# EFFECTIVENESS OF MARKING POWERLINES TO REDUCE SANDHILL CRANE COLLISIONS

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November, 1990

## ACKNOWLEDGMENTS

We appreciate the excellent support of cooperators: Dr. J. Lewis, U. S. Fish and Wildlife Service; R. Breuer and M. Czaplewski, Nebraska Public Power District; and P. Darby and R. George, Dawson Public Power District.

C. Cole, J. Jenniges, C. Kingen, T. Neal, T. Parrish, and B. Schoenhofer helped tremendously with field work. Personnel of Nebraska Game and Parks Commission, Fort Kearny; U. S. Fish and Wildlife Service's Rainwater Basin Wetland Management District, Kearney; U. S. Fish and Wildlife Service Enhancement Field Office, Grand Island, especially T. Fannin; and Rowe Audubon Sanctuary greatly assisted in various ways.

W. Hubert, Dept. Zoology, and E. Williams, Dept. Veterinary Sci., Univ. Wyoming, R. Brewer and M. Czaplewski, Nebraska Public Power District, and J. Lewis, U.S. Fish and Wildlife Service, reviewed drafts. Drs. L. McDonald and D. Anderson, Dept. Statistics, Univ. Wyoming, provided statistical consultation. W. Brown, Wildlife Research Institute, Univ. Idaho, contributed many ideas for obtaining flight behavior data.

Financial support was provided by the U.S. Fish and Wildlife Service, Dawson Public Power District, and the Nebraska Public Power District.

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# INTRODUCTION

In the last several years, there has been a growing interest by public, government, and power-utility officials regarding the impact of electrical transmission lines on bird flight and mortality from collisions (U. S. Fish and Wildlife Service 1978). Bird collisions with powerlines have been widely documented, though the majority were isolated cases of bird casualties, primarily waterfowl and passerine species (Dailey 1978, Avery et al. 1980). Many investigators concluded that such mortality was not biologically significant for bird populations (Krapu 1974, Stout and Cornwell 1976, Kroodsma 1978, Cassell et al. 1979, James and Haak 1979). However, the extent of bird-powerline collisions is often underestimated; many incidences go unnoticed or unreported, especially along powerline rights-of-way where human activity is limited (Cornwell and Hochbaum 1971, Krapu 1974, Thompson 1978, Malcolm 1982, Faanes 1984). Dead birds are often concealed in vegetation or water along powerline rights-of-way or are removed by predators and scavengers, thus precluding public awareness of avian mortality from powerline collisions

(Scott et al. 1972, McGlauchlin 1977, Bealaurier 1981, Malcolm 1982, Faanes 1984).

Bird mortality from collisions with powerlines can be detrimental for threatened and endangered species, or for locally concentrated populations (Brown et al. 1984, Faanes 1984). Some examples include the red-crowned crane (Grus japonensis) (Archibald 1987), Eurasian eagle owl (Bubo bubo) (Herren 1969), brown pelican (Pelecanus occidentalis) (McNeil et al. 1985), and mute swan (Cygnus olor) (Harrison 1963, Beer and Ogilivie 1972, Sisson 1975). Of particular significance, the principal known cause of death for fledged whooping cranes (Grus americana) is collision with powerlines (Lewis 1986).

BIOLOGICAL SIGNIFICANCE

Powerline collision mortality is a significant factor affecting long-term recovery of whooping cranes (Howe 1989). Whooping cranes are currently listed as a federally endangered species under the Endangered Species Act of 1973 (16 U. S. C., 1531-1543; 87 Stat. 884), and in 1989 numbered about 150 wild birds. Since 1956, 19 whooping cranes have reportedly collided with powerlines, accounting for 25% of known losses in the Aransas-Wood Buffalo flock (J. C. Lewis, U. S. Fish and

Wildlife Service, unpubl. data) and 40% in the cross-fostered Rocky Mountain flock (Brown et al. 1987). Whooping cranes risk colliding with powerlines primarily during migration when they stop to rest and feed in areas criss-crossed by powerlines (Kuyt 1983, Lingle 1987). Additional powerline construction is expected because of continual demands for rural electrification throughout whooping crane migration corridors across midcontinental and Rocky Mountain states; thereby raising concern for continued whooping crane mortality from collisions with powerlines (Krapu et al. 1982, Faanes 1984, U. S. Fish and Wildlife Service 1986).

Whooping crane researchers have emphasized the need for research on factors responsible for powerline collisions and methods for minimizing collision potential (Howe 1989). The Whooping Crane Recovery Plan called for actions to minimize mortality on migration routes and wintering grounds by developing and applying methods to prevent powerline collisions (U. S. Fish and Wildlife Service 1986).

## MITIGATION TECHNIQUES

Various methods have been applied or suggested for minimizing bird collisions with powerlines. These include:

site planning and powerline structure modification, underground burial of wires, static wire removal, and increasing visibility of the wires (Thompson 1978, Beaulaurier 1981).

Careful routing of powerlines to avoid migratory bird corridors or modifying tower and line designs can reduce potential bird collision problems (Miller 1978, Thompson 1978). Nevertheless, constraints on land acquisition for alternative routes and technically feasible line design can limit the extent of applying such mitigation procedures (Miller 1978, Beaulaurier 1981, Keller and Rose 1984).

Underground burial of wires has been used to reduce for bird collisions (Rigby 1978, Thompson 1978, Anonymous 1989). However, high construction and maintenance costs make this an unacceptable alternative in most circumstances (Beaulaurier 1981, Kauffeld 1982).

Removal of static wires has been investigated as mitigation for bird collisions with powerlines. Non-electrical static wires, also called neutral, shield, or ground wires, are typically placed 2-10 m above electrical conductor wires to intercept lightning that otherwise would cause power outage (Miller 1978). Static wires are typically smaller than conductor wires, and birds may avoid the conductor wires only to strike the less visible static wires (Scott et al. 1972, James and Haak 1979, Brown et al. 1984, Fannes 1987). A study by Beaulaurier (1981) involved the removal of static wires from a segment of transmission line and found waterfowl collision rates to be reduced by half. Brown et al. (1987) also found a substantial decline in crane and waterfowl collisions after removal of static wires, and a subsequent increase in collisions when the wires were replaced. Nonetheless, static wire removal would reduce the electrical reliability and increase maintenance of transmission lines, especially in lightning-prone areas, such as the Great Plains region (Thompson 1978, Beaulaurier 1981).

Three methods have been used for increasing wire visibility: color device-marking, increasing wire diameter, and night flood-lighting. Beaulaurier (1981) summarized 17 studies which used color-marking devices placed on static or conductor wires, including orange aviation balls, black-and-white ribbon, and yellow plastic streamers. Average percent reduction in bird collisions at marked lines was 45% compared to unmarked lines. Various yellow markers installed on powerlines in Japan have contributed to the reduction of red-crowned crane collision mortality (Yamaguchi 1984, Archibald 1987). Bird collisions were eliminated for 3 years following installation of orange aviation balls on powerlines traversing Bosque del Apache National Wildlife Refuge, New Mexico (Rigby 1978). Brown et al. (1987) investigated the effect of increasing static wire diameter from 0.95 cm to 2.54 cm on reducing bird collisions. Preliminary findings indicated no reduction in bird collisions with enlarged wires, but results were inconclusive. Large diameter wires may be more visible against overcast skies, but may not be effective under sunny conditions because they lack reflectivity (Thompson 1978). Lastly, night flood-lighting of powerlines was another suggested measure for increasing wire visibility; however, birds may actually be attracted to lighted wires and become disoriented, adding to bird collision-mortality (Herbert 1970, Thompson 1978). Available literature indicated that increasing visibility of powerlines by placing markers on wires was the most cost-effective and logistically feasible method for reducing bird collisions.

## PROJECT BACKGROUND

Although a review of prior studies provided information on various techniques to reduce collisions, statistical analyses on the effectiveness of marking powerlines were absent (Beaulaurier 1981). Consequently, the U. S. Fish and Wildlife Service and Wyoming Cooperative Fish and Wildlife Research Unit initiated research to statistically evaluate the effectiveness of marking powerlines in reducing whooping crane collisions. Because whooping cranes were not abundant, they selected the sandhill crane (G. canadensis) as a substitute research species for the whooping crane.

Preliminary research is commonly conducted using a closely related and more abundant species as a substitute in endangered species research (Carpenter 1977). Sandhill cranes were appropriately selected because they are morphologically similar to whooping cranes. While whooping crane flight behavior differs somewhat from a sandhill's because of body size and wing beat, both species are tall long-legged birds with average wingspans of 221 cm and 185 cm, respectively, which limit flight speed and maneuverability. Cranes are more vulnerable to collisions with powerlines than are smaller, swifter species (Faanes 1984, Krapu 1984).

Sandhill cranes also suffer appreciable losses because of collisions with powerlines, particularly where powerlines bisect roosting and foraging habitats (Nesbitt and Gilbert 1976, Tacha et al. 1979, Brown et al. 1984, Faanes 1984, Keller and Rose 1984). Drewien (1973) concluded that powerline collisions accounted for 37% of known losses of sandhill cranes in the Rocky Mountain region.

An opportunity to investigate sandhill crane mortality and flight behavior in relation to powerlines existed along the Platte River in southcentral Nebraska that would not have been possible with the less numerous whooping crane. Approximately 500,000 sandhill cranes are present in southcentral Nebraska for an extended period each spring, and powerlines are widely distributed across habitats used traditionally by the cranes. Researchers in Nebraska reportedly collected dead sandhill cranes below powerlines for food habits studies (Reinecke and Krapu 1978, Tacha and Lewis 1979), and several others reported sandhill crane mortality because of collisions with powerlines (Walkinshaw 1956, Wheeler 1966, Lewis 1974, Krapu et al. 1984, Windingstad 1988). Consequently, the Wyoming Cooperative Fish and Wildlife Research Unit conducted a 5-year project in Nebraska to study the effectiveness of marking powerlines to reduce sandhill crane collisions. Baseline studies in 1986-87 assessed the magnitude of crane collision mortality and located suitable sites for subsequent research activities (Ward et al. 1986, 1987).

This report summarizes findings from the final three years of research on sandhill crane flight behavior and mortality in relation to powerlines along the Platte River, Nebraska, conducted in March and April of 1988, 1989, and 1990. Primary research objectives were:

1) to evaluate the effectiveness of placing 30-cm yellow fiberglass balls with a vertical black stripe on static wires to reduce sandhill crane collisions with transmission lines, and

2) to identify factors contributing to sandhill crane collisions with powerlines along the Platte River, Nebraska.

Research findings based on sandhill crane mortality and flight behavior should lend insight into whooping crane interactions with powerlines, and provide guidelines for marking powerlines to reduce the potential of whooping crane collisions.

# STUDY AREA AND METHODS

## GENERAL DESCRIPTION

The study area extended 3.2 km north and 1.6 km south of the Platte River and from Overton 60 km eastward to Gibbon in southcentral Nebraska, including portions of Dawson, Buffalo, and Kearney counties (Figure 1). Interstate Highway 80 parallels the Platte River through the study area. Mean elevation in the study area was 635 m.

Habitats along the Platte River and their importance for migratory birds have been described in detail by Krapu (1981) and Currier et al.(1985). Major habitat types were cropland, grassland, hayland, deciduous woodland, and river channel. Other habitat types included business and residential areas, sand and gravel development, highway rights-of-way, farmsteads, and feedlots (Krapu et al. 1984).

Corn (Zea mays) constituted 88% of cultivated crops; less common crops were milo (Sorghum vulgare), winterwheat (Friticum spp.), soybeans (Glycine max), Sudan grass (Sorghum sudanese), and oats (Avena sativa) (Krapu 1981).

Most native grasslands have been converted for crop or hay production. Existing grasslands were maintained primarily

## CRANE STAGING AND HABITAT USE

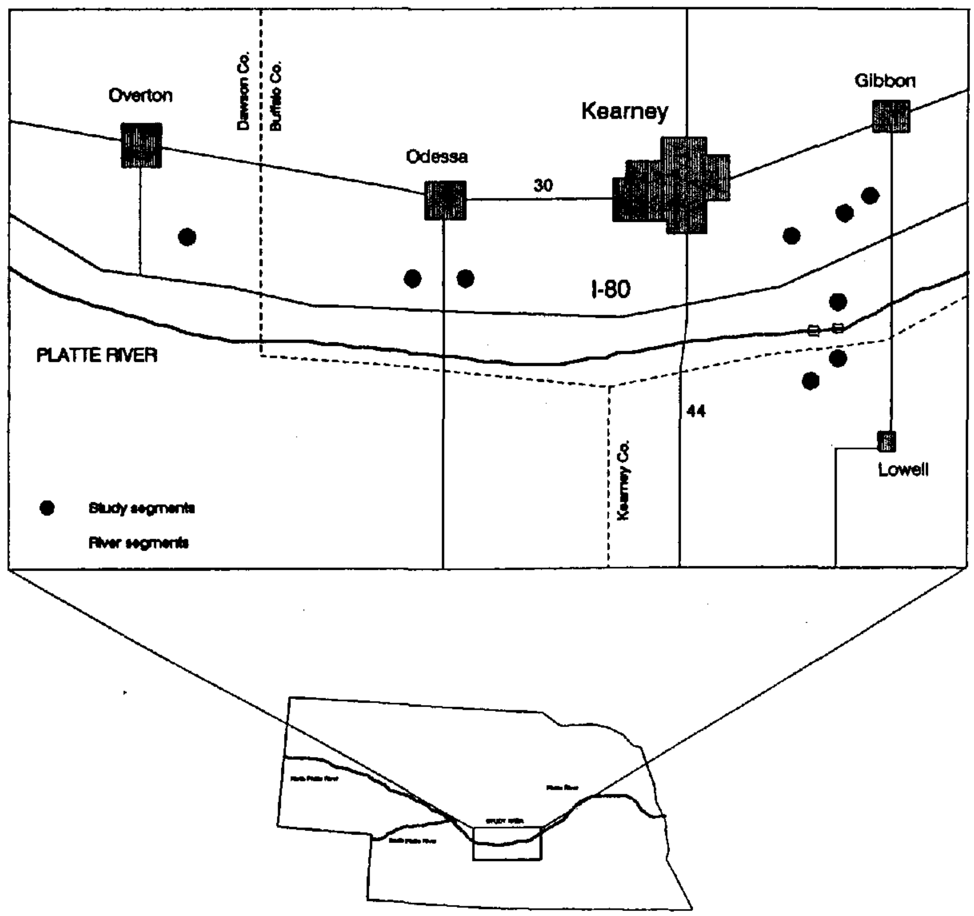
Nearly 500,000 sandhill cranes (referred to as "cranes" hereafter, unless stated otherwise), equivalent to 80% of the midcontinental population, use the Platte River, North Platte River, and adjacent habitats as a principal staging area in spring. Suitable roosting and foraging habitat which are centrally located along the spring migration route attract unparalleled concentrations of cranes for the staging period. Cranes forage and rest in various habitat types during the day and roost in the river channel at night (Krapu et al. 1984). Cranes also visit the Platte River valley during fall migration but in substantially fewer numbers for a shorter duration. Whooping cranes migrating between the Texas Gulf Coast and the Northwest Territories of Canada occasionally use the Platte River as a stopover site (Johnson 1982).

Three subspecies of cranes gather in the valley each spring, including the entire continental population of Canadian sandhill cranes (*G. c. rowani*) and all but 20,000 of the continental population of lesser sandhill cranes (*G. c. canadensis*) (Lewis 1977). In addition, several thousand greater sandhill cranes (*G. c. tabida*) stage along eastern portions of the Platte River (Frith and Faanes 1982).

Distribution of cranes on the staging area is influenced by the availability of suitable roosting habitat on the Platte River (Krapu et al. 1984). Reduction of peak annual flows as a result of rising agricultural, municipal, and industrial demands has dramatically changed the river's hydrological characteristics. As water flows diminished, woody vegetation invaded former channels and sandbars, and existing channels became narrower. As a result, cranes have become more concentrated on limited roosting habitat (Hadley and Eschner 1982, Krapu 1979). About 111 km of river channel between Overton and Grand Island are currently used as roosting habitat. Cranes typically roost in shallow water and on adjacent sandbars in open channels no less than 50-150 m wide (Krapu et al. 1982, 1984).

Three-quarters of the crane population stage in two discrete areas along the Platte River: 350,000 cranes near Kearney to Grand Island, and 50,000 cranes near Overton to west of Kearney. The remaining population stages on the North Platte River near Hershey and Lewellen (Krapu et al. 1984). Diurnal concentrations of cranes vary throughout the study area during peak staging, ranging from 121 cranes per km near

Figure 1. Powerline study segments monitored in 1988-90 along Platte River, Nebraska.



for livestock grazing, though some wet meadows are preserved for wildlife habitat on lands owned by the National Audubon Society and Platte River Whooping Crane Habitat Maintenance Trust (Krapu 1981). Grassland communities were composed of big bluestem (Andropagon gerardi), western wheatgrass (Agropyron smithii), Indian bluegrass (Sorghastrum avenaceum), Kentucky bluegrass (Poa pratensis), and various other prairie species (Hopkins 1951).

Deciduous woodland communities along the river were dominated by cottonwoods (Populus deltoides), with an understory of red cedar (Juniperus virginia), rough-leaf dogwood (Cornus drummondii), and various subdominant species. Low shrub islands and vegetated sandbars included peach-leaf willow (Salix amygdaloides), sandbar willow (S. exigua), indigo bush (Amorpha fruticosa), lovegrass (Eragrostis pectinacea), nut sedge (Cyperus spp.), barnyard grass (Echinochloa crus-galli), and cocklebur (Xanthium strumarium) (Krapu 1981).

Ninety-five percent of land in the Platte River valley was in private ownership and agriculture represented the predominant land use. Nonagricultural areas included urban development, and state and federally-owned land (Krapu 1981).

Fort Kearny to 2105 cranes per km on Fort Farm and Kilgore islands (Frith and Faanes 1982).

