Ranking the hazard level of wildlife species to aviation

Richard A. Dolbeer, Sandra E. Wright, and Edward C. Cleary

Abstract Aircraft collisions with birds and other wildlife are a serious economic and safety problem. However, all wildlife species are not equally hazardous to aviation. In implementing programs to reduce wildlife hazards, airport operators need guidance on the relative risk posed by various species so that management actions can be prioritized by the most hazardous species. Our objective was to rank various wildlife species as to their relative hazard to aircraft. We selected 21 species or species groups (e.g., gulls [*Larus* spp.]) for which there were ≥17 strike reports in the Federal Aviation Administration's (FAA) Wildlife Strike Database for civil aircraft in the United States, 1991–1998. We ranked the 21 groups for relative hazard to aircraft based on the percentage of strikes causing damage, major damage, and an effect-on-flight. Deer (Cervidae, primarily *Odocoileus virginianus)*, vultures (Cathartidae), and geese (Anserini, primarily *Branta canadensis*) were ranked 1, 2, and 3, respectively, in the composite ranking for most hazardous species groups. Based on the relative hazard score, deer were clearly the most hazardous group, with the second (vultures) and third (geese) groups being only 52 to 63% as hazardous as deer. The 3 lowest-ranked groups (19–21; blackbirds–starlings [Icterinae–*Sturnus vulgaris*], sparrows [Emberizidae excluding Icterinae, Passeridae], and swallows [Hirundinidae]) were only 2 to 9% as hazardous as deer. Relative hazard score was strongly related ($P<0.01$) to mean body mass for the 21 species groups. Vultures and ospreys (*Pandion haliaetus*) showed a greater-than-expected hazard score relative to their mean body masses, whereas coyotes (*Canis latrans*) showed a less-than-expected rating. We believe this initial hazard rating system provides a useful guide to assist airport operators in prioritizing management actions to reduce strike hazards. These ratings should be used in conjunction with site-specific wildlife surveys to determine relative abundance and use patterns of wildlife species for the airports in question. A critical action needed to improve the rating system is to increase the identification of species struck by aircraft, which presently stands at <50%.

Key words aircraft, airport, aviation, bird strike, deer, goose, safety, vulture

Aircraft collisions with birds and other wildlife (wildlife strikes) are a serious economic and safety problem. Cleary et al. (1999) estimated that wildlife strikes cost the civil aviation industry in the United States over $300 million/year from 1990 to 1998. Costs resulting from wildlife strikes to civil and military aviation in North America likely exceed $500 million/year (MacKinnon 1998). Over 300 people have been killed worldwide from bird strikes (Richardson 1994, 1996; Thorpe 1996; Dolbeer, unpublished data).

Airports, many of which are located close to water and have large expanses of grasslands, are often attractive to birds and other wildlife (Dolbeer

Address for Richard A. Dolbeer and Sandra E. Wright: United States Department of Agriculture, National Wildlife Research Center, 6100 Columbus Avenue, Sandusky, OH 44870, USA; e-mail for lead author: richard.a.dolbeer@usda.gov. Address for Edward C. Cleary: Federal Aviation Administration, Office of Airport Safety and Standards, 800 Independence Avenue, Washington, DC 20591, USA.

et al. 1993). Management programs to reduce wildlife activity on airports are critical because over 80% of wildlife strikes occur in the airport environment (Cleary et al. 1999). However, all wildlife species are not equally hazardous to aviation. In developing and implementing programs to reduce wildlife hazards, airport operators need guidance on the relative risk posed by various species so that management actions can be prioritized by the most hazardous species.

Our objective was to rank various wildlife species observed on and near airports in the United States as to their relative hazard to aircraft. We based rankings on strike statistics for the species from the Federal Aviation Administration's (FAA) National Wildlife Strike Database for civil aircraft in the United States (hereafter referred to as the National Wildlife Strike Database).

Table 1. Categories of damage (from International Civil Aviation Organization 1989) and effect-on-flight assigned to wildlife strike reports in the National Wildlife Strike Database, January 1991–May 1998.

