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Behavioral Traits and Airport Type Affect Mammal Incidents with U.S. Civil Aircraft

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Abstract Wildlife incidents with aircraft cost the United States (U.S.) civil aviation industry >US$1.4 billion in estimated damages and loss of revenue from 1990 to 2009. Although terrestrial mammals represented only 2.3 % of wildlife incidents, damage to aircraft occurred in 59 % of mammal incidents. We examined mammal incidents (excluding bats) at all airports in the Federal Aviation Administration (FAA) National Wildlife Strike Database from 1990 to 2010 to characterize these incidents by airport type: Part-139 certified (certificated) and general aviation (GA). We also calculated relative hazard scores for species most frequently involved in incidents. We found certificated airports had more than twice as many incidents as GA airports. Incidents were most frequent in October ($n = 215$ of 1,764 total) at certificated airports and November ($n = 111$ of 741 total) at GA airports. Most (63.2 %) incidents at all airports ($n = 1{,}523$) occurred at night but the greatest incident rate occurred at dusk (177.3 incidents/hr). More incidents with damage ($n = 1{,}594$) occurred at GA airports (38.6 %) than certificated airports (19.0 %). Artiodactyla (even-toed ungulates) incidents incurred greatest (92.4 %) damage costs ($n = 326$; US$51.8 million) overall and mule deer (*Odocoileus hemionus*) was the most hazardous species. Overall, relative hazard score increased with increasing log body mass. Frequency of incidents was influenced by species relative seasonal abundance and behavior. We recommend airport wildlife officials evaluate the risks mammal species pose to aircraft based on the hazard information we provide and consider prioritizing management strategies that emphasize reducing their occurrence on airport property.

Keywords Airport · Airport management · Aviation hazard · Mammals · United States · Wildlife-aircraft incident · Wildlife strike

Introduction

Wildlife-vehicle collisions (WVCs) can result in substantial economic costs and human safety risks. Worldwide, it is estimated that WVCs annually cost >US$4 billion from vehicle collisions on roads and civil aircraft collisions (Langley and Mathison 2008; International Civil Aviation Organization (ICAO) 2009). Temporal variation in WVCs has been reported in the United States (U.S.) and abroad, and may be attributed in part to species breeding seasonality and daily activity. For example, road moose-vehicle collision may peak in late spring and summer due to increased moose activity (Dussault et al. 2006).

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However, deer-vehicle collisions occur most frequently in fall and winter due to increased activity of white-tailed deer during breeding (Hughes et al. 1996; Haikonen and Summala 2001; Bissonette et al. 2008). Increased frequency of WVCs in Australia has corresponded with increases in movements and juvenile recruitment of kangaroo (*Macropus* spp.) (Klöcker et al. 2006). Most road WVCs occur at night (Hughes et al. 1996; Haikonen and Summala 2001; Joyce and Mahoney 2001; Dussault et al. 2006; Bissonette et al. 2008) with greatest rates during dusk and dawn (Hughes et al. 1996; Haikonen and Summala 2001; Bissonette et al. 2008). In addition to decreased visibility from dusk through dawn, diel activity patterns of species, such as nocturnal activity of raccoons (*Procyon lotor*) (Gehrt 2003), may increase the risk at dawn, dusk, or night. Understanding relationships between animal behavioral traits and temporal distributions of WVCs can be used to better understand wildlife-vehicle or wildlife-aircraft collision risk.

Wildlife collisions with aircraft (hereafter incidents) cost the U.S. civil aviation industry an estimated >US$1.4 billion in damages and loss of revenue from 1990 to 2009 (Biondi et al. 2011). Birds accounted for 97.2 % of wildlife incidents with U.S. civil aircraft from 1990 to 2010; however, 87 % of bird incidents do not cause damage to aircraft (Dolbeer et al. 2012). In contrast, terrestrial mammals represent only 2.3 % of wildlife incidents, but 59 % of these incidents caused damage to aircraft (Dolbeer et al. 2012). Dolbeer et al. (2012) found that almost half of aircraft destroyed in wildlife incidents from 1990 to 2010 were damaged by mammals. Although mammal species can be extremely hazardous to civil aircraft (Dolbeer and Wright 2009; Biondi et al. 2011; Dolbeer et al. 2012), these incidents have not been examined in detail by airport type.

Most airports in the U.S. are categorized as Part-139 certified (certificated) or general aviation (GA) (Federal Aviation Administration (FAA) 2012a). Certificated airports are those which receive regularly scheduled passenger flights with >9 seats or unscheduled flights with >30 seats, or are otherwise required by the FAA Administrator to hold a certificate (Federal Aviation Administration (FAA) 2012a). General aviation airports are typically smaller and do not use scheduled passenger services (Federal Aviation Administration (FAA) 2012a). General aviation airports often have inadequate fencing (DeVault et al. 2008; Dolbeer et al. 2008; Cleary and Dickey 2010), an effective exclusion technique for medium and large mammals (Conover 2002; Seamans and VerCauteren 2006; DeVault et al. 2008). Because medium and large mammals are likely more hazardous to aircraft (see Dolbeer et al. 2000; DeVault et al. 2011), GA airports may be more vulnerable to damaging incidents. Therefore, it is important to determine which species are most hazardous at each airport type and how management can be improved to reduce risk.

