BIRD MORTALITY AT ROTOR SWEPT AREA EQUIVALENTS, ALTAMONT PASS AND MONTEZUMA HILLS, CALIFORNIA

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ABSTRACT: Bird mortality at wind energy facilities has become the focus of diverse research to understand the causes of collisions and to find methods to reduce and/or eliminate mortality of birds. My study evolved out of 7 years of avian mortality research in the Altamont Pass and the Montezuma Hills, California. In 1992 Kenetech Windpower began installing their new variable speed wind turbine (KVS-33) with a blade diameter of 33 m. This turbine was designed to replace the older smaller KCS-56 turbine with a blade diameter of 18.5 m. The ratio of the area swept by the rotor (RSA) between the KVS-33 and the KCS-56 turbines is 3.18:1. The U.S. Fish and Wildlife Service put forth the hypothesis that the larger KVS-33 wind turbine would potentially kill more birds by sweeping more area than the KCS-56 turbine. I tested the RSA hypothesis by surveying 53 KVS-33 turbines at 3 locations in the Altamont Pass and Montezuma Hills wind energy fields and compared them to randomly selected KCS-56 turbine strings for an RSA that was equivalent. Observers searched areas adjacent to all turbines twice weekly for 18 months. Eighty-five collision mortalities were confirmed during the time when turbines of both types were in operation. The avian mortality ratio between the RSA-equivalent sets of KVS-33 and KCS-56 turbines was 1:3.47. This ratio was significantly different than the even ratio that would be expected from my experimental design. The evidence does not support the hypothesis that the larger rotor-swept-area of the KVS-33 wind turbines resulted in more mortalities.

Key words: Altamont Pass, bird mortality, California, wind energy, rotor area

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Bird mortality at wind energy facilities has become the focus of diverse research to understand the causes of collisions and to find methods to reduce and/or eliminate mortality of birds. My study evolved out of 7 years of avian mortality research in the Altamont Pass and the Montezuma Hills, California. Kenetech Windpower installed their new variable speed wind turbine type in late 1992. The KVS-33 (33M-VS) wind turbine with a blade diameter of 33 m was designed to replace the older smaller KCS-56 (56-100) wind turbines with a blade diameter of 18.5 m. Because of the larger blade diameter, the U.S. Fish and Wildlife Service (FWS) put forth the hypothesis that the larger KVS-33 wind turbine would sweep more area than the KCS-56 wind turbines potentially killing more birds. The ratio of the area swept by the rotor between the KVS-33 and KCS-56 is 3.18:1. Based on this hypothesis of increased rotor swept area (RSA), they predicted that a KVS-33 wind turbine would have 3 times the likelihood of an avian collision than a KCS-56 turbine.

The purpose of my project was to test the RSA hypothesis. This was done by comparing avian mortality at adjacent KVS-33 and KCS-56 turbine strings. Twenty and 16 KVS-33 turbines were installed in late 1992 and 1993, at Dyer and at Midway, respectively, in the Altamont Pass, Alameda and Contra Costa counties, California. I selected these KVS-33 turbines for the study. An additional 17 KVS-33 wind turbines were installed in mid 1994 in the Montezuma Hills, Solano County, California. I also included these KVS-33 turbines in the study. For comparison, I selected adjacent strings of KCS-56 turbines to provide total RSA that was equivalent to that of the selected KVS-33 turbines.

Bird collisions with wind turbines in the Altamont Pass and Montezuma Hills of central California were systematically studied specifically for Kenetech Windpower (Howell and DiDonato 1990, Howell et al. 1991, Howell and Noone 1992) and in general for the industry in the Altamont Pass (Orloff and Flannery 1992). During this period 6 sampling years were recorded, 4 sampling years in the Altamont Pass and 2 sampling years in the Montezuma Hills. The mean raptor mortality from pooled data for the 2 Altamont studies equaled 2.857/100 turbines/year (SD = 2.813, n = 4), and the mean raptor mortality for Solano equaled 2.839/100 turbines/year (SD = 1.519, n = 2). The means were not significantly different (Student's t-test for unequal sample sizes, $P > 0.05$). These results indicated that between site mortality was similar.

