Suggested Practices for Monitoring Bird Populations, Movements and Mortality in Wind Resource Areas

by

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Introduction

This paper emphasizes the needs for minimum standards in formulating study designs for measuring low-altitude bird movements, and conducting dead and injured bird searches within wind resource areas and at specific wind development sites during pre- and post-construction periods. If future studies use standardized protocols, comparisons between data sets will be facilitated, prediction of regional impacts of wind resource development on birds will be possible, and all will be accomplished in a more timely manner.

In order to accurately assess the environmental impact of a wind farm project, pre-construction studies are indispensable. The function of a pre-construction study is to document baseline conditions that can be used to predict (1) changes in the distribution and abundance of avian populations on and near the wind farm, and (2) collisions with wind turbine blades, towers, guy wires, and transmission lines in the project area. These baseline data are also essential for the quantification of the actual impact after development (Jones 1986).

Population Assessment Studies

Sampling Design and Statistical Analysis.—Once the utility or developer decides to conduct a pre-construction assessment of bird populations and movements, a sampling design must be chosen. Green (1979) provided a useful guide to sampling designs and statistical analyses for environmental studies. The design and associated statistical analyses can be set in a "spatial-by-temporal" framework that generates options (Green 1979). He suggests that an optimal impact study design must meet four prerequisites:

- the study must begin before the impact occurs, so before-impact baseline data can be collected to provide a temporal control for post-impact data,
- the type of impact and time and place of occurrence must be known so a sampling design appropriate for the relevant tests of hypotheses can be devised,
- it must be possible to measure all relevant biological and environmental variables in association with the individual samples, and
- an area that will not receive the impact must be available as a spatial control.

The first and last prerequisites dictate that controls in both space and time are necessary. The prerequisites also define a design with at least one time of sampling before impact and at least one after impact, at least two locations differing in degree of impact, and coordinated measurements of environmental and biological variables. The optimal impact study design is referred to as an "areas-by-times factorial design", and the appropriate statistical analysis of the data is an analysis of variance (ANOVA) procedure, with or without covariates.

Study Site Selection.—For a pre-construction study, specific study sites must be selected within and adjacent to the proposed wind farm site. These sites should be located at the same sites where wind resource data are being gathered. During the pre-construction bird study, the meteorological towers installed to measure wind resources can be used as references to estimate the heights of bird flights over the sites in the absence of wind turbines. Dead bird searches can also be made around these towers to assess mortality from the towers and guy wires. In the selection of study sites it is important to remember that two sites, at the very least, should be studied. One or (ideally) more of the sites will serve as control sites once construction activities begin. The control and treatment (wind turbine) sites should be matched as much as possible with regard to physiognomy (the topography and other geophysical characteristics of a land form and its vegetation) and landscape structure (e.g., species composition and species abundance in relation to the sizes, shapes, numbers, types, and configurations of habitats [Turner 1989]). Each study site should be mapped with respect to topographic features and habitats.

Most past and current bird studies at wind turbine sites have not used control areas, so pre- to post-construction changes cannot be attributed positively to construction and operation of the wind farm. At existing wind farms it is possible to establish control areas so future population fluctuations of birds can be compared between treatment and nontreatment sites. However, in the absence of corresponding pre-construction data, this will provide no information about pre-construction vs. post-construction differences in bird populations or habitat use. The optimal design requires pre- and post-construction surveys of both the wind farm and the spatial control site(s).

Recommended Monitoring Techniques.—It is important to use a technique for monitoring bird populations that will provide sufficient information for assessing the impact of the wind development on the avian resource. A monitoring program should provide information on (1) estimated population sizes and trends for various species of birds, (2) estimated demographic parameters for at least some of the populations, and (3) habitat data to link population size and demographic parameters to habitat characteristics. Because of the lack of information on the species at risk at wind farm developments, all species should be monitored. However, emphasis may have to be placed on particular species (e.g., endangered or threatened species) or groups of special concern (e.g., raptors). Many monitoring techniques are available, but the techniques differ depending on the bird species that require monitoring. Several techniques have been used to estimate populations of non-game birds (shorebirds, raptors, songbirds), and these techniques have been treated by several authors and assembled into volumes dealing with survey designs and statistical methods for estimating avian populations (Ralph and Scott 1981; Sauer and Droege 1990; Bibby et al. 1992).

Despite the number and diversity of techniques available for monitoring populations of different species groups, point counts like those used in the Breeding Bird Survey (BBS) can gather data on all species of birds seen and heard during each census stop. The BBS uses 3 minute census stops, although other durations are used in some point count studies (Ralph et al. 1995). BBS counts, known as extensive point counts, are done at a series of points, placed a minimum of 250 m apart, largely on roads or trails over an entire region (Ralph et al. 1993). The procedure for making these point counts can be found in Ralph et al. (1993). It is important to include a brief description of the habitat for each point count (e.g., vegetation types, major layers with some information on heights and densities). This includes information on elevation, slope, aspect of slope [compass direction the observer faces when looking down hill], and presence or absence of water within 50 m of plot center). Additional details can be found in Ralph et al. (1993, 1995). The final paper in Ralph et al. (1995) consists of recommended standards for point counts, as developed during a workshop on point count methodology.

If manpower and financial resources permit, Breeding Bird Censuses (BBC) at study sites are very desirable for gathering data on the number of breeding pairs of birds per unit area. The BBC procedures have been developed primarily for songbirds and not for raptors and other large, sparsely-distributed species. The spot-mapped counts of the BBC determine the mean density of territories for each species per 40 hectares. The plots may range in size from 10 to 20 hectares for passerines, grided in 50 m squares, or they may be larger and grided in 100 m squares. The former is typical for woodland and brush areas while the latter is suggested for open terrain (e.g., grasslands). BBCs should be in relatively homogeneous habitat. It is desirable to have paired plots in different habitats in the windplant and control areas. All birds seen or heard are "mapped" on grided data sheets during a walk-through. A minimum of eight visits (one per morning) and one or two late afternoon or evening visits is recommended. A morning walk-through should begin about sunrise and continue for approximately three to four hours. The data are summarized for each species, and the mean number of territories per 40 hectares is calculated. Additional information on conducting a Breeding Bird Census can be found in Ryder (1986) and in *Audubon Field Notes*, 24:723-726 (1970).

For plot studies during the nonbreeding season, the format recommended for Winter Bird-Population Studies should be followed. Most plots range in size from 6 to 20 hectares (14.8 to 49.4 acres) and the plots are visited 6 to 10 times in midwinter. The totals for each species are averaged and the results are expressed in terms of birds per square kilometer and birds per 40.5 hectares (100 acres). Kolb (1965) provides additional details for conducting Winter Bird-Population Studies.

