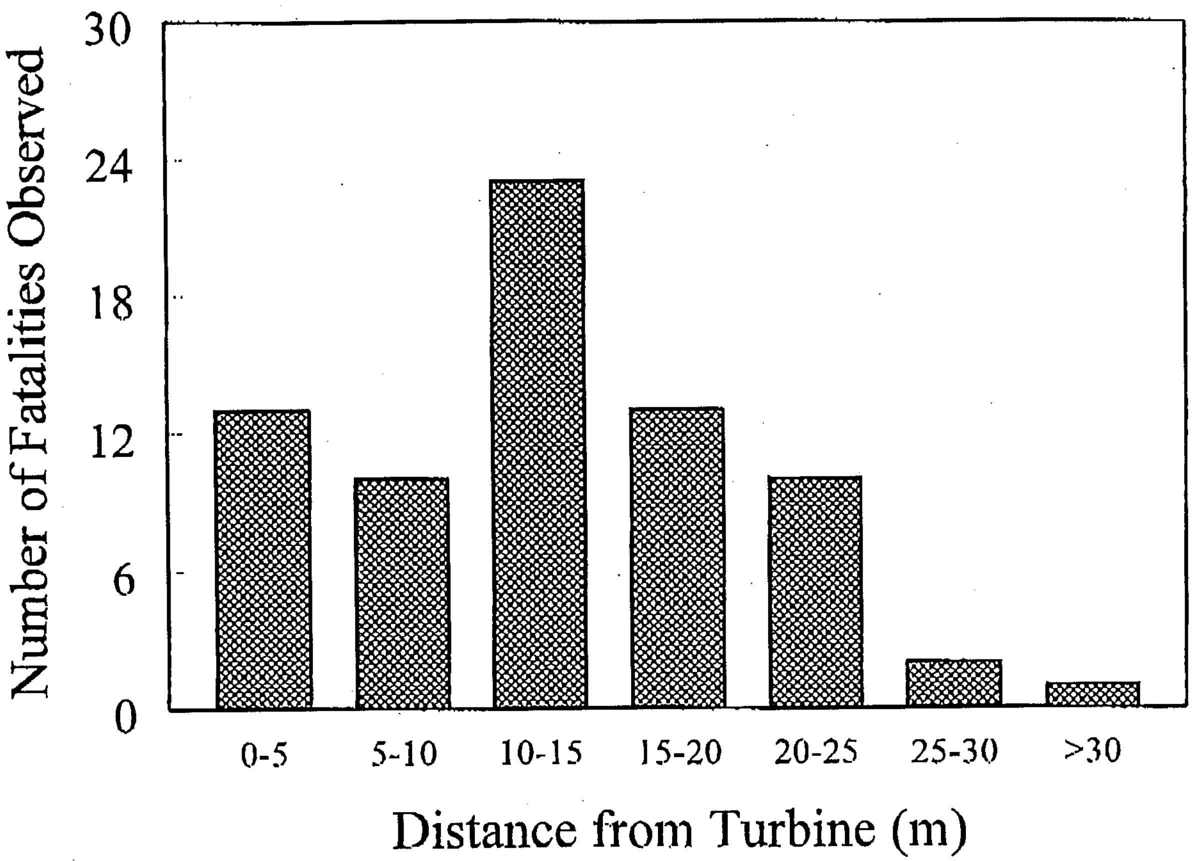

Figure 1. Distance from wind-energy turbines that bat carcasses were located during biweekly fatality searches performed between 17 July and 7 October, 2000.

