BIRD MOVEMENTS AND COLLISION MORTALITY AT A LARGE HORIZONTAL AXIS WIND TURBINE

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ABSTRACT

We have been studying bird movements and collision mortality as part of Pacific Gas and Electric Company's performance monitoring program for a 350 foot Boeing Mod-2 wind turbine. This machine is located on the western edge of the Suisun Marsh 4 miles south of Cordelia, Solano County, California.

Raptor and waterfowl movements were surveyed prior to construction. In the fall of 1982 we monitored nocturnal migration over the site for 6 weeks using a portable ceilometer-image intensifier system. Dead bird searches were conducted 5 days a week during this period and once weekly thereafter. Weather data were collected to determine the relationship between bird movements and weather conditions. Studies to date have shown low rates of waterfowl movement and nocturnal passerine migration over the wind turbine site. Raptor use of the area is moderate to high. Migration traffic rates are comparable to those in other parts of the western United States and lower than typical eastern migration rates. Collisions have occurred during all lighting and weather conditions, but collision mortality to date has been insignificant.

INTRODUCTION

In April 1982, Pacific Gas and Electric Company (PG&E) started operation of a 350 ft. Boeing Mod-2 horizontal axis wind turbine, the first large wind turbine built by a private utility in the United States. As part of PG&E's performance appraisal of the machine, the Company was interested in determining whether it would be a hazard to birds in flight. Previous studies of bird collisions have shown that tall, lighted structures can cause significant bird mortality, particularly of migratory passerines (Avery et al. 1980). However, almost all previous studies of passerine migration and bird mortality at tall structures have been done east of the Rockies and have questionable applicability in California. Our studies concentrate on two areas: 1) determining bird movements, including nocturnal passerine migration, in the vicinity of the Solano Wind Turbine, and 2) determining collision mortality.

Ned Gruenhagen conducted the raptor surveys and assisted with the waterfowl surveys. Lin Bowie, Nancy Crane, Marilyn Keller, Craig Seltenrich, Julie Grubb, Mark Jenkins, Dave Longanecker, Rick Williams, and Jim Adams assisted in the passerine migration studies. W. F. Whitlatch provided meteorological data. The operators of the wind turbine, Doug Runkle, Rich Barnes and Rich Baxter provided on-site support and notification of mortalities. The Calistoga Glider Port allowed us to use their airstrip to calibrate equipment. Laraine Chaney prepared the illustrations. The assistance of all is gratefully acknowledged.

STUDY AREA

The Solano Wind Turbine is located about 4 miles south of Cordelia, Solano Co., and 1/2 mile west of the boundary of Suisun Marsh. The turbine is on a northwest-southeast oriented ridge at about 600 ft elevation. The habitat is mostly annual grassland, with scattered woodlands in drainages.

Additional facilities on the site include a 350 ft guyed meteorological tower 600 ft northwest of the wind turbine, a small substation and a 115 kV pole line connecting the substation to an existing transmission line about 1 mile to the northwest. The wind turbine itself has a 300 ft diameter rotor mounted on a 200 ft tower (Fig. 1). It is an upwind machine, and the nacelle rotates in a 360 degree axis to face into the wind. In accordance with Federal Aviation Administration regulations, a high intensity strobe light is mounted on the nacelle and four flashing red lights on the tower. The wind turbine cuts in at a wind speed of 14 mph, reaches rated power output of 2-1/2 megawatts at 27 mph, and cuts out at 60 mph. The rotor revolves at 17-1/2 rpm, reaching a tip speed of 194 mph.

