Evaluation of Two Power Line Markers to Reduce Crane and Waterfowl Collision Mortality
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Evaluation of two power line markers to reduce crane and waterfowl collision mortality

Wendy M. Brown and Roderick C. Drewien

Abstract Collisions with power lines are a source of mortality to cranes (*Grus americana* and *Grus canadensis*), waterfowl, and other birds. We evaluated 2 power line markers for reducing crane and waterfowl mortality in the San Luis Valley, Colorado and examined factors contributing to collisions and marker effectiveness. Collision mortality rates at 8 segments (about 0.8 km each) of power lines marked with either yellow spiral vibration dampers or yellow fiberglass swinging plates were compared with 8 adjoining unmarked segments. During 3 spring and 3 fall migration periods (1988–1991), estimated mortality on study segments was 706, including ≥35 species. Waterfowl and cranes constituted >80% of mortality. Both marker types reduced mortality ($P < 0.005$). Birds reacted to marked lines at greater distances and increased their altitude as compared to unmarked lines ($P < 0.0001$). Factors affecting collisions or marker effectiveness included wind ($P = 0.008$), nocturnal flights and disturbance ($P < 0.005$), and age of sandhill cranes ($P < 0.001$). Neither marker performed better in all study seasons; each may have had unique benefits. Plates damaged distribution lines, precluding their continued use; however, a new marker from Europe which incorporates the benefits of both plates and dampers should be evaluated, as it may best protect against collision losses.

Key words collisions, endangered species, *Grus americana*, *Grus canadensis*, mortality, power line markers, power lines, sandhill crane, waterfowl, whooping crane

Avian mortality from collisions with power lines is well documented (Walkinshaw 1956, Cornwell and Hochbaum 1971, Tacha et al. 1979, Malcom 1982, Faanes 1987, Morkill and Anderson 1991). Although rarely affecting healthy populations with good reproductive potential, collision mortality can be biologically significant to local populations (Beer and Ogilvie 1972) and endangered species (Thompson 1978, Faanes 1987). Power line collisions were the greatest (39.0%) known cause of mortality for fledged whooping cranes (*Grus americana*) in the introduced Rocky Mountain population (Brown et al. 1987). Most of these collisions occurred in the San Luis Valley, Colorado, the primary migration stop for Rocky Mountain whooping cranes and greater sandhill cranes (*G. canadensis tabida;* Drewien and Bizeau 1974, 1978). The Aransas-Wood Buffalo population of whooping cranes also has sustained losses from collisions (Kuyt 1987, Lingle 1987).

Potential for collisions in avian concentration areas can be reduced by management practices such as manipulating habitat to reduce bird flights over lines, using vegetation and topographical features to encourage birds to fly above lines, and reducing human disturbance (Thompson 1978, Brown 1993). However, such options may be limited by land use and ownership or by physiography. Options for line modification include burying, removing the uppermost non-conducting (static) wire, and line marking (Beaulaurier 1981). Burying lines is often technolog-

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ically and financially prohibitive. Removing static wires, which are generally smaller in diameter and thus less visible than conductors, can be effective, but is costly and may lead to lightning-caused power outages (Thompson 1978, Brown et al. 1987). Although line marking often is proposed as a mitigation method, rigorous evaluation has been lacking until recently, when Morkill and Anderson (1991) found that yellow aviation marker balls reduced sandhill crane collisions in Nebraska.

We evaluated effectiveness of 2 power line markers, yellow spiral vibration dampers and yellow fiberglass swinging plates, for reducing crane and waterfowl collision mortality in the San Luis Valley. We also examined factors contributing to collisions and marker effectiveness.

Study area

The San Luis Valley in south-central Colorado is a flat, arid, high-elevation (2,280–2,380 m) agricultural valley approximately 160-km long by 130-km wide, surrounded by the Sangre de Cristo and San Juan mountains. Climate, soils, and vegetation were described by Kauffeld (1982, 1987) and Jeske (1991). Large concentrations of cranes and waterfowl seasonally use wetlands along the Rio Grande and in the Alamosa and Monte Vista National Wildlife Refuges (NWR). Our principal study area was the 5,758-ha Monte Vista NWR. The refuge contained uplands, wet meadows, constructed ponds, and croplands. It is primarily managed as a waterfowl production area and seasonally used by sandhill and whooping cranes, waterfowl, bald eagles (*Haliaeetus leucocephalus*) and other migratory birds (Kauffeld 1982, 1987, Brown et al. 1987).

The valley is a corridor for several electricity transmission lines (230 kV, 115 kV, and 69 kV) and numerous electricity distribution lines that serve wells, irrigation systems, and community energy needs. Many power lines traverse crane and waterfowl concentration areas.

