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ASSESMENT OF DEVICES DESIGNED TO LOWER THE INCIDENCE OF AVIAN POWER LINE STRIKES

A Thesis
Submitted to the Faculty
of
Purdue University
by
Michael R. Crowder

In Partial Fulfillment of the
Requirements for the Degree
of
Master of Science

December 2000

I dedicate this work to my mother, Mary Ann Wools,
for her guidance and patience; you were, and are a good mom.

I also dedicate to this work to my “Granny”, Regina Crowder.
You are the toughest person I know, and I admire and love you for that.

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ABSTRACT

Crowder, Michael R., M.S., Purdue University, December 2000. Assessment of Devices Designed to Lower Incidence of Avian Power Line Strikes. Major Professor: Olin E. Rhodes, Jr.

Ground wires associated with high voltage power transmission lines have been identified as a source of mortality for numerous avian species. Collisions between birds and power lines have been studied by numerous researchers to better understand the factors that are involved in these collisions and the effectiveness of mitigation measures. There are three chapter included in this thesis; the first being a review of avian power line collisions that includes a literature review of collision incidents, factors that influence collisions, and methods of avoiding strikes. The second chapter discusses the relationships between wing morphology and behavioral responses to unmarked transmission lines. This research was conducted at the Cinergy-PSI Gibson County Power Generating Station located in Gibson County, Indiana. This site was a secondary focal area to the main research location in Knox County, Indiana. Bird flight observations were conducted along with corresponding ground searches to determine the species specific reactions of birds to the power lines. Birds most likely to react to power lines were those that approached the lines at a height between the conductor and ground wires, and a significant difference was found in the reaction distances between flocks >10 birds and single birds. The third chapter consists of the results from the main focus of the study conducted in Knox County, Indiana, in which the effectiveness of ground wire marking devices was tested. This research was conducted over two consecutive winter field seasons to include a control year and a treatment year. The treatment field season consisted of the use of two ground wire marking devices, Bird Flight Diverters (BFD) and Swan Flight Diverters (SFD), both in yellow and gray, tested sequentially. During each field season, estimates were calculated for research biases (i.e., search, removal, habitat, and crippling biases), which, in combination with ground search data, were subsequently used to estimate the total number of collisions with power lines. The estimated total number of collisions for marked lines was reduced by 51.4% compared to the same spans before marking. The BFDs reduced collision mortality by 73.3%, and the SFDs reduced collision mortality by 37.5%.

CHAPTER 1

AVIAN COLLISIONS WITH POWER LINES: A REVIEW

Introduction

Collisions with power lines and especially overhead ground wires associated with power lines have been documented as a source of mortality for a large number of avian species. As early as 1876, large numbers of avian deaths were caused by collisions with telegraph wires in the United States (Coues 1876, Cohen 1896). In September 1898, Emerson (1904) noted the deaths of over 70 birds in a 2 day period caused by collisions with a telephone wire. Avian mortality associated with power line strikes has been most publicized for the occurrences that involve threatened or endangered species, incidents that involve large numbers of individuals, and fatalities that occur in small populations.

Available literature suggests that waterfowl casualties involving power line strikes tend to be isolated, but relatively common events (Faanes 1987). Although collision mortality is common, most collisions are in remote areas where public awareness is low and hence the strikes are unreported and unnoticed (Cornwell and Hochbaum 1971). In an extensive review of non-hunting mortality of fledged North American waterfowl, Stout and Cornwell (1976) found that only 0.07% of reported casualties came from collisions with wires. Although collision mortality rarely affects healthy populations with good reproductive success, collisions can be biologically significant to local populations (Harrison 1963, Beer and Ogilvie 1972) and endangered species (Thompson 1978, Faanes 1987, Crivelli et al. 1988).

There are two factors that power utility companies use to prioritize avian mortality due to collisions with power lines, biological significance and political significance. Biological significance is thought of in terms of birth rates, death rates, and other population-based parameters. As cited in a recent Avian Power Line Interaction

Committee report (APLIC 1994), biological significance is the effect of collision mortality upon a bird population's ability to sustain or increase its numbers locally and throughout the range of the species. The loss of 1,000 Mallards (*Anas platyrhynchos*) due to power line collisions would not affect the success of the total population and would not be biologically significant, but if one California Condor (*Gymnogyps californicus*), one Whooping Crane (*Grus americana*), or one Wattled Crane (*Grus carunculatus*) was killed due to a collision, that event could have an effect on the population that would be considered biologically significant. If the same 1000 Mallards were to die under the direct observation of environmental groups or the general public, or in a situation where the media or politicians would be notified, a politically-significant event would have occurred (Willard 1978).

Reports of collision mortality involving endangered species include Whooping, Wattled, and Red-crowned (*Grus japonensis*) Cranes, and the California Condor. Beginning in the 1960's, Red-crowned Crane losses resulting from collisions with power lines threatened their numbers in Japan. Between 1962 and 1980, losses from a total population of 300 birds due to collisions with power lines accounted for 2.1% of adult and 13.4% of juvenile fatalities (Archibald 1987). The greatest known cause of mortality for fledged Whooping Cranes in North America is collisions with power lines. Between 1977 and 1985, power line collisions account for 39% (n = 8) of all known casualties of a population of cross-fostered Whooping Cranes in the Rocky Mountain population, and the Aransas-Wood Buffalo population of Whooping Cranes have sustained significant losses of 25% (n = 6, 1956-1985) due to power lines (Brown et al. 1987, Morkill and Anderson 1991). The Wattled Crane is considered endangered in South Africa and globally vulnerable. Van Rooyen and Ledger (1999) reported two Wattled Crane deaths due to collisions, accounting for only 0.8% of the total population, but with 250 individuals in the total population, this represents a serious threat to the ultimate survival of the species.

Several authors have reported collisions events resulting in large numbers of avian deaths. One of the largest known kills, and one of the few instances where non-endangered species collision mortality could be considered potentially biologically significant, was near Billings, Montana. Two years after a 230-kV line was built across a dry basin, the area was flooded and numerous waterfowl were attracted to the area. An estimated 2,530 birds died from wire strikes over a 6 month period. In addition, the carcasses acted as a substrate for the botulism bacteria to grow, and the disease claimed many additional birds. The botulism outbreak was deadlier than it would have been without the dead birds as a substrate (Beaulaurier et al. 1982).

Wheeler (1966) reported the deaths of several hundred Sandhill Cranes (*Grus canadensis*) during a fierce winter storm that resulted in nearly zero visibility. The cranes were feeding in harvested cornfields when the storm hit and attempted to fly back to the roosting areas in the storm. Along the way, many were killed as they hit power lines and trees. On 9 February 1978, 52 Sandhill Cranes were killed by high voltage transmission lines while returning to roosts in a dense fog (Tacha et al. 1979).

Blokpoel and Hatch (1976) reported the deaths of up to 75 Snow Geese (*Chen caerulescens*) feeding in a stubble field in southern Manitoba due to power transmission line collisions. The geese were startled out of the field by a low flying aircraft and hit a transmission line in their confusion. The lines were broken and a local power failure resulted. Schroeder (1977) reported the deaths of 46 Snow Geese that had hit a power line on a clear morning without fog or precipitation. Along with the dead and injured birds, there were also wings, legs, and heads lying on the ground. The author noticed blood and feathers on a distribution line that was only 50 meters from the birds. One possible explanation to the deaths of the geese is that they were feeding near the power line, which ran along the side of a gravel road, and they were disturbed into the air by a passing vehicle and struck the line in the process.

An example of large numbers of birds being killed from a single small population occurred at Romney Marsh, Kent, England in the early 1960's. Thirty percent (n = 21) of a local population of 70 Mute Swans (*Cygnus olor*) were killed over a period of 1 or 2 months by a 400 meter stretch of a distribution line serving a large isolated farm. The line was placed only 9 meters above the ground and crossed a regular flight path used by swans returning to the marsh to roost (Harrison 1963). Since the swans often returned to the area in times of low visibility, wires of the distribution line were difficult to detect.

Currently, some power companies assess the potential for bird/power line interactions in the planning stages of right-of-way development, and if possible, design power line placement to minimize the potential of collisions. In many instances, established power lines and new lines through areas of high potential for avian interaction cannot be rerouted, often increasing the likelihood of strikes. There are many factors in which decisions on power line placement and possible mitigation measures are eventually based. While these factors may be political, legal, social, or economic in nature, only those that are cost effective are generally considered.

Recently, however, the United States Fish and Wildlife Service (USFWS) has been requiring mitigation measures on new lines that have a high potential to receive strikes, and the retrofitting of existing lines that have been found to contribute to avian mortality due to collisions (Rick Harness. pers. comm.). Violations of the "take" provisions of the Migratory Bird Treaty Act, the Bald and Golden Eagle Protection Act, and the Endangered Species Act can be levied against a utility company if prompt action is not taken to modify a line after it has been identified as a problem location (Suazo 2000). If a utility company is found not to comply with rulings, fines up to $500,000 could be levied against the company. Not only the company could be fined, but also the officers of the company could personally be charged with a felony and fined up to $250,000 each. In a related case, a recent precedence-setting judgement was levied against the Moon Lake utility company in Colorado for the electrocutions of eagles. Moon Lake was fined $100,000, asked to retrofit lines that were found to contribute or possibly contribute to mortality, and was placed on 3 years probation (Williams 2000).

To allow *in situ* treatments of power lines with high probabilities of contributing to avian mortality, a number of power line and ground wire marking devices have been developed. Although some data exist regarding the effectiveness of particular marking devices at lowering incidence of avian interactions with power lines (Morkill and Anderson 1991, Brown and Drewien 1995, Savereno et al. 1996, Janss and Ferrer 1998), few studies have performed head-to-head comparisons of the effectiveness of these marking devices under the same experimental (i.e., environmental and biological) conditions. In addition, although a variety of studies have addressed the topic of power line strikes as a source of avian mortality, many were inconclusive, because researchers have failed to either test the assumptions associated with their methods or to design their studies within the framework of a rigorous statistical design.

For many years, researchers have recognized that certain biases influence the accurate assessment of the numbers of birds that collide with power lines (Meyer 1978, James and Haak 1979, Beaulaurier 1981, Faanes 1987, Brown and Drewien 1995, Savereno et al. 1996). APLIC (1994) discussed four common biases associated with dead bird searches and provided formulas for estimation of the influence of these biases. These include search bias (researcher bias), removal bias (predator removal bias), habitat bias (the amount of searchable area in a study site), and crippling bias (number of birds that strike power lines that land under the lines).

Factors Influencing Collisions

APLIC (1994) identified and reviewed several factors that are thought to influence avian wire strikes, including line placement and configuration, the habitat use of bird species, body and wing size, flight and flocking behavior, the time of day of flights, the age and sex of bird species, weather conditions, and disturbances of birds near power lines; this report served as a model for the remainder of this section. Anderson (1978) also suggested that the number of birds present in the study area, species composition, and familiarity of the birds to the area contributed to the rate of collision mortality in his study. However, Thompson (1978) and Brown and Drewien (1995) suggested that the relationship between mortality rates and environmental conditions were unpredictable.

Line Placement and Configuration

Overhead ground wires, also known as earthen, static, or shield wires have been cited as the primary source of avian collisions with power lines (Scott et al. 1972, Brown et al. 1987, Faanes 1987, Savereno et al. 1996; Fig. 1.1). The main function of ground wires is to protect the energized conductors from lightning strikes, which can cause outages, disable equipment, or affect service reliability. Ground wires are usually small in diameter (0.9 to 1.3 cm) and set above conductor wires. Since these ground wires are smaller in diameter than conductor wires, they sometimes become nearly invisible to birds because of background or lighting conditions.

Removal of the ground wires is not an option in all areas because of the need for protection from lightning strikes. The isokeuranic level (the number of days per year with lightning storms) in an area will determine the level of protection needed from lightning strikes (APLIC 1994). However, recent advances in polymer lightning arresters have given biologists and utility engineers the option to remove ground wires on lines between 4.2 kV and 230 kV. Arresters based on newer polymer technologies can be put on distribution or transmission lines to protect them from lightning strikes in the place of overhead ground wires. However, one drawback of the polymer lightning arresters is that they cannot be used in areas of high raptor use because of energized jumper wires creating an unsafe place for birds to perch (APLIC 1994).

The proximity of lines to resting and feeding areas has been identified as a critical component of collision mortality in many avian species (Brown et al. 1987, Faanes 1987, Morkill and Anderson 1991). As mentioned previously, lines that are placed in an area that separates two habitat types may contribute to avian mortality. Power lines that are placed in areas where trees or other vegetation are at or above conductor height are less likely to be involved in avian strikes (Fig. 1.2). Lines that are placed at or near the base of a cliff or any other tall object also have a lower probability of receiving strikes (Thompson 1978; Fig. 1.3). In addition, lines that are placed perpendicular to local avian flight patterns are more likely to experience collisions than those placed parallel to those patterns (Scott et al. 1972). Thompson (1978) suggested that clustering power lines within the same right-of-way would make the lines more visible, and birds would only have to make one ascent to get over all of the lines (Fig. 1.4). A drawback to line clustering would be that in times of reduced visibility the lines would act as a barrier (Fig. 1.5).

Habitat Use

The type of habitat that is adjacent to power lines affects the rate of collisions. For instance, a power line that is in or near a primary avian habitat would be more likely to receive strikes than a line that is not in an area of frequent bird activity. Another factor influencing the relationship between collision frequency and habitat type is that of line placement of lines within or among habitats. For example, a power line that separates a wetland from a grain field in close proximity may be expected to have a high probability of strikes because of waterfowl leaving the wetlands to feed on waste grain. Some authors have suggested that lines separating different habitat types are more likely to cause collisions than those in homogeneous landscapes (Brown et al. 1987, Faanes 1987, Morkill and Anderson 1991). However, Willard et al. (1977) suggested that lines through a single habitat type pose a bigger threat to birds than those bisecting habitats. Alternatively, APLIC (1994) suggested that it was not necessarily the number of habitats that determined the frequency of power line strikes by birds, but rather the number of times birds crossed a power line each day. A power line that is crossed only once per day by waterfowl would pose less of a threat than a line that is crossed multiple times per day.

Body and Wing Size

Body size and maneuverability make certain species more susceptible to wire strikes than others. Large birds with low maneuverability are susceptible to wire strikes because of their large wingspans that makes them unable to quickly adjust their flight to avoid power lines. Large-bodied birds such as cranes (*Grus* spp.)(Archibald 1987, Brown et al. 1984, 1987, 1995, Morkill and Anderson 1991, Alonso et al. 1994, Janss and Ferrer 1998, van Rooyen and Ledger 1999), swans (*Cygnus* spp.) (Banko 1956, Harrison 1963, Beer and Ogilvie 1972), storks (family Ciconiidae) (Alonso et al. 1994, Janss and Ferrer 1998, Barbraud 1999), flamingos (family Phoenicopteridae) (McNeil et al. 1985, Janss and Ferrer 1998), and pelicans (*Pelicanus* spp.) (Willard et al. 1977, McNeil et al. 1985, Crivelli et al. 1988) fit this category. Bevanger (1994, 1998) stated that wing loading (ratio of body weight to wing area) and aspect ratio (ratio of wing span squared to wing area) are crucial to bird flight performances. Bevanger (1998) predicted that as wing loading of a bird increased, so does its susceptibility to collisions.

Smaller birds also are frequently reported as collision victims. However, small birds species that belong to the order Passeriformes that are killed by power lines are less visible and harder to find than larger ones, hence, may be under-represented in collision mortality studies. Also, small birds may be under-represented in power line casualty lists because small birds may be removed faster by predators than larger birds (Raevel and Tombal 1991, as cited in APLIC 1994, Brown and Drewien 1995).

Flight and Flocking Behavior

Flight altitude has a large impact on the probability of avian interactions with power lines. In addition, as cited in Brown et al. (1984, 1987), the distance a bird has to travel from the roost area to feeding areas is a major factor in collision mortality. If the feeding area is less the 1.6 km from the roost area, birds do not normally fly as high as they would if the distance between the two habitat types were greater; birds flying at lower altitudes are obviously more likely to collide with power lines. James and Haak (1979) concluded that the birds at the greatest risk of collisions are those birds that are approaching power lines at or below conductor height. Bevanger (1995) reported that Tetranoids were particularly at risk of wire collisions, which was surprising due to their behavior as ground dwellers. Because of differences in average flight duration and altitude, researchers have found that puddle ducks (e.g., Mallards, Northern Pintails *Anas acuta*) are more susceptible to wire collisions than diving ducks (e.g., Lesser Scaup *Aythya affinis*, Ring-necked Ducks *Aythya collaris*)(James and Haak 1979, Faanes 1987).

Birds that travel in flocks are particularly susceptible to collision mortality. Often, confusion resulting from power line encounters can lead to strikes. Flocking activity also reduces the vision of the trailing birds. When power lines are encountered by a flock, birds will even collide into each other in their panic (Brown 1993). Collision rates of solitary raptors, which routinely fly at or near power line levels, are generally lower than those of other less maneuverable flocking avian species. This may be because the binocular vision of raptors allows detection of the lines at a greater distance (Bevanger 1994).

Time of Day

The timing of daily flights is an important factor affecting collision mortality. Waterfowl and other birds routinely fly before sunrise and after sunset when visibility is low, and often collide with wires that they cannot readily see (Scott et al. 1972, Krapu 1974, James and Haak 1979, Brown and Drewien 1995; Fig. 1.6). During waterfowl hunting seasons, collision probabilities are enhanced when ducks and geese feed at night to avoid hunting pressure during the day, or when hunters flush birds from their roosts before daylight (Brown and Drewien 1995). Anderson (1978) estimated that collisions during daylight hours, when visibility was good, were very rare with only one collision occurring for every 250,000 power line over-flights.

Age and Sex of Birds

Many avian species seem to be less susceptible to collisions as they grow older and presumably more maneuverable (Thompson 1978, McNeil et al. 1985, Brown et al. 1987, Crivelli 1988, Savereno et al. 1996). For instance, juvenile Sandhill Cranes collide with wires more often than adults (Brown et al. 1987, Morkill and Anderson 1991, Brown and Drewien 1995). However, this may not be a consistent trend either within or across species. Ogilvie (1966) suggested that Mute Swans did not learn how to avoid power lines with increasing age because collision rates for mature birds were no different from those of immature birds. Conversely, Mathiasson (1993, 1999) stated that in Sweden, Mute Swans learn to avoid lines, based on evidence that higher numbers of juveniles than adults were found dead due to collisions. Anderson (1978) found that adult Mallards were more likely to collide with wires than were juveniles.

Differences in strike probabilities between sexes also have been documented. In particular, several studies have demonstrated that male ducks are more likely to strike power lines than female ducks (Boyd 1961, Avery et al. 1977, Willard et al. 1977, Brown and Drewien 1995). This sex bias in strike probabilities is most likely due to the differential movement behaviors of the sexes in most duck species during mating flights (Faanes 1987).

Weather

Inclement weather events such as fog (Fig.1.7), snow, or high winds have been identified as factors contributing to collision mortality, with low visibility cited as a factor contributing to power line collisions by Wheeler (1966), Tacha et al. (1979), and Brown et al. (1987). Visibility problems are the worst when weather events come on quickly and unexpectedly (APLIC 1994). Brown and Drewien (1995) stated that cranes and waterfowl usually remained at their roosting sites until morning fog had lifted.

Wind also has been demonstrated to be a major factor in contributing to power line collisions. In high winds, birds may inadvertently fly into lines that are fully visible because of lost flight control (Brown et al. 1987, Morkill and Anderson 1991, Brown and Drewien 1995). Savereno et al. (1996) found that birds approaching power lines with tail winds were more likely to collide with lines than birds that approach lines with a head wind because of their higher speed at approach.

Disturbances

Disturbances by humans or predators can lead to panic among birds near power lines and cause the birds to fly into wires, even when the wires are clearly visible. This seems to be a major factor in many collisions, especially when birds that are disturbed are flocked together. When disturbed, birds will even collide with the larger and more visible conductor wires as well as the ground wires (Crowder, unpl. data). The flocking behavior of some species of birds adds to the confusion and leads to wire strikes by trailing birds within a startled flock.

Methods Of Preventing Strikes

The mitigation of power line strikes should effectively reduce wildlife-transmission line conflicts, not interfere with line reliability, not result in adverse impacts on other resources, and be economically feasible (Beaulaurier 1981). Again, the USFWS is enforcing mitigation measures on new lines and the retrofitting of old lines where bird strikes have been a problem or could become problems in the future. There are many methods used to mitigate avian power line interactions. The Avian Power Line Interaction Committee (APLIC) suggested several methods to lower the power line strike frequency of birds which include: power line route planning, modification of habitat near power lines, education of farmers and other officials that work near power lines, and modification of power line structures.

Route Planning

The most important mitigation tool for avian-power line collisions is the initial decision of where to build the line. It is crucial to identify and avoid areas with high potential for bird strikes. High potential areas can include wetlands, waterfowl concentration areas, flyways, roosts, and feeding areas (Thompson 1978). The identification and avoidance of areas of potential concern prior to line construction will alleviate the need for mitigation of losses in the future. The construction of power lines that bisect areas used frequently by birds, such as feeding and roosting areas, should be avoided if possible. Brown et al. (1984, 1987) found that no Sandhill Cranes were killed by power lines if the distance between feeding and roosting areas on either side of the lines was greater that 1.6 km. Birds flying over power lines from adjacent roosting or foraging sites have less time to react and avoid wires than birds flying over lines from sites that are greater distances apart (Scott et al. 1972, Thompson 1978, Beaulaurier 1981, Brown et al. 1987, Howard et al. 1987, Faanes 1987, Morkill and Anderson 1991).

Habitat Modification

Habitat modification to lower the incidence of bird collisions with power lines can include planting of trees or other natural vegetation to shield power lines from strikes, modifying habitat near power lines to change its attractiveness to birds, and modifying land use to reduce potential disturbances to avian species using habitats near power lines. Planting trees that can grow near or above the height of power lines will cause birds to fly above the easily visible vegetation and clear the power line in the process (Thompson

1978; Fig. 1.2). Modifying habitat near power lines has the greatest mitigation potential when the interested agency controls the land use adjacent to the power lines. For instance, wildlife refuges and lands that are owned by power line companies would be good candidates for habitat modification mitigation (APLIC 1994). Habitat modifications, such as creating feeding and resting areas on the same side of a power line, alleviates the need for birds to cross the lines multiple times each day, also would be a potential mitigation practice (Thompson 1978; Fig. 1.8).

Education

Educating employees of wildlife refuges, utility company personnel, and farmers to avoid unnecessary disturbances near power lines, thus keeping birds from flushing in a confusion, will reduce power line strikes. An example would be instructing refuge employees to drive slower when they are near large flocks of birds to keep them from flushing (APLIC 1994).

Modification of Structures

Modification of power line structures also can be an option to reduce collisions. This option includes line relocations, underground burial of lines, removal of over-head ground wires, and the marking of ground wires to make them more visible to birds in flight.

Line Relocation

The relocation of an existing line is the last option that is usually considered when trying to mitigate avian collisions. The huge expense of creating a new line and right-of-way usually can not be justified unless there are biologically significant mortalities.