Statistical procedures for estimating avian population trends can be found in Sauer and Droege (1990). An analysis of variance procedure can be used to compare wind farm and control areas. Additional statistical recommendations can be found in Green (1979).

Monitoring Low-altitude Bird Movements

Comprehensive data on the number of low-altitude flights through the zone of potential collision are necessary if one is to calculate meaningful estimates of the numbers of birds at risk from collisions. The study methods that follow are generic and represent a synthesis of methods used in studies of low-altitude movements of birds over diverse landscapes, in different seasons, and during the day and at night. Methods for conducting assessment studies will vary somewhat depending on circumstances (e.g., different turbine designs and arrangements, different topographies, and different types of birds). Consequently some flexibility in methodological detail is required, but the fundamental design of an assessment study should be as standardized as possible.

Three types of observations should be made during pre- and post-construction monitoring studies of bird flights in a project area: (1) corridor observations, (2) circular scans, and (3) surveillance radar.

Schedule of Observations.—Initially full day and partial day visual observations extending from one-half hour before sunrise to one-half hour after sunset should be made for each study area. The frequency and duration of watches will depend on whether they are corridor or circular scan observations (see below). Other observation times should be scheduled so that flight counts are made during inclement weather and during darkness. (A few resident species may be active at night, and much migration occurs at night.) Twilight observations are feasible if observers position themselves so that birds are silhouetted against the horizon, and observations with 7 x 50 binoculars are also possible on nights with bright moonlight (Lee and Meyer 1977). However, image intensifiers and forward looking infrared devices are recommended for twilight and nighttime observations. Once the temporal patterns of daily movements have been worked out, visual sampling can be concentrated in periods of greatest activity.

Visual Corridor Observations.—Visual observation (often aided with binoculars or spotting scopes) is the most common type of monitoring in studies of low-flying birds, because no other method enables the observer(s) to identify readily and to count accurately the birds in a flight. Knowledge of the kinds and total numbers of birds and when and where they cross through the proposed or existing wind farm is essential for the times when dead bird counts are conducted. Data from these observations provide a basis for interpreting mortality levels obtained from dead bird counts and provide information on the effects of various turbine designs and placements on bird flight behavior under different environmental conditions. Many studies have used periodic and systematic observations of bird flights across an area or near existing man-made objects such as a string of wind turbines, broadcast towers and transmission lines, e.g., Rogers et al. (1977), Avery et al. (1977), McCrary et al. (1981, 1983), Gauthreaux (1985), Hugie et al. (1992). These studies have used fundamentally similar visual observation techniques. Based on the information in those studies, the following procedures are recommended during visual observations of bird flights at planned and existing wind resource development sites.

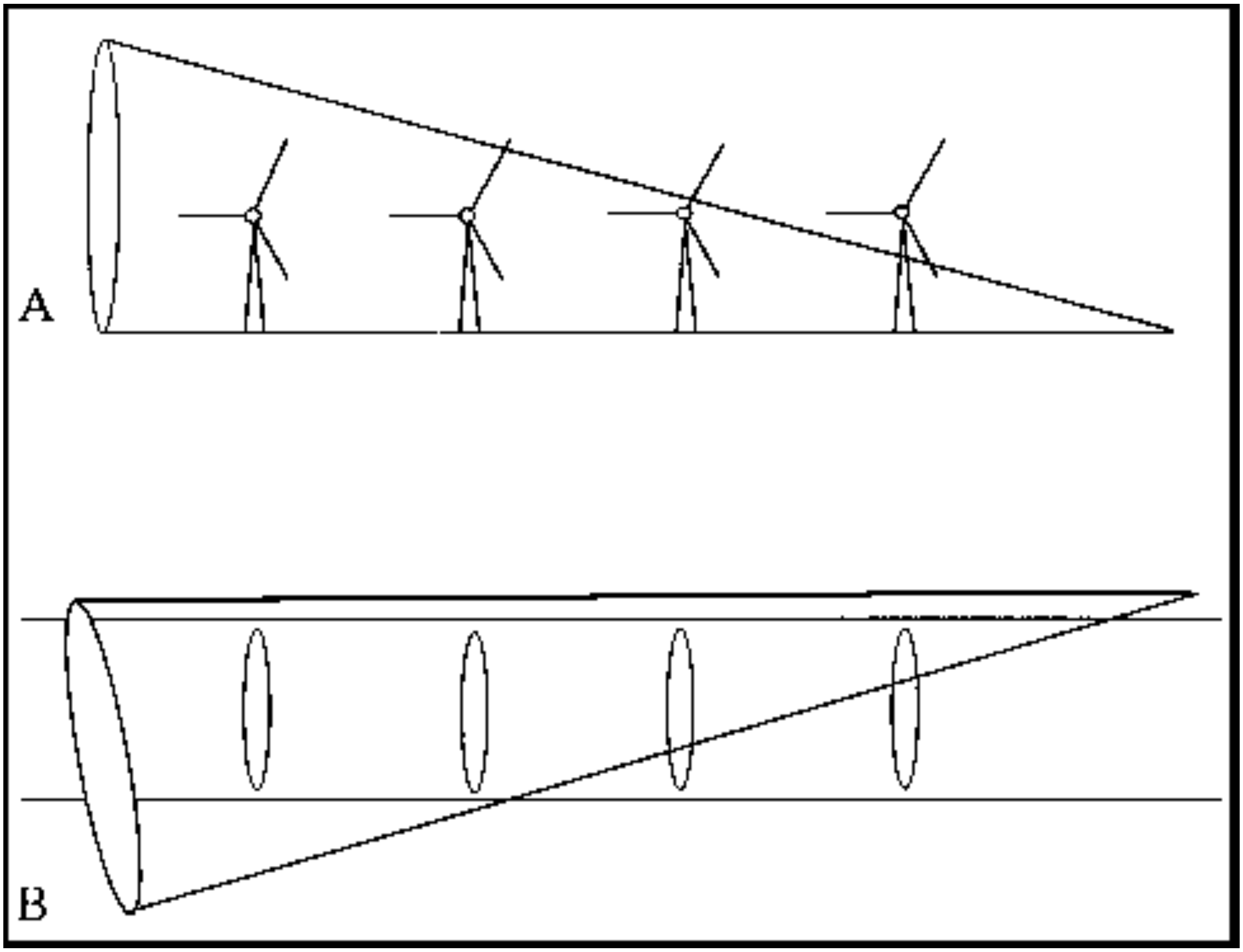

Figure 1. Cones of observation at a string of wind turbines. ***(A)*** The vertical sampling area increases as a function of distance. This area should be calculated in order to determine accurately the number of bird crossings per area sampled. ***(B)*** If the observer is positioned off the line of turbines, then distance to bird can be determined more accurately. Marine surveillance radar can also be used to determine distance to bird.