Criteria Categories	Definition
Damage	
Destroyed	Damage sustained makes it inadvisable to restore aircraft to airworthy condition.
Substantial	Aircraft incurs damage or structural failure that adversely affects the structure strength, performance, or flight characteristics and which would normally require major repair or replacement of the affected component.
Minor	Aircraft can be rendered airworthy by simple repairs or replacements and an extensive inspection is not necessary.
Unknown	Damage occurred; report did not give sufficient information to determine extent.
None	No damage noted, although delays and other costs caused by inspections may have been incurred after landing.
Not reported	Report did not give sufficient information to determine if any damage occurred.
Effect-on-flight	
Aborted take-off	Pilot aborted take-off.
Engine shutdown	Engine was shutdown by pilot or stopped running because of strike.
Precaution landing	Pilot landed at other-than-destination airport after strike.
Other	Miscellaneous effect such as reduced speed because of shattered windshield, emergency landing at destination airport, or crash landing.
None	Flight continued as scheduled although delays and other costs caused by inspections or repairs may have been incurred after landing.
Not reported	Report did not give sufficient information to determine if effect-on-flight occurred.

Methods

The FAA has a standard form (5200-7) for the voluntary reporting of aircraft strikes by birds and other wildlife. Although FAA personnel have monitored these reports since 1965 to determine general patterns, no quantitative analyses of these data were conducted until 1995.

The United States Department of Agriculture's (USDA) National Wildlife Research Center, through an interagency agreement with the FAA, initiated a project in 1995 to obtain more objective estimates of the magnitude and nature of the wildlife strike problem nationwide for civil aviation. This project included 1) editing all strike reports (FAA Form 5200-7) sent to the FAA since 1991 to ensure consistent, error-free data; 2) entering all edited strike reports since 1991 in a National Wildlife Strike Database; and 3) supplementing FAA-reported strikes with additional, nonduplicating strike reports from other sources. Cleary et al. (1999) presented a general summary of strike data for 1990–1998.

We selected 21 wildlife species or species groups (e.g., gulls [*Larus* spp.]) for which there were $\geq$17 strike reports from January 1991 to May 1998. For each of these species or groups, we categorized the strikes by reported extent of damage (International Civil Aviation Organization 1989) and effect-on-flight (Table 1). We then used these data to estimate the percentage of strikes causing damage, major damage (i.e., aircraft destroyed or substantial damage incurred; Table 1), and an effect-on-flight. These 3 variables were used separately to rank the species groups as to their relative hazard to aircraft (1 = species group with greatest percentage and thus most hazardous, 21 = least percentage and least hazardous). A composite ranking was then developed by comparing the relative rank of each species group with every other group for the 3 variables, placing the species group with the greatest hazard rank (least rank number) for ≥2 of the 3 variables above the next greatest ranked group, and then proceeding down the list. Finally, we developed a relative hazard score for each species group by summing the percentage values for the 3 variables and scaling the scores downward from 100 (with 100 being the score for the species group with maximum summed values).

We tested the hypothesis that mean body mass and relative hazard score were correlated positively for the 21 species groups using regression analysis (Statistix 1996). We obtained an estimate of mean body mass for each bird (Dunning 1993) and mammal (Chapman and Feldhamer 1982) species group. When mass estimates were provided for males and females, we used the mean of the 2 sexes. For groups with multiple species (e.g., gulls), we calculated the mean mass based on all struck species weighted by the proportion of the total strikes that each identified species comprised.

We also attempted to provide a ranking of the 21 species groups based on mean reported cost/strike. Unfortunately, cost estimates were provided in only 22% of the reports in which damage was indicated (Table 2). Thus, 12 of the 21 species groups had <10 reports with cost estimates and were excluded from this ranking, resulting in only 9 of the groups being ranked by this criterion.

Results

The database contained 18,083 strike reports from January 1991 to May 1998, of which 52% provided no information on the species of wildlife struck. For the 21 species groups selected for analysis, there were 7,876 reports. The actual species was identified in 2,669 of these reports. Sample size ranged from 17 for pelicans (*Pelecanus occidentalis, P. erythrorhynchos*) to 2,599 for gulls (Table 2).

Hazard ranking based on damage

Reported strikes that resulted in damage ranged from 1% for swallows (Hirundinidae) to 87% for deer (Cervidae, primarily *Odocoileus virginianus*; Table 3). For six of the 21 species groups, ≥50% of strikes resulted in damage; for only 3 did ≤10% of strikes result in damage. Reported strikes that resulted in major damage ranged from <1% for swallows and sparrows (Emberizidae excluding

Table 2. Ranking of 21 species groups by number of strikes reported to the National Wildlife Strike Database, January 1991–May 1998. Number of reports noting damage, effect-on-flight (EOF), and cost resulting from strikes also is provided.