Burying Power Lines

Underground burial of power lines is another option available to managers in areas of high collision risk. Burial of power lines can obviously reduce collisions, but has many drawbacks. The costs of burying lines can be from 3 to 20 times higher than constructing overhead lines, and such costs are related to the line voltage, type and length of cable, cable insulation, soil conditions, local regulations, reliability requirements, requirement of termination areas, and right-of-way layout. Other negative aspects of cable burial include: lack of economical methods of burying extra high voltage lines, the potential to contaminate water supplies if insulating oil leaks from buried lines, and extended outage risks due to the difficulty in locating cable failures (APLIC 1994).

Ground Wire Removal

The removal of overhead ground wires as a means of avian strike mitigation has been tested by researchers (Beaulaurier 1981, Brown et al. 1987). Since most strikes involve ground wires (Scott et al. 1972, Lee 1978, Meyer 1978, James and Haak 1979, Brown et al. 1987, Faanes 1987, Savereno et al. 1996), the removal of these wires should decrease the number of collisions. It was previously thought that ground wire removal would not be feasible in many areas because of the need for lightning protection; however, with the advances in polymer lightning arresters, the use of ground wires may not be needed on lines between 4.2 kV and 230 kV. Larger static wires were tested by Brown et al. (1987) with little effect on collision mortality.

Power Line Marking

The marking of overhead ground wires to increase their visibility is usually considered to be the most economical mitigation option for reducing collision mortality and is the mitigation technique most often used today. Most avian species react at greater distances and fly higher over marked verses unmarked lines (Morkill and Anderson 1991, Brown and Drewien 1995). Numerous marking devices designed to reduce collision risk have been tested, including: flags (Koops de Jong 1982, as cited in APLIC 1994), ribbons (Scott et al. 1972), tape (Scott et al. 1972), stripes (Janss and Ferrer 1998), aluminum balls (Leppers 1966, as cited in APLIC 1994), raptor silhouettes (Heijnis 1975, as cited in Beaulaurier 1981, Janss et al. 1999), plastic tubes (Archibald 1987), fishing floats (Kaiser and McKelvey 1978, as cited in Beaulaurier 1982), strobe lights (Willdan Assoc. 1981), aviation spheres (Tacha et al. 1979, Willdan Assoc. 1981, Howard et al. 1987, Morkill and Anderson 1991, Savereno et al. 1996; Fig. 1.9), swinging plates (Brown and Drewien 1995; Fig. 1.10), PVC spirals (Alonso et al. 1994), polypropylene spirals (Janss and Ferrer 1998), neoprene crossed bands with a phosphorescent stripe (Janss and Ferrer 1998), spiral vibration dampers (Brown and Drewien 1995), bird flappers (cited in van Rooyen and Ledger 1999), and bird flight diverters (Koops and de Jong 1982, as cited in APLIC 1994; Fig. 1.11) with different color combinations and spacing (Table 1.1).

Yellow is thought to be a good color for marking power lines to reduce avian collisions since the eyes of most avian species are more sensitive to this color, and yellow is more reflective in low light conditions than international orange (APLIC 1994). According to Beaulaurier (1981), the maximum sensitivity of avian rod pigments in low light conditions is around 500 nm, which is blue-green, and for daylight conditions it is around 560 nm, yellow-green. Factors such as safety codes, ice loading, wind resistance, and economics should be considered when making decisions on which marking device to use (APLIC 1994).

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Table 1.1 Review of marking devices, color, size, spacing, and effectiveness of previous power line marking studies.

Year	Author	Marker Type [a]	Color	Size	Spacing (m)	Collision Reduced	% Reduction
1972	Scott et al.	Black Tape	Black	15 cm	1.9 m	Yes	NA
1972	Scott et al.	Luminous Bands	Orange	5 cm	1.2 m	No	
1972	Scott et al.	Stripes	Orange	5 cm	1.2 m	No	
1982	Koops and de Jong [b]	Bird Flight Diverters	NA	5 cm	5 m	Yes	86-89%
1982	Koops and de Jong [b]	Bird Flight Diverters	NA	5 cm	10 m	Yes	57-58%
1982	Koops and de Jong [b]	Bird Flight Diverters	NA	10 cm	15 m	Yes	65-74%
1987	Archibald	Plastic Pipes	Yellow	NA	NA	Yes	NA
1987	Howard et al.	Aviation Balls	Red	51 cm	Center		
1991	Morkill and Anderson	Aviation Balls	Yellow/Black Stripe	30 cm	100 m	Yes	NA
1994	Alonso et al.	PVC Spirals	Red	30 cm x 1 m	10 m	Yes	60%
1995	Brown and Drewien	Spiral Vibration Damper	Yellow	1.27 x 125 cm	3.3 m	Yes	61%
1995	Brown and Drewien	Swinging Plates	Yellow/Black Stripe	30.5 x 30.5 cm	23 -32 m	Yes	63%
1996	Savereno et al.	Aviation Balls	Yellow	30 cm	61 m	Yes	53%
1998	Janss and Ferrer	Polypropylene Spirals	White	30 cm x 1 m	10 m	Yes	81%
1998	Janss and Ferrer	Crossed Bands with a Phosphorescent stripe	Black	5 x 35 cm 4 x 5 cm	20 m	Yes	76%
1998	Janss and Ferrer	Plastic Stripes	Black	0.8 x 70 cm	12 m	No	
1999	Janss et al.	Raptor Models	NA	130% normal	On Poles	No	

[a] On ground wire unless otherwise noted

[b] Cited in Janss and Ferrer (1998), APLIC (1994)

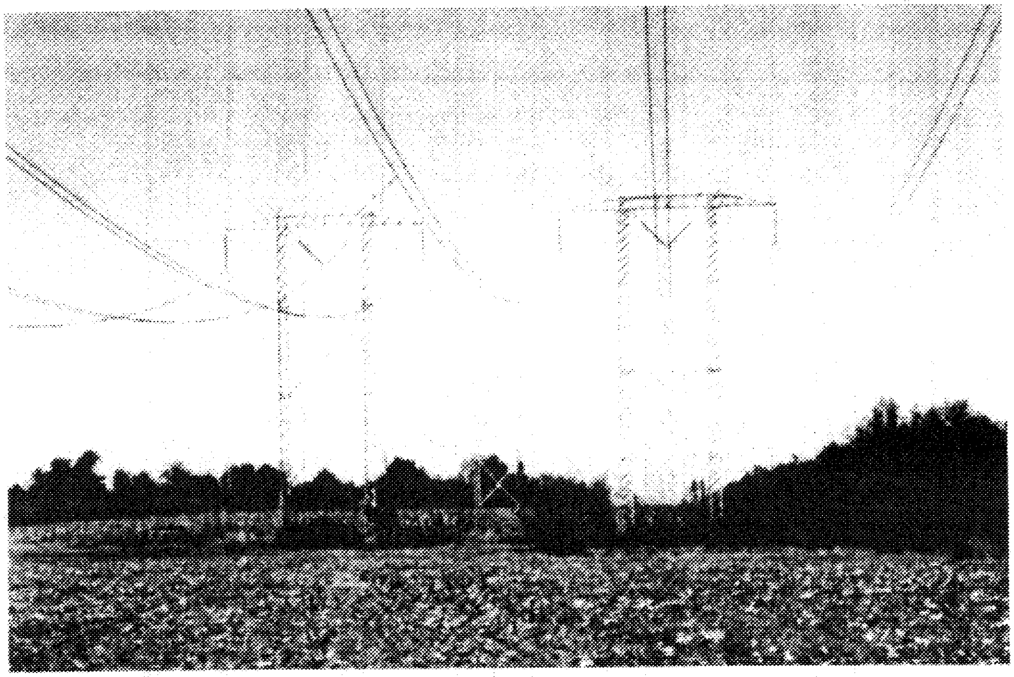

Fig. 1.1 Ground wires associated with transmission lines (two top wires) are smaller in diameter than the energized conductors (bottom three sets of wires).

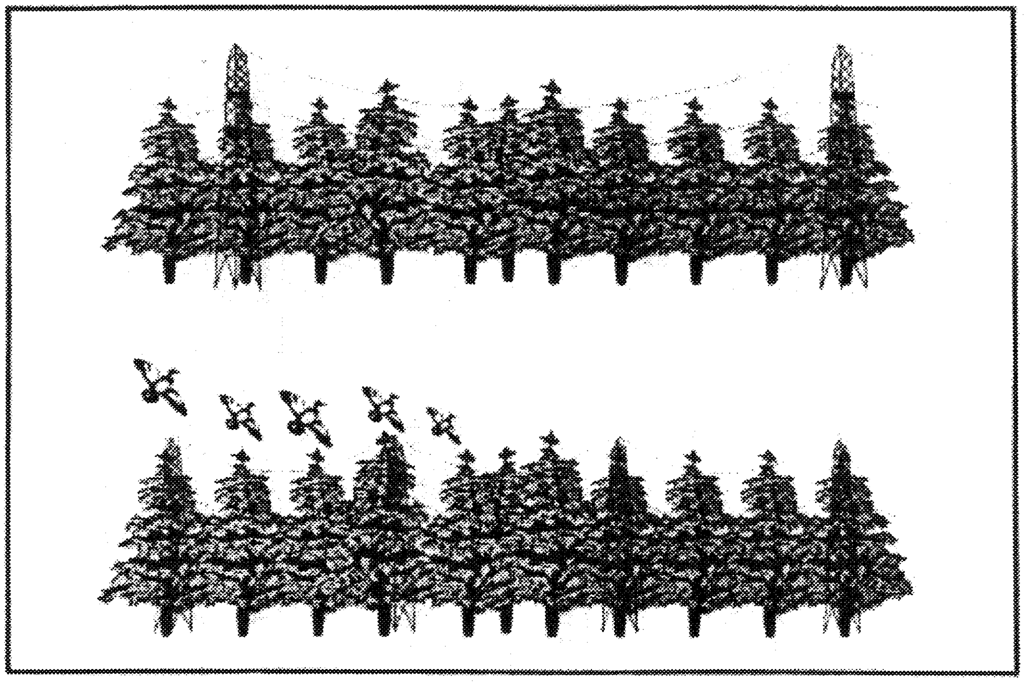

Fig. 1.2 Power lines in wooded areas should be placed at or below the height of nearby trees to minimize interactions with birds (from APLIC 1994).

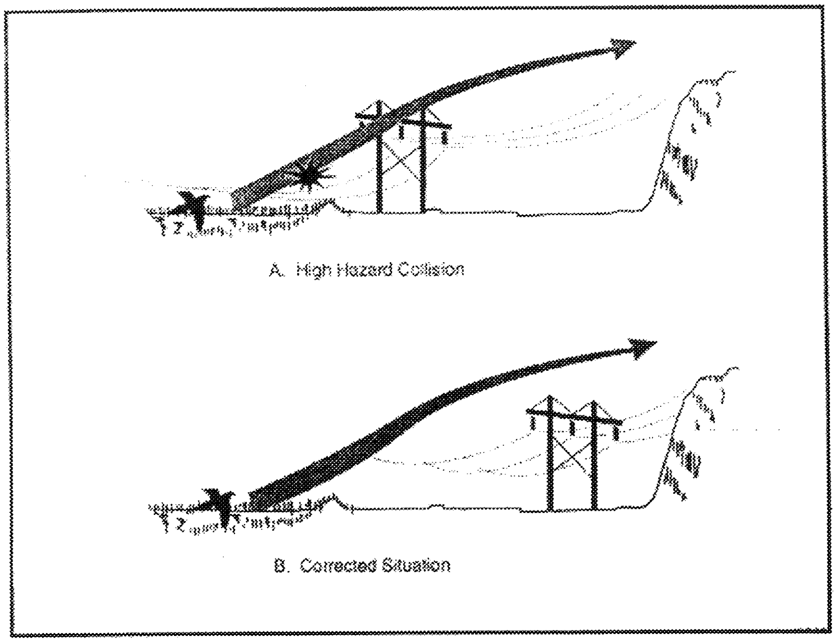

Fig. 1.3 Power lines should be placed near large objects such as a tall buildings or cliffs when possible so birds will react to the highly visible objects (from APLIC 1994).

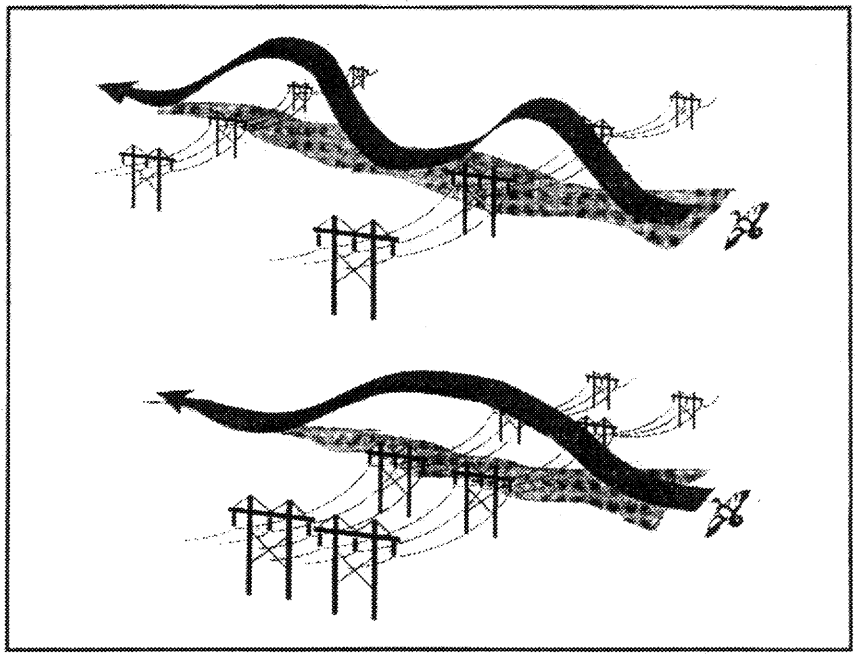

Fig. 1.4 Clustering power lines into a single right-of-way (bottom) alleviates the need for birds to make multiple ascents and descents to cross the lines (from APLIC 1994).

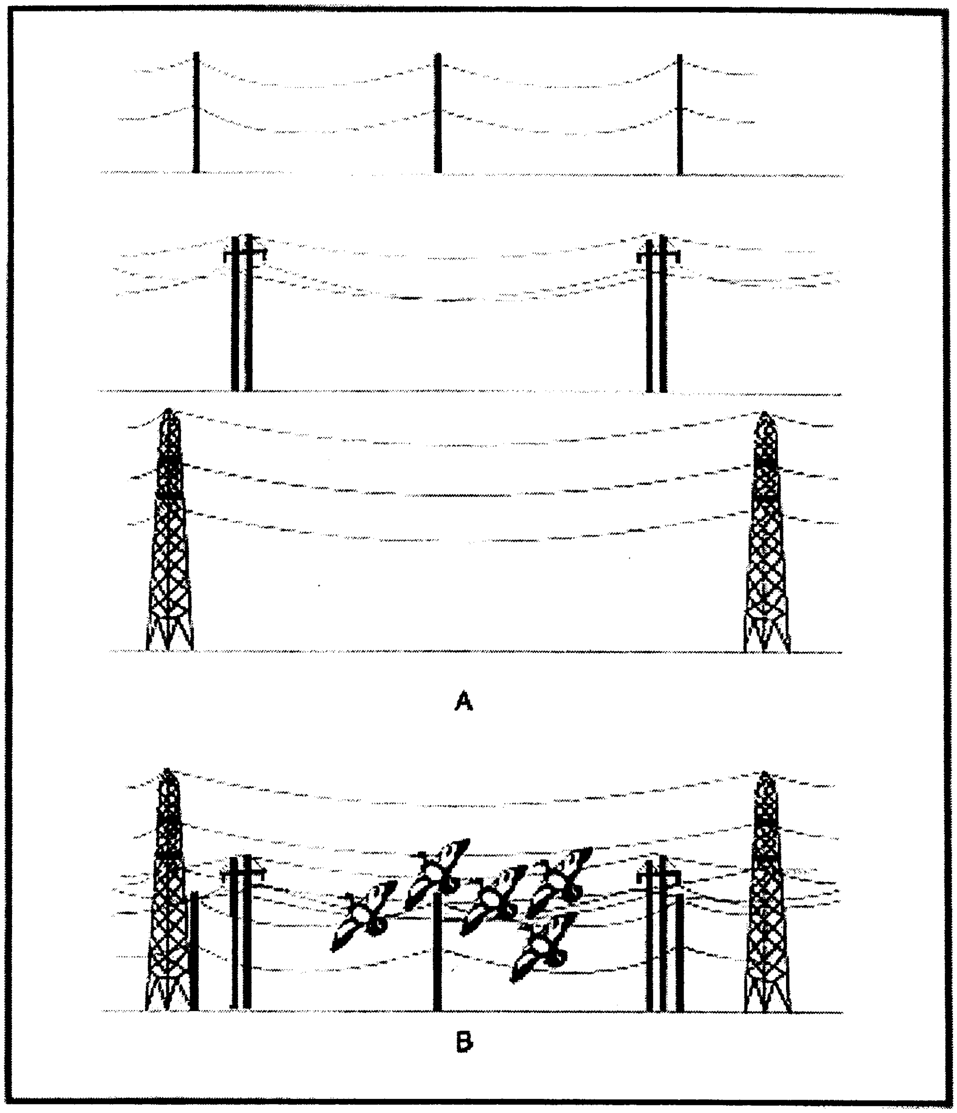

Fig. 1.5 Clustered power lines can act a significant barrier to avian species in times of low visibility; collision risks for each separate line (A), and lines clustered together (B) (from APLIC 1994).

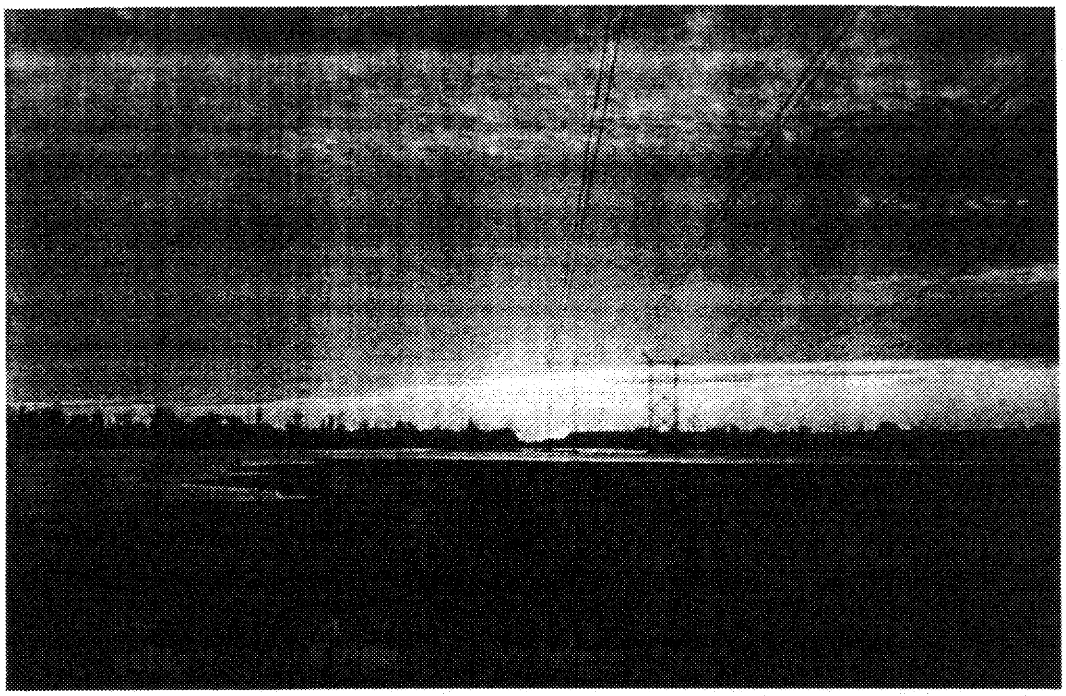

Fig. 1.6 Power lines during a low visibility time at sunset.

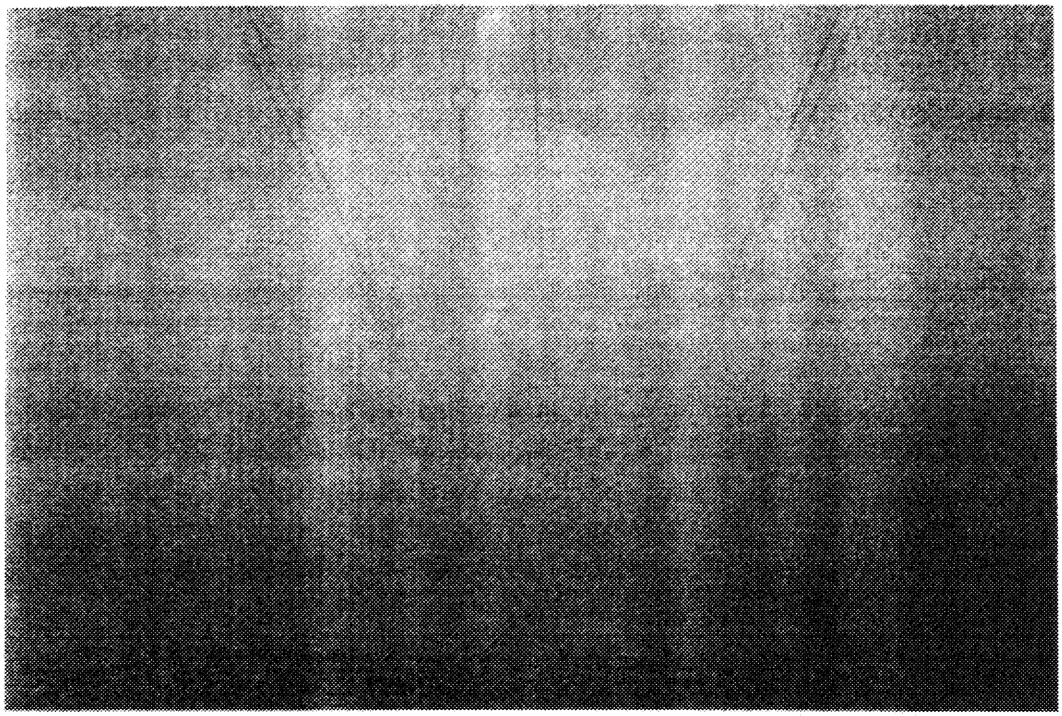

Fig. 1.7 Power lines during times of extremely low visibility due to dense fog.