All observations of bird flights through a corridor where wind turbines will be or are located should last 30 minutes. An observer should be positioned slightly off the corridor line so that the distance to the birds crossing the corridor can be determined. Observers should station themselves so that their presence will not affect the flight behavior of the birds in the area and so that the observation point allows a view of the greatest linear distance for which birds can be readily observed (Fig. 1).

Observers should endeavor to record each bird crossing the corridor of observation. This can be accomplished by scanning the corridor with binoculars or by directing a telescope down the corridor and watching continuously. The optical equipment used to make observations should also be noted on the data sheet, e.g., 7 x 50 binoculars, 20 x 60 telescope. Ten power binoculars are ideal for identifying birds at a distance and provide good depth of field. Spotting scopes (20x, 30x) are useful for observing birds at greater distances, but have a limited depth and breadth of field, and have less maneuverability because they must be mounted on a tripod to steady the image. Binoculars having objective lenses with diameters in mm greater than 5 times the magnification power (e.g., 7 x 50) provide bright images and are excellent for twilight observations. The cone of observation for each optical device should be determined because this information will be useful in calculating the sampling area and rates of passage (Fig. 1). Observers should use blinds or vehicles as observation stations. When large expanses of water are involved, observations can be made from an anchored boat. Single observers should use a tape recorder so that monitoring can be continuous when flights are frequent and contain many birds. Data can be transcribed from tape to data sheets after observation periods end. If two observers are involved, they can be separated with one person at each end of a string of turbines and can communicate via two-way radio. One observer should record all of the data. The observers can alternate assignments between watches. Two observers can also be positioned side-by-side with one observer monitoring movements within a few hundred meters of the station and the other observer monitoring movements at greater distances (Gauthreaux 1991). Each observer should be trained to record data the same way and checked and evaluated by the project leader on a regular basis. The maximum distance that can be monitored without loss of information will depend on visibility conditions (heat distortion, haze) and is about a mile (1.6 km) in warm, high humidity conditions and is greater in cool, dry conditions.

An example of a data sheet for bird movement observations can be found in Appendix 1. This data sheet can be used for three different types of observations: (1) corridor, (2) circular scan, and (3) marine surveillance radar. The information that should be encoded in each column of the data sheet can be found in Appendix Table 1. At the beginning of a watch (or the resumption of a disrupted watch) the observer(s) should fill out columns 1-12, 14-25, 45-46 and 47 when appropriate; the rest of the columns should be left blank. A check in column 12 indicates the start of a watch with a duration of 30 minutes. For each bird flight across the corridor a new line of data should be added to the data form. Most of the information added to the data sheet at the beginning of the watch will not change during the watch so there is no need to add this information for each bird crossing—simply draw lines to indicate that the information is unchanged. When a bird flight *crosses* the corridor, the pertinent information should be placed in columns 20-43. AOU numbers (columns 30-33) can be added at a later time if needed for data analysis. Corridor observations should last for 30 minutes, and at the end of a watch (or time out) the observer should indicate a stop time by checking column 13 and filling in columns 20-23. If no birds were observed, only the start time and finish time lines should appear on the data sheet.

The altitudes of birds passing through the corridor will have to be estimated. This is most difficult during pre-construction studies when turbines of known height are lacking. However, it is often possible to use meteorological towers or other objects of known height for reference. For more accurate altitudinal measurements a clinometer can be used to measure the elevation angle of the birds as they cross the corridor. Elevation angles and exact or estimated distances from the observer are required to compute the altitude of flight. Marine surveillance radar can be used to measure exact distances (see below).

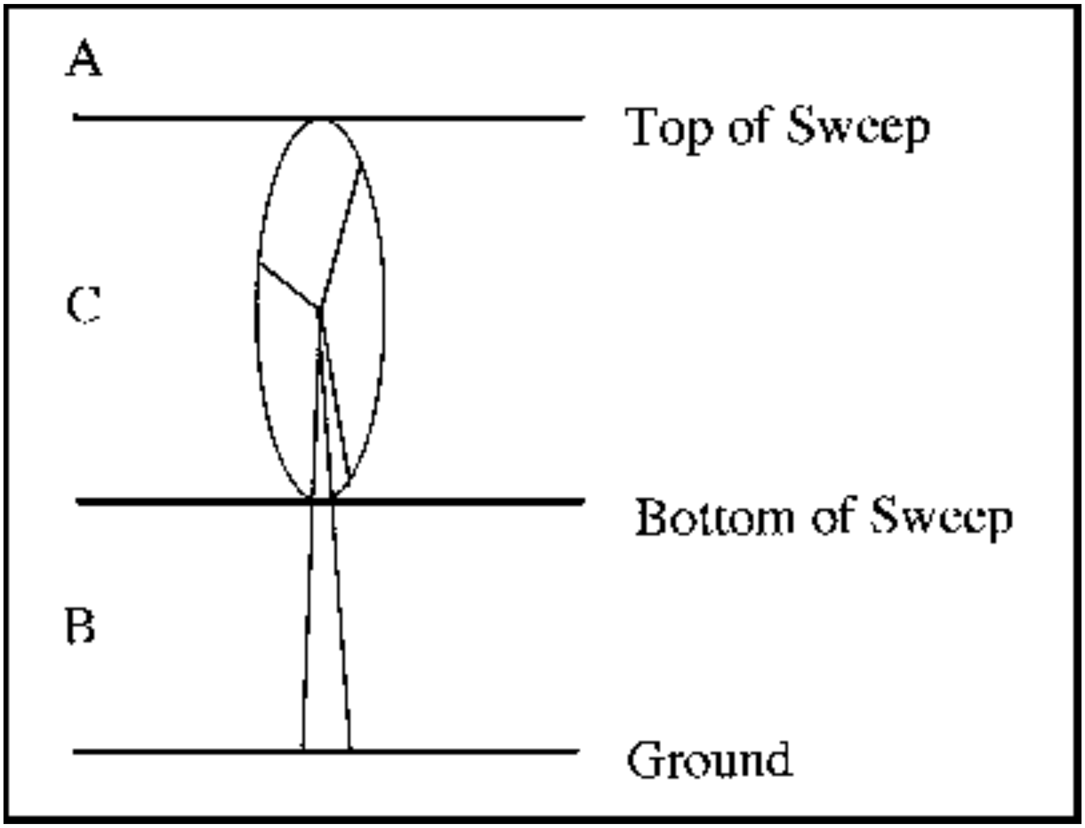

Figure 2. Altitudinal zones of bird flight relative to the wind turbine. **A**=above turbine. **C**=zone of potential turbine collision; also "zone of risk". **B**=below turbine, but in zone of potential collision with supporting tower and guylines.