Methods

Power line segments and markers

We selected 8 power-line segments totaling 13.2 km in crane and waterfowl concentration areas in and near Monte Vista NWR. Power lines bisected or bordered wetland roost sites and nearby croplands used for feeding, and most had a history of collision mortality (Brown et al. 1987). Study segments were 1.2–2.4 km long. Four were low-voltage (7.2 kV) distribution lines and 4 were high-voltage (69–115 kV) transmission lines (Table 1). Half of each segment was randomly selected to be marked with spiral vibration dampers (dampers) or swinging fiberglass plates (plates); the remaining were unmarked control.

Table 1. Characteristics of power line segments and marker placement for evaluation of 2 marking techniques designed to reduce avian collision mortality in the San Luis Valley, Colorado, 1988–1991.

Characteristic	Distribution lines	Transmission lines	
Voltage (kV)	7.2	69	115[a]
Height of top wires above ground (m)	7–9	13–14	18–22
Length of spans between poles (m)	78–140	104–170	173–202
No. plates/span	3–4	3–4	5
No. spiral vibration dampers/span	21–31	22–36	40–44
Total length of study segments (km)	6.8	6.4	1.6

[a] This segment was used only from 1988–1989. Because of decreased avian activity, we monitored a different 1.6-km segment of 69-kv line in fall, 1989. Total length of study segments at any time was 13.2 km.

Each marker type was tested on 2 transmission and 2 distribution lines. Dampers were 112–125-cm lengths (1.27-cm diam) of polyvinyl chloride plastic twisted around overhead wires to reduce wind vibration (Fig. 1). Normally gray, dampers were extruded with bright yellow color to enhance visibility. Yellow was selected because various studies have shown the avian eye is most sensitive to yellow-green color (Donner 1953, Armington and Thiede 1956, Ikeda 1965, cited in Beaulaurier 1981). Yellow also is more reflective in low light than international orange.

Transmission lines were marked with dampers about 3.3 m apart on the uppermost static wire (27.5% coverage). Distribution lines had 3 conductor wires about the same height; best visual coverage and weight distribution were achieved by staggering dampers 3.3 m apart on all 3 wires. This arrangement produced a visual equivalent of 27.6% coverage, although individual wires were only covered 9.2% (Fig. 1).

Plates were yellow fiberglass squares (30.5 x 30.5 cm) with a 5-cm wide black diagonal stripe across the face for contrast. Plates were clamped to conductor or static wires and hinged, allowing them to swing in the wind, which reduced wind resistance and enhanced marker visibility. Because of greater size and weight, we attached only 3-5 plates/span (depending on span length) to static wires or center conductors 23-32 m apart (Table 1, Fig. 1).

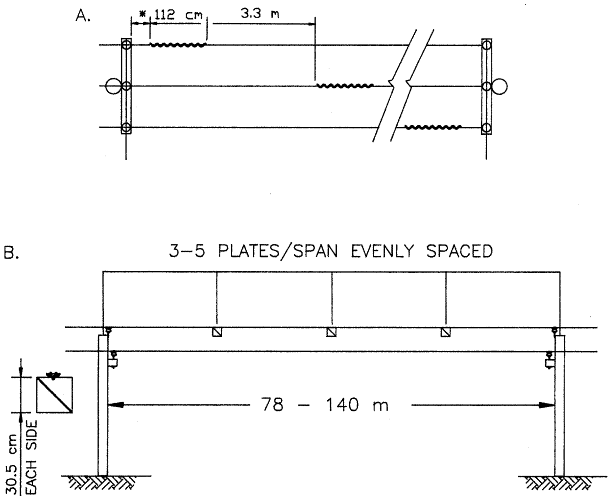

Fig. 1. Top view (A) of spiral vibration dampers and their placement on a 7.2 kV power line. Side view (B) of swinging fiberglass plates and their placement on a 69 kV power line in the San Luis Valley, Colorado, 1988–1991.

Assessing avian mortality

We searched 100-m wide transects along each power line segment for evidence of mortality 5–7 times/week during 3 fall (Sep–Nov 1988–1990) and 3 spring (Mar–May 1989–1991) migrations. Dead (including depredated remains or feather spots) or injured birds were removed, and their locations were plotted on maps. We recorded species, age, sex, body condition, evidence of disease, date, cause, and estimated time of death. Birds were classified as collision victims if physical trauma was evident or remains were found within 10 m (horizontal measurement) of lines.

Search efficiency (proportion of carcasses found) was assessed by placing marked wings and intact carcasses on study segments and monitoring their recovery by searchers. We also monitored condition of remains to assess scavenging rates. Total mortality (TM) was estimated as

$$TM = FM/[(1 - S)(E)],$$

where FM = found mortality, S = proportion of carcasses removed by scavengers in 24 hours, and E = estimated search efficiency.

