Interspecific Variation in Wildlife Hazards to Aircraft: Implications for Airport Wildlife Management

Travis L. DeVault
USDA/APHIS/WS National Wildlife Research Center, Travis.L.DeVault@aphis.usda.gov

Jerrold L. Belant
Mississippi State University

Bradley F. Blackwell
USDA/APHIS/WS National Wildlife Research Center, bradley.f.blackwell@aphis.usda.gov

Thomas W. Seamans
USDA/APHIS/WS National Wildlife Research Center, thomas.w.seamans@aphis.usda.gov

Wildlife Society Bulletin 35(4):394–402; 2011; DOI: 10.1002/wsb.75

Original Article

Interspecific Variation in Wildlife Hazards to Aircraft: Implications for Airport Wildlife Management

TRAVIS L. DEVAULT,[1] *United States Department of Agriculture, Animal and Plant Health Inspection Service, Wildlife Services, National Wildlife Research Center, Ohio Field Station, 6100 Columbus Avenue, Sandusky, OH 44870, USA*

JERROLD L. BELANT, *Carnivore Ecology Laboratory, Forest and Wildlife Research Center, Mississippi State University, Box 9690, Mississippi State, MS 39762, USA*

BRADLEY F. BLACKWELL, *United States Department of Agriculture, Animal and Plant Health Inspection Service, Wildlife Services, National Wildlife Research Center, Ohio Field Station, 6100 Columbus Avenue, Sandusky, OH 44870, USA*

THOMAS W. SEAMANS, *United States Department of Agriculture, Animal and Plant Health Inspection Service, Wildlife Services, National Wildlife Research Center, Ohio Field Station, 6100 Columbus Avenue, Sandusky, OH 44870, USA*

ABSTRACT Understanding the relative hazards of wildlife to aircraft is important for developing effective management programs. We used Federal Aviation Administration National Wildlife Strike Database records from 1990 to 2009 in the United States to rank the relative hazard of wildlife to aircraft. We summarized data for 77 species or species groups with ≥20 records where collisions occurred ≤500 ft (152 m) above ground level. We also assessed the effects of avian body mass, body density, and group size on relative hazard scores. The 3 most hazardous species or species groups were mule deer (*Odocoileus hemionus*), white-tailed deer (*O. virginianus*), and domestic dogs. "Other geese" (snow goose [*Chen caerulescens*], brant [*Branta bernicla*], and greater white-fronted goose [*Anser albifrons*]) was the most hazardous bird group. Ten of the 15 most hazardous bird species or species groups are strongly associated with water. Avian body mass was strongly associated with percentage of all strikes that caused damage, but not for species exceeding median body mass (1,125 g) of birds in damaging strikes. In contrast, percentage of damaging strikes increased when multiple birds were involved, but only for those species with body mass ≥1,125 g. Managers should prioritize efforts that will reduce habitat suitability for those species most hazardous to aircraft. We recommend use of exclusion (e.g., fences) for managing large mammals and habitat modifications (e.g., reductions in standing water) accompanied by hazing for reducing bird use of airports. We also recommend that evaluations of jet turbine engine performance following bird ingestions consider using multiple birds with body mass >1,000 g. © 2011 The Wildlife Society.

KEY WORDS airport, airport management, aviation hazard, bird strike, body mass, wildlife–aircraft collision, wildlife hazard score, wildlife strike.

Wildlife collisions with aircraft (wildlife strikes) pose increasing risks and economic losses to the aviation industry worldwide. Annual economic losses from wildlife strikes with civil aircraft are conservatively estimated to exceed US$ 1.2 billion worldwide (Allan 2002) and US$ 600 million in the United States alone (Dolbeer et al. 2009). Wildlife strikes have resulted in the loss of >219 human lives and >200 military and civil aircraft since 1988 (Richardson and West 2000, Dolbeer and Wright 2008, Thorpe 2010). Public awareness of wildlife collisions with aircraft is presently at an all-time high following the highly publicized ditching of US Airways Flight 1549 in the Hudson River in January 2009 (Marra et al. 2009).

Numerous efforts are currently employed to mitigate wildlife-strike hazards at airports (Washburn et al. 2007; Blackwell et al. 2008, 2009*a*; DeVault et al. 2008) and at higher altitudes (DeVault et al. 2005, Van Belle et al. 2007, Blackwell et al. 2009*b*). Airport biologists have made considerable progress in reducing the overall number of damaging strikes (Dolbeer et al. 2010) and strikes in the airport environment (Dolbeer 2011) during the past decade. Nonetheless, most damaging strikes still occur at low altitudes in the airport environment (Dolbeer 2006). Consequently, efforts to reduce strikes should be concentrated at airports. To better prioritize airport wildlife-hazard management, particularly habitat management (Washburn et al. 2007), land-use planning (Blackwell et al. 2009*a*), and nonlethal dispersal (i.e., frightening techniques), an improved understanding of which species are most hazardous is necessary. At least 415 bird and 35 nonvolant mammal species were struck by aircraft from 1990 to 2009 (Dolbeer et al. 2010). Overall, 14% of all strikes with birds and 61% of all strikes with mammals caused some damage (Dolbeer et al. 2010). However, the severity and probability of damage is

Received: 13 May 2011; Accepted: 20 August 2011;
Published: 17 October 2011

[1]*E-mail: travis.l.devault@aphis.usda.gov*

species-specific (Dolbeer et al. 2000, 2010; Dolbeer and Wright 2009).

Dolbeer et al. (2000) provided an initial ranking of wildlife species by relative hazard level to aircraft. However, at that time (May 1998) the Federal Aviation Administration (FAA) National Wildlife Strike Database for Civil Aviation in the United States contained only 18,038 records. Because of limited data, Dolbeer et al. (2000) was able to rank relative hazard levels for only 21 wildlife species or groups. The annual reporting rate of wildlife strikes has increased markedly (currently >7,500 reports/yr) and now represents about 39% of all strikes at airports certificated for passenger travel by the FAA (i.e., 61% of all strikes are never reported; Dolbeer 2009). Consequently, this database contained 99,411 strikes through 2009, warranting a reassessment of wildlife hazard rankings.

More recently, Dolbeer and Wright (2009) provided hazard rankings and classified species into several hazard-level categories using the percentages of strikes that caused damage. However, they did not use a composite hazard score that incorporated damage level (e.g., substantial damage; see Dolbeer et al. 2000) and effect on flight. Zakrajsek and Bissonette (2005) ranked wildlife strike hazards for military aircraft with species–group hazard rankings that differed from Dolbeer et al. (2000). This disparity was likely due to differences in flight characteristics and procedures between military and civil aircraft (e.g., serious strikes to military aircraft are often incurred during low-altitude, high-speed training flights), but also because Zakrajsek and Bissonette (2005) used the number of damaging strikes and the cost of such strikes as their primary criteria for hazard ranking, whereas Dolbeer et al. (2000) used percentages of strikes that caused some type of damage.