During post-construction bird studies, the flight altitudes of the birds can be coded with reference to the turbines (Fig. 2), but information on heights of flights (in meters) will be necessary for across-study comparisons. It is essential that the height categories in Figure 1 be measured in meters for the different turbine designs studied. Because of the differences in turbine designs and heights, details of the turbines such as configuration, size, rotational speed, tower design (lattice, solid, guy lines), and size of development (wind farm) should be noted for each observation location. This information should be the same for all observations at a particular study site.

Visual Circular Scans.—It is important to collect information on bird movements and activity in the general vicinity of the proposed or existing wind farm, not just along the corridor(s) where turbines will be placed or where string(s) already exist. Therefore, circular (360°) visual scans should be made. All circular scan observations should last for 8 minutes with 2 min devoted to scanning each of four sectors: NE, SE, SW, NW. The data form for corridor observations can be used for circular scans. At the beginning of a watch information should be added on the data sheet in columns 1-12, 14-25, 45-46 and possibly 47, and the remaining blanks left uncoded. The entry in column 12 will signify the beginning of the watch. The observer, using a compass, should start at N and slowly turn clockwise while scanning the sky up and down. When bird(s) are detected, the information in columns 20-44 should be recorded onto the datasheet or audiotape. At the very least the data should include information on species, number of birds (if a flock is observed), distance, and direction to bird(s). Altitudes of birds seen during this type of watch may be difficult to estimate, but if it is possible to indicate altitude above ground (column 40) this information could prove to be valuable. The addition of column 44 in the circular scan protocol (not used in corridor observations) permits coding the direction of the bird(s) from the observer:

Col. (44) Direction to Bird(s):

1-N	(337.5-022.5°)	5-S	(157.5-202.5°)
2-NE	(022.5-067.5°)	6-SW	(202.5-247.5°)
3-E	(067.5-112.5°)	7-W	(247.5-292.5°)
4-SE	(112.5-157.5°)	8-NW	(292.5-337.5°)

Marine Radar Observations.—Radar studies of bird movements are recommended during pre- and post-construction phases of wind farm development. They can rapidly provide information on low-altitude movements of birds in the project area. Moreover, radar surveillance is essential for monitoring low-altitude movements after dark during spring and fall migration. Small marine surveillance radars can provide useful information on the movements of birds within a range of a few kilometers, the units are relatively inexpensive, and they can be mounted on a small truck or van and powered by a small 500 W gasoline generator (e.g., Williams et al. 1972; Gauthreaux 1981, 1884, 1985; McCrary et al. 1981; Cooper et al. 1991). Small marine radars (10 kW peak power) can detect individual small birds (swallows) out to 1.2 km (0.75 mi.) and single larger birds (e.g., Ring-billed Gull, *Larus delawarensis*) out to 2.4 km (1.5 mi). Marine radars can detect birds crossing a corridor more readily than can observers with binoculars (Korschgen et al. 1984), and radar surveillance allows investigators to study nighttime, dusk, and dawn bird movements when visual observations are unreliable or impossible. Marine radar also operates well in fog when typical visual techniques are ineffective, but cannot detect birds in widespread rainfall.

Modern marine radars cost about $1,000 per kW of transmitter peak power; 10 kW marine radars cost about $10,000 US. They can be obtained with digital color displays that show echoes of differing reflectivities in different colors, and they have the capability of on screen plotting and an alarm function. On screen plotting allows the display of previous echo positions for a specified time period such that the tracks of the echoes are displayed on the radar screen. This facilitates gathering information on direction and speed of flight for each bird target. The alarm function is of great benefit when the amount of movement is very low. This function sounds a beep when an echo enters a user-defined zone on the radar screen. The color display makes observing bird movements easier, but a monochrome display provides better resolution, is easier to video tape, and is less expensive. A marine radar for monitoring low-altitude flights of birds should have the following specifications:

- 3 cm (X-band) wavelength
- 10 to 25 kW transmitter power (peak power)
- 1.22 m (4 ft) antenna for 10 kW and 2.4 m (8 ft) antenna for 25 kW
- high resolution monochrome radar display
- echo trail to assess target's speed and direction
- audio-visual alert for targets in guard zone

On an X-band radar, a standard "slotted waveguide" antenna with a 1.22 m (4 ft) length has a nominal 25° vertical beamwidth and a 1.9° horizontal beamwidth. A 2.4 m (8 ft) antenna has 20° x 0.95° beamwidths.

The on screen plotting (echo trail) function displays echoes from targets detected during every antenna rotation within a 15 s, 30 s, or 1, 3 or 6 min period before screen refresh, or continuously. Thus it is possible to see the entire flight paths of birds as they pass through the area of radar surveillance. The radar display can be videotaped so that a single observer can make visual observations while the radar is simultaneously gathering information on bird movements in the area. Once the display has been photographed or briefly videotaped, the screen can be cleared for another cycle of on-screen plotting. The optimum interval will depend on the intensity of bird movement. The guard zone function will trigger an alarm when a target penetrates a perimeter delineated on the radar screen. These features, available on various "off the shelf" units, enhance the radar operator's ability to obtain information on movements of birds.

Special modifications to the antenna and development of a ground clutter reduction screen make bird detection near the radar easier (Cooper et al. 1991). A marine radar can be powered by a gasoline generator, by a series of fully charged deep-cycle marine batteries, or by 110/220 VAC, 50-60 Hz with a rectifier. Helpful instructions for using marine radars for monitoring bird movements can be found in Williams (1984).

For observations with a marine surveillance radar, the radar should be tuned correctly and all clutter suppression circuitry set in the off condition. The guard zone feature of the radar should cover areas without permanent ground echoes. If permanent echoes are within the guard zone, the alarm will sound every time the antenna rotates. Once the guard zone(s) are defined using the setup procedures, the range and azimuth settings of the guard zone(s) should be the same for every radar watch. The azimuth and range settings for the guard zone should be recorded in a notebook and photographed on the radar screen if possible. In most instances the range of the radar should be set to 0.75 nautical miles. The data sheet for corridor and circular scan visual observations can also be used for the radar data (see Appendix 1, including Appendix Tables 1 and 2).