We classified sandhill cranes by subspecies (Walkinshaw 1965, Johnson and Stewart 1973), determined sex by gonads during necropsy, and determined age by plumage characteristics (Lewis 1979); age and sex of waterfowl were determined according to Carney (1964). Comparative age data for cranes were obtained by observing flocks through spotting scopes during fall 1988–1990 and determining the proportion of juveniles by wing molt and crown characteristics (Lewis 1979, Drewien and Brown unpubl. data).

We necropsied suitable carcasses to assess causes of death. Body condition was classified as poor, fair, good, or excellent from pectoral muscle bulk and subcutaneous fat (Wobeser 1981). Internal organs were examined for gross lesions associated with lead poisoning, avian cholera (*Pasteurella multocida*), and avian tuberculosis (*Mycobacterium avium*) (Friend 1987).

We compared mortality rates (proportion of mortalities/overflights) on marked and unmarked segments for sandhill cranes, Canada geese (*Branta canadensis*), and ducks (Anseriformes). Two observers simultaneously counted overflights (number of birds [≥1 individuals crossing lines as a unit] ≤15 m above the top wire) from vehicles at the ends of marked and unmarked portions of a segment. Counts were made on each segment every 3–4 days, alternating between dawn (0.3 hour before to 1 hour after sunrise) and dusk (0.5 hour before to 0.5 hour after sunset), when maximum overflights occurred. In fall 1990, we contracted radar monitoring to assess nocturnal flights (Cooper and Mabee 1990), and in fall 1990 and spring 1991, we searched segments weekly at dusk and the following dawn for fresh collision victims to evaluate nocturnal collisions.

To evaluate response to marking, 2 observers in vehicles simultaneously recorded flight behavior at marked and unmarked study segments. Each person watched 2 spans within their segment where overflights were greatest. Factors recorded for each overflight of cranes, geese, and ducks included: flock size, time, weather, distance from point of crossing to origin and destination of flight, bird reaction to the line, distance from the line when a reaction was observed, and height birds flew above lines. Height-of-flight estimates were aided by the periodic use of a clinometer to verify observer accuracy, and distance estimates were aided by placing survey flags at measured distance categories from lines. Because it was not possible to record every overflight, groups were selected by identifying a reference point where flights first became visible and recording the next flight crossing the reference point after the last was recorded.

An automated weather station on Monte Vista NWR monitored temperature, solar radiation, wind speed, and wind direction. We recorded fog and precipitation at the study site.

Data analysis

Marker effectiveness was evaluated for sandhill cranes, Canada geese, and ducks. We partitioned mortality data into 2 categories: (1) total mortality included known collisions and unidentified causes, and (2) minimum mortality included only known collisions. The latter category was used to calculate mortality rates for statistical analyses.

Because collision numbers for individual species groups were low in some seasons, observed mortality rates on marked and unmarked lines were first combined over species groups and compared seasonally for each marker type using the binomial test of equal proportions (Zar 1984). In a separate analysis, the effects and interactions of line marking, marker type, year, season, and individual species groups were examined using log-linear models (Poisson regressions, Agresti 1990). We used the GLIM 3.77 software system for modeling (Payne 1987). To compensate for zeros in some mortality counts, a constant (0.2) was added to each cell in cross-tabulated tables so that predicted mortality rates could be calculated.

Two separate log-linear analyses were performed to compare bird flight behavior for overflights originating ≤250 m from marked and unmarked lines. The first analysis investigated relationships among (1) reaction to lines, (2) species group (cranes, geese, or ducks), (3) height-of-flight above the line, and (4) line marking. The second analysis examined associations among (1) species group, (2) height above the line, (3) reaction distance, and (4) line marking for flights in which altitude adjustment (the most common reaction) was observed. We used BMDP 4F software for modeling (Dixon et al. 1988). Because novice observers were inconsistent in the way they collected data, our analyses excluded observations of those who worked ≤2 field seasons.

Weather analyses included the following variables for each day of field observation: (1) collision occurrence, (2) line marking, (3) winds ≥24 kph (hourly average), (4) precipitation (fog, rain, sleet, hail, or snow), (5) average daily wind speed, (6) average temperature, and (7) average solar radiation. Associations of categorical weather variables (winds ≥24 kph, precipitation) with line marking and collision occurrence were examined using log-linear analyses of cross-tabulated tables (Wickens 1989, Agresti 1990). Days with and without collisions also were compared for differences in median average wind speed, temperature, and solar radiation using the large-sample approximation of the Wilcoxon rank sum test (Hollander and Wolfe 1973).

The adult to juvenile ratio of greater sandhill cranes found under power lines was compared to their respective proportions in the population using a chi-square goodness-of-fit test (Zar 1984).