STUDY AREA

Two of the three study sites were located in the Altamont Pass (eastern Alameda and south eastern Contra Costa counties)(Fig. 1). The 2 study areas are 11 km apart. Dyer lies north of U.S. Interstate Highway 580 (I-580), and Midway lies south of Highway I-580. Altamont Pass exhibits wide diversity in topographic relief. Hill top elevations to the north of Highway I-580 range from about 230 m to 375 m above sea level. The valley elevations range from about 78 m to 188 m above sea level. Hill top elevations to the south of Highway I-580 range from about 345 m to 470 m above sea level.

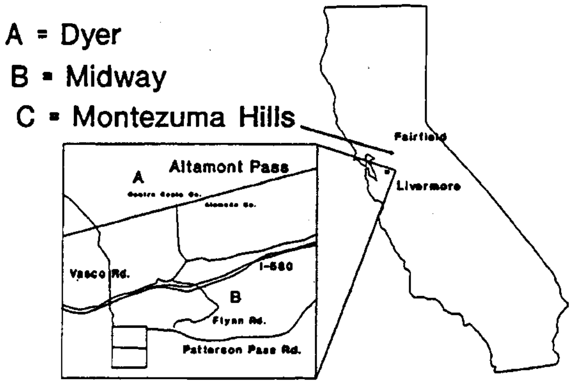

Fig. 1. Study site locations, Altamont Pass, Alameda and Contra Costa counties, and Montezuma Hills, Solano Co. California.

The valley elevations range from 188 m to 345 m above sea level. The Altamont Pass land use was almost exclusively cattle grazing on non-native annual grassland. The grass grows rapidly during the rainy season, sets seed and dies during the long summer drought. The KCS-56 turbines are spaced at approximately 24.4-30.5 m (80-100 foot) intervals along prominent ridges in linear formation perpendicular to prevailing winds. The KVS-33 turbines are spaced at approximately 45.7 m (150 foot) intervals along prominent ridges in linear formation perpendicular to prevailing winds.

The third study site was located in the Montezuma Hills, southeastern Solano County (Fig. 1). Montezuma Hills exhibits less diversity in topographic relief. Hill top elevations range from about 63 m to 95 m above sea level. The valley elevations range from about 8 m to 16 m above sea level. The principle vegetation of the area was grain fields. After the grain harvest, domestic sheep (*Ovis aries*) grazed the stubble. Some of the fields were fallow or disked to bare soil. Heating in the Central Valley of California produces winds by drawing in the cooler, dense marine air through topographic gaps in the Coast Range such as the Altamont Pass and over the Montezuma Hills in the Sacramento-San Joaquin Delta region. The spacing and physical location of the two turbine types are similar to the Altamont Pass.

METHODS

I designed methods to survey the Dyer and Midway KVS-33 turbines and sample the randomly selected strings of KCS-56 turbines, within an area immediately adjacent to the KVS-33 turbines. Sets of turbines, rather than individual machines, were randomly chosen to keep KCS-56 turbine strings as units of study. All wind turbines were on lattice towers. The KCS-56 turbines were on towers with horizontal braces. The KVS-33 turbines were on towers with diagonal braces. The KCS-56 turbines had, by experimental design, a combined RSA approximately equal to the combined RSA of the KVS-33 turbines. The same approach was used to select a KCS-56 RSA equivalent in the Montezuma Hills for the Sacramento Municipal Utility District wind plant.

I randomly selected 7 KCS-56 turbine strings from 17 turbine strings surrounding the 20 KVS-33 turbines at the Dyer site totaling 68 turbines (Table 1). At the Midway site I randomly selected 4 KCS-56 turbine strings from 15 turbine strings surrounding the 16 KVS-33 turbines totaling 61 turbines, and at the Montezuma

Table 1. Randomly selected KCS-56 wind turbine strings, Altamont Pass and Montezuma Hills, California, December 1993 to August 1995.

Location					
Dyer		Midway		Montezuma Hills	
Tower no.'s	No. of turbines	Tower no.'s	No. of turbines	Tower no.'s	No. of turbines
2038-2053	16	1283-1307	25	8037-8050	14
2206-2209	4	1256-1269	14	8101-8115	15
2210-2219	10	1176-1183	8	8116-8127	12
2232-2242[1]	10	1162-1175	14	8148-8158	11
2355-2373	19			8270-8276	7
2289-2292	4				
2294-2298	5				

[1] 2240 excluded

Hills site I randomly selected 5 KCS-56 turbine strings from 20 turbine strings 1.6 km east of the 17 KVS-33 turbines totaling 59 turbines.