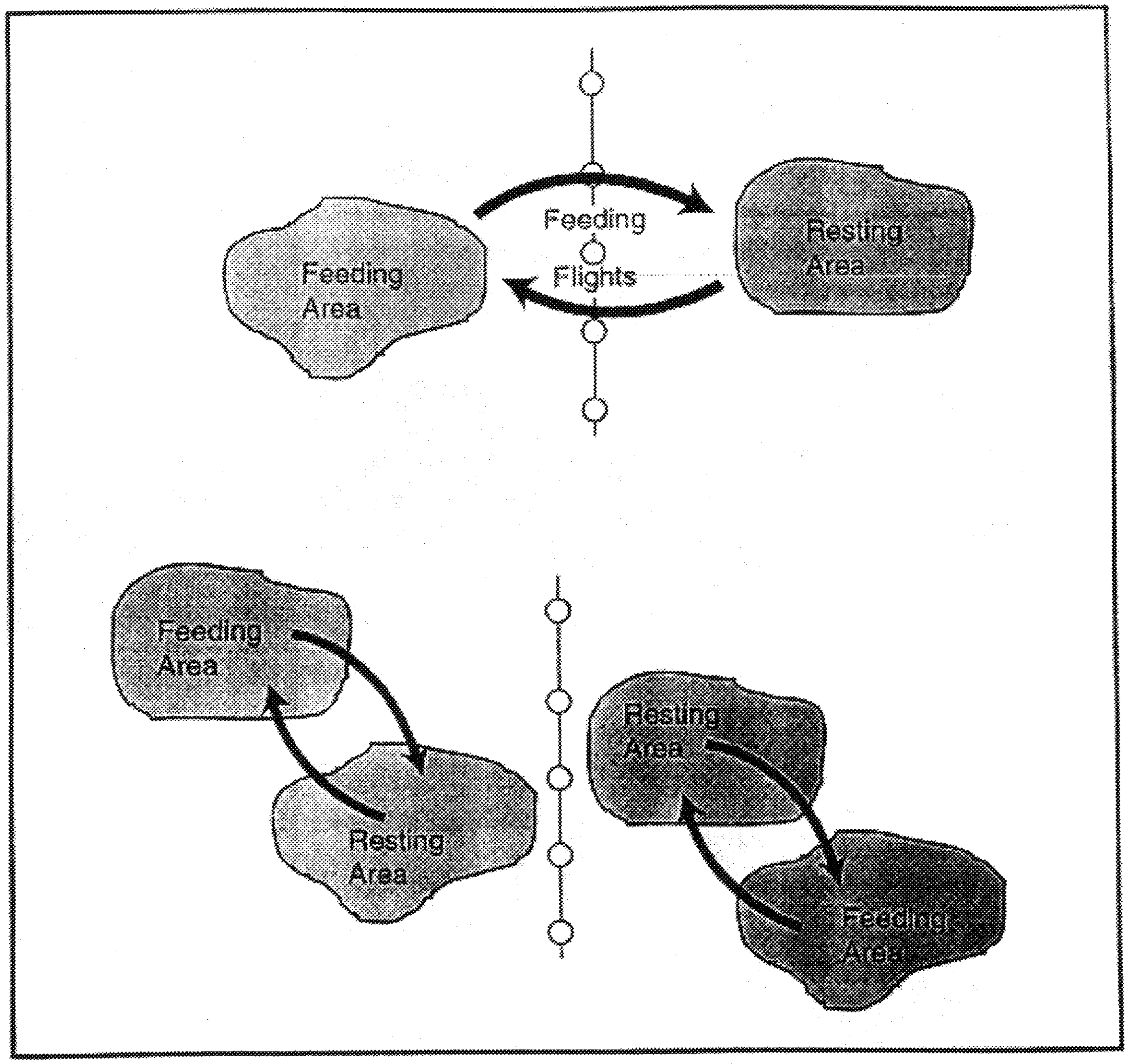

Fig. 1.8 Creating roosting and feeding areas on the same side of power lines would eliminate the need for birds to cross power lines multiple times per day (from APLIC 1994).

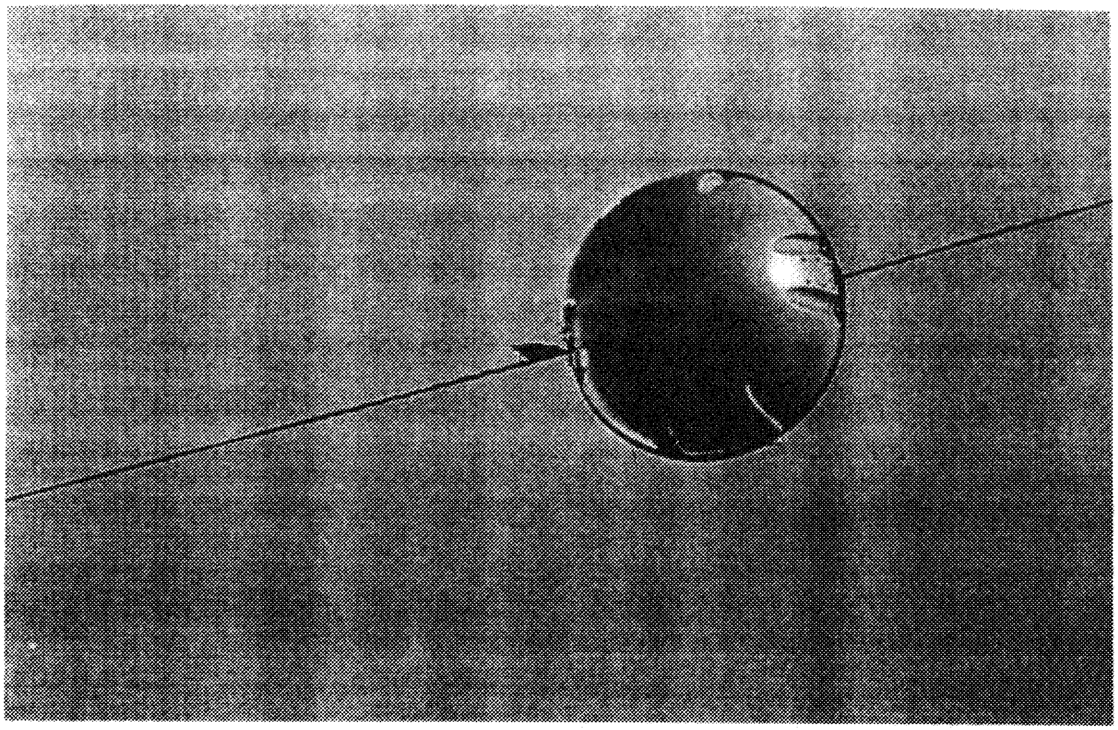

Fig. 1.9 Aviation marking spheres used to increase visibility of ground wires to birds.

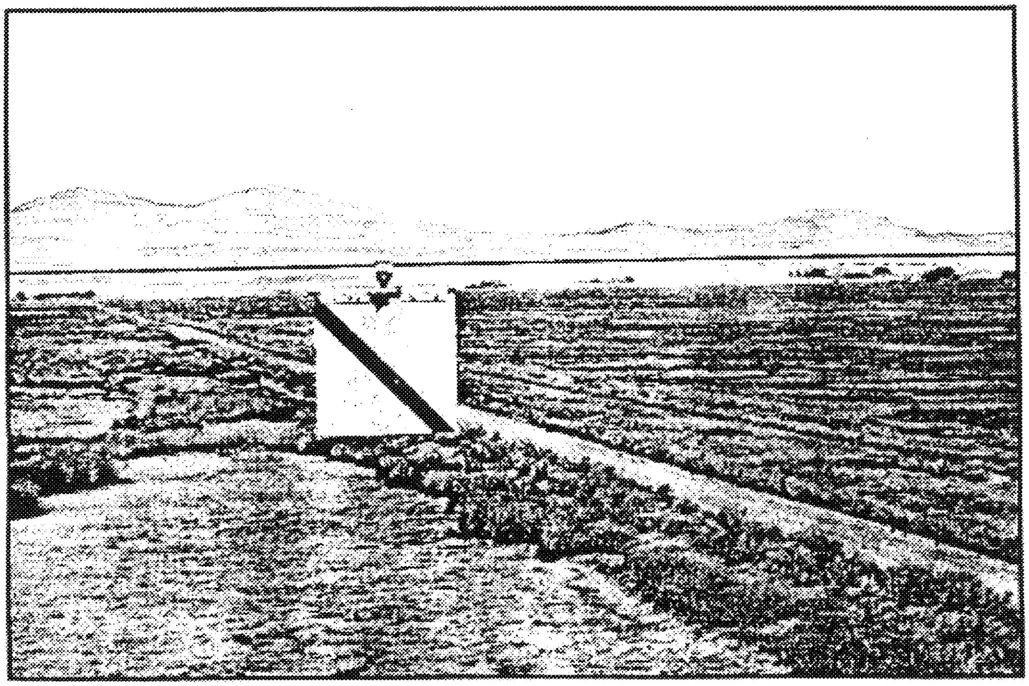

Fig. 1.10 Swinging plates used by Brown and Drewien (1995) to reduce bird collisions with power lines (from APLIC 1994).

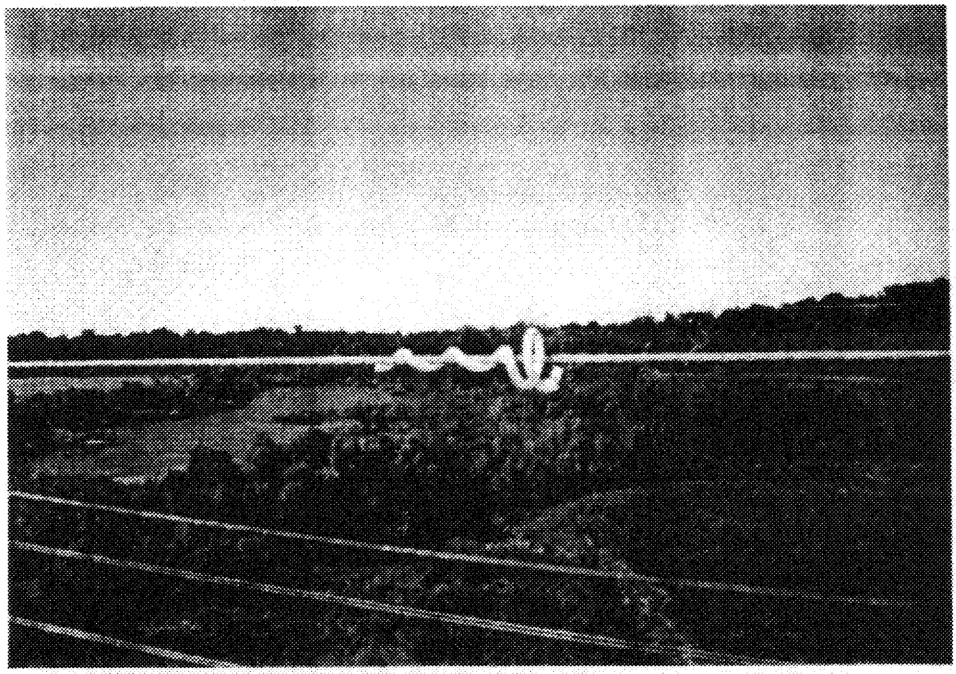

Fig. 1.11 Bird flight diverter placed on transmission line ground wire to reduce bird collisions.

CHAPTER 2

RELATIONSHIPS BETWEEN WING MORPHOLOGY AND BEHAVIORAL RESPONSES TO UNMARKED POWER TRANSMISSION LINES

Abstract

Ground wires associated with high voltage power transmission lines have been identified as a source of mortality for numerous avian species. This research, was conducted at the Cinergy-PSI Gibson County Power Generating Station in Gibson County, Indiana, U.S.A. This site is characterized by a high density of power transmission lines with a 1,214 ha cooling lake and numerous small wetlands in close proximity. Large numbers of waterfowl and other wetland-associated avian species utilize this area in the fall and winter. Bird flight observations were conducted along with corresponding ground searches to determine the species specific reactions of birds to the power lines. The birds most likely to react to power lines were those that approached the lines at a height between the conductor and ground wires. No relationship between flock size and the proportion of birds reacting to the lines was found; however, a significant difference was found in the reaction distances between flocks >10 birds and single birds. Species were grouped into four categories according to wing morphology, and it was determined that species at the greatest risk for collisions were those that showed high wing loading and low wing aspect ratio.

Introduction

Avian mortality associated with power line strikes has been well documented with numerous studies on the effects of power line related mortality on avian species (Willard et al. 1977, Anderson 1978, Meyer 1978, James and Haak 1979, Faanes 1987, Bevanger 1995). In addition, numerous power line ground wire marking studies have been conducted to test the effectiveness of marking devices in reducing avian collisions (Alonso et al. 1994, Brown and Drewien 1995, Savereno et al. 1996, Janss and Ferrer 1998). Utility companies are concerned about this issue for two major reasons: 1) collisions kill thousands of birds each year that are protected by the Migratory Bird Treaty Act and related treaties, and 2) reliability of service to their customers can be compromised by bird strikes.

Due to a more competitive deregulated market system, power utilities companies are anxious to alleviate problems that could create poor public relations or compromise service to their customers. Utilities that do not correct collision hazards promptly could at worst face large fines and/or imprisonment of company employees, and at least face bad publicity in the local media. For example, the Moon Lake Electric Association was required to pay $100,000 in penalties, to retrofit poles to make them bird friendly, and to serve 3 years probation for the electrocution of 170 raptors, mostly Golden Eagles (*Aquila chrysaetos*; Williams 2000). Research on bird reactions to power lines could help design future power grids that reduce collision probabilities; this will better serve the customer by a reduced risk of interruptions, and better serve the company through lower risks of negative publicity.

Previous research has shown that characteristics such as normal flight altitude and flock size can influence the frequency of power line strikes by birds. The size of a bird and its wing shape and morphology also can play an important role in determining the susceptibility of avian species to power line strikes. Rayner (1988) used principal component analysis (PCA) applied to wing morphology to derive statistically independent measures of wing size and wing proportions. Variables based on wing loading (i.e., ratio of body weight to wing area), wing aspect ratio (i.e., ratio of wing span^2 to wing area), and body weights of avian species were used in PCA. A scatterplot was then constructed of the size independent components of wing aspect and wing loading for a large number of avian species (Fig. 2.1, after Bevanger 1998, from Rayner 1988).

Using the information generated by Rayner (1988), Bevanger (1994, 1998) compared known "collision species" from 16 previous studies on avian power line collisions (Scott et al. 1972, McKenna and Allard 1976, Anderson 1978, Meyer 1978, Gylstorff 1979, Christensen 1980, Grosse et al. 1980, Heijnis 1980, Willdan Associates 1980, Longridge 1986, Rusz et al. 1986, Bevanger 1988, Thingstad 1989, Hartman et al. 1992, Bevanger 1993, Bevanger and Sandaker 1993) to species categorized as having high wing loading and found an interesting relationship. In general, as the wing loading of a bird increases, so does its susceptibility to collisions with power lines. Alternatively, as a bird's wing aspect ratio decreases, so does its susceptibility to collisions.

In theory, birds that are most susceptible to wire strikes are those with high wing loading (e.g., small wings for its body size) and low wing aspect ratio (e.g., broad wings; Fig. 2.1, Quadrant IV). This group includes Rayner's (1988) "poor" fliers, which contains many birds in the orders of Galliformes (e.g., grouse and quail) and Gruiformes (e.g., rails and cranes). Rayner (1988) points out that birds in Quadrant IV (Fig. 2.1) have few favorable aspects of flight performance and have probably never faced serious pressure to improve sustained flight performance. Many of these species are ground dwelling birds that use flight only for rapid escape.

My objectives in this research were to: 1) document collision mortality through direct observation and ground searches, 2) describe the relationship between wing morphology (after Bevanger 1998) and collision mortality, and 3) determine whether the frequency at which birds reacted to power lines or the distances at which they reacted are influenced by flock size or wing morphology.

Methods

Study Area

This research was conducted on unmarked power transmission lines during the fall and early winter of 1999-2000. The study site was the Cinergy-PSI Gibson County Power Generating Station which sits on the edge of the Wabash River in southwest Indiana (Fig. 2.2). This area attracts numerous avian species because of its close proximity to the river and the 1,214 ha Gibson Lake and associated wetlands (Fig. 2.3). Gibson Lake is a manmade, elevated lake that is the source of the cooling water for the

Gibson plant site (Fig. 2.4). The lake stays warm and open all year. Large numbers of waterfowl and other wetland-related species are attracted to this area in the fall and winter during migration south, especially at times when other lakes and wetlands in the area are frozen. At one point in the study, 27 January 2000, nearly 41,000 birds were counted on the lake and associated wetlands, with the vast majority of the birds being waterfowl (Anseriformes) species. This area serves as a good model for study of bird reactions to power lines, not only because of the large numbers of birds present, but also due to the presence of several transmission lines situated over the wetland complex. Three specific locations were used for behavioral observations and dead bird searches near the power plant, these lines were named the Gibson Line (Fig. 2.5), the High Line (Fig. 2.6), and the Flooded Timber Line (Fig. 2.7).

Field Observations

To examine the relationship between wing morphology and behavioral responses to unmarked power lines, observational data were collected a minimum of once per week from 27 September 1999 to 13 December 1999. Behavior response data included the physical reactions (if any) of birds to the power lines (for categories see Appendix A and B) and the relative distances at which birds reacted to the power lines. As suggested by the Avian Power Line Interaction Committee (APLIC 1994), additional data collected for each power line over-flight included flock size, species, flight direction, and altitude during approach, crossing, and departure from the lines. Data also were collected on human activity at the study site along with wind speed, wind direction, temperature, light intensity, cloud cover, precipitation, visibility, and line corona noise (in 0.5 hour intervals; Appendix A).

Bird flight observational periods lasted a minimum of 2.5 hours. Observational data were collected with the aid of 7X50 light gathering binoculars from the cover of a ground blind strategically placed to have clear sight of all lines being recorded (Fig. 2.5). When observing lines that had no ground blind in place, researchers observed from existing ground cover so as not to disturb passing birds. Power line spans were chosen for observation on the basis of location (transmission lines ran over water commonly used by waterfowl and other wetland related species) and degree of bird activity in the area. The specific line selected for flight observation was chosen daily so as to achieve the greatest flight intensities in the allotted time period. Because of difficulties in identification of many Passerines, they were grouped into 1 category with the exception of the American Crow (*Corvus brachyrhynchos*).

Dead Bird Searches

Following each behavioral observation period from 27 September 1999 to 13 December 1999, two of the three focal transmission lines were searched for dead birds or feather piles regardless of the focal line observed that day. Ground searches were also conducted from 22 December 1999 to 1 April 2000, but were not included in over-flight/kill data. The Flooded Timber Line was not searched for dead birds due to underlying water. Areas under lines that were not submerged were searched in a slow zigzag fashion so as to maximize coverage of the search zones. Search zones were minimally the width of the right-of-way, but if water conditions permitted, as during the fall and winter of 1999-2000, most areas were searched up to 50 m beyond the outer edge of the lines. All birds and feather piles (Fig. 2.8) found were removed or clearly marked to avoid duplicate counting. Unknown birds were marked and bagged for later identification. It was assumed that all crippled or dead birds and feather piles found under the lines were collision mortalities. There was no hunting allowed in this area and admittance was restricted to researchers and plant personnel.

Using the results of PCA based on wing morphology (Rayner 1988), I classified birds into four quadrants, based on size adjusted variables representing wing loading and wing aspect (Fig 1). Using data from power line observations and ground searches, I calculated the number of over-flights/kill for each species and compared these data among quadrants. This was accomplished by dividing the total number of over-flights in each quadrant by the number of dead birds found in each quadrant after the initial dead bird searches were conducted.

No statistical analyses were performed to compare numbers of over-flights/kill among quadrants. This decision was made on the basis that two potential biases may exist in the dead bird search data set. First, the dead bird searches may be biased if searches resulted in the detection of a higher percentage of larger birds than of smaller birds. Larger birds are easier to find and collect than smaller ones, and previous removal bias studies indicate that smaller birds are often removed faster by predators than larger ones (Raevel and Tombal 1991, Brown and Drewien 1995). Thus, weekly dead bird searches might incorrectly lead to the conclusion that larger bird species strike the power lines relatively more frequently than actually is the case. My second potential bias in the calculation of numbers of over-flights/kill is related to the fact that the over-flight data and the dead bird searches are not precisely matched. The fact that the Flooded Timber Line could be observed but not searched as well as the fact that only one line could be observed at a time, means that the observation data may not always reflect the intensity of over-flights that produced the observed mortalities.

Behavioral Responses

Only data from non-Passerine species approaching the power lines at 10m above the ground wires or below were included in analyses of behavioral responses. Variables were defined for analysis in the following manner. I defined the distance at which birds reacted to the lines (if a reaction was recorded) in a continuous manner (i.e., Reaction Distance; 1 = 0-5m, 2 = 6-10m, 3 = 11-25m; 4 = 26-45m, 5 = >45m). I defined all recorded bird reactions to the lines in a bivariate manner such that the birds were classified as either having reacted to the line (i.e., collision, near collision, flare, altitude change, abort, direction change, flutter, or landed) or no reaction was recorded (Reaction; Yes or No). I recorded flock sizes of birds that reacted to the lines as a discrete variable (i.e., Flock Size; 1 = 1 bird, 2 = 2-5 birds, 3 = 6-10 birds, and 4 = >10 birds). I classified birds into 4 groups, with differing expected susceptibilities to power line strikes, based on a plot of principle component scores for wing aspect and loading (Quadrant; I, II, III, or IV, after Rayner 1988, Fig. 2.1). I defined the altitude at which birds approached the power lines as a discrete variable with three classes (Approach; 1 = ground to conductor height, 2 = conductor to ground wire, and 3 = <10 meters above ground wires).

Data analyses were performed using subroutines in the Statistical Analysis System (SAS; 1989) and all statistical tests were considered significant at a probability value of 0.05 (unless corrected for multiple comparisons). I used Contingency Chi Squared statistics to test the hypothesis that birds approaching the power lines at different altitudes (Approach) did not differ in the frequency with which they reacted (Reaction) to the line. I also used Contingency Chi Squared statistics to test the hypotheses that the frequency at which birds reacted to the lines was independent of Flock Size and Quadrant. I used general linear models to test the hypotheses that the mean distances (Reaction Distance) at which birds reacted to the power line did not differ in regard to either Flock Size or Quadrant. If the main effect of Flock Size or Quadrant was found to account for a significant proportion of the total variance, a means separation test corrected for multiple comparisons using the Dunn-Sidak correction was used to test for differences among mean values of Reaction Distance.

Results

Collisions

During the course of this investigation, I observed and recorded a minimum of 33 species of birds interacting with three transmission lines on the Gibson County Power Generating Station study site with a total of 36,327 over-flights including Passerine species, and a total of 7,993 over-flights of non-Passerine species. During a total of 47.5 hours of observation, there were three instances in which bird collisions with conductors or overhead ground wires were observed.

A total of five collisions were observed during bird flight observations in three separate instances. These collisions involved four Mallards (*Anas platyrhynchos*) and one Double-crested Cormorant (*Phalacrocorax auritus*). The first instance involved a single Double-crested Cormorant flying north at an altitude between the conductor and ground wires of the Gibson Line at 0755 hours on 9 September 1999. The bird reacted to the line less that 5 meters from the edge of the conductors, flared away from the lines, and struck the ground wire in the process. It fell down to the water and swam over to a nearby group of three other cormorants. The bird was observed for over 30 minutes before it flew away, exhibiting no ill effects from the collision. The wind was calm at the time of the collision (10.1 km/hour) with good visibility.