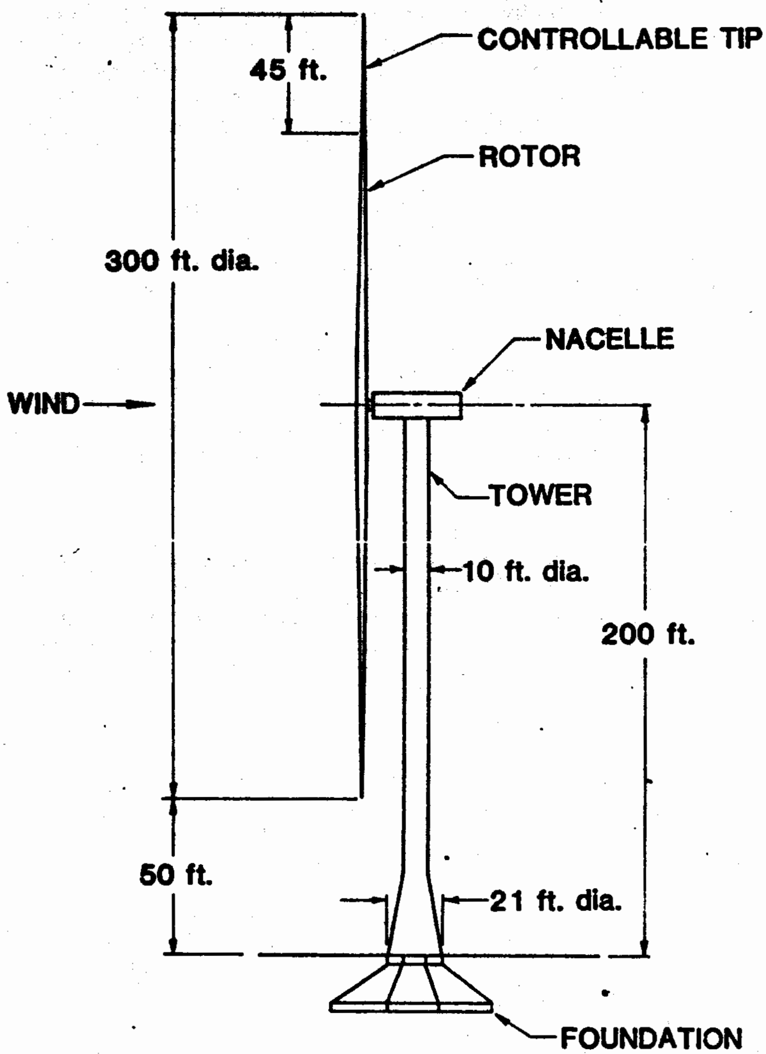

Figure 1. Solano wind turbine.

METHODS

BIRD MOVEMENTS

We surveyed waterfowl movement and raptor use of the airspace in the vicinity of the wind turbine prior to construction. Nocturnal passerine migration was observed for 6 weeks in the fall of 1982, and another 6 week observation period is scheduled for the spring of 1983.

Waterfowl -- Waterfowl movements were surveyed from November 1980, through March 1981. A modification of the scan sample of Altman (1974) was used. Six sample areas, 3 in Suisun Marsh and 3 near the wind turbine site, were observed in rotation from the wind turbine site for 5 minutes each. Species and number of waterfowl in flight were recorded, as well as flight direction, type, and height. In addition, all flights over the wind turbine property were noted, but only those seen during a sample period were used in calculations of traffic rates. Types of flight were characterized as jump flights; short, low flights characteristic of waterfowl approaching the breeding season; local flights from one sample area to an adjacent area; and long distance flights. Only the latter two flight types were used in determining volume and average direction of waterfowl movement.

Observations were made from approximately 2 hours before sunset until shortly after sunset on 12 days for a total of 26 hours of observation. Attempts to observe waterfowl shortly after dawn were frequently stymied by fog. Five hours of morning observations were made. In addition, 13 hours of nighttime observations were made at the wind turbine site using a portable ceilometer-binocular system. The system is identical to that described below, with binoculars replacing the night vision device.

Raptors -- Raptor use of the airspace near the wind turbine site was studied in September and October, 1980. Six weekly observations of about 3 hours each were made at midday. A 360 degree scan sample was used (modified from Altman 1974). Species and various flight characteristics, including altitude and distance from observer were recorded.

Nocturnal Passerines -- Nocturnal passerine migration was studied with a portable ceilometer-image intensifier system (Gauthreaux 1980). Two 100-watt lamps were placed about 30 ft apart and produced overlapping cones of light illuminating the undersides of birds passing overhead. We observed through a Javelin Model 226 night viewing device with a 135 mm lens. Major groups of birds can be distinguished with this system, but species identification is rarely possible.

Two observers alternated viewing and recording for 4 hours each night, starting about an hour after sunset. Observations were made on 25 nights between September 7 and October 15, 1982. Generally, no observations were made on weekends or foggy or rainy nights. Directions were recorded as clockface directions and later converted to true compass directions. Mean nightly direction was determined by vector addition and tested for significance with Rayleigh's test (Batschelet 1965). Hourly migration traffic rate (MTR = birds per mile of front per hour) was estimated by multiplying the number of birds seen by factors correcting for the shape of the sample space and the altitudinal distribution of migratory birds.