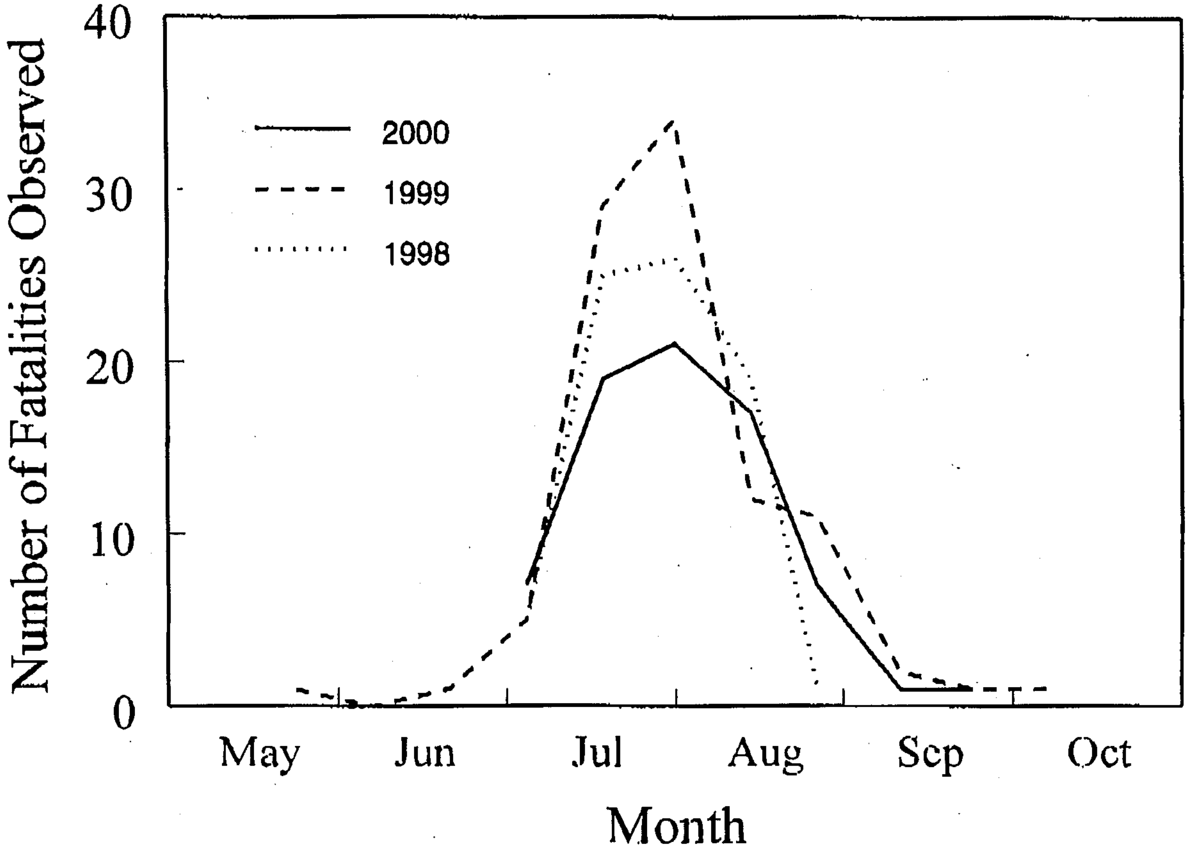

Figure 2. Temporal distribution of bat fatalities at Buffalo Ridge, Minnesota during 1998-2000. Bat fatalities were located during regular biweekly fatality searches conducted at 70 wind-energy turbines.

Appendix 1. Raw data for bat fatalities located during 7 biweekly sampling periods between 17 July and 7 October, 2000.

Phase	Date	Turbine	Species	Sex	Habitat
II	7/17/2000	22	Hoary bat (*Lasiurus cinereus*)	?	Corn
II	7/18/2000	109	Big brown bat (*Eptesicus fuscus*)	F	Pasture
II	7/31/2000	3	Hoary bat (*Lasiurus cinereus*)	M	Corn/CRP
II	7/31/2000	5	Hoary bat (*Lasiurus cinereus*)	F	Corn
II	7/31/2000	39	Hoary bat (*Lasiurus cinereus*)	F	Bean
II	7/31/2000	28	Hoary bat (*Lasiurus cinereus*)	M	Corn
II	7/31/2000	26	Hoary bat (*Lasiurus cinereus*)	F	Bean
II	7/31/2000	23	Eastern red bat (*Lasiurus borealis*)	?	Corn
II	7/31/2000	83	Hoary bat (*Lasiurus cinereus*)	F	Corn
II	7/31/2000	83	Hoary bat (*Lasiurus cinereus*)	M	Corn
II	7/31/2000	86	Hoary bat (*Lasiurus cinereus*)	M	Bean
II	7/31/2000	67	Hoary bat (*Lasiurus cinereus*)	?	Bean/Corn
II	8/14/2000	39	Hoary bat (*Lasiurus cinereus*)	M	Bean
II	8/14/2000	32	Eastern red bat (*Lasiurus borealis*)	?	Corn
II	8/14/2000	26	Hoary bat (*Lasiurus cinereus*)	?	Bean
II	8/14/2000	21	Hoary bat (*Lasiurus cinereus*)	M	Corn
II	8/14/2000	21	Hoary bat (*Lasiurus cinereus*)	F	Corn
II	8/14/2000	53	Hoary bat (*Lasiurus cinereus*)	M	Corn
II	8/14/2000	121	Hoary bat (*Lasiurus cinereus*)	F	CRP
II	8/14/2000	121	Eastern red bat (*Lasiurus borealis*)	?	CRP
II	8/25/2000	5	Hoary bat (*Lasiurus cinereus*)	?	Corn
II	8/25/2000	18	Eastern red bat (*Lasiurus borealis*)	F	Pasture
II	8/25/2000	44	Eastern red bat (*Lasiurus borealis*)	M	CRP
II	8/25/2000	44	Silver-haired bat (*Lasionycteris noctivagens*)	M	CRP
II	8/25/2000	21	Hoary bat (*Lasiurus cinereus*)	F	Corn
II	8/25/2000	22	Hoary bat (*Lasiurus cinereus*)	M	Corn
II	8/25/2000	123	Hoary bat (*Lasiurus cinereus*)	M	CRP
II	9/9/2000	138	Hoary bat (*Lasiurus cinereus*)	M	CRP
II	9/9/2000	140	Eastern red bat (*Lasiurus borealis*)	M	CRP
II	9/9/2000	76	Silver-haired bat (*Lasionycteris noctivagens*)	?	Corn
II	9/9/2000	41	Hoary bat (*Lasiurus cinereus*)	?	Corn
II	9/9/2000	56	Silver-haired bat (*Lasionycteris noctivagens*)	F	Bean
III	7/18/2000	26	Eastern red bat (*Lasiurus borealis*)	F	CRP
III	7/18/2000	62	Big brown bat (*Eptesicus fuscus*)	M	Corn
III	7/18/2000	80	Eastern red bat (*Lasiurus borealis*)	F	Bean/Corn
III	7/18/2000	96	Eastern red bat (*Lasiurus borealis*)	M	Corn
III	7/19/2000	107	Hoary bat (*Lasiurus cinereus*)	M	CRP
III	8/1/2000	8	Hoary bat (*Lasiurus cinereus*)	M	Bean
III	8/1/2000	48	Silver-haired bat (*Lasionycteris noctivagens*)	F	Bean