On 10 November 1999, at approximately 1730 hours, a flock of three Mallards were flying north at an altitude between the conductor and ground wires when 1 hen struck the ground wires of the Gibson Line and flew off apparently unharmed. The light intensity was low (23 lux) with a wind speed of 7.5 km/hour. Finally, on 13 December 1999, at 0930 hours, a group of approximately 400 Mallards were feeding in the water under the Flooded Timber Line when a truck moving up the levee of Gibson Lake, which is adjacent to this area, flushed the birds. In the confusion, two birds struck the ground wires and one struck the conductor itself. All three birds flew off, apparently unharmed.

Dead Bird Searches

A total of 48 crippled birds, dead birds, or feather piles, representing 14 species, were found under the power lines during ground searches. Of these, 20 birds were found and identified on the initial power line searches and 13 birds were found after bird flight observations were stopped, leaving only 15 birds that were included in the calculation of over-flights/kill (Table 2.1). Over-flights/kill ranged from 423/0 in Quadrant II to 59.1/1 in Quadrant III (Fig. 2.1).

Behavioral Responses

My analysis indicated that the proportions of birds that reacted to the power lines were not independent of the altitude at which they approached the power line ($\chi^2 = 253$, 2 df, $P<0.001$, $N = 725$). Birds approaching the power lines at an altitude between the conductor and ground wires were much more likely to react (66.5% reacting) than were birds below the conductor height (13.5% reacting) or < 10m above the ground wires (4% reacting, Table 2.2). In addition, my analysis indicated that the proportions of birds reacting to the power lines were not independent of the structural wing morphology (Quadrant) of the bird species represented on my study area ($\chi^2 = 14$, 3 df, $P<0.002$, $N = 734$). Birds with high wing loading (Quadrants I and IV; 25.5% and 28% reacting, respectively) were about twice as likely to react to the power lines as birds with low wing loading (Quadrants II and III; 15% and 14% reacting, respectively; Table 2.2) regardless of wing aspect. I detected no relationship between flock size and the proportions of birds reacting to the power lines ($\chi^2 = 0.47$, 3 df, $P<0.93$, $N = 731$; Table 2.2).

My analysis of the relationship between reaction distance and flock size indicated that there were significant differences in mean reaction distances of birds traveling in different sized groups ($F = 2.7$, 3 df, $P = 0.048$, $N = 146$). Further analysis of differences among mean values indicated that birds travelling in groups of >10 individuals reacted to the power lines at a greater distance ($\bar{x} = 3.08$; ~11.2 m away from outer ground wire) than did birds travelling alone ($\bar{x} = 2.24$; ~6.96 m away from outer ground wire; Table 2.3). My analysis of the relationship between reaction distance and structural wing morphology (Quadrant) indicated that there were significant differences in mean reaction distances of birds with differing wing loading and aspect characteristics ($F = 4.84$, 3 df, $P = 0.0031$, $N = 147$). Further analysis of differences among mean values indicated that birds with the highest aspect and highest wing loading factors (Quadrant I) reacted to the power lines at a greater distance ($\bar{x} = 2.59$; ~8.36 m away from outer ground wire) than did birds with the lowest aspect and highest wing loading factors (Quadrant IV; $\bar{x} = 1.71$, ~3.55 m away from ground wire; Table 2.3).

Discussion

Avian collisions with power lines are relatively rare events, with the majority of strikes occurring during low light conditions or inclement weather. Anderson (1978), in a study of avian interactions with power lines in central Illinois, estimated that one collision occurred for every 250,000 over-flights and stated that waterfowl almost never collide with power lines during daylight hours when visibility is good. My data indicate that the total rate of collision for non-Passerine species on the Gibson County Power Generating Plant site in southern Indiana is much higher than would be predicted from Anderson's work. In fact, my observation of five collisions with power lines in only 7,993 over-flights is among the higher reported collision rates. However, it should be noted that three of the strikes I observed were a result of non-researcher human disturbance.

Bevanger (1998) predicted that the birds that were most susceptible to collisions with power transmission lines were “high risk” species with high wing loading and low wing aspect characteristics (Quadrant IV), and that the birds that were least susceptible to collisions were those with low wing loading and high wing aspect characteristics (Quadrant II; Fig. 2.1). My estimates of the number of over-flights/kill for these quadrants fit this prediction well, although the lowest number of over-flights per kill was actually observed in Quadrant III. However, if Mourning Doves (*Zenaida macroura*), with strong flying abilities compared to other Quadrant IV species, are omitted from the calculations in Quadrant IV, the average number of over-flights/kill drops to 19.0, by far the lowest observed. Alternatively, there were 423 over-flights in Quadrant II with no dead birds found, indicating, as expected, that this quadrant experiences little collision mortality. In general, my data on number of over-flights per kill indicate that as wing aspect decreases (e.g., become broader) collision mortality increases.

My data on distances at which birds react to power lines support the general trends observed in the over-flight per kill data, specifically for those birds in Quadrants representing high wing loading. Of birds that have high wing loading values (i.e., species found in Quadrants I and IV) average reaction distances are significantly smaller for those species showing low wing aspect (Quadrant IV) as opposed to species showing high wing aspect (Quadrant I). This finding strengthens the conclusion that birds with low wing aspect and high wing loading are “poor” fliers relative to species with other wing morphologies and may have a higher probability of experiencing collision mortality than most other species. Additionally, the data on how frequently birds with differing wing morphologies react to power lines suggests that regardless of wing aspect, birds with high wing loading values may be almost twice as likely to react to power lines as those with low wing loading values.

Flock size has long been recognized as a factor influencing the probability of avian interactions with power lines, and has been cited as a factor that can lead to collisions due to reduced visibility of trailing birds in a flock (Scott et al. 1972, James and

Haak 1979). My data show no statistical relationship between flock size and the proportion of birds that reacted to the power lines. Thus, the frequency at which single birds reacted to the power lines was not different from the frequency of reaction by larger groups of birds. However, for those birds that did react to the power lines, I found that the mean distance at which flocks of >10 birds reacted to the power line ($\bar{x} = 3.08$; ~11.2 m away from outer ground wire), was significantly greater than the distance at which solitary birds reacted to the lines ($\bar{x} = 2.24$; ~6.96 m away from outer ground wire). While this finding seems logical, in that the more eyes there are in a flock scanning for obstacles the faster a flock could react to power lines or other objects that are in their way, it does not rule out the possibility that the trailing birds in large flocks may have a higher risk of power line collision than would single birds. Unfortunately, my data are insufficient to test that particular hypothesis.

Conclusion

I recorded a total of 7,993 power line over-flights representing over 33 non-Passerine avian species during 47.5 hours of power line observations at the Gibson County Power Generating Station. Fifteen birds were found during ground searches under the focal power lines after bird flight observation periods. Five avian collisions were observed during observation periods involving four Mallards and one Double-crested Cormorant. The number of crossings per collision observed during this study was much lower than those reported by other researchers, suggesting that there is a potential problem with strike mortality at this site.

Birds most likely to react to power lines are those that approach power lines between the conductor and ground wires, as opposed to under the conductor or <10m above the ground wires. This would indicate that birds approaching power lines near the height of the wire are likely to perceive the lines and react to avoid them. There was no relationship found between flock size and the proportion of birds reacting to the lines; however, birds in flocks >10 reacted to power lines at greater distances that did solitary birds.

My data suggest that the avian species that are at the greatest risk for collision mortality are those with high wing loading and low wing aspect. In addition, species with high wing loading were nearly twice as likely to react to power lines than were birds with lower wing loading characteristics, although species with high wing loading and low wing aspect react to the lines at greater distances than do species with high wing loading and low wing aspect.

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Table 2.1 Totals for dead bird searches and over-flight data for the Gibson County Power Generation Station study site for 1999-2000.

Species	Scientific Name	Total Number of Birds Found	Number of Dead Birds Included[a]	Number of Over flights[b]	Quadrant[c]
American Bittern	*Bothaurus lentiginosus*			7	3
American Black Duck	*Anas rubripes*	3	2	15	1
American Coot	*Fulica americana*	3	1	1	4
American Crow	*Corvus brachyrhynchos*			98	3
American Wigeon	*Anas americana*			12	1
American Woodcock	*Scolopax minor*			1	1
Black-crowned Night-Heron	*Nycticorax nycticorax*	1	1	0	3
Blue-winged Teal	*Anas discors*			12	1
Canada Goose	*Branta canadensis*			117	1
Common Goldeneye	*Bucephala clangula*			3	1
Common Snipe	*Gallinago gallinago*	1		3	1
Double-crested Cormorant	*Phalacrocorax auritus*	4		18	4
Gadwall	*Anas strepera*	2	2	107	1
Great Blue Heron	*Ardea herodias*	7	5	194	3
Great Egret	*Ardea alba*	10	1	112	3
Green-winged Teal	*Anas crecca*			19	1
Hooded Merganser	*Lophodytes cucullatus*			181	1
Killdeer	*Charadrius vociferus*			62	2
Lesser Scaup	*Aythya affinis*			1	1
Mallard	*Anas platyrhynchos*	6	1	5918	1
Mourning Dove	*Zenaida macroura*			357	4
Northern Harrier	*Circus cyaneus*			3	2
Northern Pintail	*Anas acuta*			30	1
Northern Shoveler	*Anas clypeata*	2	1	20	1
Red-winged Blackbird	*Agelaius phoeniceus*	3			.
Ring-billed Gull	*Larus delawarensis*			300	2
Rock Dove	*Columba livia*	1	1	3	1
Sandhill Crane	*Grus canadensis*			1	3
Snow Goose	*Chen caerulescens*			29	1
Wood Duck	*Aix sponsa*	1		309	1
Yellow-billed Cuckoo	*Coccyzus americanus*	2		0	2
Raptorial spp.				2	3
Shorebird spp.				58	2
Unknown		2			.
Totals		48	15	7993	

[a] Total number of dead birds found minus the birds found on initial searches, and birds found after bird flight observations had stopped.

[b] The total number of overflights did not include Passeriformes species.

[c] From Fig. 2.1

Table 2.2 The number and proportion of birds that reacted to power lines by approach altitude class (1 = below conductor height; 2 = between conductor and ground wires; 3 = <10 m above the ground wires), flock size group, and quadrant (quadrants based on wing morphology from Fig 2.1).

Altitude Class

	1	2	3
Yes	37	101	12
%	13.45	66.45	4.03
No	238	51	286
%	86.55	33.55	95.97

Flock Size

	1	2-5	6-10	>10
Yes	77	49	10	13
%	19.74	20.68	20.41	23.64
No	313	188	39	42
%	80.26	79.32	79.59	76.36

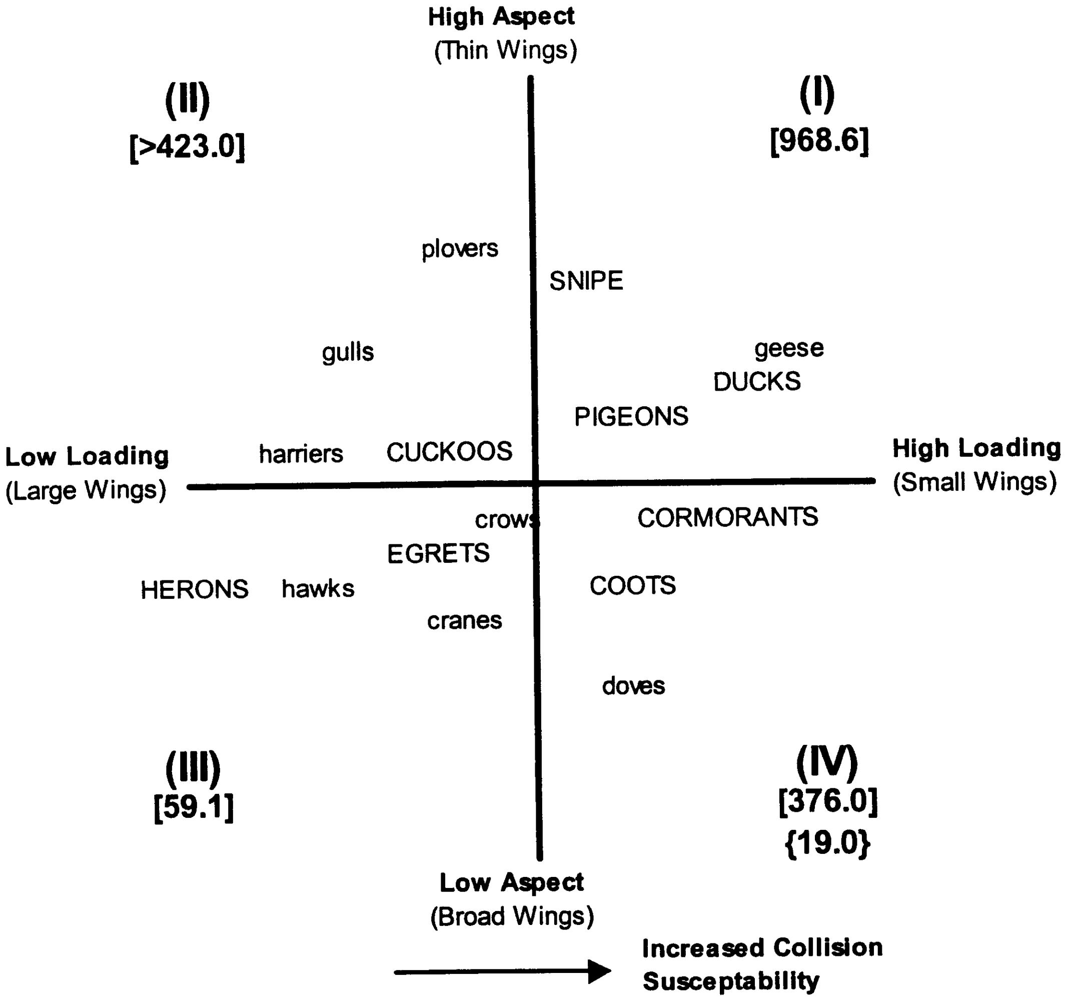
Quadrant

	I	II	III	IV
Yes	85	99	251	50
%	24.45	15.15	14.34	28.00
No	249	84	215	36
%	74.55	84.85	85.66	72.00

Table 2.3 Mean values for bird reaction distance from the power lines for each flock size group and quadrant (quadrants based on wing morphology from Fig 2.1).

	Flock Size			
	1	2-5	6-10	>10
$\bar{x}$	2.24	2.25	2.40	3.08
SE	0.11	0.15	0.31	0.38
n	76	48	10	13

	Quadrant			
	I	II	III	IV
$\bar{x}$	2.59	2.07	2.08	1.71
SE	0.11	0.23	0.16	0.27
N	83	15	36	14



ALL CAPS: Groups of birds found dead in our study site under power lines.
lower case: Groups of birds that interacted with the power lines that were not found dead.
[]: Indicates the number of overflights per kill in each quadrant.
{}: Indicates the number of overflights per kill in Quadrant IV, not including Mourning Doves.

Fig. 2.1 Groups of birds that interacted with power lines on our study site arranged according to wing morphology expressed in principal component form where statistically independent measures of size and wing proportions are derived (modified from Bevanger 1998, after Rayner 1988).

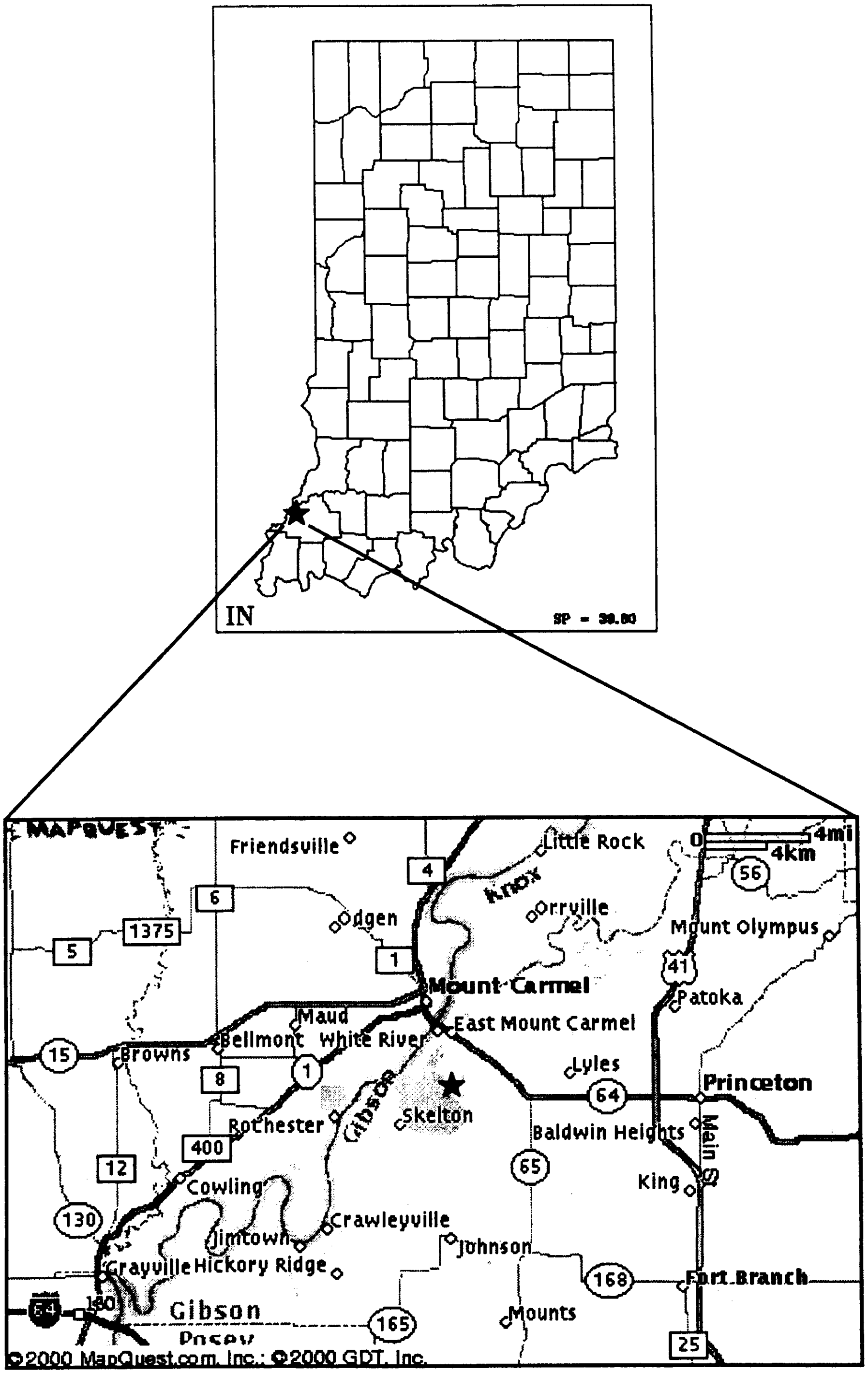


Fig. 2.2 Study (represented as a star) area located at the Cinergy-PSI Gibson County Generating Station.

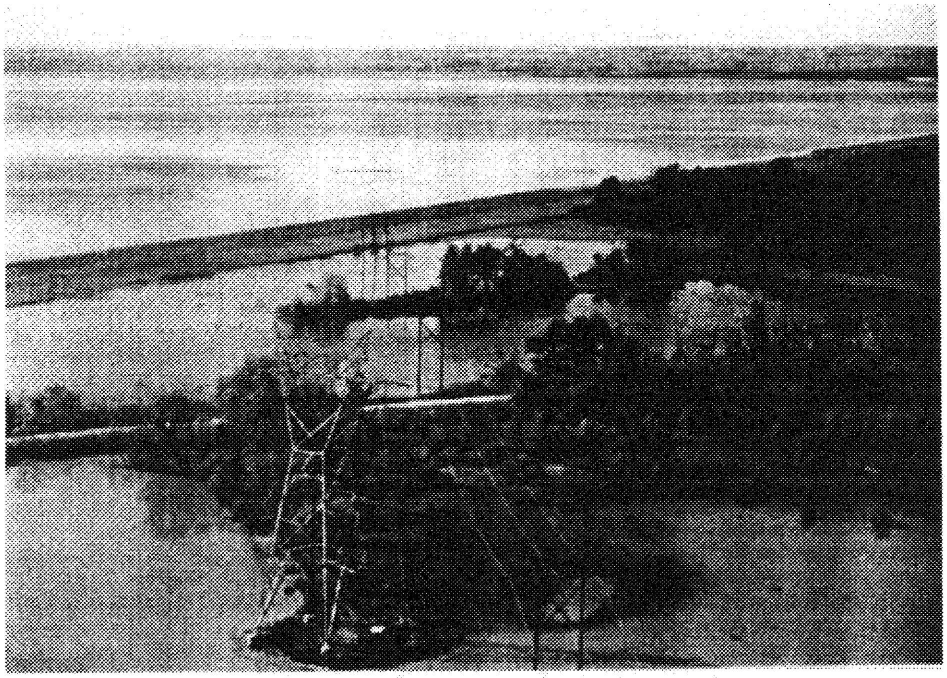


Fig. 2.3 Gibson Lake (top) and associated wetlands on the Cinergy-PSI Gibson County Power Generating Station.

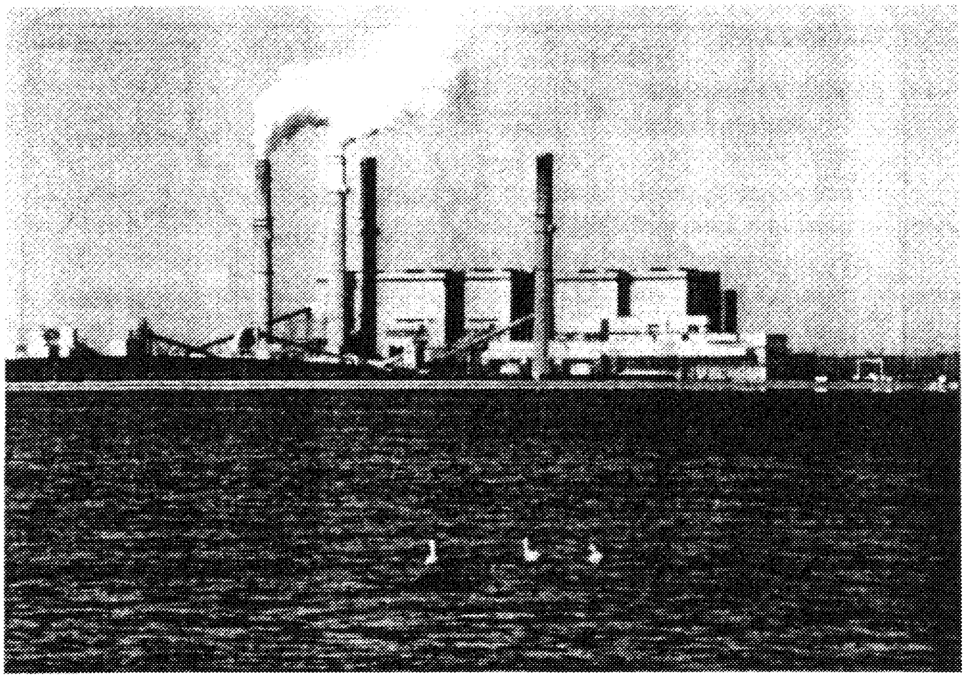


Fig. 2.4 Gibson Lake with the Gibson County Power Generating Station.