Sandhill cranes begin arriving in the valley in late February from wintering grounds in Texas, New Mexico, and Mexico. Groups of cranes spend an average of 4 weeks on the staging area feeding, resting, and reinforcing or establishing pair bonds. Habitat use during daylight hours occurs primarily in cropland, native grassland, and tame hayland within 3.2 km of the river (Faanes and Frank 1982, Krapu et al. 1984). Waste corn is a significant food item and a principal source of energy, constituting 96% of the cranes' spring diet. The remainder of their diet is primarily invertebrates, which provide an important protein supplement. The storage of energy reserves and protein during staging sustains the cranes for the remainder of their migration and subsequent nesting activities (Reinecke and Krapu 1979).

Numbers of cranes on the staging area build gradually and peak in mid-March. Favorable weather conditions in mid-April signal the cranes' departure northward to nesting grounds as far as Canada, Alaska, and Siberia. Cranes depart rapidly within a few days, as compared to a gradual arrival (Lewis 1979a).

## WEATHER

Climate in Nebraska has been characterized as continental with light rainfall, low humidity, and considerable yearly variation in temperature and rainfall. Rapid fluctuations in weather conditions occur during spring months with heavy snowfall, sleet, rain, and thunderstorms developing quickly, and accompanied by sharp changes in temperature and wind speed (Schwartz 1977). Temperatures for March and April averaged 2.6 C and 9.9 C, respectively. Average annual precipitation in southcentral Nebraska is 56 cm, with nearly 80% falling from April to September. Snowfall is highest in March and freezes occur as late as May (Gale Research Co. 1985). Prevailing winds in southcentral Nebraska average 22 km/hr from the north-northwest; occasional low pressure systems cause winds to shift from the south at 0-32 km/hr (Ward et al. 1986).

# POWERLINE STUDY SEGMENTS

## UPLAND STUDY SEGMENTS

Within the study area, nine upland segments of powerline were selected as study sites for evaluating the effectiveness of marking wires in reducing sandhill crane collisions with powerlines (Appendix A). These segments had the highest known proportion of dead cranes during baseline surveys (Ward et al. 1986, 1987), and continued to represent a high proportion throughout this study. Each segment consisted of at least 1 km of high voltage transmission line located within 3.2 km of the Platte River. All segments bisected one or more upland habitat type used by cranes for diurnal activities (Table 1).

Standard 30-cm-diameter fiberglass balls, typically used to warn low-flying aircraft of powerline wires, were selected as markers. The balls were yellow with a vertical black stripe. Personnel of Dawson and Nebraska Public Power Districts installed the balls on designated static wires in the spring of 1988 prior to the cranes' staging period. Balls were placed on wires between alternating sets of support poles (referred to hereafter as "span") to represent an experimental design of alternating marked and unmarked spans along a segment. Number of balls per span and number of marked spans per site varied with powerline type and length of the study segment (Figure 2a). Each ball was placed at approximately 100 m intervals on opposite static wires for adequate coverage of the span (Figure 2b).

Table 1. Description and location of nine upland study segments.

| Site | Powerline type[a] | Length (km) | Marked spans: total spans | Number of balls/span | Direction | Habitat type | General location |
|---|---|---|---|---|---|---|---|
| 22 | 9 | 1.6 | 4:8 | 2 | E-W | hay | 3 km north of the river, 2.4 km east of Overton road |
| 2 | 8 | 2.5 | 3:6 | 5 | N-S | grass, hay, corn | 1 km north of river, 0.8 km west of Odessa exit off I-80 |
| 21 | 7 | 1.6 | 5:10 | 1 | E-W | hay | 2 km north of river, heads east from road to Odessa |
| 3 | 9 | 1.6 | 3:6 | 2 | E-W | hay, grass | 3.2 km north of the river, heads east from road to Minden |
| 6 | 9 | 1.6 | 3:6 | 2 | N-S | corn, hay, grass | 1 km north of river, 2 km west of road to Gibbon |
| 20 | 9 | 1.0 | 3:6 | 2 | E-W | corn | 2.4 km north of the river, 0.5 km west of road to Gibbon |
| 4 | 10 | 1.6 | 4:8 | 2 | E-W | grass | 0.8 km south of the river, 3.2 km east of Highway 10 to Minden |
| 5 | 9 | 1.2 | 2:4 | 2 | NE-SW | hay, grass, corn | 0.4 km south of the river, 1.6 km west of road to Lowell |
| 9 | 9 | 1.1 | 2:4 | 2 | N-S | corn, grass | next to river, 2.5 km west of road to Lowell |

[a] see Figure 2a

Figure 2a. Powerline types.

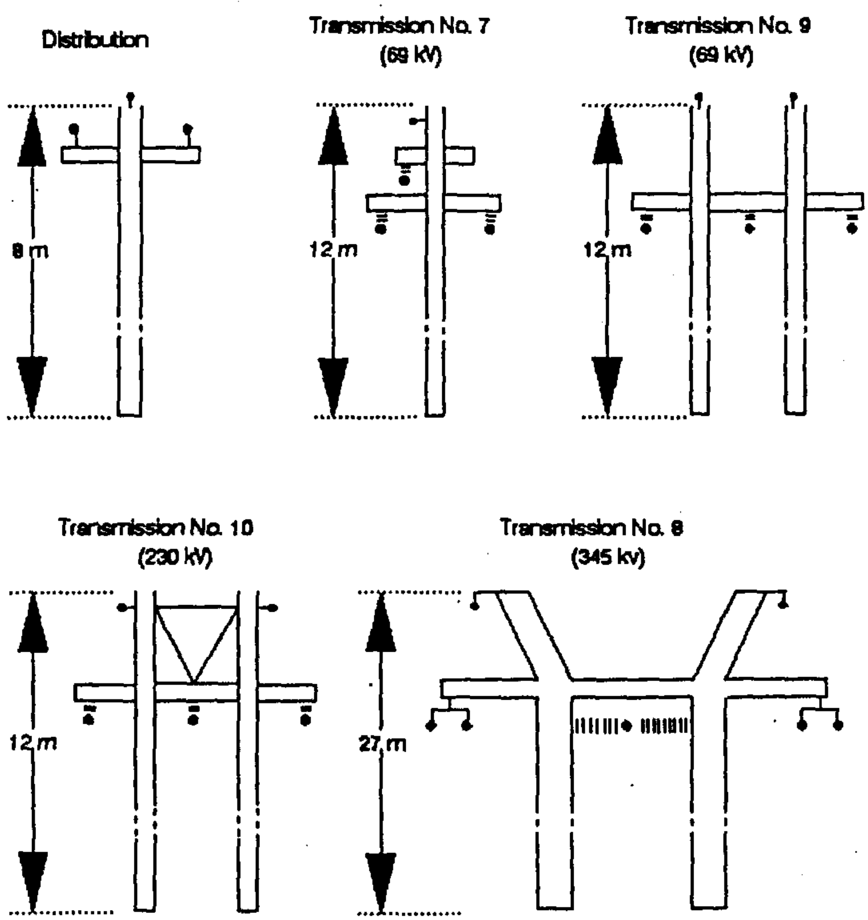
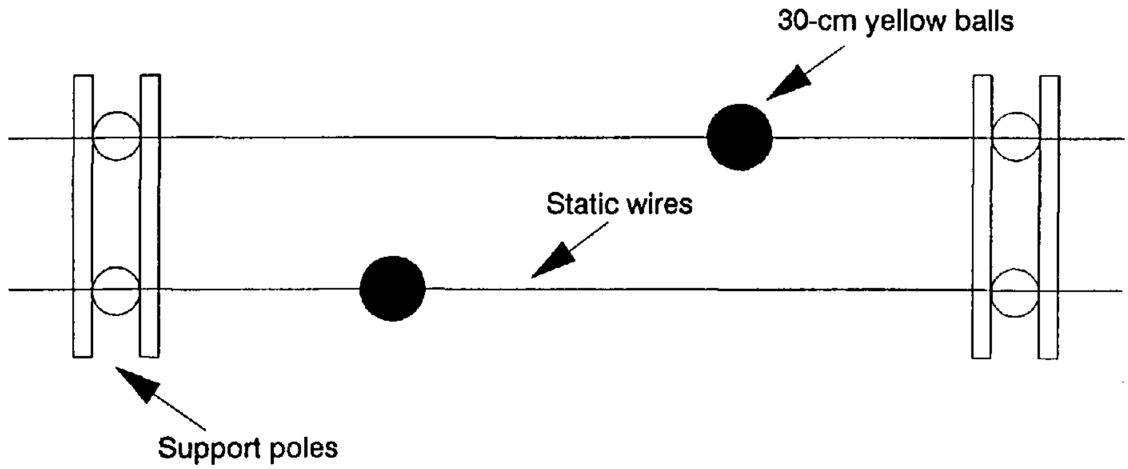


Figure 2b. Ball installation.



## ADDITIONAL SEGMENTS

Supplemental data on crane mortality was collected along an additional 26 km of transmission line traversing upland habitats within the study area. Two river segments were also selected to evaluate the impact of powerline wires spanning the river near major sandhill crane roosts on the Platte River (Appendix A). Site R2 consisted of two unmarked spans of 69-kV transmission line suspended over the main river channel. Site R3 consisted of one span of 69-kV transmission line suspended over the river. Four yellow 50-cm-diameter balls were installed on this span prior to the 1990 field season. Data collected at these segments were evaluated separately from data collected at the marked/unmarked upland study segments.

# FIELD METHODS

## EFFECTIVENESS OF MARKERS

To evaluate the effectiveness of marking static wires with 30-cm-diameter yellow balls in reducing sandhill crane collisions, data was collected on crane mortality and flight behavior in relation to marked and unmarked spans at the nine upland study segments. Supplemental data collected at the additional upland and river segments were not included in the statistical analysis of marker effectiveness.

Crane Mortality

In 1988, each of the nine upland segments was searched to locate dead cranes following a morning observation and again prior to an evening observation. In 1989 and 1990, all nine segments were searched daily so that evidence was discovered within 24 hours of a collision. Searches were initiated with the arrival of cranes on the study area about the first week of March, and terminated after most cranes had departed by the second week of April. Evidence of dead cranes included intact carcasses, scavenged remains, and featherspots. A collision mortality was confirmed for intact carcasses based on trauma and proximity of the carcass to the powerline.

Powerlines bisecting fields were searched on foot: observers walked along one side of the powerline and returned along the opposite side. Powerlines paralleling a road were searched during one pass from a slow-moving vehicle. A 60-m-wide strip along each powerline was searched. Search width was increased to 120 m at Site 2 where wires were twice as high as at other sites, and cranes could potentially fall a greater distance out from the wires. Searchability was good along nearly all study segments because most habitat types traversed included mowed hay meadows, grazed pasture, or corn stubble, and carcasses were easily detected. Powerline rights-of-way with dense vegetation were searched thoroughly by walking a zig-zag pattern to locate concealed carcasses.

Information recorded upon discovery of each dead crane included: carcass condition, span (marked or unmarked), perpendicular distance to powerline, distance to nearest support poles, powerline type, and habitat type. All intact crane carcasses were collected and necropsied.

During 1989 and 1990 field seasons, the total numbers of cranes flying over each upland study segment within 30 m above the wires were counted during 2-hour morning and evening periods throughout the field season. The purpose was to determine general distribution and flight patterns of cranes in relation to study segments and to estimate collision rates.

<u>Crane Flight Behavior</u>

Crane flights over each upland study segment were observed during morning and evening peak flight times as cranes flew between roosting and foraging sites. Morning observations began at first light and lasted until 1.5 hours after sunrise, and evening observations commenced 1.5 hours prior to sunset and continued until last light.

In an attempt to quantify crane reactions to yellow markers, observers monitored crane flights over a set of one marked and one unmarked span, from a vehicle. The vehicle was situated at a distance from the powerline such that the observer could confidently document which span a flock crossed over, while retaining a good view for recording other behavior variables. Flight intensity was too great to record all crane flocks crossing over an observed set of spans. Consequently, crane flocks were randomly selected for observation by a focal group sampling method (Altmann 1974) in 2-minute intervals to ensure independence between flocks. A flock was defined as a distinct group of cranes (one or more birds) flying as an independent unit.

Data recorded in all years included estimated number of birds in flock, whether the span flown over was marked or unmarked, flock's height above static wires, and flock reaction. Reactions included no reaction, increase of altitude, change of flight direction, flare, and collision. Flares were distinguished from an increase of altitude by being a more abrupt reaction where a crane dropped its legs and flapped vigorously to rise vertically. In 1989-90, horizontal distance from wires at which cranes reacted, and the distances from flight origin and destination were also noted.

FACTORS CONTRIBUTING TO COLLISIONS

Supplemental crane mortality and flight behavior data was collected at two river segments and along an additional 26 km of powerline within the study area to 1) evaluate the impact of powerlines suspended across the river near crane roosts, 2) identify factors which contribute to the probability of crane collisions, and 3) fully document crane injuries from colliding with powerlines. These supplemental data were not included in the statistical analysis to evaluate the effectiveness of yellow markers in reducing crane collisions.

Observations of crane flights over river segments were begun prior to sunset and for three hours after darkness. Observers on the river bank noted flight activity (ie. number of flocks, flight direction), reactions, and weather conditions. Cranes were observed through a night-viewing device (Model AN-PVS, U. S. Department of the Army) during darkness. The device was a portable, battery powered, electro-optical instrument that intensified natural light, such as moon or starlight, of the night sky to illuminate observed objects. The river channel was searched once in 1989 to locate evidence of cranes that were observed colliding with a river segment the previous night.

Additional upland powerline segments were searched as often as study segments to locate dead cranes. Search methods and recorded data were the same as for study segments.

Age Classification

The wing molt patterns of dead cranes were examined to distinguish between first-year juveniles and older birds, a technique recently described by Nesbitt (1987). Identification of juvenile cranes by relying on head plumage alone was impractical after January because young birds acquire adult body and head plumage over winter (Lewis 1979b). While the presence of brown nape feathers indicated a juvenile, the lack of such feathers did not necessarily indicate an adult, particularly by March (Tacha and Vohs 1984). However, differences in wing molt patterns separating juveniles from older age classes are evident for birds examined in-hand throughout the year. Juveniles retain even-aged feathers in the wing primaries, secondaries and tertiaries, and buff-tipped greater-upper primary coverts;

whereas older birds gradually replace wing feathers in a descending pattern from inner secondaries to outer primaries over several molts (Lewis 1979b, Nesbitt 1987). New feathers from a recent molt are generally characterized by a black sheen with smooth unworn edges, whereas older feathers are faded brown with worn edges (Lewis 1979b).

Subspecies Classification

Standard morphological measurements of wing chord, exposed culmen, tarsus, and middle toe (without claw) were recorded to determine subspecies classification (Lewis 1979a).

Weather

To relate incidence of crane collisions with powerlines and concurrent weather conditions, hourly weather data was obtained from automated weather stations operated by the Center for Agricultural Meteorology and Climatology, University of Nebraska-Lincoln, near Gibbon and Lexington. The Gibbon station was located within one to five miles of six of the study segments. Daily weather data were obtained from the Nebraska Department of Aeronautics at the Kearney Airport.

Necropsies

Fresh carcasses were collected and necropsied to determine sex by gonadal examination. Physical condition was evaluated by examining pectoral muscle bulk and amount of subcutaneous adipose tissue (Wobeser 1981). External and internal injuries were described.

## STATISTICAL ANALYSIS

### EFFECTIVENESS OF MARKERS

#### Crane Mortality

A chi-square goodness of fit statistic was calculated to evaluate differences between observed and expected numbers of dead cranes found below marked and unmarked spans at the nine upland study segments. Yates correction for continuity ($X^2_c$) was used when degrees of freedom = 1 (Zar 1984). Significance level was set at $p < 0.10$, with highly significant differences occurring at $p < 0.01$. The significance level was recommended by a statistician apriori and is widely accepted in biological studies (Dr. L. McDonald, Dept. Statistics, Univ. Wyoming, pers. commun.).

Counts of cranes flying over study segments in 1989 and 1990 were doubled, assuming cranes cross twice a day on flights to and from roosts and fields, multiplied by 45 days, and divided by number of count surveys to obtain a conservative estimate of potential number of cranes flying over each segment during the 6-week staging period. Collision rates were then calculated to provide information on how many collisions per 100,000 cranes could have occurred relative to the total number of cranes flying over a study segment during a 6-week staging period.

Crane Flight behavior

Categorical flight behavior data from randomly-selected crane flocks flying over the nine upland study segments were organized into contingency tables to assess relationships among variables. Chi-square goodness of fit statistics were obtained for two-way (2 X 2) contingency table analysis in Statistical Package for the Social Sciences (SPSS Release 2.1) to test for homogeneity or independence of observed cell frequencies (SPSS Inc. 1988, Zar 1984). The chi-square test was recommended over analysis of variance methods because of the qualitative, categorical nature of the data (Drs. L. McDonald and D. Anderson, Dept. Statistics, Univ. Wyoming, pers. commun.).

Multidimensional contingency tables were formed from cross-classification of flight behavior variables to test for interrelationships. Stepwise logistic regression in BioMedical Data Program (BMDP) was used to formulate a model that predicted the probability of an outcome of a dichotomous response (dependent variable) given several categories of independent variables (Engleman 1988).

## FACTORS CONTRIBUTING TO COLLISIONS

### Age Classification

Age ratio of dead cranes was statistically compared to reported population age ratio by calculating a chi-square goodness of fit statistic.

### Subspecies Classification

Each crane specimen was subjectively assigned to one of three subspecies by comparing its morphometric measurements with average measurements reported in the literature (Aldrich 1979, Johnsgard 1983). Measurements and initial classifications were subsequently submitted to discriminant analysis in SPSS (SPSS Inc. 1988). Body measurements vary between sex and age classes (Tacha et al. 1985), thus each were treated separately in the analysis. The analysis procedure evaluated the discriminating ability of each measurement, and predicted the probabilities of a specimen's membership in a specific group (Klecka 1980, SPSS Inc. 1988). Initial subjective classification of a specimen does not bias the computer program's classifications if sample sizes are adequate (Guthery and Lewis 1979).

### Weather

Incidence of crane collisions was compared to hourly weather data to test for effects of weather on probability of collisions with powerlines. Time period in which a crane likely collided was estimated within 24 hours based on carcass condition and time since previous search, and compared to concurrent wind speeds during that period. A chi-square statistic tested for differences in observed and expected values.

