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Increasing trend of damaging bird strikes with aircraft outside the airport boundary: implications for mitigation measures

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Abstract--A basic tenet of programs to mitigate the risks of bird strikes has been to focus management efforts at airports since various historical analyses of bird strike data for civil aviation have indicated the majority of strikes occur in this environment (during take-off and landing at ≤500 feet above ground level). However, a trend analysis of bird strike data involving commercial air carriers from the U.S. National Wildlife Strike Database for Civil Aviation, 1990-2009, indicates that this tenet should be revised. The percentage of all strikes that occurred at >500 feet increased significantly from about 25% in 1990 to 30% in 2009. The percentage of all damaging strikes that occurred at >500 feet increased at a greater rate, from about 37% in the early 1990s to 45% in 2005-2009. I also examined trends in strike rates (strikes/1 million commercial aircraft movements) for strikes occurring at ≤ and >500 feet. From 1990-2009, the damaging strike rate at >500 feet increased from about 2.5 to 4.0, whereas the damaging strike rate for strikes at ≤500 feet has remained stable since 2000. An analysis of strike data for Canada geese (*Branta canadensis*), the most frequently struck bird species with a body mass >1.8 kg, showed a pattern similar to that for all species. I conclude that mitigation efforts incrementally implemented at airports in the USA over the past 20 years have resulted in a reduction of damaging strikes in the airport environment. This reduction in strikes has occurred in spite of increases in populations of Canada geese and many other species hazardous to aircraft. However, these successful mitigation efforts, which must be sustained, have done little to reduce strikes outside the airport. Increased efforts now are needed to eliminate bird attractants within 5

miles of airports, to further develop bird-detecting radar and bird migration forecasting, and to research avian sensory perception to enhance aircraft detection and avoidance by birds.

Introduction

Highly successful programs funded by governmental and conservation organizations during the past 40 years (e.g., pesticide regulation, expansion of wildlife refuge systems, wetlands restoration, environmental education), coupled with land-use changes, have resulted in dramatic increases in populations of many large (>1.8 kg) bird species in North America (Dolbeer and Eschenfelder 2003). As one example, the population of Canada geese (*Branta canadensis*, >3.6 kg) in North America increased from 2.5 million to 5.3 million, 1990-2009 (U.S. Fish and Wildlife Service 2009, Dolbeer and Seubert 2009). The non-migratory component of the Canada goose population almost quadrupled from 1.0 million to 3.9 million. Many of these larger birds have adapted to urban environments and find that airports, with expanses of grass and pavement, are attractive habitats for feeding and resting. In addition, modern turbofan-powered aircraft, with quieter engines, are less obvious to birds compared to noisier piston-powered aircraft and older turbine-powered aircraft (Burger 1983, Kelly et al. 2001).

For these reasons, birds and other wildlife in the vicinity of airports are an increasing problem for the aviation industry. At least 229 people died and 221 aircraft were destroyed worldwide as a result of bird and other wildlife strikes with civil and military aircraft from 1988-2009 (Richardson and West 2000; Thorpe 2003, 2005; 2008; Dolbeer, unpublished data).

The U.S. Federal Aviation Administration (FAA) has initiated several programs to address this safety issue. A foundation for these programs was the development of a National Wildlife Strike Database for Civil Aviation which contains all strikes reported to the FAA since 1990. Various analyses of these strike data aggregated over years have indicated that, on average, over 70% of bird strikes with civil aircraft occurred below a height of 500 feet (152 m) above ground level (AGL, Dolbeer 2006, Dolbeer et al. 2009). Based on these analyses, guidance developed by the FAA to mitigate the risks of bird strikes has focused on dispersing birds from the airport environment (Cleary and Dolbeer 2005 [first edition published in 1999]). The airport environment, as discussed in this paper, encompasses an area out to 10,000 feet (3,048 m) from Air Operation Areas (AOA, runways, taxiways, and ramps) which is the distance where aircraft on approach typically descend below 500 feet AGL. FAA-recommended restrictions on land-uses that attract birds (e.g., landfills) extend to a distance of 10,000 feet from runways and taxiways for airports servicing turbine-powered aircraft (FAA Advisory Circular 150/5200-33b [FAA 2010*a*, Cleary and Dolbeer 2005]).

Airports in the USA certificated by the FAA for passenger traffic that experience wildlife hazards are required (14 Code of Federal Regulations Part 139.337) to conduct a Wildlife Hazard Assessment and, in most cases, develop and implement a Wildlife Hazard Management Plan. There has been a steady increase in the development and improvement of Wildlife Hazard Management Plans for certificated airports in the USA over the past 20 years. For example, biologists from the U.S. Department of Agriculture, Wildlife Services (USDA/WS) program provided assistance on 822 airports, (including 410 of the 559 certificated airports) to mitigate wildlife risks in 2009 compared to only 42 and 193 airports (certificated and non-certificated) assisted in 1990 and 1998, respectively (Begier and Dolbeer 2010).. As another example of the increasing importance of wildlife management at airports, attendance at Bird Strike Committee-USA annual meetings (which focus primarily on mitigation efforts at airports) grew from about 100 attendees in 1992-1995 to 200 in 1998 and 450 in 2008 (Dolbeer, unpublished data).