We examined incidents in the Federal Aviation Administration (FAA) National Wildlife Strike Database to characterize and analyze mammal incidents by airport type. We hypothesized (1) seasonal variation of incidents at all airports, (2) time-of-day variation for frequency and rate of incidents at all airports, (3) damage variation by species body size at all airports, and (4) variation of frequency, damage, and species richness for incidents by airport type. Based on previous patterns noted with WVCs, we expected a greater frequency of incidents during October–November, dawn or dusk, and night due to species breeding, juvenile abundance and dispersal, and daily activity. We also expected damage to increase as mammal species body size increased, as demonstrated with birds (Dolbeer et al. 2000; DeVault et al. 2011). Finally, we predicted that GA airports would have a greater frequency of total incidents, damaging incidents, higher incident rates, and greater species richness than certificated airports because of reduced management.

Methods

Following Biondi et al. (2011), we searched the FAA National Wildlife Strike Database containing data from 1990 to 2010 for incidents involving mammals and U.S. civil aircraft within the airport environment (≤152.4 m above ground) at certificated airports, GA airports, and other airports. Other airports were private, non-certificated outside the U.S., or of unknown classification. We used the FAA Airport Facilities Data Report (Federal Aviation Administration (FAA) 2010) to identify certificated airports; all other airports were classified as GA unless private, non-certificated outside the U.S., or unknown classification. We excluded bat incidents as they may have occurred outside the airport environment (see Dolbeer 2006; Biondi et al. 2013). The FAA National Wildlife Strike Database is comprised information reported to the FAA by pilots and airports using FAA Form 5200–7 (Dolbeer and Wright 2009). Because reporting an incident is voluntary, many reports were incomplete; therefore, sample sizes varied among variables examined.

Due to the small sample size of incidents at other airports, these were not considered in analyses by airport type; thus, comparisons by month, species richness, phase of flight, and damage category refer only to certificated and GA airports. However, results that summarize all airports refer to certificated, GA, and other airports. We summarized the number of mammal incidents for all airports reported annually and calculated annual mammal incident rates/1 million U.S. civil aircraft movements within the

U.S. by airport type using the FAA Terminal Area Forecast Summary Report (Federal Aviation Administration (FAA) 2012b); 2010 flight data were presented as estimates. We determined the number of mammal incidents reported monthly for all airports and calculated monthly mammal incident rates/1 million U.S. civil aircraft movements for all airports within the U.S. using the FAA Air Traffic Activity System (Federal Aviation Administration (FAA) 2012c). We determined species richness by month for all airports and by airport type. We calculated the number of incidents/hr by time of day for all airports, as categorized in the FAA National Wildlife Strike Database. Dawn and dusk represented 0.75 h each, whereas night and day represented 11.25 h each (Wright et al. 1998; Biondi et al. 2011). We also summarized the number of incidents by state for all airports and by airport type.

To assess frequency of mammal incidents by aircraft phase of flight for all airports, an aircraft was classified in landing roll or take-off run when all wheels were on the ground during landing and take-off, respectively (Dolbeer and Wright 2009). We defined climb as an aircraft engaged in take-off with at least one wheel off the ground to any altitude below designated leveled flight altitude. En route was defined as an aircraft flying at the maximum altitude designated for that flight. Descent was an aircraft descending from en route altitude, but >6,858 m above ground. Approach was defined as an aircraft engaged in landing from ≤6,858 m above ground with at least one wheel off the ground. Parked was stationary aircraft. Taxi was an aircraft moving between the gate and the runway. Because taxi occurs twice during each flight, before take-off run and after landing roll, we reduced percentage of incidents during taxi by half to standardize incidents by movement type. We defined landing as the combination of approach and landing roll, and take-off as the combination of climb and take-off run. We summarized aircraft components (e.g., engine, wing or rotor, other) damaged in incidents at all airports as reported in the FAA National Wildlife Strike Database.

We used damage classes (none, minor, substantial, and destroyed) for all airports from the FAA National Wildlife Strike Database to estimate damage incurred (Dolbeer et al. 2000) by all mammals and by taxonomic order at all airports and by airport type. None was defined as no damage occurred. Minor damage could be fixed by simple repairs or replacement of parts and extensive inspection was not necessary. Substantial damage affected structural strength, performance, or flight characteristics, and the aircraft required major repair or replacement of parts. Destroyed damage included aircraft that could not be restored to airworthy condition. All forms of damage were combined to make an overall damage category termed any damage. We summarized effect on flight and aircraft out of service for all airports as provided by the FAA National Wildlife Strike Database. Effect on flight was any deviation from a normal flight routine (e.g., aborted take-off or landing, delayed flight). An aircraft was considered out of service when not in use while undergoing repairs.

We estimated total direct cost of damage for incidents at all airports by averaging reported costs for each damage class, multiplied these averages by the total number of incidents within each respective damage class, and summed all estimates. For comparison, we similarly calculated estimated total direct cost of damage for all other reported wildlife incidents. Costs were taken from the FAA National Wildlife Strike Database and adjusted for inflation to 2011 values using the U.S. Consumer Price Index.