We determined the sample space by orienting the ceilometer-image intensifier system horizontally on an airstrip and measuring the maximum distance at which bird skins mounted with the wings extended could be detected. An average-sized passerine can be observed to about 1,000 ft, and the width of the observation field at 1,000 ft is 122.4 ft. A correction factor of two is used to account for the conical shape of the beam. We estimated from various studies (Belrose 1971, Gauthreaux 1971) that half the volume of passerine migration is below 1,000 ft, thus the correction factor for altitudinal distribution of birds is 2. This factor will no doubt be changed as we obtain more information on the actual distribution of migrants in the airspace. Our equation for estimating MTR is:

$$\begin{aligned} MTR &= \text{birds seen/hr} \times 43.2 \text{ fields/mi} \times 2 \times 2 \\ &= \text{birds seen/hr} \times 172.8 \end{aligned}$$

Weather -- At the wind turbine site we collected data on the following weather variables: wind speed and direction at 350 ft, cloud cover, surface temperature, and barometric pressure. Relative humidity and precipitation were taken from the Local Climatological Data Summaries for Sacramento (U.S. National Oceanic and Atmospheric Administration 1982a). Visibility was measured at PG&E's Pittsburg Power Plant, Pittsburg, California, with a forward scatter meter. Information on the passage of frontal systems was provided by PG&E's Meteorology Department and by inspection of Daily Weather Maps (U.S. National Atmospheric and Oceanographic Administration 1982b).

General synoptic weather was defined as 1 of 5 categories, based partially on Moorhouse (1982). These are:

1. Pacific high dominating. This is typical summertime California weather.
2. Low pressure system and associated cold front passing over.
3. Low pressure system to the east. This category is arbitrarily defined as the first 2 nights after the passage of a front.
4. Continental high connecting with the Pacific high. This is a continuation of the events in categories 2 and 3, and occurs as the cold front continues to the east.
5. Tropical low pressure system dominating. This occurs when a tropical storm moves north from the coast of Mexico.

MORTALITY

A one year monitoring study of collision mortality was begun in September, 1982. Searches for dead birds were made 5 days a week from September 7 through October 15, and once a week thereafter. We searched the areas under the wind turbine, the meteorological tower and other site developments, and a 100 ft strip around these. Also, operators of the wind turbine notified us whenever they found dead birds.

RESULTS

BIRD MOVEMENTS

Waterfowl -- Table 1 gives the average rate of waterfowl traffic in each of the 6 sample areas. The average traffic rate is significantly higher over marsh sample areas than over the wind turbine property ($t=15.96$, $p>.01$).

Table 1. Rates of waterfowl movement in 6 sample areas.

Area	Location	Birds/hr
1	Marsh	192.0
2	Wind Turbine Property	0.8
3	Marsh	58.8
4	Wind Turbine Property	0.4
5	Marsh	39.6
6	Wind Turbine Property	20.0*

* Represents a single flight of 50 ducks.

Figure 2 shows flight directions of birds in the 6 sample areas. Duck flights within Suisun Marsh were in a predominantly northwest-southeast direction, corresponding to the local geography of the areas sampled. Waterfowl make 2 types of flights over the wind turbine property. The first type presumably represents feeding flights between Suisun Marsh and the Napa Marshes and is characterized by straight line directions and high altitudes (>500 ft). Two flights of this type were observed. One was a group of 7 northern shovelers (Anas clypeata) and 4 cinnamon teal (Anas cyanoptera) which flew southeast over the property, and the other was a group of 50 unidentified ducks flying toward the northwest but driven in a northerly direction by a 22 mph wind.