Results

Mortality

We found 597 mortalities involving 35 species, including 474 on study segments and 123 beneath other power lines (Table 2). Waterfowl (primarily mallards, *Anas platyrhynchos*) comprised 65% of mortalities; sandhill cranes 15%, and 23 species and 11 unidentified specimens comprised the remainder.

We established cause of death or injury for 284 specimens: 84% died from power line collisions. We also identified mortalities from collisions with fences and automobiles, raptor predation, lead poisoning, avian cholera, and shooting. Only 136 remains (23%) were found intact. We found 24 cripples (4%); the remainder were scavenged carcasses or feather spots.

Over 6 field seasons, we found 86 of 119 specimens (72%) placed on segments to test search efficiency. Only 20.1% of specimens were found within 24 hours. There was no difference in search efficiency on marked and unmarked segments $\chi^2 = 0.03$, 1 df, $P > 0.90$).

Examining 49 intact carcasses revealed that 65% were scavenged. Twenty percent were removed by scavengers within 1 week, but only 4% were removed within 24 hours. Scavenging rates on marked and unmarked segments were identical.

We incorporated search efficiency and scavenging rates to estimate a total of 706 mortalities on study segments for all seasons. We had no measure of unrecovered crippling loss. Anderson (1978) and Meyer (J. R. Meyer, Effects of transmission lines on bird flight behavior and collision mortality, West. Interstate Comm. for Higher Educ., Portland, Oreg., 1978) suggested that up to 75% of waterfowl and shorebirds striking power lines may continue flying out of the search area. Applying this figure as a worst-case analysis yielded an estimated 2,824 moralities on study segments.

Marker effectiveness

Observed mortality rates. Small sample sizes in fall required us to pool observed mortalities across species groups for analysis (Table 3, Fig. 2). On lines equipped with dampers, known collision mortality was lower on marked portions in fall ($Z = -3.445$, $P = 0.0003$), in spring, $Z = -2.337$, $P = 0.0096$), and when combined across seasons ($Z = -3.975$, $P < 0.0001$).

On lines equipped with plates, collision mortalities were lower on marked portions when data were combined across seasons ($Z = -3.339$, $P = 0.0012$).

Table 2. Birds found dead beneath power lines in the San Luis Valley, Colorado, spring and fall, 1988–1991.[a]

Species	*n*	%
Sandhill crane (cumulative)	90	15.1
Greater (*Grus canadensis tabida*)	40	
Lesser (*G. c. canadensis*)	10	
Canadian (*G. c. rowani*)	2	
Unidentified subspecies	38	
Canada goose (*Branta canadensis*)	20	3.4
Ducks (cumulative)	371	62.1
Green-winged teal (*Anas crecca*)	31	
Mallard (*A. platyrhynchos*)	218	
Northern pintail (*A. acuta*)	29	
Blue-winged teal (*A. discors*)	4	
Cinnamon teal (*A. cyanoptera*)	24	
Unidentified teal (*Anas* sp.)	6	
Northern shoveler (*A. clypeata*)	4	
Gadwall (*A. strepera*)	12	
Redhead (*Aythya americana*)	2	
Common merganser (*Mergus merganser*)	1	
Ruddy duck (*Oxyura jamaicensis*)	2	
Unidentified duck	38	
Other (cumulative)	105	17.6
Great blue-heron (*Ardea herodias*)	1	
Red-tailed hawk (*Buteo jamaicensis*)	2	
Rough-legged hawk (*B. lagopus*)	1	
Golden eagle (*Aquila chrysaetos*)	2	
American kestrel (*Falco sparverius*)	2	
Unidentified raptor	1	
Ring-necked pheasant (*Phasianus colchicus*)	17	
American coot (*Fulica americana*)	26	
Sora (*Porzana carolina*)	2	
Killdeer (*Charadrius vociferus*)	1	
American avocet (*Recurvirostra americana*)	1	
Marbled godwit (*Limosa fedoa*)	1	
Unidentified shorebird	1	
Black-legged kittiwake (*Rissa tridactyla*)[b]	1	
Mourning dove (*Zenaida macroura*)	3	
Great horned owl (*Bubo virginianus*)	4	
Horned lark (*Eremophila alpestris*)	2	
Barn swallow (*Hirundo rustica*)	1	
Black-billed magpie (*Pica pica*)	1	
Sage thrasher (*Oreoscoptes montanus*)	1	
European starling (*Sturnus vulgaris*)	5	
White-crowned sparrow (*Zonotrichia leucophrys*)	2	
Red-winged blackbird (*Agelaius phoeniceus*)	9	
Western meadowlark (*Sturnella neglecta*)	4	
Yellow-headed blackbird (*Xanthocephalus xanthocephalus*)	3	
Unidentified passerine	11	
Unidentified species	11	1.8
Total	597	100.0

[a] Includes specimens found outside study segments; these were excluded from mortality rate estimates.