We ranked the hazard level for species with ≥10 incidents at all airports using a composite ranking comprised three hazard categories: percent any damage, percent substantial damage, and the percent effect on flight (Dolbeer et al. 2000; DeVault et al. 2011). We ranked species/groups for each category then summed category rankings to produce a composite rank. We calculated a relative hazard score by proportionally scaling the composite ranking for each species/group from 100 (most hazardous) to 0 (least hazardous). Species with $n < 10$ were grouped into taxonomic families to achieve an $n \geq 10$ when possible. Body masses were from Whitaker and Hamilton (1998) or Feldhamer et al. (2003) and averaged by sexes when body mass dimorphism occurred. We also summarized frequency of all mammal species and groups involved in incidents at all airports.

We used linear regression (program R version 2.13.1, The R Foundation for Statistical Computing, Vienna, Austria) to assess trends in incidents across years by damage at all airports and airport type. We used Chi square analyses (program SAS version 9.3, SAS Institute, Cary, North Carolina) to compare the number of incidents by airport type among months, species richness, phase of flight, and incident rates/hour by time of day (e.g., day, night). We log transformed body mass and used a general linear model with a quadratic term (R Core Team, version 2.13.1, The R Foundation for Statistical Computing, Vienna, Austria) to estimate the relationship between relative hazard score and log body mass for species at all airports.

Results

Characteristics of Incidents

Overall, 2,558 mammal incidents with U.S. civil aircraft were reported; 1,764 occurred at certificated airports, 741 occurred at GA airports, and 53 occurred at other airports (Fig. 1). Incidents comprised 45 known species or groups overall (Table 1) in seven taxonomic orders, with

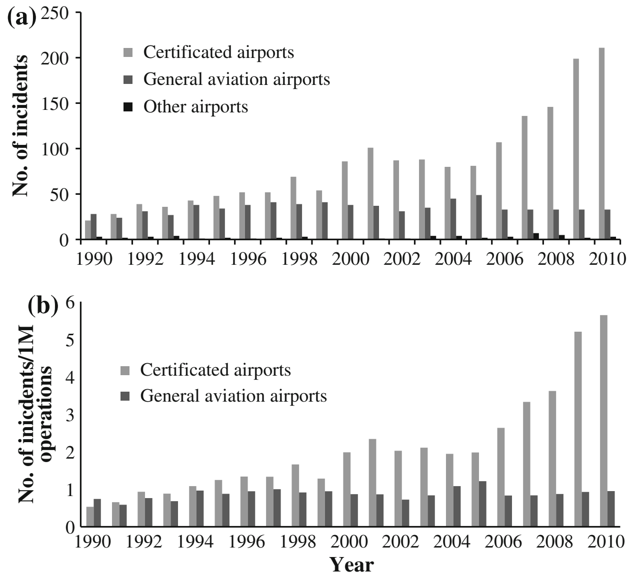

Fig. 1 **a** Number of mammal incidents ($n = 2{,}558$) and **b** incident rate (incidents/1 M operations) with U.S. civil aircraft by year and airport type, 1990–2010

Artiodactyla ($n = 1{,}036$), Carnivora ($n = 833$), and Lagomorpha ($n = 368$) most frequently reported. Most (61.4 %) airports where an incident occurred ($n = 780$) were GA airports. However, 51.5 % of all certificated airports in the U.S. ($n = 585$) had reported ≥ 1 incident, whereas only 2.5 % of all GA airports ($n = 19{,}152$) reported ≥ 1 incident.

The highest cumulative incident rate occurred in 2010 at certificated airports (5.64 incidents/1 M operations), whereas 2005 had the highest cumulative incident rate at GA airports (1.22 incidents/1 M operations). Overall, cumulative incident rate at certificated airports (2.1 incidents/1 M operations) was more than twice as great as GA airports (0.88 incidents/1 M operations). Frequency of reported incidents increased across years ($y = 62.1 + 0.16x + 0.35x^2$; adjusted $r^2 = 0.908, P \leq 0.001$) for all airports. Similarly, annual number of incidents at certificated airports increased ($y = 37.8 - 2.17x + 0.44x^2$; adjusted $r^2 = 0.887, P \leq 0.001$). Annual number of incidents at GA airports depicted a quadratic response ($y = 23.0 + 2.66x - 0.11x^2$; adjusted $r^2 = 0.405$, $P < 0.004$). There was an interaction between year and airport type with incidents at certificated airports increasing by >10 times that of GA airports ($y = 32.1 + 0.29x_1 - 31.6x_2 + 7.3x_1x_2$; adjusted $r^2 = 0.857, P \leq 0.001$).

Incidents occurred in every state, Washington, D.C, and seven other countries. However, there were no reported incidents at GA airports in North Dakota, Delaware, or Washington, D.C. The four states with the most incidents at all airports were Colorado ($n = 210$), New York ($n = 186$), California ($n = 155$), and Texas ($n = 151$). These four states also had the most mammal incidents at

Table 1 Number of mammal incidents with U.S. civil aircraft reported in the Federal Aviation Administration's National Wildlife Strike Database by taxonomic order and species or group, 1990–2010

