

Population increases of large birds in North America pose challenges for aviation safety

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Abstract: There is a strong correlation between bird mass and the likelihood of aircraft damage during a bird–aircraft collision. Thus, the U.S. Federal Aviation Administration (FAA) has established airworthiness standards related to bird mass for engines, airframes, and windshields. Most standards use large (1.8 kg) and medium (1.1 kg) birds as benchmarks (the empennage and certain large turbofan engines use a 3.6-kg bird). There are 20 large (≥ 1.8 kg) and 16 medium (1.1–1.7 kg) bird species in North America with ≥ 20 strikes reported for civil aircraft (FAA National Wildlife Strike Database), 1990 to 2018. I analyzed the population changes of these 36 species from 1990 to 2018 in relation to flocking behavior. For the 20 large species, the combined population had a net gain of 27.8 million birds (129% increase). For the 16 medium species, the combined population had a net gain of 6.7 million birds (20% increase). Notably, all 9 species with body mass ≥ 3.6 kg indicated population increases. In agreement with the increased numbers of birds, the number of strikes involving large and medium birds showed significant ($P < 0.01$) positive trends from 1990 to 2020 as did strikes involving multiple birds. The threat to aviation safety from large and medium birds, especially flocking species, was much higher in 2018 than in 1990. Although progress is being made to mitigate the risk by management programs to keep large and medium birds away from airport properties, these actions do little to mitigate the threat during climb and approach phases of flight. Enhanced airworthiness standards for aircraft components, bird-detecting radar to provide real-time warnings, and aircraft lighting schemes to improve visibility of aircraft to birds are priority areas of research and development to mitigate these off-airport threats to aviation safety.

Key words: aircraft, airport, airworthiness standards, bird mass, bird strike, damage, flocking

ABOUT 72% OF BIRD STRIKES to civil aircraft occur at ≤ 152 m above ground level during takeoff and landing (Dolbeer et al. 2019). Thus, implementation of integrated management programs to reduce populations of birds hazardous to aircraft in airport environments is essential to minimize bird strikes (Cleary and Dolbeer 2005, DeVault et al. 2013). However, given the diversity and mobility of avian species, programs to manage birds at airports will never exclude all hazardous birds from aircraft movement areas and will do nothing to prevent strikes outside the airport environment. Because there is a strong correlation between bird mass and the likelihood of aircraft damage during a bird–aircraft collision (Dolbeer et al. 2000, DeVault et al. 2011), a second critical component to reduce the risk and economic cost of bird strikes is the development of airworthiness standards for airframes, windshields, and engines, including shielding of important aircraft systems, that ensure aircraft can operate safely in the event of a bird strike. A third component involves the restriction of airspeeds to 250 knots (129 m/second) below 3,048 m

(Code of Federal Regulations 2013).

The U.S. Federal Aviation Administration (FAA) has developed airworthiness standards for airframes and windshields of transport aircraft (>19 passenger seats) using a single 1.8-kg bird as the maximum mass that must be tested (with the exception of a 3.6-kg bird for the empennage). Standards for commuter aircraft (10–19 seats) are less stringent (FAA 2001). The bird mass required for turbine-engine testing varies by engine size but generally involves 1–3 birds with masses of 1.1 kg (medium bird test) and a single 1.8 or 3.6-kg bird (large bird test; Croft 2011, 14 CFR Part 33-77). For the large bird test, the engine does not have to keep operating after the ingestion to pass these standards; rather, the engine must contain the damage, not catch fire, and be capable of shut-down. MacKinnon et al. (2001) provide a more detailed discussion of airworthiness standards related to bird strikes.

The forced landing of U.S. Airways flight 1549 in the Hudson River in January 2009 after Canada geese (*Branta canadensis*; mean body mass >3.6



Figure 1. On January 15, 2009, U.S. Airways Flight 1549 (Airbus 320), with 155 persons aboard, made a forced landing in the Hudson River after ingesting Canada geese (*Branta canadensis*; mean mass >3.8 kg) into both engines. The strike occurred at about 870 m above ground level and 8 km from LaGuardia Airport, New York, USA, where the aircraft had just departed. This incident highlights the risk to aviation posed by large, flocking species of birds, especially at altitude outside the airport boundaries where traditional wildlife management techniques are not effective. Most turbofan engines are not certified to withstand the impact of birds with a mass >1.8 kg and none are certified for birds >3.6 kg (photo courtesy of S. Day, Associated Press).

kg) were ingested in both engines on an Airbus 320 (Marra et al. 2009, National Transportation Safety Board 2010; Figure 1) motivated the aviation industry to review engine certification standards related to birds. In March 2013, the FAA tasked the Aviation Rulemaking Advisory Committee (ARAC) to review the standards and advisory material for bird ingestion requirements of turbofan engines used on commercial aircraft. The ARAC recommended changes to testing regarding medium (1.1 kg) birds but left unchanged the tests for large (1.8 kg or 3.6 kg) birds (ARAC 2015).