We emphasize "Which species are the most hazardous if struck?" as a question different than "Which species cause the most damage?" The former question addresses the proportion of strikes by a species that causes damage to aircraft in relation to the total number of strikes involving that species. The latter question is, in part, a consequence of overall species abundance and current management at airports. There are numerous additional factors that limit our ability to assess which species cause the most damage to aircraft, including multiscale patterns of species distributions, airport locations, and timing and frequency of aircraft arrivals and departures at airports. Consequently, we addressed only the first question, as did Dolbeer et al. (2000) and Dolbeer and Wright (2009), whereas Zakrajsek and Bissonette (2005) and the annual FAA wildlife strike report summaries (e.g., Dolbeer et al. 2010) addressed the second question.

Because our goal was to provide an assessment of wildlife hazards relevant to management of the airport and its immediate vicinity, we used only strikes ≤500 ft (152 m) above ground level (AGL) in our analyses. Previous wildlife hazard rankings for civil aircraft (Dolbeer et al. 2000, Dolbeer and Wright 2009) used wildlife strike data from all altitudes due to limited sample sizes. Use of all strike data is likely biased because species vary in strike frequency across altitude bands (Dolbeer 2006) and strikes at different altitudes occur at various aircraft velocities. For example, Dolbeer et al. (2000) reported that vultures (turkey vultures [*Cathartes aura*] and black vultures [*Coragyps atratus*]) and osprey (*Pandion haliaetus*) had higher hazard scores than predicted by average body masses. These differences were attributed to these species soaring at high altitudes, increasing their vulnerability to being struck by aircraft traveling at greater velocities. We considered mammals in our hazard rankings, but not when investigating factors that contribute to hazard level. Although mammals can be extremely hazardous to aircraft, particularly large mammals (e.g., white-tailed deer [*Odocoileus virginianus*]; Biondi et al. 2011), they can be managed effectively with appropriate exclusion and deterrents (e.g., DeVault et al. 2008, VerCauteren et al. 2010).

In addition to providing an updated hazard ranking to assist airport wildlife management, we also sought to understand why bird species differ in hazard level. Previous studies have identified avian body mass (Dolbeer et al. 2000, Dolbeer and Eschenfelder 2003), body density (Seamans et al. 1995), and flocking behavior (Dolbeer and Eschenfelder 2003) as potential contributors to hazard level; however, no formal analyses on body density and flocking behavior have been conducted. Consequently, we investigated these factors to determine which attributes influenced hazard level.

METHODS

For the 20-yr period (1990–2009), 99,411 strikes were reported to the FAA (Dolbeer et al. 2010). We used FAA National Wildlife Strike Database records for the United States from 1990 through 2009 that included identified species and were ≤500 ft AGL (thus, in the airport environment; Dolbeer 2006), which represented 23,503 reports. Only species–groups with ≥20 total strikes were used in our analyses. We combined some similar species into groups to increase sample size to ≥20 (e.g., "sparrows"), or because similarities in form and behavior facilitated pooling data (e.g., western meadowlark [*Sturnella neglecta*] and eastern meadowlark [*S. magna*] were combined into a "meadowlark" group), which resulted in 77 species–groups for analyses.

We calculated rankings for birds and mammals combined and for birds only. We provided the former ranking to demonstrate the relative hazards of mammal species and the latter ranking because bird management at airports is more complex and often considered separately from mammals. We used the database to calculate the percentage of total strikes for each species or group that 1) resulted in any level of damage to the aircraft (ranging from minor repairs to aircraft destroyed); 2) resulted in substantial damage to the aircraft (adversely affecting structural strength, performance, or flight characteristics and which generally requires major repair or replacement of the aircraft component struck); and 3) caused an effect on flight (e.g., aborted take-off or emergency landing; see table 1 in Dolbeer et al. [2000] for detailed definitions of damage categories and effect on flight). Damaging strikes differed from nondamaging strikes in that the former required some level of repair or replacement of an aircraft component, whereas the latter

Table 1. Ranking of 77 bird and mammal species or groups (1 = most hazardous) as to relative hazard to aircraft in airport environments (i.e., ≤500 ft [152 m] above ground level), based on a composite rank. The composite rank reflects 3 variables: the percentage of total strikes (for that species–group) that caused any level of damage to the aircraft, the percentage of total strikes that caused substantial damage to the aircraft, and the percentage of total strikes that caused an effect on flight (EOF). See Dolbeer et al. (2000) for detailed definitions of damage and EOF. Strike data are from the Federal Aviation Administration National Wildlife Strike Database, for strikes that occurred in the United States from 1990 to 2009.

