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ABSTRACT: Bird-aircraft collisions (bird strikes) are an increasing safety and economic concern to the USA civil aviation industry, costing over $400 million each year. One approach to reducing risks associated with strikes is to require commercial aircraft components to meet certain standards of safe performance in the event of a bird strike. The Federal Aviation Administration has developed airworthiness standards for airframes, windshields and engines using a single 4-lb (1.82-kg) bird mass as the maximum that must be tested (with the exception of a single 8-lb bird for the empennage, 6-lb bird for certain mid-sized engines that may be developed in the future, and an 8-lb bird for certain large-intake engines on aircraft such as the Boeing 777). Because of concern within the aviation industry that populations of certain flocking bird species weighing more than 4 lbs, such as Canada geese (*Branta canadensis*), have increased dramatically, discussions are underway in the USA and Europe regarding the need to revise 4- and 8-lb test standards to heavier body masses or to include multiple strikes. To help clarify this issue, we surveyed the avian literature and determined that 36 and 14 of the approximately 700 bird species that nest in North America (north of Mexico) have average body masses (for at least 1 gender) greater than 4 and 8 lbs, respectively. Of the 31 species for which population trend data were available, 24 (77%) showed population increases over the past 20-40 years, 2 showed declines and the other 5 were stable. Thirteen of the 14 species with mean body masses over 8 lbs showed population increases, with the remaining 1 species having an unknown population status. Furthermore, multiple birds were involved in 30% of the strikes with >4-lb birds and 39% of the strikes with >8-lb birds. Therefore, we conclude that airframe, windshield and engine standards should be reevaluated to address the threat posed by increased populations of large flocking birds. Furthermore, because most critical aircraft components are not designed to withstand strikes by birds greater than 4 lbs, wildlife biologists who work at airports should increase efforts to detect, remove and disperse these large birds from airport environments.

KEY WORDS: aircraft, airframe, airport, bird strike, engine, Federal Aviation Administration, mass, safety, standards, windshield

INTRODUCTION

Aircraft collisions with birds (bird strikes) are a serious economic and safety problem. Cleary et al. (2002) estimated wildlife strikes (97.5% involving birds) cost the civil aviation industry in the USA over $400 million/year, 1990-2000. Allan (2002) projected that bird strikes annually cost commercial aviation over $1.2 billion worldwide in 1999-2000. At least 138 people died worldwide as a result of bird strikes from 1990-2000 (Thorpe 1996, 1998; Richardson and West 2000; Dolbeer, unpublished data).

About 71% of bird strikes to civil aircraft occur below 500 feet during takeoff and landing (Cleary et al. 2002). Thus, implementation of integrated management programs to reduce bird populations in airport environments is essential to minimize bird strikes (Cleary and Dolbeer 1999). However, given the diversity and mobility of avian species, programs to manage bird hazards at airports will never exclude all birds from aircraft movement areas (e.g., Dolbeer 1999) and will do nothing to prevent strikes outside the airport environment. Therefore, a second critical component to reduce the hazards and economic costs of bird strikes is the development of airworthiness standards for airframes, windshields and engines that ensure aircraft can operate safely in the event of a bird strike.

The Federal Aviation Administration (FAA) has developed airworthiness standards for airframes and windshields of transport aircraft (>19 passenger seats) using a single 4-lb (1.82 kg)

bird as the maximum-sized mass that must be tested (with the exception of 8 lbs [3.64 kg] for the empennage). Standards for commuter aircraft (10-19 seats) are less stringent (Table 1). The maximum mass required for turbine-engine testing is a single 4-lb bird for most engines currently in service, a single 6-lb bird for certain mid-sized engines that may be developed in the future, and a single 8-lb bird for certain large-intake engines used on new wide-bodied aircraft such as the Boeing 777. The engine does not have to keep operating after a 4-, 6- or 8-lb bird ingestion to pass these standards; rather, the engine must contain the damage, not catch fire and be capable of shut-down (Table 1). MacKinnon et al. (2001) provide a more detailed discussion of airworthiness standards related to bird strikes.

Table 1. Maximum bird masses required in tests for airworthiness standards for airframes, windshields, and engines for transport- (>19 passenger seats) and commuter- (10-19 passenger seats) category aircraft, U.S. Federal Aviation Administration (FAA).