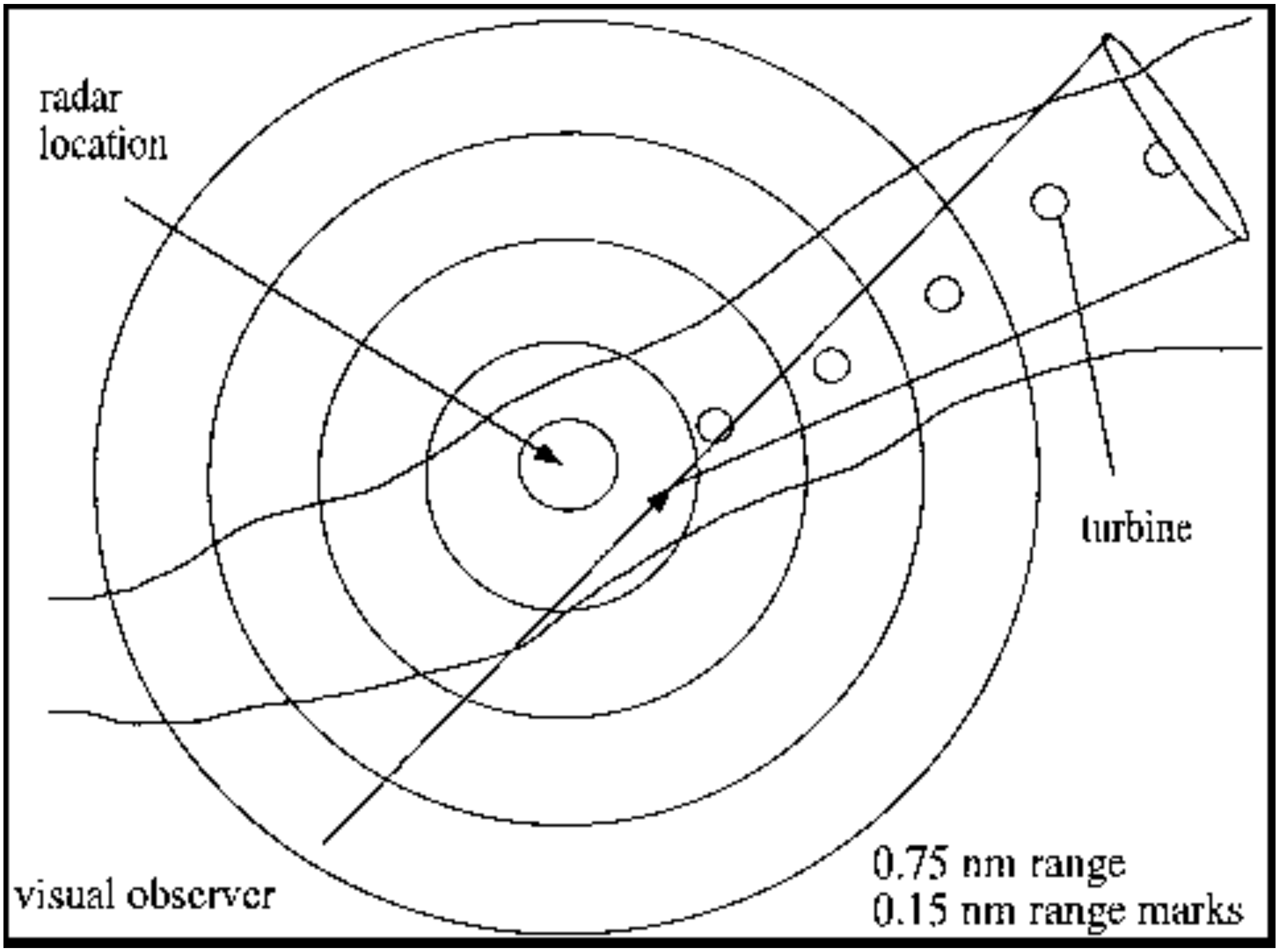

Figure 3. Radar and visual surveillance at a wind turbine site.

The positioning of a marine surveillance radar will determine the amount of ground clutter detected. Birds flying over ground clutter will not be visible on the radar screen, so it is important to position the radar unit in such a way as to minimize extensive ground return. Because wind turbines are often located on ridgelines, it is possible to monitor bird movements across the ridgelines by detecting them to either side of the ridge (Fig. 3). Birds moving across the screen will be easily detected as light echoes on a dark background. These echoes will "disappear" as they move over the ground clutter representing the ridge on the screen, and will reappear once they leave the area of ground clutter. Direct visual observations during daytime radar surveillance are strongly recommended. This is the only way to accurately identify the types of birds responsible for the echoes on radar.

Night Vision Device (NVD) Observations.—Because it is necessary to assess the amount of bird movement during twilight and after dark, some kind of night vision device (NVD) is required. Image intensifiers are readily available and the third generation devices offer increased resolution and sensitivity in very dark conditions. Technologically advanced forward-looking infrared (FLIR) devices have also been used for nocturnal observations of birds. The high cost of FLIRs may make them less attractive for an assessment study, but their ability to detect birds in total darkness is of value. The availability and capabilities of FLIR units are increasing, and FLIR may become a method of choice in the future.

Image Intensifier Observations: Second and third generation image intensifiers can be used to observe low-altitude bird flights after dark. Although results are best when an observer is viewing directly through the scope, most night vision systems can be fitted with video, 16-mm movie, and 35-mm single-lens reflex cameras. Slow shutter speeds and the need for film development make the 16 mm and 35 mm cameras obsolete. The video camera/image intensifier combination provides the best method for monitoring and documenting night movements of birds near the ground when the observer cannot monitor directly through the night vision scope. Observations are made directly from the high resolution video monitor and a record can be videotaped.

A NVD with a 135 mm or 300 mm lens is best for most observations. A NVD works best when birds can be seen as dark forms against a lighter background, but an infrared spotlight (200,000 candle power) can be used to illuminate birds and make them quite visible against a dark background without affecting their behavior (as can happen if a conventional spotlight is used). During observations, the NVD is placed in a fixed position at approximately a 15° angle to the corridor or string of turbines. The height band that can be sampled will be restricted by the narrow field of view, and will change as a function of distance. Near the observer only a very small altitudinal sample is possible, but at greater distances the range of heights that can be sampled increases. Because the field of view will vary depending on the type of NVD and the attached lens, one should measure the field of view at some known distance so the sampling space can be calculated. Observers should record the same types of data as are gathered during daylight observations.