Species[a]	Total strikes reported	% With damage	% With substantial damage	% With EOF	Damage rank	Substantial damage rank	EOF rank	Composite rank	Relative hazard score
Mule deer (*Odocoileus hemionus*)	47	96	38	83	1	1	1	1	100
White-tailed deer (*Odocoileus virginianus*)	814	87	36	68	2	2	3	2	88
Domestic dog	21	53	26	75	4	4	2	3	71
Other geese	20	68	32	32	3	3	8	4	61
Canada goose (*Branta canadensis*)	776	51	16	34	7	9	7	5	46
Turkey vulture (*Cathartes aura*)	159	46	16	34	10	7	6	5	44
Other ducks	77	49	24	30	8	5	11	7	48
Great horned owl (*Bubo virginianus*)	29	52	16	27	6	8	17	8	44
Double-crested cormorant (*Phalacrocorax auritis*)	24	52	13	29	5	13	13	8	43
Brown pelican (*Pelecanus occidentalis*)	31	35	13	38	14	14	5	10	40
Wild turkey (*Meleagris gallopavo*)	38	37	6	43	13	28	4	11	40
Sandhill crane (*Grus canadensis*)	66	43	10	28	11	19	15	11	37
Glaucous-winged gull (*Larus glaucescens*)	27	48	9	28	9	21	16	13	39
Bald eagle (*Haliaeetus leucocephalus*)	74	40	7	30	12	25	10	14	36
Great black-backed gull (*Larus marinus*)	20	26	21	22	18	6	23	14	32
Osprey (*Pandion haliaetus*)	77	32	12	26	16	15	19	16	32
Great blue heron (*Ardea herodius*)	132	32	8	28	15	23	14	17	31
Ring-necked pheasant (*Phasianus colchicus*)	45	26	14	22	20	10	26	18	29
Herring gull (*Larus argentatus*)	291	25	13	24	23	12	21	18	29
Snowy owl (*Bubo scandiacus*)	28	23	12	26	24	17	20	20	28
Mallard (*Anas platyrhynchos*)	221	31	11	21	17	18	28	21	29
Great egret (*Ardea alba*)	24	26	4	29	21	32	12	22	28
Red-tailed hawk (*Buteo jamaicensis*)	534	26	8	21	19	24	27	23	25
California gull (*Larus californicus*)	23	14	14	20	33	11	30	24	22
Cattle egret (*Bubulcus ibis*)	112	17	6	27	32	27	18	25	23
Ring-billed gull (*Larus delawarensis*)	362	21	8	20	26	22	33	26	23
Franklin's gull (*Larus pipixcan*)	26	9	9	23	41	20	22	27	19
Raccoon (*Procyon lotor*)	23	18	12	14	28	16	40	28	20
Coyote (*Canis latrans*)	231	14	3	31	36	41	9	29	22
Rock dove (*Columba livia*)	1,035	18	6	19	29	26	34	30	20
Swainson's hawk (*Buteo swainsoni*)	24	17	4	20	31	33	31	31	19
Other hawks	34	14	4	22	34	37	25	32	18
Laughing gull (*Larus atricilla*)	106	14	4	21	35	34	29	33	18
Mew gull (*Larus canus*)	21	25	0	16	22	52	37	34	19
Peregrine falcon (*Falco peregrinus*)	44	18	5	7	30	29	53	35	14
Laysan albatross (*Phoebastria immutabilis*)	29	22	0	17	25	53	35	36	18
Rabbits (Leporidae)	78	11	3	15	37	39	39	37	13
Upland sandpiper (*Bartramia longicauda*)	32	8	4	16	43	36	36	37	13
Short-eared owl (*Asio flammeus*)	58	10	4	11	39	35	43	39	12
Black-bellied plover (*Pluvialis squatarola*)	20	18	0	16	27	54	38	40	15
Red fox (*Vulpes vulpes*)	31	8	0	22	42	55	24	41	14
American crow (*Corvus brachyrhynchos*)	141	10	3	13	40	40	41	41	12
Spotted dove (*Streptopelia chinensis*)	46	7	4	10	48	31	45	43	10
Barn owl (*Tyto alba*)	174	11	3	9	38	38	49	44	11
Mourning dove (*Zenaida macroura*)	1,313	7	3	13	45	42	42	45	10
Blackbirds	976	7	2	10	44	46	44	46	9
European starling (*Sturnus vulgaris*)	1,408	7	2	10	47	43	46	47	9
Bats (Chiroptera)	44	5	5	8	55	30	51	47	8
Killdeer (*Charadrius vociferus*)	553	6	1	7	51	48	52	49	7
American kestrel (*Falco sparverius*)	536	4	1	7	57	47	55	50	6
Zebra dove (*Geopelia striata*)	54	4	2	6	56	44	59	50	5
Snow bunting (*Plectrophenax nivalis*)	84	1	0	20	66	66	32	52	10
Common myna (*Acridotheres tristis*)	21	6	0	6	50	58	56	52	6
Bank swallow (*Riparia riparia*)	49	5	0	9	54	61	50	54	6
Meadowlarks	361	3	2	6	61	45	60	55	5
Woodchuck (*Marmota monax*)	41	7	0	3	46	56	68	56	5
Horned lark (*Eremophila alpestris*)	372	3	1	6	60	49	61	56	4
Sparrows	1,799	3	0	6	62	51	58	58	4
Northern harrier (*Circus cyaneus*)	24	5	0	5	52	59	62	59	5
American robin (*Turdus migratorius*)	159	2	0	10	64	65	47	60	5
Burrowing owl (*Athene cunicularia*)	20	6	0	0	49	57	73	61	3
Barn swallow (*Hirundo rustica*)	486	2	0	3	65	50	69	62	2
Wrens	28	4	0	4	58	62	66	63	3
Terns	45	5	0	0	53	60	74	64	2

Table 1. (*continued*)

Species[a]	Total strikes reported	% With damage	% With substantial damage	% With EOF	Damage rank	Substantial damage rank	EOF rank	Composite rank	Relative hazard score
Finches	55	0	0	10	71	71	48	65	4
Chimney swift (*Chaetura pelagica*)	34	0	0	6	70	70	57	66	3
Common nighthawk (*Chordeiles minor*)	38	3	0	0	59	63	75	66	1
Pacific golden-plover (*Pluvialis apricaria*)	204	1	0	4	67	67	64	68	2
Purple martin (*Progne subis*)	57	2	0	2	63	64	72	69	2
Western sandpiper (*Calidris mauri*)	31	0	0	7	76	76	54	70	3
Cliff swallow (*Petrochelidon pyrrhonota*)	164	1	0	2	68	68	71	71	1
Skunks (Mephitidae)	30	0	0	4	74	74	63	72	2
Nutmeg mannikin (*Lonchura punctulata*)	26	0	0	4	72	72	67	72	2
Chestnut manikin (*Lonchura malacca*)	28	0	0	0	69	69	76	74	0
Wood warblers	30	0	0	4	77	77	65	75	2
Tree swallow (*Tachycineta bicolor*)	109	0	0	2	75	75	70	76	1
Opossum (*Didelphis virginiana*)	25	0	0	0	73	73	77	77	0

[a] Other geese = snow goose (*Chen caerulescens*), brant (*Branta bernicla*), greater white-fronted goose (*Anser albifrons*); other ducks = 23 species in the family Anatidae; other hawks = Cooper's hawk (*Accipter cooperii*), sharp-shinned hawk (*A. striatus*), rough-legged hawk (*Buteo lagopus*), red-shouldered hawk (*B. lineatus*), broad-winged hawk (*B. platypterus*), ferruginous hawk (*B. regalis*); blackbirds = red-winged blackbird (*Agelaius phoeniceus*), brown-headed cowbird (*Molothrus ater*), common grackle (*Quiscalus quiscula*); meadowlarks = eastern meadowlark (*Sturnella magna*), western meadowlark (*S. neglecta*); sparrows = 19 species in the family Emberizidae; wrens = house wren (*Troglodytes aedon*), Carolina wren (*Thryothorus ludovicianus*), marsh wren (*Cistothorus palustris*); terns = common tern (*Sterna hirundo*), arctic tern (*S. vittata*), Caspian tern (*S. caspia*), least tern (*S. antillarum*), fairy tern (*S. nereis*); finches = house finch (*Carpodacus mexicanus*), American goldfinch (*Carduelis tristis*); wood warblers = 13 species in the family Parulidae.

necessitated no repair or replacement of components (although some costs might have been incurred due to delay or aircraft inspection after landing). Also, by definition, strikes resulting in substantial damage also are included in the calculation for any level of damage, but not all strikes resulting in an effect on flight caused damage. Following Dolbeer et al. (2000), we ranked the 77 species–groups for each of the 3 hazard criteria (i.e., percentage of strikes with damage, percentage of strikes with substantial damage, and percentage of strikes with an effect on flight) from 1 (most hazardous) to 77 (least hazardous). We created a composite rank by summing those category ranks and then ordered species or groups from most to least hazardous, including tied ranks. We then calculated a relative hazard score (Dolbeer et al. 2000) by summing the scores of the 3 hazard criteria for each species–group, and scaling to a maximum of 100.