Species or group	Total incidents reported
Didelphimorphia	**104**
Virginia opossum (*Didelphis virginiana*)	104
Cingulata	**24**
Nine-banded armadillo (*Dasypus novemcinctus*)	24
Lagomorpha	**368**
Black-tailed jackrabbit (*Lepus californicus*)	137
White-tailed Jackrabbit (*Lepus townsendii*)	32
Desert cottontail (*Sylvilagus audubonii*)	14
Eastern cottontail (*Sylvilagus floridanus*)	61
Unknown rabbit	124
Carnivora	**833**
Domestic cat	22
Small asian mongoose (*Herpestes javanicus*)	3
Coyote (*Canis latrans*)	346
Domestic dog	32
Common gray fox (*Urocyon cinereoargenteus*)	5
Red fox (*Vulpes vulpes*)	81
Unknown canids	3
Unknown foxes	74
Badger (*Taxidea taxus*)	3
American mink (*Neovison vison*)	1
River otter (*Lontra canadensis*)	2
Striped skunk (*Mephitis mephitis*)	98
Unknown skunk	95
Raccoon (*Procyon lotor*)	66
Ringtail (*Bassariscus astutus*)	1
White-nosed coati (*Nasua narica*)	1
Perissodactyla	**4**
Burro (donkey)	1
Domestic horse	3
Artiodactyla	**1,036**
Swine (pigs)	1
Collared peccary (*Pecari tajacu*)	2
Moose (*Alces alces*)	5
Mule deer (*Odocoileus hemionus*)	58
White-tailed deer (*Odocoileus virginianus*)	909
Red deer (*Cervus elaphus*)	11
Caribou (*Rangifer tarandus*)	2
Pronghorn (*Antilocapra americana*)	9
Deer (*Odocoileus Spp.*)	29
Domestic cattle	10
Rodentia	**172**
Black-tailed prairie dog (*Cynomys ludovicianus*)	24
Gunnisons prairie dog (*Cynomys gunnisoni*)	12
Squirrel (*Sciuridae*)	2

Table 1 continued

Species or group	Total incidents reported
Woodchuck (*Marmota monax*)	94
Unknown prairie dog	7
Pocket gopher	3
Muskrat (*Ondatra zibethicus*)	16
Woodrat (*Neotoma spp.*)	2
North American porcupine (*Erethizon dorsatum*) *dorrdorsatum)*	11
North American beaver (*Castor canadensis*)	1
Unknown	**17**

Bold values indicate the overall incident count

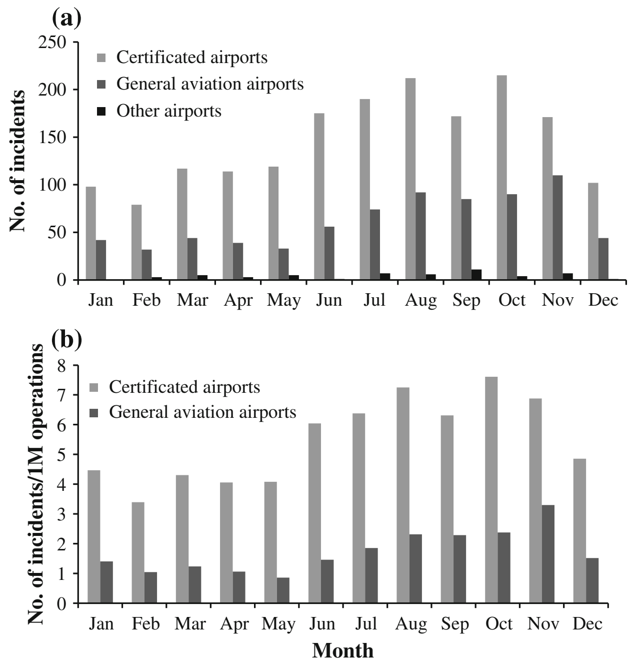

Fig. 2 **a** Number of mammal incidents ($n = 2{,}558$) and **b** incident rate (incidents/1 M operations) with U.S. civil aircraft by month and airport type, 1990–2010

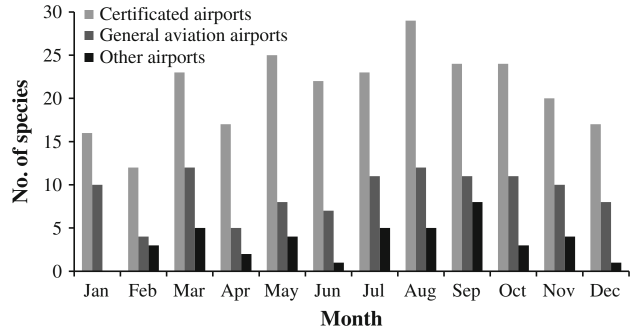

Fig. 3 Number of species ($n = 41$) involved in mammal incidents with U.S. civil aircraft by month and airport type, 1990–2010

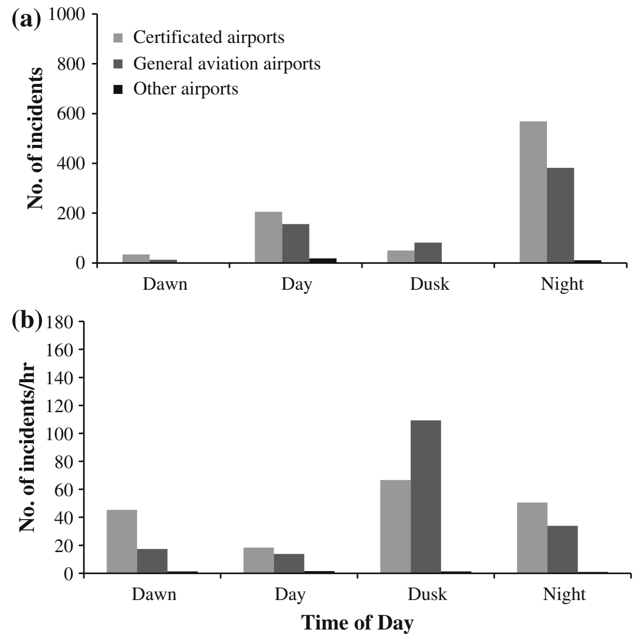

Fig. 4 **a** Number of mammal incidents ($n = 1{,}523$) and **b** incident rate (incidents/hr) with U.S. civil aircraft by time of day and airport type, 1990–2010