## RESULTS

### EFFECTIVENESS OF MARKERS

#### CRANE MORTALITY

Evidence of 45 dead cranes that had collided with powerlines were recovered along 13.2 km of the nine upland study segments in 1988, 1989, and 1990 (Table 2). Number of dead cranes on upland study segments was substantially lower in 1988 than in subsequent years. Number of dead cranes per km was estimated at 0.4, 1.3, and 1.6 for each year, respectively.

Markers were effective in reducing mortality of sandhill cranes from collisions with powerlines at the nine upland study segments. Nine cranes were either found alive or were dragged away from the line by scavengers; therefore those were excluded from comparison of mortality at marked and unmarked spans. Of the remaining 36 carcasses, 11 cranes collided with marked spans and 25 cranes collided with unmarked spans. Mortality was different ($p < 0.025$) between marked and unmarked spans at the nine upland study segments.

A total of 183,300 sandhill cranes in 1989 and 176,400 in 1990 were counted flying over the nine upland study segments

Table 2. Sandhill crane mortalities from collisions at nine upland study segments, 1988-90.

| Site | Year | Total number of dead cranes | Number below marked spans | Number below unmarked spans | Span unknown |
|---|---|---|---|---|---|
| 2 | 1988 | 1 | 1 | 0 | 0 |
| | 1989 | 1 | 0 | 1 | 0 |
| | 1990 | 7 | 4 | 3 | 0 |
| 3 | 1988 | 0 | 0 | 0 | 0 |
| | 1989 | 1 | 0 | 1 | 0 |
| | 1990 | 6 | 1 | 4 | 1 |
| 4 | 1988 | 2 | 0 | 0 | 2 |
| | 1989 | 4 | 1 | 2 | 1 |
| | 1990 | 3 | 0 | 2 | 1 |
| 5 | 1988 | 1 | 0 | 0 | 1 |
| | 1989 | 4 | 1 | 3 | 0 |
| | 1990 | 0 | 0 | 0 | 0 |
| 6 | 1988 | 2 | 0 | 2 | 0 |
| | 1989 | 2 | 1 | 1 | 0 |
| | 1990 | 1 | 0 | 1 | 0 |
| 9 | 1988 | 0 | 0 | 0 | 0 |
| | 1989 | 1 | 0 | 0 | 1 |
| | 1990 | 0 | 0 | 0 | 0 |
| 20 | 1988 | 0 | 0 | 0 | 0 |
| | 1989 | 3 | 0 | 2 | 1 |
| | 1990 | 2 | 1 | 1 | 0 |
| 21 | 1988 | 0 | 0 | 0 | 0 |
| | 1989 | 2 | 0 | 1 | 1 |
| | 1990 | 0 | 0 | 0 | 0 |
| 22 | 1988 | 0 | 0 | 0 | 0 |
| | 1989 | 0 | 0 | 0 | 0 |
| | 1990 | 2 | 1 | 1 | 0 |
| Total | | 45 | 11 | 25 | 9 |

during 151 2-hour surveys. No counts were conducted in 1988. There was no significant difference between the number of cranes flying over marked versus unmarked spans; therefore cranes flying over study segments were assumed to have had an equal probability of colliding with either a marked or unmarked span. Estimated total number of cranes flying over all nine segments during the 6-week period was 2,030,100 and 1,600,900 each spring, respectively (Table 3). Number of cranes counted at each site varied year to year. Substantially more cranes were counted at Sites 2, 3, 21, and 22, and fewer cranes at 4 and 5 in 1990 than in 1989.

Collision rates at marked and unmarked spans varied between 1989 and 1990 at each segment (Table 3). Overall, collision rates were lower at marked spans than unmarked spans. Mortalities increased in 1990 at Sites 2, 3, and 22, corresponding to an increased number of crane flights. Similarly, mortalities decreased in 1990 at Sites 4 and 5, as did crane flights.

CRANE FLIGHT BEHAVIOR

A total of 3,080 randomly-selected crane flocks were observed during 404 hours of survey in 1988, 1989, and 1990. Flock size averaged nine cranes (s.d.=39), ranging from one to

Table 3. Estimated number of crane flights and collision rates at nine upland study segments, 1989-90.

| | 1989 | | | | | | 1990 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Total | Total | Marked | | Unmarked | | Total | Total | Marked | | Unmarked | |
| Site | flights | dead | No. | Rate[a] | No. | Rate | flights | dead | No. | Rate | No. | Rate |
| 2 | 41,800 | 1 | 0 | 0.0 | 1 | 4.8 | 90,500 | 7 | 4 | 8.8 | 3 | 6.6 |
| 3 | 21,900 | 1 | 0 | 0.0 | 1 | 9.1 | 131,500 | 5 | 1 | 1.5 | 4 | 6.1 |
| 4 | 374,800 | 3 | 1 | 0.5 | 2 | 1.1 | 360,300 | 0 | 0 | 0.0 | 0 | 0.0 |
| 5 | 838,200 | 4 | 1 | 0.2 | 3 | 0.7 | 259,000 | 0 | 0 | 0.0 | 0 | 0.0 |
| 6 | 189,200 | 1 | 1 | 1.1 | 0 | 0.0 | 175,100 | 1 | 0 | 0.0 | 1 | 1.1 |
| 9 | 265,400 | 0 | 0 | 0.0 | 0 | 0.0 | 305,400 | 0 | 0 | 0.0 | 0 | 0.0 |
| 20 | 250,500 | 2 | 0 | 0.0 | 2 | 1.6 | 188,600 | 2 | 1 | 1.1 | 1 | 1.1 |
| 21 | 26,600 | 1 | 0 | 0.0 | 1 | 7.5 | 57,600 | 0 | 0 | 0.0 | 0 | 0.0 |
| 22 | 15,700 | 0 | 0 | 0.0 | 0 | 0.0 | 33,100 | 2 | 1 | 6.0 | 1 | 6.0 |
| Total | 2,030,100 | | 3 | 0.3 | 10 | 1.0 | 1,601,000 | | 7 | 0.9 | 10 | 1.2 |

[a] Collision rate per 100,000 cranes

2,000. Flocks of 1-3 and 4-20 cranes were observed with equal frequency, accounting for 91% of the flocks observed. Over half of all observed flocks did not react noticeably to the wires. Of those that did react (n=1112), 77% increased altitude, 18% changed flight direction, and 5% flared. No collisions were observed during flight behavior surveys. Nearly half of 839 flocks reacted at 6-25 m from the wires, while other flocks reacted at either 1-5 m or farther than 25 m from wires with equal frequency. Half of observed flocks flew 6-10 m above static wires; approximately one quarter flew over lines either at 1-5 m or 10-30 m. Eighty-four percent of crane flights originated farther than 250 m from powerline segments and continued farther than 250 m after crossing over segments (Table 4). Chi-square tests of two-way contingency tables indicated significant associations among behavior variables (Appendix B).

Presence of yellow balls on static wires significantly effected crane flight behavior. Cranes reacted more often to marked spans than unmarked spans ($p < 0.001$). Reaction type varied in relation to presence of balls (Figure 3). In reaction to marked spans, cranes were more likely to increase altitude or change flight direction than cranes flying over

Table 4. Observation data for crane flight behavior, 1988-1990.

| | Flock size | | | Reaction[a] type | | | | Reaction distance (m) | | | Height above wires (m) | | | Origin (m) | | Destn. (m) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1-3 | 4-20 | >20 | 0 | 1 | 2 | 3 | 1-5 | 6-25 | >25 | 1-5 | 6-10 | >10[b] | <250 | >250 | <250 | >250 |
| n | 1438 | 1366 | 276 | 1968 | 851 | 206 | 55 | 225 | 386 | 228 | 825 | 1348 | 907 | 373 | 1981 | 284 | 2070 |
| % | 46.4 | 44.4 | 8.9 | 63.9 | 27.6 | 6.7 | 1.8 | 26.8 | 46.0 | 27.2 | 26.8 | 43.8 | 29.4 | 15.84 | 84.16 | 12.06 | 87.94 |

[a] 0=no reaction, 1=increased altitude, 2=changed direction, 3=flared
[b] recorded heights >10m in 1989-1990 only; excluded from data analysis

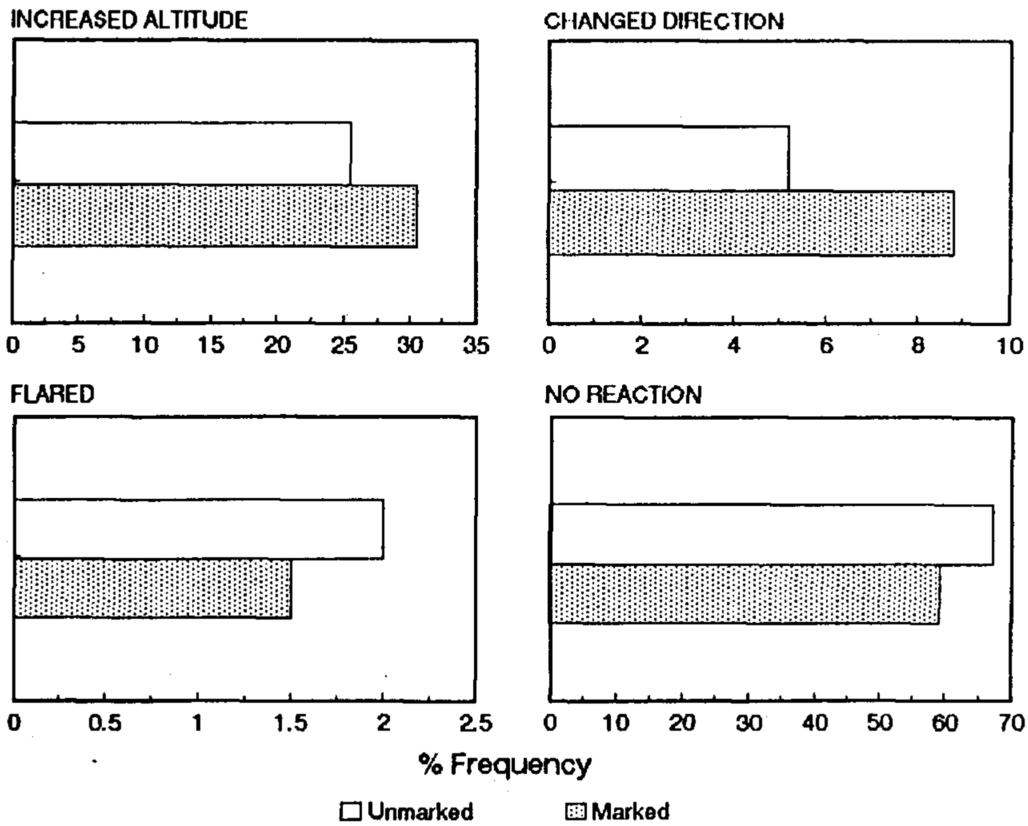



Figure 3. Crane reactions to marked and unmarked spans at nine upland study segments, 1988-90.

unmarked spans. Among cranes flying over unmarked spans, flare reactions were comparatively more common. This behavior suggested that cranes approaching marked spans saw the balls and were more likely to adjust their altitude or direction to avoid the balls. On the other hand, cranes approaching unmarked spans may have been less aware of the wires and were more likely to flare from the wires. Data on reaction distances and height flown over wires support the significant effect of markers on crane flight behavior.

Reaction type and reaction distance differed between marked and unmarked spans ($p < 0.001$) (Figure 4). More cranes increased altitude at distances farther than 25 m from marked wires than at unmarked spans, suggesting that cranes saw the balls at a distance and adjusted altitude accordingly. In contrast, cranes flared more often within 1-5 m of unmarked wires, perhaps because they were unaware of the wires and approached closely before flaring away. Cranes changed direction at all distances more often at marked spans than unmarked spans.

Cranes which reacted to powerlines tended to be those flying over lines at a height of 1-5 m above the static wires ($p < 0.001$) (Figure 5). There was not a significant

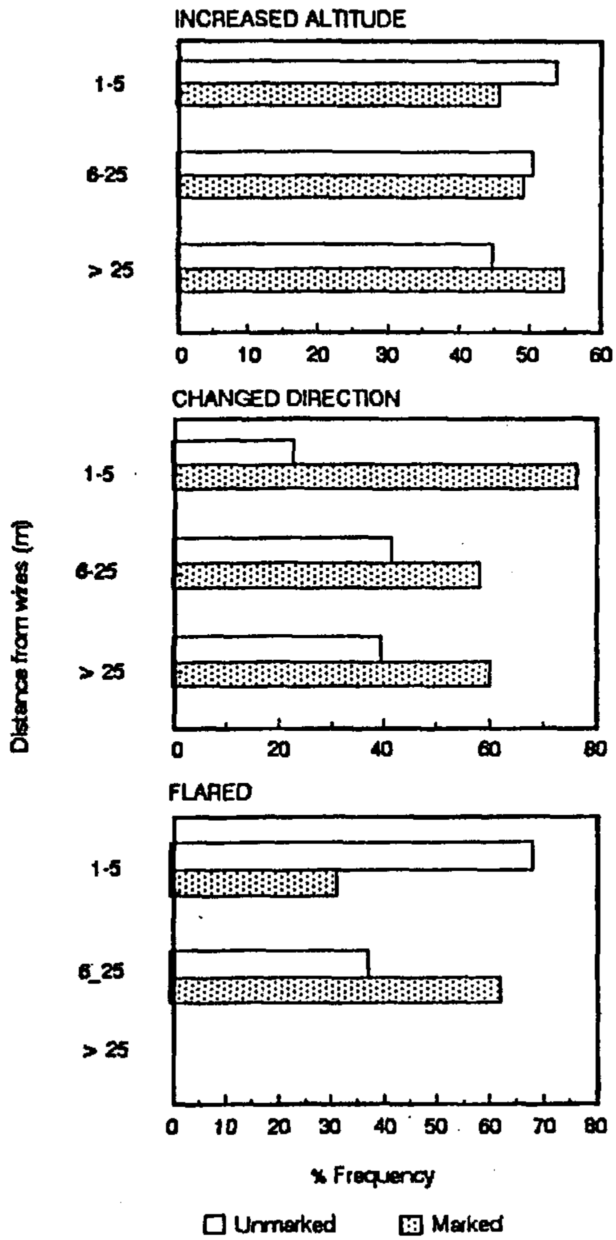



Figure 4. Crane reaction distances at marked and unmarked spans at nine upland study segments, 1989-90.

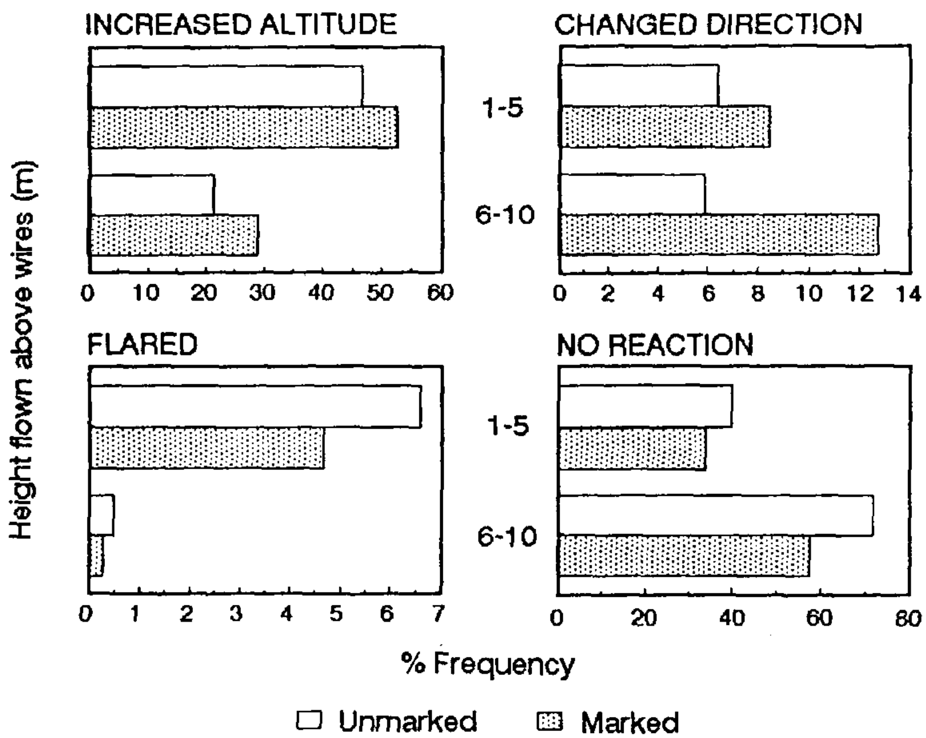



Figure 5. Crane reactions and flight altitude at marked and unmarked spans at nine upland study segments, 1988-90.

difference in height of cranes flying over marked and unmarked lines detectable by the selected height categories. Cranes were more likely to fly at low altitudes over powerlines and react to the wires when making short foraging or local flights. Crane flocks reacted more often when flights originated within 250 m of the span ($p < 0.001$), and similarly when they landed within 250 m of the span after crossing over ($p < 0.001$) than for longer flight distances (Figure 6). Flight distance was also related to height flown above wires; cranes flying less than 250 m prior to or following an overflight tended to fly 1-5 m above the wires, while flocks flying farther than 250 m to or from a line tended to fly higher than 6 m above the wires ($p < 0.001$) (Figure 7).

Reaction type differed between different flock size categories ($p < 0.001$). Flocks of 4-20 cranes were more likely to react by increasing altitude than other flock sizes; whereas flocks of 1-3 flared more often in reaction to wires.