Night vision devices must be used in an enclosed shelter during adverse weather such as rain, and in cold, wet weather the lens has a tendency to fog. A battery powered heating strip around the barrel of the scope will usually eliminate this problem. Some larger image intensifiers (e.g., VARO Model AN/TVS-5) weigh 3 kg (6.6 lb) and require a tripod, limiting mobility while viewing and the area sampled. The greatest drawback is that NVDs cannot be used in fog. Because NVDs are extremely sensitive to lights, a NVD should be placed such that marker lights will not be in the NVD's field of view. Additional details concerning image intensifier observations of nocturnal bird movements can be found in Gauthreaux (1985), McCrary et al. (1988), and Hartman et al. (1992).

Forward Looking Infra-red (FLIR) Devices: One of the most recent technological advances that may assist researchers in monitoring the movements of birds at night is thermal imaging. Unlike image intensifiers, which require some very low level of light to function, FLIR devices detect the thermal (infra-red) emissions of the targets and electro-optically generate detailed visual images on the screen of a video monitor. Because FLIRs can operate in the absence of any ambient light, they are ideally suited to monitoring bird movements at night, but the cost of a high quality thermal imaging unit

($75,000-$125,000 US) is considerably higher than the cost of a high quality image intensifier ($4,000-$10,000 US). Additional information about using FLIR devices to monitor bird movements at night can be found in Winkelman (1992, 1994), Cooper and Day (1992), and Liechti et al. (1995).

Dead Bird Searches

Search Area.—The search area around a wind turbine should be circular and the minimum radius determined by the height of the turbine. Taller turbines will require greater search radii. When the turbines are in a string, it may be most efficient to search a strip along both sides of the string and around the end turbines. Winkelman (1989) searched for dead birds within 60 m on both sides of a row of 25 mid-sized wind turbines (30 m tower height, rotor diameter 25 m). The distance between wind turbines was 125 m and the total length of the row of turbines was 3 km. In another study, Winkelman (1992a) searched for dead birds within 50 m around each of 18 wind turbines (tower height 35 m, rotor diameter 30 m). Most victims were found in the area behind the rotor or on the right front side of it. The search around each turbine took approximately 45 minutes.

Searches encompassing an area within 70 m (230 ft) from a turbine or meteorological tower should be sufficient for locating dead birds. A spiraling outward search path is most efficient, but a tight zigzag search pattern is also effective, particularly when turbines are in a string and less than 140 m apart. Depending on wind conditions, the height of the turbine, and the slope of the terrain (bigger radius if steep downslope), search areas may require enlargement. It would be useful if some post-construction studies were able to quantify the distribution of dead birds around turbines of different heights. When the positions of all dead birds are plotted one can assess if the area searched is adequate (see Hartman et al. 1992 for an example from a transmission line study). If the area is adequate, there will be very few or no dead birds near the outer edges of the areas searched.

At wind farms, searches along transmission lines should cover the entire right-of-way and the width of the search area should be chosen with reference to the height of the power line (James and Haak 1979; Ravel and Tombal 1991). The height of the line is, of course, dependent on the voltage of the line and local topography. Searchers should use a zigzag course in searching so the area is covered systematically. The following widths are suggested based on previous studies:

- out to 50 m (164 ft) from outer conductor on either side of a 500 kV transmission line
- out to 45 m (147.6 ft) for a 230 kV line
- out to 20 m (65.6 ft) for a 115 kV line.

Timing of Dead Bird Searches.—Although dead bird searches are time consuming, it is essential that searches be conducted daily, and if at all possible, twice daily—at first light in the morning and just before dark in the late afternoon (James and Haak 1979). In this way the collision victims can be categorized as colliding during the day or the night. In the Meyer (1978) study, searches were conducted daily and as early as possible, light permitting. This was done to minimize scavenger removal. Beaulaurier (1981) conducted searches before afternoon flight observations and again the next day after morning observations. This schedule enabled the estimation of numbers of birds killed and injured at night, between observation periods. Winkelman (1992a) searched a wind park in the Netherlands once or twice a week in spring and on most week-days during autumn migration. Orloff and Flannery (1992) searched each sample site in their study for five weeks: twice a week in spring and once a week in five remaining seasons of their study. Although they found little evidence of scavenger removal, scavenging rates are known to be high in some areas, especially for small birds. Therefore, searches need to be done at more frequent intervals—ideally twice daily.

Data Records for Collision Victims.—A map showing the locations of all the turbines searched should be made. For each bird found the following information should be tabulated:

- nearest turbine identification number; bearing and distance from that turbine
- species
- sex
- age (adult or juvenile) if possible
- approximate time of death
- physical condition (including broken bones, lacerations, abrasions, blood, discolorations, gun shot wounds, decomposition, feeding damage by scavengers)
- probable cause of death
- necropsy (if possible)

In some studies all birds found were photographed and a waterproof tag with an identification number was attached to each bird's leg. A marker indicated the position of each dead bird that was left in place so that rates of scavenger damage and removal and of decomposition could be measured. Feather spots were recorded and listed separately from birds. When a dead bird is scavenged by a raptor or coyote, a rather tight cluster of feathers (feather spots) remains. For each feather spot the following information should be noted:

- date
- species or group
- location

Both dead birds and feather spots can be used in estimating the amount of collision mortality in relation to the number of flyovers. In certain cases, dead birds may be found without firm evidence of collision mortality; other factors may have been responsible for the mortality. In such instances some additional laboratory analysis (e.g., toxicological analysis) may be advised. Fluoroscopy has been used to detect lead pellets in dead birds and gizzards have been examined to see if they contained lead pellets (Anderson 1978). Because some mortality at wind farms is not related to collisions or electrocution, a necropsy may be necessary to determine the probable cause of death. A veterinarian specializing in birds can be consulted. A state or federal wildlife agent will know who to contact for this service.

A data form for dead bird searches is given in Appendix 1 (see also Appendix Table 3).

Biases in Dead and Injured Bird Searches.—Three biases cause underestimation of the number of dead birds: search bias, removal bias, and crippling bias. The objective is to develop correction factors for biases, so that the number of actual collisions is not underestimated. In addition, some habitats (e.g. water) may be unsearchable, resulting in the need for a fourth correction factor for "habitat bias". In some wind turbine/bird mortality studies, efforts have been undertaken to measure these four biases (see Winkelman 1989, 1992a).