certificated airports: Colorado ($n = 200$), New York ($n = 150$), California ($n = 121$), and Texas ($n = 114$). Michigan ($n = 53$), New Jersey ($n = 49$), Wisconsin ($n = 44$), and Texas ($n = 37$) had the highest number of incidents at GA airports.

The number of reported incidents varied ($n = 2{,}505$; $\chi^2_{11} = 23.6$, $P = 0.01$) across months and airport type (Fig. 2). Incidents were most frequent in October ($n = 215$) at certificated airports and November ($n = 111$) at GA airports, but overall more incidents were reported in August ($n = 310$). Incidents at certificated airports generally increased from January to October and then decreased through December. Incidents at GA airports continued to increase from January through November before decreasing almost 60 % in December. The highest monthly incident rate at certificated airports occurred in October (7.6 incidents/1 M operations), whereas the highest monthly incident rate at GA airports occurred in November (3.3 incidents/1 M operations).

Species richness did not vary ($n = 240$; $\chi^2_{11} = 10.4$, $P = 0.495$) across months but overall was greater ($n = 361$; $\chi^2_1 = 56.64$, $P \leq 0.001$) at certificated airports (Fig. 3). Overall, certificated airports had incidents with more species or groups ($n = 41$) than GA airports ($n = 28$) or other airports ($n = 20$).

Most (63.2 %) incidents at all airports ($n = 1{,}523$) occurred at night; however, mammal incident rates varied ($n = 355$; $\chi^2_3 = 26.4$, $P \leq 0.001$) by time of day and

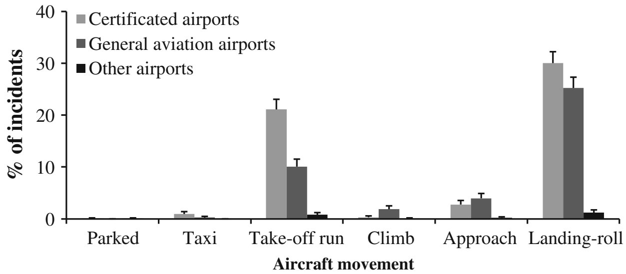

Fig. 5 Percent (+95 % CI) of mammal incidents ($n = 1{,}668$) with U.S. civil aircraft by aircraft movement and airport type, 1990–2010

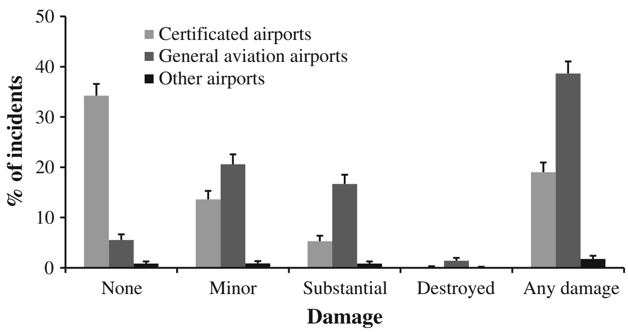

Fig. 6 Percent (+95 % CI) of mammal incidents ($n = 1{,}594$) with U.S. civil aircraft by damage class and airport type, 1990–2010

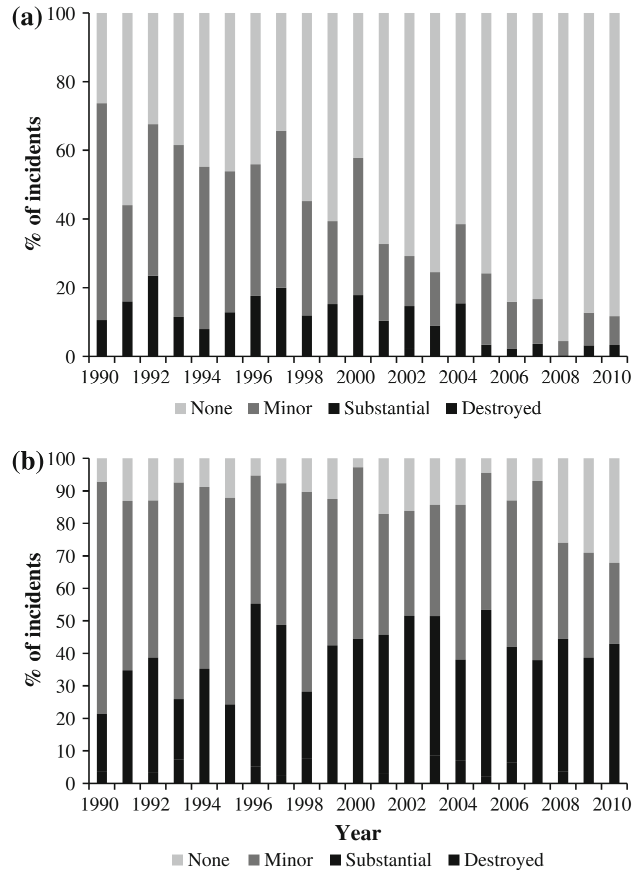

Fig. 7 Percent of mammal incidents with U.S. civil aircraft at **a** Certificated airports ($n = 848$) and **b** General aviation airports ($n = 702$) by damage type and year, 1990–2010

airport type (Fig. 4). For all airports, the greatest incident rate occurred at dusk (177.3 incidents/h) and the lowest incident rate occurred during day (33.8 incidents/h).