Some behavior variables varied with time of day. Flocks of 1-3 cranes were observed more often during morning surveys, whereas flocks of 4-20 and greater than 20 cranes were more commonly seen during evening surveys ($p < 0.001$). Small flocks consisting of pairs and family units leave roosts in

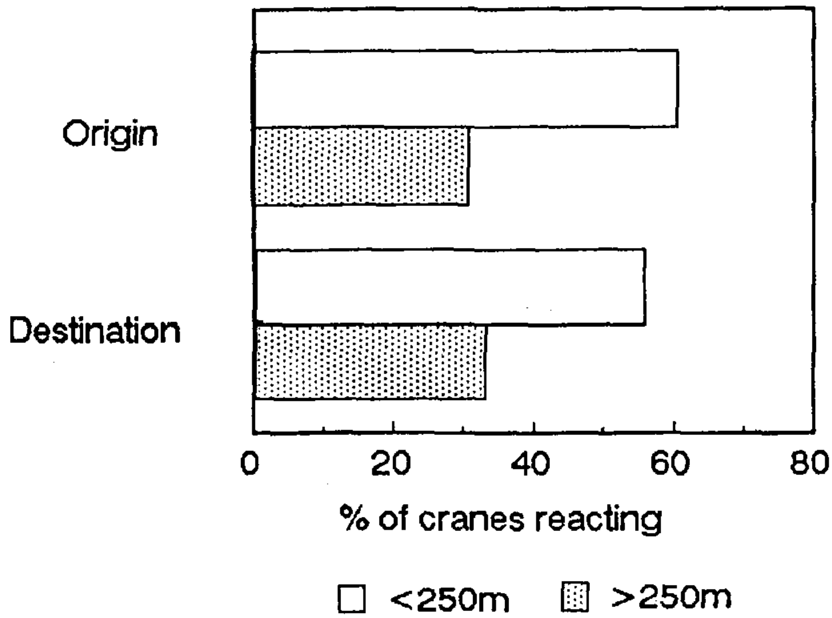



Figure 6. Crane reactions to nine upland study segments in relation to flight distance from origin and destination, 1989-90.

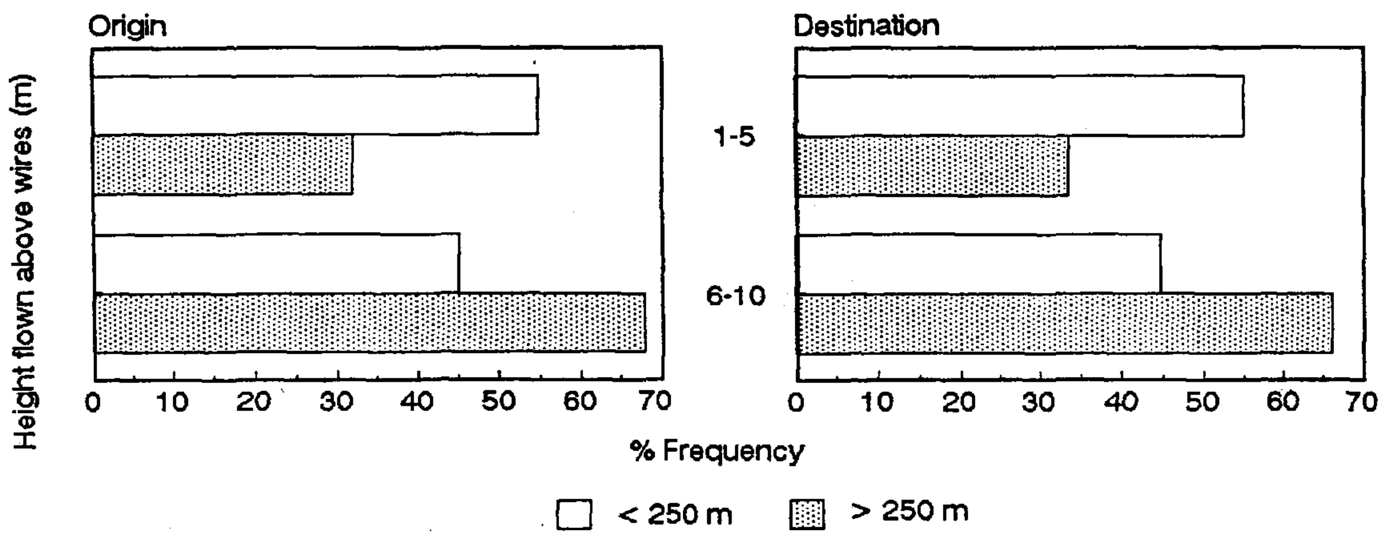



Figure 7. Crane flight altitude above wires in relation to flight distance from origin and destination at nine upland study segments, 1989-90.

the morning, and form larger feeding flocks during the day before returning to roosts (Stephen 1967, Faanes and Frank 1982, Tacha 1988). Cranes flew closer (1-5 m) over wires in the morning, but higher (>6 m) in the evening ($p < 0.001$).

Powerline type influenced frequency of reactions. More cranes reacted when flying over the 27-m high 345-kV transmission line than expected, while fewer cranes reacted to the 12-m high 69-kV transmission lines than expected ($p < 0.001$).

Results from logistic regression analysis did not contribute to an understanding of relationships between flight behavior variables, beyond what the two-way analysis had shown previously. Logistic regression modelling selected height flown above wires as the only significant independent variable that predicted whether or not cranes reacted to a powerline, regardless of time of day, flock size, presence or absence of markers, and flight distance from flock's origin. Reaction type was the only independent variable selected to predict whether cranes flew over marked or unmarked spans.

Collisions

Cranes were observed colliding or nearly colliding with wires at upland study segments on six occasions, although not during recorded observation periods. In every incidence, cranes struck the static wires of the unmarked spans. The trailing crane of a flock on two occasions was the one that collided, as if it was following the cranes ahead rather than watching the powerline. Also, cranes flying with a tailwind in three cases had poor flight maneuverability, even though wind speeds varied.

## FACTORS CONTRIBUTING TO COLLISIONS

### RIVER SEGMENTS

Crane flights were observed at Sites R2 and R3 on 13 and 21 nights, respectively. At R2, cranes roosted in the river approximately 300 m both upriver and downriver of the two spans. At R3, cranes roosted downriver as close as 100 m of the single span. As the cranes settled onto roosts in the evening, there was substantial flight activity back and forth between roosts and over powerline segments spanning the river following sunset.

Cranes were not observed colliding with either of two spans at R2 in any years. Site R3 was not monitored in 1988. In 1989, R3 was monitored on 11 nights, and 14 collisions were observed on eight of the 11 nights, involving a total of 40 sandhill cranes. All cranes struck the static wires of the single span, just after darkness.

Following the second night of collisions observed in 1989, the river channel was searched for crane carcasses downriver along the riverbank and islands. Seventeen individual crane featherspots and numerous waterfowl featherspots were subsequently located. In addition, a live crane with a nearly severed wing was found 250 m downriver on a sandbar. The injured crane likely collided with the span but somehow traveled to the roost and was unable to leave.

As a consequence of these observations, Dawson Public Power District installed four 50-cm-diameter yellow balls on the R3 span in December, 1989. Subsequently, the marked span at R3 was monitored in March-April, 1990 on 10 evenings, and only a single collision was observed in which a lone crane struck a static wire yet continued flying. Flight activity and weather conditions were similar during observations in both years.

In 1990, a tally was kept of whether or not each flock, regardless of flock size, reacted to river spans on four nights. At R2, only 16% (n=337) of flocks showed any apparent reaction to the two spans. In contrast, 68% (n=311) reacted to the single marked span at R3. The above data were not included in the statistical analysis on the effectiveness of markers presented in the previous section.

ADDITIONAL UPLAND SEGMENTS

One hundred-and-twentysix sandhill cranes collided with powerlines in the study area during March and April of 1988, 1989, and 1990, including the 45 found along upland study segments (Appendix C). Success in locating cranes killed from powerline collisions was effected by search effort, scavenging of carcasses, and departure of crippled birds from the searched area.

Selected search width of 30 m either side of the wires was effective for locating most crane carcasses along powerline rights-of-way. Of 86 unscavenged crane carcasses for which perpendicular distance from wires was recorded, 70% were found within 10 m, 22% within 10-20 m, 2% within 20-30 m, and 6% at distances greater than 30 m (Figure 8). Unscavenged carcasses were found as far out as 47 m from the wires.

Of 111 cranes, only 17% (19) were scavenged by avian or mammalian scavengers. Only two were scavenged within 24 hours of the previous search, while others were found under non-study segments searched less frequently. Predators may have

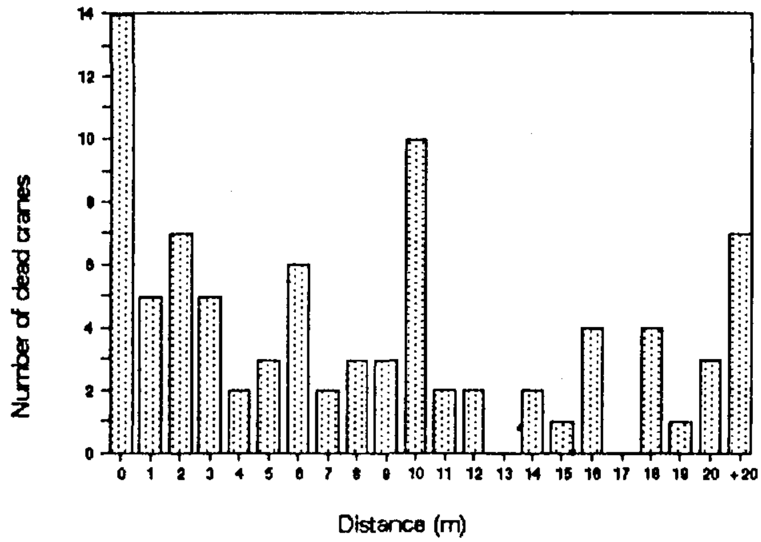



Figure 8. Perpendicular distance of dead cranes from powerline.[a]

[a] Data includes dead cranes found in study area below nine upland study segments and additional upland segments

removed carcasses; however, such removal was minimized particularly on the nine upland study segments by searching segments daily in 1989 and 1990.

Eleven live crippled cranes accounted for 12% of the sample of cranes colliding with powerlines. Eight cranes had debilitating injuries, such as broken or missing wings or legs, which would eventually prove fatal. One crane with temporary leg paralysis was captured and transported to a zoo for rehabilitation. Two other crippled cranes were capable of fleeing from pursuit and escaped capture. In addition, I found severed limbs below powerlines on four occasions, suggesting that cranes collided with the powerlines but flew or walked out of the searched area to die. We commonly saw cranes flying with broken or missing legs, and received many reports each spring of crippled cranes lying below powerlines elsewhere in the Platte River valley.

Powerline Type

Of all dead cranes collected throughout the study area, 88% (111) were found below high-voltage transmission lines, and 12% (15) below distribution lines. Data were similar to preliminary surveys of Ward et al. (1987): cranes collided more often with transmission lines than distribution lines, even though distribution lines were five times more numerous in the study area. Cranes colliding with distribution lines were frequently electrocuted by contacting two wires, and I noted evident burn marks on five cranes found dead below distribution lines.

Distance of dead cranes from the nearest support poles was recorded for 79 carcasses. Thirty-seven percent of dead cranes were located midway between pole structures (Figure 9). Cranes may avoid pole structures but are less likely to see the wires suspended between poles, which ranged in distance from 85 m (distribution line) to 445 m (345-kV transmission line).

<u>Disturbance</u>

Based on crane mortality data, I identified circumstances in which cranes collided with a powerline as a result of disturbance on two occasions. In 1988, six cranes were found dead below a single span of 69-kV transmission line paralleling a gravel road, with cornfields on both sides. Cranes feeding in adjacent fields often flushed as vehicles passed. I believe these dead cranes were in a flock that flew up into the line in a panic flush. Similarly, in 1989, 11 cranes were found dead below a single span of 69-kV

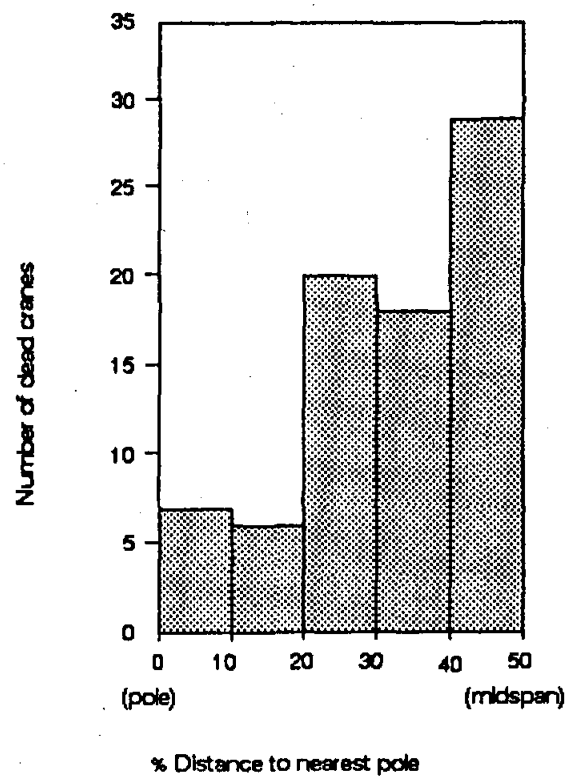



Figure 9. Distance of dead cranes to nearest support pole. [a]

[a] Data includes dead cranes found in study area below nine upland study segments and additional upland segments

transmission line angling away from a gravel road and bisecting an alfalfa and corn field. Cranes frequently fed and loafed near or under the powerline. The road was regularly traveled by local residents and crane-watchers, and cranes within 300 m of the road repeatedly flushed near the wires as vehicles passed.

Age Classification

Juvenile cranes were significantly more susceptible to collisions with powerlines than older cranes. I examined wing molt patterns for 84 cranes killed by colliding with powerlines and classified 20 first-year juveniles (J), 46 second-year and third-year subadults, and 18 adults. Combining subadults and adults into a single age class (A), sample age ratio was 24 J : 76 A, which was statistically different ($p < 0.001$) from the population age ratio of 12 J : 88 A (Buller 1979, Tacha et al. 1986).

Subspecies Classification

Thirty-nine crane carcasses were classified as *G. c. canadensis*, 35 as *G. c. rowani*, and five as *G. c. tabida*, based on discriminant analysis using four morphmetric measurements.

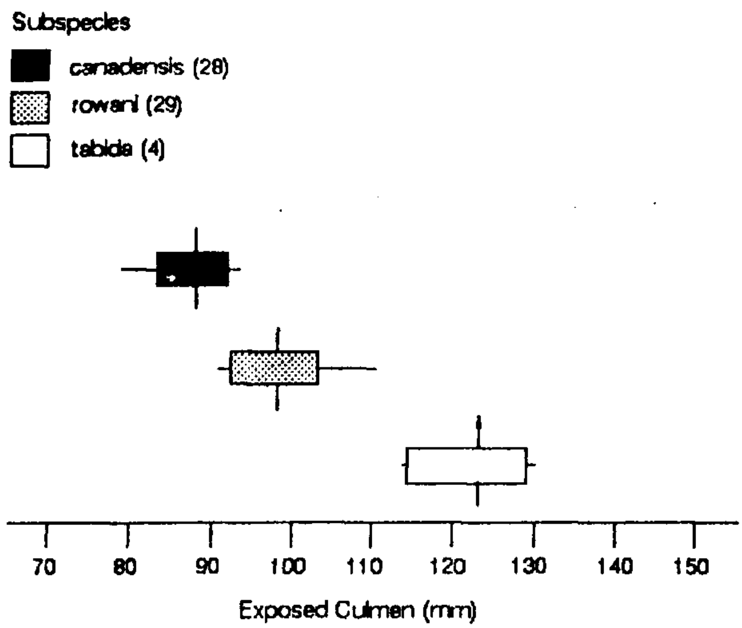
Results of male versus female subspecies discrimination indicated that group means of all measurements for each sex fit well within the limits of means for adult and juvenile groups with sexes combined. Sample sizes were small for known females (20) and males (13); therefore I combined sexes within their respective age groups for the general purpose of subspecies classification.

Ninety-one percent of adult canadensis and rowani specimens were classified correctly, as were 100% of adult tabida and all juvenile specimens.

Exposed culmen length was shown to be the best discriminating variable. Culmen length maximized separation of subspecies groups for both adults (Wilk's lambda = 0.2391) and juveniles (Wilk's lambda = 0.2462). Although culmen all but overlapped between canadensis and rowani, which produced 8.33% of incorrect classifications, differences were distinct between rowani and tabida (Figure 10).

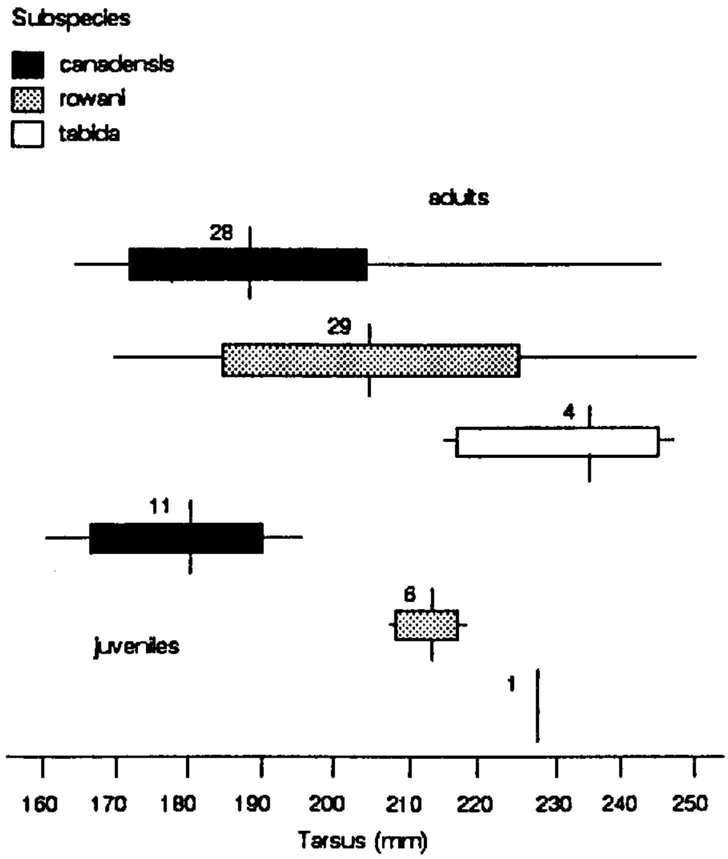
Tarsus length was selected secondarily as a discriminant function for juveniles (Wilk's lambda = 0.1786), but not for adults (Wilk's lambda = 0.7048). Small sample size of juveniles may have led to a biased selection of tarsus, which overlapped substantially between adult subspecies (Figure 11).