In a broader context, the need for this review of engine standards was related to the fact that populations of many large bird species had increased in North America since the 1970s when government regulations and programs by public and private organizations were implemented for environmental protection (e.g., pesticide regulation, expansion of wildlife refuge systems, wetlands restoration). Dolbeer and Eschenfelder (2003) determined that populations of most of the bird species in North America with mean body masses ≥ 1.8 kg (large birds) had increased from the 1970s to about 2000. My objective is to update and expand this analysis on population trends for large species as well as for species with mean body masses from 1.1–1.7 kg

(medium birds) that have been struck by civil aircraft from 1990 to 2018. The year 1990 was the initial year of data in the FAA National Wildlife Strike Database (NWSDB; Dolbeer et al. 2019). The goal is to provide objective data on the population numbers, population trends, and flocking characteristics for these large and medium bird species as well as trends in the number of strikes and strikes involving multiple (≥ 2) birds, 1990–2018. This information will assist the FAA, ARAC, military aviation branches, and airport biologists in setting priorities for management actions and new technologies to mitigate the costs and risks of bird strikes.

Methods

I determined from the NWSDB (Dolbeer et al. 2019) the number of strikes, number of strikes causing damage, and number of strikes involving ≥ 2 birds for all bird species in North America with ≥ 20 strikes from 1990 to 2018 and with a mean body mass of ≥ 1.1 kg for at least 1 gender, or if data were unavailable by gender, a mean body mass ≥ 1.1 kg for unknown gender (Dunning 2008). For all analyses, I separated the species into 2 groups to correspond with the standards for bird ingestions into engines: large birds (≥ 1.8 kg) and medium birds (1.1–1.7 kg).

For waterfowl species (ducks and geese [Anatidae]), sandhill cranes (*Grus canadensis*), and wood storks (*Mycteria americana*), the mean population estimate for 1989 to 1991 and 2016 to 2018 was used for 1990 and 2018, respectively (U.S. Fish and Wildlife Service reports; see Appendix A). For other species, population data were obtained for various years from various sources (e.g., U.S. Fish and Wildlife Service reports, the Partners-in-Flight and North America Waterbird Conservation Plan population databases; Appendix A) and projected back to 1990 and forward to 2018 based on index and trend data from the North American Breeding Bird Survey (Sauer 2017). Population estimates were rounded to nearest 1,000.

To calculate the net change in the total population for a species from 1990 to 2018, I subtracted the estimated population in 1990 from the estimated population in 2018. I then divided the net change from 1990 to 2018 by the 1990 population estimate to calculate the percent change in the population, 1990 to 2018. Species with changes of greater than +10%, -10% to +10%, and less than

Table 1. Strike statistics for the 20 large bird species (mean body masses ≥ 1.8 kg) that have been struck by civil aircraft ≥ 20 times in North America, 1990 to 2018. Species are ranked by number of damaging strikes. See Appendix A for scientific names of species.

Damage rank	Species	Body mass (kg) ^a	Strikes with civil aircraft (1990–2018)			Flocking behavior ^b
			Total	% with damage	% with ≥ 2 birds	
1	Canada goose	4.18	1,775	48.8	40.8	Strong
2	Turkey vulture	2.00	817	50.1	5.4	Limited
3	Black vulture	2.16	213	62.0	6.1	Limited
4	Snow goose	2.74	173	72.8	53.2	Strong
5	Bald eagle	5.35	289	36.7	5.9	Limited
6	Great blue heron	2.48	463	18.8	1.7	Limited
7	Sandhill crane	4.80	158	38.6	27.8	Strong
8	Double-crested cormorant	2.09	166	32.5	15.7	Intermediate
9	Greater white-fronted goose	3.00	71	66.2	56.3	Strong
10	Brown pelican	3.70	76	42.1	11.8	Intermediate
11	Wild turkey	7.80	84	29.8	16.7	Intermediate
12	Snowy owl	2.28	309	7.8	0.6	Solitary
13	Common loon	5.46	42	54.8	0.0	Solitary
14	Tundra swan	7.20	23	73.9	52.2	Strong
15	American white pelican	6.33	23	65.2	39.1	Strong
16	Greater black-backed gull	1.83	128	9.4	8.6	Limited
17	Greater sage-grouse	3.19	41	29.3	36.6	Strong
18	Wood stork	2.70	21	28.6	19.0	Intermediate
19	Golden eagle	4.63	25	24.0	4.0	Limited
20	Glaucous gull	1.86	40	10.0	12.5	Intermediate
Totals			4,937	41.8	22.1	

^aMean body mass of heavier gender, or if gender unknown, mean body mass of all birds in sample (Dunning 2008).