Rank	Species group[a]	Total strikes reported	Reports noting damage[b]	Reports noting EOF[b]	Reports estimating cost of damage	Total cost reported ($ millions)
1	Gulls	2,599	461	350	87	6.940
2	Blackbirds–starling	1,052	55	73	15	0.549
3	Sparrows	622	14	26	6	0.003
4	Geese	532	283	129	76	19.543
5	Hawks (buteos)	452	95	67	22	0.389
6	Ducks	401	141	67	29	1.618
7	Deer	367	307	194	46	3.914
8	Rock dove	346	60	51	10	2.669
9	Herons	215	34	30	6	0.643
10	Swallows	209	2	4	0	0.0
11	Shorebirds	196	17	16	10	0.232
12	Owls	171	22	11	6	0.395
13	Vultures	152	94	48	32	5.121
14	Crows–ravens	149	14	12	6	0.008
15	Mourning dove	139	11	6	3	0.045
16	American kestrel	138	8	7	3	0.315
17	Coyote	49	4	8	2	0.105
18	Cranes	28	14	6	4	0.006
19	Eagles	24	9	5	3	0.074
20	Osprey	18	6	4	3	0.003
21	Pelicans	17	9	4	3	0.034
	Totals	7,876	1,659	1,117	372	42.604

[a] Gulls (*Larus* spp.), blackbirds–starlings (Icterinae-*Sturnus vulgaris*), sparrows (Emberizidae excluding Icterinae; Passeridae), geese (Anserini, primarily *Branta canadensis*), hawks (*Buteo* spp.), ducks (Anatinae), deer (Cervidae, primarily *Odocoileus virginianus*), rock dove (*Columba livia*), herons (Ciconiiformes, primarily *Ardea herodias, Bubulcus ibis*), swallows (Hirundinidae), shorebirds (Charadriidae and Scolopacidae, primarily *Charadrius vociferus*), owls (Strigiformes), vultures (Cathartidae), crows–ravens (*Corvus* spp.), mourning dove (*Zenaida macroura*), American kestrel (*Falco sparverius*), coyote (*Canis latrans*), cranes (Gruidae), eagles (*Aquila chrysaetos, Haliaeetus leucocephalus*), osprey (*Pandion haliaetus*), pelicans (*Pelecanus occidentalis, P. erythrorhynchos*).

[b] Reports indicated that damage (destroyed, substantial, minor or unknown) or an effect-on-flight (aborted take-off, engine shutdown, precautionary landing or other) did occur (Table 1).

Table 3. Ranking of 21 species groups by percentage of wildlife strikes resulting in damage to aircraft and listing of percentage of strikes resulting in major damage, based on data from the National Wildlife Strike Database, January 1991–May 1998.

Rank	Species group	Reports noting status of damage[a]	% with damage[b]	% with major damage[c]
1	Deer	353	87.0	46.0
2	Vultures	140	67.1	24.4
3	Geese	502	56.4	21.4
4	Cranes	25	56.0	20.0
5	Pelicans	17	52.9	12.5
6	Osprey	12	50.0	18.2
7	Ducks	346	40.8	13.3
8	Eagles	24	37.5	4.5
9	Hawks (buteos)	374	25.4	6.8
10	Gulls	2,275	20.3	8.0
11	Rock dove	302	19.9	10.6
12	Herons	168	19.6	6.1
13	Owls	133	16.5	6.9
14	Mourning dove	68	16.2	9.0
15	Coyote	32	12.5	3.1
16	American kestrel	71	11.3	8.6
17	Shorebirds	152	11.2	2.0
18	Crows–ravens	129	10.9	3.9
19	Blackbirds–starling	905	6.1	2.1
20	Sparrows	572	2.4	0.4
21	Swallows	173	1.2	0.6
	Totals	6,773	24.5	9.7

[a] Reports provided enough information to determine if damage did or did not occur.

[b] Aircraft incurred at least some damage (destroyed, substantial, minor or unknown; Table 1) from strike.

[c] Aircraft was destroyed or received substantial damage (Table 1) from strike.

Table 4. Ranking of 21 species groups by percentage of wildlife strikes resulting in effect-on-flight (EOF) of aircraft, based on data from the National Wildlife Strike Database, January 1991–May 1998.