Aircraft category	Aircraft component	Federal Aviation Regulation	Latest update of standard	Max. bird mass (lbs)	Comments
Transport	Airframe	Part 25.571	1978	4	Safely complete flight after striking 1 4-lb bird at design cruise speed (V_C)
Transport	Empennage	Part 25.631	1970	8	Safely complete flight after striking 1 8-lb bird at design cruise speed (V_C)
Transport	Windshield	Part 25.775	1977	4	Withstand impact of 4-lb bird w/o penetration at design cruise speed (V_C)
Transport/ commuter	Turbine engine	Part 33.76	2000	4-8[a]	Engine will not catch fire, have uncontained failure, or lose capacity to be shut down
Commuter	Airframe/ empennage				No standards
Commuter	Windshield	Part 23.775	1996	2	Withstand impact of 1 2-lb bird at maximum approach flap speed (V_{FE})

[a] One 4-lb bird for most existing aircraft engines, 1 6-lb bird for certain mid-sized engines that may be developed in the future; 1 8-lb bird for large-intake (3.9 m^2) engines (RR Trent, P&W 4084, GE90) for new wide-bodied aircraft such as Boeing 777.

Aggressive programs by natural resource and environmental agencies and organizations during the past 30 years (e.g., pesticide regulation, expansion of wildlife refuge system), coupled with land-use changes, have resulted in dramatic increases in populations of many wildlife species in North America (Dolbeer 2000). In addition, certain of these wildlife species that are a proven threat to aviation, such as Canada geese (*Branta canadensis*) (Cleary et al. 2000), have adapted to urban environments (Smith et al. 1999), making the risk of wildlife strikes at airports much greater. Because of concern within the aviation industry with populations of large bird species, discussions are underway in North America (FAA and Transport Canada) and Europe (Joint Aviation Authorities) regarding the need to revise the 4- and 8-lb test standards to heavier body masses or to include multiple strikes by these large birds as part of the standards (e.g., MacKinnon et al. 2001, Eschenfelder 2001).

To help clarify this issue, we surveyed the avian literature to determine the number, flocking characteristics, and population status of bird species with body masses greater than 4

and 8 lbs that inhabit North America. In addition, we determined the reported number of single and multiple bird strikes involving these species for civil aircraft in the USA, 1990-2001. Our goal is to provide objective data on the numbers, population trends, flocking characteristics, and strike patterns for these large bird species to aide regulatory bodies, engineers and biologists in developing standards and strategies to reduce the costs and hazards of bird strikes.

METHODS

Alsop (2001) was our primary reference source to initially screen, from the approximately 700 bird species that nest in North America (USA, Canada and Caribbean Islands), those species having a mean body mass approximating 4 lbs or more. This list was refined by examining data on avian body masses from Dunning (1993) and other sources. Those species included in the final list had a mean body mass >4.0 lbs for at least one gender, or if data were unavailable by gender, a mean body mass >4.0 lbs for unknown gender.

We obtained population data (numbers of birds and mean annual % change in numbers) for each species from various sources such as the North American Breeding Bird Survey (BBS), Christmas Bird Counts (CBC), North American Waterfowl Survey reports, North America Waterbird Conservation Plan, and the scientific literature. For BBS or CBC data, populations were classified to be increasing or decreasing if a significant ($P < 0.05$) mean annual percent change was detected for the years considered (generally 1966-2000 for BBS data; 1959-1988 for CBC data; Sauer et al. 1996, 2001). For other species, we calculated the mean annual percent change from a baseline year (earliest year [1959-1987] for which a reliable population estimate was available) and the most current (1994-2001) population estimate (Belant and Dolbeer 1993). Sources of information for each species are listed in Appendix 1.

We subjectively classified the social behavior of each species relevant to bird strikes as strongly flocking, limited flocking, or generally solitary based on our general knowledge of the species and discussions among ornithologists. We also classified each species as soaring or non-soaring. Finally, we determined the number of reported strikes to civil aircraft in the USA involving these species, 1990-2001 (Cleary et. al. 2002, S. E. Wright, U.S. Department of Agriculture, unpublished data). We also noted for each reported strike event whether a single bird or multiple birds were struck.

RESULTS

Thirty-six species, about 5% of the approximately 700 species that breed in North America, had mean body masses >4 lbs for at least 1 gender (Table 2). Of the 31 species for which a population trend could be estimated, 24 (77%) indicated increases, 2 (6%) indicated declines and 5 (16%) were stable (Table 3). All 13 (100%) of the 14 species with body masses above 8 lbs for which a population trend could be estimated indicated population increases.

Table 2. Population status for 36 bird species in North America that have mean body mass for at least 1 gender >4 pounds (see Appendix 1 for more detailed mass data and sources of information).