III	8/1/2000	71	Hoary bat (*Lasiurus cinereus*)	F	Corn/CRP
III	8/1/2000	66	Hoary bat (*Lasiurus cinereus*)	M	Corn
III	8/1/2000	80	Hoary bat (*Lasiurus cinereus*)	F	Bean/Corn
III	8/1/2000	80	Hoary bat (*Lasiurus cinereus*)	F	Bean/Corn
III	8/1/2000	80	Hoary bat (*Lasiurus cinereus*)	F	Bean/Corn
III	8/1/2000	75	Hoary bat (*Lasiurus cinereus*)	F	Corn
III	8/1/2000	102	Eastern red bat (*Lasiurus borealis*)	M	CRP
III	8/15/2000	21	Big brown bat (*Eptesicus fuscus*)	M	Bean/Pasture
III	8/15/2000	48	Hoary bat (*Lasiurus cinereus*)	?	Bean
III	8/15/2000	53	Hoary bat (*Lasiurus cinereus*)	?	Bean
III	8/15/2000	57	Hoary bat (*Lasiurus cinereus*)	F	Bean
III	8/15/2000	57	Eastern red bat (*Lasiurus borealis*)	F	Bean
III	8/15/2000	57	?	?	Bean
III	8/15/2000	62	Hoary bat (*Lasiurus cinereus*)	?	Corn
III	8/15/2000	71	Hoary bat (*Lasiurus cinereus*)	M	Corn/CRP
III	8/15/2000	66	Hoary bat (*Lasiurus cinereus*)	F	Corn
III	8/15/2000	66	Hoary bat (*Lasiurus cinereus*)	F	Corn
III	8/15/2000	75	Hoary bat (*Lasiurus cinereus*)	F	Corn
III	8/15/2000	96	Hoary bat (*Lasiurus cinereus*)	M	Corn
III	8/15/2000	115	Hoary bat (*Lasiurus cinereus*)	F	Bean
III	8/25/2000	3	Hoary bat (*Lasiurus cinereus*)	M	Bean
III	8/25/2000	3	Hoary bat (*Lasiurus cinereus*)	F	Bean
III	8/25/2000	8	Hoary bat (*Lasiurus cinereus*)	F	Bean
III	8/25/2000	53	Eastern red bat (*Lasiurus borealis*)	F	Bean
III	8/25/2000	53	Big brown bat (*Eptesicus fuscus*)	F	Bean
III	8/25/2000	48	Hoary bat (*Lasiurus cinereus*)	F	Bean
III	8/26/2000	88	Hoary bat (*Lasiurus cinereus*)	M	Pasture
III	8/26/2000	102	Eastern red bat (*Lasiurus borealis*)	F	CRP
III	8/26/2000	129	Hoary bat (*Lasiurus cinereus*)	M	Bean
III	8/26/2000	129	Big brown bat (*Eptesicus fuscus*)	F	Bean
III	9/8/2000	9	Silver-haired bat (*Lasionycteris noctivagens*)	M	Corn
III	9/8/2000	66	Hoary bat (*Lasiurus cinereus*)	F	Corn
III	9/22/2000	57	Silver	M	Bean
III	10/6/2000	134	Silver	F	Corn/CRP