Rank	Species group	Reports noting status of EOF[a]	% of reports with EOF[b]
1	Deer	253	76.7
2	Vultures	119	40.3
3	Osprey	11	36.4
4	Geese	404	31.9
5	Pelicans	15	26.7
6	Coyote	27	25.9
7	Cranes	24	25.0
8	Ducks	289	23.2
9	Eagles	22	22.7
10	Hawks (buteos)	320	20.9
11	Rock dove	251	20.3
12	Herons	150	20.0
13	Gulls	1,907	18.4
14	Shorebirds	141	11.3
15	Crows–ravens	112	10.7
16	American kestrel	67	10.4
17	Mourning dove	60	10.0
18	Blackbirds–starling	743	9.8
19	Owls	113	9.7
20	Sparrows	461	5.6
21	Swallows	144	2.8
	Totals	5,547	19.9

[a] Reports provided enough information to determine if effect-on-flight did or did not occur.

[b] Strike had some effect-on-flight (aborted take-off, engine shutdown, precautionary landing, other; Table 1).

Icterinae; Passeridae) to 46% for deer. For 13 of the 21 species groups, ≤10% of the strikes resulted in major damage.

Hazard ranking based on effect-on-flight

Reported strikes that resulted in an effect-on-flight ranged from 3% for swallows to 77% for deer (Table 4). Rankings were generally similar to those based on damage, with one exception: Coyotes (*Canis latrans*), which were ranked 15 of 21 regarding damage, were ranked 6 based on effect-on-flight.

Hazard ranking based on cost per strike

Geese (Anserini, primarily *Branta canadensis*) and vultures (Cathartidae) were ranked 1 and 2, respectively, for mean cost/strike for all reported strikes; rock doves (*Columba livia*) and geese were ranked 1 and 2, respectively, based on mean cost for reported strikes providing cost estimates (Table 5). Hawks (*Buteo* spp.) and blackbirds-starlings (Icterinae-*Sturnus vulgaris*) each were ranked last (9) for one of the 2 measures of mean cost/strike.

Composite ranking and relative hazard score

Deer, vultures, and geese were ranked 1, 2, and 3, respectively, in the composite ranking for most hazardous species groups (Table 6). For the relative hazard score, deer were clearly the most hazardous group, with the second (vultures) and third (geese) groups being only 52-63% as hazardous as deer. The 3 lowest-ranked groups (19-21; blackbirds-starlings, sparrows, swallows) were only 2-9% as hazardous as deer.

Table 5. Ranking of 9 species groups by mean cost/strike based on data from National Wildlife Strike Database, January 1991–May 1998. Species groups having less than 10 strikes for which cost was estimated (Table 1) are excluded from rankings.

Rank	Species group	Number of strikes: All	Number of strikes: With cost estimated	Mean cost ($)/strike: All strikes	Mean cost ($)/strike: Strikes with cost estimated
1	Geese	532	76	36,735	257,144
2	Vultures	152	32	33,691	160,033
3	Deer	367	46	10,666	85,093
4	Rock doves	346	10	7,713	266,870
5	Ducks	401	29	4,036	55,806
6	Gulls	2,599	87	2,670	79,767
7	Shorebirds	196	10	1,183	23,190
8	Hawks (buteos)	452	27	861	17,680
9	Blackbirds–starlings	1,052	15	522	36,610
Total		6,097	327	6,741	125,306

Relative hazard score and body mass

Relative hazard score was related strongly to mean body mass for the 19 bird species groups ($R^2 = 0.79$, 17 df, $P<0.01$) and for the combined 19 bird and 2 mammal groups ($R^2 = 0.71$, 19 df, $P<0.01$, Figure 1). This relationship also held within a species group (gulls), for which there were sufficient numbers of strikes (9-83) by identified species. Great black-backed gulls (*L. marinus*, mean body mass of 1,659 g) had a relative hazard score of 100 compared to relative hazard scores of 35, 20, and 12 for herring gulls (*L. argentatus*, 1,135 g), ring-billed gulls (*L. delawarensis*, 519 g), and laughing gulls (*L. atricilla*, 325 g), respectively.

Discussion

Airport operators typically are faced with a diversity of wildlife species in the airport environs that may be struck by aircraft. For example, at least 56 species of birds were struck by aircraft at JFK International Airport, New York, from 1979 to 1992 (Dolbeer et al. 1993). Furthermore, wildlife management plans implemented on airports to discourage certain species (e.g., tall grass for gulls; Brough and Bridgman 1980) may increase the abundance of other species such as small mammals and raptors (Allen 1998). Our analysis is an initial attempt to rank species as to their relative hazard to assist managers in focusing efforts on the species most likely to cause problems.