^bBased on % of strikes in which multiple birds were struck by aircraft (Strong = $\geq 20\%$; Intermediate = 10–19%; Limited = 1–9%; Solitary = $<1\%$).

-10% were classified as increasing, unchanged, or decreasing, respectively.

I objectively classified the flocking behavior of each species using data on the percentage of strikes involving multiple (≥ 2 birds) from 1990 to 2018: $\geq 20\%$ = strong flocking; 10–19% = intermediate flocking; 1–9% = limited flocking; and $<1\%$ = solitary. I also provided a summary of strike data for species with body masses ≥ 1.1 kg struck <20 times by civil aircraft in North America from 1990 to 2018.

I examined trends in reported strikes with large and medium bird species for 1990 to 2018 by linear regression analysis (Steele and Torrie 1960). I also examined trends in strikes involving multiple birds.

Results

Number of large and medium species and flocking behavior

There were 20 large species with ≥ 20 strikes, 1990 to 2018 (Table 1; Appendix A). These 20

Table 2. Strike statistics for the 16 medium bird species (mean body masses 1.1–1.7 kg) that have been struck by civil aircraft ≥20 times in North America, 1990 to 2018. Species are ranked by number of damaging strikes. See Appendix A for scientific names of species.

Damage rank	Species	Body mass (kg) ^a	Strikes with civil aircraft (1990–2018)			Flocking behavior ^b
			Total	% with damage	% with ≥2 birds	
1	Red-tailed hawk	1.22	2,944	13.7	2.3	Limited
2	Mallard	1.25	1,063	20.3	22.5	Strong
3	Herring gull	1.15	1,442	9.0	10.3	Intermediate
4	Osprey	1.57	427	23.2	1.4	Limited
5	Great horned owl	1.56	299	13.0	0.7	Solitary
6	Glaucous-winged gull	1.18	138	18.8	12.3	Intermediate
7	Swainson’s hawk	1.11	175	13.1	2.9	Limited
8	Anhinga	1.23	45	48.9	13.3	Intermediate
9	Ring-necked pheasant	1.32	95	18.9	6.3	Limited
10	Western gull	1.13	157	11.5	7.6	Limited
11	Brant	1.37	51	31.4	29.4	Strong
12	Western grebe	1.43	48	31.3	20.8	Strong
13	Canvasback	1.25	27	51.9	33.3	Strong
14	American black duck	1.40	69	11.6	27.5	Strong
15	Crested caracara	1.22	23	26.1	4.3	Limited
16	Ferruginous hawk	1.78	44	11.4	0.0	Solitary
Totals			7,047	15.0	8.0	

^aMean body mass of heavier gender, or if gender unknown, mean body mass of all birds in sample (Dunning 2008).

^bBased on % of strikes in which multiple birds were struck by aircraft (Strong = ≥20%; Intermediate = 10–19%; Limited = 1–9%; Solitary = <1%).

Table 3. Estimated change in North American population from 1990 to 2018 for 36 bird species with mean body masses ≥1.1 kg that have been struck by civil aircraft ≥20 times in North America, 1990 to 2018 (see Tables 1, 2, 5 and 6 for data on individual species).

Bird mass	Number of species	Estimated population ^a		Population change ^b	
		1990	2018	Net	Percent
Large (≥1.8 kg)	20	21,621,000	49,448,000	27,827,000	129
Medium (1.1–1.7 kg)	16	33,796,000	40,508,000	6,712,000	20
Total	36	55,417,000	89,956,000	34,539,000	62

^aSee Appendix A for sources of population estimates and trend data.

^bPercent change = 100 * Net population change/population estimate for 1990.

species had 4,937 strikes reported, of which 42% caused damage and 22% involved multiple birds. Flocking behavior was strong, intermediate, limited, and solitary for 7, 5, 6, and 2 of the 20 large species, respectively (Table 1).

There were 16 medium species with ≥20 strikes from 1990 to 2018 (Table 2; Appendix A). These

16 species had 7,047 strikes reported, of which 15% caused damage and 8% involved multiple birds. Flocking behavior was strong, intermediate, limited, and solitary for 5, 3, 6, and 2 of the 16 medium species, respectively (Table 2).