We assessed hazard scores in relation to avian body mass, body density, and group size. We obtained body mass data from Dunning (1993). When body mass estimates were provided for both sexes, we averaged them. For body masses of "groups" we calculated a weighted average using the number of strikes for each species in that group. We obtained mean bird body densities for 14 species (Seamans et al. 1995; T. W. Seamans, unpublished data). Unpublished density estimates were for American white pelicans (*Pelecanus erythrorhynchos*), double-crested cormorants (*Phalacrocorax auritus*), horned larks (*Eremophila alpestris*), American kestrels (*Falco sparverius*), red-tailed hawks (*Buteo jamaicensis*), great black-backed gulls (*Larus marinus*), and common nighthawks (*Chordeiles minor*). For all species, we used "plucked" body density estimates (Seamans et al. 1995); methods used to estimate density were identical for published and unpublished species. Bird flock size is poorly reported in the FAA National Wildlife Strike Database (Dolbeer et al. 2000), although all strikes are reported as involving single or multiple birds. Consequently, we used the percentage of strikes in which multiple (>1) birds were struck as our group-size estimate.

We log-transformed bird body masses to normalize them before assessing possible autocorrelation among predictor variables. We used relative hazard score as the dependent variable in all analyses and species–group as the sample unit. We first examined bivariate scatterplots of relative hazard score against log body mass and relative hazard score against percentage of strikes involving multiple birds, then used either linear or quadratic regression (based on best model fit) to assess relationships between these variables.

RESULTS

Considering birds and mammals combined, the top 3 species in composite ranking were large mammals (mule deer [*O. hemionus*], white-tailed deer, and domestic dog; Table 1). The next most hazardous mammal species were raccoon (*Procyon lotor*) and coyote (*Canis latrans*), with composite rank scores of 28 and 29, respectively. Based on relative hazard score, the top bird species–group was other geese (snow goose [*Chen caerulescens*], brant [*Branta bernicla*], and greater white-fronted goose [*Anser albifrons*]), which was 61% as hazardous as mule deer. Percentage of strikes with damage ranged from 95.6% (mule deer) to 0% (9 species–groups), percentage with major damage ranged from 37.8% (mule deer) to 0% (28 species–groups), and percentage with effect on flight ranged from 83.3% (mule deer) to 0% (5 species–groups; Table 1).

Considering birds only, other geese was the most hazardous species–group, followed by a 3-way tie between Canada geese (*Branta canadensis*), other ducks (23 species in the family Anatidae), and turkey vultures (Table 2). These 3 species–groups were 73–78% as hazardous as other geese

Table 2. Ranking of 66 bird species or groups (1 = most hazardous) as to relative hazard to aircraft in airport environments (i.e., ≤500 ft [152 m] above ground level), based on a composite rank. The composite rank reflects 3 variables: the percentage of total strikes (for that species–group) that caused any level of damage to the aircraft, the percentage of total strikes that caused substantial damage to the aircraft, and the percentage of total strikes that caused an effect on flight (EOF). See Dolbeer et al. (2000) for detailed definitions of damage and EOF. Strike data are from the Federal Aviation Administration National Wildlife Strike Database, for strikes that occurred in the United States from 1990 to 2009.

Species[a]	Total strikes reported	Damage rank	Substantial damage rank	EOF rank	Composite rank	Relative hazard score	Body mass (g)	Body density (g/cm^3)	% of strikes with multiple birds
Other geese	20	1	1	5	1	100	2,290		60.0
Other ducks	77	5	2	7	2	78	916		46.8
Canada goose (*Branta canadensis*)	776	4	6	4	2	76	3,564	0.917	47.9
Turkey vulture (*Cathartes aura*)	159	7	4	3	2	73	1,467	0.916	9.0
Great horned owl (*Bubo virginianus*)	29	3	5	13	5	72	1,309		3.4
Double-crested cormorant (*Phalacrocorax auritis*)	24	2	10	9	5	71	1,674	0.994	16.7
Brown pelican (*Pelecanus occidentalis*)	31	11	11	2	7	66	3,348		9.7
Sandhill crane (*Grus canadensis*)	66	8	15	11	8	61	5,571		44.6
Wild turkey (*Meleagris gallopavo*)	38	10	24	1	9	65	5,811		23.7
Glaucous-winged gull (*Larus glaucescens*)	27	6	17	12	9	64	1,010		25.9
Bald eagle (*Haliaeetus leucocephalus*)	74	9	21	6	11	59	4,740		12.2
Great black-backed gull (*Larus marinus*)	20	15	3	19	12	53	1,659	0.914	15.0
Osprey (*Pandion haliaetus*)	77	13	12	15	13	53	1,485		2.6
Great blue heron (*Ardea herodius*)	132	12	19	10	14	51	2,390		2.3
Ring-necked pheasant (*Phasianus colchicus*)	45	17	7	21	15	47	1,135		8.9
Herring gull (*Larus argentatus*)	291	20	9	17	16	47	1,125	0.880	22.0
Snowy owl (*Bubo scandiacus*)	28	21	13	16	17	46	2,043		0.0
Mallard (*Anas platyrhynchos*)	221	14	14	23	18	47	1,082	0.959	24.4
Great egret (*Ardea alba*)	24	18	27	8	19	45	874		12.5
Red-tailed hawk (*Buteo jamaicensis*)	534	16	20	22	20	42	1,126	0.960	2.2
California gull (*Larus californicus*)	23	29	8	25	21	37	691		21.7
Cattle egret (*Bubulcus ibis*)	112	28	23	14	22	37	338		29.5
Ring-billed gull (*Larus delawarensis*)	362	23	18	28	23	37	519	0.928	29.6
Franklin's gull (*Larus pipixcan*)	26	35	16	18	23	31	280		48.0
Rock dove (*Columba livia*)	1,035	25	22	29	25	33	355	0.987	47.2
Swainson's hawk (*Buteo swainsoni*)	24	27	28	26	26	32	989		4.2
Other hawks	34	30	32	20	27	30	661		2.9
Laughing gull (*Larus atricilla*)	106	31	29	24	28	29	325	0.935	33.0
Mew gull (*Larus canus*)	21	19	45	32	29	31	403		28.6
Peregrine falcon (*Falco peregrinus*)	44	26	25	45	29	23	782		4.5
Laysan albatross (*Phoebastria immutabilis*)	29	22	46	30	31	30	3,042		0.0
Upland sandpiper (*Bartramia longicauda*)	32	36	31	31	31	21	151		25.0
Short-eared owl (*Asio flammeus*)	58	33	30	36	33	19	347		0.0
American crow (*Corvus brachyrhynchos*)	141	34	34	34	34	19	448		17.7
Black-bellied plover (*Pluvialis squatarola*)	20	24	47	33	35	25	220		30.0
Spotted dove (*Streptopelia chinensis*)	46	40	26	38	35	16	159		8.7
Barn owl (*Tyto alba*)	174	32	33	42	37	18	523		0.6
Mourning dove (*Zenaida macroura*)	1,313	38	35	35	38	17	119		35.0
Blackbirds	976	37	39	37	39	14	65		34.3
European starling (*Sturnus vulgaris*)	1,408	39	36	39	40	14	82	1.027	47.5
Killdeer (*Charadrius vociferus*)	553	43	41	44	41	11	97		19.9
American kestrel (*Falco sparverius*)	536	48	40	47	42	9	116	0.997	6.0
Zebra dove (*Geopelia striata*)	54	47	37	51	42	9	56		25.9
Common myna (*Acridotheres tristis*)	21	42	49	48	44	9	110		28.6
Snow bunting (*Plectrophenax nivalis*)	84	57	57	27	45	16	42		84.5
Bank swallow (*Riparia riparia*)	49	46	52	43	45	10	15		61.2
Meadowlarks	361	52	38	52	47	8	95		19.9
Horned lark (*Eremophila alpestris*)	372	51	42	53	48	7	31	1.055	38.7
Sparrows	1,799	53	44	50	49	7	25		28.9
Northern harrier (*Circus cyaneus*)	24	44	50	54	50	8	436		4.2
American robin (*Turdus migratorius*)	159	55	56	40	51	9	77		8.2
Burrowing owl (*Athene cunicularia*)	20	41	48	63	52	5	155		5.0
Barn swallow (*Hirundo rustica*)	486	56	43	59	53	3	16		21.2
Wrens	28	49	53	57	54	6	10		25.0
Terns	45	45	51	64	55	4	224		35.6
Finches	55	62	62	41	56	7	18		32.7
Common nighthawk (*Chordeiles minor*)	38	50	54	65	57	2	62	0.992	10.5
Chimney swift (*Chaetura pelagica*)	34	61	61	49	58	5	24		14.7
Pacific golden-plover (*Pluvialis apricaria*)	204	58	58	55	58	4	153		26.0
Purple martin (*Progne subis*)	57	54	55	62	58	3	49		33.3
Western sandpiper (*Calidris mauri*)	31	65	65	46	61	5	42		67.7
Cliff swallow (*Petrochelidon pyrrhonota*)	164	59	59	61	62	2	22		23.2
Nutmeg mannikin (*Lonchura punctulata*)	26	63	63	58	63	3	14		65.4
Chestnut manikin (*Lonchura malacca*)	28	60	60	66	64	0	16		50.0