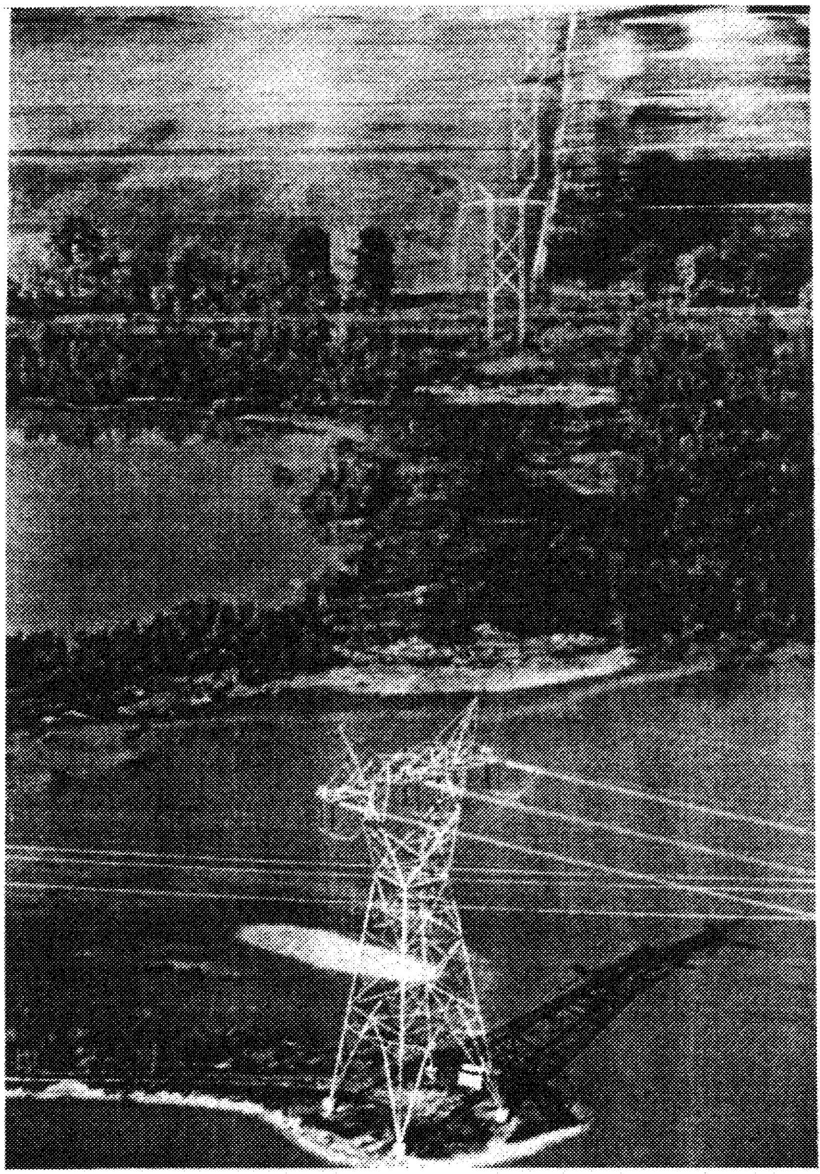


Fig. 2.5 Overhead view of the Gibson Line observation area. Note observation blind at the base of the tower in foreground.

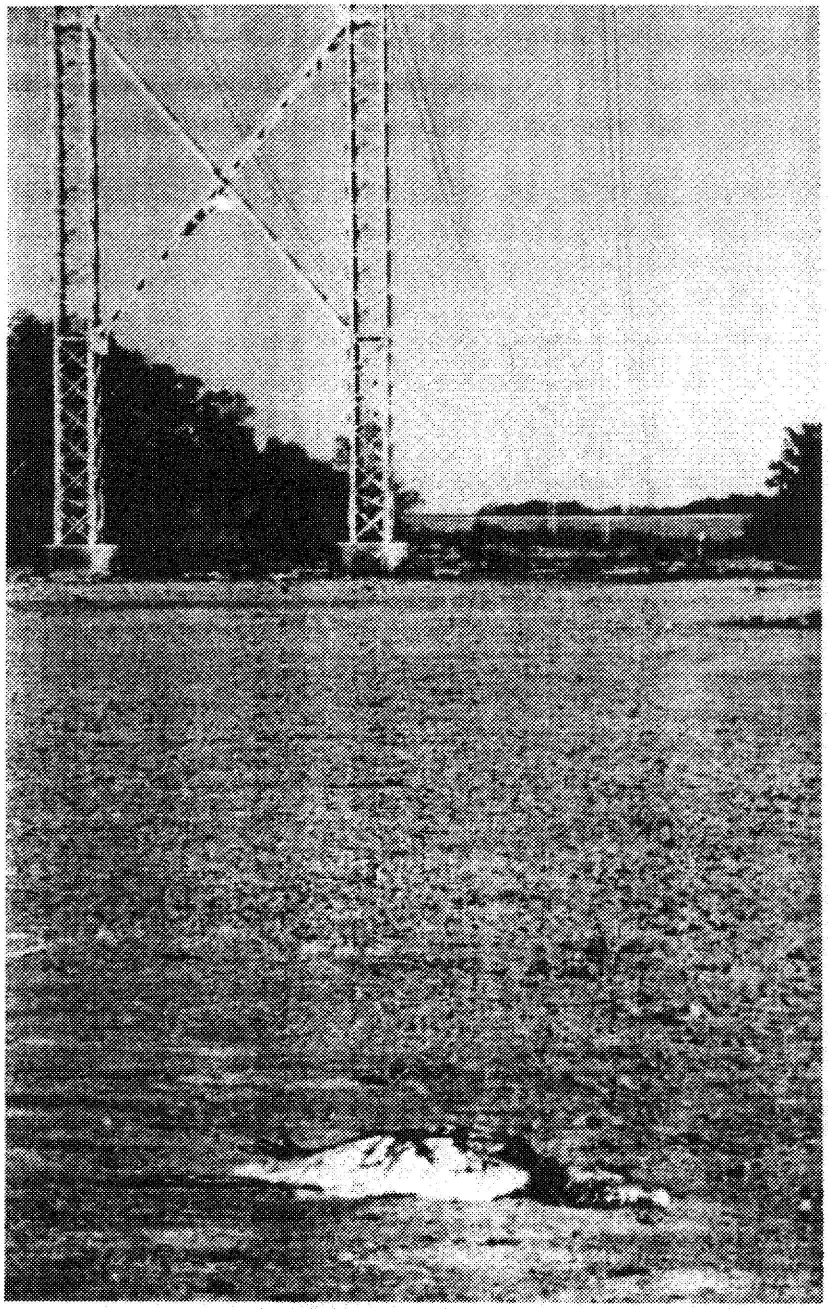


Fig. 2.6 The High Line observation area with dead Great Egret found beneath.

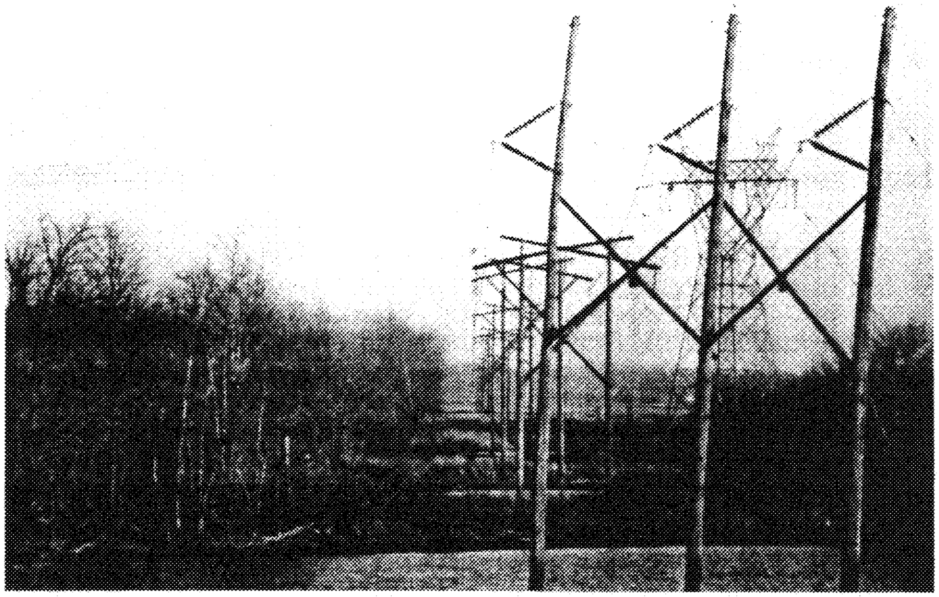


Fig. 2.7 The Flooded Timber Line observation area.

Fig. 2.8 Example of typical feather pile found during ground searches.

CHAPTER 3

POWER LINE MARKING TO REDUCE WATERFOWL COLLISIONS IN SOUTHERN INDIANA

Abstract

Avian mortality caused by collisions with power transmission lines have previously been reported and several power line marking devices have been tested to reduce the number of collisions. In this study, the effectiveness of yellow and gray Bird Flight Diverters (BFD) and Swan Flight Diverters (SFD) was tested in reducing waterfowl (Anseriformes) and other avian collision mortality in southern Indiana, USA. This was accomplished through 125 ground searches under focal spans during two consecutive field seasons to detect birds killed by collisions. Ground searches were conducted during the winter months to maximize the numbers of birds that were using the study area, with the first field season being the control phase (no markers present), and the second field season used as the treatment phase (markers present). Research biases also were calculated for search, removal, habitat, and crippling biases. The estimated total number of collisions for marked lines was reduced by 51.4% compared to the same spans before marking. The BFDs reduced collision mortality by 73.3%, including a 76.3% and 57.3% reduction in collision mortality by yellow and gray BFDs, respectively. The SFDs reduced collision mortality by 37.5%, including 25.0% and 43.8% reduction in collision mortality by yellow and gray SFDs, respectively.

Introduction

Avian mortality associated with power line collisions has been studied for many years (Scott et al. 1972, Avery 1978, Meyer 1978). Most research in the field of avian power line strikes tends to address "worst case scenarios" such as lines that run through wetland areas with high concentrations of waterfowl or lines that bisect adjacent roosting and feeding sites. In situations such as these, the collision rates of birds can be quite high (Faanes 1987). Avian mortality associated with power line collisions is not thought to affect healthy populations, but can have a significant effect on populations with low numbers of individuals, such as endangered species [Avian Power Line Interaction Committee (APLIC) 1994].

Generally, power line casualties are thought to be isolated and relatively uncommon events (Faanes 1987), although the additive effects of such collisions are poorly understood. The United States Fish and Wildlife Service (USFWS) has been aware of problems associated with bird collisions and electrocutions for many years, however, only recently has this agency began to use the threat of prosecution to modify the behavior of power utilities toward collision mortalities. Violations of the "take" provisions of the Migratory Bird Treaty Act, the Bald and Golden Eagle Protection Act, and the Endangered Species Act can be levied against a utility company if prompt action is not taken to modify a line after it has been identified as a problem location. Penalties for violations of these acts can involve fines of $10,000 - $500,000, along with two years of imprisonment (Suazo 2000). Thus, mitigation of avian mortality due to power line collision has recently become a focal area of research for power utilities companies.

Research has indicated that most collisions between birds and power line structures occur with overhead ground wires (Scott et al. 1972, Brown et al. 1987, Faanes 1987, Savereno et al. 1996), also known as earthen wires, shield wires, or static wires. The primary function of ground wires is to protect energized conductors from lightning strikes (APLIC 1994). Studies focused on reduction of collision mortality have investigated solutions such as ground wire removal (Beaulaurier 1981, Brown et al. 1987), enlarged ground wires (Brown et al. 1987), and ground wire marking devices (Morkill and Anderson 1991, Alonso et al. 1994, Brown and Drewien 1995, Savereno et al. 1996, Janss and Ferrer 1998). Of the available options, ground wire marking is usually considered best for reducing collisions on existing lines because: 1) enlarging ground wires has not been found effective in reducing collisions (Brown et al. 1987), 2) it is not feasible to remove ground wires in most areas because of the need for lightning protection (APLIC 1994), 3) the removal of ground wires is no more effective in reducing collisions than marking them (Beaulaurier 1981, Brown et al. 1987), and 4) marking of ground wires effectively reduces avian collisions without compromising reliability of electrical service to customers.

Numerous marking devices designed to reduce collision risk to avian species have been tested, and it has been determined that most avian species react at greater distances and fly higher over marked verses unmarked lines (Morkill and Anderson 1991, Brown and Drewien 1995). Marking devices tested include: flags (Koops de Jong 1982, as cited in APLIC 1994), ribbons (Scott et al. 1972), tape (Scott et al. 1972), stripes (Janss and Ferrer 1998), aluminum balls (Leppers 1966, as cited in APLIC 1994), raptor silhouettes (Heijnis 1975, as cited in Beaulaurier 1981, Janss et al. 1999), plastic tubes (Archibald 1987), fishing floats (Kaiser and McKelvey 1978, as cited in Beaulaurier 1982), strobe lights (Willdan Assoc. 1981), aviation spheres (Tacha et al. 1979, Willdan Assoc. 1981, Howard et al. 1987, Morkill and Anderson 1991, Savereno et al. 1996), swinging plates (Brown and Drewien 1995), PVC spirals (Alonso et al. 1994), polypropylene spirals (Janss and Ferrer 1998), neoprene crossed bands with a phosphorescent stripe (Janss and Ferrer 1998), spiral vibration dampers (Brown and Drewien 1995), bird flappers (cited in van Rooyen and Ledger 1999), and bird flight diverters (Koops and de Jong 1982, as cited in APLIC 1994) with different color combinations and spacing (Crowder and Rhodes In Press).

Because of the low probability of actually observing avian collisions with power lines, ground searches for dead birds often have been used by researchers to assess levels of avian mortality from power line collision (Faanes 1987, Morkill and Anderson 1991, Alonso et al. 1994, Brown and Drewien 1995, Janss and Ferrer 1998). Consequently, ground searches also have been used to assess the effectiveness of power line marking systems by comparing numbers of birds found under focal spans before and after marking, or by comparing the numbers of birds found under marked spans to unmarked spans during the same time frame. Although data collected via ground searches for dead birds provide direct evidence of avian mortality associated with power lines collisions, certain biases (i.e., search, removal, habitat, and crippling) are recognized to affect estimates of total avian mortality generated from search data (Meyer 1978, James and Haak 1979, Beaulaurier 1981, Faanes 1987, APLIC 1994, Brown and Drewien 1995, Savereno et al. 1996). Thus, it is imperative that these biases be estimated if ground search data are to be used to estimate levels of avian mortality associated with power line collisions.

In this study, I tested the effectiveness of two power line marking devices for reducing avian collisions with power lines using estimates of collision mortality based on ground searches for dead birds. My objectives were to: 1) determine rates of collision mortality on marked and unmarked power lines by means of regular ground searches, and 2) estimate biases associated with ground search data collected on my study area.

Study Area

The study area was located in Knox County, Indiana, USA, a heavily farmed and waterfowl rich area of southwestern Indiana (Fig. 3.1). The power line under observation consisted of two, clustered (i.e., two power lines in the same right-of-way), 345-kV power transmission lines, each with a pair of overhead ground wires (Fig. 3.2). These lines are owned by the local power utility, Cinergy-PSI, and run through a privately owned wetland complex that is heavily used by waterfowl species during the winter months. The study site was selected for research because the transmission lines on the site bisected roosting and feeding sites that were heavily used by waterfowl and separated by less than 200 meters (Fig. 3.3). Power lines that separate roosting and feeding sites are particularly hazardous in that birds are forced to cross the power lines multiple times each day to gain access to both habitat types. In addition, research has demonstrated that power lines bisecting adjacent roosting and feeding sites create a situation in which birds using these areas have less time to react to the lines after taking flight than those using areas that are separated by greater distances (Brown et al. 1984, 1987, Faanes 1987, Morkill and Anderson 1991).

The roosting sites on my study area, located on the north side of the transmission line, consisted of flooded hardwood timber (Figs. 3.4 and 3.5), open water marsh areas (Fig. 3.6), and moist soil management units (Fig. 3.7). The main feeding area for waterfowl was located on the south side of the transmission line and consisted of a flooded corn field. Although the corn field was used for normal agricultural production, it was intentionally flooded each year after the crops were harvested to attract waterfowl (Fig. 3.8). The food base for waterfowl on the feeding areas during this study consisted of wild weed seed and corn (*Zea mays*). The configuration of the study site provided an excellent opportunity to test collision mitigation devices due to: 1) high waterfowl numbers in close proximity to the power lines, 2) large numbers of daily over-flights on each span, and 3) the fact that these lines bisected adjacent roosting and feeding sites.

Methods

Design and Set Up

The study design was guided by recommendations made by APLIC (1994) for post-construction monitoring and line modification studies. Because of the extremely localized collision hazard in the study area (Fig. 3.9), this study utilized only three adjacent focal spans; from west to east they are Alternate 2 (A2; 304.8 m; Fig. 3.10), Main Line (ML; 307.8 m; Fig. 3.11), and Alternate 1 (A1; 304.8 m; Fig. 3.11). The localized nature of the focal spans prohibited the simultaneous utilization of control and treatment spans due to the potential for shadowing effects. Alonso et al. (1994) suggested that birds avoided marked spans by changing their flight direction and either flew through adjacent unmarked spans or aborted their flight, suggesting that marked spans influence results on adjacent control spans (shadowing).

Data were collected during winter months to maximize the number of waterfowl presents. During the first field season prior to installation of marking devices (149 days; 6 November 1998 to 4 April 1999), ground searches were conducted on all focal spans. During the second field season (191 days; 27 September 1999 to 31 March 2000), two ground wire marking devices were installed sequentially. Dulmison™ Bird Flight Diverters (BFD; 24.1 cm x 7.0 cm; Fig. 3.12) and Swan Flight Diverters (SFD; 63.5 cm x 19.1 cm; Fig. 3.13), each in yellow and gray, were placed at 6 m intervals on the two outermost ground wires of the clustered transmission lines (Fig. 3.14). Bird Flight Diverters were installed and monitored on ML (yellow) and A1 (gray) from 27

September 1999 to 28 February 2000 (159 days; Fig. 3.15). Subsequently, SFDs replaced BFDs on ML (gray) and A1 (yellow) and monitored from 29 February 2000 to 31 March 2000 (32 days; Fig. 3.16). Due to factors beyond the control of the researchers, replacement of the BFDs with SFDs was delayed, resulting in 63 fewer days of monitoring activity for this marker type than expected. Colors were alternated between focal spans for each marker type to reduce the influence of span location on the assessment of color effectiveness. Only two contiguous spans, ML and A1, received sufficient numbers of over-flights in year one to warrant their selection for the treatment phase of the study.

Dead Bird Searches

Searches for dead or crippled birds and feather piles were conducted under focal research spans a minimum of one time per week during each field season. The search zone extended perpendicularly 45 m beyond the outer conductors on each side of the clustered lines. Prior to the initiation of ground searches in each field season, all dead birds and feather piles were cleaned from the search zone. Ground searches were conducted in a zigzag pattern throughout the searchable area under the northernmost line from west to east, and from east to west under the southernmost line. All birds and feather piles detected during search activities were removed from the study site to prevent duplicate counting. When birds or feather piles were found under the lines, they were collected and bagged for identification, assigned a unique number, and their locations were marked on a map. When possible, data collected for each bird included; date, time, location, species, sex, age, approximate time of death, physical condition, and estimated cause of death. If only a feather pile was found, data collected included; date, time, species (if possible), and location unless evidence was found to suggest that a bird was not killed by the power line. All dead birds, crippled birds, and feather piles were considered to be collision mortalities. Thus, my data represent a maximum estimate of collision mortality on the site.

Bias Estimates

For many years, researchers have recognized that certain biases influence the accurate assessment of the numbers of birds that collide with power lines (Meyer 1978, James and Haak 1979, Beaulaurier 1981, Faanes 1987, Brown and Drewien 1995, Savereno et al. 1996). APLIC (1994) discussed four common biases associated with dead bird searches and provided formulas for estimation of the influence of these biases on estimates of total collisions.

Total of Dead Birds Found

All dead birds (Figs. 3.17 and 3.18), crippled birds, and feather piles (Fig. 3.19) collected on ground searches under lines ML and A1 in the first (n = 38 searches; unmarked) and second (n = 61 searches; marked) field seasons were used to calculate the total number of dead birds found (TDBF).

Search Bias

The search bias takes into account birds that are not detected during ground searches due to the lack of observer experience, terrain, or vegetation. This bias was calculated for my research by planting dead birds in the study area, conducting ground searches for dead birds, and determining the percentage of birds found. The formula used to determine search bias was SB = (TDBF/PBF) - TDBF, where the SB = search bias, TDBF = total dead birds, feather piles, and crippled birds found, and PBF = the proportion of planted birds found by searchers.

Removal bias

The removal bias takes into account the proportion of birds that are completely removed by scavengers before researchers conduct ground searches. The removal bias was calculated for this research by planting dead birds in the study area and determining the proportion of birds that were removed by scavengers without a trace within 1 week as suggested by APLIC (1994). The formula used to determine the removal bias was RB =

(TDBF + SB)/PNR - (TDBF + SB), where RB = removal bias and PNR = proportion of planted birds not removed by scavengers.

Habitat Bias

The habitat bias takes into account areas in the search zone that are unsearchable due to thick vegetation or water in at least 1 year of the survey. To calculate this bias, a digitized aerial photo of the study site was downloaded from Microsoft® Terraserver onto ArcView®. First, the total area (m^2) of the search zone was calculated (Fig. 3.20). Next, the percent searchable area within the total area during control and treatment years was calculated. The formula used to determine the habitat bias was HB = (TDBF + SB + RB)/PS - (TDBF + SB + RB), where HB = habitat bias, and PS = the proportion of an area that is searchable.

Crippling Bias

The crippling bias takes into account the number of birds that strike power line ground wires or conductors that either do not fall or fall outside the designated search zone. This bias assumes that all birds that strike power lines ultimately die due to injuries received from collisions. The crippling bias in this study was calculated based on 702.5 hours of unpublished observational data collected concurrent to collection of ground search data, supplemental observations of power line collisions seen while on the study site were also included. Of all biases that are calculated to better estimate the number of collisions to power lines, the crippling bias is the bias mostly likely to create the greatest error into the final number. The formula used to determine the crippling bias was CB = (TDBF + SB + RB + HB)/PBK – (TDBF + SB + RB + HB), where CB = crippling bias, and PBK = the proportion of observed collisions falling within the search zone.

Collision Estimates

Estimate of Total Collisions

Using data on the total numbers of dead birds found and estimates for each research bias, I calculated the estimated total number of collisions (ETC) for each field season. These estimates utilized all dead birds found during ground searches in the first (n = 38 searches; 6 November 1998 to 4 April 1999) and second (n = 61 searches; 6 November 1999 to 4 April 2000) field seasons. The formula used to calculate the estimated total number of collisions was ETC = TDBF + SB + RB + HB + CB.