There were 15 large (≥1.8 kg) and 17 medium (1.1–1.7 kg) species that were struck <20 times by

Table 4. Net change in estimated population by flocking behavior for 36 species of birds in North America with mean body masses ≥ 1.1 kg and at least 20 strikes with civil aircraft, 1990 to 2018 (see Tables 1, 2, 5 and 6 for data on individual species).

Body mass (kg)	Net change in population (1990–2018)				Total
	Flocking behavior ^a				
	Strong	Intermediate	Limited	Solitary	
1.1–1.7	5,029,000	-249,000	1,918,000	14,000	6,712,000
≥ 1.8	16,260,000	3,560,000	7,857,000	150,000	27,827,000
Total	21,289,000	3,311,000	9,775,000	164,000	34,539,000

^aBased on percent of strikes in which multiple birds were struck by aircraft (Strong = $\geq 20\%$; Intermediate = 10–19%; Limited = 1–9%; Solitary = $< 1\%$).

Table 5. Estimated change in North American population from 1990 to 2018 for 20 large bird species (mean body masses ≥ 1.8 kg) that have been struck by civil aircraft ≥ 20 times in North America, 1990 to 2018. Species are listed in descending order by net population change.

Species	Estimated population ^a		Population change ^b	
	1990	2018	Net	Percent
Snow goose	4,270,000	15,120,000	10,850,000	254
Turkey vulture	4,807,000	10,469,000	5,662,000	118
Canada goose ^c	3,112,000	7,499,000	4,387,000	141
Wild turkey ^c	3,900,000	6,200,000	2,300,000	59
Black vulture	616,000	2,756,000	2,140,000	347
Double-crested cormorant	460,000	2,259,000	1,799,000	391
Greater white-fronted goose	1,023,000	1,587,000	564,000	55
American white pelican ^c	53,000	567,000	514,000	969
Brown pelican ^c	107,000	423,000	316,000	296
Bald eagle ^c	35,000	230,000	195,000	556
Common loon ^c	548,000	698,000	150,000	27
Sandhill crane ^c	473,000	609,000	136,000	29
Wood stork	196,000	248,000	52,000	26
Tundra swan ^c	16,000	56,000	40,000	253
Great blue heron	74,000	96,000	22,000	30
Golden eagle ^c	57,000	64,000	7,000	12
Snowy owl	30,000	30,000	0	0
Greater black-backed gull	252,000	83,000	-169,000	-67
Greater sage-grouse	652,000	409,000	-243,000	-57
Glaucous gull	940,000	45,000	-895,000	-95
Total	21,621,000	49,448,000	27,827,000	129

^aSee Appendix A for sources of population estimates and trend data.

^bPercent change = $100 \times \text{Net population change} / \text{population estimate for 1990}$.

^cSpecies with body masses > 3.6 kg (Table 1).

civil aircraft in North America from 1990 to 2018 (Appendix B). These 32 species had 195 strikes reported (1.6% of the 11,984 strikes reported for the 36 species with ≥ 20 strikes), of which 34% caused damage and 14% involved multiple birds.

Population changes

From 1990 to 2018, 26 of the 36 species with mean body masses ≥ 1.1 kg indicated population increases, 5 indicated declines, and 5 had no change (Table 3). The combined population

Table 6. Estimated change in North American population from 1990 to 2018 for 16 medium bird species (mean body masses 1.1–1.7 kg) that have been struck by civil aircraft ≥ 20 times in North America, 1990 to 2018. Species are listed in descending order by net population change.

Species	Estimated population ^a		Population change ^b	
	1990	2018	Net	Percent
Mallard	6,689,000	11,598,000	4,909,000	73
Red-tailed hawk	1,960,000	3,065,000	1,105,000	56
Osprey	194,000	547,000	353,000	183
Swainson's hawk	646,000	861,000	215,000	33
Canvasback	503,000	718,000	215,000	43
Crested caracara	28,000	163,000	135,000	485
Ring-necked pheasant	17,397,000	17,499,000	102,000	1
Western grebe	101,000	137,000	36,000	36
Anhinga	21,000	54,000	33,000	150
Ferruginous hawk	89,000	117,000	28,000	32
Brant	280,000	303,000	23,000	8
Western gull	84,000	92,000	8,000	10
Great horned owl	4,011,000	3,997,000	-14,000	0
Glaucous-winged gull	392,000	358,000	-34,000	-9
American black duck	970,000	816,000	-154,000	-16
Herring gull	431,000	183,000	-248,000	-58
Total	33,796,000	40,508,000	6,712,000	20

^aSee Appendix A for sources of population estimates and trend data.