However, not all serious strike events occur at ≤500 feet AGL. A notable example occurred on 15 January 2009 when US Airways Flight 1549 made a miraculous forced landing in the Hudson River after ingesting birds in both engines of the Airbus 320 at about 2,800 feet AGL and 4.5 miles from LaGuardia Airport, New York (National Transportation Safety Board 2010). Subsequent analyses of bird remains retrieved from each engine showed that the strike was caused by a flock of migratory Canada geese (Marra et al. 2009). This highly publicized event dramatically demonstrated to the world at large that birds can bring down large transport aircraft. The event also demonstrated that wildlife management actions at airports to mitigate bird strikes, such as habitat alterations and bird dispersal programs emphasized by FAA guidance (Cleary and Dolbeer 2005), would not have prevented this strike.

If airport-based management actions are reducing bird strikes, then the strike rate (number of strikes and damaging strikes per 1 million aircraft movements) should be declining in the airport environment. Because there have been no operational efforts launched to date for civil aviation to mitigate strikes away from the airport, strike rates outside the airport environment should not have declined or perhaps even increased in concert with increasing populations of many bird species that are hazardous to aircraft (Dolbeer and Eschenfelder 2003). To test these hypotheses, I undertook a trend analysis of reported bird strikes in the database occurring at ≤ and >500 feet AGL, 1990-2009.

Methods

I selected all reported strikes from the database, 1990-2009, involving birds and commercial aircraft (air carrier, air taxi, and commuter aircraft). Strikes involving mammals and reptiles (<2% of strike reports) were excluded because these strikes always occur on the airport (with the exception of bats which comprised <0.3% of the strike reports). I used commercial aircraft only because these aircraft almost exclusively use certificated airports where most of the wildlife hazard mitigation efforts have occurred (Dolbeer et al. 2008). Reports in which the height AGL at which the strike occurred was unknown also were excluded from the analysis.

The reporting of strikes involving civil aircraft is voluntary but strongly encouraged by the FAA (Cleary et al. 2005, Dolbeer 2009). An analysis of strike reports has indicated a bias toward reporting damaging strikes as opposed to non-damaging strikes (Dolbeer 2009). Thus, my trend analyses examined all reported strikes (those with and without reported damage), and as subsets of all reported strikes, those strikes reporting any level of damage to aircraft (from minor to destroyed) and those strikes reporting substantial damage (including aircraft destroyed). Strikes are classified as substantial damage when the aircraft incurs damage or structural failure which adversely affects the structure strength, performance, or flight characteristics and which would normally require major repair or replacement of the affected component (International Civil Aviation Organization 1989, Dolbeer et al. 2009). As another means of minimizing bias that may result from uneven reporting among years, I compared the percent of strikes (as opposed to absolute numbers) occurring at ≤ and > 500 feet AGL. To examine trends in strike rates over years, I calculated the number of strikes per 1 million commercial aircraft movements (FAA 2010*b*).

Canada geese are the most frequently struck large (>1.8 kg) bird species in the database (Dolbeer and Eschenfelder 2003; Dolbeer et al. 2009), and one of the most hazardous (i.e., likely to cause damage if struck) species to aviation (Dolbeer and Wright 2009). Thus, I conducted analyses similar to that described above for Canada geese only. Because the population of Canada geese in North America is estimated each year (U. S. Fish and Wildlife Service 2009), I also examined population-adjusted trends in yearly strike rates(strikes per 1 million aircraft movements per 1 million Canada geese).

Linear regression analysis was conducted to determine if there were statistically significant trends in the percent of strikes at ≤ and >500 feet AGL for the 20-year period, 1990-2009. R^2 values >0.31 were significant at the 0.01 probability level with 18 df (Steele and Torrie 1960). For the analyses of strike rates, I compared empirically the mean rates for four 5-year time intervals (1990-1994, 1995-1999, 2000-2004, and 2005-2009).

Results

Composition of data, 1990-2009 - Overall, the database contained 99,411 strike reports for 1990-2009 of which 50,941 involved birds and commercial aircraft in which height AGL of strike was reported (Table 1). Of these 50,941 strikes, 4,832 (9.5%) indicated damage to the aircraft and 1,327 (3%) indicated substantial damage (Table 2).

The database contained 1,238 strikes involving Canada geese of which 584 involved commercial aircraft in which the height AGL of strike was reported (Table 1). Of these 584 strikes, 287 (49%) indicated damage to the aircraft and 101 (17%) indicated substantial damage (Table 2). The estimated Canada goose population in North America increased 2.1 fold from about 2.5 million in 1990 to 5.3 million in 2009 (Table 1).

Commercial aircraft movements in the USA increased from 23.3 million in 1990 to a peak of 29.5 million in 2000. Movements from 2001-2009 fluctuated between 25.5 million and 29.3 million (Table 1).

Trends in strikes at ≤ and >500 feet AGL for all birds, 1990-2009 - The percentage of all reported strikes that occurred at >500 feet increased ($P < 0.01$)from about 25% in the early 1990s to 30% in 2005-2009 (Fig. 1). The percentage of all damaging strikes that occurred at >500 feet increased ($P < 0.01$ to a greater extent), from about 37% in the early 1990s to 45% in 2005-2009. The percentage of all substantial-damage strikes occurring above 500 feet AGL also increased ($P < 0.01$) from about 20% in the early 1990s to 35% in 2005-2009.