Field technicians surveyed 36 KVS-33 turbines in 6 strings with a combined RSA of 30,609 m^2 in the Altamont Pass. They surveyed 129 KCS-56 turbines in 11 randomly selected strings with a combined RSA of 31,811 m^2 in the Altamont Pass. The difference in RSA between the KCS-56 and KVS-33 turbines was 1,202 m^2 in the Altamont Pass. Field technicians surveyed 17 KVS-33 turbines in 1 string with a combined RSA of 14,454 m^2 in the Montezuma Hills. Field technicians surveyed 59 KCS-56 turbines in 5 randomly selected strings with a combined RSA of 14,549 m^2 in the Montezuma Hills. The difference in RSA between the KCS-56 and KVS-33 turbines was 95 m^2 in the Montezuma Hills.

Turbine strings were sampled twice each week between December 1993 and September 1995 in the Altamont Pass, and between November 1994 and September 1995 in the Montezuma Hills. Field technicians used ground search methods described in Howell et al. (1991) and Howell and Noone (1992). Two field observers searched 78 m (250 feet) wide plots upwind and downwind of the turbines strings by walking parallel transects to find carcasses of birds. The transect width was reduced to 47 m (150 feet) because carcass distribution data indicated that the original transect was too wide. I included observations of carcasses in the study areas reported by Kenetech Windpower personnel because samples were small (n = 6) and equal between KVS-33 and KCS-56 wind turbines. This was the basis for determining bird mortality associated with the 36 KVS-33 and 129 KCS-56 wind turbines in the Altamont Pass and 17 KVS-33 and 59 KCS-56 wind turbines in the Montezuma Hills. Carcasses were visually examined (without touching per FWS request) to determine species. Other information collected included nature and extent of injuries and weather conditions at estimated time of death (sample data sheet attached). We tagged raptor carcasses with blue flagging, reported to Kenetech Windpower's avian specialist, and left the carcass for recovery by FWS staff (per their request).

I compared mortality by counting the number of carcasses per month between turbine types. I analyzed data with the Chi-square and Student's t-test procedures of Steel and Torrie (1960) and Norusis (1988:B97-99:C35-36). Other factors such as turbine height were not examined. Observer bias and scavenging rates were assumed equal within the 3 study sites (Howell and DiDonato 1990, Howell et al. 1991, Howell and Noone 1992).

RESULTS

A total of 104 birds and 1 mammal were recovered from the Altamont Pass and Montezuma Hills during the field surveys. Of the 104 birds, field surveyors identified a total of 72 confirmed collision mortalities in the Altamont Pass during the 18 month period when both turbine types were operating from December 1993 to May 1994, and August 1994 to September 1995. Field surveyors identified 13 confirmed collision mortalities in the Montezuma Hills during the 10 month period from November 1994 to September 1995. Ten birds recovered at KCS-56 turbines were excluded because the KVS-33 turbines were not in service for 3 months in the Altamont Pass. Field surveyors attributed 7 mortalities to other causes through visual inspection, such as predation and soaking by oil. Two injured birds were rehabilitated and released to the wild.

We identified carcasses of 16 species including 7 species of raptors and 1 species of bat. We also had 2 unidentified raptors and 3 unidentified passerines. Bird mortalities in the Altamont Pass consisted of 44 raptors and 28 non-raptors. The KVS-33 wind turbines were not operational in the Altamont Pass from May through July 1994. No avian mortalities were recorded at the KVS-33 wind turbines while 9 mortalities and 1 injury occurred at the KCS-56 wind turbines during that interval. Data from that period were, therefore, excluded from the analysis. One red-tailed hawk was found under a power pole, and 1 American kestrel was recovered with oil coating the plumage. Scientific names are in Table 2. We recovered 21 red-tailed hawks, 12 American kestrels, 5 barn owls, 1 great horned owl, 1 burrowing owl, 1 Swainson's hawk, and 1 prairie falcon (Table 2). Seasonal variation in mortalities at Midway and Dyer occurred with a greater number observed in late summer through early winter at KCS-56 turbines (Fig. 2) and KVS-33 turbines (Fig. 3). No seasonal pattern was apparent for Montezuma Hills (Fig 4).

