220

Avian behavior and mortality at power lines in coastal South Carolina

Anthony J. Savereno, Lynette A. Savereno, Ruth Boettcher, and Susan M. Haig

Abstract We compared avian behavior and mortality associated with two 115-kV transmission lines on the central South Carolina coast during 3,392 hours of observation from May 1991 through May 1994. One line was marked with 30-cm-diameter yellow aviation markers. The second line was unmarked, but was similar in most other aspects. We conducted ground searches (n = 445) beneath each line year-round to document avian mortality due to power-line collisions. At marked lines, birds that approached at line height changed behavior more at unmarked lines ($P < 0.001$), and fewer crossed between static and conductor wires. Collision rate was 53% lower at marked than unmarked lines. Among collisions at both sites, 82% of birds collided with static wires. Based on observed collisions and carcass recoveries, wading birds particularly appeared to be at risk. We concluded that aviation markers were effective at increasing line visibility and reducing collisions and recommend marking static wires of power lines in potentially sensitive areas.

Key words avian behavior, avian mortality, power lines, salt marsh, South Carolina

Avian mortality from power-line collisions is well documented (Thompson 1978, Brown 1993, Avian Power Line Interaction Comm. [APLIC] 1994). Avian loss is often greatest where power lines cross migratory paths, bisect feeding and nesting-roosting sites, or occur adjacent to major avian use areas (Scott et al. 1972, Malcolm 1982, McNeil et al. 1985, Brown et al. 1987, Faanes 1987, Morkill and Anderson 1991, Brown and Drewien 1995). High risk also exists when land topography funnels birds through power-line corridors (Faanes 1987, Bevanger 1990, 1994). This mortality may be significant for species that are endangered or threatened or occur in small local populations (Owen and Cadbury 1975, Anderson 1978, Lee 1978:67, Faanes 1987, Crivelli et al. 1988).

Factors that influence the risk of collision to individual birds as they encounter power lines are varied and include species' flight characteristics, previous experience with power lines (typically a function of age), weather, and power-line structural characteristics (Thompson 1978, Brown 1993, APLIC 1994). Numerous methods of mitigating avian collisions with power lines have been proposed and tested (Thompson 1978, Brown 1993, APLIC 1994). Among the most promising is the use of markers of various designs to increase visibility of static (or ground) wires, which are the major source of collision mortality (Morkill and Anderson 1991, Alonso et al. 1994, Brown and Drewien 1995).

In 1991, a 4-km, 115-kV power line was constructed through saltmarsh separating a barrier island and the South Carolina mainland. There was high potential for avian mortality because the line bisected feeding and nesting habitat in an area of major avian use and connected 2 land masses that could funnel birds through the power-line corridor. The U.S. Fish and Wildlife Service (FWS) stipulated that the static wires be marked with aviation spheres like those described and tested by Morkill and Anderson (1991). We monitored the line intensively for 3 years. Our

Authors' address during this research: South Carolina Cooperative Fish and Wildlife Research Unit, Clemson University, Clemson, SC 29634, USA. Current address for Anthony J. Savereno and Lynette A. Savereno: 854 Fairlawn Circle, Mt. Pleasant, SC 29464, USA. Current address for Ruth Boettcher: North Carolina Wildlife Resources Commission, PO Box 178, Marshallburg, NC 28532, USA. Current address for Susan M. Haig: Forest and Rangeland Ecosystem Science Center, U.S. Geological Survey Oregon State University, 3200 SW Jefferson Way, Corvallis, OR 97331, USA.

study objectives were to: (1) determine if aviation spheres affected flight behavior and reduced observed collision rates, (2) determine how the presence of power lines affected flight behavior, (3) determine the effects of taxonomic group, bird age, flight altitude, weather, and light intensity on avian behavior near power lines, and (4) estimate bird injury and mortality rates attributable to power-line collisions. Few published studies have examined the behavior of multiple species during encounters with power lines. No published work has documented the effectiveness of aviation spheres in reducing power-line collision mortality in species indigenous to Atlantic salt marsh habitat.

Study area and methods

Study area

The study was conducted from May 1991 to May 1994 in Charleston County, South Carolina. We examined two 115-kV transmission lines, 1 marked and 1 unmarked. The segment of marked line was 3,927 m long and extended from Mt. Pleasant to Isle of Palms, ranging 1-4 km from the Atlantic Ocean. The segment of unmarked line was on James Island, approximately 10 km from the ocean, and was 1,230 m long. Yellow aviation spheres (30-cm diameter with a black, vertical stripe) were hung from each static wire at Isle of Palms at intervals of 61 m. Markers were staggered in such a way that when viewed from the side they appeared to be 30.5 m apart (Fig. 1). Although a comparison of adjacent marked and unmarked sections of the same power line would have provided less bias for an evaluation of marker effects, concerns of the FWS over the threat posed to threatened and endangered species precluded the removal of any markers that had been installed prior to our involvement. We selected the James Island site because it was the nearest unmarked line with characteristics similar enough to the lines at Isle of Palms to allow meaningful comparisons (Table 1). Both study areas were characterized by saltmarsh dominated by cord grasses (*Spartina* spp.) and needlerush (*Juncus roemerianus*) and were interspersed with tidal creeks and navigable waterways. The Isle of Palms power line intersected 2,751 m of salt marsh (70%), 928 m of water (24%), 160 m of upland habitat (4%), and 88 m of dredged spoil (2%). No markers were placed on static wires at James Island where the power line intersected 1,010 m (82.0%) salt marsh, 152.4 m (12.4%) water, and 67.6 m (5.6%) upland habitat. Habitat types were determined by power company drawings, aerial photographs, and on-site inspections.

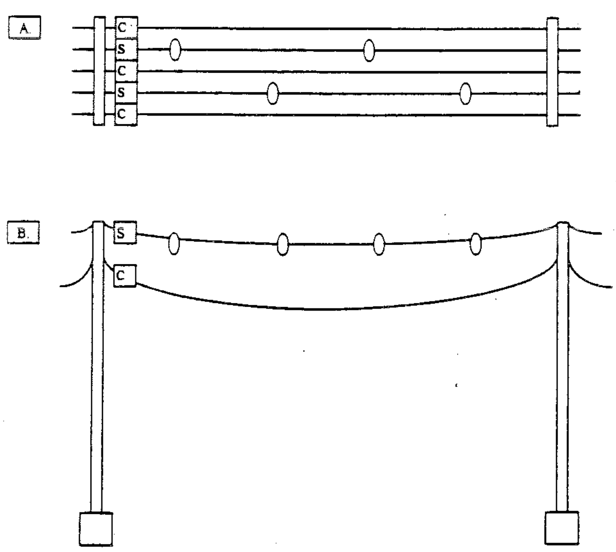


Fig. 1. Overhead (A) and side (B) views showing arrangement of markers (0), conductor wires (C), and static wires (S) on the 115-kV Isle of Palms power line, Charleston, South Carolina. Intraline distance between markers = 30.5 m.

Table 1. Characteristics of 2 power lines with (Isle of Palms) and without (James Island) line markers for reducing avian-collision mortality, Charleston County, South Carolina, May 1991–May 1994.