The rankings and relative hazard scores are based on empirical data and thus represent predicted hazard based on past experience. One variable ignored in this analysis was number of individual animals involved in a strike event. Obviously, an aircraft striking a large flock of birds is more likely to have damage or a negative effect-on-flight than an aircraft striking a single bird. For example, bird strikes that resulted in 62 human fatalities in Massachusetts in 1960 and 35 human fatalities in Ethiopia in 1988 involved flocks of starlings and speckled pigeons (*Columba guinea*), respectively (Thorpe 1996). Unfortunately, number of birds struck is usually not noted accurately on strike reports, making this variable unavailable for analysis. However, because the analyses are empirically based, flock size is incorporated into the rankings and hazard scores were based on the patterns of effects and damages that have occurred for the species groups.

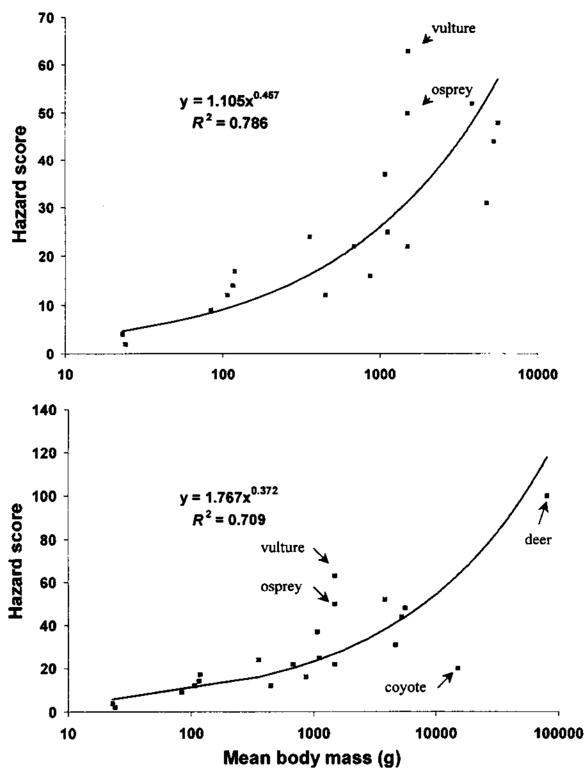

Figure 1. Predicted relative hazard scores (from Table 6) for 19 bird groups (top) and 19 bird and 2 mammal groups (bottom) in relation to mean body masses of the groups.

Table 6. Ranking of 21 species groups (1 = most hazardous) as to relative hazard to aircraft based on 3 criteria (damage, major damage [Table 3], effect-on-flight [Table 4]), a composite ranking based on all 3 rankings, and a relative hazard score. Data were derived from National Wildlife Strike Database, January 1991–May 1998.

Species group	Ranking by criteria: Damage	Major damage	Effect on flight	Composite ranking[a]	Relative hazard score[b]
Deer	1	1	1	1	100
Vultures	2	2	2	2	63
Geese	3	3	4	3	52
Cranes	4	4	7	4	48
Osprey	6	5	3	5	50
Pelicans	5	7	5	6	44
Ducks	7	6	8	7	37
Hawks (buteos)	9	13	10	8	25
Eagles	8	15	9	9	31
Rock dove	11	8	11	10	24
Gulls	10	11	13	11	22
Herons	12	14	12	12	22
Mourning dove	14	9	17	13	17
Owls	13	12	19	14	16
Coyote	15	17	6	15	20
American kestrel	16	10	16	16	14
Shorebirds	17	19	14	17	12
Crows–ravens	18	16	15	18	12
Blackbirds–starling	19	18	18	19	9
Sparrows	20	21	20	20	4
Swallows	21	20	21	21	2

[a] Relative rank of each species group was compared with every other group for the 3 variables, placing the species group with the greatest hazard rank (least rank number) for ≥ 2 of the 3 variables above the next greatest-ranked group and then proceeding down the list.

[b] Percentage values for the 3 variables (Tables 3 and 4) were summed and the scores were scaled downward from 100 (with 100 being score for species group with maximum summed values).