Unmarked vs. Marked Lines

Observational data on avian over-flights of the focal power line spans (702.5 hours of observation; unpublished) were collected during the same time frame as were data from ground searches. I used these observational data to estimate the temporal distribution of waterfowl species on the site during each field season. Using these data, I observed that while the relative proportions of waterfowl species on the site were consistent over time between field seasons, the distribution of waterfowl species on the site changed over time within field seasons. Thus, to maintain consistency in species composition for comparisons of all subsets of marked and unmarked lines, I used only those ground search data that were collected during the same time frame in each field season for comparisons of marked (overall, BFD only, and SFD only) and unmarked lines.

For the overall comparison of numbers of birds found per search under marked versus unmarked lines, all ground search data collected on lines ML and A1 in the first (n = 38 searches; unmarked) and second (n = 61 searches; marked) field seasons were used. For the comparisons of numbers of birds found per search under unmarked lines versus lines marked with BFDs, overall and by color, only ground search data collected on lines ML and A1 during the period from 6 November to 28 February in each field season (n = 32 searches in 1998-99 and n = 45 searches in 1999-00) were used. Specific comparisons involving yellow BFDs used data only from line ML while those for gray BFDs used data only from line A1. For the comparisons of numbers of birds found per search under unmarked lines versus lines marked with SFDs, overall and by color, only ground search data collected on lines ML and A1 during the period from 29 February to 4 April in each field season (n = 6 searches in 1998-99 and n = 16 searches in 1999-00) were used. Specific comparisons involving yellow SFDs used data only from line A1 while those for gray SFDs used data only from line ML. The numbers of birds per search were calculated for each data set by dividing the number of birds found by the corresponding number of ground searches conducted for each comparison of marked versus unmarked lines. The percent reduction in numbers of birds found per search for each comparison of marked versus unmarked lines was calculated as [1-((BPS marked set)/(BPS unmarked set))].

Results

Bias Estimates

Total of Dead Birds Found

There was a total of 35 birds found during the first field season, and 17 birds found during the second field season (TDBF) on ground searches conducted under lines ML and A1.

Search Bias

Searchers found 40 of 42 (95.2%) planted birds the first field season and 18 of 19 (94.7%) planted birds the second field season. Consequently, the data sets were pooled to obtain a total of 58 of 61 (95.1%) planted birds found. Thus, I estimated that 1.80 birds the first field season, and 0.88 birds the second field season were missed during ground searches.

Removal Bias

Predators removed 8 of 27 (29.6%) planted birds without a trace within one week the first field season and 4 of 13 (30.8%) birds the second field season. Consequently, the data sets were pooled to obtain a total of 12 of 40 (30.0%) birds removed by scavengers within one week without a trace. Thus, it was estimated that 15.77 birds the first field season, and 7.66 birds the second field season were removed by scavengers before researchers could find the birds. During this study, Virginia opossums (*Didelphis virginiana*; Fig 3.21), raccoons (*Procyon lotor*; Fig 3.22), striped skunks (*Mephitis*

mephitis), and Northern Harriers (*Circus cyaneus*) were observed scavenging on dead birds on the study site.

Habitat Bias

I determined that 40.8% of the search zone was searchable during both field seasons. Thus, I estimated that 76.29 birds the first field season, and 37.05 the second field season were missed in the unsearchable area caused by thick vegetation or water.

Crippling Bias

Based on 702.5 hours of unpublished observational data, along with supplemental observations of power line collisions on the study site, 2 of 11 birds striking power lines landed within the search zone. One bird landed within the outer conductor, and one bird landed within 5 meters of the outer line. Therefore, I estimated that a crippling bias of 81.8% existed for the study area. Using a crippling bias of 81.8%, I estimated that 579.18 birds in the first field season, and 281.31 in the second field season struck the power lines but landed outside of the search zones.

Collision Estimates

Estimate of Total Collisions

Using data from all birds found during ground searches in both field seasons and taking into account estimates for all research biases, I estimated the total number of collisions that occurred with the focal spans during the study to be 708.04 for the first field season, and 343.91 for the second field season. Therefore, I observed a 51.4% reduction in ETCs involving marked versus unmarked lines.

Unmarked vs. Marked Lines

In my overall analysis of the data from marked vs. unmarked lines, 35 birds were found under unmarked lines (0.92 birds per search; BPS), and 17 birds were found under marked lines (0.28 BPS). This represented a 69.7% reduction in the number of birds found per search under marked as opposed to unmarked lines.

Unmarked Lines vs. BFDs

Thirty-two birds were found under unmarked lines in the first field season (1.00 BPS), and 12 birds were found under lines marked with BFDs in the second field season (0.27 BPS). This represented a 73.3% reduction in the number of birds found per search under marked as opposed to unmarked lines. When these data were further separated by marker color, 27 birds were found under line ML (unmarked) in the first field season (0.84 BPS), and 9 birds were found under line ML (marked with yellow BFDs), in the second field season (0.20 BPS). This represented a 76.3% reduction in the number of birds found per search under lines marked with yellow BFDs as opposed to unmarked lines. Five birds were found under the unmarked A1 line in the first field season (0.16 BPS), and 3 birds were found under line A1, marked with gray BFDs, in the second field season (0.07 BPS). This represented a 57.3% reduction in the number of birds found per search under lines marked with gray BFDs as opposed to unmarked lines.

Unmarked Lines vs. SFDs

Three birds were found under unmarked lines in the first field season (0.50 BPS), and 5 birds were found under lines marked with SFDs in the second field season (0.31 BPS). This represented a 37.5% reduction in the number of birds found per search under marked as opposed to unmarked lines. When markers were further separated by color, 1 bird was found under line A1 (unmarked) in the first field season (0.17 BPS), and 2 birds were found under line A1, marked with yellow SFDs during the second field season (0.13 BPS). This represented a 25.0% reduction in the number of birds found per search under lines marked with yellow SFDs as opposed to unmarked lines. Two birds were found under the unmarked line ML in the first field season (0.33 BPS), and three birds were found under the ML line marked with gray SFDs, in the second field season (0.19 BPS). This represented a 43.8% reduction in the number of birds found per search under lines marked with gray SFDs as opposed to unmarked lines.

Discussion

My data indicate that the estimated total number of avian collisions with power lines on the study site decreased from 708 in the first field season to 344 in the second field season. This represents a 51% reduction in numbers of collisions with marked versus unmarked lines. To show that the number of over-flights during the treatment phase of the project was not significantly different than the control phase, the number of over-flights per observation hour was calculated. There were a total 53,833 over-flights recorded in 291.5 hours of observation during the control field season (184.7 over-flights/hour), and 50,953 over-flights were recorded in 265 hours of observation during the same time span of the treatment field season (192.3 over-flights/hour; unpublished data), actually showing there was a slight increase in the number of over-flights per hour. Thus, my data strongly suggest that the power line marking devices used in this research significantly reduced the numbers of power line collisions involving avian species on this site.

Other than the actual numbers of dead birds found under power lines, the magnitude of my estimates of total numbers of collisions were primarily influenced by two factors, the accuracy of my estimates for crippling and habitat bias. The probability of observing bird strikes on power lines is low, and thus, it is often difficult to accurately estimate the crippling bias on any given site (APLIC 1994). Although few estimates of crippling bias exist, published data indicate that the average crippling bias for many sites ranges from 71 to 75 percent (e.g., 75%, Meyer 1978; 73%, James and Haak 1979; 74%, Beaulaurier 1981; and 73%, Savereno et al. 1996). During over 700 hours of power line observations on my study site (unpublished data), I observed only 11 power line collisions involving avian species. Of these 11, only two birds fell within the search zone, resulting in an estimated 82% crippling bias on my study site. Given the numbers of collisions I observed and the compatibility of my estimate of crippling bias with published data, I am confident in the accuracy of this estimate. However, because all birds that collide with power lines may not die, it should be noted that my estimate of total collisions (including crippling bias), actually represents an estimate of the total number of birds that interacted with the lines in some manner, regardless of the outcome.

The habitat bias also can have a large impact on the overall magnitude of the estimate of total numbers of collisions on any given study site. This is a direct result of the estimated number of birds missed due to habitat bias as well as the influence of habitat bias on estimates of crippling bias. In turn, the proportion of the habitat in the search zone that cannot be effectively surveyed for dead birds determines the extent of the habitat bias. Ultimately, a higher proportion of unusable area within a search zone leads to a higher level of uncertainty in the estimate of total number of collisions on a site. This is largely because of the assumption that the probability of finding dead birds in the searchable area under power lines is equal to that for unsearchable areas.

While this assumption may be valid in most cases, my study area was somewhat problematic. By extending the search zone to 45m beyond the outer limits of the transmission wires, as is recommended by APLIC (1994) based on the width of focal spans, I included a large segment of unsearchable habitat. In fact, an estimated 59% of the search area was unsearchable during the course of my study. Interestingly, all birds observed to have collided with the power line as well as over 98% of dead birds recovered, were found within 15 meters of the outer conductors. Therefore, by extending my search zone to the recommended width, I created a situation in which I was including a substantial area which in fact did not have an equal probability of holding birds killed by the power lines. Thus, using a habitat bias estimated on a search zone extending only 15 m beyond the outer conductors, I would have lowered my estimates of total numbers of collisions in the first field season from 708 to 459 and in the second field season from 344 to 223. Also, the minimum number of mortalities would have been lowered from 129 to 83 in the first field season, and from 63 to 41 in the second field season. It is clear that the issue of appropriate search zone width should be further investigated relative to the potential habitat bias on the study site as well as the probability of carcass distribution around the focal spans.

The BFDs, and larger SFDs, in this study, combined to reduce collision mortality by nearly 70% in comparison to that observed for unmarked lines. My estimate of the reduction in mortality associated with marked lines is much greater than those reported by Beaulaurier (1981), who published a review of 17 power line marking studies and found an average collision reduction of 45% on marked lines versus unmarked lines. However, recent studies of the effectiveness of marking devices, similar in size and shape to BFDs and SFDs, have documented reductions in mortality on marked versus unmarked lines ranging from 60-81%. For instance, Alonso et al. (1994) concluded that red PVC spirals (30 cm x 1 m) placed at 10 m intervals reduced collision frequency by 60% on marked versus unmarked spans. Additionally, Brown and Drewien (1995) found that yellow spiral vibration dampers (1.27 x 125 cm), placed at 3.3 m intervals, reduced mortality by 61%, and Janss and Ferrer (1998) determined that white polypropylene spirals (30 cm x 1 m) at 10 m intervals reduced collisions by 81%. Thus, my estimate of the reduction in collision mortality associated with the BFD and SFD line marking devices is within the range of previously reported values for similar devices.

Brown and Drewien (1995) stated that BFDs incorporated both horizontal coverage and silhouette, and recommended that these markers be evaluated for their effectiveness in reducing collisions. In this study, BFDs produced a 73.3% reduction in mortality compared to unmarked lines, which is within the range of the reductions in mortality observed by Koops and de Jong (57-89%; 1982, as cited in Brown and Drewien 1995, Janss and Ferrer 1998) while testing BFDs as a power line marking device in The Netherlands. However, when the data for collision mortality were analyzed for Swan Flight Diverters, the reduction in collision mortality relative to unmarked lines was much less dramatic at only 37.5%.

Although the differences in percentage reduction in collision mortality between the two marker types tested in this study were substantial, the actual difference in numbers of birds detected per search for each marker type was minimal (0.27 BPS for BFDs and 0.31 BPS for SFDs). Thus, the effectiveness of the two marker types relative to one another was very consistent. The observed differences in reduction of collision mortality between the marker types was probably driven by limitations of data collection rather than true differences in efficiency (Fig. 3.23). Specifically, because of logistical difficulties in the installation of SFDs, BFDs were monitored nearly 5 times longer (159 days) than were SFDs (32 days). When comparisons between marked and unmarked lines were made during the same temporal periods in each field season, differences in monitoring times for the two marker types resulted in BPS estimates for unmarked lines based on 6 versus 32 ground searches in comparisons involving SFDs and BFDs respectively. It is likely that the difference I observed in the reduction in collision mortality between the marker types used in the is study was the result of the low number of ground searches used to estimate the BPS value for unmarked lines in the assessment of SFD efficiency.

The selection of yellow and gray markers for the comparisons performed in this research were based on the premise that brightly colored markers would perform much better in deterring avian collisions with power lines than would drab, low visibility markers. This in fact was the case for BFDs with the data indicating a 76.3% reduction in collision mortality for yellow BFDs and only a 57.3% reduction in collision mortality for gray BFDs. However, the data for SFDs indicated the opposite trend with the gray color (43.8% reduction) outperforming the yellow color (25% reduction) in our field tests. Unfortunately, the low number of ground searches used to determine the numbers of birds per search for the unmarked lines used in comparisons involving SFDs remained a problem in the interpretation of these data.

To address the sample size problem associated with the color comparisons involving SFDs, I recalculated the percentage reduction in collision mortality for the various maker/color combinations using the overall BPS value (0.92) for unmarked lines in the first field season, rather than using only those data corresponding to the same temporal period. While such a modified approach does lose the resolution gained by making paired comparisons of individual spans over temporally consistent time frames, the overall BPS value for the first field season is likely a more accurate estimate of the collision mortality associated with unmarked lines. Using the data from these modified comparisons, I determined that the percentage reductions in collision mortality associated with my various marker/color combinations were: 78% for yellow BFDs versus 92% for gray BFDs and 86% for yellow SFDs versus 79% for gray SFDs. Interestingly, while the performance of the marker/color combinations changed in the revised analysis, the data indicate that all marker/color combinations produced reductions in collision mortality of greater than 78%, reflecting the relative low variation in BPS estimates observed on individual lines marked with flight diverters of different colors (BPS range from 0.07 to 0.20). Thus, it is likely that both colors were effective in reducing collision mortality on the site.

Although I chose not to vary marker spacing in this study, Koops and de Jong (1982) tested BFDs in two sizes and spacings, and found that differences in marker effectiveness were related to horizontal spacing on the lines (as cited in Brown and Drewien 1995). In this study, both marker types used were placed at 6 m intervals on the two outer ground wires of each focal span. While my study design did not allow for comparisons of marker effectiveness relative to spacing, my marker configuration did differ from the normal practice of staggering markers between ground wires and thus, allowed me to evaluate a new ground wire marking configuration for clustered transmission lines. In most published studies, markers are staggered between the paired ground wires of each transmission line at 10 m intervals to achieve horizontal coverage that appears to be at 5 m intervals. I made the decision not to stagger the marking devices on the respective paired ground wires of the two, clustered transmission lines used in this research primarily due to the logistical difficulties of marker installation on the interior ground wires. The results of my research, using this particular marker configuration, were very consistent with those from studies utilizing staggered configurations and suggest that installation of marking devices only on the outer ground wires of clustered transmission lines is a reasonable alternative.

Management Implications

The results of my research indicate that each of the ground wire marking devices assessed was effective in reducing the numbers of birds that collide with power lines. This result was confirmed both from the perspective of the estimated total numbers of collisions and the numbers of birds detected per search under marked versus unmarked lines. In addition, my data indicated that both marker types tested (BFDs and SFDs) were highly effective in reducing levels of collision mortality, regardless of color (yellow versus gray). However, given the disparity in monitoring periods used to assess the two marking devices, I would recommend that future research is needed to further clarify the importance of marker color in determining the efficiency of these marking devices in reducing collision mortality.

Although the topic was not specifically addressed in this study, it is clear that the "optimum" spacing of marking devices should be evaluated in future research. Based on my experiences during the course of this research, it became apparent that marking devices should be placed on lines at a spacing that maximizes visibility while minimizing ice and wind loading concerns. Such spacing optimization studies would alleviate the necessity for costly and time consuming efforts at tower reinforcement.

Brown and Drewien (1995) stated that large swinging plates installed on distribution lines were more visible to birds at long distances than were smaller, spiral vibration dampers. In addition, significant reductions in collision mortality have been documented for "larger" markers such as aviation spheres (Morkill and Anderson 1991, Savereno et al. 1996), and my data clearly demonstrate the effectiveness of smaller marking devices such as BFDs and SFDs. Concerns associated with large marking devices have generally been related to cost and weight (e.g., ice and wind loading). Thus, I suggest that combinations of "large" (i.e., aviation spheres) and "small" (i.e., SFDs, BFDs) markers could be more effective at reducing collision mortality than would either sized marking device alone. Such combinations would present excellent horizontal coverage, in a cost effective and logistically acceptable manner, while providing adequate visibility at both short and long distances.

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Table 3.1 Numbers of dead birds, crippled birds, and feather piles found during ground searches at the Knox County, Indiana study site, along with estimates for birds missed through associated research biases during two consecutive field seasons from November 1998 to April 2000.

Component	Unmarked[1]	Marked[2]
Total Dead Birds Found	35	17
Search Bias	1.80	0.88
Removal Bias	15.77	7.66
Habitat Bias	76.29	37.05
Crippling Bias	579.18	281.31
Estimated Total Collisions	708.04	343.90

[1] 6 November 1998 to 4 April 1999

[2] 27 September 1999 to 31 March 2000

Table 3.2 Numbers of dead birds found, by species, during ground searches conducted under unmarked and marked lines on the Knox County, Indiana study site during two consecutive field seasons from November 1998 to April 2000.

Species		Unmarked[1]	Marked[2]	Total
American Coot	*Fulica americana*	3	4	7
American Tree Sparrow	*Spizella arborea*		1	1
Brewer's Blackbird	*Euphagus cyanocephalus*		1	1
Brown-headed Cowbird	*Molothrus ater*	1		1
Canada Goose	*Branta canadensis*	4		4
Common Snipe	*Gallinago gallinago*	1	2	3
Dark-eyed Junco	*Junco hyemalis*	1		1
European Starling	*Sternus vulgaris*	2		2
Green-winged Teal	*Anas crecca*	1	2	3
Mallard	*Anas platyrhyncos*	10	2	12
Mourning Dove	*Zenaida macroura*	2		2
Northern Pintail	*Anas acuta*	2	1	3
Red-winged Blackbird	*Agelaius phoeniceus*		2	2
Swamp Sparrow	*Melospiza georgiana*	1		1
White-crowned Sparrow	*Zonotrichia leucophrys*		1	1
Wood Duck	*Aix sponsa*	7		7
Unknown			1	1
Totals		35	17	52

[1] 6 November 1998 to 4 April 1999

[2] 27 September 1999 to 31 March 2000

Table 3.3 Numbers of birds found per ground search (BPS), along with time periods, numbers of ground searches, and spans involved (Main Line = ML, Alt. 1 = A1) for all marking schemes on the Knox County, Indiana study site during two consecutive field seasons from November 1998 to April 2000.

Comparison	Marking Status	Time Period	Searches	Line	BPS
All Data					
	Unmarked	11/06/98 – 4/04/99	38	ML, A1	0.92
	Marked	11/06/99 – 4/04/00	61	ML, A1	0.28
BFD[1]					
	Unmarked	11/06/98 – 2/28/99	32	ML, A1	1.00
	Marked	11/06/99 – 2/28/00	45	ML, A1	0.27
Yellow BFD					
	Unmarked	11/06/98 – 2/28/99	32	ML	0.84
	Marked	11/06/99 – 2/28/00	45	ML	0.20
Gray BFD					
	Unmarked	11/06/98 – 2/28/99	32	A1	0.16
	Marked	11/06/99 – 2/28/00	45	A1	0.07
SFD[2]					
	Unmarked	2/29/99 – 4/04/99	6	ML, A1	0.50
	Marked	2/29/00 – 4/04/00	16	ML, A1	0.31
Yellow SFD					
	Unmarked	2/29/99 – 4/04/99	6	A1	0.17
	Marked	2/29/00 – 4/04/00	16	A1	0.13
Gray SFD					
	Unmarked	2/29/99 – 4/04/99	6	ML	0.33
	Marked	2/29/00 – 4/04/00	16	ML	0.19

[1] Bird Flight Diverters

[2] Swan Flight Diverters

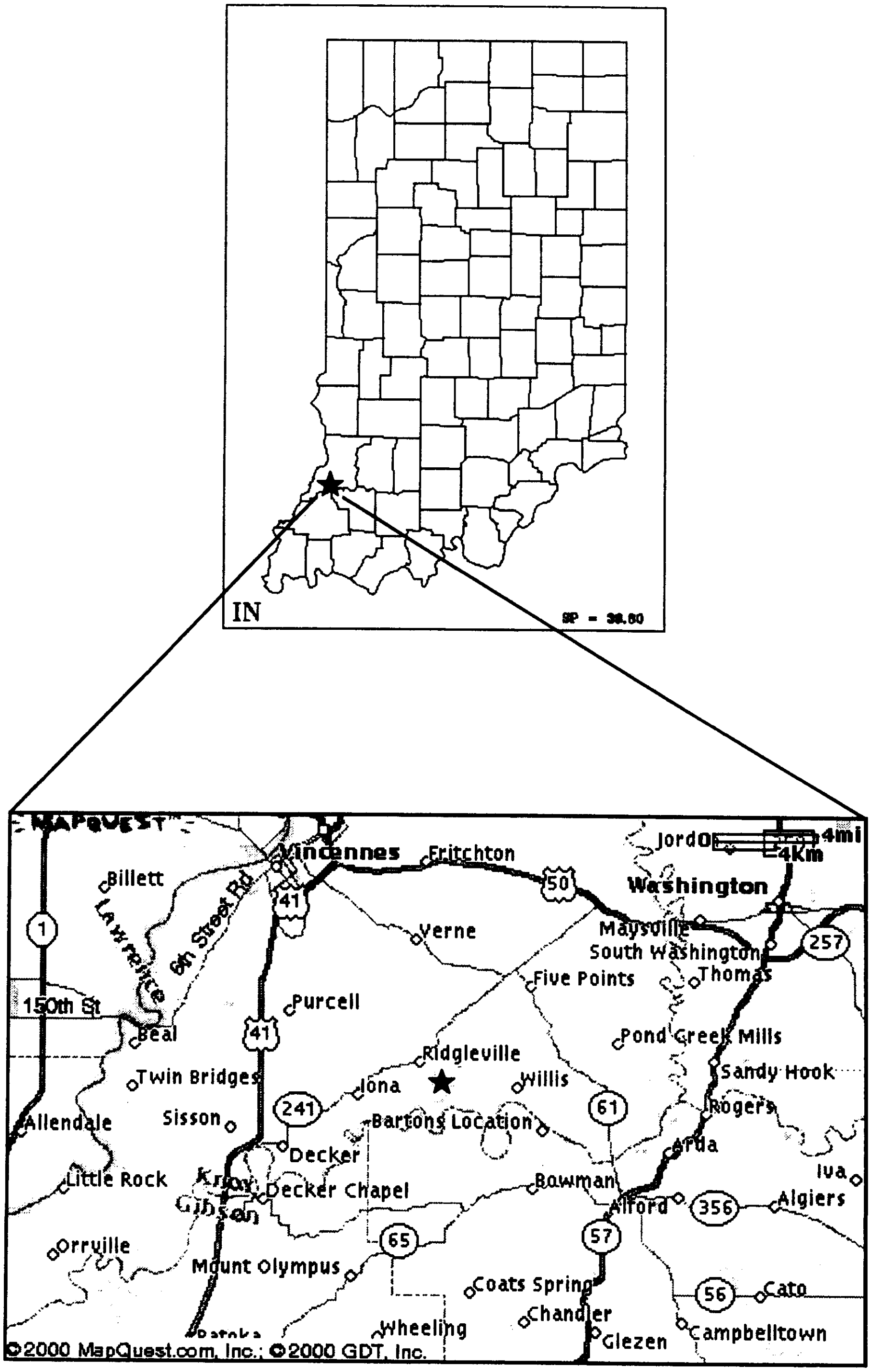

Fig. 3.1 Study area (represented by a star) located in Knox County, Indiana.