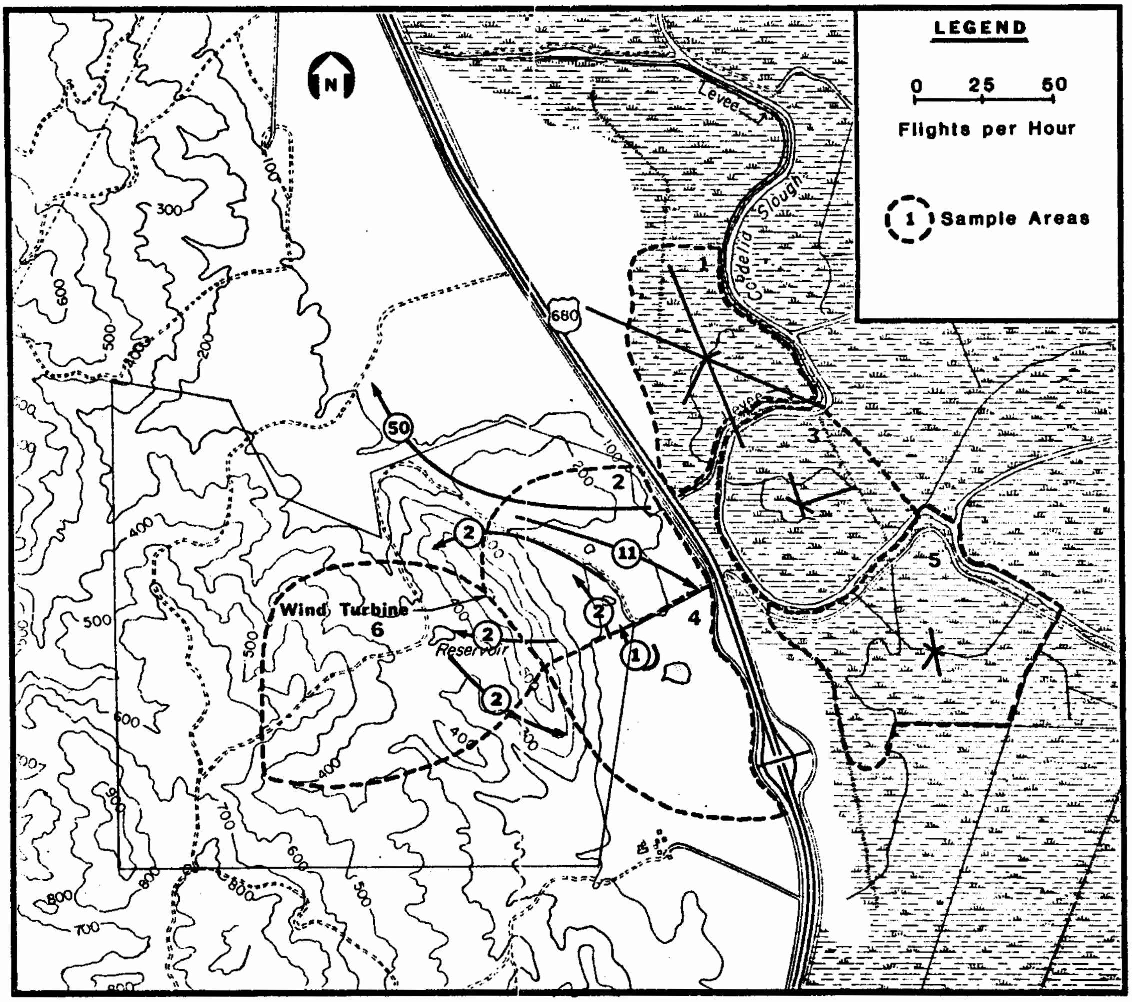

Figure 2. Waterfowl movements in six sample areas. Data for areas 1, 3, and 5 are presented as compass rose diagrams. Directions of the rays correspond to estimated compass headings of birds and lengths of rays indicate relative magnitude of flights in that direction. For areas 2, 4, and 6, actual paths of bird flights observed are shown. These include all flights seen whether during sample periods or not.

Small numbers of dabbling ducks also utilize stock ponds scattered through the Cordelia Hills. In flying between these ponds and Suisun Marsh, ducks fly at low altitudes (<60 ft) and detour around ridges and high ground. No ducks were observed flying over the wind turbine site, although 2 flew over a saddle on the wind turbine ridge. No ducks were seen above the wind turbine site in the 13 hours of nighttime observation made in 1980 and 1981.

Raptors -- A total of 224 raptor sightings were recorded. Common species accounted for most of the observations, with red-tailed hawks (*Buteo jamaicensis*) and kestrels (*Falco sparverius*) being most numerous. A total of 9 species of raptors was observed. The red-tailed hawk was the only species which showed a clear preference for using altitudes corresponding to the height of the wind turbine rotor. Results are reported in more detail elsewhere (Gruenhagen and Byrne 1981).

Nocturnal Passerines -- Average night migration traffic rates (MTR) varied from 0 to 2722 birds/mi of front/hr. The highest hourly rate was 4320. The overall MTR was 890.