[b] Verified record (Andrews and Righter 1992).

Seasonal partitioning revealed no difference between marked and unmarked portions (fall, $Z = 1.324$, $P = 0.0934$; spring, $Z = -1.573$, $P = 0.0582$).

The total number of overflights was higher on marked lines than on unmarked lines, except for plates in spring (Table 3). This trend varied in individual fall and spring seasons and appeared to be related to crop location and water conditions which changed during the course of the study.

Log-linear model. We examined relationships among line marking (W), marker type (M), year (Y), season (S), and species group (G). The log-linear model that best described these relationships was W, Y x S, M x S, Y x M x G ($G^2 = 43.70$, 49 df, $P = 0.25$).

Whether lines were marked (W) was the only main effect. Predicted mortality rates were lower ($P < 0.005$) for both marker types, all species groups, in all seasons and years. Interaction between marker type and season (M x S, $P = 0.005$) suggested that the relative effectiveness of plates and dampers was not consistent. Mortality rates were generally higher for dampers in fall and plates in spring. Whether mortality rates were higher in spring or fall varied by year (Y x S, $P = 0.005$; Table 4).

The relative effectiveness of marker types for cranes, geese, and ducks also varied among years (Y x M x G, $P = 0.005$). This interaction obscured the main effects and 2-way interactions of these parameters.

Response to markers. We examined flight behavior and relationships among whether a reaction was observed (R), species group (G), height above the line (H), and line marking (M, H x M, G x R x M, G x R x H; $G^2 = 10.228$, 10 df, $P = 0.4207$). Most flights were observed at 3–6 m above the line and fewest at >6 m (Table 5). Flocks flew higher above marked lines than unmarked lines (H x M, $P < 0.0001$).

Species groups reacted differently to line marking (G x R x M, $P = 0.005$). Cranes reacted more often to marked lines. Geese reacted more to unmarked lines; however, sample size for geese was small (Table 5).

We found an interaction among species group, reaction, and flight height above the line (G x R x H, $P = 0.002$). Ducks had the highest proportion of flocks crossing the line at >6 m, cranes had the smallest. For all species groups, birds that visibly reacted to lines flew higher than those that did not. Cranes that did not react to lines were more likely than ducks or geese to be <3 m above the line when crossing. Marking did not change these effects.

Among flocks reacting to lines, the most frequent reaction was adjusting altitude, followed by flaring or changing direction (Table 5). Ducks flew under lines most frequently, especially unmarked lines.

For flocks that reacted by adjusting altitude ($N = 975$), the log-linear model D x H x M, G x D x H, G x M best described associations among species group (G), reaction distance (D), height above the line

Table 3. Avian mortality at marked (M) and unmarked (U) portions of 4 power line segments testing spiral vibration damper markers (dampers) and 4 segments testing fiberglass swinging plate markers (plates) in the San Luis Valley, Colorado, fall and spring, 1988–1991.

	Fall 1988–1991				Spring 1990–1991			
	Dampers		Plates		Dampers		Plates	
	M	U	M	U	M	U	M	U
Cranes								
Total mortalities[a]	1	6	0	1	7	8	0	2
Collisions	1	6	0	1	5	8	0	2
Overflights (1,000's)	47.5	26.4	68.7	43.0	76.5	42.6	8.5	9.6
Mortality rate[b]	2	23	0	2	7	19	0	21
Geese								
Total mortalities[a]	1	1	1	0	2	6	0	0
Collisions	0	0	0	0	1	5	0	0
Overflights (1,000's)	1.9	1.4	6.8	4.0	12.5	9.1	2.6	4.1
Mortality rate[b]	0	0	0	0	8	55	0	0
Ducks								
Total mortalities[a]	8	29	4	8	77	74	62	62
Collisions	2	9	1	2	24	24	18	30
Overflights (1,000's)	25.0	6.5	50.5	26.2	75.6	59.9	16.4	17.5
Mortality rate[b]	8	138	2	8	32	40	110	172
Total								
Total mortalities[a]	10	36	5	9	86	88	62	64
Collisions	3	15	1	3	30	37	18	32
Overflights (1,000's)	74.4	34.3	126.0	73.2	164.6	111.6	27.5	31.2
Mortality rate[b]	4	44	1	4	18	33	65	103

[a] Total mortalities include known collisions and unknown causes; other known causes were excluded.
[b] Minimum mortality rates are known collisions/100,000 overflights ≤15 m above power lines, rounded to the nearest integer. Rates are an index to comparative mortality and flight intensity; they do not represent actual mortality rates.