Characteristic	Site: Isle of Palms	Site: James Island
Voltage (kV)	115	115
Study segment length (m)	3,927	1,230
Tower heights (m)	26–51	20–36
Tower construction	steel H-frame	wood H-frame
No. of sections	14	5
Length of sections (m)	146–442	203–305
No. of markers/section	4–14	None
Static wire diameter (mm)	7.8	7.8
Conductor wire diameter (mm)	27.9	34.2
Highest point of static wires (m)	51	36
Vertical distance between static and conductor wires (m)	4.3	4.5

Behavioral sampling

To examine bird behavior near power lines under varying conditions, we recorded behaviors of all species of birds, except passerines, during encounters with power lines from first light (10 lux) until 3 hours after sunrise, and from 3 hours before sunset until dark (10 lux). The observation corridor or area under surveillance included the length of the study segment and an approach and exit zone (approx 30 m perpendicular to either side of the line). Because entire observation corridors could not be surveyed by a single observer from 1 vantage point, viewing posts were established along the lengths of the corridors. Observers were rotated among posts and time periods to reduce observer bias. Length of line observed from posts at both sites did not exceed 1,371 m.

Four viewing posts were established at Isle of Palms. Twice a month, we simultaneously monitored 1 pair of adjacent posts, once during the morning sampling period and once during the evening sampling period. We sampled each pair every other month to ensure equal sampling among all 4 posts. Behavioral observations were simultaneously made from all 4 posts, 1 day/week during morning and evening sampling periods. These data were also included in analyses. We monitored the entire observation corridor at the James Island site from 2 viewing posts. We conducted simultaneous observations from both posts 6 times/month.

Flight behavior was recorded in 15-minute blocks. At the beginning of each block, we recorded time (EST), precipitation, wind speed, wind direction, light intensity (measured with a light meter in lux), and visibility. We used a combination of focal group and sequence sampling (Altmann 1974) to collect behavioral data. The first flock to approach the line at the beginning of each sampling period was selected as the focal flock. A flock was defined as ≥1 birds flying as an independent unit (Brown et al. 1987, Morkill and Anderson 1991). We recorded flight behavior from the time when a focal flock entered the approach zone until it: crossed the line and departed from the exit zone, landed within the observation corridor, reversed flight in the observation corridor and departed in the same direction from which it approached, or flew parallel to the line and entered an adjacent section of line assigned to another observer without exiting the observation corridor.

Data recorded for each flock that entered the approach zone were: (1) species or closest identifiable taxonomic level on avian group (e.g., tern, gull, shorebird), (2) number of individuals in flock before and after the encounter, (3) age class (adult or juvenile), (4) location of encounter (section of line between consecutive towers), (5) approach and exit heights (altitude of birds in the approach and exit zones relative to the power line; Height 1—below conductor wires, Height 3—between conductor and static wires, and Height 5—above static wires), (6) crossing height (Height 1—between ground level and 3 m below conductor wires; Height 2—within 3 m, but below conductor wires; Height 3—between conductor and static wires; Height 4—above, but within 3 m of static wires; and Height 5—more than 3 m above static wires), and (7) behaviors exhibited during the encounter. The following behavior categories were established during preliminary field work and adapted from Faanes (1987) and Morkill and Anderson (1991): (1) no alteration of behavior within the observation corridor, (2) collision with lines or support structures, (3) gradual altitude increase or decrease, (4) abrupt altitude increase or decrease, (5) landed on the power line or support structures, (6) landed within the observation corridor, (7) flew parallel to power line, (8) circled during approach or crossing, (9) reversed flight within observation corridor during approach, crossing, or departure, and (10) vertical rise or drop through the lines. Multiple behaviors were recorded in the sequence in which they occurred. The size and behavior of each subflock were recorded if individuals within flocks exhibited different reactions. We deleted data from analyses if behavior of all individuals or subflocks within a flock could not be observed. We classified birds that could not be identified to species or an avian group as unknown.

Collision rates

We compared collision rates between sites to determine if aviation markers at Isle of Palms were effective at reducing collisions. We obtained rates for each site by dividing the number of collisions observed, prior to which birds had approached at Height 3 (the zone between conductor and ground wires where collision risk is greatest), by the number of birds that approached at Height 3. We made comparisons only for approaches at Height 3 because of the difference in absolute line heights between sites and the necessity of keeping collision-rate data as consistent as possible (Beaulaurier 1981:52). We multiplied results by 100,000 to obtain collision rates/100,000 birds.

Mortality estimates

At both sites, we conducted ground searches for dead and injured birds 2-3 times/week. Under sections of lines that could be walked, 2 observers, approximately 15 m apart, walked a zigzag pattern (Brown et al. 1987, Faanes 1987, Morkill and Anderson 1991, Hartman et al. 1992) along a 30-m-wide transect to either side of the middle conductor wire. We examined, diagnosed, and when possible, rehabilitated injured birds. We recorded the location of all carcasses and partial remains (e.g., feathers, bones) prior to removing them from the search area. Bird remains were examined in the field. A local veterinarian specializing in wild bird rehabilitation x-rayed and necropsied 20 intact carcasses to determine cause of death. Injured birds, carcasses, and partial remains were identified to species (or group), sexed, and aged when possible.

Because of tidal fluctuations, length of line, and instability and variability of substrate it was not possible at either site to search the entire study area by foot or conventional motorboat. All ground searches at James Island and most at Isle of Palms were conducted in sections that could be searched on foot; these sections comprised only 10% (377 m) of the Isle of Palms study site and 34% (413 m) of the James Island study site. At both sites, area searched was contiguous, except for the channels and immediate margins of tidal creeks, and consisted of regularly flooded saltmarsh, margins of salt marsh flooded only during atypical high tides, and upland habitats.

To allow comparison of our mortality estimates with other studies, we used data from ground searches to estimate power-line mortality for those sections searched. A mortality estimate (ME), which represented total dead birds found (TDBF; non-passerines only) adjusted by correction factors, was calculated for each ground search. Minimum and maximum estimates were obtained using 2 different sets of TDBF data. The minimum estimate used a TDBF that only included those carcasses for which internal or external injuries were consistent with collisions. The maximum estimate used a TDBF that also included carcasses and feather spots (≥25 feathers, or <25 feathers plus tissue or bone) for which cause of death could not be determined.

The formula used to obtain mortality estimates for each ground search was adapted from Faanes (1987) and included the following bias estimates: (1) search bias—a measure of observer error in detecting dead birds during ground searches, (2) scavenger removal rates—proportion of carcasses removed by scavengers between ground searches, (3) habitat expansion factor—proportion of area that could be searched within the established search corridor, and (4) crippling bias—proportion of observed birds that collided, but flew out of the observation corridor.

We conducted search-bias and scavenger-removal experiments to determine adjustment factors for both sources of error. We conducted 6 observer-bias trials at each site to evaluate searching ability of 2 pairs of observers that conducted ground searches. Before each trial, a random number of duck carcasses with numbered leg bands (mostly female mallards, *Anas platyrhynchos*) were placed in randomly selected sites within the search area by a fifth person. One pair of observers at a time walked through the search area. When a duck was found, its number was recorded. The mean proportion of birds found (MPBF) calculated for each observer pair at each site served as observer bias adjustments.