Trends in strike rates for all strikes and for damaging strikes showed different patterns (Fig. 2). From 1990 to 2009, the overall strike rate increased steadily both for strikes at ≤500 feet and for strikes at >500 feet. In concert with the overall strike rate, the damaging strike rate above 500 feet also increased steadily from about 2.6 in 1990-1994 to 4.3 in 2005-2009. In contrast, the damaging strike rate at ≤500 feet increased from 4.4 in 1990-1994 to 5.3 in 1995-1999 but then has remained near this level (5.3 – 5.4) in 2000-2004 and 2005-2009. The substantial-damage strike rate at ≤500 feet has declined from about 1.9 - 2.1 in 1990-1994 and 1995-1999 to 1.3 in 2005-2009. In contrast, the rate for substantial damage strikes above 500 feet has changed little, fluctuating between 0.5 in 1990-1994 to 0.9 in 1995-1999 and 0.8 in 2005-2009.

Trends in strikes at ≤ and >500 feet AGL for Canada geese, 1990-2009 – Trends in strikes for Canada geese showed patterns similar to, but more pronounced than, those for all species. The percentage of all Canada goose strikes that occurred at >500 feet increased ($P < 0.01$) from about 25% in the early to mid-1990s to about 40% in 2005-2009 (Fig. 3). The increase in the percentage of all damaging strikes and substantial-damage strikes that occurred above 500 feet was more dramatic, growing from about 25% in the early 1990s to about 50% in 2005-2009 ($P < 0.01$).

The rates for all Canada goose strikes occurring at ≤ and >500 feet exhibited similar trends of increase from 1990-1994 to 2000-2004 and subsequent declines in 2005-2009. However, the decline was greater (from 0.83 to 0.53, 36%) for strikes at ≤500 feet than for strikes at >500 feet (from 0.48 to 0.39, 19%; Fig. 4). For damaging and substantial-damage strike rates, the pattern of increase for strikes occurring at ≤ and >500 feet was similar to that shown for all strikes from 1990-1994 to 1995-1999. However, for both damaging strikes and substantial-damage strikes, the rate for strikes occurring at ≤500 feet subsequently declined from being equal to or above the rate for strikes at >500 feet in 2000-2004 to below the rate for strikes at >500 feet in 2005-2009.

Trends in strike rates for Canada geese at ≤ and > 500 feet adjusted for the 2.1-fold increase in the goose population from 1990 to 2009 also showed clear differences (Fig. 5). The population-adjusted strike rate at ≤500 feet declined from about 0.19 in 1990-2004 to 0.11 in 2005-2009. In contrast, the population-adjusted strike rate at >500 feet showed little change from 1990-1994 to 2005-2009, and approached the declining rate for strikes at <500 feet in 2005-2009. The population-adjusted rates for damaging strikes and substantial-damage strikes at ≤500 feet were higher than the rates for strikes at >500 feet in 1990-1994 and 1995-1999 but had declined below the rates for strikes at >500 feet in 2005-2009.

Discussion and conclusions

The trend analyses of strike data for all birds and for Canada geese support the hypothesis that mitigation efforts incrementally implemented at airports in the USA since 1990, and especially since about 2000, have resulted in a reduction of damaging strikes in the airport environment. Begier and Dolbeer (2010) and Wenning et al (2004) provide examples of these successful mitigation efforts. However, these successful mitigation efforts at airports have done little to reduce strikes outside the airport environment. Based on trends in damaging strikes for all birds and for Canada geese, my hypothesis was supported that the risk to commercial aircraft for strikes above 500 feet AGL is growing faster than the risk for strikes below 500 feet.

The steady increase in the overall strike rate for all species both at ≤ and >500 feet AGL from 1990 to 2009 can be explained, at least in part, by the fact that there has been an increase in the voluntary reporting of strikes during this time period (Dolbeer 2009). This increase in the reporting of strikes for all species, coupled with the overall 2.1-fold increase in the Canada goose population and increases in many other large-bird species (Dolbeer and Eschenfelder 2003), makes the decline in the number and rate of damaging strikes at ≤500 feet AGL even more impressive. The decline in Canada goose strikes at ≤500 feet AGL is especially remarkable because the non-migratory (resident) component of the population, which attempts to graze and rest on airports year-round, has increased almost 4-fold from 1990-2009 (U.S. Fish and Wildlife Service 2009, Dolbeer and Seubert 2009).

Although the data indicate that damaging strikes at airports (≤500 feet AGL) have not increased in the USA since about 2000, these low-altitude strikes still comprise the majority of damaging strikes. Furthermore, 27 of the 30 bird strikes that have resulted in the destruction of large (>5,700 kg take-off mass) transport aircraft worldwide since 1967 occurred at ≤500 feet AGL (Dolbeer 2008, unpublished data). Thus, efforts to reduce the number of damaging strikes at airports must be sustained, building upon the successes demonstrated above and guidance provided in Cleary and Dolbeer (2005).

There are at least 3 areas where efforts should be enhanced to mitigate the risk of damaging bird strikes occurring outside of the airport at >500 feet AGL. First, there should be increased attention directed to elimination of bird attractants within the 10,000-foot separation distance from AOAs and within 5 miles of AOAs in departure and arrival airspace (FAA Advisory Circular 150/5200-33b [FAA 2010*a*], Blackwell et al. 2009).

Second, there is a need to integrate real-time and historical knowledge of movements of hazardous bird species into flight planning for airports. Specifically, increased efforts are needed in the field-testing and refinement of bird-detecting radar systems (Nohara et al. 2005) to monitor arrival and departure airspace at airports (e.g., Klope et al. 2009). The ultimate goal will be to integrate bird-detecting radar into Air Traffic Control in a manner analogous to what has been accomplished with wind-shear detection and avoidance. In conjunction with airport-based radar, bird migration forecasting based on historical bird migration and bird strike data and real-time information from NexRad weather radar (filtered to detect birds and not weather) should be developed for civil aviation in a manner now used by the military (DeFusco 2000, Kelly et al. 2000).