Table 2. (*continued*)

Species[a]	Total strikes reported	Damage rank	Substantial damage rank	EOF rank	Composite rank	Relative hazard score	Body mass (g)	Body density (g/cm^3)	% of strikes with multiple birds
Wood warblers	30	66	66	56	65	3	12		10.0
Tree swallow (*Tachycineta bicolor*)	109	64	64	60	65	2	20		39.4

[a] Other geese = snow goose (*Chen caerulescens*), brant (*Branta bernicla*), greater white-fronted goose (*Anser albifrons*); other ducks = 23 species in the family Anatidae; other hawks = Cooper's hawk (*Accipter cooperii*), sharp-shinned hawk (*A. striatus*), rough-legged hawk (*Buteo lagopus*), red-shouldered hawk (*B. lineatus*), broad-winged hawk (*B. platypterus*), ferruginous hawk (*B. regalis*); blackbirds = red-winged blackbird (*Agelaius phoeniceus*), brown-headed cowbird (*Molothrus ater*), common grackle (*Quiscalus quiscula*); meadowlarks = eastern meadowlark (*Sturnella magna*), western meadowlark (*S. neglecta*); sparrows = 19 species in the family Emberizidae; wrens = house wren (*Troglodytes aedon*), Carolina wren (*Thryothorus ludovicianus*), marsh wren (*Cistothorus palustris*); terns = common tern (*Sterna hirundo*), arctic tern (*S. vittata*), Caspian tern (*S. caspia*), least tern (*S. antillarum*), fairy tern (*S. nereis*); finches = house finch (*Carpodacus mexicanus*), American goldfinch (*Carduelis tristis*); wood warblers = 13 species in the family Parulidae.

based on relative hazard scores. There were 23 bird species–groups with relative hazard scores <10; 17 of these (74%) have average body masses <100 g (Table 2).

Avian body density was strongly negatively associated with log body mass ($r = -0.77$; $P = 0.001$) and, consequently, excluded from analyses. Preliminary examination of the association between relative hazard score and log body mass suggested the relationship diminished once log body mass reached about 3.0 (1,000 g). Thus, we first examined data on body masses for all strikes in 2 groups—those that resulted in damage and those that resulted in no damage. Median body mass for birds involved in damaging strikes was 1,125 g; median body mass for birds involved in nondamaging strikes was 97 g (Fig. 1). We then used median body mass (log body mass = 3.05) for birds involved in damaging strikes as a cut-off point for further analyses. We subsequently examined relative hazard score versus log body mass and percentage of strikes with multiple birds involved for 2 groups separately (in addition to all birds combined): species–groups <1,125 g ($n = 49$), and species–groups ≥1,125 g ($n = 17$).

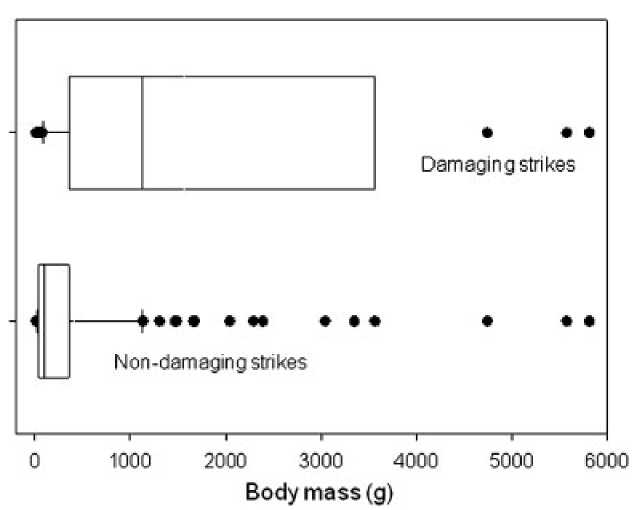

Figure 1. Frequency distribution of body masses for birds involved in damaging and nondamaging strikes with aircraft. Boxes outline the mid-range (25–75 percentiles), medians are indicated by the vertical lines within the boxes, whiskers mark the 10th and 90th percentiles, and outlying points are marked with solid circles. Only strikes in airport environments (i.e., ≤500 ft [152 m] above ground level) are included. Data are from the Federal Aviation Administration National Wildlife Strike Database, for strikes that occurred in the United States from 1990 to 2009.

For all bird species–groups, relative hazard score increased with body mass (Fig. 2). This relationship was similar for those species–groups with body mass <1,125 g; however, no relationship for species with body mass ≥1,125 g was observed. Although no relationship between relative hazard score and percentage of strikes involving multiple birds existed when considering all bird species–groups or those with body mass <1,125 g, relative hazard scores did increase with percentage of strikes involving multiple birds for species–groups ≥1,125 g (Fig. 3).