^bPercent change = $100 \times \text{Net population change} / \text{population estimate for 1990}$.

Table 7. Population status (increase, no change, decrease)^a for 36 species of birds in North America with mean body masses ≥ 1.1 kg and at least 20 strikes with civil aircraft, 1990 to 2018 (see Tables 1, 2, 5, and 6 for data on individual species). Species are classified by flocking behavior.

Flocking behavior ^b	20 species ≥ 1.8 kg			16 species 1.1–1.7 kg		
	Increase	Decrease	No change	Increase	Decrease	No change
Strong	6	1		3	1	1
Intermediate	4	1		1	1	1
Limited	5	1		5		1
Solitary	1		1	1		1
Totals	16	3	1	10	2	4

^aIncrease = Population change greater than +10%; No change = -10% to +10%; Decrease = less than -10%.

^bBased on % of strikes in which multiple birds were struck by aircraft (Table 1; Strong = $\geq 20\%$; Intermediate = 10–19%; Limited = 1–9%; Solitary = $<1\%$).

of these 36 species showed a net gain of 34.5 million birds (62% increase). Bird species with strong flocking behavior were responsible for 21.3 million (62%) of the net gain of 34.5 million birds (Table 4).

Large species. From 1990 to 2018, 16 of the 20 species indicated population increases, 3 indi-

cated declines, and 1 had no change (Tables 5 and 7). The combined population of large species showed a net gain of 27.8 million birds (129% increase; Table 5). Snow geese (*Anser caerulescens*; 10.9 million), turkey vultures (*Cathartes aura*; 5.7 million), Canada geese (*Branta canadensis*; 4.4 million), wild turkeys

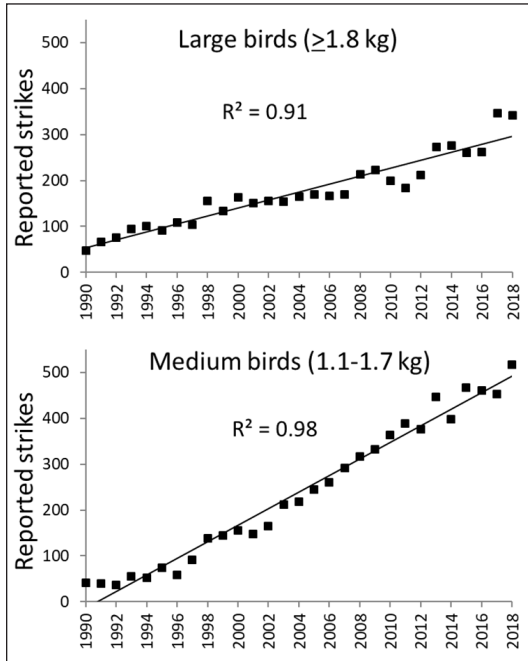


Figure 2. Trend in number of strikes in National Wildlife Strike Database involving large (≥ 1.8 kg; top graph) and medium (1.1–1.7 kg) bird species (bottom graph) in North America, 1990–2018. See Tables 1, 2, and Appendix B for total number of strikes by species. R^2 values >0.33 indicate a significant trend (linear regression) at the 0.01 level of probability (Steele and Torrie 1960).

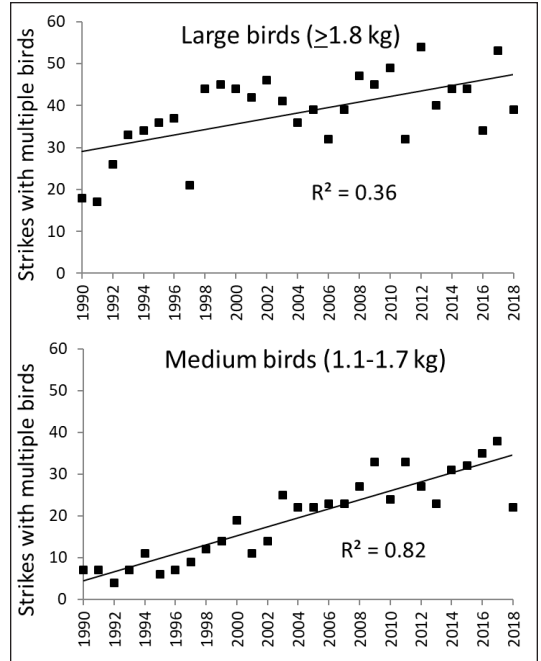


Figure 3. Trend in number of strikes in National Wildlife Strike Database involving large (≥ 1.8 kg; top graph) and medium (1.1–1.7 kg) bird species (bottom graph) in which multiple (≥ 2) birds were struck in North America, 1990–2018. See Tables 1, 2, and Appendix B for total number of strikes by species. R^2 values >0.33 indicate a significant trend (linear regression) at the 0.01 level of probability (Steele and Torrie 1960).