Search Bias: This bias represents the fact that not all dead birds present are detected during searches, given the effects of terrain, vegetation, and the searcher's ability and experience on detectability. To measure this bias an assistant should randomly place dead birds in the search area. The normal dead bird search procedure should then be followed by another investigator (the individual being evaluated). The percentage of "planted" birds not found determines the search bias:

$$SB = (TDBF/PBF) - TDBF,$$

where SB = search bias, TDBF = total dead birds and feather spots found in the search area during the study, excluding those found during the initial search, and PBF = proportion of planted birds found during the plant/recovery study. A separate estimate of dead birds for each species collected should be calculated, because the calculated search bias varies as a function of the conspicuousness of the bird and because scavenger removal and habitat biases often vary over time and location. In Winkelman's (1992a) study of 18 wind turbines, 18, 21 and 86 small birds were placed around the turbines and 39, 52 and 40 per cent were found in three different years. For large birds, 9 and 12 individuals were placed around turbines on the wind farm in two different years, and 89 and 75 per cent were recovered. This illustrates that correction factors for small and large birds must be calculated separately. The same is true for different habitats in the wind farm.

Removal Bias: This bias occurs when scavengers remove dead birds prior to a search. To measure removal bias, a number of dead birds is placed throughout the search area. Each day for a week, the condition of these birds should be monitored. Removal bias is the percentage of birds missing with no trace remaining and is expressed by the following formula:

$$RB = (TDBF + SB)/PNR - (TDBF + SB),$$

where RB = removal bias by scavengers and PNR = proportion of "planted" birds not removed by scavengers. Ravel and Tombal (1991) and others have noted that removal bias varies with the size of the birds such that smaller birds disappear more frequently and more quickly. This pattern was also noted by Brown and Drewien (1995). They found that crane carcasses sometimes remained for as much as a year after death and no crane carcasses were removed by scavengers during the removal studies. In contrast, passerines frequently disappeared overnight. Consequently the effects of size must be included in calculations of removal bias and must be considered when planning a removal bias study.

Habitat Bias: This bias occurs when some portions of a study area may not be searchable because of water or dense vegetation. Investigators can estimate the percentage of unsearchable habitat from on-ground surveys using the following formula:

$$HB = (TDBF + SB + RB)/PS - (TDBF + SB + RB),$$

where HB = habitat bias and PS = proportion of area that is searchable. Habitat bias estimates should not be used as a replacement for field work. Researchers should not extrapolate beyond the area sampled, because conditions could cause the rate of collision to differ in different habitats. Habitat bias estimates should be used only in very limited situations where unsearchable habitat is finely interspersed with searchable habitat and where the researchers can demonstrate that the numbers of dead birds occurring per unit area in searchable and unsearchable habitats are similar.

Crippling Bias: When some birds fall outside of the search area or fall in the search area, move out of the area, and subsequently die, they are missed by searchers. This miss factor is called crippling bias. Estimates need to be calculated for wind turbines of different designs. The adjustment for crippled birds can be calculated from the following formula:

$$CB = (TDBF+SB+RB+HB)/PBK - (TDBF+SB+RB+HB)$$

where CB = crippling bias; PBK = proportion of observed collisions falling within search area.

Crippling bias estimates are extremely difficult to obtain because of the effort required to witness an adequate sample of injury-causing collisions. Consequently, crippling bias is the least likely factor to be calculated in a study. However, the application of estimates from other studies may be inappropriate and may be very misleading. Once again, the size of the bird may make a significant difference because of flight dynamics considerations. Smaller birds might have a higher crippling bias than large birds. This possibility needs to be examined in future assessments of bird collisions with wind turbines and transmission lines. Winkelman (1992a) reported that 17 per cent of the 76 collision victims she found in a study of 18 wind turbines during six spring and four autumn periods were wounded but still alive.

Estimate of Total Collisions (ETC).—The estimate of total collisions (ETC) equals the total dead birds and feather spots found plus each of the estimates of the biases such that

$$ETC = TDBF + SB + RB + HB + CB.$$

Although this formula includes HB and CB, estimates of these biases should be included only if credible numbers have been calculated on-site. The shortcomings of estimating HB and CB have been addressed above.

Collision Rate Estimate (CRE).—An important statistic in studies of bird collisions with man-made structures such as wind turbines and transmission lines is the collision rate estimate—the percentage of birds that collide with the structure relative to the number that pass the structure in the zone of risk. This estimate should be calculated for different species groups (e.g., raptors, songbirds), and must be calculated using the estimated total collisions (ETC) and the estimated total flights (TF) for the study period, multiplied by 100 to convert to a percentage:

$$CRE = (ETC/TF) \times 100.$$

The method of computation of total flights (TF) is very important because there is tremendous variance in the way these data are collected. In general, only crossings at altitudes where collisions seem possible should be included. Winkelman (1992b) has emphasized that only those birds attempting to cross through the rotor of a turbine are at risk. She noted that, during daylight, 14 birds were observed trying to cross through the rotors and one of these (7%) collided. During twilight and darkness, 51 birds tried to cross the rotors and 14 (28%) collided. Because there are no hard and fast rules for defining at-risk crossings, and definitions of the zone of probable collision may vary, it should be standard practice to compute collision rate estimates for birds crossing within a narrowly defined altitudinal band (at-risk crossing) as well as for birds crossing within the broadly defined altitudinal band (all crossings).

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Discussion

Appropriate Degree of Standardization.—Some attendees suggested that the most appropriate field sampling protocols will differ between projects depending on specific project objectives and local circumstances. They suggested that study objectives need to be defined before the list of variables to be recorded is determined. They further suggested that, for some studies, some of the variables on the suggested data sheets (see Appendix) will be unnecessary. Some attendees questioned whether one observer could record all the variables on the suggested data form, and suggested that investigators should be advised to focus on the variables actually needed in their particular studies.

Other attendees indicated that a considerable degree of standardization across studies is desirable to make the results from different locations and different investigators directly comparable. Dr. Gauthreaux indicated that all variables on the "Bird Movement Observation Form" (see Appendix) can be recorded by a single observer. However, some attendees recommended that only a selected subset of priority variables should be recorded so the field observers can focus on gathering a large sample of precise data.

Dr. Gauthreaux indicated that his main concern was that any study include effective measurements of all key variables. He emphasized that data on numbers of birds flying through the wind farm are needed to interpret results from dead bird searches.

There was agreement that some refinement of any "standard" procedures will be necessary in each study. However, further discussion is needed concerning the most appropriate balance between standardization across projects vs. adaptation of procedures to individual objectives and circumstances.

Study Design.—There were several questions concerning the most appropriate temporal and spatial layout of sampling by the various methods described in the White Paper. What are the independent units of observation? Dr. Gauthreaux indicated that the units of observation are "birds seen per half-hour watch" during a corridor scan, and "birds seen per 5-min watch" during a circular scan. He suggested that there should be one scan of each type per hour. It should be recognized, however, that sequential scans 1 h apart might not be statistically independent of one another, at least for resident birds. The specific locations where the observation methods would be applied need to be determined taking local circumstances into account. It was agreed that these design issues need to be discussed in more detail during refinement of protocols.