DISCUSSION

Understanding the relative hazards of wildlife to aircraft is critical for developing effective management programs. We encourage biologists and managers to prioritize efforts that reduce use of airport property for those species ranked most hazardous to aircraft; that is, those species with the greatest percentage of total strikes that cause some form of damage (either direct aircraft damage or an effect on flight) and are observed using the airspace and habitats in and around the airport in question (see also Dolbeer and Wright 2009). We emphasize that our composite rankings do not necessarily represent species that cause the most economic damage nor the relative frequency of species involved in damaging strikes; rather, our rankings reflect those species most likely to cause damage when struck by aircraft. Thus, prioritizations for managing hazardous wildlife species also should consider frequency of species occurrence on airports (Dolbeer and Wright 2009).

Large mammals, particularly deer, are clearly the most hazardous wildlife to aircraft (see also Biondi et al. 2011). Dolbeer et al. (2000) similarly reported deer as having the highest relative hazard score. Consequently, we recommend airports implement a no-tolerance policy for deer or other large-bodied mammals (e.g., dogs) on airfields. Exclusion devices are highly effective for deer and fencing should be a priority at all airports (DeVault et al. 2008, VerCauteren et al. 2010). Although less effective, lower cost alternatives to 2.3–3-m woven-wire or chain-link fencing are available (e.g., Seamans and VerCauteren 2006). It is critical that fences

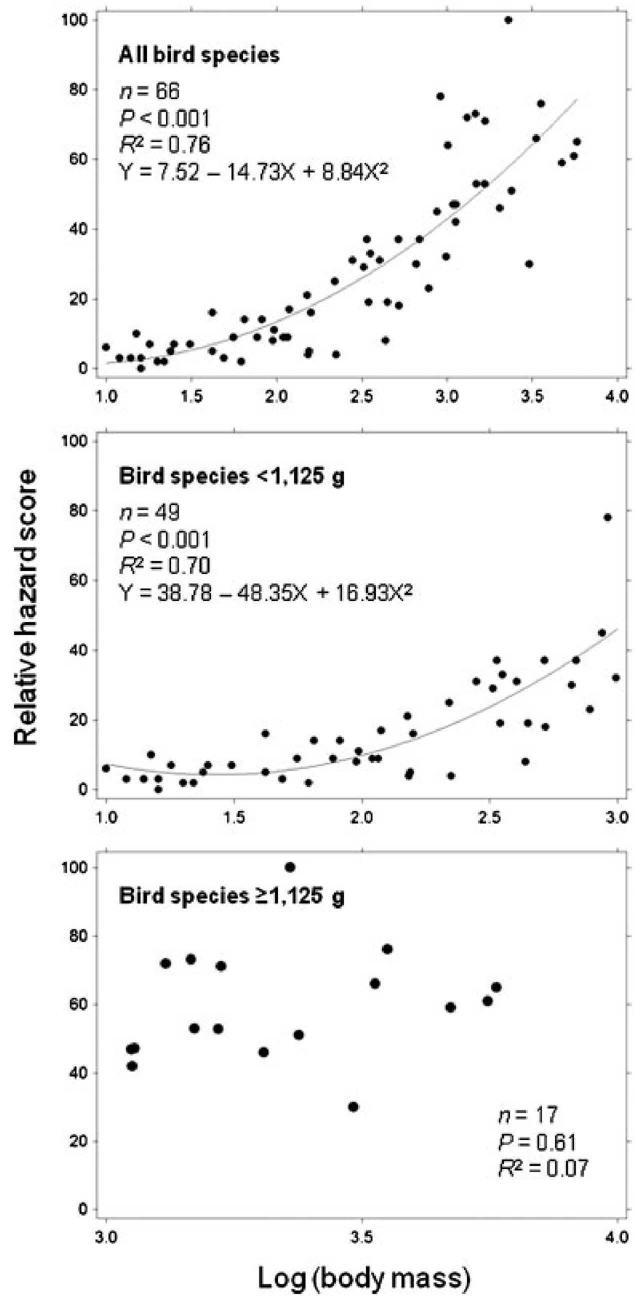

Figure 2. Relative hazard scores as predicted by body mass for 66 bird species–groups (top), for species–groups <1,125 g (middle), and for species–groups ≥1,125 g (bottom) with ≥20 strikes ≤500 ft (152 m) above ground level at airports in the United States, from 1990 to 2009.

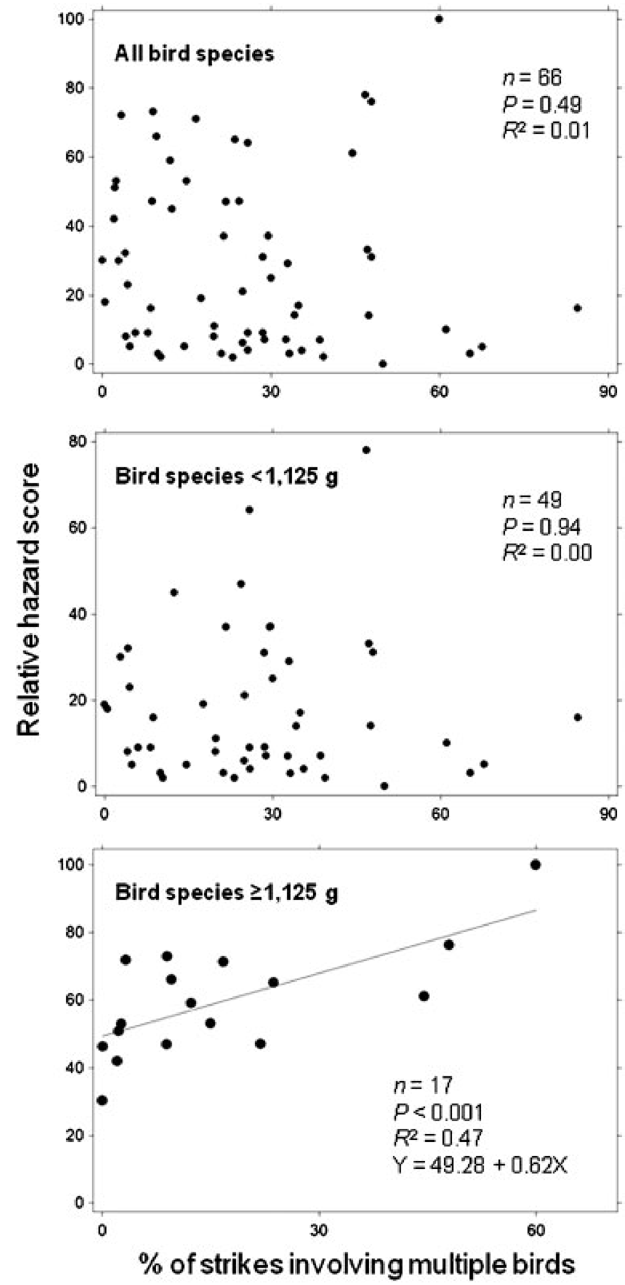

Figure 3. Relative hazard scores as predicted by the percentage of total strikes involving multiple birds for 66 bird species–groups (top), for species–groups <1,125 g (middle), and for species–groups ≥1,125 g (bottom) with ≥20 strikes ≤500 ft (152 m) above ground level at airports in the United States, from 1990 to 2009.

have no gaps or holes that would allow large mammals to cross (DeVault et al. 2008, VerCauteren et al. 2010); consequently, regular fence maintenance must be conducted.