To obtain scavenger-removal rates, duck carcasses (Isle of Palms: n = 8, James Island: n = 11) were placed throughout both ground-search areas with their locations flagged. We monitored carcasses daily for the first 5 days and then 2 or 3 times/week for 60 days or until all remains were removed. During these visits, we recorded the presence or absence of a carcass, stage of decomposition, and scavenging activity. The proportion of ducks not removed (PNR) was calculated after each search.

We used the following equations to calculate a ME for each ground search:

Search Bias (SB) = (TDBF ÷ MPBF) - TDBF where MPBF corresponded to the corresponding site and pair of observers;

Scavenger Removal (SR) = ((TDBF + SB) ÷ PNR) - (TDBF + SB) where the PNR used depended on the time interval between the previous and current search, rarely exceeding 10 days;

Habitat Factor (HF) = ((TDBF + SB + SR) ÷ PS) - (TBDF + SB + SR) where PS was the proportion of the search area that was accessible during all searches;

Mortality Estimate (ME) = (TDBF + SB + SR + HF) ÷ (1 - CB) where CB represented crippling bias calculated for each site. Mortality Estimates were summed to obtain total minimum and maximum mortalities at each site in those sections searched.

Statistical analyses

To examine gross taxonomic differences in behavior, we placed all birds except for those identified as "unknown" in 1 of the following taxonomic groups: raptors, shorebirds, gulls, terns, waterbirds (ducks, geese, swans, grebes, and loons), wading birds (ibis, egrets, storks, bitterns, and herons), cormorants, doves, kingfishers, and pelicans. We excluded from the analyses seldom observed birds that did not fit in 1 of the above groups. We divided power-line encounters into 2 groups: those during which flocks exhibited no change in flight behavior and those during which they did. Encounters that resulted in a changed behavior were assigned to one of the following categories created by combining the most common behavioral sequences recorded in the field: (1) gradual adjustment—gradual altitude increase or decrease, (2) flare—an abrupt and rapid altitude change, (3) hesitation—any behavior that indicated some degree of hesitation prior to a successful crossing (e.g., parallel flight along lines with no altitude change; reversed flight during approach or crossing followed by another crossing attempt; circling in approach zone), and (4) abort—reversed flight within approach zone without a subsequent crossing. We eliminated collisions from analyses because we observed too few collisions to include them in our analyses.

To compare observations among weather and light-intensity values, we transformed variables into categorical data as follows: precipitation (rain or no rain); wind speed (calm = no wind, light = 16 km/hr, moderate = 18–32 km/hr, and strong = > 34 km/hr); and wind direction (cross winds = perpendicular to flight path, tail winds = in same direction as flight, and head winds = against direction of flight). We also created fair- and foul-weather categories adapted from Brown et al. (1987) to determine combined effects of weather conditions on flight behavior. Fair weather was defined as good visibility (no rain or fog), calm to moderate winds, and high light intensity (>100 lux). Foul weather included rain, fog, or strong winds.

We used the Statistical Analysis System's FREQ procedure (SAS Inst., Inc. 1988) to perform chi-square tests of independence between frequencies of behaviors at Isle of Palms and the following factors: taxonomic group, age, approach height, weather (rain, wind, and visibility), and light intensity. We compared frequencies of behaviors between sites to determine if birds changed behavior in the presence of aviation markers and if so, what types of change occurred. To maximize comparability between sites, we used only those observations that met the following criteria: precipitation = no rain; approach height = 3 (line height); wind speed = calm or light; light intensity >100 lux. If chi-square values of complex (df > 1) contingency tables were significant, we used Bonferroni confidence intervals (Neu et al. 1974, Byers et al. 1984) to ascertain which observed cell values deviated significantly from expected. Significant deviation of observed values from expected values indicated a lack of independence between variables. To reduce the likelihood of a Type I error in the numerous chi-square tests, we set an a priori level of significance of $\alpha = 0.01$.

To test whether search effort increased when observers knew they were being tested for bias, we compared mean time elapsed during test ground searches with a random sample of normal ground searches. Comparisons were made using a *t*-test with a level of significance of $\alpha = 0.05$.

Results

Behavior

At Isle of Palms, we made observations on 229 days (13,974 time blocks; 3,392 observer hrs). We recorded 64,512 flock/power-line encounters (129,428 birds), yielding an encounter rate of $\bar{x}$ = 38.4 (SE = 0.6) birds/km/hour (n = 13,974). We identified 71,607 individuals to 92 species. Another 53,938 individuals that could not be identified to species were placed in 27 broader taxonomic groups. We assigned 125,099 birds to 10 taxonomic groups for analyses (Table 2).

At James Island, we made observations on 212 days (5,627 time blocks; 1,358 observer hrs). We observed 17,391 flocks/power-line encounters (28,507 birds), yielding an encounter rate of $\bar{x}$ = 39.8 (SE = 1.0) birds/km/hour (n = 5,627). We successfully identified 19,863 individuals to 70 species, and 8,208 to 22 broader taxonomic groups. Of the identifiable birds, we assigned 27,727 to 10 taxonomic groups for analyses (Table 2).

At Isle of Palms, 65% (n = 42,508) of flocks approached at Height 1, whereas only 15% (n = 9,819) and 20% (n = 13,178) approached at Heights 3 and 5, respectively. At James Island, 36% (n = 6,287) of flocks approached at Height 1, 24% (n = 4,209) approached at Height 3, and 40% (n = 6,979) approached at Height 5. Of flocks that approached at Height 3, only 4% (n = 358) went on to cross at Height 3 at Isle of Palms, whereas 24% (n = 966) crossed at Height 3 at James Island.

Nearly 34% of birds exhibited changes in behavior at Isle of Palms, whereas 40% changed behavior at James Island (Table 3). Gradual adjustment was the

Table 2. Nonpasserine birds observed during encounters with marked (Isle of Palms) and unmarked (James Island) power lines, Charleston County, South Carolina, May 1991–May 1994.

Taxonomic group	Marked (%)	Unmarked (%)
Cormorant	10,133 (7.8)	1,346 (4.7)
Dove	2,541 (2.0)	3,212 (11.3)
Gull	35,803 (27.7)	7,667 (26.9)
Kingfisher	931 (0.7)	130 (0.5)
Pelican	4,442 (3.4)	787 (2.8)
Raptor	2,047 (1.6)	1,424 (5.0)
Shorebird	29,777 (23.0)	2,229 (7.8)
Tern	7,150 (5.5)	1,827 (6.4)
Wading bird	27,666 (21.4)	8,537 (29.9)
Waterbirds	4,609 (3.6)	568 (2.0)
Unknown	3,883 (3.0)	436 (1.5)
Other[a]	446 (0.3)	344 (1.2)
Total	129,428 (100.0)	28,507 (100.0)

[a] Species that occurred in insufficient numbers to permit analyses.