(*Meleagris gallopavo*, 2.3 million), black vultures (*Coragyps atratus*; 2.1 million), and double-crested cormorants (*Phalacrocorax auratus*; 1.8 million) had the greatest increases. These 6 species accounted for 97% of the net population increase (Table 5). Notably, all 9 species with body mass ≥ 3.6 kg, including 7 with strong or intermediate flocking behavior, indicated population increases since 1990 (Table 5). The 7 large species with strong flocking behavior contributed 59% (16.3 million) of the 27.8 million net increase in large bird numbers (Tables 1 and 5).

Medium species. From 1990 to 2018, 10 of the 16 species indicated population increases, 2 indicated declines, and 4 had no change (Tables 6 and 7). The combined population of medium species showed a net gain of 6.7 million birds (20% increase, Table 6). Mallards (*Anas platyrhynchos*; 4.9 million) and red-tailed hawks (*Buteo jamaicensis*; 1.1 million) contributed 90% of the net increase for medium birds. Three species with strong flocking behavior (mallard, canvasback [*Aythya valisineria*], and western

grebe [*Aechmophorus occidentalis*]) contributed 75% of the net gain of 6.7 million birds in the population (Tables 2 and 6).

Trends in reported strikes and strikes involving multiple birds

The number of strikes per year involving large and medium bird species showed significant ($P < 0.01$) positive trends from 1990 to 2020 (Figure 2). Strikes involving large species increased from <100 annually in the early 1990s to >300 during 2017–2018. Strikes involving medium species increased from about 50 annually in the early 1990s to >400 during 2017–2018. Strikes involving multiple birds also showed positive trends for large and medium bird species (Figure 3).

Discussion

A meta-analysis by Rosenberg (2019) indicated that the overall bird population in North America had declined by 3 billion birds (29%) since 1970 with the decline primarily coming from small species such as grassland birds and neotropical migrants. In contrast to this overall

decline, my analysis indicates that populations of most large and medium (≥ 1.1 kg) bird species have increased, many substantially. Thus, the threat to aviation safety from large and medium bird species, especially flocking species, was much higher in 2018 than in 1990. In agreement with the increased numbers of large and medium bird species, the number of strikes involving large and medium bird species also increased from 1990 to 2020.

One area of particular concern is the increase in strikes involving multiple birds of these large and medium bird species from 1990 to 2018. Commercial air carriers have replaced their older 3- or 4-engine aircraft fleets with more efficient and quieter 2-engine aircraft. In 2017, only 4% of the 6,900 turbine-powered aircraft registered in the United States had 3 or 4 engines compared to 40% in 1990 (Aeroweb 2020, U.S. Department of Transportation 2020). In the event of a multiple ingestion event with large or medium flocking birds (e.g., the US Airways Flight 1549 incident on January 15, 2009), aircraft with 2 engines do not have the added redundancies of their 3- or 4-engine counterparts. In addition, previous research has indicated that birds are less able to detect and avoid modern jet aircraft with quieter turbofan engines (Chapter 3, International Civil Aviation Organization 1993) than older aircraft with noisier (Chapter 2) engines (Burger 1983, Kelly et al. 1999).

Management implications

Although progress is being made to mitigate risks of bird strikes by management programs to keep large and medium birds away from airport properties (Dolbeer et al. 2014, Rutledge et al. 2015, Begier et al. 2019, Dolbeer et al. 2019, Washburn 2019), these actions do little to mitigate the threat during climb and approach phases of flight (Dolbeer 2011). Because wildlife management actions to mitigate these off-airport strikes are limited, enhanced airworthiness standards for aircraft engines and airframes, bird-detecting radar to provide real-time warnings of flocking bird activity (Gerringer et al. 2016, Nohara et al. 2011), and aircraft lighting schemes to enhance visibility of aircraft to birds (Blackwell et al. 2012, Dolbeer and Barnes 2017, Mandernach 2018, Dwyer et al. 2019) are priority areas of research and development to mitigate these threats to aviation safety.

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Appendix A. Scientific names and sources of information on population status for 36 species of birds in North America with a mean body mass ≥ 1.1 kg and ≥ 20 reported strikes with civil aircraft in North America, 1990 to 2018. Species are ranked by body mass.