Considering birds only, 10 of the 15 most hazardous bird species–groups are strongly associated with water (other geese, Canada goose, other ducks, double-crested cormorant, brown pelican [*Pelicanus occidentalis*], glaucous-winged gull [*Larus glaucescens*], bald eagle [*Haliaeetus lecucephalus*], great black-backed gull, osprey, and great blue heron [*Ardea herodias*]). Similarly, Dolbeer and Wright (2009) found 6 of 8 bird species (snow goose, northern pintail [*Anas acuta*], Canada goose, brown pelican, bald eagle, double-crested cormorant) in the highest hazard category ("extremely high"; >40% of all strikes causing damage) are commonly associated with water. Potential risk to aircraft has increased as populations of some species, such as Canada geese, have increased in recent years, especially resident populations (Sauer et al. 2008). Consequently, strategies with long-term effectiveness to reduce goose and other waterbird use at airports are imperative. Fresh water, including standing water following rainfall, is common at certificated airports (Gabrey and Dolbeer 1996, Brown et al. 2001) and at general aviation facilities (DeVault et al. 2009). Proper storm-water and open-water management should be a high priority for airports (Barras and Seamans 2002, Blackwell et al. 2008).

Other bird species with high composite rank scores are typically associated with specific cover types (e.g., great-horned owl [*Bubo virginianus*] and wild turkey [*Meleagris gallopavo*]—forest; sandhill crane [*Grus canadensis*]—cropland; ring-necked pheasant [*Phasianus colchicus*]—grassland and cropland). In cases of multiple hazardous bird species using several cover types at airports, we recommend managers consider the most hazardous species and manage for cover type that is least attractive overall. The importance of management programs that consider multiple components of wildlife habitat or resource use (e.g., roosts and food) is recognized (e.g., Blackwell and Wright 2006). However, the feasibility for reducing the amount of resources selected by hazardous species on airports will vary. For example, it is often necessary to maintain grasslands, including short grass near taxiways and runways, which are often used for loafing or foraging by several species. In these situations, modifying vegetation height and planting less palatable plant species may reduce habitat suitability for some species (Pochop et al. 1999, Sheffield et al. 2001, Washburn et al. 2007, Whittingham and Devereux 2008). Also, agriculture is a surprisingly common land use at airports (Blackwell et al. 2009*a*, DeVault et al. 2009); avoiding production of small grains and corn exploited by many species will almost certainly reduce overall wildlife use.

Populations of most large birds hazardous to aircraft are increasing in the United States (Dolbeer and Eschenfelder 2003). Overall, body mass was clearly the primary determinant of hazard level to aircraft, and flocking behavior was secondary (see also Dolbeer et al. 2000, Dolbeer and Eschenfelder 2003). However, we note the relationship between body mass and hazard level held only for birds with body mass less than about 1 kg; relative hazard did not increase for species exceeding about 1 kg body mass. This concept also was demonstrated by Dolbeer and Eschenfelder (2003), who found that 50% of strikes with birds >1.8 kg caused damage and 51% of strikes with birds >3.6 kg caused damage.

According to Dolbeer and Eschenfelder (2003), 67% of the 36 bird species in North America >1.8 kg exhibit strong flocking behavior and 25% exhibit limited flocking behavior. We demonstrated that strikes involving multiple birds were a contributing factor to damaging strikes for large bird species. We were surprised to find, however, that the percentage of strikes involving multiple birds was not an important predictor of damaging strikes for smaller birds. Some of the most devastating strikes (in terms of loss of human life) were caused by large flocks of European starlings (*Sturnus vulgaris*) and rock doves (*Columba livia*; Thorpe 2005). However, we lacked consistent data on flock size for analyses; our binary measure of single or multiple birds involved in strikes may have masked an effect of flock size for small species. It is possible that for small bird species, only large flocks are particularly hazardous. Thus, airport managers and biologists should not ignore the potential threat posed by large flocks of small birds. Even so, the greatest avian strike hazards to aircraft are clearly large (>1 kg) flocking species.

MANAGEMENT IMPLICATIONS

Our recommendations target airport wildlife managers and engine manufacturers, respectively. First, although numerous hazing and exclusion techniques have been demonstrated to reduce wildlife use of airports, we encourage airport managers to concurrently implement programs that reduce wildlife habitat suitability whenever feasible. Creating habitat less suitable for hazardous wildlife should reduce their overall use of airport environments and also may enhance effectiveness of hazing techniques. We recommend management programs first prioritize local wildlife species by hazard level, and then emphasize reducing habitat suitability for the most hazardous species. Certainly, perimeter fences to exclude large mammals and reductions in standing water to reduce use by many of the most hazardous bird species should be priorities for airports.

Current FAA design standards require jet turbine engines to sustain ingestions of 8 675-g birds or 1 1.8-kg bird without catching fire, bursting, increasing load beyond maximum design load, or losing the ability to be shut down (Eschenfelder 2000). In addition, engines tested using 675-g birds also must maintain ≥75% power or thrust and not fail within 5 min of bird ingestion (Eschenfelder 2000). Our results suggest consideration for using multiple birds exceeding 1-kg body mass for jet turbine engine testing, rather than multiple birds <1 kg or a single bird >1.8 kg, as is currently required.

ACKNOWLEDGMENTS

Our work was supported by the United States Department of Agriculture, Mississippi State University, and the FAA under agreement DTFACT-04-X-90003. We thank P. M. Schmidt, B. E. Washburn, J. A. Schmidt, M. J. Begier, and 3 anonymous reviewers for providing constructive comments on this manuscript. Opinions expressed in this study do not necessarily reflect current FAA policy decisions regarding the control of wildlife on or near airports.

LITERATURE CITED

Allan, J. R. 2002. The costs of bird strikes and bird strike prevention. Pages 147–155 *in* L. Clark, editor. Proceedings of the National Wildlife Research Center symposium, human conflicts with wildlife: economic considerations, U.S. Department of Agriculture, National Wildlife Research Center, Fort Collins, Colorado, USA.

Barras, S. C., and T. W. Seamans. 2002. Habitat management approaches for reducing wildlife use of airfields. Proceedings of the Vertebrate Pest Conference 20:309–315.

Biondi, K. M., J. L. Belant, J. A. Martin, T. L. DeVault, and G. Wang. 2011. White-tailed deer incidents with U.S. civil aircraft. Wildlife Society Bulletin 35:303–309.

Blackwell, B. F., T. L. DeVault, E. Fernández-Juricic, and R. A. Dolbeer. 2009*a*. Wildlife collisions with aircraft: a missing component of land-use planning for airports. Landscape and Urban Planning 93:1–9.

Blackwell, B. F., E. Fernández-Juricic, T. W. Seamans, and T. Dolan. 2009*b*. Avian visual system configuration and behavioural response to object approach. Animal Behaviour 77:673–684.