Table 3. Frequencies of behavioral changes (Abort, Flare, Hesitation, and Gradual Adjustment) observed at marked (Isle of Palms) and unmarked (James Island) power lines, Charleston County, South Carolina, May 1991–May 1994.

Taxonomic group	No behavioral change (%)[a]	Abort	Flare	Hesitation	Gradual adj.	(%)[b]
		Behavioral change				
Cormorant						
Marked-	2,821 (65.4)	89	25	156	1,197	(34.6)
Unmarked-	400 (53.2)	19	7	27	275	(46.8)
Dove						
Marked-	845 (74.1)	24	14	51	197	(25.9)
Unmarked-	511 (45.3)	71	32	27	500	(54.7)
Gull						
Marked-	15,029 (65.4)	476	312	1,684	5,189	(34.6)
Unmarked-	3,270 (65.1)	49	80	231	1,352	(34.9)
Kingfisher						
Marked-	372 (42.7)	111	1	37	268	(57.3)
Unmarked-	15 (12.2)	27	0	1	90	(87.8)
Pelican						
Marked-	2,801 (73.6)	94	11	132	615	(26.4)
Unmarked-	368 (64.2)	5	5	18	155	(35.8)
Raptor						
Marked-	1,142 (57.6)	53	14	111	467	(42.4)
Unmarked-	499 (36.2)	80	9	88	567	(63.8)
Shorebird						
Marked-	2,329 (51.7)	217	159	362	1,448	(48.3)
Unmarked-	341 (33.6)	137	22	63	417	(66.4)
Tern						
Marked-	3,529 (63.0)	202	83	350	1,414	(37.0)
Unmarked-	966 (64.3)	13	19	45	457	(35.7)
Wading bird						
Marked-	11,980 (68.1)	922	206	978	2,986	(31.9)
Unmarked-	3,809 (66.8)	131	145	195	1,383	(33.2)
Waterbird						
Marked-	1,256 (66.8)	115	18	83	369	(33.2)
Unmarked-	109 (49.6)	9	8	8	89	(50.4)
Total						
Marked-	42,104 (66.5)[a]			21,240 (33.5)[b]		
Unmarked-	10,288 (60.0)			6,856 (40.0)		

[a] Percentage that did not change behavior.
[b] Percentage that changed at least 1 behavior.

most common behavior, and flares were least common at both sites. Of flocks that approached at Height 3, 98% (n = 6,208) changed behavior at Isle of Palms and 89% (n = 2,885) at James Island.

Taxonomic group effects. Behavior was related significantly to taxonomic group (Table 4). Shorebirds changed behavior more than expected, but pelicans changed behavior less than expected. This relationship was true for all individual behavioral categories as well. There was also a significant relationship between taxonomic group and approach height (χ^2 = 3,852.4, 18 df, $P < 0.001$; Table 5).

Age effects. Among species that could be aged, age was significantly related to changes in behavior only in laughing gulls (*Larus atricilla*; χ^2 = 183.8, 1 df, $P < 0.001$). Immature laughing gulls changed behavior more than expected, and adults changed behavior less than expected. Age was related to whether laughing gulls flared (χ^2 = 93.3, 1 df, $P < 0.001$), aborted flights (χ^2 = 21.4, 1 df, $P < 0.001$), hesitated (χ^2 = 117.4, 1 df, $P < 0.001$), or performed gradual altitude adjustments (χ^2 = 56.5, 1 df, $P < 0.001$). Immature laughing gulls flared, aborted flights, hesitated, and performed gradual altitude adjustments significantly more than expected by chance alone, and adults did not. Age also was significantly related to approach height for laughing gulls at Isle of Palms (χ^2 = 189.6, 2 df, $P < 0.001$). Immature laughing gulls approached at Heights 3 and 5 more often than expected and at Height 1 less than expected. Adult laughing gulls approached at Height 1 more than expected, Height 3 less than expected, and Height 5 as frequently as expected.

Other species that could be aged did not indicate any effect: double-crested cormorants (*Phalacrocorax auritus*; χ^2 = 0.006, 1 df, P = 0.938), brown pelicans (*Pelecanus occidentalis*; χ^2 = 0.7, 1 df, P = 0.397), little blue herons (*Egretta caerulea*; χ^2 = 0.026, 1 df, P = 0.873), or white ibis (*Eudocimus albus*; χ^2 = 5.9, 1 df, P = 0.015).

Approach height effects. We found a significant relationship between approach height and behavior (Table 6). Flocks often changed behavior at approach Height 3 but less so at approach Heights 5 and 1 for all behavioral categories, except aborts, which frequently occurred at Height 1. Approach height was related to cohesiveness of multi-bird flocks (χ^2 = 570.8, 2 df, $P < 0.001$). Generally, flocks split more at approach Height 3 and less at approach Height 5. Behavior at Height 1 was not predictable.

Weather effects. Behavior was related significantly to weather (foul or fair; χ^2 = 9.3, 1 df, P =

Table 4. Frequencies of behavioral changes (9 df) by flocks of birds during encounters with marked (Isle of Palms) and unmarked (James Island) power lines, expressed as a proportion[a] of all observed encounters, Charleston County, South Carolina, from May 1991–May 1994.

Taxonomic group	Behavior change	Gradual adj.	Hesitation	Flare	Abort
χ^2	844.7*	791.7*	212.3*	242.7*	616.0*
Cormorant	0.023	0.018+	0.002–	<0.001–	0.011–
Dove	0.005–[b]	0.003–	0.001	<0.001	<0.001
Gull	0.123	0.080	0.026+	0.005	0.007–
Kingfisher	0.008+	0.004+	0.001	<0.001–	0.002+
Pelican	0.016–	0.010–	0.002–	<0.001–	0.002–
Raptor	0.013+	0.007	0.002	<0.001	0.001
Shorebird	0.034+	0.022+	0.006+	0.002+	0.003+
Tern	0.032	0.022+	0.005	0.001	0.003
Wading bird	0.087–	0.046–	0.015	0.003	0.014+
Waterbird	0.010	0.006	0.001	<0.001	0.002+

* $P \leq 0.01$.
[a] Calculated by: No. of flocks in each cell divided by total no. of flocks at Isle of Palms.
[b] Results of Bonferroni Z-test (α = 0.01, k = 20). – = observed significantly less than expected; + = observed significantly more than expected.

0.002). More flocks changed behavior during foul weather than fair. More flocks aborted flights in foul weather (χ^2 = 14.4, 1 df, P < 0.001), but weather conditions were not related to flares (χ^2 = 1.4, 1 df, P = 0.239), gradual adjustments (χ^2 = 1.4, 1 df, P = 0.243), or hesitations (χ^2 = 0.5, 1 df, P = 0.494).

There was no relationship between rain and behavior (χ^2 = 0.4, 1 df, P = 0.519). However, we found a significant relationship between wind speed and behavior (χ^2 = 94.0, 3 df, P < 0.001). Flocks changed behavior during moderate to strong winds. Likewise, wind direction relative to flight direction was related to behavior (χ^2 = 97.1, 3 df, P < 0.001). Behaviors changed more during head winds, less during tail winds, and unpredictably during calm and cross winds.