Body mass rank	Species common name	Species scientific name	Mean mass (kg) ^a	Source for most recent population estimate ^b	Source for population trend (1990–2018) ^b
1	Wild turkey	<i>Meleagris gallopavo</i>	7.80	NWTF 2020, PIF 2019	NWTF 2020, Kobilinsky 2018
2	Tundra swan	<i>Cygnus columbianus</i>	7.20	USFWS 2018	USFWS 2018
3	American white pelican	<i>Pelecanus erythrorhynchos</i>	6.33	Kushlan et al. 2002	Sauer et al. 2017
4	Common loon	<i>Gavia immer</i>	5.46	Evers 2004	Sauer et al. 2017
5	Bald eagle	<i>Haliaeetus leucocephalus</i>	5.35	PIF 2019	Sauer et al. 2017
6	Sandhill crane	<i>Grus canadensis</i>	4.80	Dubovsky 2018	Dubovsky 2018
7	Golden eagle	<i>Aquila chrysaetos</i>	4.63	PIF 2019	Sauer et al. 2017
8	Canada goose	<i>Branta canadensis</i>	4.18	USFWS 2018	USFWS 2018
9	Brown pelican	<i>Pelecanus occidentalis</i>	3.70	Kushlan et al. 2002	Sauer et al. 2017
10	Greater sage-grouse	<i>Centrocercus urophasianus</i>	3.19	PIF 2019	Sauer et al. 2017
11	Greater white-fronted goose	<i>Anser albifrons</i>	3.00	USFWS 2018	USFWS 2018
12	Snow goose	<i>Anser caerulescens</i>	2.74	USFWS 2018	USFWS 2018
13	Wood stork	<i>Mycteria americana</i>	2.70	USFWS 2015	Sauer et al. 2017
14	Great blue heron	<i>Ardea herodias</i>	2.48	Kushlan et al. 2002	Sauer et al. 2017
15	Snowy owl	<i>Bubo scandiacus</i>	2.28	PIF 2019	Audubon CBC 2019
16	Black vulture	<i>Coragyps atratus</i>	2.16	PIF 2019	Sauer et al. 2017
17	Double-crested cormorant	<i>Phalacrocorax auritus</i>	2.09	Kushlan et al. 2002	Sauer et al. 2017
18	Turkey vulture	<i>Cathartes aura</i>	2.01	PIF 2019	Sauer et al. 2017
19	Glaucous gull	<i>Larus hyperboreus</i>	1.86	Kushlan et al. 2002	Audubon CBC 2019
20	Great black-backed gull	<i>Larus marinus</i>	1.83	Kushlan et al. 2002	Sauer et al. 2017
21	Ferruginous hawk	<i>Buteo regalis</i>	1.78	PIF 2019	Sauer et al. 2017
22	Osprey	<i>Pandion haliaetus</i>	1.57	PIF 2019	Sauer et al. 2017

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23	Great horned owl	<i>Bubo virginianus</i>	1.56	PIF 2019	Sauer et al. 2017
24	Western grebe	<i>Aechmophorus occidentalis</i>	1.43	Kushlan et al. 2002	Sauer et al. 2017
25	American black duck	<i>Anas rubripes</i>	1.40	USFWS 2018	Sauer et al. 2017
26	Brant	<i>Branta bernicla</i>	1.37	USFWS 2018	USFWS 2018
27	Ring-necked pheasant	<i>Phasianus colchicus</i>	1.32	PIF 2019	Sauer et al. 2017
28	Canvasback	<i>Aythya valisineria</i>	1.25	USFWS 2018	USFWS 2018
29	Mallard	<i>Anas platyrhynchos</i>	1.25	USFWS 2018	USFWS 2018
30	Anhinga	<i>Anhinga anhinga</i>	1.24	Kushlan et al. 2002	Sauer et al. 2017
31	Red-tailed hawk	<i>Buteo jamaicensis</i>	1.22	PIF 2019	Sauer et al. 2017
32	Crested caracara	<i>Caracara cheriway</i>	1.22	PIF 2019	Sauer et al. 2017
33	Glaucous-winged gull	<i>Larus glaucescens</i>	1.18	Kushlan et al. 2002	Sauer et al. 2017
34	Herring gull	<i>Larus argentatus</i>	1.15	Kushlan et al. 2002	Sauer et al. 2017
35	Western gull	<i>Larus occidentalis</i>	1.14	Kushlan et al. 2002	Sauer et al. 2017
36	Swainson's hawk	<i>Buteo swainsoni</i>	1.11	PIF 2019	Sauer et al. 2017

^aMean body mass of heavier gender, or if gender unknown, mean body mass of all birds in sample (Dunning 2008).