Rank	Common Name	Mean mass (lb)	Population status				Comments
			Years covered	Trend	MAPC[a]	Most recent population estimate[b]	
1	Mute swan	26.01	1966-2000	Increase	13.9	7,000	Maryland population increased from 5 (1962) to 4,000 (1999)
2	Trumpeter swan	25.13	1968-2000	Increase	5.9	23,647	Pop increased from about 3,722 (1968) to 23,647 (2000)
3	California condor	22.28	1987-2001	Increase		54	Wild pop. increased from 0 (1987) to 54 (2001)
4	Wild turkey	16.31	1959-1994	Increase	6.1	4,000,000	Population increased from 500,000 (1959) to 4,000,000 (1994)
5	Tundra swan	15.65	1970-2001	Increase	1.7	189,000	Both western and eastern populations are increasing
6	American white pelican	15.43	1980-2000	Increase	2.9	120,000	USA pop. had 4.8% MAPC, USA/Canada breeding pop. estimate
7	Whooping crane	12.84	1966-2000	Increase	5.8	282	Wild population increased from 42 in 1966 to 282 in 2000
8	Sandhill crane	12.78	1966-2000	Increase	6.9	520,000	Total population estimate for 1995
9	Yellow-billed loon	12.13	2001	Unknown		>3,000	Alaska population estimated at ~3,000
10	Bald eagle	11.79	1966-2000	Increase	8.0	70,000	Breeding pop. in contiguous USA:1,582 (1974), 11,496 (1998)
11	Golden eagle	10.83	1980-2000	Increase	4.8		
12	Canada goose	9.22	1966-2000	Increase	10.5	4,900,000	Estimate for resident USA population is about 3,000,000
13	Common loon	9.11	1966-2000	Increase	2.9		
14	Brown pelican	8.16	1980-2000	Increase	2.1	93,000	Breeding population in USA
15	Greater flamingo	7.80	1970s-2000	Increase		>245,000	Caribbean Islands, coastal Yucatan & Venezuela
16	Snow goose[c]	7.61	1980-2000	Increase	3.1	3,927,000	Greater (eastern) subspecies has MAPC of 8.2 %, 1970-2000
17	Arctic loon	7.40	2001	Unknown		>100	About 100 individuals nest in extreme W and NW Alaska
18	Laysan albatross	7.12	1962-1995	Increase	4.4	>775,708	Estimate for Midway Atoll (71% of total pop in 1996)
19	Greater sage grouse	7.03	1980-1999	Decline		>140,000	Estimated decline from 1980 to 1999 was 35-80%.
20	Black-footed albatross	6.94	1958-1998	Increase	2.2	>170,000	Pop. trend estimate for Midway Atoll (40,480 birds in 1998)
21	Northern gannet	6.76	1959-1988	Increase	6.1	155,000	Pop. trend estimate for 1959-1988, pop. estimate for 2001
22	Emperor goose	6.05	1984-2001	Stable		84,000	
23	Greater white-fronted goose	5.96	1980-2001	Increase	8.2	1,375,000	Trend is for Pacific pop.; total pop for Pacific & Mid-continent
24	Wood stork	5.96	1983-2000	Increase	>2.4	>32,000	USA population is about 12,000
25	Great blue heron	5.68	1966-2001	Increase	2.4	266,000	Population estimate in 1997
26	Red-faced cormorant	5.57	2001	Stable		<50,000	Breeding population
27	Double-crested cormorant	5.15	1966-2000	Increase	10.1	>744,000	
28	Great cormorant	5.03	2001	Unknown		11,600	Breeding population
29	Snowy owl	5.02	1959-1988	Stable			
30	Common eider	4.89		Unknown			
31	Black vulture	4.79	1966-2000	Increase	2.7		
32	Brandt's cormorant	4.64	2001	Stable		151,000	
33	Masked booby	4.62	2001	Unknown		~100,000	Body mass data from Hawaii; Pop. data from Caribbean/Hawaii
34	Pelagic cormorant	4.48	1966-2000	Stable		130,000	
35	Turkey vulture	4.21	1966-2000	Increase	1.5		
36	Great black-backed gull	4.03	1966-2000	Decline	-2.0	121,000	Breeding population

[a]MAPC = Mean percent annual change for years indicated based either on North American Breeding Bird Survey estimate or by calculating MAPC from estimated population in first and last year covered (Belant and Dolbeer 1993).
[b]Population estimate for most species represents adult breeding population and does not include subadult birds.
[c]Body mass presented is for "greater" subspecies, "lesser" subspecies mean body mass = 6.05 lbs.

Twenty-four (67%) of the 36 species exhibit strong flocking behavior, 9 (25%) exhibit limited flocking behavior, and only 3 (8%) exhibit solitary behavior (Tables 3, 4). Five (14%) of the species regularly exhibit soaring behavior.

Seventeen of the 36 species were not involved in a reported strike with civil aircraft in the USA, 1990-2001 (Table 4). The 19 species reported as struck were involved in 1,529 strikes of which 30% involved multiple birds. The 9 struck species with body masses >8 lbs were involved in 1,033 strikes of which 39% involved multiple birds. Sixteen (84%) of these 19 struck species have exhibited population increases; all 9 (100%) of the species with body masses >8 lbs showed population increases (Table 5). Seventeen of the 19 struck species exhibit strong (12) or limited (5) flocking behavior.