Incidents varied ($n = 1{,}630$; $\chi^2_5 = 74.7$, $P \leq 0.001$) among aircraft phase of flight and airport type (Fig. 5). Overall, fewer incidents occurred during take-off run at GA airports ($n = 694$; 24.2 %) than certificated ($n = 936$; 37.6 %) or other airports ($n = 38$; 34.2 %). More ($n = 1{,}668$; $\chi^2_4 = 27.6$, $P \leq 0.001$) incidents occurred during landing (63.4 %) than take-off (34.2 %) or other movements (2.5 %). Aircraft components most likely damaged when struck during incidents ($n = 2{,}197$) at all airports were lights ($n = 37$; 97.3 %), tail ($n = 59$; 96.7 %), and wing rotor ($n = 242$; 91.7 %).

Frequency of damage ($n = 1{,}553$; $\chi^2_3 = 455.2$, $P \leq 0.001$) varied among classes and airport type (Fig. 6). More incidents at all airports had no damage (40.6 %) than minor (35.1 %), substantial (22.8 %), or destroyed (1.6 %). Although damage decreased at all airports across years ($y = 76.4 + 0.44x - 0.13x^2$; adjusted $r^2 = 0.792$, $P \leq 0.001$) (Fig. 7), more incidents with damage ($n = 1{,}594$) occurred at GA airports (38.6 %) than certificated airports (19.0 %) or other airports (1.76 %). Most (88.0 %) aircraft destroyed ($n = 25$) in incidents also occurred at GA airports. Artiodactyla comprised 54.8 % of damage costs for incidents at all airports ($n = 1{,}592$). However, Artiodactyla caused damage in ≥ 2 times as many incidents at GA airports ($n = 708$; 82.2 %) or other airports ($n = 41$; 63.4 %), than certificated airports ($n = 845$; 31.4 %).

Effects of Incidents

Twice as many incidents had an effect on flight at GA airports ($n = 479$; 72.4 %) or other airports ($n = 25$; 79.2 %) than certificated airports ($n = 717$; 35.8 %). Artiodactyla had the greatest effect on flight ($n = 1{,}211$; 40.0 %) at all airports, followed by Carnivora (9.4 %). All other taxonomic orders resulted in <1 % of incidents with an effect on flight. Total time aircraft were reported out of service more than five times greater at GA airports ($n = 195$; 25.7 years) than at certificated airports ($n = 89$; 4.8 years) or other airports ($n = 2$; 1.0 years). Artiodactyla accounted for 94.4 % of aircraft out-of-service time at all airports ($n = 286$), followed by Carnivora (5.2 %). Remaining taxonomic orders each comprised <1 % of out-of-service time.

Overall, mammal incidents ($n = 1{,}549$; 61.1 %) were almost five times more likely to incur damage than all other

Table 2 Number of incidents, percent, and sample size by damage type and effect on flight, and relative hazard score of mammal species incidents ($n \geq 30$) with U.S. civil aircraft, 1990–2010

Species	Total incidents reported	Damage			Effect on flight		Relative hazard score
		n	% Any	% Substantial	*n*	%	
Mule deer (*Odocoileus hemionus*)	58	56	80.0	60.0	34	82.4	100
White-tailed deer (*Odocoileus virginianus*)	909	880	92.9	37.5	591	69.4	89
Domestic dog	32	28	39.2	17.9	21	85.7	78
Raccoon (*Procyon lotor*)	66	19	15.8	10.5	23	13.0	67
Coyote (*Canis latrans*)	346	246	12.2	2.0	214	35.0	56
Black-tailed Jackrabbit (*Lepus californicus*)	137	22	9.1	4.5	19	5.3	44
Red fox (*Vulpes vulpes*)	81	39	7.7	0	40	17.5	44
Woodchuck (*Marmota monax*)	94	32	0	0	39	7.7	22
Virginia opossum (*Didelphis virginiana*)	104	24	4.2	0	26	0	11
Striped skunk (*Mephitis mephitis*)	98	12	0	0	14	0	0

Incident frequencies and damage percentages were from Federal Aviation Administration's National Wildlife Strike Database

wildlife ($n = 67{,}031$; 12.4 %). Artiodactyla incidents incurred the greatest (92.4 %) damage costs ($n = 326$; US$51.8 million) at all airports, followed by Carnivora (7.3 %). All wildlife incidents including direct damage costs totaled >US$430.0 million with an estimated cost of >US$1.24 billion from 1990 to 2010. Mammal incidents comprised 2.7 % of all wildlife incidents ($n = 94{,}773$), yet incurred 12.0 % of total costs. Total damage costs of mammal incidents reported at certificated airports ($n = 90$) were >US$17.7 million with an estimated cost of >US$34.0 million. GA airports reported >US$33.7 million in damage costs ($n = 231$) with an estimated cost >US$66.7 million. Other airports reported >US$288 thousand in damage costs ($n = 5$) with an estimated cost >US$1.8 million.