Figure 10. Exposed culmen length of adult sandhill crane specimens.




Verical line is mean, horizontal line is range, rectangle is standard deviation, and number in parentheses is sample size.

Figure 11. Tarsus length of juvenile and adult sandhill crane specimens.




Vertical line is mean, horizontal line is range, rectangle is one standard deviation, and number is sample size.

Walkinshaw (1949) was able to distinguish subspecies on the basis of tarsus as well as culmen length.

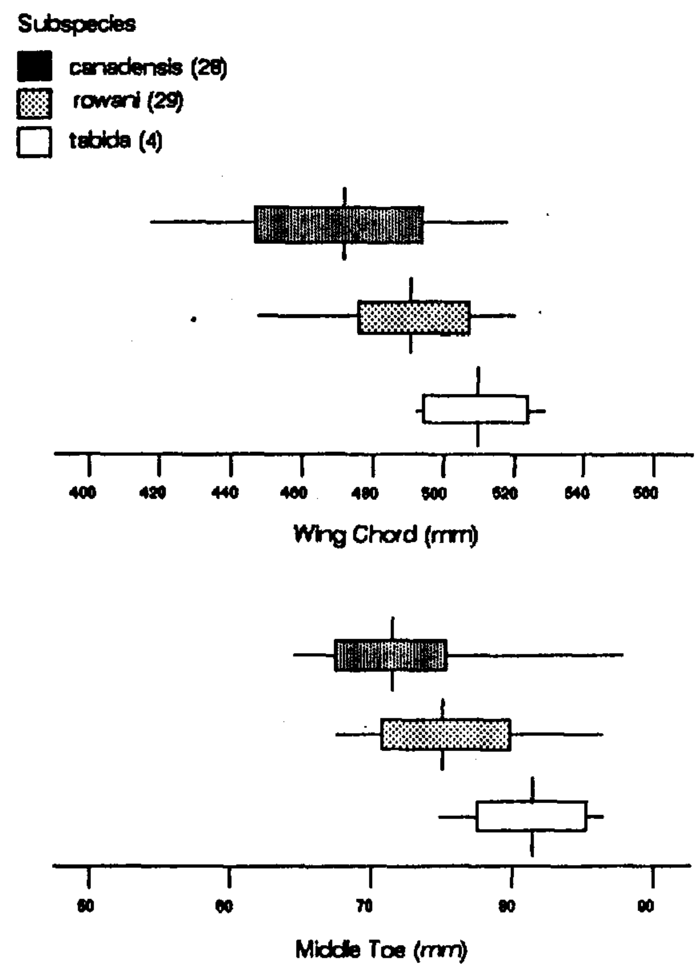
There was considerable overlap of wing chord and middle toe measurements between adjoining subspecies in the sample (Figure 12). Lambda values were greater than 0.7027 for adults and 0.4104 for juveniles, indicating comparatively poor discriminating abilities. Gaines and Warren (1984) found no distinction of subspecies based on wing chord or middle toe; whereas Aldrich (1979) used wing chord to distinguish between adjoining subspecies.

Weather

Weather conditions in March and April at Kearney, Nebraska varied slightly from year to year during the 3-yr study (Table 5). In 1988, it was warmer and drier than the 40-year average, and March was the second driest on record for that month. In 1989, it was colder than average, and more snow fell in 1989 than either 1988 or 1990. In 1990, March was warmer and wetter than average, but April was colder and drier. Mean wind speeds (gusts included) in all years were average (Ward et al. 1986).

Probability of collision was twice as high on days when wind speed exceeded 24 km/hr ($p < 0.05$). The occurrence of 35

Figure 12. Wing chord and middle toe lengths of adult sandhill crane specimens.




Vertical line is mean, horizontal line is range, rectangle is one standard deviation, and number in parentheses is sample size.

Table 5. Weather conditions at Kearney, Nebraska for March and April, 1940-80 and 1988-90.

| Date | Temperature °C | | | $\bar{X}$ Wind speed (km/hr) | Total rain (cm) | Total snow (cm) |
|---|---|---|---|---|---|---|
| | Min | Max | Mean | | | |
| 1940-1980[a] | | | | | | |
| March | | | 2.56 | | 2.82 | |
| April | | | 9.94 | | 6.12 | |
| 1988 | | | | | | |
| March | -4.61 | 11.95 | 3.67 | 22.72 | 0.23 | 5.08 |
| April 1-14 | 1.55 | 18.69 | 10.12 | 21.84 | 2.08 | 0.00 |
| 1989 | | | | | | |
| March | -6.14 | 9.12 | 1.49 | 21.70 | 0.89 | 12.70 |
| April 1-12 | -1.34 | 16.34 | 7.50 | 19.65 | 0.13 | 0.00 |
| 1990 | | | | | | |
| March | -2.19 | 11.13 | 4.47 | 21.12 | 11.51 | 2.54 |
| April 1-12 | -0.79 | 12.64 | 5.92 | 22.35 | 0.38 | 0.00 |

[a] Gale Research Co. 1985

mortalities within a known 24-hr period were compared to concurrent hourly wind speeds. Even though calm (<24 km/hr) and windy (>24 km/hr) days occurred with equal frequency, 24 (69%) collisions occurred on windy days while only 11 (31%) collisions occurred on calm days (Figure 13).

Sex

Equal numbers of male (29) and female (29) cranes were found after colliding with powerlines. Reinecke and Krapu (1986) found a 50:50 sex ratio in most sandhill crane populations. Assuming this to be true for crane populations staging along the Platte River during the 3-yr study, there was no differential mortality between sexes.

NECROPSIES

Various external injuries sustained by cranes that collided with powerlines were documented, including broken culmen and neck, fractured or completely severed wing and tarsus, and abrasions. Of 73 closely-examined crane specimens, 95% had obvious external injuries, and 38% of those sustained a combination of two or more injuries.

Necropsies were completed on 53 crane specimens. Most (78%) were in good to excellent physical condition. We

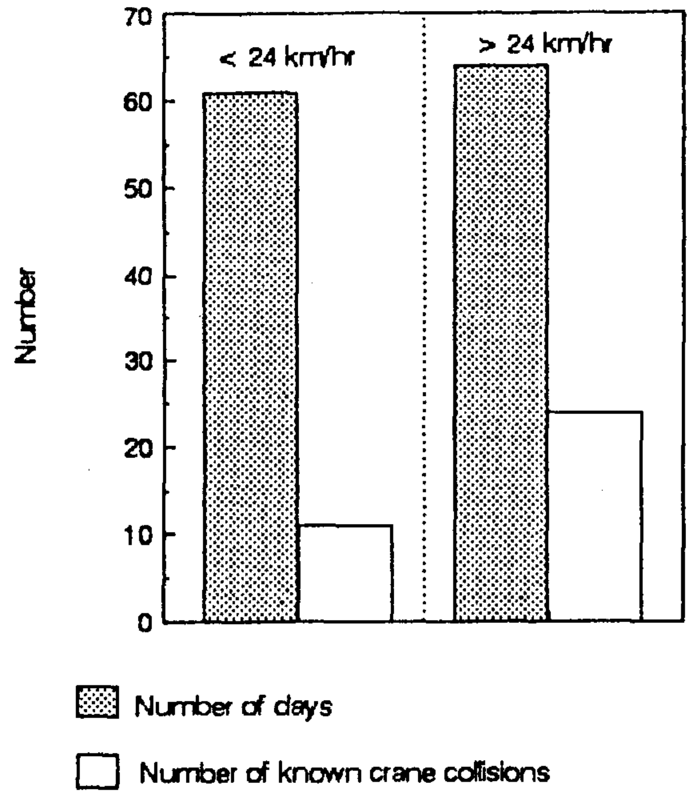



Figure 13. Occurrence of crane collisions in relation to wind speed. [a]

[a] Data includes dead cranes found in study area below nine upland study segments and additional upland segments

observed dramatically greater amounts of fat in cranes collected in April than in March.

Gross findings from internal examinations included one or a combination of the following: fractured vertebrae, clavical, sternum, ribs, and pelvis; ruptured liver, kidney, lungs, and intestines; and minor to extensive hemorrhaging in pectoral muscle, heart, liver, kidney, lungs, thoracic air sacs, neck region, and brain. All dead cranes were diagnosed with severe trauma caused by collision with a powerline or subsequent impact upon falling to the ground.

# DISCUSSION

## EFFECTIVENESS OF MARKERS

Yellow balls on static wires were effective in reducing sandhill crane collisions with transmission lines along the Platte River valley of southcentral Nebraska. A statistically significant difference in number of crane mortalities was observed at marked and unmarked spans at nine upland study segments over 3 years. Furthermore, crane flight behavior suggested that yellow balls evoked avoidance reactions by cranes; whereas cranes reacted less often to spans without balls. Cranes approaching marked spans typically increased altitude at farther than 25 m from the wires, suggesting that they saw the balls from a distance and avoided them. On the other hand, cranes were more likely to flare within 5 m of unmarked spans, as if they were unaware of the wires until closer approach. Observations of crane flights over powerlines suspended across the river near roosts also showed that cranes reacted more frequently where balls were present on the static wires. Research indicates that birds' eyes are most sensitive to yellow-green under daylight conditions

(Beaulaurier 1981); therefore the yellow coloration was most likely visible to the cranes.

In our opinion, the most substantial evidence on the effectiveness of yellow balls was the virtual elimination of crane collisions after marking the single span suspended across the river at Site R3. While these data were not statistically analyzed as were the flight behavior data from the nine upland study segments, the difference in observed collisions before and after marking is obvious. Powerlines routed across a river channel, particularly near roosts, present hazardous obstacles to cranes and other waterbirds flying along a river's course (Willard et al. 1977). Fifty-one crane carcasses were recovered in 1981 at a powerline that crossed the Platte River east of Kearney (Windingstad 1988), which was the same location as Site R3 (K. Strom, Rowe Audubon Sanctuary, Gibbon, pers. commun.). In the evening, cranes flew into roosts on both sides of the span, and it appeared that many cranes frequently left the east roost to move upriver; consequently, cranes crossed the span numerous times. Ward et al. (1986) also observed cranes leaving one roost to fly to another after twilight. Frith (1974) reported that cranes on the Platte River were active until midnight and short flights on the river were common. The roost located downriver of Site R3 was known to hold as many as 30,000 cranes in a night (C. Frith, National Audubon Society, Grand Island, pers. commun.).

No collisions, however, were observed upriver at Site R2. Prior to marking, Site R3 was more hazardous for cranes to fly over than R2 because of pole structure placement. At Site R3, a single span of wires was suspended over the river between poles set on opposite banks; in contrast, two spans were suspended over the river with a set of poles midstream at Site R2. Cranes may have seen the middle set of poles and adjusted their altitude, but they were less likely to see the wires at Site R3 and risked collision. Cranes regularly flew along the river at altitudes such that they would collide with the wires if no evasive action were taken.

While random observations at river segments revealed a significant risk posed by powerlines suspended across the water to nearby crane roosts and indicated a significant effect of markers, this study was initially designed to evaluate daytime flight behavior of cranes at upland segments. Further study should be initiated to adequately address the hazard of powerlines suspended across rivers which birds travel at night.

The magnitude of powerline collision mortality of sandhill cranes in the Platte River valley was higher than the collected sample of dead cranes indicated, considering unknown crippling losses. Crippling of birds was substantial in several studies of bird collisions with powerlines (Krapu 1974, Anderson 1978, James and Haak 1979, Beaulaurier 1981, Faanes 1984).

## FACTORS CONTRIBUTING TO COLLISIONS

Crane collisions were related to several factors: proximity of powerlines to crane habitat, weather, disturbance, number of crane flights over powerline segments, and age were important factors contributing to sandhill crane collisions along the Platte River.

Cranes were more vulnerable to colliding with powerlines that bisected flight routes between roosts and/or fields. Crane flight behavior indicated that cranes flying less than 250 m before crossing over a powerline were lower in relation to the wires and increased their altitude to avoid wires. Cranes travelling farther than 2-3 km fly at higher altitudes

(Tacha 1984). Bealaurier (1981) and Brown et al. (1987) also observed cranes fly at low altitudes over powerlines in association with short flights.

Cranes were frequently observed flying 10-15 m above the ground between fields; as a consequence, 12-m-high transmission lines obstructed their typical flight path. Cranes were never observed flying under transmission lines except when flushed, and it seemed counter to their habit to do so intentionally. Even at the 27-m-high transmission line at Site 2, cranes were reluctant to fly under the line, but instead flew vigorously upwards to cross over the wires. Waterfowl and geese also seldom fly under powerlines but rise to pass over (Hunt 1972, Willard et al. 1977, Cassell et al. 1979).

Birds flying over powerlines adjacent to roosting or foraging sites have less time and distance in which to react and avoid wires (Scott et al. 1972, Andersen-Harild and Bloch 1973, Kroodsma 1978, Thompson 1978, Beaulaurier 1981, Brown et al. 1987, Howard et al. 1987, Faanes 1987, and others). Powerlines situated near potential whooping crane use sites would pose a hazard (Lingle 1987). Coupled with inclement weather and/or disturbance factors, the case where powerlines bisect crane flight paths was an important factor contributing to sandhill crane collisions with powerlines.

Inclement weather conditions limited the ability of cranes to detect and avoid powerlines in their flight path. Wind speed was significantly related to crane collision mortalities in this study. Cranes flying with a tailwind approached wires faster and had less time to maneuver. Cranes typically lowered their legs and flapped vigorously to rise upward over static wires; however strong winds and gusts rendered such a strategy less effective. Hence, cranes often broke or severed their legs upon striking the wires. Several near-collisions were observed where cranes flying with a tailwind flared at static wires.

Precipitation and fog occurred infrequently during all years of the study; therefore mortality data did not reflect the potential for collisions under such conditions. However, others have documented considerable crane mortalities from powerline collisions following snowstorms accompanied by high winds and limited visibility (Wheeler 1966, Brown et al. 1987, Ward et al. 1986, 1987), and under foggy conditions (Tacha et al. 1979). Inclement weather contributes to other bird collision mortality as well (Krapu 1974, Stout and Cornwell

1976, Thompson 1977, Willard et al. 1977, Anderson 1978, Faanes 1984).

Cranes were disturbed by vehicles and people, both inadvertantly and intentionally. Cranes frequently flushed from fields as vehicles passed on adjacent roads, even when separated by distances greater than 300 m. Bird-watchers and photographers easily disturbed cranes when they approached on foot, and a photo of a flushed flock was seemingly more desirable than one of cranes on the ground. Occasionally, cranes tolerated stationary vehicles or a person walking a regular route. Disturbed cranes could likely flush wildly away from the disturbance into a powerline in their path. Brown et al. (1987) reported that crane collisions were likely to occur when cranes were flushed near a powerline. Archibald (1987) attributed powerline collision mortality of red-crowned cranes to disturbance by photographers. Several researchers concluded that disturbance was a major factor contributing to bird collisions with powerlines (Blokpoel and Hatch 1975, Willard et al. 1977, James and Haak 1979, McDonald 1979, McNeil et al. 1985).

The potential for crane collisions increased with crane use adjacent to powerlines, as shown by annual variation in collision rates corresponding to crane flights at upland study segments. Crane distribution from Overton to Odessa has shifted eastward in recent years as availability of roosting habitat diminishes due to vegetative encroachment on the river (Frith 1974; K. Strom, Rowe Audubon Sanctuary, Gibbon, pers. commun.); which may explain the increasing number of cranes observed at Sites 2 and 21 near Odessa. At Site 22 near Overton, low numbers of cranes were expected each year because of limited roosting habitat nearby; however, more cranes were observed in 1990 because of several thousand cranes began roosting nightly in a shallow lake 0.6 km northwest of Site 22 (T9N R19W S32 SW1/4, Dawson Co.). These cranes flew across Site 22 to feed in corn and alfalfa fields; consequently, more crane flights, as well as collision mortalities, were recorded in 1990. The lake roost had not been identified in previous years. Others have reported that collisions with powerlines coincided with peak numbers of birds, especially during migration (Scott et al. 1972, Krapu 1984, Stout and Cornwell 1976, Thompson 1977, Anderson 1978, McDonald 1979, Malcolm 1982, Brown et al. 1984, Faanes 1987).

Juvenile sandhill cranes were considerably more vulnerable to powerline collisions than adult cranes.

Juveniles may have lacked flight experience and were unfamiliar with the area their first year, and thus were less adept at avoiding powerlines. Brown et al. (1987) and Ward et al. (1986, 1987) also reported significantly higher proportions of juvenile crane mortalities from powerline collisions compared to adults. Others have concluded that inexperienced and immature birds were more susceptible to powerline collision mortality than adults (Krapu et al. 1974, Fitzner 1975, Stout and Cornwell 1976, McNeil et al. 1985). Of 13 whooping cranes of known age that have collided with powerlines, eight were juveniles, three subadults, and two adults (Ward et al. 1986). Both sandhill and whooping cranes have low annual recruitment rates of less than 12%, therefore mortality of young birds raises concern (Krapu et al. 1982). Collision mortality of young whooping cranes is an adverse factor effecting the population growth of whooping cranes (U. S. Fish and Wildlife Service 1986).

## RECOMMENDATIONS

Based on field observations and evaluation of the effect of yellow balls on static wires on sandhill crane flight behavior and mortality, the following recommendations are offered for marking transmission lines to reduce crane collisions.

Transmission lines should be marked to reduce the probability of a whooping crane collision. Particular sites should be selected for marking based on historic use of a site or high probability that a site will be used by whooping cranes.

Sandhill crane mortality from collisions with powerlines is not biologically significant for the species as a whole; nevertheless, mortality of any migratory bird should be minimized. Flight patterns and mortality in relation to powerlines should be determined to assess the occurrence or potential of collisions. Marking efforts should be concentrated in areas of historically high bird use and high mortality.