Avian mortality in the Altamont Pass was different for the RSA of the two turbine types (Table 3). The total avian mortality ratio was 1:3.67 between KVS-33 and KCS-56 turbines with equivalent RSA, and the raptor mortality ratio was 1:3.01. These ratios are significantly (Chi-square = 26.94, df = 3, $P < 0.001$, n = 4) different than the even ratios expected if RSA was a factor. The null hypothesis of no difference between KVS-33 and KCS-56 turbine strings with equivalent RSA's was rejected. Bird mortality at KVS-33 turbine strings was 25% of the mortalities observed at the KCS-56 turbine strings. A 33% ratio was evident for raptors in the Altamont Pass.

Bird mortality for all species in the Montezuma Hills at the 2 turbine types was not significantly different (Chi-square = 0.69, df = 1, $P > 0.25$), but the species composition was different. From November 1994 to September 1995, 1 red-tailed hawk and 4 American kestrels were recovered under KVS-33 wind turbine strings. Four red-tailed hawks, 1 mallard, 1 rock dove, and 2 red-winged blackbird were recovered under KCS-56 turbine strings. By combining the Montezuma Hills data with the Altamont Pass data the avian mortality ratio was 1:3.47 (Chi-square = 25.98, df = 1, $P < 0.001$) for KVS-33 and KCS-56 wind turbine strings. This ratio is significantly different than the even ratio that would be expected if RSA was a factor.

DISCUSSION

The evidence to date from the Altamont Pass does not support the hypothesis that the larger rotor swept area of the KVS-33 wind turbines contributes proportionately to avian mortality; that is larger area results in more mortalities. On the contrary, the ratio of KCS-56 turbines to KVS-33 turbines rather than RSA was approximately 3.0:1, which was consistent with the 3.6:1 mortality ratio. It appears that the mortality occurred on a per-turbine basis; that is each turbine simply represented an obstacle. This would mean that replacing the RSA of KCS-56 turbines with KVS-33 turbines would reduce mortality by 66% for the same energy output. In addition, the KVS-33 had relatively low numbers of non-raptor species recovered during mortality searches. Tucker (1996a, 1996b) independently developed a mathematical theory that in part explains this observed mortality ratio and described the parameters necessary for future research of bird collisions with wind turbines.

It is reasonable to assume that within-site scavenging rates and observer search abilities were the same between the 2 turbine types because conditions at each site were very similar and distances between turbine types were small (Howell and Noone 1992). The sampling period of twice each week - 1, 3 day interval and 1, 4 day interval - was an effort to minimize scavenging bias, since previous studies showed that raptor carcass scavenging was very low in the first few days (Howell and Noone 1992, Orloff and Flannery 1992). This was es-

Table 2. Species recovered during mortality searches under KVS-33 and KCS-56 wind turbines, Altamont Pass and Montezuma Hills, California, December 1993 to August 1995, (excludes May - July 1994, since KVS-33's were out of service).

	Number of mortalities per turbine type	
	KVS-33	**KCS-56**
Red-tailed hawk (*Buteo jamaicensis*)	5 (1)[1]	16 (4)
Swainson's hawk (*Buteo swainsoni*)		1
American kestrel (*Falco sparverius*)	2 (4)	10
Prairie falcon (*Falco mexicanus*)		1
Barn owl (*Tyto alba*)	2	3
Great horned owl (*Bubo virginianus*)		1
Burrowing owl (*Athene cunicularia*)		1
Unknown raptor		2
Mallard (*Anas platyrhynchos*)		(1)
Black-crowned night heron (*Nycticorax nycticorax*)		1
Rock dove (*Columba livia*)		7 (1)
European starling (*Sternus vulgaris*)	1	2
Western meadowlark (*Sternella neglecta*)	1	7
Horned lark (*Eremophila alpestris*)		3
Brewers blackbird (*Euphagus cyanocephalus*)		2
Red-winged blackbird (*Agelaius phoeniceus*)		(2)
Mountain bluebird (*Sialia currucoides*)	1	
Unknown passerine	1	2
Hoary bat (*Lasiurus cinereus*)	1	
TOTAL	**15 (5)**	**58 (8)**

[1] Number in parentheses are birds recovered from Montezuma Hills.