For all airports, Artiodactyla ($n = 31$), Carnivora ($n = 2$), Lagomorpha ($n = 1$), and Perissodactyla ($n = 1$) were involved in incidents resulting in human injuries. The only human death reported involved an incident with a white-tailed deer at a certificated airport; overall, injuries were categorized as minor to severe. General aviation airports reported 30 of 35 human injuries.

Hazard Ranking

Mule deer (*Odocoileus hemionus*) was the most hazardous (hazard score = 100) species, followed by white-tailed deer (89) and domestic dog (78) (Table 2). These three species also had the greatest body masses of the 10 species or groups with adequate data to calculate hazard scores. Overall, relative hazard score increased with increasing log body mass ($y = -28.1 + 5.01x^2$; $r^2 = 0.785$, $P \leq 0.001$) (Fig. 8).

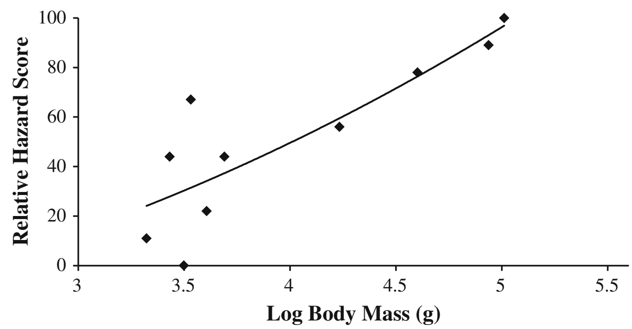

Fig. 8 Relationship between relative hazard scores and body mass for mammal species/groups ($n \geq 10$) involved in incidents with U.S. civil aircraft, 1990–2010

Discussion

Behavioral Traits

Frequency of mammal incidents with aircraft and incident rates was influenced by relative abundance of species and behavioral traits including daily activity, breeding, and juvenile dispersal. The overall greater frequency of incidents during August likely corresponds with increased abundance of species and individual movements due to juvenile recruitment and dispersal for many species (Cypher 2003; Flinders and Chapman 2003; Gardner and Sunquist 2003). In addition, the higher incident rates in November at both certificated and GA airports correspond with the mating season of white-tailed deer (Miller et al. 2003), the species most frequently involved in incidents at GA and certificated airports. Deer are less vigilant toward aircraft at this time (Iverson and Iverson 1999) which can increase the likelihood of deer incidents (Biondi et al. 2011).

The relatively low incident rates during winter (December–February) correspond with reduced activity of many mammal species during this period; half of species with ≥10 incidents have reduced activity in winter. For example, white-tailed deer, the second most hazardous mammal species, reduce movements and increase use of cover during winter (Pauley et al. 1993). Coyotes (*Canis latrans*; Bekoff and Gese 2003), skunks (Rosatte and Larivière 2003), and opossums (*Didelphis virginiana*; Gardner and Sunquist 2003) also exhibit restricted movements in winter. Woodchucks (*Marmota monax*), a relatively low hazard species, hibernate during winter (Armitage 2003).

The temporal frequency and rate of mammal incidents overall are similar to deer incidents with U.S. civil aircraft (Wright et al. 1998; Biondi et al. 2011) and road WVCs in general (Hughes et al. 1996; Haikonen and Summala 2001; Joyce and Mahoney 2001; Dussault et al. 2006; Bissonette et al. 2008). Many mammal species, including coyote (Bekoff and Gese 2003), foxes (Cypher 2003), opossums (Gardner and Sunquist 2003), raccoon (Gehrt 2003), and white-tailed deer (Miller et al. 2003), exhibit crepuscular or nocturnal activity. Reduced pilot visibility (Mastro et al. 2010) during these periods would likely decrease detection of mammals and contribute to the greater incident frequency and rate during these periods (Inbar and Mayer 1999; Iverson and Iverson 1999; Haikonen and Summala 2001; Conover 2002; Dussault et al. 2006; Grilo et al. 2009; Biondi et al. 2011).

The greater frequency of incidents during landing may be a result of several factors involving mammal and pilot behavior. Pilots and mammals would be more likely to detect each other during take-off and other phases of flight due to increased visibility of both while aircraft are on the ground, as opposed to approaching from above (Wright et al. 1998; Biondi et al. 2011). During landing, aircraft speed combined with limited maneuverability makes it difficult to avoid animals even when detected (Biondi et al. 2011). Mammals may also habituate to loud noises or activities that do not pose risk (Bomford and O'Brien 1990; Belant et al. 1996; Cleary and Dolbeer 2005) and not immediately perceive an incoming plane as a threat.

That Artiodactyl incidents caused greatest damage overall was expected considering their typically greater body mass (Biondi et al. 2011). Relative hazard scores of mammals increased with increasing body mass, similar to birds (Dolbeer et al. 2000; DeVault et al. 2011), indicating that larger mammals pose a greater risk. The relatively larger body mass of species within Artiodactyla and Carnivora involved in incidents makes damage to aircraft, effect on flight, increases in aircraft out-of-service time, higher direct damage costs, and injuries more likely during an incident.