Table 3. Summary of population trend estimates and flocking and soaring characteristics for 36 species of birds in North America with mean body masses >4 lbs for at least 1 gender.

Body-mass category	Number of species	Species exhibiting population:					Species exhibiting[a]:		
		In-crease	De-crease	Sta-bility	Un-known		Strong flocking	Limited flocking	Solitary behavior
4-8 lbs	22	11	2	5	4		15 (0)	6 (2)	1 (0)
>8 lbs	14	13	0	0	1		9 (0)	3 (1)	2 (2)
Total	36	24	2	5	5		24 (0)	9 (3)	3 (2)

[a] Values in parentheses are the number of species exhibiting soaring behavior.

Table 4. Flocking and soaring behavior for 36 species of birds in North America that have mean body mass for at least 1 gender >4 pounds ranked by number of reported strikes to civil aircraft in USA from 1990-2001 involving these species.

Species	Mean mass (lb)	Flocking/ soaring behavior [a]	Reported strikes	
			Total number	No. (%) involving >1 bird [b]
Canada goose	9.22	Strong flocking	529	238 (46)
Turkey vulture	4.21	Limited flocking/soaring	138	8 (6)
Great blue heron	5.68	Limited flocking	94	2 (2)
Bald eagle	11.79	Limited flocking/soaring	40	3 (8)
Snow goose	7.61	Strong flocking	39	21 (54)
Sandhill crane	12.78	Strong Flocking	38	13 (35)
Snowy owl	5.02	Solitary	23	0
Wild turkey	16.31	Strong flocking (on ground)	19	2 (11)
Brown pelican	8.16	Strong flocking	19	2 (11)
Great black-backed gull	4.03	Strong flocking	19	0
Double-crested cormorant	5.15	Strong flocking	16	1 (6)
Black vulture	4.79	Limited flocking/soaring	10	3 (30)
Common loon	9.11	Limited flocking	4	0
Tundra swan	15.65	Strong flocking	3	2 (67)
Mute swan	26.01	Strong flocking	2	0
Golden eagle	10.83	Solitary/soaring	2	0
Wood stork	5.96	Strong flocking	2	0
Common eider	4.89	Strong flocking	2	1 (50)
Greater white-fronted goose	5.96	Strong flocking	1	0
Trumpeter swan	25.13	Strong flocking	0	0
California condor	22.28	Solitary /soaring	0	0
American white pelican	15.43	Strong flocking	0	0
Whooping crane	12.84	Strong flocking	0	0
Yellow-billed loon	12.13	Limited flocking	0	0
Greater flamingo	7.80	Strong flocking	0	0
Arctic loon	7.40	Limited flocking	0	0
Laysan albatross	7.12	Strong flocking	0	0
Greater sage grouse	7.03	Limited flocking (on ground)	0	0
Black-footed albatross	6.94	Strong flocking	0	0
Northern gannet	6.76	Strong flocking	0	0
Emperor goose	6.05	Strong flocking	0	0
Red-faced cormorant	5.57	Strong flocking	0	0
Great cormorant	5.03	Strong flocking	0	0
Brandt's cormorant	4.64	Strong flocking	0	0
Masked booby	4.62	Limited flocking	0	0
Pelagic cormorant	4.48	Strong flocking	0	0
Total (all strikes identified to species)			1,000	296 (30)
Geese (unknown species)			366	139 (39)
Vultures (unknown species)			149	19 (13)
Eagles (unknown species)			5	1 (20)
Pelicans (unknown species)			4	0
Swans (unknown species)			2	0
Cormorants (unknown species)			1	0
Total (all strikes with species or species group >4 lbs)			1,529	455 (30)
Total (all strikes with species or species group > 8 lbs) [c]			1,033	400 (39)

[a] Strong flocking = Birds normally associate in dense flocks while feeding, traveling or nesting; Limited flocking = Birds often found in small groups while soaring, migrating, feeding or breeding; Solitary = Birds normally feed and travel as individuals; Soaring = Birds typically soar while searching for food, often in loose flocks or "kettles" with other members of same species.
[b] A total of 25 strike reports did not indicate whether or not multiple birds were involved: sandhill crane (1), Canada goose (6), brown pelican (1), great blue heron (2), turkey vulture (4), unidentified geese (10), unidentified vultures (1). These reports were excluded from total strikes when calculating percent of strikes involving >1 bird.
[c] Assuming all unidentified swan, pelican, eagle and goose strikes were with birds >8 lbs.

Table 5. Summary of population trend estimates and flocking and soaring characteristics for 19 of the 36 species of birds in North America with mean body masses for at least 1 gender >4 lbs that have been identified as involved in at least 1 reported strike with civil aircraft in USA, 1990-2001 (Table 4).