Third, research is needed on avian sensory perception and reaction to moving objects. Such research may lead to the development of aircraft lighting systems (which could include various pulse rates and wavelengths in the electromagnetic spectrum) to enhance detection, speed perception, and avoidance of departing and arriving aircraft by birds (Blackwell and Bernhart 2004, Dolbeer and Wright 2004, Blackwell et al. 2009). As an added bonus, these 3 initiatives should also assist in further reducing strikes at ≤500 feet as well as at >500 feet AGL.

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Table 1. Reported strikes at ≤500 and >500 feet above ground level (AGL) involving all birds and Canada geese only for commercial aircraft (air carrier, commuter, and air taxi) in USA; and number of Canada geese and number of commercial aircraft movements, 1990 to 2009.[a]

	No. of strikes (all birds)			No. of strikes (Canada geese)				
Year	≤500 ft AGL	>500 ft AGL	Total	≤500 ft AGL	>500 ft AGL	Total	No. of C. geese (x 10^6)[b]	Aircraft movements (x 10^6)[c]
1990	837	344	1,181	10	5	15	2,514	23.27
1991	1,105	388	1,493	12	7	19	2,780	24.79
1992	1,178	381	1,559	10	5	15	3,096	25.18
1993	1,144	382	1,526	21	6	27	3,505	25.57
1994	1,230	371	1,601	26	8	34	3,729	26.59
1995	1,256	412	1,668	26	9	35	4,284	27.05
1996	1,253	419	1,672	19	7	26	4,461	27.59
1997	1,408	502	1,910	13	3	16	4,457	27.77
1998	1,469	513	1,982	28	14	42	4,507	28.01
1999	1,675	622	2,297	26	12	38	4,996	28.76
2000	2,049	774	2,823	25	14	39	4,960	29.54
2001	1,965	754	2,719	23	18	41	4,732	29.16
2002	2,078	840	2,918	31	13	44	5,187	27.63
2003	2,155	827	2,982	24	12	36	5,418	27.91
2004	2,392	932	3,324	16	12	28	5,200	28.89
2005	2,323	1,098	3,421	15	15	30	5,057	29.25
2006	2,485	1,023	3,508	16	10	26	5,484	28.31
2007	2,687	1,099	3,786	8	12	20	5,495	28.47
2008	2,556	1,110	3,666	14	11	25	5,461	27.95
2009	3,428	1,477	4,905	21	7	28	5,298	25.48
Total	36,673	14,268	50,941	384	200	584		

[a] Data from National Wildlife Strike Database (Dolbeer et al. 2009), excluding 17,526 and 61 strikes involving all birds and Canada geese, respectively, in which height AGL was not reported.

[b] Estimated population of Canada geese in Canada and USA (U.S. Fish and Wildlife Service 2010).

[c] Departures and arrivals by commercial aviation aircraft in USA (FAA 2010*b*).

Table 2. Reported strikes causing damage (substantial damage) at ≤500 and >500 feet above ground level (AGL) involving all birds and Canada geese only for commercial aircraft (air carrier, commuter, and air taxi) in USA, 1990 to 2009.[a]

	No. of damage (substantial damage) strikes (all birds)			No. of damage (substantial damage) strikes (Canada geese)		
Year	≤500 ft AGL	>500 ft AGL	Total	≤500 ft AGL	>500 ft AGL	Total
1990	96 (47)	57 (7)	153 (54)	6 (2)	2 (0)	8 (2)
1991	107 (53)	69 (14)	176 (67)	5 (3)	2 (1)	7 (4)
1992	102 (39)	64 (16)	166 (55)	7 (3)	3 (0)	10 (3)
1993	109 (40)	70 (16)	179 (56)	5 (3)	3 (1)	8 (4)
1994	140 (60)	71 (16)	211 (76)	8 (3)	5 (2)	13 (5)
1995	143 (69)	90 (26)	233 (95)	15 (6)	7 (1)	22 (7)
1996	133 (67)	87 (26)	220 (85)	8 (3)	4 (1)	12 (4)
1997	163 (59)	105 (26)	268 (85)	2 (1)	3 (1)	5 (2)
1998	145 (35)	104 (25)	249 (60)	12 (7)	9 (2)	21 (9)
1999	154 (56)	122 (26)	276 (82)	13 (4)	8 (3)	21 (7)
2000	176 (52)	139 (20)	315 (72)	9 (4)	11 (1)	20 (5)
2001	153 (45)	102 (12)	255 (57)	12 (6)	10 (2)	22 (8)
2002	152 (44)	114 (17)	266 (61)	14 (4)	10 (4)	24 (8)
2003	154 (40)	118 (21)	272 (61)	7 (4)	10 (5)	17 (9)
2004	145 (41)	106 (21)	251 (62)	6 (3)	7 (2)	13 (5)
2005	145 (55)	123 (29)	268 (84)	3 (1)	7 (4)	10 (5)
2006	143 (36)	132 (22)	275 (57)	6 (2)	9 (2)	15 (4)
2007	145 (25)	111 (24)	256 (49)	3 (1)	8 (5)	11 (6)
2008	132 (28)	113 (13)	245 (40)	5 (0)	8 (0)	13 (0)
2009	173 (37)	125 (25)	298 (62)	10 (2)	5 (2)	15 (4)
Total	2,810 (928)	2,002 (399)	4,832 (1,327)	156 (62)	131 (39)	287 (101)

[a] Data from National Wildlife Strike Database (Dolbeer et al. 2009). These data exclude 2,120 and 24 damaging strikes involving all birds and Canada geese, respectively, in which height AGL was not reported.