We were unable to evaluate effects of fog on bird reactions to power lines. When visibility was poorest, and therefore collision risk highest, observers were unable to observe the behavior of birds as they encountered power lines.

Light intensity. We found no significant relationship between light intensity and the frequency with which behaviors changed (χ^2 = 0.6, 1 df, P = 0.458).

Site effects. For all taxonomic groups combined, there was a significant relationship between site and behavior (Table 7). Flocks changed behaviors more than expected at the marked lines on Isle of Palms, and less at the unmarked lines on James Island. This pattern was also true for hesitations and gradual adjustments. However, there was no significant relationship between site and the frequency of flares or aborted flights.

Behavior and site were related significantly for several taxonomic groups (Table 7). This was also true for each of the individual behavior categories. In nearly all cases where independence was lacking, behaviors changed more at Isle of Palms and less at James Island. The only exception was among shorebirds, which aborted flights more at James Island and less at Isle of Palms (Table 7).

Site and approach altitude also were related significantly (χ^2 = 3464.9, 2 df, P < 0.001). At Isle of Palms, more flocks approached at Height 1, and fewer than expected approached at Heights 3 and 5. Conversely, at James Island, fewer flocks approached at Height 1, and more than expected approached at Heights 3 and 5.

Table 5. Frequencies of observed encounters of birds with marked power lines at 3 approach heights by flocks of individual taxonomic groups, expressed as a proportion[a] of all observed encounters, (Isle of Palms) Charleston County, South Carolina, May 1991–May 1994.

Approach height[b]	Taxonomic group: Cormorant	Dove	Gull	Kingfisher	Pelican	Raptor	Shorebird	Tern	Wading bird	Waterbird
1	0.037–[c]	0.015+	0.218–	0.012	0.050+	0.017–	0.028–	0.055	0.202+	0.020
3	0.009	0.002–	0.068+	0.001–	0.003–	0.004	0.017+	0.017+	0.026–	0.002–
5	0.020+	0.002–	0.073	<0.001–	0.006–	0.008+	0.025+	0.016	0.043–	0.005

[a] Calculated by: No. of flocks in each cell divided by total no. of flocks at Isle of Palms.
[b] Approach height 1 = between ground level and conductor wires; Approach height 3 = between conductor and static wires; Approach height 5 = above static wire.
[c] Results of Bonferroni Z-test (α = 0.01, k = 30). – = observed less than expected; + = observed more than expected.

Table 6. Frequencies of behavioral changes exhibited by flocks of birds (combined taxonomic groups) during encounters with marked power lines at 3 approach heights, expressed as a proportion[a] of all observed encounters, (Isle of Palms) Charleston County, South Carolina, May 1991–May 1994.

		Approach height[b]		
	χ^2	1	3	5
Behavior change	21,464.7	0.170–[c]	0.147+	0.028–
Gradual adj.	22,335.2	0.088–	0.118+	0.011–
Hesitation	1,233.7	0.032–	0.020+	0.008–
Flare	1,617.4	0.004–	0.008+	< 0.001–
Abort	333.8	0.026+	0.007+	0.002–

2 df, $P \leq 0.01$.

[a] Calculated by: No. of flocks in each cell divided by total no. of flocks at Isle of Palms.

[b] Approach height 1 = below conductor wires; approach height 3 = between conductor and static wires; approach height 5 = above static wires.

[c] Results of Bonferroni Z-test (α = 0.01, k = 6). – = observed significantly less than expected; + = observed significantly more than expected.

Mortality

Observed collisions. We observed 35 collisions (Isle of Palms: n = 20; James Island: n = 15). At James Island, 1 collision between a little blue heron and a supporting guy wire was deleted from analyses because no guy wires were present at Isle of Palms. Of the remaining collisions, 85% (n = 17) at Isle of Palms were with static wires, and 15% (n = 3) were with conductor wires. At James Island, the respective percentages were 79% (n = 11) and 21% (n = 3).

Most collisions involved birds that approached at Height 3 (Isle of Palms: 90%, n = 18; James Island: 79%, n = 11). The remainder approached at Height 1. Using only those observed collisions prior to which birds had approached at Height 3, and observed encounters during which birds approached at Height 3 (Isle of Palms = 23,524; James Island = 6,753), the collision rate at Isle of Palms (76/100,000) was less than half that at James Island (163 collisions/100,000 encounters). Considering all collisions and all individual bird encounters (Isle of Palms: n = 129,428; James Island: n = 28,507), collision rates were 15/100,000 at Isle of Palms and 49/100,000 at James Island. At Isle of Palms, observed collisions included 7 wading birds, 7 gulls, 3 shorebirds, 2 terns, and 1 raptor. At James Island, 8 wading birds, 4 gulls, and 2 shorebirds collided.

Ten percent of birds (n = 2) did not change behavior prior to colliding at Isle of Palms. Of the 18 birds that changed, 30% (n = 6) hesitated, 30% (n = 6) performed gradual adjustments, and 20% (n = 4) flared. The remaining 2 birds hesitated and then flared before colliding. At James Island, 7% (n = 1) did not change behavior before colliding. Of the remaining birds, 29% (n = 4) hesitated, 21% (n = 3) performed gradual adjustments, 36% (n = 5) flared, and 7% (n = 1) performed a gradual adjustment and then flared before colliding.

At Isle of Palms, 15 birds that collided recovered sufficiently to fly out of the search corridor, yielding a crippling bias of 75%. Of the 5 birds that fell within the corridor, only 1, an immature white ibis, could be located and recovered. At James Island, 71% (n = 10) of birds flew out of the corridor after colliding. The collision with a guy wire mentioned previously was included in calculating a crippling bias, thus yielding a bias of 73%. The remaining birds could not be located (n = 1) or landed in areas that could not be searched (n = 3).

Most observed collisions at both sites took place during fair weather (85% at Isle of Palms; 86% at James Island). At both Isle of Palms and James Island, 90% of all observed encounters occurred during fair weather. Most collisions occurred when light, moderate, and tail winds were prevalent (Table 8). Collisions at both sites occurred most often during high light intensities, good visibility, and no rain.

Mortality estimates. We recovered 54 carcasses, feather spots, and injured birds during 235 ground searches at Isle of Palms. Death or injury of 46% of birds was attributed to collisions with the power line (n = 25; 17 passerine, 2 rail, 2 wading birds, 1 cormorant, 1 dove, 1 gull, 1 shorebird). Typical causes of death or injuries were severed head, broken bones, or massive trauma to the body. Injury and death of 6% (n = 3) of birds was attributed to entanglement with monofilament line (1 gull) and an old wire fence (1 wading bird and 1 dove). Cause of injury and death for 48% of recovered birds (n = 26; 6 passerine, 7 wading birds, 4 dove, 2 rail, 3 waterbirds, 1 gull, 1 raptor, 1 tern, and 1 unknown) could not be determined because of advanced decomposition, incomplete remains (e.g., feather spots), or failure to capture the injured bird (n = 1). Twenty-seven birds were used to calculate mortality estimate calculations.