Body mass category	Number of species	Species exhibiting population:					Species exhibiting[a]:		
		In-crease	De-crease	Sta-bility	Un-known		Strong flocking	Limited flocking	Solitary behavior
4-8 lbs	10	7	1	1	1		6 (0)	3 (2)	1 (0)
>8 lbs	9	9	0	0	0		6 (0)	2 (1)	1 (1)
Total	19	16	1	1	1		12 (0)	5 (3)	2 (1)

[a] Values in parentheses are the number of species exhibiting soaring behavior.

DISCUSSION

Populations of most of the large (>4-lb) bird species in North America, including at least 13 of the 14 species with masses >8 lbs, have shown substantial increases during the past 20-40 years. Although some of these species are unlikely to be struck by aircraft, species such as Canada geese, turkey vultures, great blue herons, bald eagles, snow geese and sandhill cranes have been struck numerous times during the past 11 years. Of significance is the fact that many (30-39%) of these large-bird strikes involved multiple birds. We also note that 56% the 33,500 bird-strike reports in the FAA Wildlife Strike Database, 1990-2000, list the species struck as unknown (Cleary et al. 2002). Furthermore, an estimated 80% of strikes to civil aircraft in the USA go unreported (Cleary et al. 2000). Thus, the number of strikes reported for large (>4-lb) species (Table 3) should be considered an index of strikes and not an actual measure of strike rates. Undoubtedly, there have been many strikes with >4-lb birds (including some of the 17 species with no strikes recorded) that either have not been reported or reported as unknown species.

Our analysis clearly indicates that aviation regulatory and industry groups need to reexamine existing airworthiness standards with regard to bird-strike tolerances. Many of the regulations have not been revised since the 1970s when large-bird (>4 lbs) populations were much lower. Of particular concern is that existing standards for transport aircraft regarding large birds (in most cases 4 lbs being the maximum tested) do not even consider multiple-bird strikes or engine ingestions. Yet, our data for 1990-2001 indicate 30% of strikes with >4-lb birds and

39% of strikes with >8-lb birds have involved multiple birds (see also Budgey and Allan 1999). The fact that current large-bird standards for engines only require that the damage be contained and that the engine can be shut down safely has serious implications for multiple-bird strikes involving 2 engines. Over 80% of transport aircraft in operation by 2010 will have only 2 engines (Dolbeer 2000). Although beyond the scope of this paper, analysis of data from the long-term bird-strike databases that are now available (e.g., Cleary et al. 2000) should be invaluable in objectively guiding decisions regarding bird-strike airworthiness standards for transport, commuter and general-aviation aircraft (e.g., Martindale and Reed 1998).

Although revisions in airworthiness standards may be needed in response to increased populations of large flocking and soaring birds, existing aircraft and engines certified under current (single 4-lb bird) standards will remain in service for many years (Alge 1996). Furthermore, even if standards are revised and engineering improvements made, it will be impossible to completely "bird-proof" engines and airframes against high-speed collisions with birds of large mass. For example, a 4-lb bird struck by a transport aircraft going 150 knots at lift-off generates about 14,000 lbs of impact force (MacKinnon et al. 2001). Thus, it is imperative that aviation regulatory agencies in North America and elsewhere develop and maintain rigorous standards for bird hazard management programs at airports that emphasize the threat posed by these large birds and the need to minimize their presence in the airport environment. The deployment of bird-detecting radar systems to alert pilots and Air Traffic Control personnel may also prove useful in avoiding strikes with large flocking birds, especially during periods of migration (Kelly et al. 2001, Blokpoel and MacKinnon 2001). Finally, proposals to allow commercial aircraft to use high-speed (over 250 knot) operations below 10,000 feet to facilitate air traffic flow (National Transportation Safety Board 1999) should be reevaluated in light of increased populations of large-mass birds. Because of a fundamental relationship between energy (e), mass (m) and velocity (v) expressed in the equation $e = \frac{1}{2} mv^2$, aircraft velocity is even more critical than bird mass in determining the energy imparted to an aircraft by a strike. For example, a 20 % increase in bird mass results in a 20% increase in energy on impact whereas a 20% increase in aircraft velocity results in a 44% increase in energy imparted.

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REFERENCES CITED

Ainley, D. G., W. J. Sydeman, S. A. Hatch, and U. W. Wilson. 1994. Seabird population trends along the west coast of North America: causes and extent of regional concordance. Studies in Avian Biology 15:119-133.

Alge, T. L. 1999. Airport bird threat in North America from large flocking birds (geese) as viewed by an engine manufacturer. Pages 11-22 *in* Bird Strike '99, Proceedings of Bird

Strike Committee-USA/Canada Meeting, Vancouver, B.C., Transport Canada, Ottawa, Ontario, Canada.