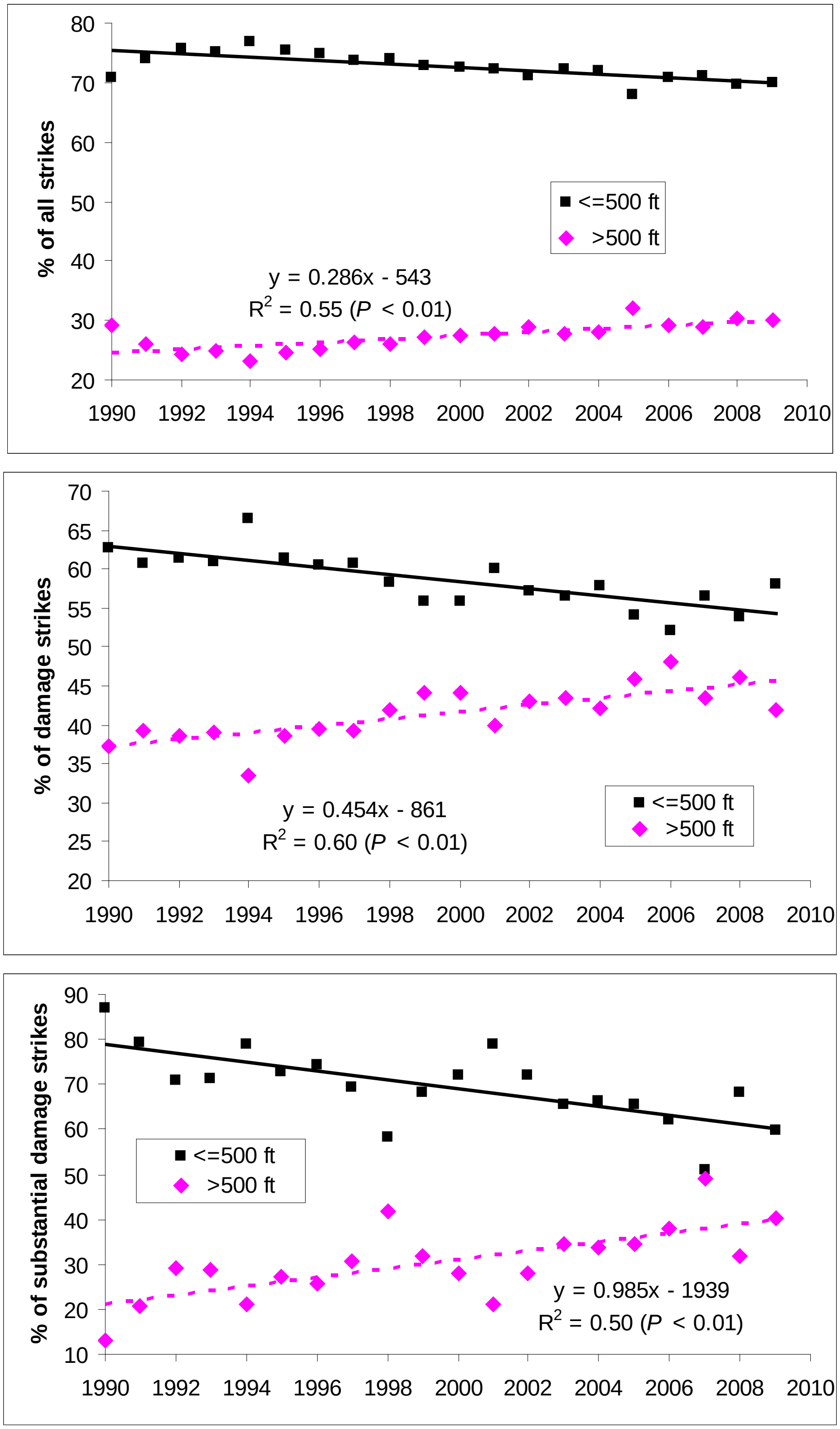

Figure 1. Percentage of reported bird strikes (top graph), strikes indicating damage (middle graph), and strikes indicating substantial damage (bottom graph) at ≤ and >500 feet above ground level for commercial aircraft in USA, 1990–2009 (see Tables 1 and 2 for sample sizes). In each graph, the equation and R^2 value are presented only for strikes at >500 feet (R^2 value is the same and slope is the same [but negative] for strikes ≤500 feet). R^2 values >0.31 are significant ($P < 0.01$, 18 df, Steel and Torrie 1960).