We recovered 28 carcasses during 210 ground searches at James Island. Eighty-two percent (n = 23; 5 passerine, 4 wading birds, 4 dove, 5 rail, 1 waterbirds, 1 shorebird, 3 unknown) were too decomposed or mutilated to determine cause of death. Cause of death for 5 carcasses (3 wading birds, 2 doves) was attributed to collisions with the power line. Twenty-three nonpasserines were subsequently used to calculate MEs.

Table 7. Frequencies of behavioral changes by flocks of individual and combined taxonomic groups (1 df) at marked (Isle of Palms) and unmarked (James Island) power lines, expressed as a proportion[a] of all observed encounters, Charleston County, South Carolina, May 1991–May 1994.

Behavioral type			Type of line	
Taxonomic group[b]	χ^{2c}	*n*	Marked	Unmarked
Behavioral change				
Combined groups	514.2*	9,607	0.646+[d]	0.300–
Dove	15.6*	448	0.179+	0.632–
Gull	144.5*	3,690	0.720+	0.240–
Raptor	0.1	406	0.323	0.598
Tern	9.8*	1,023	0.685+	0.294–
Wading bird	154.1*	1,969	0.544+	0.370–
Gradual adjustment				
Combined groups	48.3*	9,602	0.514+	0.247–
Cormorant	3.8	480	0.673	0.173
Dove	10.3*	448	0.154+	0.529–
Gull	2.3	3,690	0.572	0.203
Kingfisher	2.7	86	0.291	0.221
Pelican	18.2*	197	0.690+	0.203–
Raptor	18.9*	406	0.273+	0.362–
Shorebird	0.3	962	0.582	0.147
Tern	4.7	1,023	0.562	0.266
Wading bird	16.9*	1,969	0.425+	0.307–
Waterbird	0.8	169	0.544	0.272
Hesitation				
Combined groups	112.7*	9,602	0.092+	0.023–
Cormorant	8.0*	480	0.083+	0.021–
Gull	21.1*	3,690	0.116+	0.027–
Raptor	1.3	406	0.037	0.047
Shorebird	7.6*	962	0.135+	0.019–
Tern	19.0*	1,023	0.098+	0.015–
Wading bird	20.5*	1,969	0.067+	0.027–
Flare				
Combined groups	0.8	9,607	0.037	0.018
Gull	0.9	3,690	0.036	0.011
Shorebird	7.0*	962	0.074+	0.007–
Tern	0.5	1,023	0.028	0.010
Wading bird	0.5	1,969	0.044	0.040
Abort				
Combined groups	2.3	9,607	0.032	0.014
Gull	7.3*	3,690	0.027+	0.005–
Kingfisher	0.0	86	0.174	0.093
Raptor	2.4	406	0.017	0.059
Shorebird	10.4*	962	0.050–	0.027+
Tern	4.0	1,023	0.024	0.004
Wading bird	22.1*	1,969	0.042+	0.012–

*1 df, $P \leq 0.01$.

[a] Calculated by: No. flocks in each cell divided by total no. flocks at each site.

[b] Not all taxonomic groups are included for all behavior categories due to insufficient sample sizes.

[c] Analyses of 2 x 2 χ^2 tables were restricted to observations that met the following criteria: approach height = 3; precipitation = no rain; wind speed = calm or light; and light intensity >100 lux.

[d] Deviation from expected. – = observed significantly less than expected; + = observed significantly more than expected.

Percentage of test carcasses found by observers during search-bias tests averaged 66% at Isle of Palms and 73% at James Island. Search time during these tests averaged 31.8 minutes (SE = 0.05) and did not differ significantly ($t = 0.9$, 46 df) from actual ground-search time ($\bar{x} = 29.7$ min, SE = 0.4), indicating that observers did not expend more effort during test trials. The proportion of search area accessible during ground searches was estimated to be 91% at Isle of Palms and 82% at James Island. Removal of carcasses by scavengers appeared to be a greater problem at Isle of Palms. At James Island, no carcasses were completely removed until 10 days had elapsed, at which point 91% of carcasses remained. By contrast, at Isle of Palms only 75% of carcasses remained after 1 day, 62% after 2 days, and only 50% after 10 days. By the end of 2 months, 38% of carcasses remained at Isle of Palms, and 73% remained at James Island. Stray dogs were frequently seen and their tracks were numerous in the search area at Isle of Palms. Raccoon (*Procyon lotor*) tracks were common at both sites. The maximum number of days that a carcass or feather spot remained was 137 at Isle of Palms and 112 at James Island. Summed mortality estimates for sections of lines searched were 49 (min.)-236 (max.) birds and 31 (min.)-142 (max.) birds for the Isle of Palms and James Island power lines, respectively. Accounting for the difference in line length, summed minimum and maximum mortality estimates were 1.7 and 1.8 times larger at Isle of Palms (130-626 birds/km) than James Island (76-344 birds/km), respectively.

Discussion

Behavior

Several studies have reported that most birds do not change behavior when encountering power lines (Meyer 1978:46, James and Haak 1979:52-56, Beaulaurier 1981, Faanes 1987, Morkill and Anderson 1991). Conversely, in studies using behavior categories similar to ours, birds reacted most commonly by gradual height adjustments (usually an increase in altitude) and least commonly by flares (Meyer 1978:28, James and Haak 1979:52-56, Beaulaurier 1981, Morkill and Anderson 1991). Our findings are consistent with these and may indicate that birds were usually aware of the lines and reacted to avoid them.

Birds that approach power lines at or near lines-level, change behavior more often than those approaching either well above or well below the lines (Meyer 1978:28, James and Haak 1979:52, Beaulaurier 1981:35, Morkill and Anderson 1991). We also

Table 8. Weather conditions during observed bird collisions with marked (Isle of Palms) and unmarked (James Island) power lines, Charleston County, South Carolina, May 1991–May 1994.

	Number of collisions												
	Wind speed[a]				Wind direction[a]			Light intensity[a]		Visibility		Precipitation	
Site	Calm	Light	Moderate	Strong	Head	Tail	Cross	High	Low	Poor	Good	Rain	No Rain
Marked	1	9	7	2	6	11	1	16	3	1	19	0	20
Unmarked	1	9	4	0	2	9	2	12	2	2	12	0	14

[a] Data not available for 1 collision at Isle of Palms.

observed more behavior changes among birds approaching at the level of the power lines, indicating that birds did perceive power lines as barriers to flight and reacted to avoid them. We found that most birds approaching power lines at line height did not cross at that altitude, behavior also observed by Meyer (1978:41–43), and James and Haak (1979:42). Power lines disrupted flock integrity, with more flocks breaking up permanently or temporarily separating when they approached at line height.