Allan, J. R. 2002. The costs of birdstrikes and birdstrike prevention. Journal of Wildlife Management 66: In press.

Alsop, F. J., III. 2001. Birds of North America, Eastern Region (751 pages), Western Region (752 pages). DK Publishing, Inc., New York, New York.

Baldassarre, G. A., and F. Arengo. 2000. A review of the ecology and conservation of Caribbean flamingos in Yucatan, Mexico. Waterbirds 23 (Special Publication 1): 70-79.

Belant, J. L., and R. A. Dolbeer. 1993. Population status of nesting laughing gulls in the United States 1977-1991. American Birds 47(2): 220-224.

Belant J. L., and L. A. Tyson. 1997. Nesting populations of double-crested cormorants, great blue herons, and great egrets in the United States and Canada: implications for management. Proceedings of the Eastern Wildlife Damage Management Conference 8:In Press.

Blokpoel, H., and B. MacKinnon. 2001. The need for a radar-based, operational bird-warning system for civil aviation. Pages 227-231 *in* Bird Strike 2001. Proceedings of the Bird Strike Committee-USA/Canada meeting, Calgary, Alberta. Transport Canada, Ottawa, Ontario, Canada.

Braun, C. E. 1999. Historic and present distribution/status of sage grouse in North America. Synopsis of expert's panel presentations. Proceedings of the Northern Sage Grouse Status Conference. Boise, Idaho.

Budgey, R., and J. R. Allan. 1999. A model to determine the severity of a birdstrike with flocks of Canada geese. Pages 254-259 *in* Bird Strike '99, Proceedings of Bird Strike Committee-USA/Canada Meeting, Vancouver, B.C., Transport Canada, Ottawa, Ontario, Canada.

California Department of Fish and Game. 2001. www.lazoo.org.

Caithamer, D. F. (Compiler). 2001. Trumpeter swan population status, 2000. Division of Migratory Bird Management, U.S. Fish and Wildlife Service, Laurel, Maryland 20708-4016.

Cleary, E. C., S. E. Wright, and R. A. Dolbeer. 2000. Wildlife strikes to civil aircraft in the United States, 1990-1999. U.S. Department of Transportation, Federal Aviation Administration, Serial Report No. 6 DOT/FAA/AS/00-6(AAS-310). 62 pages.

Cleary, E. C., S. E. Wright, and R. A. Dolbeer. 2002. Wildlife strikes to civil aircraft in the United States, 1990-2000. U.S. Department of Transportation, Federal Aviation Administration, Serial Report No. 7. DOT/FAA/AS/00-6(AAS-310). 36 pages.

Cleary, E. C., and R. A. Dolbeer. 1999. Wildlife hazard management at airports, a manual for airport personnel. U.S. Department of Transportation, Federal Aviation Administration, Office of Airport Safety and Standards, Washington, D.C. 248 pages.

Dickson, J. G. (Editor). 1992. The wild turkey: biology and management. Stackpole Books, Harrisburg, Pennsylvania. 463 pages.

Dickson, J. G. 2001. Return of wild turkeys. http://biology.usgs.gov/s+t/noframe/b028.htm.

Dolbeer, R. A. 1999. Aerodrome bird hazard prevention: case study at John F. Kennedy International Airport. Pages 157-166 *in* Proceedings of the International Seminar on Flight Safety and Birds in the Middle East, International Center for the Study of Bird Migration, Latrun, Israel, Editors, Y. Leshem, Y. Mandelik, and J. Shamoun-Baranes. Israel.

Dolbeer, R. A. 2000. Birds and aircraft: fighting for airspace in crowded skies. Proceedings of the Vertebrate Pest Conference 19:37-43.

Dolbeer R. A., D. P. Arrington, E. LeBoeuf, and C. Atkins. 1996. Can albatrosses and aircraft coexist on Midway Atoll? Proceedings of Bird Strike Committee Europe 23:327-35.

Dunning, J. B., Jr. (Editor). 1993. Avian body masses. CRC Press. Boca Raton, Florida. 371 pages.

Earnst, S. L. (Principal Investigator). 2001. Habitat-specific distribution and abundance of yellow-billed loons on the arctic coastal plain of Alaska. U.S. Geological Survey (http://srfs.boisestate.edu/yellow-b.htm.

Eschenfelder, P. 2001. Let no new thing arise: wildlife hazards to aviation. Pages 175-178 *in* Bird Strike 2001. Proceedings of the Bird Strike Committee-USA/Canada meeting, Calgary, Alberta. Transport Canada, Ottawa, Ontario, Canada.

Espinoza, F. et al. 2000. Numbers and distribution of the Caribbean flamingos in Venezuela. Waterbirds 23 (Special Publication 1): 80-86.