(H), and line marking (M) $G^2 = 22.37$, 16 df, $P = 0.132$. Interaction among distance, height above the line, and line marking ($P < 0.0001$) indicated that birds reacted at greater distances to marked lines and that birds that reacted at greater distances flew higher. Ducks tended to react farthest from lines and flew >6 m above lines; geese reacted at shortest distances and flew lower; cranes were intermediate in response and height (G x D x H, $P = 0.025$). The G x M interaction ($P = 0.047$) was not particularly meaningful, indicating that cranes were more often observed over marked lines, whereas ducks and geese were more often observed over unmarked lines.

Factors affecting mortality

Weather. We examined relationships among days with maximum hourly winds ≥24 kph (W), days with collisions occurring (C), and line marking (M, C x W, M x C, $G^2 = 0.42$, 2 df, $P = 0.81$). Collisions occurred more frequently on days with winds >24 kph (C x W, $G^2 = 7.089$, 1 df, $P = 0.008$). It was 1.82 times more likely that at least 1 collision occurred on windy days. Collisions occurred less frequently on marked lines (M x C; $G^2 = 6.0$, 1 df, $P = 0.014$); however, wind increased the collision rate regardless of whether lines were marked. We found no evidence that precipitation (P) affected collisions (P, M x C; $G^2 = 5.69$, 9 df,

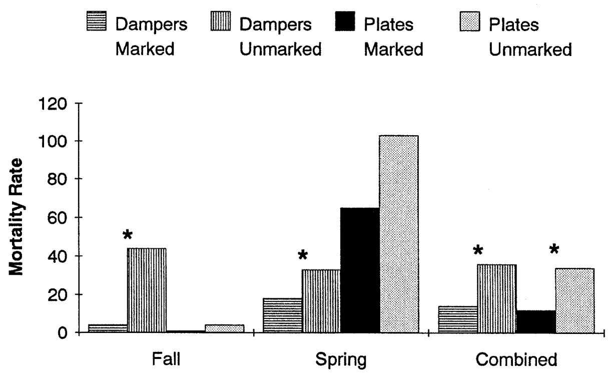

Fig. 2. Combined mortality rates (collisions/100,000 overflights ≤15 m above power lines) for cranes, geese, and ducks at marked and unmarked portions of 4 power line segments testing spiral vibration damper markers (dampers) and 4 segments testing fiberglass swinging plate markers (plates) in the San Luis Valley, Colorado, fall and spring 1988–1991. Differences at $P \leq 0.05$ (binomial test of equal proportions) are indicated by an asterisk.

Table 4. Predicted avian mortality rates/100,000 overflights ≤15 m above power lines, based on log-linear model of mortality at marked and unmarked portions of 4 power line segments testing spiral vibration damper markers (dampers) and 4 segments testing fiberglass swinging plate markers (plates) in the San Luis Valley, Colorado, fall and spring, 1988–1991.[a]

Species season	Treatment	1988–1989		1989–1990		1990–1991		All years	
		Marked	Unmarked	Marked	Unmarked	Marked	Unmarked	Marked	Unmarked
Cranes									
Fall	Dampers	6.45	19.63	6.17	18.77	9.90	30.12	7.78	23.41
	Plates	1.14	3.47	1.40	4.24	0.15	0.47	0.70	2.47
Spring	Dampers	3.51	10.68	1.68	5.12	20.97	63.77	7.34	16.23
	Plates	15.15	46.07	9.27	28.20	7.90	24.01	10.60	30.37
Geese									
Fall	Dampers	43.25	131.57	9.96	30.31	23.35	71.03	23.29	84.96
	Plates	1.83	5.59	1.92	5.84	0.20	0.62	1.35	4.86
Spring	Dampers	23.55	71.62	2.71	8.26	49.44	150.39	2.54	35.61
	Plates	24.37	74.13	12.77	38.81	10.45	31.78	14.42	42.10
Ducks									
Fall	Dampers	64.79	197.04	44.79	136.23	12.04	36.61	17.99	85.93
	Plates	12.58	38.26	2.87	8.74	3.40	10.35	6.09	12.20
Spring	Dampers	35.27	107.27	12.21	37.13	25.49	77.51	21.81	68.28
	Plates	167.00	507.93	19.09	58.07	175.62	534.16	124.57	155.88

[a] All values of marked differ from unmarked at $P \leq 0.05$.

$P = 0.77$). Analysis of median daily average wind speed, temperature, and solar radiation for days with and without collisions also showed only wind speed was important to collision occurrence ($Z = 3.318$, 1 df, $P = 0.0009$; Table 6).

Nocturnal flights and disturbance. By walking segments at dusk and the following dawn, we found 7 mortalities in fall 1990 and 12 in spring 1991 that occurred at night. The proportion of night collisions to total collisions was much higher in fall (31.8%, n = 22), than spring (7.7%, n = 156; $\chi^2 = 24.24$, 1 df, $P < 0.005$). Radar monitoring detected increases in bird flights before dawn during the waterfowl hunting season, indicating that either birds adjusted their behavior to avoid hunters or that hunters disturbed birds from night roosts.