The static wire, also referred to as the shield or groundwire, has posed the greatest collision danger to birds (Scott et al. 1972, Lee 1978:68, Meyer 1978:160, James and Haak 1979:102, Brown et al. 1987, Faanes 1987). We observed that most collisions occurred with a static wire, when birds increased their altitude in apparent attempts to avoid conductor wires. Birds maneuvering to avoid the conductor wires actually increased collision risk, and in the absence of static wires most collisions could have been avoided. If power lines must be placed above ground, the risk of colliding would probably be reduced if all wires were in a single horizontal plane (Bevanger 1994). This could be achieved by positioning static wires in the same plane as the conductors or by eliminating static wires altogether. However, for static wires to be effective at intercepting lightning strikes, they must be above the plane of the conductors (Thompson 1978:107) at a distance sufficient to both provide a tent of protection extending 30° from vertical and encompassing all conductors (Miller 1978:83) so as to prevent flashover of current from conductors to static wires. Removal of static wires has effectively reduced collision rates (Jackson et al. 1982:82, Brown et al. 1987) but is not a practical solution, particularly where lightning is common. Increasing static wire diameter to improve visibility has not proven effective at reducing collision rates (Brown et al. 1987, Bevanger 1994).

A better understanding of the relationship between bird age and avoidance of power-line collisions may lead to knowledge of which individuals are likely to be affected most by power lines. Brown et al. (1987) found that 48.8% of all sandhill crane (*Grus canadensis*) mortality attributable to power-line collisions involved juveniles, even though the mean proportion of juveniles in the study area during the same period was only 9.9%. They attributed the higher mortality of juveniles to their relative lack of agility, flight experience, and familiarity with their surroundings compared to adult birds. McNeil et al. (1985) and Crivelli et al. (1988) also found higher juvenile mortality at power lines for brown pelicans (approx 75%) and Dalmation pelicans (*Pelecanus crispus*, 92.9%), respectively. In our studies, immature laughing gulls reacted more than adults, possibly because they approached power lines at the line height more often than adults. Perhaps only after repeated encounters and increased familiarity with power lines do young birds adjust their altitude before reaching the lines.

Wind speed and direction affect a bird's ability to react to power lines. Morkill and Anderson (1990) observed that maneuverability of sandhill cranes was severely impaired during tailwinds. Strong winds likewise impaired the ability of sandhill cranes to avoid power lines (Brown et al. 1987) and have even increased their likelihood of colliding by as much as a factor of 2 (Morkill and Anderson 1990). Wind speed and direction relative to flight direction were the most significant weather factors affecting flight behavior during our study. Birds flying in moderate or strong winds appeared to have difficulty controlling flight movements and were subject to rapid altitude changes. In addition to wind speed, wind direction relative to flight direction influenced risk to birds crossing power lines. Flying into strong winds slowed the flight speed of birds, which may have given them time to react to the lines before crossing. On the other hand, when flying with strong winds, avian mortality, design of power lines may limit the size and number of markers that can be placed on static wires (Morkill and Anderson 1991). Thompson (1978:27-52), Miller (1993), and APLIC (1994) discussed recent developments in marker technology, as well as alternatives to mitigation. Brown and Drewien (1995) reported 61% less mortality at power lines where static wires had been marked with yellow spiral vibration dampers than at unmarked lines. Alonso et al. (1994) observed a 60% decrease in mortality after static wires had been marked with red spiral vibration dampers. Both studies were based on carcass recovery data. We found that yellow aviation spheres may have reduced collisions by 53%, and ≤85% of the remaining collisions could have been avoided in the absence of static wires. Future research should look for ways of minimizing the vertical profile of power lines without compromising protection against lightning strikes in high-risk areas.

In conclusion, we found that birds reacted differently to marked and unmarked power lines. Birds changed behavior more frequently when approaching marked lines at line level, and fewer birds crossed between conductor and static wires. Collisions with wires occurred at a lower rate at marked lines than unmarked lines, and we attribute this in part to increased visibility of static wires. We recommend marking static wires if power lines must be constructed in areas where the potential for avian collision is high.

Acknowledgments. Research was funded by the South Carolina Electric and Gas Company. The U.S. Fish and Wildlife Service provided a vehicle for field work and access to their literature on power-line research. We thank the National Oceanic and Atmospheric Administration's National Marine Fisheries Laboratory in Charleston, South Carolina, for providing office space and access to their facilities. We appreciate the advice of R. Banks, W. Bridges, L. Duncan, S. Gauthreaux, K. Harper, C. Marsh, and F. Schlicht. A special thanks to B. Findley for providing administrative support. We thank P. Dunn, R. Rundell, D. Shelton, and K. Whiddon for their valuable and cheerful assistance with fieldwork and L. Hanuaska for preparing the figure. We thank the R. Glave family, The Beach Co., Long Seasides Farms, and Charleston County Parks for granting access to their properties. Thanks to J. Pfaff and A. Beck for providing care to injured birds and performing necropsies. We thank R. Brown for duck carcasses and S. Murphy, C. Hope, and T. Murphy for transporting them. Finally, sincere thanks to W. Post for his help with identifying bird remains.

Literature cited

ALONSO, J. C., J. A. ALONSO, AND R. MUINALLY, SI. 1994. Mitigation of bird collisions with transmission lines through groundwire marking. Biol. Conserv. 67:129-134.

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

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

AVIAN POWER LINE INTERACTION COMMITTEE (APLIC). 1994. Mitigating bird collisions with power lines: the state of the art in 1994. Edison Electric Inst., Washington, D.C. 120pp.

BEAULAURIER, D. L. 1981. Mitigation of bird collisions with transmission lines. Bonneville Power Admin., Portland, Oreg. 83pp.

BEVANGER, K. 1990. Topographic aspects of transmission wire collision hazards to game birds in the central Norwegian coniferous forest. Fauna norv. Ser. C, Cinclus 13:11-18.

BEVANGER, K. 1994. Bird interactions with utility structures: collision and electrocution, causes and mitigating measures. Ibis 136:412-425.

BROWN, W. M. 1993. Avian collisions with utility structures: biological perspectives. Pages 12.1-12.13 *in* J. W. Huckabee, ed. Proceedings of the international workshop on avian interactions with utility structures. Electric Power Res. Inst., Palo Alto, Calif.

BROWN, W. M., AND R. C. DREWIEN. 1995. Evaluation of two power line markers to reduce crane and waterfowl collision mortality. Wildl. Soc. Bull. 23:217-227.

BROWN, W. M., 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, Nebr.

BYERS, C. R., R. K. STEINHORST, AND P. R. KRAUSMAN. 1984. Clarification of a technique for analysis of utilization-availability data. J. Wildl. Manage. 48:1050-1053.

CRIVELLI, A. J., H. JERRENTRUP, AND T. MITCHEV. 1988. Electric power lines: a cause of mortality in *Pelecanus crispus* Bruch, a world endangered bird species, in Porto-Lago, Greece. Colon. Waterbirds 11:301-305.

FAANES, C. A. 1987. Bird behavior and mortality in relation to power lines in prairie habitats. U.S. Fish and Wildl. Serv. Tech. Rep. 7. 24pp.

HARTMAN, P. A., S. BYRNE, AND M. F. DEDON. 1992. Bird mortality in relation to the Mare Island 115-kV transmission line: final report. Pacific Gas and Electric Co., San Ramon, Calif.