Fisher, H. I. 1966. Aerial census of Laysan albatrosses breeding on Midway Atoll in December, 1962. Auk 83:670-673.

Hobson, K. A. 1997. Pelagic cormorant (*Phalacrocorax pelagicus)*. *In* The Birds of North America, No. 282 (A. Poole and F. Gill, eds.). The Academy of Natural Sciences, Philadelphia, Pennsylvania and The American Ornithologists' Union, Washington, DC. 28 pages.

Kelly, T. A., R. Merritt, A. Smith, R. L. White, M. Howers, and T. West. 2001. Advances in radar technology for bird strike risk assessment. Pages 9-12 *in* Bird Strike 2001. Proceedings of the Bird Strike Committee-USA/Canada meeting, Calgary, Alberta. Transport Canada, Ottawa, Ontario, Canada.

MacKinnon, B., R. Sowden, and S. Dudley (Editors). 2001. Sharing the skies: an aviation guide to the management of wildlife hazards. Transport Canada, Aviation Publishing Division, AARA, 5th Floor, Tower C, 330 Sparks Street, Ottawa, Ontario, K1A 0N8, Canada. 316 pages.

Martindale, I. G., and J. M. Reed. 1998. Birdstrike statistics as a design tool. Proceedings of the International Bird Strike Committee 24:97-104.

Meine, C. D. and G. W. Archibald (Editors). 1996. The cranes: - Status survey and conservation action plan. IUCN, Gland, Switzerland, and Cambridge, U.K. 294 pages. Northern Prairie Wildlife Research Center Home Page. http://www.npwrc.usgs.gov/resource/distr/birds/cranes/cranes.htm (Version 02MAR98).

Mute Swan Task Force. 2001. www.thechesapeakebay.com/mute_swan_task_force.shtml.

National Audubon Society. 2001. www.audubon.org/bird/watch/rfc/rfc.html.

National Transportation Safety Board. 1999. Safety Recommendations A-99-86 to A-99-94. Report to Administrator, Federal Aviation Administration by National Transportation Safety Board, Washington, D.C., 19 November 1999.

NAWCP. 2001. Review Draft II - North America Waterbird Conservation Plan, Volume 1: Seabirds and colonial waterbirds, 23 October 2001, Waterbird Conservation Plan Steering Committee, Washington, D.C. (www.nacwcp.org/).

North American Loon Fund. 2001. Pacific loon, arctic loon. http://facstaff.uww.edu/wentz/nalf/apalo.html.

Rice, D. W. 1959. Birds and aircraft on Midway Islands. Special Scientific Report—Wildlife Number 44. U.S. Department of Interior, Fish and Wildlife Service, Washington, D.C. 49 pages.

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. 2001. The North American Breeding Bird Survey, Results and Analysis 1966 - 2000. Version 2001.2, U.S. Geological Survey, Patuxent Wildlife Research Center, Laurel, Maryland, USA.

Sauer, J. R., S. Schwartz, and B. Hoover. 1996. The Christmas Bird Count home page. Version 95.1, U.S. Geological Survey, Patuxent Wildlife Research Center, Laurel, Maryland, USA.

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

Smith, A., S. R. Craven, and P. D. Curtis. 1999. Managing Canada geese in urban environments. Jack Berryman Institute Publication 16, and Cornell Cooperative Extension, Ithaca, New York, 42 pages.

Thorpe, J. 1996. Fatalities and destroyed aircraft due to bird strikes, 1912-1995. Proceedings of Bird Strike Committee Europe 23:17-31.

Thorpe, J. 1998. The implications of recent birdstrike accidents and multiple engine ingestions. Proceedings of the International Bird Strike Committee 24:11-22.

Tyson L. A., J. L. Belant, F. Cuthbert, and C. Weseloh. 1999. Nesting populations of double-crested cormorants in the United States and Canada. Pages 17-25 *in* M. E. Tobin, Technical Coordinator, Symposium on Double-Crested Cormorants: Population Status and Management Issues in the Midwest. U.S. Department of Agriculture, Animal and Plant Health Inspection Service Technical Bulletin 1879.

University of Georgia. 2001. www.uga.edu/srel/Fact_Sheets/wood_storks.htm.

USFWS. 2001a. U.S. Fish and Wildlife Service. Waterfowl population status, 2001. U.S. Department of the Interior, Washington, D.C. 50 pages.

USFWS. 2001b. U.S. Fish and Wildlife Service at http://midwest.fws.gov/eagle/; www.baldeagleinfo.com.

USFWS. 2001c. U.S. Fish and Wildlife Service at http://midway.fws.gov/wildlife/

USGS. 2000. U.S. Geological Survey, Patuxent Wildlife Research Center at http://whoopers.usgs.gov/faqs.htm

Vogel, H. 1996. How many loons are there in Canada. Birdwatch Canada, Summer: 7-8.