Blackwell, B. F., L. M. Schafer, D. A. Helon, and M. A. Linnell. 2008. Bird use of stormwater-management ponds: decreasing avian attractants on airports. Landscape and Urban Planning 86:162–170.

Blackwell, B. F., and S. E. Wright. 2006. Collisions of red-tailed hawks (*Buteo jamaicensis*), turkey vultures, and black vultures (*Coragyps atratus*) with aircraft: implications for bird strike reduction. Journal of Raptor Research 40:76–80.

Brown, K. M., R. M. Erwin, M. E. Richmond, P. A. Buckley, J. T. Tanacredi, and D. Avrin. 2001. Managing birds and controlling aircraft in the Kennedy Airport-Jamaica Bay Wildlife Refuge complex: the need for hard data and soft opinions. Environmental Management 28:207–224.

DeVault, T. L., J. E. Kubel, D. G. Glista, and O. E. Rhodes, Jr. 2008. Mammalian hazards at small airports in Indiana: impact of perimeter fencing. Human–Wildlife Conflicts 2:240–247.

DeVault, T. L., J. E. Kubel, O. E. Rhodes, Jr., and R. A. Dolbeer. 2009. Habitat and bird communities at small airports in the Midwestern USA. Proceedings of the Wildlife Damage Management Conference 13:137–145.

DeVault, T. L., B. D. Reinhart, I. L. Brisbin, Jr., and O. E. Rhodes, Jr. 2005. Flight behavior of black and turkey vultures: implications for reducing bird–aircraft collisions. Journal of Wildlife Management 69:601–608.

Dolbeer, R. A. 2006. Height distribution of birds recorded by collisions with civil aircraft. Journal of Wildlife Management 70:1345–1350.

Dolbeer, R. A. 2009. Trends in wildlife strike reporting, part 1—voluntary system1990–2008. U.S. Department of Transportation, Federal Aviation Administration Report, DOT/FAA/AR-09/65, Washington, D.C., USA.

Dolbeer, R. A. 2011. Increasing trend of damaging bird strikes with aircraft outside the airport boundary: implications for mitigation measures. Human–Wildlife Interactions 5(2):30–43.

Dolbeer, R. A., and P. Eschenfelder. 2003. Amplified bird-strike risks related to population increases of large birds in North America. Proceedings of the International Bird Strike Committee Meeting 26: 49–67.

Dolbeer, R. A., and S. E. Wright. 2008. Wildlife strikes to civil aircraft in the United States, 1990–2007. U.S. Department of Transportation, Federal Aviation Administration, Office of Airport Safety and Standards, Serial Report 14, Washington, D.C., USA.

Dolbeer, R. A., and S. E. Wright. 2009. Safety management systems: how useful will the FAA National Wildlife Strike Database be? Human–Wildlife Conflicts 3:167–178.

Dolbeer, R. A., S. E. Wright, and E. C. Cleary. 2000. Ranking the hazard level of wildlife species to aviation. Wildlife Society Bulletin 28:372–378.

Dolbeer, R. A., S. E. Wright, J. Weller, and M. J. Begier. 2009. Wildlife strikes to civil aircraft in the United States1990–2009. U.S. Department of Transportation, Federal Aviation Administration, Office of Airport Safety and Standards, Serial Report 15, Washington, D.C., USA.

Dolbeer, R. A., S. E. Wright, J. Weller, and M. J. Begier. 2011. Wildlife strikes to civil aircraft in the United States 1990–2008. U.S. Department of Transportation, Federal Aviation Administration, Office of Airport Safety and Standards, Serial Report 16, Washington, D.C., USA.

Dunning, J. B. 1993. Avian body masses. CRC, Boca Raton, Florida, USA.

Eschenfelder, P. 2000. Jet engine certification standards. Proceedings of the International Bird Strike Committee 25:535–540.

Gabrey, S. W., and R. A. Dolbeer. 1996. Rainfall effects on bird–aircraft collisions at two United States airports. Wildlife Society Bulletin 24:272–275.

Marra, P. P., C. J. Dove, R. A. Dolbeer, N. F. Dahlan, M. Heacker, J. F. Whatton, N. E. Diggs, C. France, and G. A. Henkes. 2009. Migratory Canada geese cause crash of US Airways Flight 1549. Frontiers in Ecology and the Environment 7:297–301.

Pochop, P. A., J. L. Cummings, K. L. Wedemeyer, R. M. Engemean, and J. W. Davis, Jr. 1999. Vegetation preferences of captive Canada geese at Elmendorf Air Force Base, Alaska. Wildlife Society Bulletin 27:734–740.

Richardson, W. J., and T. West. 2000. Serious birdstrike accidents to military aircraft: updated list and summary. Proceedings of the International Bird Strike Committee 25:67–98.

Sauer, J. R., J. E. Hines, and J. Fallon. 2008. The North American breeding bird survey, results and analysis, 1996–2007. U.S. Geological Survey Patuxent Wildlife Research Center, Laurel, Maryland, USA.

Seamans, T. W., D. W. Hamershock, and G. E. Bernhardt. 1995. Determination of body density for twelve bird species. Ibis 137:424–428.

Seamans, T. W., and K. C. VerCauteren. 2006. Evaluation of ElectroBraid^{TM} fencing as a white-tailed deer barrier. Wildlife Society Bulletin 34:8–15.

Sheffield, L. M., J. R. Crait, W. D. Edge, and G. Wang. 2001. Response of American kestrels and gray-tailed voles to vegetation height and supplemental perches. Canadian Journal of Zoology 79:380–385.

Thorpe, J. 2005. Fatalities and destroyed aircraft due to bird strikes, 2002–2004 (with an appendix of animal strikes). Proceedings of the International Bird Strike Committee 27:17–24.

Thorpe, J. 2010. Update on fatalities and destroyed civil aircraft due to bird strikes with appendix for 2008 & 2009. Proceedings of the International Bird Strike Committee 29:1–9.

Van Belle, J., J. Shamoun-Baranes, E. Van Loon, and W. Bouten. 2007. An operational model predicting autumn bird migration intensities for flight safety. Journal of Applied Ecology 44:864–874.

VerCauteren, K. C., T. R. VanDeelen, M. J. Lavelle, and W. H. Hall. 2010. Assessment of abilities of white-tailed deer to jump fences. Journal of Wildlife Management 74:1378–1381.

Washburn, B. E., S. C. Barras, and T. W. Seamans. 2007. Foraging preferences of captive Canada geese related to turfgrass mixtures. Human–Wildlife Conflicts 1:214–223.

Whittingham, M. J., and C. L. Devereux. 2008. Changing grass height alters foraging site selection by wintering farmland birds. Basic and Applied Ecology 9:779–788.

Zakrajsek, E. J., and J. A. Bissonette. 2005. Ranking the risk of wildlife species hazardous to military aircraft. Wildlife Society Bulletin 33:258–264.

Associate Editor: Breck.