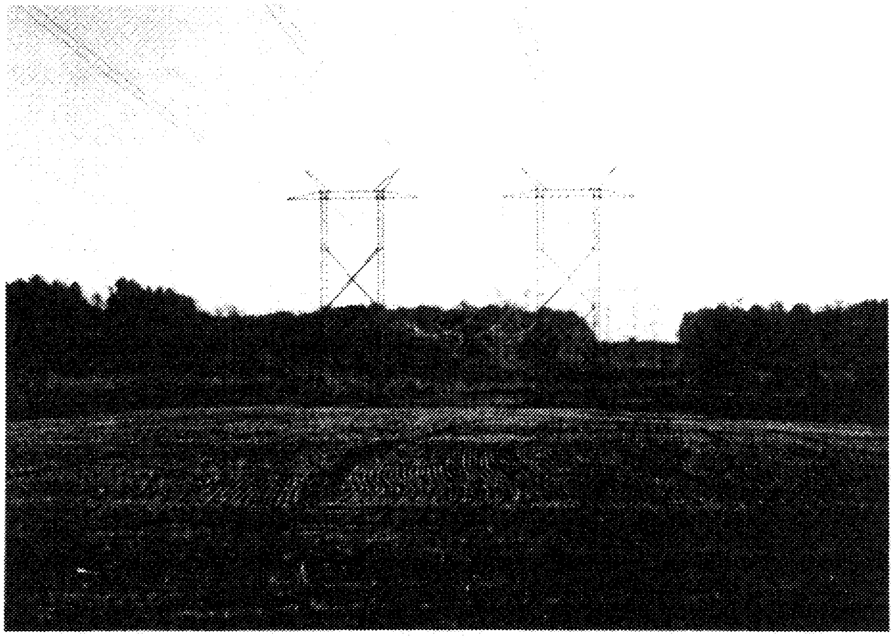

Fig. 3.2 View of the Knox County, Indiana study area taken from observation blind. Note pair of "clustered" 345 kV transmission lines studied.

Fig. 3.3 Aerial view of Knox County, Indiana study area showing array of habitat types.

Fig. 3.4 Flooded hardwood timber north of focal transmission line used as a roosting site by waterfowl species during the study. Note low water level at time of picture.

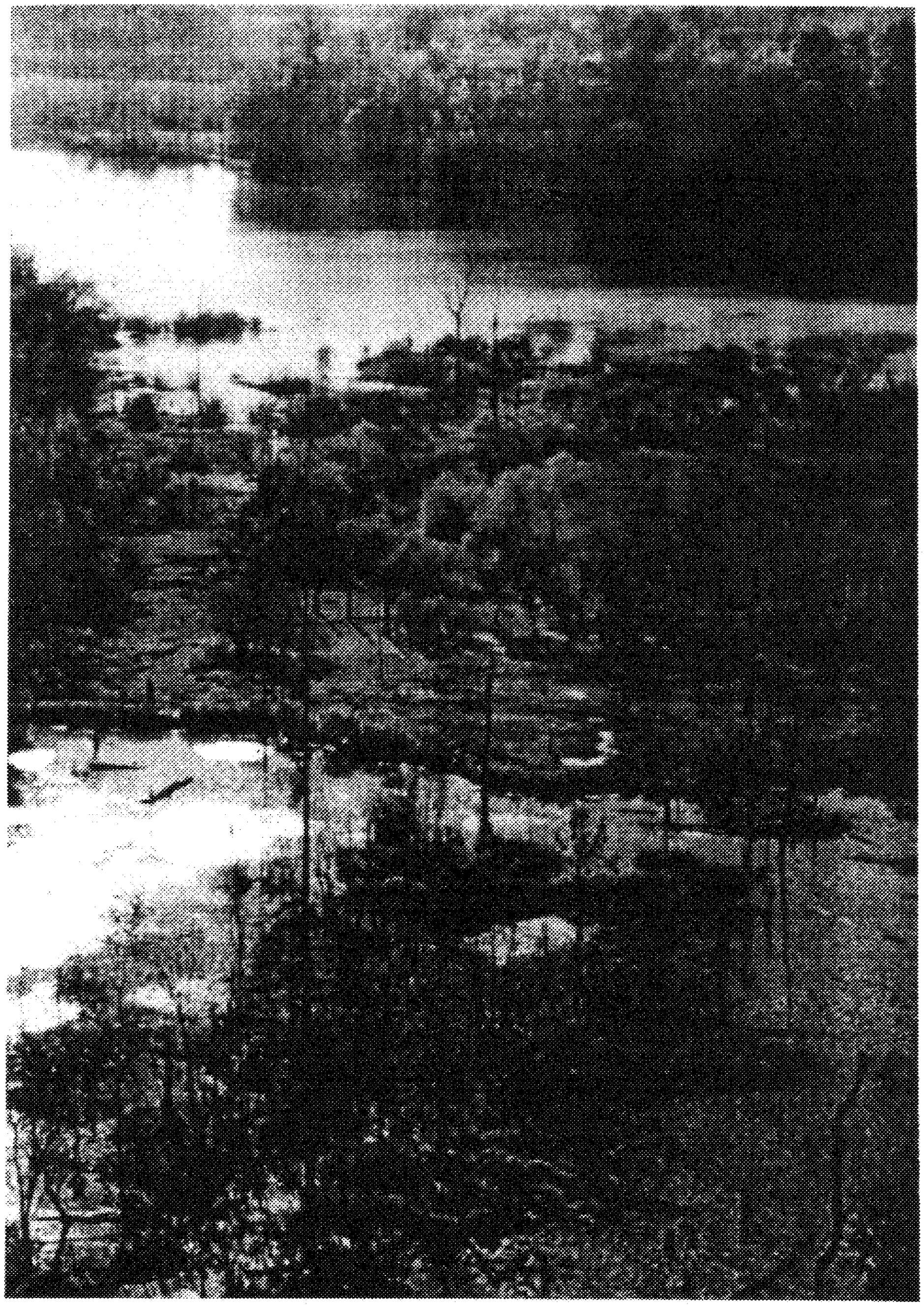

Fig. 3.5 The edge of the flooded timber and open slough north of the focal transmission line on the Knox County, Indiana study site.

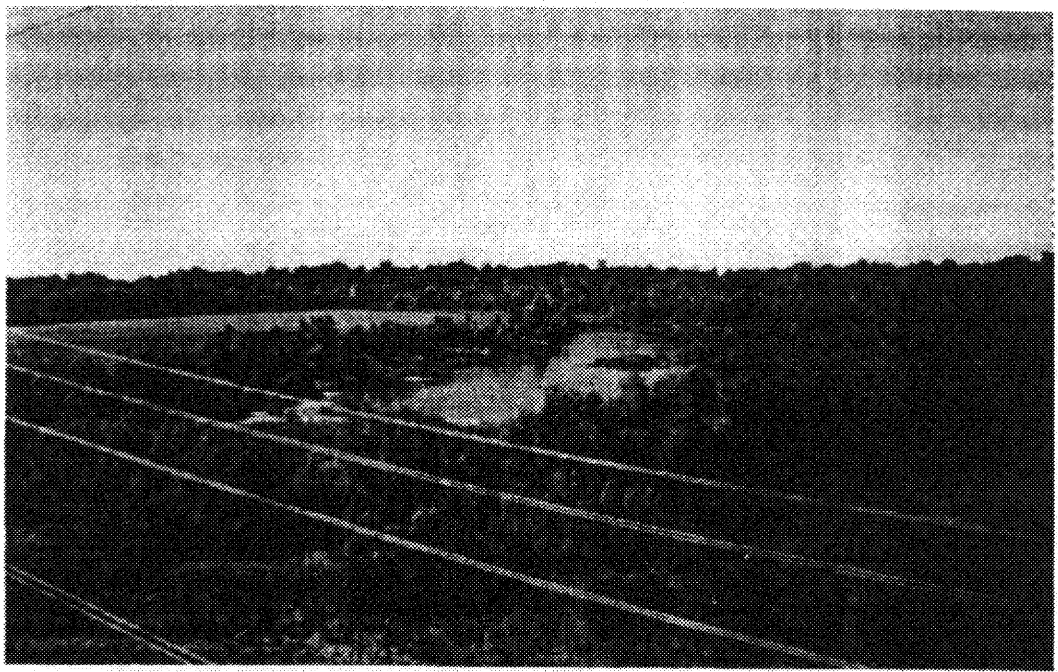

Fig. 3.6 McCormick's Slough, just north of the focal transmission line, was commonly used as a roosting area by waterfowl species on the Knox County, Indiana study site.

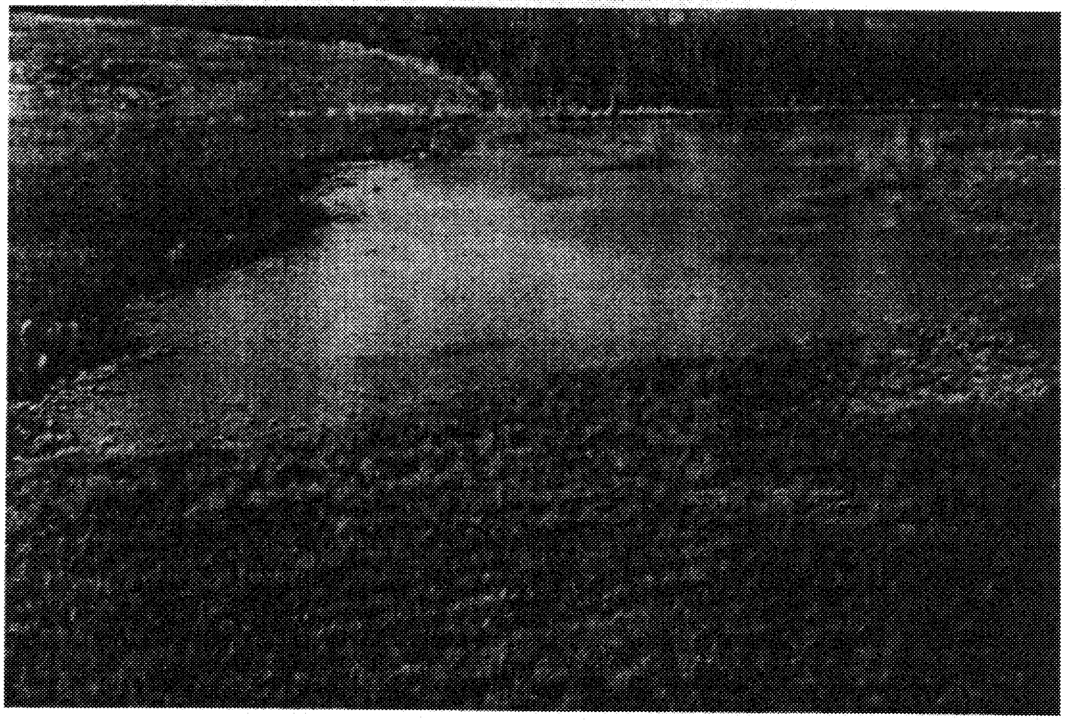

Fig. 3.7 Moist soil unit commonly used as a roosting and feeding site by waterfowl species on the north side of the focal transmission line.

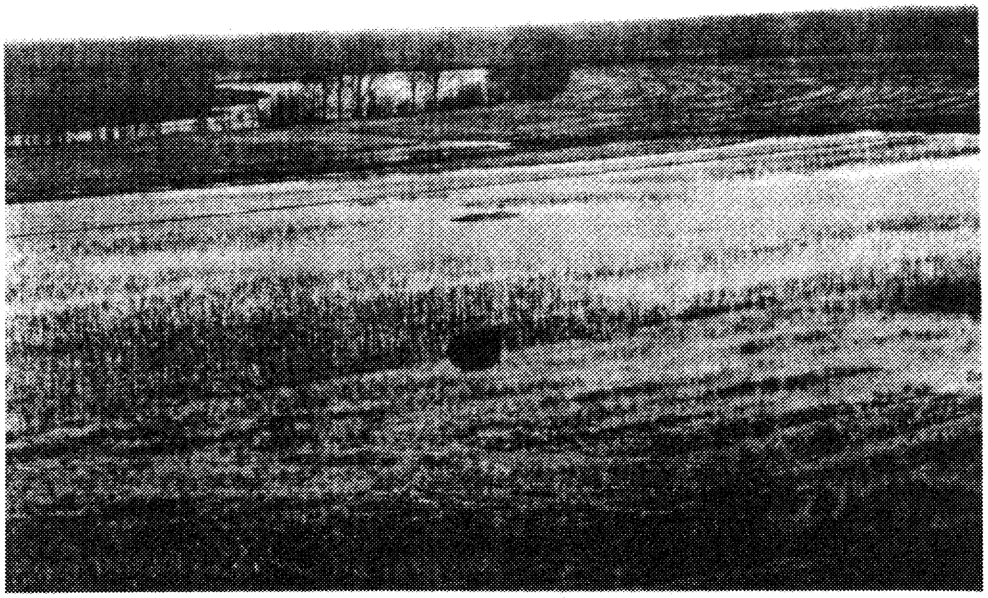

Fig. 3.8 Feeding area most often used by waterfowl just south of transmission line. This area is used for normal agricultural production but flooded in the winter months to attract waterfowl. Note open water slough on the south edge of the feeding area.

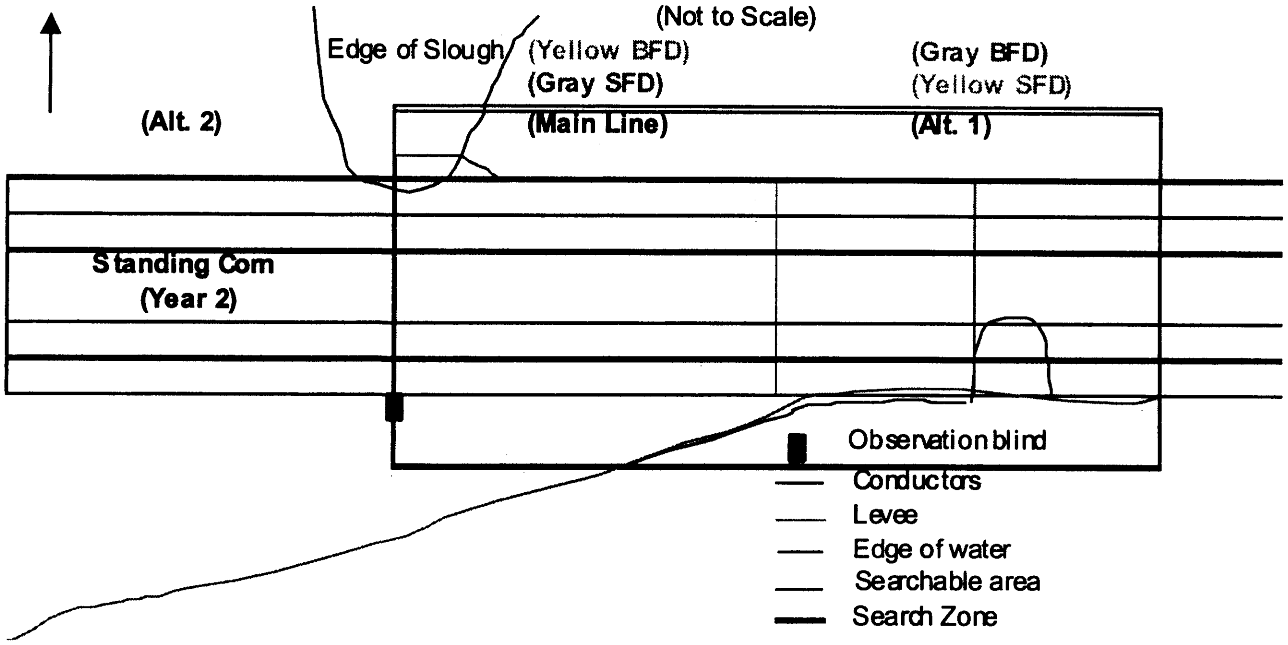

Fig. 3.9 Schematic of Knox County, Indiana study area showing the position of the observation blind in relation to the focal spans, locations and colors of marking devices in the treatment phase of the project (second field season), and searchable area within the recommended search zone.

Fig. 3.10 Alternate 2 (A2) with a dead Great Blue Heron in the foreground and observation blind near the base of the right tower.

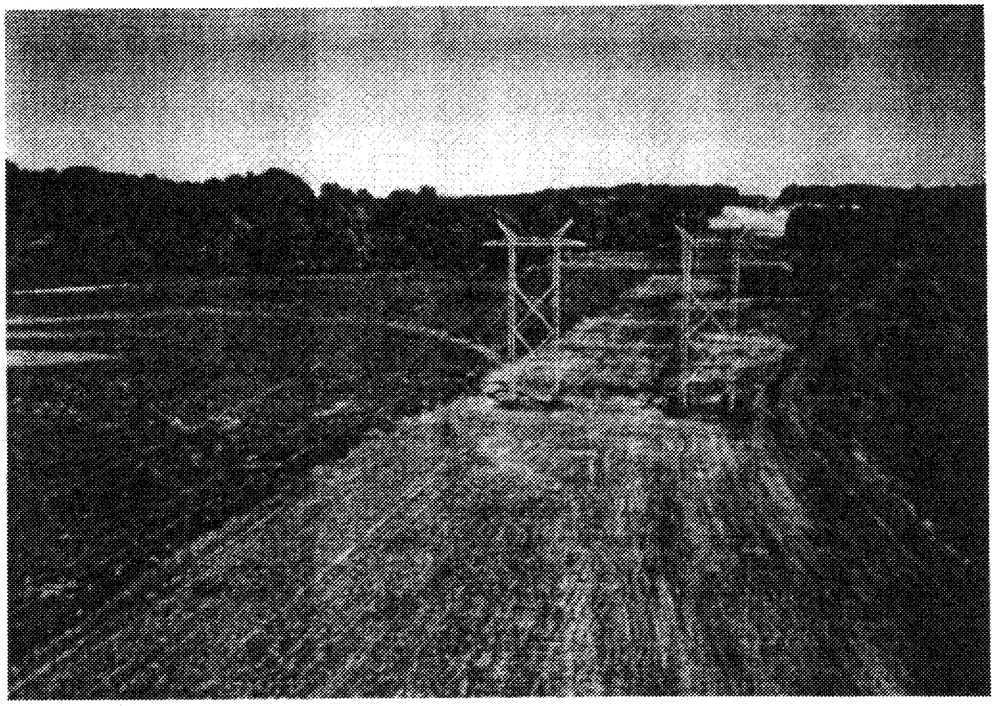

Fig. 3.11 Overhead view of the study area, with the Main Line (ML) being the first span, and Alternate 1 (A1) being the second span.

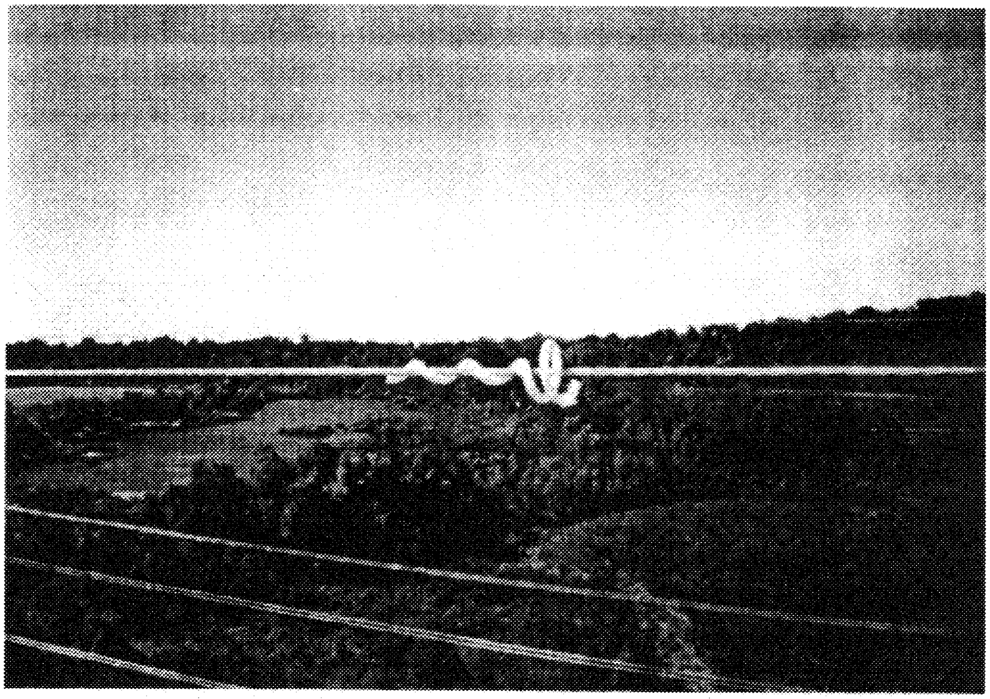

Fig. 3.12 Close up of Bird Flight Diverter placed on ground wires on the Knox County, Indiana study site.

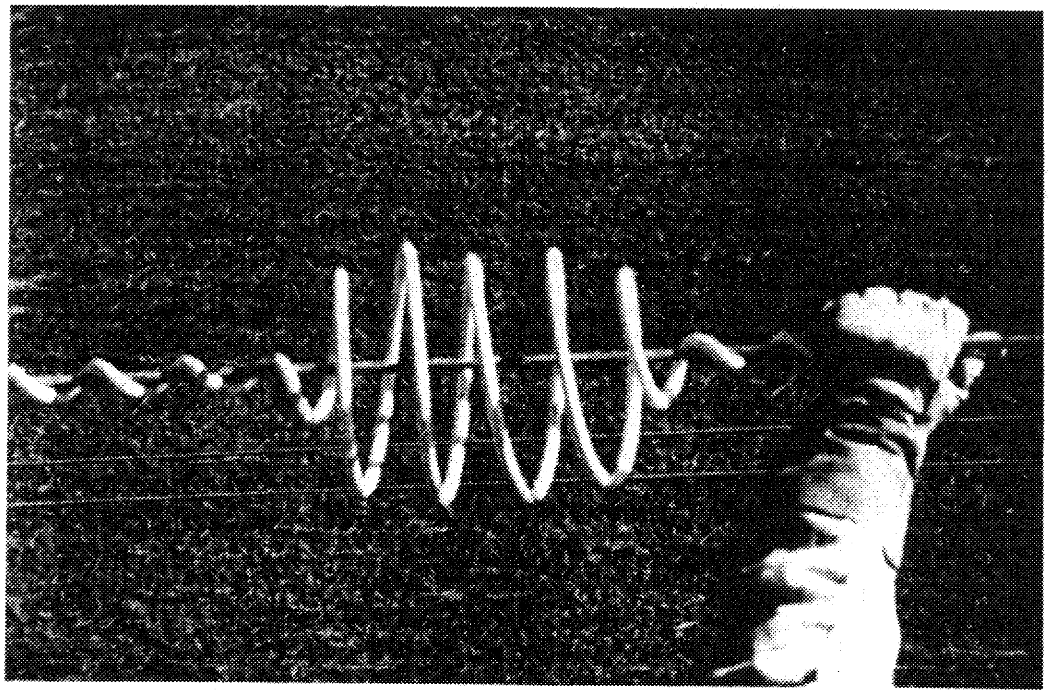

Fig. 3.13 Close up of Swan Flight Diverter on ground wires on the Knox County, Indiana study site.