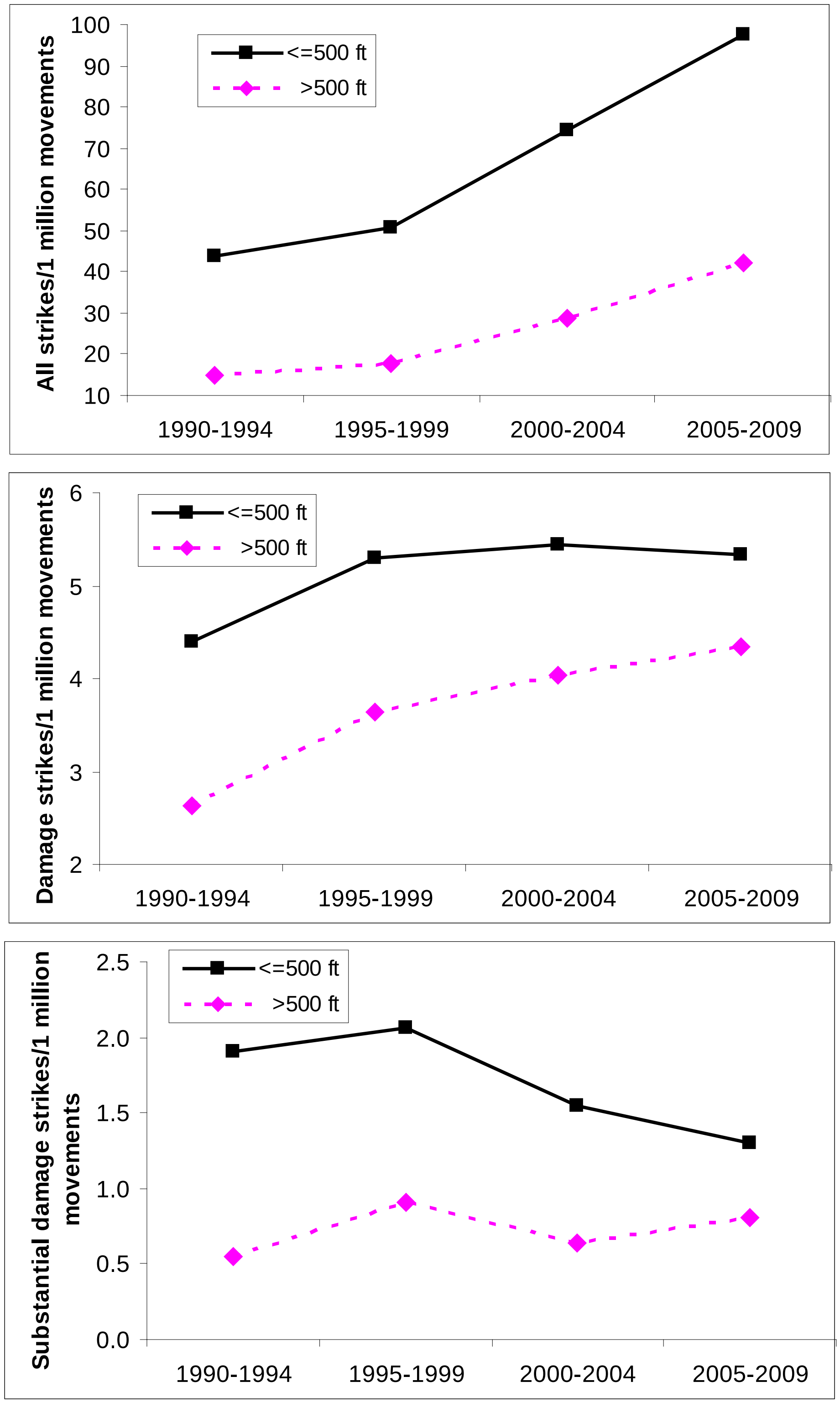

Figure 2. Mean strike rate per 5-year period (all bird strikes [top graph], strikes with damage [middle graph], and strikes with substantial damage [bottom graph] per 1 million aircraft movements) for commercial aircraft in USA, 1990–2009 (see Tables 1 and 2 for sample sizes).