Other factors. The proportion of juvenile greater sandhill cranes killed by power lines (30%, n = 40) was higher ($\chi^2 = 56.6$, 1 df, $P < 0.001$) than their average proportion in the population during fall age-ratio surveys from 1988–1990 (4.7%, n = 21,248). We did not have local population data with which to compare age and sex mortality for lesser sandhill cranes or other species.

Table 5. Behavior of sandhill cranes, Canada geese, and ducks flying over marked and unmarked portions of power lines in the San Luis Valley, Colorado, fall and spring, 1988–1991.

	% Reaction					% Reaction distance (m)				% Height above line (m)		
	Maintain altitude	Adjust altitude	Flare or change direction	Fly under wire	Strike wire	No reaction	<5	5–25	>25	<3	3–6	>6
Cranes												
marked (n[a] = 452)	23.2	70.8	5.5	0.2	0.2	23.5	16.4	30.9	29.2	27.2	60.4	12.4
unmarked (n = 287)	35.5	59.2	4.2	0.7	0.4	35.9	13.9	33.8	16.4	46.2	47.5	6.3
Geese												
marked (n = 95)	30.5	65.3	3.2	1.0	0	31.6	18.9	27.4	22.1	30.5	54.7	14.7
unmarked (n = 64)	20.3	79.7	0	0	0	20.3	18.8	29.7	31.2	32.8	51.6	15.6
Ducks												
marked (n = 275)	22.2	64.7	5.1	7.6	0.4	28.4	16.0	32.0	23.6	22.2	46.9	30.9
unmarked (n = 299)	17.4	65.2	5.7	10.7	1.0	25.1	14.0	32.8	28.1	30.4	53.2	16.4

[a] n = number of cohesive groups of ≥1 birds.

Table 6. Weather variables and avian mortality from collisions with power lines during spring and fall 1988–1991 in the San Luis Valley, Colorado.

	Days with max. hourly wind[a]		Precipitation (days)[b]		Average daily		
	<24 kph	≥24 kph	None	Some	Wind[a] (kph)	Temp (°C)	Solar radiation (kw/m²)
Days with collisions	34	62	83	13	13.8	5.4	0.14
Days without collisions	119	98	187	30	11.9	5.3	0.14

[a] Variable correlated ($P < 0.01$) with collisions.
[b] Fog, rain, hail, sleet, or snow.

We necropsied 83 specimens including 32 sandhill cranes, 7 Canada geese, 36 ducks, 7 coots, and 1 sora. Body condition of 79 (95.2%) was good-excellent; 4 others were poor-fair. One dead mallard showed evidence of disease (avian cholera).

Discussion

Marker effectiveness

Both markers significantly reduced mortality. Although direct statistical comparison is not possible because of different species and methodologies, the raw percent reduction in mortality of 61% (dampers) to 63% (plates) compares favorably with that reported for other markers in North America. Beaulaurier (1981) summarized the results of 5 marking efforts from 1972-1980 and found an average of 45% reduction (range = 28-60%). Results reported by Morkill and Anderson (1991) indicated a 54% reduction in sandhill collisions by marking lines with yellow aviation balls.

In the Netherlands, Koops and de Jong (1981) reported 57-89% reduction in collision mortality from "bird flight diverters". This device, produced in England, is essentially a spiral vibration damper with an enlarged coil at 1 end to increase its silhouette and visibility. Koops and de Jong (1981) found that variability in this marker's effectiveness was related to the distance between markers (horizontal coverage) and the size of the end coil.

The conclusions of Koops and de Jong (1981) have implications for our results. We filmed marked and unmarked lines from a helicopter, flying at dawn and dusk at speed and elevations similar to that of birds crossing lines. We observed that plates were more visible than dampers at distances >200 m, but because there were fewer plates/span, they were less visible upon close approach to lines and the position of the helicopter relative to a plate was more important. Conversely, dampers most increased visibility of lines to humans upon close approach and when directly above lines. The benefits of plates and dampers may actually have been different (i.e., plates gave more of a silhouette and were visible from a greater distance and in lower light, and thus may have provided more benefit after dusk). Dampers gave substantially greater horizontal coverage and were more visible on close approach to and above lines, which may have value when birds in large flocks encounter power lines or when distracted or frightened. This hypothesis is supported as we saw lower mortality rates for ducks at lines with plates in fall, when waterfowl increased flights before dawn and after dusk, and lower rates at damper-equipped lines in spring, when ducks were intent on courtship and pursuit flights.