The energy (e) dissipated during a wildlife strike is directly proportional to the mass (m) of the animal(s) struck and the square of the velocity (v) at impact: $e = 0.5\ mv^2$. Hovey et al. (1991) analyzed data on bird ingestions by engines of Boeing-737 aircraft and confirmed that for any given velocity, the probability of engine damage increased with the mass of the bird. Our relative hazard scores, based on actual strike data, also were correlated with body mass. Thus, our system of rating relative hazard by various wildlife groups conforms to the expected pattern of increased hazard with increased body mass.

Vultures and ospreys (*Pandion haliaetus*) showed a greater-than-expected hazard score relative to their mean body masses, whereas coyotes showed a less-than-expected rating. Vultures and ospreys perhaps soar at higher altitudes than most other birds commonly struck by aircraft and thus are more likely to be hit by aircraft traveling at greater velocities, resulting in greater damage (Buurma and Dekker 1996). Coyotes had a relatively great ranking for effect-on-flight but lesser rankings for damage because when they are seen on runways, pilots frequently abort takeoffs or landings. However, most coyotes are struck by aircraft landing gear or wheels and do little damage.

Management implications

We believe this initial rating system provides a useful guide to assist airport operators and biologists in prioritizing management actions to reduce strike hazards. These hazard ratings should be used in conjunction with site-specific wildlife surveys to determine relative abundance and use patterns of wildlife species for the airports in question (e.g., Hoffman et al. 1996). A critical action needed to improve the rating system is to increase the identification of species struck by aircraft, which presently stands at <50% in the National Wildlife Strike Database. Wildlife biologists can usually identify carcass remains, if saved, by species. Specialists can identify even small fragments of feathers or tissue by species group (Laybourne 1984, Ouelett 1994, Allan et al. 1998). With a larger sample size of strike reports identified by species, we can provide more accurate estimates of the relative hazard among species, as well as refine estimates for such factors as aircraft and engine types. This would allow adjustments of the hazard ratings for airports with different air-traffic characteristics such as large commercial passenger jets, small corporate jets, private propeller-driven aircraft, or specialized military aircraft.

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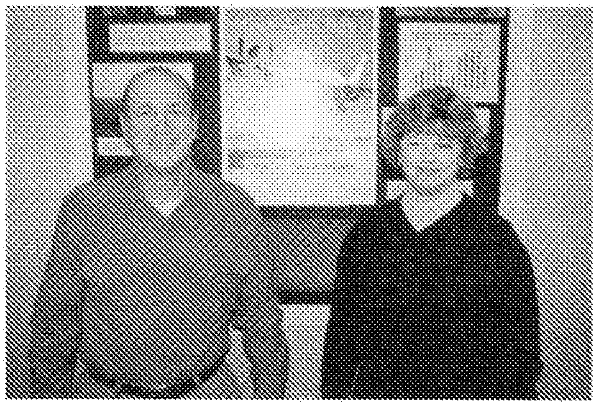

Richard A. Dolbeer (left) is a senior scientist and project leader with the National Wildlife Research Center (NWRC) of the United States Department of Agriculture's (USDA) Wildlife Services program. For the past 27 years he has been head of the NWRC's Ohio Field Station, where he has led a series of research programs to resolve wildlife-human conflicts ranging from blackbird depredations in grain crops to bird ingestions into aircraft engines. Dr. Dolbeer's research has covered population dynamics of pest species, economic assessment of losses, development of practical management techniques for resolving conflicts, and integrated pest management programs in the United States and abroad. He is a past Associate Editor of the Journal of Wildlife Management and currently serves as Chairperson of Bird Strike Committee USA. Richard received degrees from the University of the South (B.A., biology), the University of Tennessee (M.S., zoology), and Colorado State University (Ph.D., wildlife biology). ***Sandra E. Wright*** (right) has worked for USDA/NWRC in Sandusky, Ohio, since 1995 as the Federal Aviation Administration (FAA) Wildlife Strike Database Manager. She is a member of the local Experimental Aircraft Association Chapter and has co-piloted on countless trips in a Piper Cherokee. Sandy has written several articles and made numerous presentations to promote the need for reporting wildlife strikes. She works closely with FAA personnel and field biologists throughout the United States to reduce the wildlife threat at airports. She received her B.S. in education from Northern Illinois University and her M.S. in education from Chicago State University. ***Edward C. Cleary*** has been a staff wildlife biologist since 1995 with the FAA, where he deals with wildlife issues on airports nationwide. Ed previously worked for the USDA for 19 years in the Agricultural Research Service and the Wildlife Services program. He has a B.S. degree in wildlife biology and range management from Humboldt State University.

Associate editor: *Ballard*