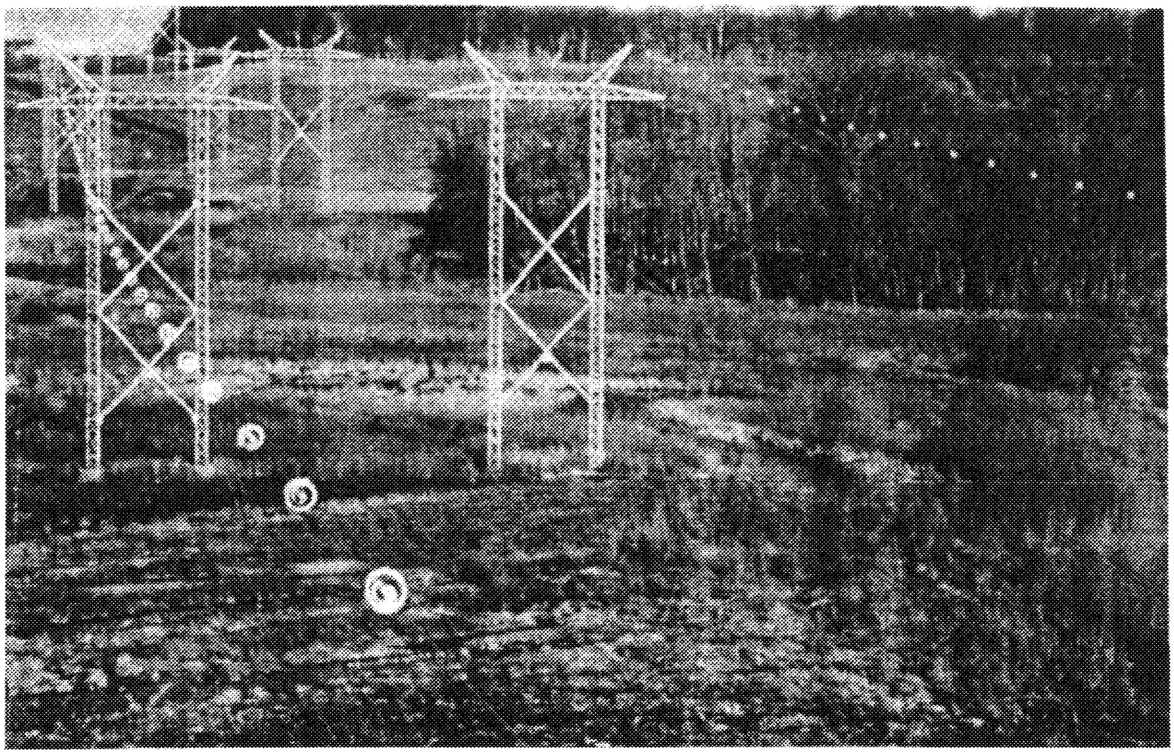

Fig. 3.14 Bird Flight Diverters and Swan Flight Diverters (shown on ground wires) were placed at 6 m intervals on outer ground wires of each transmission line on the Knox County study site.

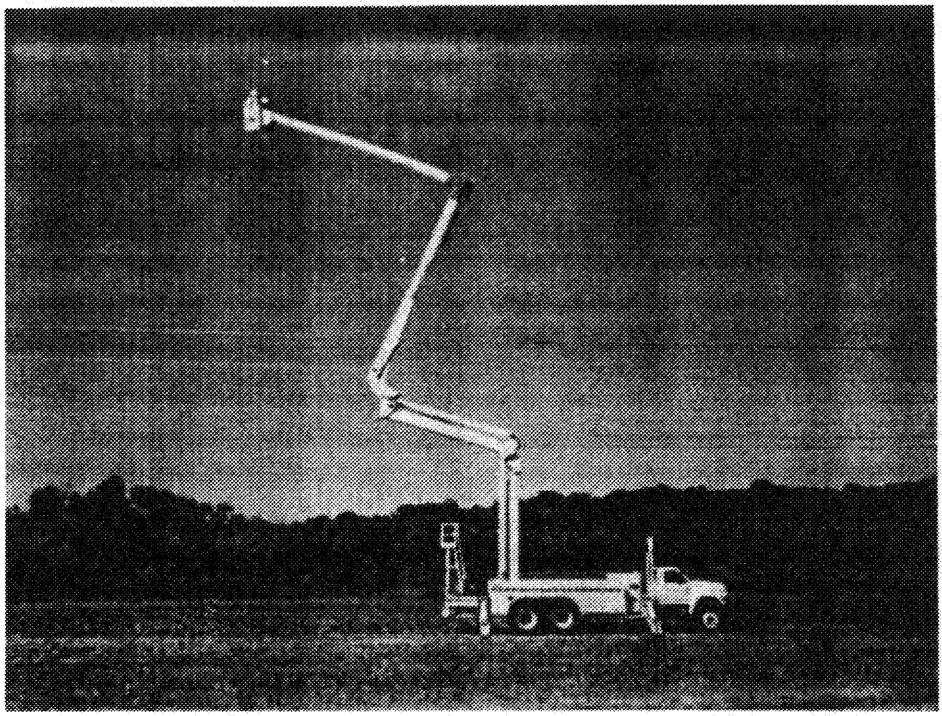

Fig. 3.15 Installation of Bird Flight Diverters with bucket truck on the Knox County, Indiana study area.

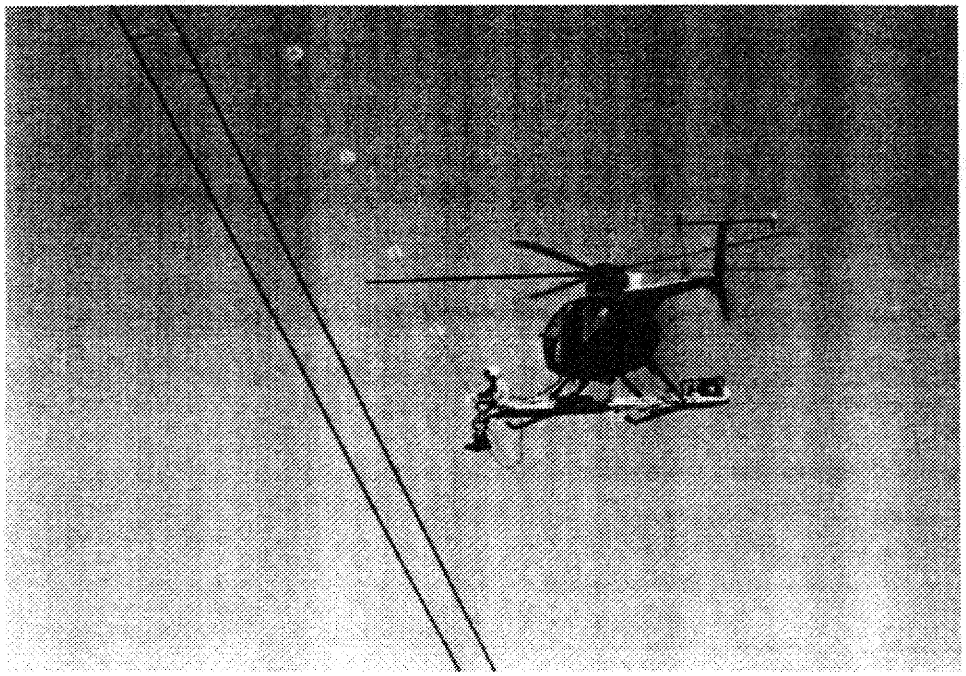

Fig. 3.16 Installation of Swan Flight Diverters with helicopter on the Knox County, Indiana study area.

Fig. 3.17 Great Blue Heron found on the Knox County, Indiana study site.

Fig. 3.18 Wood Duck found on the Knox County, Indiana study site.

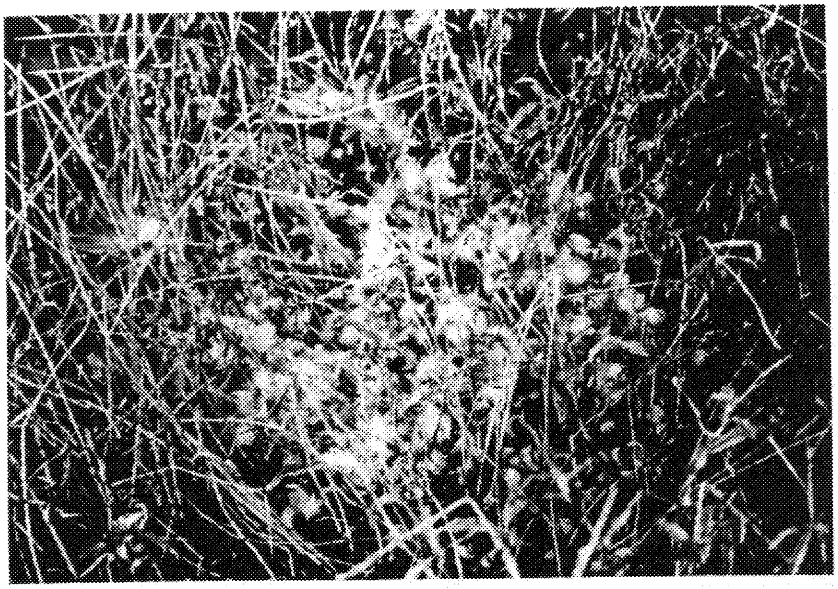

Fig. 3.19 Example of typical feather pile found during ground searches.

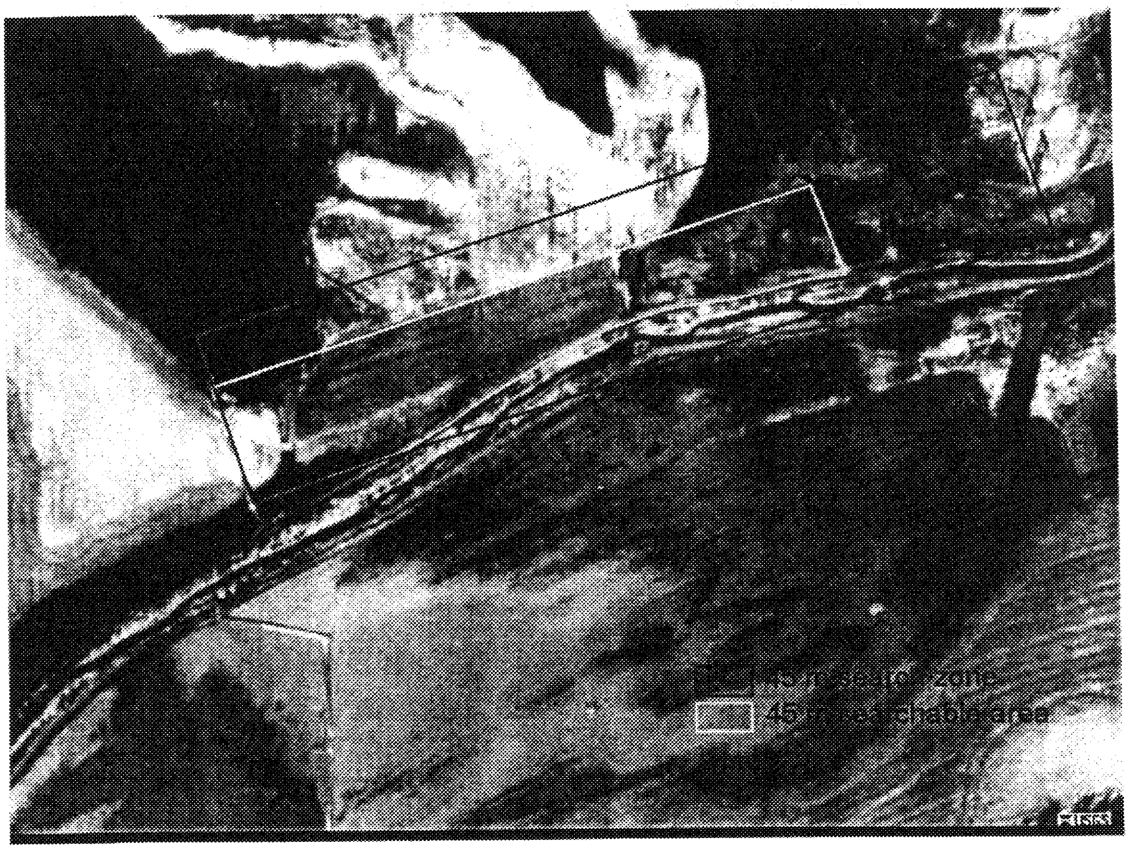

Fig. 3.20 Overhead view of Knox County, Indiana study area showing total search zone and total searchable area during both field seasons.

Fig. 3.21 Virginia opossum eating a planted bird taken with a remote camera.

Fig. 3.22 Raccoon eating a planted bird taken with remote camera.

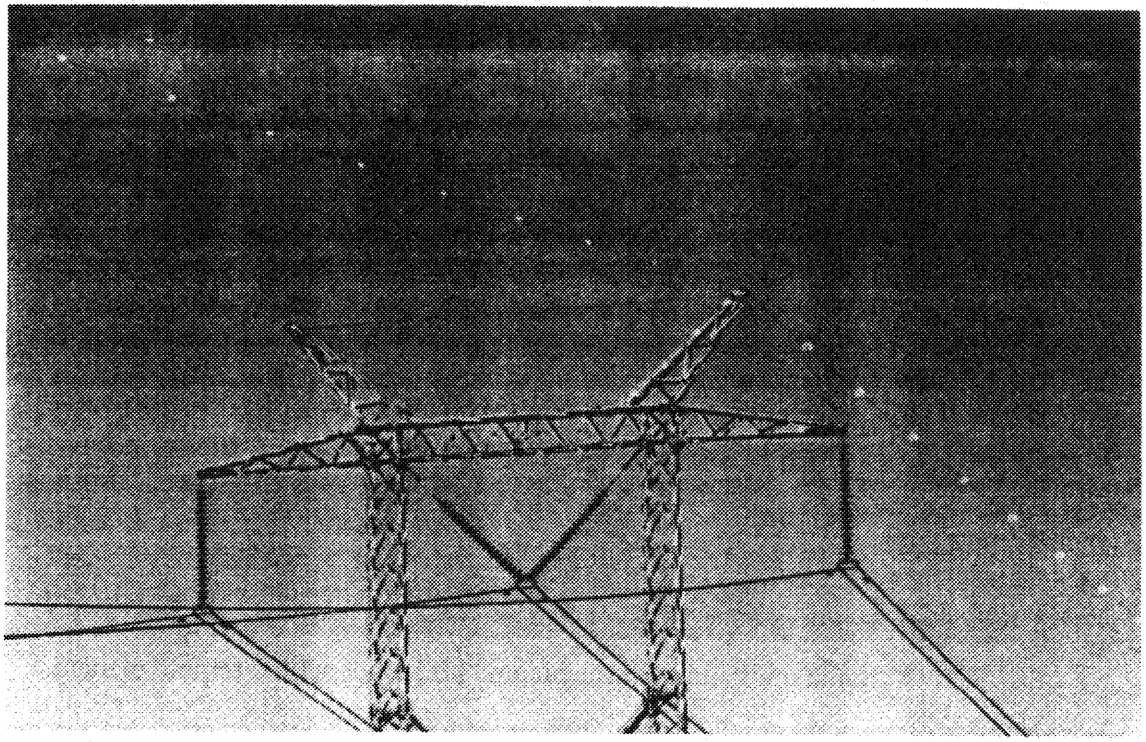

Fig. 3.23 Differences in size between Bird Flight Diverters (left) and Swan Flight Diverters (right) on ground wires taken at the time of changeover between marker types. Note that the Swan Flight Diverters are larger and more visible than Bird Flight Diverters.

APPENDICIES

Appendix A. Variables used during bird flight observations.

Wind Speed = The speed of the wind in the survey area, given in km/hour.

Temperature = Temperature of the survey area at the start of the survey given in °C.

Cloud Cover = The estimated percent cloud cover at the start of the survey period.

- Clear = C = Less than 10 % cloud cover.
- Scattered = S = Cloud cover from 10-50 %.
- Broken = B = Cloud cover from 5-90 %.
- Overcast = O = Cloud cover > 90 %.

Light Intensity = The intensity of the light on the study area, given in lumens.

Wind Direction = The direction from which the wind is coming.

- North = N
- South-West = SW
- Etc.

Precipitation = Type of precipitation on the survey area (if any).

Visibility = Visibility in the area in relation to distances due to fog or precipitation.

- Class 1 = Visibility > one km.
- Class 2 = Visibility between ½ and one km.
- Class 3 = Visibility between ¼ and ½ km.
- Class 4 = Visibility < ¼ km.

Line Noise = The amount of corona noise due to the power lines. Given as;

- Quiet
- Light
- Moderate
- Loud

Flight Direction = Flight direction of birds given as;

- North = N
- South = S
- Etc.

Altitude Classes (Approach, Crossing, and Departure) = The height of the birds being surveyed in relation to the power lines. Given as;

- Class 1 = Area between the ground and the conductor.
- Class 2 = Area between the conductor and the ground wire.
- Class 3 = Area between the ground wire and 10 m above the ground wire.
- Class 4 = Area between 10 and 50 m above the ground wire.
- Class 5 = Area above 50 m above the ground wire.

Reaction of Birds to Line = The reaction of birds to lines as they near them. Given as;

- Collisions = C = Collisions of birds with power lines and ground wires.
- Near-Collisions = NC = Birds narrowly missing the power lines and ground wires.
- Flares = F = A severe flight reaction as a bird or flock nears a power line and ground wires.
- Aborts = A = Birds turning 180° in response to power lines and ground wires.
- Altitude Change = AC = The change in altitude by a bird or flock in response to power lines and ground wires.
- Direction Change = DC = The change in direction by a bird or flock in response to power lines and ground wires.
- Flutters = FLT = A flight reaction of birds to the power lines or ground wires less severe than a flare.
- Landing on Power Lines = L = Birds landing on power lines or ground wires.

Reaction Zone = The distance in which the bird reacted to the power line and ground wire. Given as;

- Class 1 = Area between the wires and 5 m away from the wires.
- Class 2 = Area between 6 and 10 m away from the wires.
- Class 3 = Area between 10 and 25 m away from the wires.
- Class 4 = Area between 25 and 45 m away from the wires.
- Class 5 = Area greater than 45 meters away from the wires.

Appendix B. Observational data sheet used during bird flight observations.

Location______________________________ Survey Data Sheet #____________________

Date_____/_____/___ Time Period________-_______ Human Activity____________________

Wind Spd.________km Temp.___________C Light Intensity__________ Cloud Cover __________

Wind Dir.___________ Precip.___________ Visibility: > 1 km:_________ Line Noise___________

Observers____

Comments____

No.	Flock Size	Species	Flight Dir.	Appr. Alt. Class	X-ing Alt Class*	Dept. Alt Class*	Reaction: Bird/Line	Reaction Zone
1		M:	N / S	1 2 3 4 5			AC - DC - L - A - F - FLT - NC - C	
2		M:	N / S	1 2 3 4 5			AC - DC - L - A - F - FLT - NC - C	
3		M:	N / S	1 2 3 4 5			AC - DC - L - A - F - FLT - NC - C	
4		M:	N / S	1 2 3 4 5			AC - DC - L - A - F - FLT - NC - C	
5		M:	N / S	1 2 3 4 5			AC - DC - L - A - F - FLT - NC - C	
6		M:	N / S	1 2 3 4 5			AC - DC - L - A - F - FLT - NC - C	
7		M:	N / S	1 2 3 4 5			AC - DC - L - A - F - FLT - NC - C	
8		M:	N / S	1 2 3 4 5			AC - DC - L - A - F - FLT - NC - C	
9		M:	N / S	1 2 3 4 5			AC - DC - L - A - F - FLT - NC - C	
10		M:	N / S	1 2 3 4 5			AC - DC - L - A - F - FLT - NC - C	
11		M:	N / S	1 2 3 4 5			AC - DC - L - A - F - FLT - NC - C	
12		M:	N / S	1 2 3 4 5			AC - DC - L - A - F - FLT - NC - C	
13		M:	N / S	1 2 3 4 5			AC - DC - L - A - F - FLT - NC - C	
14		M:	N / S	1 2 3 4 5			AC - DC - L - A - F - FLT - NC - C	
15		M:	N / S	1 2 3 4 5			AC - DC - L - A - F - FLT - NC - C	
16		M:	N / S	1 2 3 4 5			AC - DC - L - A - F - FLT - NC - C	
17		M:	N / S	1 2 3 4 5			AC - DC - L - A - F - FLT - NC - C	
18		M:	N / S	1 2 3 4 5			AC - DC - L - A - F - FLT - NC - C	
19		M:	N / S	1 2 3 4 5			AC - DC - L - A - F - FLT - NC - C	
20		M:	N / S	1 2 3 4 5			AC - DC - L - A - F - FLT - NC - C	
21		M:	N / S	1 2 3 4 5			AC - DC - L - A - F - FLT - NC - C	
22		M:	N / S	1 2 3 4 5			AC - DC - L - A - F - FLT - NC - C	
23		M:	N / S	1 2 3 4 5			AC - DC - L - A - F - FLT - NC - C	
24		M:	N / S	1 2 3 4 5			AC - DC - L - A - F - FLT - NC - C	
25		M:	N / S	1 2 3 4 5			AC - DC - L - A - F - FLT - NC - C	

VITA

VITA

Michael R. Crowder was born 17 November 1975 in Jasper, Indiana, to Earl Crowder and Mary Ann Wools. He graduated from Loogootee Jr./Sr. High School in 1994 where he served as band vice-president and received the band directors award for best band student, along with receiving 4 varsity letter awards in baseball. While in high school, he achieved the rank of Cadet Lt. Col. in the Civil Air Patrol – United States Air Force Auxiliary. While a member of this group, he received many honors and awards, including; Cadet Squadron Commander, member of the Indiana Wing Cadet Advisory Council, first Indiana Wing cadet to receive an Honor Cadet award at a national activity, Squadron Commander at national activity, Region Commander Commendation, and was selected as International Air Cadet Exchange member to represent the United States in a goodwill mission to The Netherlands during 1994. He went on to complete an AS degree from Vincennes University during the spring of 1996 in Natural Resources and Environmental Science, and a BS degree in Natural Resources and Environmental Science from Purdue University 2 years later. Michael continued to study at Purdue in pursuit of a Master of Science degree. While at Purdue, he served as a graduate research assistant in the Department of Forestry and Natural Resources, working with Dr. Olin E. Rhodes, Jr. on power transmission line marking systems to reduce avian collisions. He also served as a teaching assistant for an avian identification laboratory, and helped the Purdue Trap and Skeet Team win 5 National Championships. Michael completed his MS degree during the fall of 2000. He has worked on numerous other research projects throughout his academic career, for Vincennes University, Purdue University, Cinergy-PSI, Eli Lilly Corp, and the Delta Waterfowl Research Foundation.