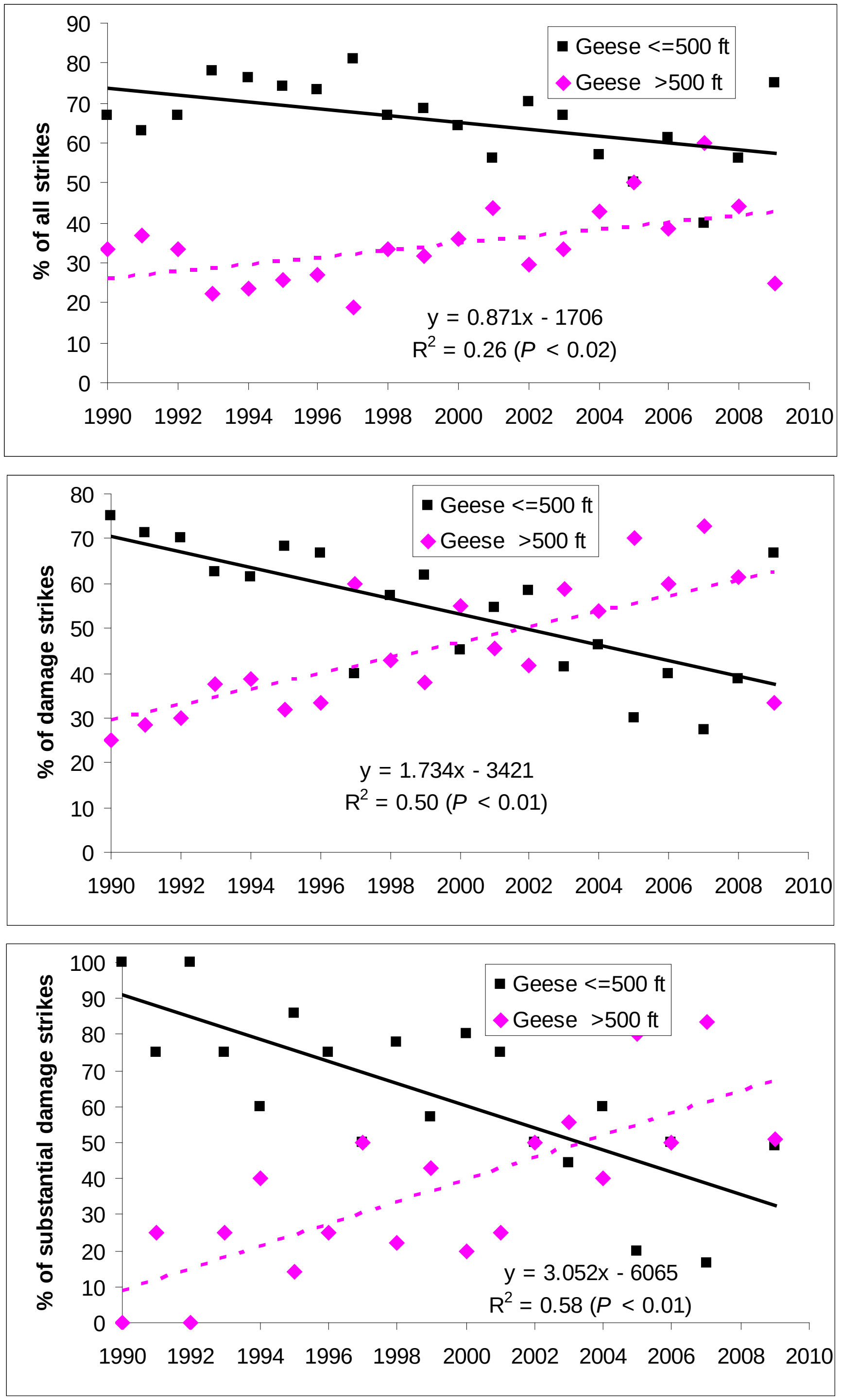

Figure 3. Percentage of reported Canada goose strikes (top graph), strikes indicating damage (middle graph), and strikes indicating substantial damage (bottom graph) at $\leq$ and >500 feet above ground level for commercial aircraft in USA, 1990–2009 (see Tables 1 and 2 for sample sizes). In each graph, the equation and R^2 value are presented only for strikes at >500 feet (R^2 value is the same and slope is the same [but negative] for strikes $\leq$500 feet). R^2 values >0.31 are significant (P < 0.01, 18 df, Steel and Torrie 1960).