^bAudubon CBC = Audubon Christmas Bird Count; NWTF = National Wild Turkey Federation; PIF = Partners in Flight; USFWS = U.S. Fish and Wildlife Service.

Appendix B. The 32 species of birds in the National Wildlife Strike Database for Civil Aviation with a mean body mass ≥ 1.1 kg and <20 reported strikes with civil aircraft in North America, 1990 to 2018. Species are ranked by body mass.

Body mass rank	Species common name	Species scientific name	Mean mass (kg) ^b	Total strikes	Strikes with damage	Strikes with ≥ 2 birds
1	Trumpeter swan	<i>Cygnus buccinator</i>	11.90	2	2	1
2	Mute swan ^c	<i>Cygnus olor</i>	11.80	9	2	2
3	Whooping crane ^d	<i>Grus americana</i>	5.83	1	1	0
4	Black-footed albatross	<i>Phoebastria nigripes</i>	3.40	5	1	0
5	Laysan albatross ^e	<i>Phoebastria immutabilis</i>	3.30	37	8	1
6	Great cormorant	<i>Phalacrocorax carbo</i>	2.86	2	1	2
7	Muscovy duck ^c	<i>Cairina moschata</i>	2.68	4	1	0
8	Brandt's cormorant	<i>Phalacrocorax penicillatus</i>	2.37	1	1	0
9	Emperor goose	<i>Anser canagica</i>	2.22	2	1	0
10	Common eider	<i>Somateria mollissima</i>	2.18	4	2	1
11	Cackling goose	<i>Branta hutchinsii</i>	2.17	19	11	7
12	Hawaiian goose	<i>Branta sandvicensis</i>	2.07	2	1	1
13	Pelagic cormorant	<i>Phalacrocorax pelagicus</i>	1.92	2	0	0
14	White-winged scoter	<i>Melanitta fusca</i>	1.87	4	3	2

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15	Egyptian goose ^c	<i>Alopochen aegyptiana</i>	1.83	1	0	1
16	Pacific loon	<i>Gavia pacifica</i>	1.75	1	1	0
17	Gyr Falcon	<i>Falco rusticolus</i>	1.71	2	0	0
18	Common merganser	<i>Mergus merganser</i>	1.70	8	2	1
19	Magnificent frigatebird	<i>Fregata magnificens</i>	1.66	8	4	0
20	Great frigatebird	<i>Fregata minor</i>	1.49	13	4	0
21	Roseate spoonbill	<i>Platalea ajaja</i>	1.49	5	1	0
22	Red-throated loon	<i>Gavia stellata</i>	1.44	13	6	0
23	Helmeted guineafowl ^c	<i>Numida meleagris</i>	1.34	2	1	2
24	Clark's grebe	<i>Aechmophorus clarkii</i>	1.28	3	1	1
25	Great gray owl	<i>Strix nebulosa</i>	1.22	2	0	0
26	Red-footed booby	<i>Sula sula</i>	1.15	3	0	0
27	Surf scoter	<i>Melanitta perspicillata</i>	1.15	2	0	0
28	Northern goshawk	<i>Accipiter gentilis</i>	1.14	4	0	0
29	Red-breasted merganser	<i>Mergus serrator</i>	1.13	9	1	1
30	Barrow's goldeneye	<i>Bucephala islandica</i>	1.12	3	0	0
31	Common goldeneye	<i>Bucephala clangula</i>	1.12	8	2	0
32	Redhead	<i>Aythya americana</i>	1.11	14	8	5
	Total			195	66	28

^aList does not include California condor (*Gymnogyps californianus*), which has no strikes reported. However, this species is worth noting because of its large mass (8.8 kg), soaring behavior, and the increase in the wild population from 0 in 1987 to 337 in 2019 (U.S. Fish and Wildlife Service 2019).

^bMean body mass of heavier gender, or if gender unknown, mean body mass of all birds in sample (Dunning 2008).

^cFeral population of non-native species.

^dWild population increased from 159 in 1990 to 668 in 2018 (International Crane Foundation 2019).

^eLaysan albatross was not included in main analysis (species with ≥ 20 strikes) because all strikes were reported from Henderson Field at Midway Atoll, where >70% of the world population of 1.6 million adult birds breed (Dolbeer et al. 1996, U.S. Fish and Wildlife Service 2017). The population was considered stable, 1992–2005 (BirdLife International 2018).