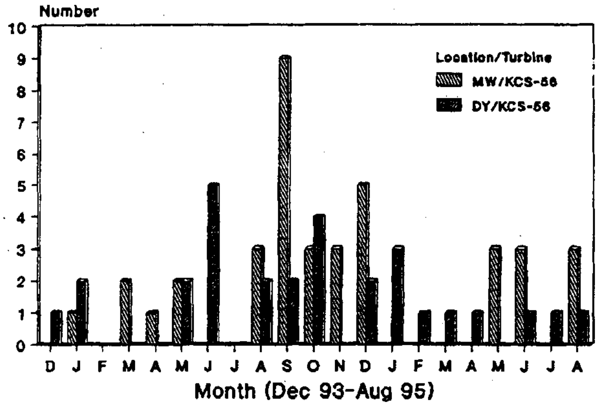

Fig. 2. Monthly bird mortality at KCS-56 wind turbines at Dyer (DY) and Midway (MW), Altamont Pass, California.

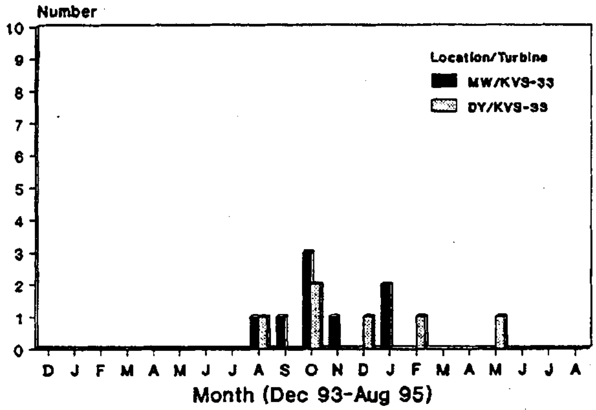

Fig. 3. Monthly bird mortality at KVS-33 wind turbines at Dyer (DY) and Midway (MW), Altamont Pass, California.

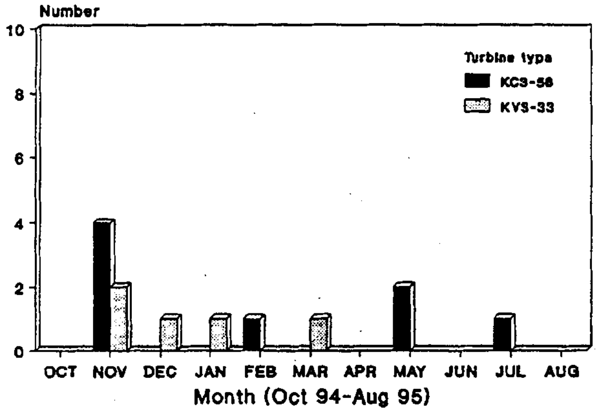

Fig. 4. Monthly bird mortality at KVS-33 and KCS-56 wind turbines at Montezuma Hills, Solano Co., California.

pecially true for larger birds such as red-tailed hawks. Search bias was assumed to be consistent across each sampling site, since the same observers used the same methods at each site. Observers have a higher probability of seeing larger birds in the short grasslands, which were the conditions that predominated during this study (Faanes 1987, Orloff and Flannery 1992).

One of my objectives was to estimate the time of death by examining the bird carcass for insect infestation and decomposition using decomposition phenology to back date to time of death. The purpose of decomposition phenology was to look for correlations between time of death, weather, and wind speeds at the sites. However, I was not permitted to examine the birds which eliminated the possibility of field necropsies. In future studies it will be important to permit researchers to conduct detailed examinations of mortalities.

Although results between turbine types in the Montezuma Hills were not significantly different, there was a difference in proportions of raptor species affected. The mortality ratio for red-tailed hawks was 4:1 for KCS-56 turbines versus KVS-33 turbines. Four American kestrels were found at KVS-33 turbines and none were found at KCS-56 turbines. I think that the small sample size and short duration of the study in that locale accounts for these results and a more accurate ratio would result given more time. Even by adding the Montezuma

Table 3. Bird mortality[1] between KVS-33 and KCS-56 wind turbines, Altamont Pass, California, December 1993 to August 1995 (excludes May - July 1994, since KVS-33's were out of service)

	Turbine Type	
	KVS-3	KCS-56
Turbine numbers	36	129
Mortality numbers		
Dyer	6	22
Midway	8	36
TOTAL	14	58
Species numbers (excludes unknown)	7	12
Raptor numbers	10	34

[1]Excludes an oil soaked American kestrel and 1 red-tailed hawk at a power pole.

Hills data to the Altamont data, the avian mortality ratio between the two turbine types was significantly different from the 1:3.4 ratio predicted by the RSA hypothesis.

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