The average direction of movement was southeasterly. Directionality was significantly different from random ($p<.05$) on 21 out of 25 nights. Mean direction of fall migration was 125 degrees, with an angular deviation of ± 29 degrees.

Regressions of a square root transformation of average nightly MTR were run against the following weather variables: average nightly wind velocity at 350 ft, partitioned into crosswind and tailwind components against the 125 degree average direction; surface temperature at 7:00 pm; 24 hr change in temperature; barometric pressure at 7:00 pm; 24 hr change in pressure; relative humidity at 7:00 pm; average cloud cover during observation hours; number of hours of reduced visibility at Pittsburg between noon and midnight; and days since the passage of a cold front (to a maximum of 5). A weak correlation exists between MTR and tailwind, barometric pressure, and days since passage of a cold front ($p<.10$). Stronger correlations ($p<.05$) were found with cloud cover and visibility. These latter correlations are strongly influenced by a few points and may be more related to our ability to detect birds than actual migration volume.

General synoptic weather provides a stronger predictor of MTR than individual weather variables (Table 2). Migration is lowest when the area is under the influence of tropical low pressure systems. Low MTRs also prevail when cold fronts are passing over, and increase in the days after the passage of the front. Migration rates are often highest 3-4 days after the passage of a front.

Table 2. Relation of migration traffic rate to general synoptic weather.

Weather Category	Average Migration Traffic Rate birds/mi of front/hr
1	635
2	541
3	898
4	1423
5	232

MORTALITY

As of January 1, 1983, 5 dead birds had been found at the Solano Wind Turbine (Table 3). Only 1 was potentially a passerine migrant; the yellow-rumped warbler. This bird and the meadowlark appear to have collided with the meteorological tower or its guy wires. A coot and a starling were found by an operator early in the afternoon of a very foggy Sunday, a day when hunting occurs in Suisun Marsh. The coot had been shot, but also had a contusion on its head typical of a collision injury. We witnessed the interaction of a kestrel with the wind turbine. This was the only bird known to have been killed while the machine was operating. The kestrel was hovering at about 250 ft above the ground in a 23 mph wind, just upwind of the wind turbine. It drifed downwind and passed through the plane of the rotor twice. Each time the rotor passed in front or behind it the bird was severely buffeted by turbulence, but did not attempt to leave the area. On its third pass through the rotor plane, the kestrel was struck by the rotor and killed.

Table 3. Collision mortality at the Solano Wind Turbine.

Species	Date	Probable Cause of Death
Western Meadowlark (*Sturnella neglecta*)	9/08/82	Collision with guy wire.
American Kestrel (*Falco sparverius*)	9/22/82	Collision with rotor.
Yellow-rumped Warbler (*Dendroica coronata*)	10/05/82	Collision with guy wire or meteorological tower.
American Coot (*Fulica americana*)	11/15/82	Shot; collision with wind turbine.
Europeon Starling (*Sturnis vulgaris*)	11/15/82	Collision with wind turbine.

DISCUSSION

Our preliminary studies of waterfowl movements indicated that waterfowl traffic over the wind turbine site was low and not likely to conflict with wind turbine development. Mortality studies to date have confirmed this, as the only dead waterbird found appeared to have collided with the wind turbine in unusual circumstances. Although raptors were common on the wind turbine site, they were not expected to collide with the wind turbine because of their diurnal habits and keen eyesight. The kestrel killed by the wind turbine was apparently aware of the machine, but was deficient in avoidance behavior. This occurrence is the only known incident of this sort of behavior since the wind turbine began operation, although kestrels commonly perch on the meteorological tower, the nacelle and even the rotor of the wind turbine.

Rates of passerine migration were considerably lower than those found in the Eastern United States, where fall migration rates vary from a few thousand to 16,000 or 17,000 birds/mi of front/hr (Able and Gauthreaux 1975, Lowery and Newman 1966). They are very close to a fall MTR of 439 birds/mi of front/hr recorded in a study in Hayward, California (Moorhouse 1982).

Fall passerine migration in the eastern United States is usually strongly correlated with weather, with highest traffic rates occurring 2 days after the passage of a cold front (Lincoln 1979). Fall migration in California does not usually occur in the "waves" seen in the East. However, we did find a significant relation between general synoptic weather conditions and the volume of migration. Weather conditions during this study were unusual for California in late summer and early fall, as several well differentiated, although weak, cold fronts passed over the area. This suggests that western passerine migrants react to weather cues in a manner similar to eastern birds, but that these cues are often not available.

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