JACKSON, P., L. OFTEDAHL, D. BARTZ, D. BEAULAURIER, AND M. JENNINGS. 1982. Impact of the Ashe-Slatt 500-kV transmission line on birds at Crow Butte Island: postconstruction study final report. Bonneville Power Admin., Portland, Oreg. 155pp.

JAMES, B. W., AND B. A. HAAK. 1979. Factors affecting avian flight behavior and collision mortality at transmission lines. Bonneville Power Admin., Portland, Oreg. 109pp.

KROODSMA, R. L. 1978. Evaluation of a proposed transmission line's impacts on waterfowl and eagles. Pages 69-76 *in* M. L. Avery, ed. Proceedings of a workshop: impacts of transmission lines on birds in flight. U.S. Fish and Wildl. Serv., Biol. Serv. Program. FWS/OBS-78/48. 151pp.

LEE, J. M., JR. 1978. Effects of transmission lines on bird flights: studies of Bonneville Power Administration lines. Pages 53-68 *in* M. L. Avery, ed. Proceedings of a workshop: impacts of transmission lines on birds in flight. U.S. Fish and Wildl. Serv., Biol. Serv. Program. FWS/OBS-78/48. 151pp.

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

MEYER, J. R. 1978. Effects of transmission lines on bird flight behavior and collision mortality. Bonneville Power Admin., Portland, Oreg. 199pp.

MCNEIL, R., J. R. RODRIQUEZ, AND H. OUELLET. 1985. Bird mortality at a power transmission line in northeastern Venezuela. Biol. Conserv. 31:153–165.

MILLER, A. D. 1993. The engineering perspective of power line marking systems to reduce avian collisions. Pages 13:1–13:14 *in* J. W. Huckabee, ed. Proceedings: avian interactions with utility structures. Electric Power Res. Inst., Palo Alto, Calif.

MILLER, W. A. 1978. Transmission line engineering and its relationship to migratory birds. Pages 53–68 *in* M. L. Avery, ed. Proceedings of a workshop: impacts of transmission lines on birds in flight. U.S. Fish and Wildl. Serv., Biol. Serv. Program. FWS/OBS-78/48. 151pp.

MORKILL, A. E., AND S. A. ANDERSON. 1990. Effectiveness of marking powerlines to reduce sandhill crane collisions. Wyoming Coop. Fish and Wildl. Res. Unit, Laramie, Wyo. 102pp.

MORKILL, A. E., AND S. A. ANDERSON. 1991. Effectiveness of marking powerlines to reduce sandhill crane collisions. Wildl. Soc. Bull. 19:442–449.

NEU, C. W., C. R. BYERS, AND J. M. PEEK. 1974. A technique for the analysis of utilization-availability data. J. Wildl. Manage. 38:541–545.

OWEN, M., AND C. J. CADBURY. 1975. The ecology and mortality of swans at the Ouse Washes, England. Wildfowl 26:31–42.

RUSZ, P. J., H. H. PRINCE, R. D. RUSZ, AND G. A. DAWSON. 1986. Bird collisions with transmission lines near a power plant. Wildl. Soc. Bull. 14:441–444.

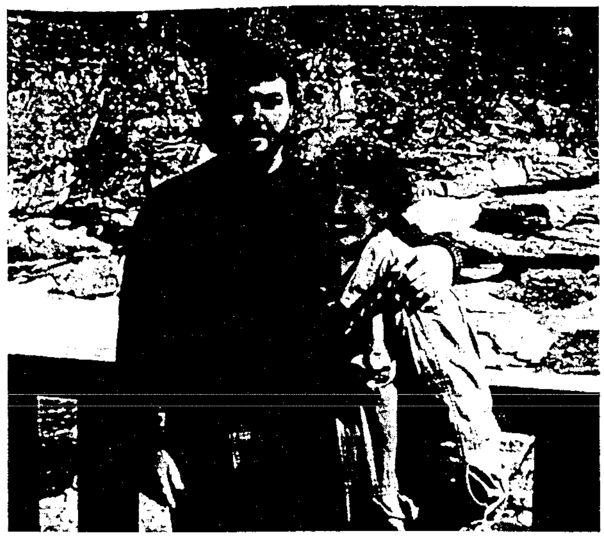
SAS INSTITUTE, INC. 1988. SAS• Procedures Guide, Release 6.03 Edition. SAS Inst., Inc., Cary, N.C. 441pp.

SCOTT, R. E., L. J. ROBERTS, AND C. J. CADBURY. 1972. Bird deaths from power lines at Dungeness. British Birds 65:273–286.

THOMPSON, L. S. 1978. Transmission line wire strikes: mitigation through engineering design and habitat modification. Pages 27–52 *in* M. L. Avery, ed. Proceedings of a workshop: impacts of transmission lines on birds in flight. U.S. Fish and Wildl. Serv., Biol. Serv. Program. FWS/OBS-78/48. 151pp.

WILLARD, D. E. 1978. The impact of transmission lines on birds (and vice versa). Pages 3–7 *in* M. L. Avery, ed. Proceedings of a workshop: impacts of transmission lines on birds in flight. U.S. Fish and Wildl. Serv., Biol. Serv. Program. FWS/OBS-78/48. 151pp.

Ruth Boettcher received her B.S. in Recreation and Park Administration (1983) from Illinois State University and her M.S. in Wildlife (1994) from Clemson University. During time away from school, Ruth has had a number of jobs involving sea turtle conservation and is now the State Coordinator for Sea Turtle Conservation in North Carolina. Her interest is primarily conservation of coastal habitats.



Anthony (T. J.) and ***Lynette Savereno*** carried out continuous field work on this project for 3 years while working as Research Associates for the South Carolina Cooperative Fish and Wildlife Research Unit. T. J. received his B.S. in Biology from Fairmont State College (1983) and then went on to complete his M.S. in Wildlife Biology at Clemson University (1991). While at Clemson, he was active in the student chapter of The Wildlife Society and is a Certified Associate Wildlife Biologist. Since then, he has worked on this powerline project and then worked as a field botanist for Tall Timbers Research Station. He now works on threatened and endangered birds and plants with the Dr. J. H. Carter III and Associates consulting firm in Charleston, South Carolina. T. J.'s main interests are in habitat conservation. Lynette received her B.S. in Zoology (1988) and M.S. in Wildlife (1992) from Clemson University. She was also active in the student chapter of the Wildlife Society at Clemson and is a Certified Associate Wildlife Biologist. Currently, she is a soil conservationist for the Natural Resources Conservation Service in Charleston, SC. Her interests encompass habitat conservation for colonial waterbirds.

Susan Haig received her B.A. in Biology (1979) from Northland College and her Ph.D. in Biology from the University of North Dakota (1987). She spent 2 years as a Smithsonian Postdoctoral Fellow before moving to Clemson University where she was an Associate Professor of Wildlife and the Assistant Unit Leader for Wildlife in the South Carolina Unit. She is now the Senior Wildlife Ecologist for the U.S. Geological Survey Forest and Rangeland Ecosystem Science Center and is an Associate Professor of Wildlife at Oregon State University. She has also been a Piping Plover Recovery Team leader since 1985. Her primary interests are conservation genetics and shorebird behavioral ecology.

Associate Editor: Steenhof