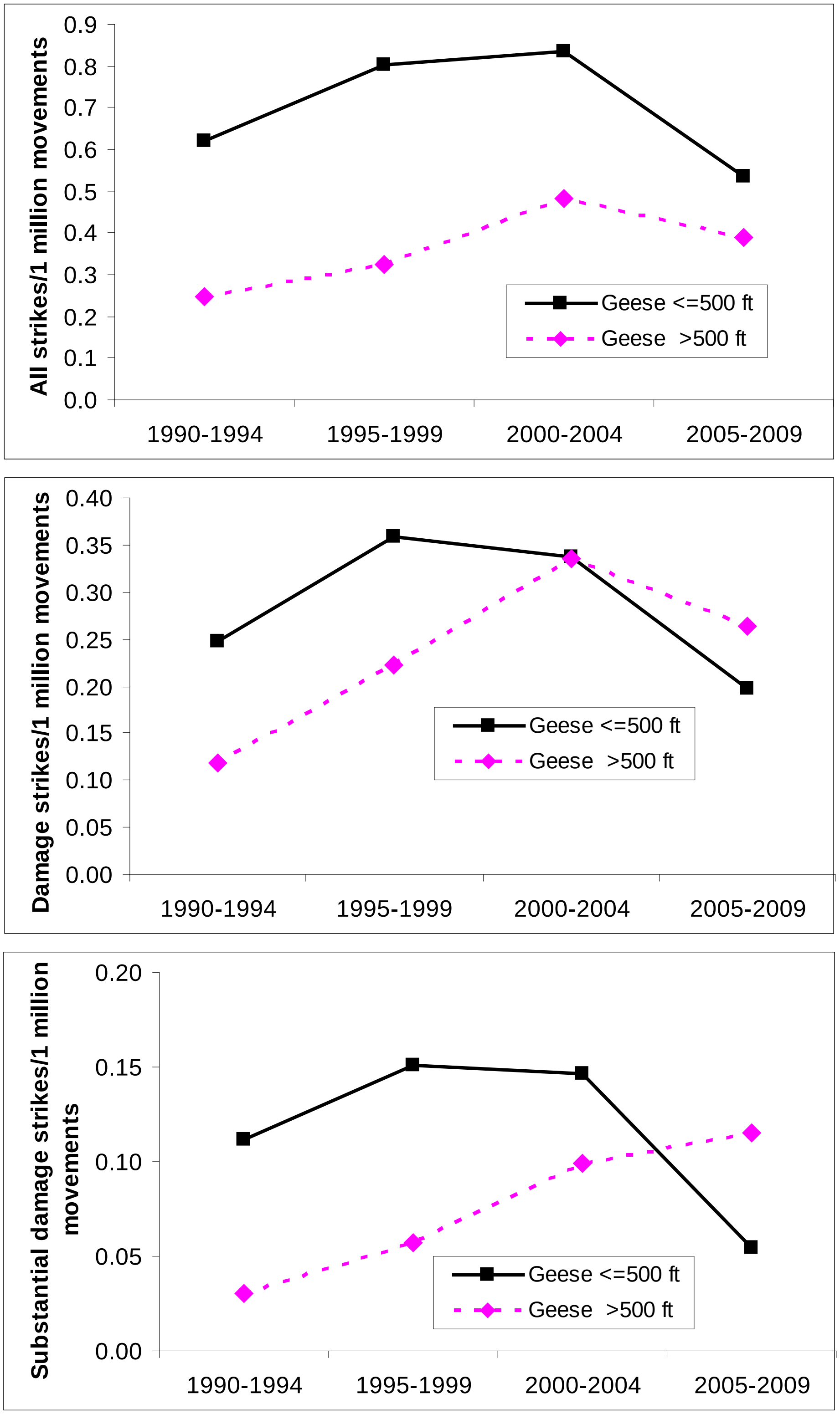

Figure 4. Mean Canada goose strike rate per 5-year period (all strikes [top graph], strikes with damage [middle graph], and strikes with substantial damage [bottom graph] per 1 million aircraft movements) for commercial aircraft in USA, 1990–2009 (see Tables 1 and 2 for sample sizes).

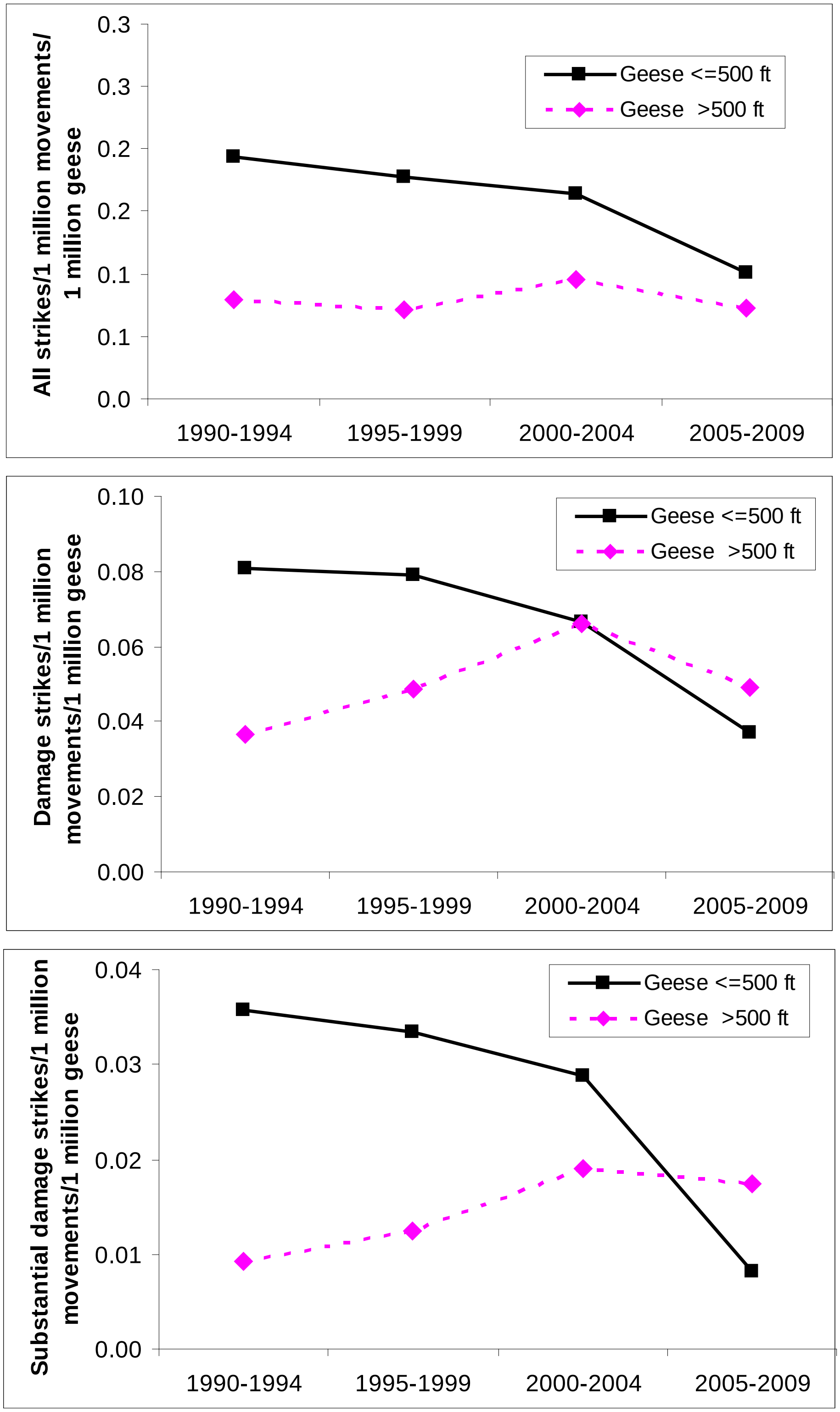

Figure 5. The population-adjusted Canada goose strike rate (all strikes [top graph], strikes with damage [middle graph], and strikes with substantial damage [bottom graph] per 1 million aircraft movements per 1 million geese) for commercial aircraft in USA, 1990–2009 (see Tables 1 and 2 for sample sizes).