***Zone of Risk*.**—Several attendees commented about difficulties and complications in defining the potential "zone of risk" in which bird flights are counted. Questions included

- whether and how to include allowance for any "downwash" effect below the area swept by the rotor,
- how to count multiple crossings of the rotor plane, e.g. by a foraging raptor, and
- how to apply the "zone of risk" concept to situations involving multiple strings of turbines, or an array of turbines.

Dr. Gauthreaux recommended counting birds in altitudinal zones where birds are at risk either of colliding with turbine blades or of suffering downwash. When multiple crossings by a single bird are observed, the number of crossings should be noted. One can record the heights of bird movements with reference to the "zone of risk" notwithstanding the number of turbines creating the zone of risk.

***Corrections for Bias in Dead Bird Searches*.**—Several attendees noted that different studies have used or are using different procedures, including different intervals between searches and native vs. non-native "planted" birds. Different investigators have given varying degrees of emphasis to the development of bias corrections. It was recognized that procedures for assessing search, removal and other biases need further discussion, and that a comprehensive assessment would be complex and require much effort.

Appendix: Codes and Explanations for Data Sheets

APPENDIX TABLE 1. Codes and explanations for visual observations data sheet.

Column Number	Description
(1)	Location—Use the same digit code (e.g., "1") to indicate the same observation segment.
(2)	Type of Watch—Corridor = 1; Circular Scan = 2; Radar Surveillance = 3.
(3)	Wind Direction: 1-N, 2-NE, 3-E, 4-SE, 5-S, 6-SW, 7-W, 8-NW
(4-5)	Wind Speed: mph (can get data from meteorological towers)
(6)	Precipitation Type: 1—none, 2—mist, 3—light drizzle, 4—light snow
(7)	Visibility: 1—<100 ft, 2—<500 ft, 3—<1000 ft, 4—<1/2 mile, 5—<1 mile, 6—<2 miles, 7—<5 miles, 8—<10 miles
(8)	Cloud Cover: (tenths) 0—clear to 1—overcast
(9-11)	Temperature: Celsius
(12)	Start Watch: check this column and add information to columns 14-23
(13)	Stop Watch: check this column and add information to columns 14-23
(14-15)	Year—last two digits only (e.g., 94)
(16-17)	Month—01 through 12
(18-19)	Day—01 through 30 or 31
(20-21)	Hour—00 through 24
(22-23)	Minute—00 through 59
(24)	Time Zone: (e.g., Eastern, Central, Pacific)

(25)	Time Basis: (e.g., Standard, Daylight Saving)
(26-29)	Species Code—use letter abbreviation codes derived from common name
(30-33)	AOU Number—use four digit AOU numbers
(34-36)	Number—the number of individuals in a flock
(37)	Sex: 1= male, 2=female, 3=unknown
(38)	Age: 1=adult, 2=immature, 3=young
(39)	Flight Behavior: 1—straight 6—flew up from corridor 2—curved 7—circling 3—zigzag 8— 4—hovering 9— 5—landed in corridor
(40)	Height of Flight: 1—0 ft and <30 ft (9 m) 4—200 ft and <400 ft (122 m) 2—30 ft and <137 ft (42 m) 5—400 ft and above 3—137 ft and <200 ft (61 m)
(41-42)	Distance from Observer: 01—0 to 500 ft (152 m) 06—2.5k ft to 3k ft (914 m) 02—500 ft to 1k ft (305 m) 07—3k ft to 3.5k ft (1067 m) 03—1k ft to 1.5k ft (457 m) 08—3.5k ft to 4k ft (1219 m) 04—1.5k ft to 2k ft (610 m) 09—4k ft to 4.5k ft (1372 m) 05—2k ft to 2.5 ft (762 m) 10—4.5k ft to 5k ft (1524 m)
(43)	Direction of Flight (towards) : 1-N, 2-NE, 3-E, 4-SE, 5-S, 6-SW, 7-W, 8-NW
(44)	Direction of Bird(s) from observer: 1-N (337.5-22.5°) 5-S (157.5-202.5°) 2-NE (22.5-67.5°) 6-SW (202.5-247.5°) 3-E (67.5-112.5°) 7-W (247.5-292.5°) 4-SE (112.5-157.5°) 8-NW (292.5-337.5°).
(45)	Number of Observers
(46)	Observer Code: apply individual codes (e.g., a, b) consistently throughout study
(47)	Recorder Code: same code letter as used above for observer code

APPENDIX TABLE 2. Additional codes and explanations for radar observations.

Col. (41-42)	Distance to Echo: 1—0 to 0.1 nm (185 m) 6—0.5 to 0.6 nm (1111 m) 2—0.1 to 0.2 nm (370 m) 7—0.6 to 0.7 nm (1296 m) 3—0.2 to 0.3 nm (556 m) 8—0.7 to 0.8 nm (1482 m) 4—0.3 to 0.4 nm (741 m) 9—0.8 to 0.9 nm (1667 m) 5—0.4 to 0.5 nm (926 m) 10—0.9 to 1.0 nm (1852 m)
Col. (43)	Direction of Flight (towards): 1-N 5-S 2-NE 6-SW 3-E 7-W 4-SE 8-NW
Col. (44)	Direction to Echo (from radar location):

1-N
2-NE
3-E
4-SE
5-S
6-SW
7-W
8-NW

APPENDIX TABLE 3. Codes and explanations for dead bird searches.

Col. (2)	Type of Search: 1=wind turbine, 2=met tower, 3=power line
Col. (43)	Approximate Time of Death: 1=6-12 hrs, 2=12-24 hrs, 3=1-2 days, 4=1 week, 5=2 weeks, 6=several weeks
Col. (44)	Physical Condition: 1=broken bones, 2=lacerations, 3=abrasions, 4=bloody, 5=discolorations, 6=gun shot wounds, 7=decomposition, 8=scavenger damage
Col. (45)	Probable Cause of Death: 1=collision, 2=electrocution, 3=hunting, 4=predation, 5=unknown
Col. (46)	Necropsy: Y=yes, N=no
Col. (47)	Specimen Number: Whenever specimens are saved for future analysis.

Note: When a dead bird search is along a power line corridor, columns 36-39 are not used and columns 40-42 will indicate distance to power line in meters.

BIRD MOVEMENT OBSERVATION FORM

DEAD BIRD SEARCH FORM

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