The number and size of balls placed on static wires will vary with the powerline type, span length, and structural limitations of the powerline. Pole structures apparently act as visual cues to the presence of wires because cranes collide more often at mid-span, thus balls should be spaced at least along the middle portion of a span. Two markers per 100 m of wire would be effective for maximum visibility. Larger marker size would also increase visibility. The larger 50-cm balls installed on the river span seemed substantially more visible from a distance than the 30-cm balls on upland study segments, and may be comparatively more visible under extreme weather or light conditions.

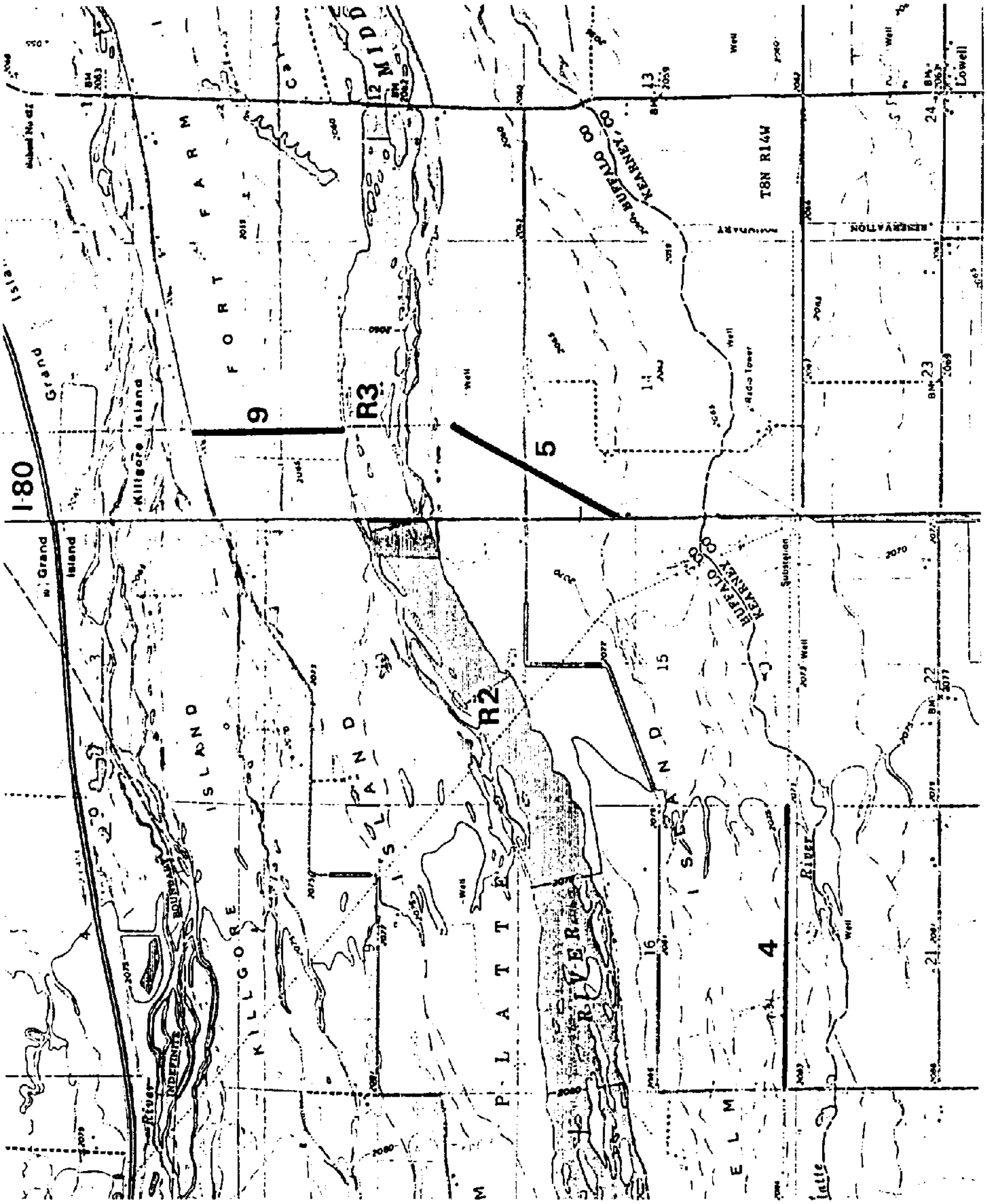
To the human eye, yellow markers were highly visible, even under low light. The black vertical stripe created an effective contrast on yellow and to the horizontal wire to which the ball was attached. The tape wrapped around the fiberglass ball remained intact for the 3-yr study. While any markers may not be effective under extreme conditions, such as thick fog or total darkness, the yellow balls seemed to be visible under a range of light conditions. Cranes evidently saw the yellow balls on the river span after twilight, and they may have perceived either the yellow color or the balls' silhouette. Luminescent tape that glows after dark wrapped onto fiberglass balls would be even more suitable in cases where birds encounter powerlines under low light conditions (Beaulaurier 1981). Yellow spiral vibration dampers and swing plates are currently being evaluated as color-marking devices to reduce crane and waterfowl collisions in the San Luis Valley, Colorado (Brown et al. 1987). Marking efforts should follow a case-by-case evaluation of the extent or potential of collision mortality at the concerned segment, and cost-effectiveness of number and size of markers to use.

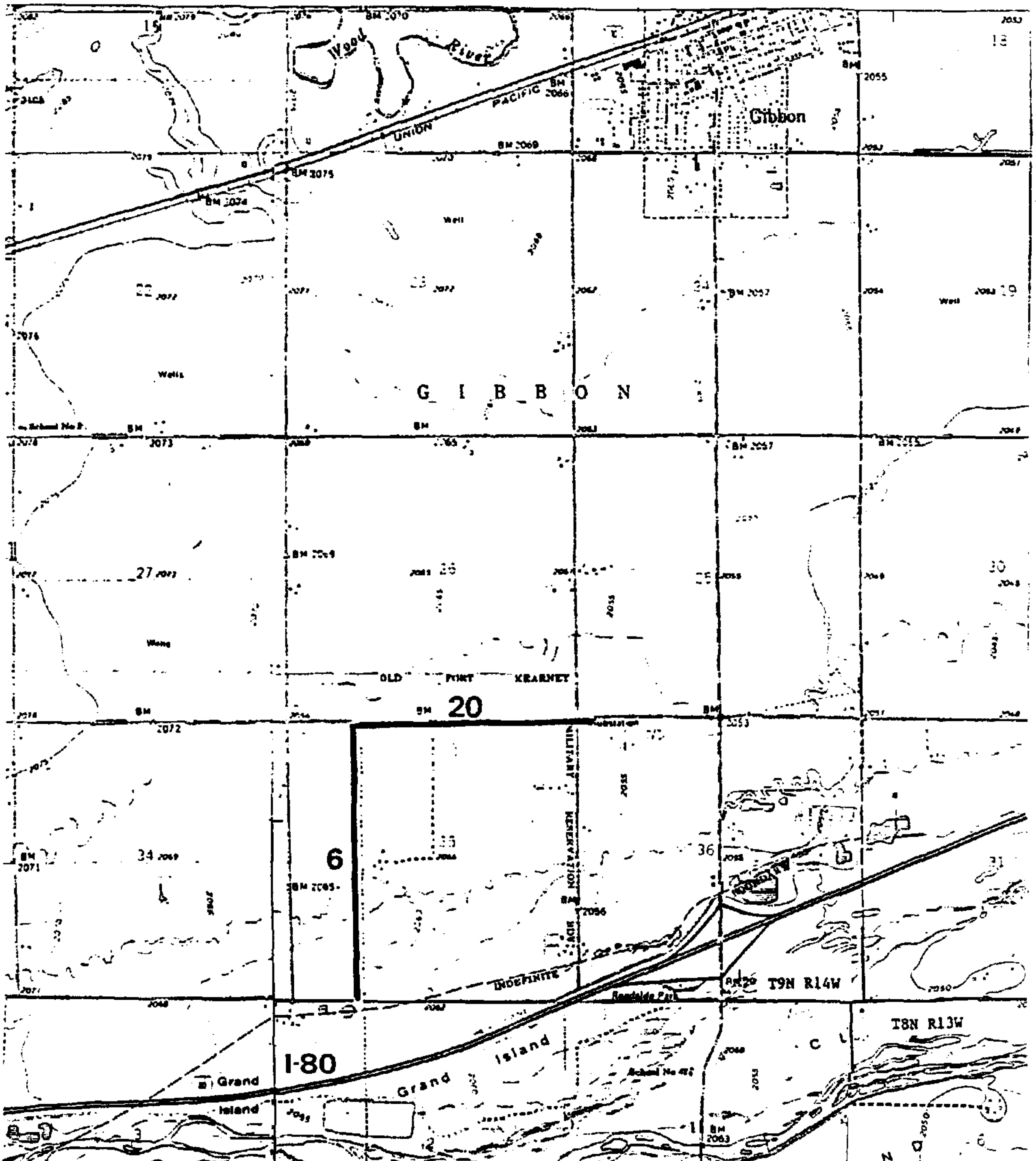
Disturbance of cranes should be minimized particularly where cranes encounter powerlines on daily local flights. Visitors to the Platte River valley were warned not to disturb or approach cranes, but some disturbance is unavoidable. Placement of shrub windbreaks or hay bales along roads would provide a barrier behind which visitors could stop their vehicles and view cranes feeding in the field without disturbance. Markers should be placed on powerlines to increase wire visibility in areas where disturbance is likely and reduce the potential for crane collisions.

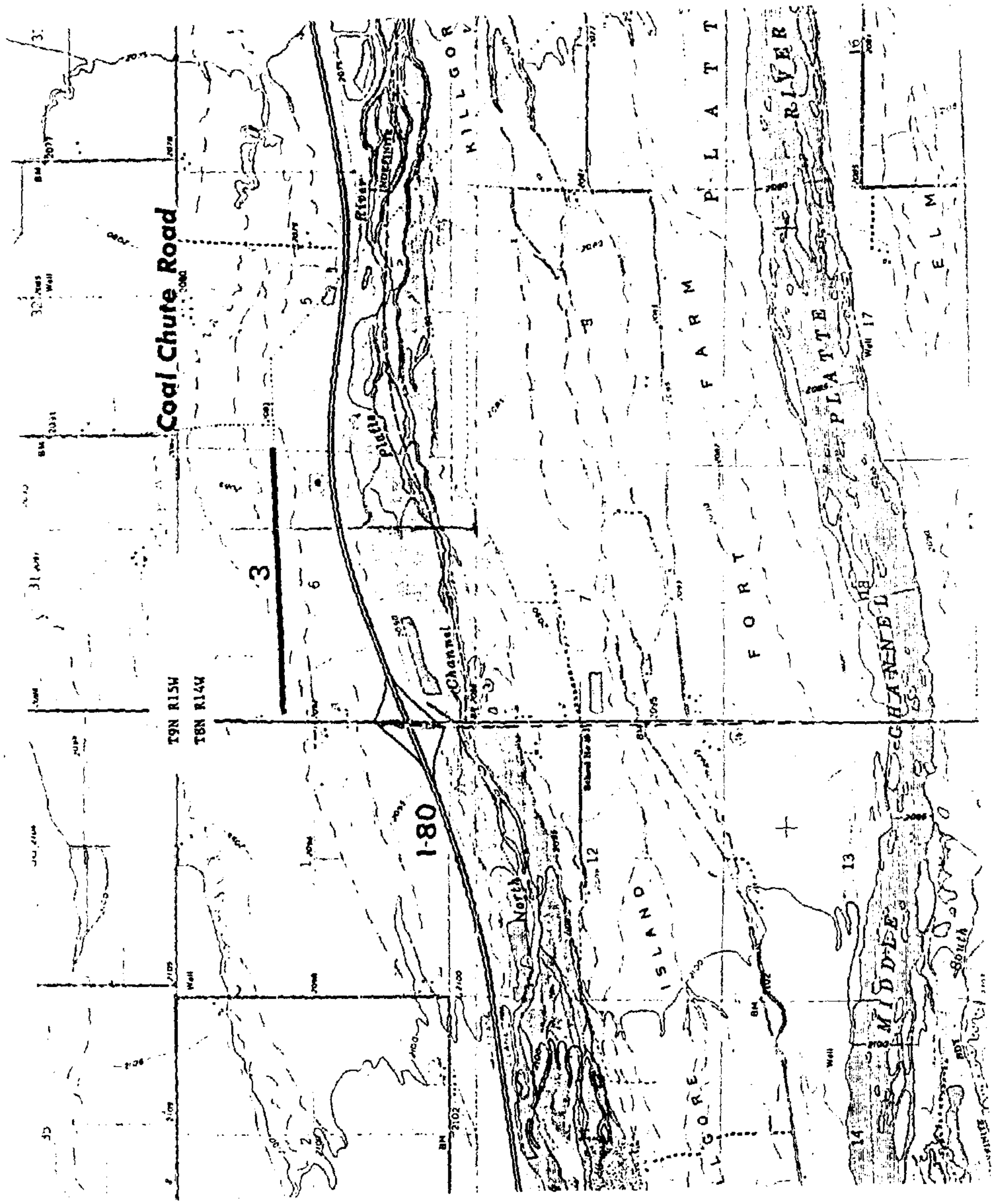
Observations of sandhill crane flight behavior in relation to powerlines suggest potential whooping crane flight behavior. Whooping cranes would be expected to react similarly to marked and unmarked powerline spans. Because whooping cranes have a larger body size and slower wing beat, they are apparently more susceptible to strike a powerline. Factors contributing to sandhill crane collisions with powerlines likely contribute to whooping crane collisions as well. Yellow balls would be effective in reducing collisions of whooping and sandhill cranes at powerlines that present a hazard to their flight.