Appendix 1. Scientific names and sources of information on population status for the 36 species of birds in North America (Canada, USA [including Hawaiian Islands], and Caribbean) that have mean body mass for at least 1 gender >4 lbs (body mass data from Dunning [1993] except for turkey vultures [Seamans et al. 1995] and double-crested cormorants [Unpublished data, M. T. Bur, U.S. Geological Survey]).

Common name	Scientific name	Mean body mass (lb)				Source of information on population status
		Male	Fe-male	Unk sex	Max	
Mute swan	*Cygnus olor*	26.01	21.32		31.53	Sauer et al. (2001), Mute Swan Task Force (2001)
Trumpeter swan	*Cygnus buccinator*	25.13	22.71			Caithamer (2001)
California condor	*Gymnogyps californianus*	22.28			31.03	California Department of Fish and Game (2001)
Wild turkey	*Meleagris gallopavo*	16.31	9.31			Dickson (1992; 2001)
Tundra swan	*Cygnus columbianus*	15.65	13.67		21.16	USFWS (2001a)
American white pelican	*Pelecanus erythrorhynchos*			15.43	29.98	Sauer et al. (2001)
Whooping crane	*Grus americana*			12.84	14.01	Meine and Archibald (1996), USGS (2000)
Sandhill crane	*Grus canadensis*	12.78	11.78		14.77	Sauer et al. (2001), Meine and Archibald (1996)
Yellow-billed loon	*Gavia adamsii*			12.13	14.11	Earnst (2001)
Bald eagle	*Haliaeetus leucocephalus*	9.11	11.79		14.11	Sauer et al. (2001); USFWS (2001b)
Golden eagle	*Aquila chrysaetos*	7.67	10.83			Sauer et al. (2001)
Canada goose (int. subspecies)	*Branta canadensis*	9.22	7.75		10.42	Sauer et al. (2001), USFWS (2001a), Alge (1999)
Common loon	*Gavia immer*			9.11	9.88	Sauer et al. (2001)
Brown pelican	*Pelecanus occidentalis*	8.16	8.10			Sauer et al. (2001)
Greater flamingo	*Phoenicopterus ruber*	7.80	5.58		9.04	Espinoza et al. (2000), Baldassarre and Agengo (2000)
Snow goose	*Chen caerulescens*	7.61	6.81			USFWS (2001a)
Arctic loon	*Gavia artica*			7.40	7.50	North American Loon Fund (2001)
Laysan albatross	*Phoebastria immutabilis*	7.12	6.29		9.04	Fisher (1966), USFWS (2001c), Dolbeer et al 1996, NAWCP (2001)
Greater sage grouse	*Centrocercus urophasianus*	7.03	3.85			Braun (1999)
Black-footed albatross	*Phoebastria nigripes*			6.94		Rice (1959), USFWS (2001c), NAWCP (2001)
Northern gannet	*Morus bassanus*	6.46	6.76		7.96	Sauer et al. (1996), NAWCP (2001)
Emperor goose	*Chen canagica*			6.05	6.88	USFWS (2001a)
Greater white-fronted goose	*Anser albifrons*	5.96	5.41		7.10	USFWS (2001a)
Wood stork	*Mycteria americana*	5.96	4.52			University of Georgia (2001), NAWCP (2001)
Great blue heron	*Ardea herodias*	5.68	4.86			Sauer et al. (2001), Belant and Tyson (1997)
Red-faced cormorant	*Phalacrocorax urile*	5.57	3.94		5.63	NAWCP (2001), National Audubon Society (2001)
Double-crested cormorant	*Phalacrocorax auritus*	5.15	4.50		6.44	Sauer et al. (2001), Tyson et al. (2000), NAWCP (2001)
Great cormorant	*Phalacrocorax carbo*	5.03	4.27		5.92	NAWCP (2001)
Snowy owl	*Nyctea scandiaca*	3.98	5.02		6.51	Sauer et al. (1996)
Common eider	*Somateria mollissima*	4.89	4.22		6.38	
Black vulture	*Coragyps atratus*	4.79	4.38			Sauer et al. (2001)
Brandt's cormorant	*Phalacrocorax penicillatus*			4.64		Ainley et al. (1994), NAWCP (2001)
Masked booby	*Sula dactylatra*	4.14	4.62		5.19	NAWCP (2001)
Pelagic cormorant	*Phalacrocorax pelagicus*	4.48	3.75		5.38	Sauer et al. (2001), Hobson (1997), Ainley et al. (1994), NAWCP (2001)
Turkey vulture	*Cathartes aura*	3.98	4.21		4.70	Sauer et al. (2001)
Great black-backed gull	*Larus marinus*	4.03	3.28		5.01	Sauer et al. (2001), NAWCP (2001)