Variability in mortality rates with respect to species groups, season, year, and marker type was probably related to local environmental conditions that affected avian concentration, species composition, and proximity to power lines. Changes in water management on Monte Vista NWR and proximity of food crops affected study segments. Because species groups responded differently to variables such as water levels in roost ponds, concentration and mortality rate varied seasonally and annually.

The relationship we observed between mortality rates and environmental conditions supports the hypothesis of Thompson (1978) that collision rates are unpredictable. We believe that it is imprudent to draw broad conclusions regarding the relative collision susceptibility of various species. Further, our results emphasize the importance of experimental design for comparing mortality on modified and unmodified lines at 1 time rather than before and after modification.

Behavioral response to markers supported their effectiveness. Cranes visibly reacted more often to marked lines, and all species groups flew higher over marked lines. Among flocks that reacted by adjusting altitude, birds reacted to marked lines at greater distances. Morkill and Anderson (1991) found similar results for cranes in Nebraska.

Factors affecting mortality

The array of species we found under power lines illustrates widespread avian vulnerability to collisions. However, all species were found in small numbers in relation to their abundance in the study area, suggesting that collisions were not a significant mortality factor.

The most common casualties were sandhill cranes and waterfowl that made daily low level flights between wetland roosts and croplands. We also frequently recovered pheasants and coots under study lines. The latter 2 species occupied habitats commonly shared with power line right-of-ways (i.e., fence lines and irrigation ditches). Because roads were also associated with right-of-ways, pheasants and coots were subject to flushing near power lines. Other studies have found habitat use and proximity to wires important to collision frequency (Scott et al. 1972, Lee 1978, Morkill and Anderson 1991).

Wind was the only weather factor that correlated with collisions in this study. We frequently witnessed near-collisions during windy conditions, and we suspect that the generally higher mortality in spring was related to increased frequency of high-velocity winds. Fog has previously been found to be a major factor in bird collisions; however, this may apply more to local populations or migrating birds forced to fly in these conditions (Scott et al. 1972, Gauthreaux 1978). Fog in the San Luis Valley often occurred in early mornings, but cranes and waterfowl usually remained in roosts until it lifted.

Juvenile cranes were more vulnerable to collisions than adults in this and other studies (Brown et al. 1987). Juvenile cranes lack flight experience and familiarity with the area; they also usually fly behind their parents and may be less able to make sudden adjustments to avoid obstacles.

Body condition and disease were not important to collisions. Conversely, our limited sampling suggested that even minimal nocturnal activity may substantially contribute to waterfowl mortality, especially when associated with disturbance. Radar monitoring of bird flights on our study area showed that although bird flights were infrequent during the night, they increased prior to dawn during waterfowl hunting season. This suggests that either birds adjusted their behavior to avoid hunters or that hunters disturbed birds from night roosts (Cooper and Mabee 1990). In Oregon, Willard (1978) found that nocturnal activity of waterfowl and collision mortality was related to hunting. Marking lines probably has reduced benefit at night, but light-colored markers that provide silhouette in minimal light will be most effective.

Management implications

The best method of minimizing avian collision mortality is to avoid constructing power lines in sensitive areas. However, if problems exist after construction, marking power lines appreciably reduces mortality.

Yellow appeared to be an effective color for marking. Raevel and Tombal (1991) suggested it may be beneficial to alternate 2 or more different-colored markers with differential detectability under varied light conditions (e.g., yellow or white for dark and cloudy conditions, red for bright sunlight). For species prone to collisions, it would be valuable to further evaluate color sensitivity and other aspects of vision such as perception of obstacles in controlled experiments. However, color fading from ultraviolet radiation is a problem. After 3 years in service, some yellow pigments faded to an off-white color in dampers and plates.

Plates caused wear on the conducting wires of 7.2 kv distribution lines from galloping vibration set up under high winds. The plates were removed from distribution lines after the study was completed.

Spiral vibration dampers are a highly effective marker and can be safely used on distribution and transmission lines. Although plates reduced mortality, they cannot provide the horizontal coverage of dampers and some damage occurred to distribution lines, precluding further use.

Staggered placement of dampers on static lines or conductors of equal height is recommended because this provides the best visual coverage with minimum stress on the line. Koops and de Jong (1981) used similar placement of bird flight diverters to mark static wires in the Netherlands with success.

Bird flight diverters became available in North America in 1993. This product incorporates important features of both dampers and plates (horizontal coverage and silhouette), and we recommend its evaluation.

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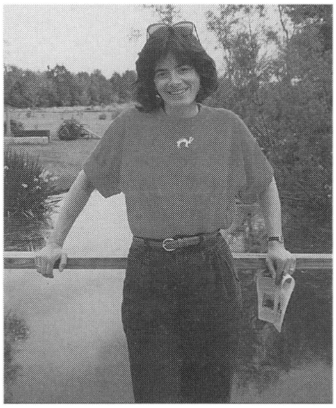

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