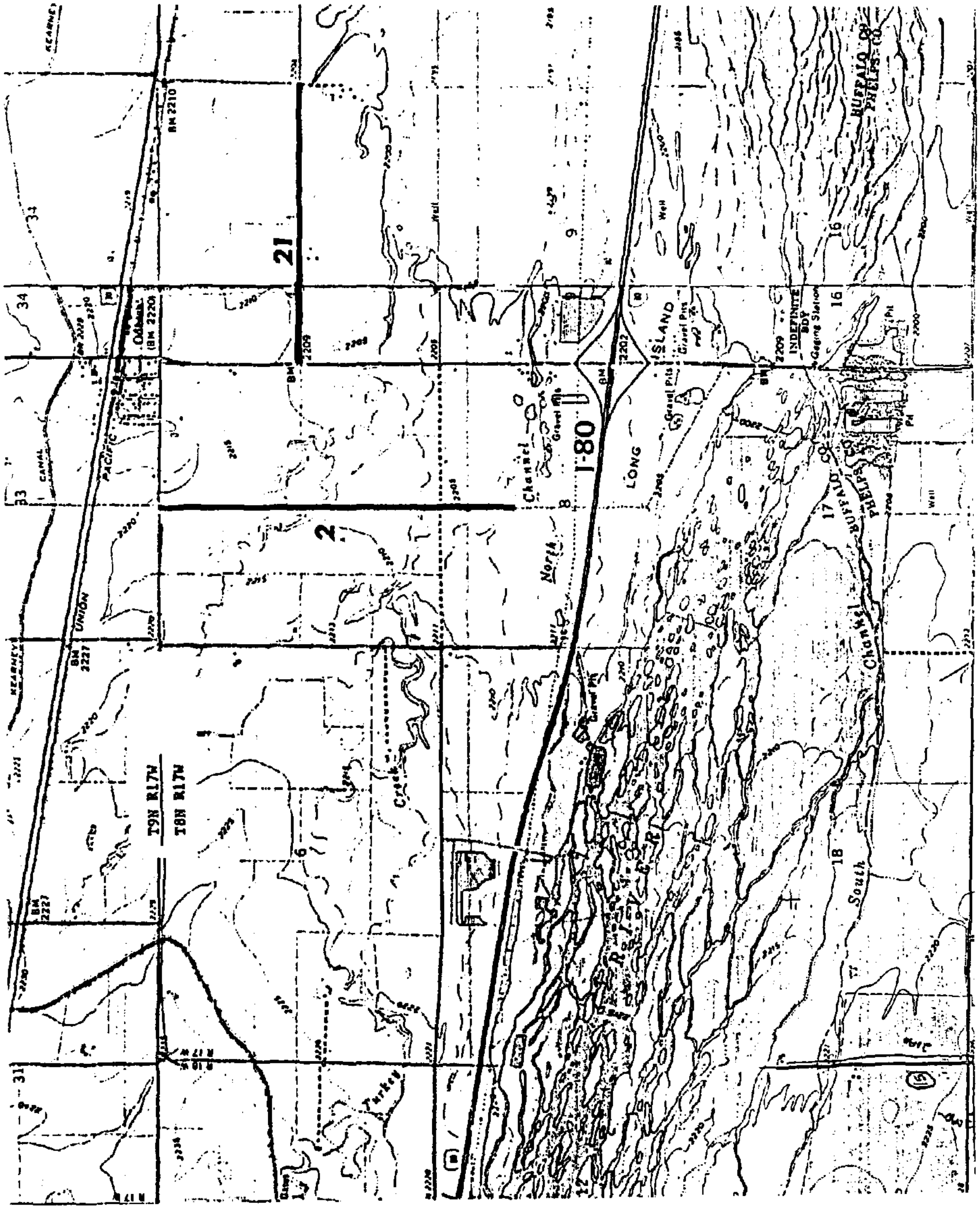
# APPENDIX A

## Powerline Study Segments

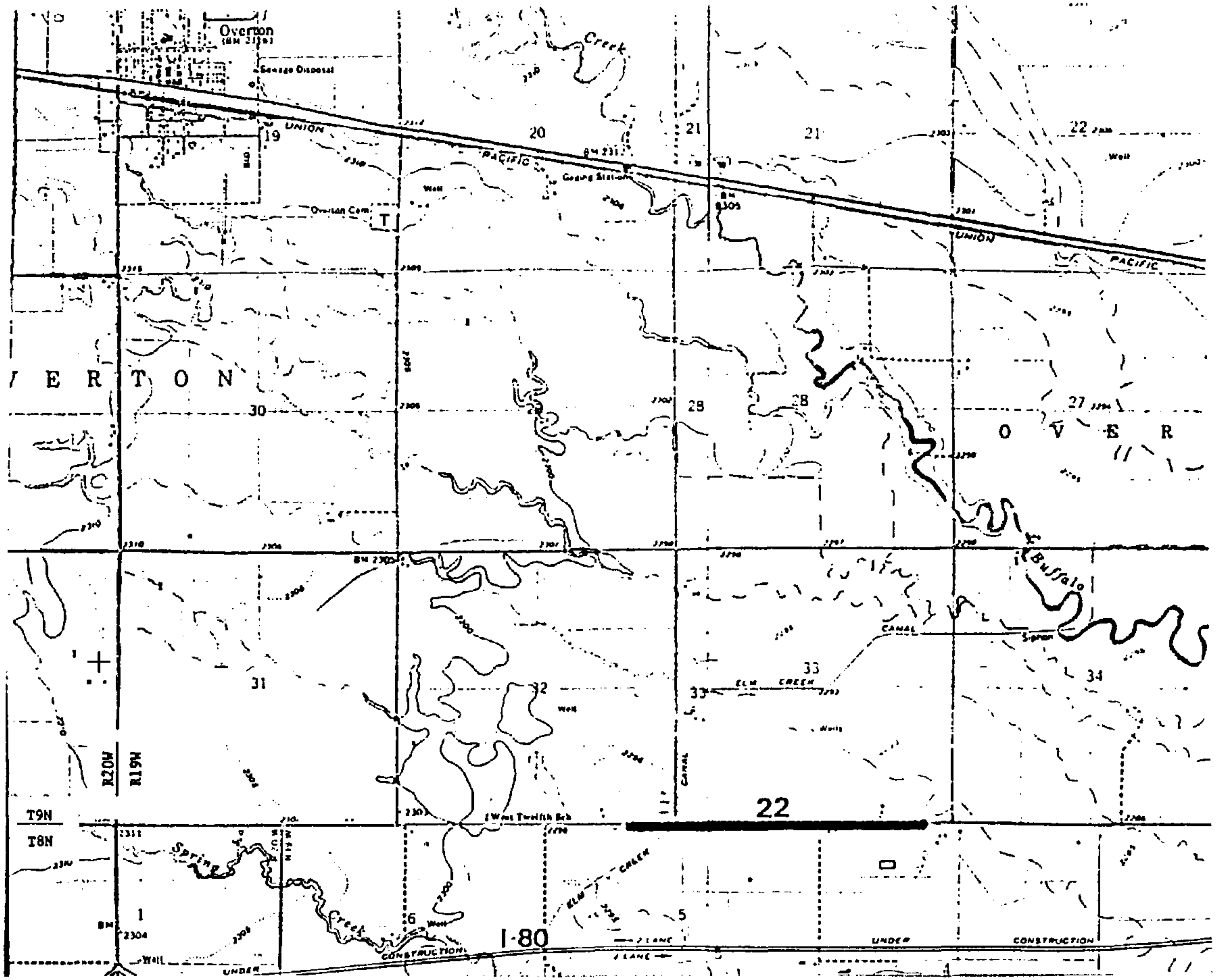

I-80
Grand Island
KILLGORE
ISLAND
Killgore Island
FORT FARM
PLATTE
RIVER
ISLAND
ELM
R2
R3
4
5
9
BUFFALO CO
KEARNEY CO
T8N R14W
RESERVATION
BOUNDARY
Lowell


Wood River
UNION PACIFIC
Gibbon
G I B B O N
OLD FORT KEARNEY
20
6
MILITARY RESERVATION
INDEFINITE
Roadside Park
T9N R14W
T8N R13W
I-80
Grand Island
Grand Island


Coal Chute Road
T9N R15W
T8N R14W
I-80
3
Channel
Platte
River
North
ISLAND
KILLGORE
FORT FARM
PLATTE RIVER
MIDDLE CHANNEL
ELM
South



I-80
LONG
ISLAND
North
Channel
South
Channel
BUFFALO CO
PHELPS CO
UNION
PACIFIC
KEARNEY
CANAL
T9N R17W
T8N R17W
Creek
Turkey
INDEFINITE
BDY
Gaging Station
Gravel Pits
Odessa
(BM 2220)
BM 2227
BM 2210
2
21


Overton
Sewage Disposal
UNION PACIFIC
Creek
Gaging Station
Overton Cem.
Well
ERTON
OVER
Buffalo
Siphon
CANAL
ELM CREEK
R20W
R19W
T9N
T8N
Spring Creek
22
I-80
UNDER CONSTRUCTION
19
20
21
22
27
28
29
30
31
32
33
34
1
5
6

# APPENDIX B

## Two-way Contingency Table Analysis

| REACTION | SPAN: Unmarked span | SPAN: Marked span | Total |
|---|---|---|---|
| None | 1200 [a] (1138.6) [b] | 768 (829.4) | 1968 |
| Increased altitude | 454 (492.4) | 397 (358.6) | 851 |
| Changed direction | 92 (119.2) | 114 (86.8) | 206 |
| Flared | 36 (31.8) | 19 (23.2) | 55 |
| Total | 1782 | 1298 | 3080 |

$\chi^2 = 30.96$
df = 3
$p < 0.00001$

| REACTION | HEIGHT FLOWN ABOVE WIRES: 1-5 m | HEIGHT FLOWN ABOVE WIRES: 6-10 m | Total |
|---|---|---|---|
| None | 310 (455.2) | 889 (743.8) | 1199 |
| Increased altitude | 407 (281.3) | 334 (459.7) | 741 |
| Changed direction | 60 (68.0) | 119 (111.0) | 179 |
| Flared | 48 (20.5) | 6 (33.5) | 54 |
| Total | 825 | 1348 | 2173 * |

$\chi^2 = 226.13$
df = 3
$p < 0.00001$

[a] Observed value
[b] (Expected value)
* Includes only data collected in 1989-90

| REACTION DISTANCE | SPAN: Unmarked span | SPAN: Marked span | Total |
|---|---|---|---|
| No reaction | 888 [a] (834.1) [b] | 627 (680.9) | 1515 |
| Increased altitude at 1-5 m | 87 (88.6) | 74 (72.4) | 161 |
| Increased altitude at 6-25 m | 161 (175.1) | 157 (142.9) | 318 |
| Increased altitude at >25 m | 81 (99.1) | 99 (80.9) | 180 |
| Changed direction at 1-5 m | 6 (14.3) | 20 (11.7) | 26 |
| Changed direction at 6-25 m | 25 (33.0) | 35 (27.0) | 60 |
| Changed direction at >25 m | 19 (26.4) | 29 (21.6) | 48 |
| Flared at 1-5 m | 26 (20.9) | 12 (17.1) | 38 |
| Flared at 6-25 m | 3 (4.4) | 5 (3.6) | 8 |
| Total | 1296 | 1058 | 2354* |

cont.

$\chi^2 = 41.17$
df = 8
$p < 0.00001$

[a] Observed value
[b] (Expected value)
* Includes only data collected in 1989-90

| REACTION TYPE | FLIGHT DISTANCE<br>Distance from origin to line<br><250 m | <br><br>>250 m | Total |
|---|---|---|---|
| No reaction | 146 [a]<br>(240.1) [b] | 1369<br>(1274.9) | 1515 |
| Increased altitude | 163<br>(104.4) | 496<br>(554.6) | 659 |
| Changed direction | 37<br>(21.2) | 97<br>(112.8) | 134 |
| Flared | 27<br>(7.3) | 19<br>(38.7) | 46 |
| Total | 373 | 1981 | 2354 * |

$\chi^2 = 160.10$
df = 3
$p < 0.00001$

| REACTION TYPE | FLIGHT DISTANCE<br>Distance from line to destination<br><250 m | <br><br>>250 m | Total |
|---|---|---|---|
| No reaction | 126<br>(182.8) | 1389<br>(1332.2) | 1515 |
| Increased altitude | 135<br>(79.5) | 524<br>(579.5) | 659 |
| Changed direction | 10<br>(16.2) | 124<br>(117.8) | 134 |
| Flared | 13<br>(5.5) | 33<br>(40.5) | 46 |
| Total | 284 | 2070 | 2354 * |

$\chi^2 = 78.16$
df = 3
$p < 0.00001$

[a] Observed value
[b] (Expected value)
* Includes only data collected in 1989-90

## FLIGHT DISTANCE

HEIGHT FLOWN ABOVE WIRES

| | Distance from origin to line | | |
|---|---|---|---|
| | <250 m | >250 m | Total |
| 1-5 m | 180[a] (122.2)[b] | 359 (416.8) | 539 |
| 6-10 m | 148 (205.8) | 760 (702.2) | 908 |
| Total | 328 | 1119 | 1447* |

$\chi^2_c = 55.41$
df = 1
$p < 0.00001$

| | Distance from line to destination | | |
|---|---|---|---|
| | <250 m | >250 m | Total |
| 1-5 m | 133 (89.8) | 406 (449.2) | 539 |
| 6-10 m | 108 (151.2) | 800 (756.8) | 908 |
| Total | 241 | 1206 | 1447* |

$\chi^2_c = 38.99$
df = 1
$p < 0.00001$

[a] Observed value
[b] (Expected value)
* Includes only data collected in 1989-90

**FLOCK SIZE**

| REACTION TYPE | Number of cranes per flock: 1-3 | 4-20 | > 20 | Total |
|---|---|---|---|---|
| No reaction | 958[a] (918.8)[b] | 832 (872.8) | 178 (176.4) | 1968 |
| Increased altitude | 350 (397.3) | 424 (377.4) | 77 (76.3) | 851 |
| Changed direction | 92 (96.2) | 93 (91.4) | 21 (18.5) | 206 |
| Flared | 38 (25.7) | 17 (24.4) | 0 (4.9) | 55 |
| Total | 1438 | 1366 | 276 | 3080 |

$\chi^2 = 28.63$
df = 6
p = 0.00007

[a] Observed value
[b] (Expected value)

| FLOCK SIZE | TIME OF DAY Morning | Evening | Total |
|---|---|---|---|
| 1-3 | 1019[a] (905.3)[b] | 419 (532.7) | 1438 |
| 4-20 | 793 (860.0) | 573 (506.0) | 1366 |
| > 20 | 127 (173.7) | 149 (102.3) | 276 |
| Total | 1939 | 1141 | 3080 |

$X^2 = 86.57$
df = 3
$p < 0.00001$

| HEIGHT FLOWN OVER WIRES | TIME OF DAY Morning | Evening | Total |
|---|---|---|---|
| 1-5 m | 567 (529.6) | 258 (295.4) | 825 |
| 6-10 m | 828 (865.4) | 520 (482.6) | 1348 |
| Total | 1395 | 778 | 2173 * |

$X^2_c = 11.56$
df = 1
$p = 0.00067$

[a] Observed value
[b] (Expected value)
* Includes data from 1989-90 only

| | POWERLINE TYPE | | | |
|---|---|---|---|---|
| REACTION TYPE | 345-kV | 2 wire 69-kV | 1 wire* 69-kV | Total |
| No reaction | 91[a] (138.0)[b] | 1824 (1775.0) | 53 (55.0) | 1968 |
| Increased altitude | 80 (59.7) | 746 (767.6) | 25 (23.8) | 851 |
| Changed direction | 35 (14.4) | 165 (185.8) | 6 (5.8) | 206 |
| Flared | 10 (3.9) | 43 (49.6) | 2 (1.5) | 55 |
| Total | 216 | 2778 | 86 | 3080 |

$X^2 = 67.41$
df = 6
$p < 0.00001$

[a] Observed value
[b] (Expected value)
* Indicates number of static wires (ie. Site 21)

## APPENDIX C

Sandhill Crane Mortalities From Collisions With Powerlines In the Study Area Along the Platte River, Nebraska, 1988-90

| Crane | Date found | Site | Line Type* | Habitat type | Carcass condition |
|---|---|---|---|---|---|
| C06 | 31488 | | T10 | Grass | Scav |
| C07 | 31588 | | T9 | Crop | |
| C10 | 32288 | | D | Crop | |
| C11 | 32288 | | D | Crop | Scav |
| C12 | 32388 | | T10 | Crop | |
| C13 | 40188 | | T9 | Crop | Scav |
| C14 | 40388 | | D | Crop | |
| C15 | 40388 | 6 | T9 | Grass | |
| C16 | 40388 | 6 | T9 | Crop | |
| C17 | 40488 | | T9 | Crop | |
| C18 | 40488 | | T9 | Crop | |
| C19 | 40588 | | D | Crop | |
| C20 | 40588 | 2 | T8 | Crop | |
| C22 | 41288 | | T7 | Crop | |
| C23 | 41288 | | T7 | Crop | Scav |
| C24 | 41388 | | D | Hay | |
| D03 | 30988 | 4 | T10 | Grass | Live |
| D04 | 31488 | | T9 | Crop | |
| D05 | 31488 | | T9 | Crop | Scav |
| D06 | 31488 | 5 | T9 | Grass | Scav |
| D08 | 31988 | 4 | T10 | Grass | Scav |
| D10 | 40188 | | T10 | Grass | |
| D11 | 40388 | | T10 | Grass | Scav |
| D12 | 40388 | | T9 | Crop | |
| D13 | 40488 | | T9 | Crop | |
| D14 | 40488 | | T9 | Crop | |
| D15 | 40488 | | T9 | Crop | |
| D16 | 40488 | | T9 | Crop | |
| D17 | 40688 | | T10 | Crop | |
| D18 | 40688 | | T10 | Crop | |
| D19 | 40688 | | T10 | Crop | |
| E01 | 30589 | | D | Crop | |
| E02 | 30589 | | D | Crop | |
| E03 | 32489 | | T9 | Grass | |
| E04 | 32489 | | T9 | Grass | |
| E05 | 32489 | | T9 | Grass | |
| E06 | 32489 | | T9 | Grass | |
| E07 | 32489 | | T9 | Grass | |
| E08 | 32489 | | T9 | Grass | |
| E09 | 32489 | | T9 | Grass | |
| E10 | 32489 | | T9 | Grass | |
| E11 | 32489 | | T9 | Grass | |
| E12 | 32489 | | T9 | Grass | |
| E13 | 32489 | | T9 | Grass | |
| E14 | 32489 | | T9 | Grass | |
| E15 | 32489 | | T9 | Grass | |

| Crane | Date found | Site | Line Type* | Habitat type | Carcass condition |
|---|---|---|---|---|---|
| E16 | 32789 | 3 | T9 | Grass | |
| E17 | 32789 | 20 | T9 | Crop | |
| E18 | 32989 | | T9 | Grass | |
| E19 | 33089 | 20 | T9 | Crop | |
| E20 | 40689 | 4 | T10 | Grass | Scav |
| E21 | 41089 | | D | Crop | |
| F04 | 31989 | | T10 | Crop | |
| F05 | 32189 | 21 | T7 | Crop | Scav |
| F07 | 32189 | | T10 | Crop | |
| F08 | 32289 | 5 | T9 | Crop | |
| F10 | 33089 | 2 | T8 | Grass | |
| F11 | 40189 | | T9 | River | |
| F12 | 40289 | | T9 | Crop | |
| F13 | 40589 | | T9 | Crop | |
| F14 | 40689 | | D | Crop | |
| F15 | 40889 | | T10 | Crop | |
| F16 | 40889 | | T7 | Crop | |
| F17 | 40889 | | T7 | Crop | |
| F18 | 40889 | | T7 | Crop | |
| F19 | 40989 | | T10 | Crop | Live |
| F20 | 40989 | | T10 | Crop | |
| G01 | 32589 | | T10 | Grass | |
| G02 | 33089 | | T9 | Grass | Scav |
| G03 | 32289 | 20 | T9 | Crop | |
| G04 | 32989 | | T10 | Grass | Scav |
| G05 | 40489 | 9 | T9 | Grass | Scav |
| G06 | 40789 | | T10 | Grass | Scav |
| G07 | 40889 | 4 | T10 | Grass | |
| G08 | 40889 | 5 | T9 | Grass | |
| G09 | 32789 | 4 | T10 | Grass | Live |
| G10 | 41089 | | T9 | Grass | Scav |
| G11 | 41189 | 6 | T9 | Grass | |
| H01 | 31389 | 5 | T9 | Grass | |
| H02 | 31789 | 4 | T10 | Grass | |
| H03 | 32989 | 6 | T9 | Grass | Scav |
| H04 | 40689 | 21 | T7 | Crop | Live |
| H05 | 40289 | 5 | T9 | Grass | |
| M01 | 31190 | 4 | T10 | Grass | Scav |
| M02 | 31390 | | T10 | Grass | Scav |
| M03 | 31490 | | D | Grass | Live |
| M04 | 31590 | 6 | T9 | Grass | |
| M05 | 31690 | 2 | T8 | Grass | |
| M06 | 31690 | 2 | T8 | Grass | |
| M07 | 32090 | 3 | T9 | Hay | |
| M08 | 32890 | | T7 | Hay | |
| M10 | 40590 | 22 | T10 | Hay | |
| M11 | 40690 | | T | Hay | Live |

| Crane | Date found | Site | Line Type* | Habitat type | Carcass condition |
|---|---|---|---|---|---|
| M12 | 40690 | | T | Hay | Live |
| M13 | 40690 | 3 | T9 | Grass | |
| M14 | 40690 | 3 | T9 | Grass | |
| M15 | 40790 | | D | Crop | |
| M16 | 40890 | 3 | T9 | Grass | Scav |
| M17 | 41390 | | T10 | Crop | Scav |
| M18 | 41590 | 4 | T10 | Grass | Scav |
| N01 | 31790 | 2 | T8 | Grass | |
| N02 | 32790 | 20 | T9 | Crop | |
| N03 | 32790 | 2 | T8 | Hay | |
| N04 | 32990 | | D | Hay | |
| N05 | 40390 | | T10 | Crop | |
| N06 | 40390 | | T10 | Crop | Scav |
| N07 | 40490 | 3 | T9 | Grass | Scav |
| N08 | 40490 | 3 | T9 | Hay | |
| N09 | 40490 | | D | Crop | |
| N10 | 40490 | | D | Grass | |
| N11 | 40490 | | T9 | Crop | |
| N15 | 40690 | | T10 | Grass | |
| N16 | 40690 | 4 | T10 | Grass | Scav |
| N17 | 40790 | | T9 | Grass | |
| N18 | 41290 | 20 | T9 | Crop | |
| N19 | 41290 | | T9 | Crop | |
| P01 | 31990 | 2 | T8 | Crop | |
| P02 | 31990 | 2 | T8 | Crop | |
| P03 | 32190 | | T7 | Crop | |
| P04 | 32190 | | T7 | Hay | |
| P05 | 32190 | | T7 | Hay | |
| P06 | 33090 | | T7 | Crop | |
| P07 | 40190 | 22 | T10 | Hay | |
| P08 | 41390 | | T9 | Crop | Live |
| P09 | 41390 | | T9 | Crop | Live |
| S01 | 32690 | 2 | T8 | Grass | |

* T = transmission, D = distribution (Figure 2a)

## LITERATURE CITED

Aldrich, J. W. 1979. Status of the Canadian sandhill crane. Pages 139-148 in J. C. Lewis, ed. Proc. 1978 Crane Workshop. Rockport, TX.

Altmann, J. 1974. Observational study of behavior: sampling methods. Behaviour 49:227-265.

Anderson, W. L. 1978. Waterfowl collisions with powerlines at a coal-fired power plant. Wildl. Soc. Bull. 6:77-83.

Anderson-Harild, P., and D. Bloch. 1973. En forelobig undersogelse over fugle draebt mod elledninger. (Birds killed by overhead wires on some locations in Denmark.) [in Danish, English summary]. Danish Ornithol. Foren. Tidsskr. 67:15-23.

Anonymous. "Utility moves line from Nature Conservancy pond to protect swans." Jackson Hole News (Wyoming), 18 October 1989, p. 14.

Archibald, K. 1987. The conservation status of the breeding ground of the red-crowned crane in Hokkaido, Japan. Pages 63-86 in G. W. Archibald and R. F. Pasquier, eds. Proc. 1983 International Crane Workshop. Bharatpur, India.

Avery, M. L., P. E. Springer, and N. S. Dailey. 1980. Avian mortality at man-made structures: an annotated bibliography. U.S. Fish and Wildlife Service, Biol. Services Program, Natl. Power Plant Team. FWS/OBS 80/54. 152pp.

Beaulaurier, D. L. 1981. Mitigation of bird collisions with transmission lines. Bonneville Power Admin., Portland, OR. 82pp.

Beer, J. V., and M. A. Ogilvie. 1972. Mortality. Pages 125-142 in P. Scott and the Wildfowl Trust. The Swans. Houghton Mifflin Co., Boston.

Blokpoel, H., and D. R. M. Hatch. 1976. Snow geese, disturbed by aircraft, crash into powerlines. Can. Field Nat. 90:195.

Brown, W. M., R. C. Drewien, and D. L. Walker. 1984. Crane flight behavior and mortality associated with powerlines in the San Luis Valley, Colorado. Idaho Coop. Wildl. Research Unit, Moscow. 31pp.

_____, R. C. Drewien, and E. G. Bizeau. 1987. Mortality of cranes and waterfowl from powerline collisions in the San Luis Valley, Colorado. Pages 128-136 in J. C. Lewis, ed. Proc. 1985 Crane Workshop. Grand Island, NE.

Buller, R. J. 1979. Recent studies of age ratios of sandhill cranes in the Central Flyway. Pages 78-85 in Proc. 1978 International Crane Workshop. Baraboo, WI.

Carpenter, J. W. 1977. Propogation and management of endangered species at Patuxent Wildlife Research Center. Pages 23-33 in Ann. Proc. Amer. Assoc. Zoo Vet. Knoxville, TN.

Cassell, J. F., D. W. Kiel, J. J. Knodel, and J. M. Wiehe. 1979. Relation of birds to certain power transmission lines in central North Dakota. Zool. Dept., North Dakota State University, Fargo, ND. 50pp.

Cornwell, G., and H. A. Hochbaum. 1971. Collisions with wires - a source of anatid mortality. Wilson Bull. 83:305-306.

Currier, P. J., G. R. Lingle, and J. G. VanDerwalker. 1985. Migratory bird habitat on the Platte and North Platte Rivers in Nebraska. Platte River Whooping Crane Critical Habitat Maintanence Trust, Grand Island, NE. 184pp.

Dailey, N. S., ed. 1978. Environmental aspects of transmission lines - a selected, annotated bibliography. Oak Ridge National Lab., Oak Ridge, TN. 192pp.

Drewien, R. C. 1973. Ecology of Rocky Mountain greater sandhill cranes. Ph.D. Thesis, University of Idaho, Moscow. 152pp.

Engleman, L. 1988. Stepwise logistic regression. Pages 941-969 in W. J. Dixon, ed. BMDP Statistical Software Manual. Vol. 2. Univ. of Calif. Press, Berkeley, CA.

Faanes, C. A. 1984. Assessment of powerline siting in relation to bird strikes in the Northern Great Plains. U. S. Fish & Wildl. Service, Northern Prairie Wildlife Research Center, Jamestown, ND. 95pp.

_____. 1987. Bird behavior and mortality in relation to powerlines in prairie habitat. U. S. Fish and Wildl. Service Tech. Report 7. 24pp.

_____, and A. M. Frank. 1982. Characteristics of diurnal sandhill crane flocks in the Platte River Valley, Nebraska. Pages 22-26 in J. C. Lewis, ed. Proc. 1981 Crane Workshop. Grand Teton Natl. Park, WY.

Fitzner, R. E. 1985. Owl mortality on fences and utility lines. Raptor Research 9:55-56.

Frith, C. R. 1974. The ecology of the Platte River as related to sandhill cranes and other waterfowl in southcentral Nebraska. M. S. Thesis, Kearney State College, Kearney, NE. 115pp.

_____, and C. A. Faanes. 1982. Inventory of sandhill crane roosting habitat on the Platte and North Platte Rivers, Nebraska. Pages 13-16 in J. C. Lewis, ed. Proc. 1981 Crane Workshop. Grand Teton Natl. Park, WY.

Gaines, G. D., and R. J. Warren. 1984. Genetics and morphology of sandhill crane populations in Texas. J. Wildl. Manage. 48:1387-1393.

Gale Research Company. 1985. Climates of the States. Vol. 1. 3rd Edition. Book Tower, Detroit, MI. 758pp.

Guthery, F. S., and J. C. Lewis. 1979. Sandhill cranes in coastal counties of southern Texas: taxanomy, distribution, and populations. Pages 121-128 _in_ J. C. Lewis, ed. Proc. 1978 Crane Workshop. Rockport, TX.

Hadley, R. F., and T. R. Eschner. 1982. Relation of hydrologic and geomorphic changes to wildlife habitat in Platte River channels. Pages 27-32 _in_ J. C. Lewis, ed. Proc. 1981 Crane Workshop. Grand Teton Natl. Park, WY.

Harrison, J. G. 1963. Heavy mortality of mute swans from electrocution. Ann. Rep. Wildfowl Trust 14:164-165.

Herbert, A. D. 1970. Spacial disorientation in birds. Wilson Bull. 82:404-419.

Herren, H. 1969. The status of the Peregrine Falcon in Switzerland. Pages 231-238 _in_ J. J. Hickey, ed. Peregrine Falcon populations - their biology and decline. Univ. of Wisconsin Press, Madison.

Hopkins, H. H. 1951. Ecology of the native vegetation of the Loess Hills of central Nebraska. Ecol. Monogr. 21:125-147.

Howard, R. P., B. L. Keller, F. L. Rose, J. Connelly, and J. Hupp. 1987. Impacts of the Tincup Loop transmission line on cranes in Caribou County, Idaho. Pages 140-144 _in_ J. C. Lewis, ed. Proc. 1985 Crane Workshop. Grand Island, NE.

Howe, M. A. 1989. Migration of radio-marked whooping cranes from the Aransas-Wood Buffalo population: patterns of habitat use, behavior, and survival. U. S. Fish and Wildlife Service, Fish and Wildl. Tech. Report 21. 33pp.

Hunt, R. A. 1972. Some field and court case experiences with waterfowl and electrical powerlines. Proc. Midwest Fish & Wildlife Conf. 34:60.

James, B. W., and B. A. Haak. 1979. Factors affecting avian flight behavior and collision mortality at transmission lines. Bonneville Power Admin., Portland, OR. 109pp.

Johnsgard, P. A. 1983. Cranes of the World. Indiana Univ. Press, Bloomington. 257pp.

Johnson, K. A. 1982. Whooping crane use of the Platte River, Nebraska - history, status and management recommendations. Pages 33-43 in J. C. Lewis, ed. Proc. 1981 Crane Workshop. Grand Teton Natl. Park, WY.

Kauffeld, J. D. 1982. Management of migratory crane habitat on Alamosa and Monte Vista National Wildlife Refuges. Pages 117-121 in J. C. Lewis, ed. Proc. 1981 Crane Workshop. Grand Island, NE.

Keller, B. L., and F. L. Rose. 1984. Impacts of the Tincup Loop transmission line on avian species near the Diamond/Lanes creeks confluence, Caribou County, Idaho. Dept. Biol. Sci., Idaho State Univ., Pocatello. 23pp.

Klecka, W. R. 1980. Discriminant Analysis. Sage Univ. Paper Series: Quantitative Applications in the Social Sciences, Series No. 07-019. Sage Publ., Beverly Hills, Ca. 71pp.

Krapu, G. L. 1974. Avian mortality from collisions with overhead wires in North Dakota. Prairie Naturalist 6:1-6.

_____ . 1979. Sandhill crane use of staging areas in Nebraska. Pages 1-5 in J. C. Lewis, ed. Proc. 1978 Crane Workshop. Rockport, TX.

_____. 1981. The Platte River ecology study: special research report. U. S. Fish and Wildl. Service, Northern Prairie Wildl. Research Center, Jamestown, ND. 186pp.

_____, D. E. Facey, E. K. Fritzell, and D. H. Johnson. 1984. Habitat use by migrant sandhill cranes in Nebraska. J. Wildl. Manage. 48:407-417.

_____, R. J. Reinecke, and C. R. Frith. 1982. Sandhill cranes and the Platte River. Trans. North Amer. Wildl. & Natural Resources Conf. 47:542-552.

Kroodsma, R. L. 1978. Evaluation of a proposed transmission line's impacts on waterfowl and eagles. Pages 117-128 in M. L. Avery, ed. Proc. Impacts of transmission lines on birds in flight. U. S. Fish and Wildl. Service, Washington D. C.

Kuyt, E. 1983. Whooping crane migration studies 1981-82. Pages 371-379 in Proc. International Crane Workshop. Baraboo, WI.

Lewis, J. C. 1974. Ecology of the sandhill crane in the southeastern Central Flyway. Ph.D. Dissertation. Oklahoma State Univ., Stillwater, OK. 213pp.

_____. 1977. Sandhill crane (Grus canadensis). Pages 5-43 in G. C. Sanderson, ed. Management of migratory birds in North America. Univ. Nebraska Press, Lincoln. 358pp.

_____. 1979a. Factors affecting the spring inventory of sandhill cranes. Pages 33-39 in J. C. Lewis, ed. Proc. 1978 Crane Workshop. Rockport, TX.

_____. 1979b. Field identification of juvenile sandhill cranes. J. Wildl. Manage. 43:211-214.

_____. 1979c. Molt of the remiges of Grus canadensis. Pages 255-259 in J. C. Lewis, ed. Proc. 1978 Crane Workshop. Rockport, TX.

_____. 1979d. Taxonomy, food, and feeding habitat of sandhill cranes, Platte River Valley, Nebraska. Pages 21-27 in J. C. Lewis, ed. Proc. 1978 Crane Workshop. Rockport, TX.

_____. 1986. The Whooping Crane. Pages 658-676 in Audubon Report 1986. National Audubon Society, Washington, D. C.

Lingle, G. R. 1987. Status of whooping crane migration habitat within the Great Plains of North America. Pages 331-340 in J. C. Lewis, ed. Proc. 1985 Crane Workshop. Grand Island, NE.

Malcolm, J. M. 1982. Bird collisions with a power transmission line and their relation to botulism at a Montana wetland. Wildl. Society Bull. 10:297-304.

McDonald, J. N. 1979. Waterfowl collisions with utility wires: two observations on the southern plains. Texas J. Sci. 31:369-370.

McGlauchlin, D. C. 1977. Description and chronology of events on Snake Creek embankment. U. S. Fish and Wildl. Service, Audubon Natl. Wildl. Refuge, Coleharbor, N. D. 9pp.

McNeil, R., J. R. Rodriguez, Sr., and H. Ouellet. 1985. Bird mortality at a power transmission line in northeastern Venezuela. Biol. Conserv. 31:153-165.

Miller, W. A. 1978. Transmission line engineering and its relationship to migratory birds. Pages 129-141 in Proc. Impacts of Transmission Lines on Birds in Flight. U. S. Fish and Wildlife Service, Oak Ridge, TN.

Nesbitt, S. A. 1987. A technique for aging sandhill cranes using wing molt - preliminary finding. Pages 224-229 in J. C. Lewis, ed. Proc. 1985 Crane Workshop. Grand Island, NE.

_____, and D. T. Gilbert. 1976. Powerlines and fence hazards to birds. Fla. Naturalist 29:23.

Reinecke, K. J., and G. L. Krapu. 1979. Spring food habits of sandhill cranes in Nebraska. Pages 13-19 in J. C. Lewis, ed. Proc. 1978 Crane Workshop. Rockport, TX.

_____, and G. L. Krapu. 1986. Feeding ecology of sandhill cranes during spring migration in Nebraska. J. Wildl. Manage. 50:71-79.

Rigby, R. W., Refuge Manager, Bosque del Apache National Wildlife Refuge, Socorro, New Mexico. 1978. Letter to Michael Avery, National Power Plant Team, Ann Arbor, MI. 19 October. 1p.

Scott, R. E., L. J. Roberts, and C. J. Cadbury. 1972. Bird deaths from powerlines at Dungeress. British Birds 65:273-286.

Schwartz, G. 1977. The Climate Advisor. Climate Guide Publ., Flushing, NY. 332pp.

Sisson, J. 1975. Death trap. Natl. Wildl. 13(2):18.

Stephen, W. J. D. 1967. Bionomics of the sandhill crane. Canadian Wildl. Service Rep. Series No. 2. 48pp.

Stout, I. J., and G. W. Cornwell. 1976. Nonhunting mortality of fledged North American waterfowl. J. Wildl. Manage. 40:681-693.

SPSS Inc. 1988. SPSS-X User's Guide. 3rd Edition. Chicago, IL. 1072pp.

Tacha, T. C. 1984. Preflight behavior of sandhill cranes. Wilson Bull. 96(3):471-477.

_____. 1988. Social organization of sandhill cranes from midcontinental North America. Wildl. Monogr. 99. 37pp.

_____, D. E. Haley, and R. R. George. 1986. Population and harvest characteristics of sandhill cranes in southern Texas. J. Wildl. Manage. 50:80-83.

_____, and J. C. Lewis. 1979. Sex determination of sandhill cranes by cloacal examination. Pages 81-83 in J. C. Lewis, ed. Proc. 1978 Crane Workshop. Rockport, TX.

_____, D. C. Martin, and C. G. Endicott. 1979. Mortality of sandhill cranes associated with utility highlines in Texas. Pages 175-176 in J. C. Lewis, ed. Proc. 1978 Crane Workshop. Rockport, TX.

_____, and P. A. Vohs. 1984. Some population parameters of sandhill cranes from mid-continental North America. J. Wildl. Manage. 48:89-98.

_____, P. A. Vohs, and W. D. Warde. 1985. Morphometric variation of sandhill cranes from mid-continental North America. J. Wildl. Manage. 49:246-250.

Thompson, L. S. 1977. Overhead transmission lines: impacts on wildlife. Montana Dept. Natural Res. & Conserv., Research Rep. 2. 51pp.

_____. 1978. Transmission line wire strikes: mitigation through engineering and habitat modification. Pages 51 -92 in M. L. Avery, ed. Proc. Impacts of transmission lines on birds in flight. U. S. Fish and Wildl. Service, Washington D. C.

U. S. Fish and Wildlife Service. 1978. Proc. Impacts of transmission lines on birds in flight. Oak Ridge Assoc. Univ., Oak Ridge, TN. 212pp.

_____. 1986. Whooping crane recovery plan. Prepared by the Whooping crane recovery team. U. S. Fish and Wildl. Service, Albuquerque, NM. 283pp.

Walkinshaw, L. H. 1949. The sandhill cranes. Cranbrook Institute of Sci. Bull. 29:6-20.

_____. 1956. Sandhill cranes killed by flying into powerline. Wilson Bull. 68:325-326.

Ward, J. P., J. J. Jenniges, and S. H. Anderson. 1987. Evaluation of the Platte River as a site to study powerline modification to reduce crane collisions: second annual report. Wyoming Coop. Fish & Wildl. Res. Unit, Laramie. 39pp.

_____, R. Romme, and S. H. Anderson. 1986. Evaluation of the Platte and North Platte Rivers as sites to study powerline modification to reduce crane collisions. Wyoming Coop. Fish & Wildl. Res. Unit, Laramie. 45pp.

Wheeler, R. H. 1966. Sandhill crane casualties in the blizzard of March 2, 1966. Nebraska Bird Review 34:69-70.

Willard, D. E., J. T. Harris, and M. J. Jaeger. 1977. The impact of a proposed 500kV transmission line on waterfowl and other birds. Oregon Public Utility Comm., Salem, OR. 89pp.

Windingstad, R. M. 1988. Nonhunting mortality in sandhill cranes. J. Wildl. Manage. 52:260-263.

Wobeser, G. A. 1981. Necropsy and sample preservation techniques. Pages 227-242 in Diseases of Wild Waterfowl. Plenum Press, NY. 300pp.

Yamaguchi, M., International Crane Foundation. 1984. Letter to J. E. Johnson, Chief, Endangered Species Office, U. S. Fish and Wildl. Service, Washington, D. C. 4pp.

Zar, J. H. 1984. Biostatistical Analysis, 2nd Edition. Prentice-Hall, Inc., Englewood Cliffs, NJ. 718pp.