Airport Type

Although a higher proportion of all certificated airports in the U.S. reported ≥1 mammal incident, over half of all airports reporting ≥1 mammal incident were GA airports. This disparity may produce biases in aircraft movements, aircraft size, and management used between airport types. The greater frequency of incidents at certificated airports may also be partially attributed to the greater reporting rate at certificated airports as they currently report about 39 % of wildlife incidents with civil aircraft (Dolbeer et al. 2012), whereas GA airports report about 5 % of wildlife strikes (Dolbeer et al. 2008; Dolbeer 2009). Wildlife incident reporting rates at certificated airports have increased from 20 % from 1990 to 1994–39 % from 2004 to 2008 (Dolbeer et al. 2012). General aviation airports typically receive smaller aircraft than certificated airports (Federal Aviation Administration (FAA) 2012a), increasing the risk of damaging incidents as damage to aircraft increases as aircraft mass decreases (Biondi et al. 2011). Also, GA airports generally have less funding to install and maintain fencing for excluding mammals (Conover 2002; Seamans and VerCauteren 2006; DeVault et al. 2008; Dolbeer et al. 2008), which increases risk from incidents relative to certificated airports.

Although annual frequency of mammal incidents increased from 1990 to 2010, annual frequency of damaging incidents decreased, similar to all wildlife incidents (Dolbeer et al. 2012). The decrease in damaging mammal incidents at certificated airports from 74 % in 1990 to 12 % in 2010 was similar to the decrease reported by Dolbeer et al. (2012) for all wildlife. Since reporting incidents to the FAA National Wildlife Strike Database is voluntary, incidents causing damage appear more likely to be reported than incidents with no damage (Dolbeer et al. 2012). The relative increase in non-damaging mammal incidents at certificated airports may be a consequence of increased annual reporting rates. In contrast, the relative consistency of percentage mammal incidents by damage class across years at GA airports suggests that reporting rates for these airports have not increased.

About 12.4 % of all terrestrial mammal species (excluding bats) in North America north of Mexico (Baker et al. 2003) were involved in ≥1 incident with U.S. civil aircraft. However, about 152 terrestrial mammal species (i.e., mice, rats, voles, and shrews) are likely not reported as they would cause little or no damage, leave no evidence of a strike, and pilots may not be aware of an incident occurred. Therefore, up to 21.2 % of terrestrial mammal species likely to be reported were involved in ≥1 incident with U.S. civil aircraft. Although species richness was similar across months, absolute species richness values mirrored monthly frequency of incidents at each airport type. Greater species richness at certificated airports may reflect the increased reporting of non-damaging incidents (Dolbeer et al. 2012), as species that cause little to no damage may be unreported at GA airports.

Management

Mammal incidents are five times more likely to incur damage to aircraft than all other wildlife. The economic impact of mammals to the U.S. civil aviation industry suggests increased management is warranted, particularly for larger mammals (e.g., deer). Fencing is the most effective mammal exclusion technique for airports (Cleary and Dolbeer 2005; Seamans and VerCauteren 2006; DeVault et al. 2008). Airports with incomplete fencing had 15 times more deer than airports with complete fencing (DeVault et al. 2008). To maximize efficiency, fences should be $\geq$2.4 m high (Cleary and Dolbeer 2005; VerCauteren et al. 2006, 2010), but are recommended to be $\geq$3.0 m with barbed wire on top (Federal Aviation Administration (FAA) 2004; Cleary and Dolbeer 2005). To further increase efficacy, about 1.2 m of fencing should be buried below ground to prevent mammals (e.g., canids) from digging under the fence (Cleary and Dolbeer 2005; DeVault et al. 2008). Fences should be maintained to repair holes $\geq$15 cm^2 to exclude deer (Cleary and Dolbeer 2005; Vercauteren et al. 2006; DeVault et al. 2008), and smaller holes to exclude other species. Deer or cattle guards (Belant et al. 1998; Cleary and Dolbeer 2005), or electrified mats (Seamans and Helon 2008) at permanent openings, such as gates or entrances, will further reduce mammal entry.

Once exclusion techniques are established, supplemental lethal and non-lethal techniques can be used to augment exclusion. Sharpshooting or euthanasia is preferable to relocation because of the high mortality rate of relocated individuals, cost (Ishmael and Rongstad 1984; O'Bryan and McCullough 1985; Jones and Witham 1990; Conover 2002; Cleary and Dolbeer 2005; DeNicola and Williams 2008), and potential disease transmission (Cleary and Dolbeer 2005; DeNicola and Williams 2008). Live traps or lethal traps can be used to capture medium-sized mammals (i.e., canids, raccoons, and woodchucks) (Cleary and Dolbeer 2005). Loud noises, from 4 to 8 kHz or 20–30 kHz for deer (D'Angelo et al. 2007), or lights may be effective at repelling mammals (Craven and Hyngstrom 1994; Cleary and Dolbeer 2005; Blackwell and Seamans 2009). Propane cannons or pyrotechnics may repel mammals temporarily but cannot be used long term because individuals habituate to the explosions (Belant et al. 1996; Cleary and Dolbeer 2005). Supplemental techniques would likely be more effective at reducing incidents if used sparingly before take-offs and landings, but are not long-term solutions.

Conclusions

Mammal incidents cause more damage to U.S. civil aircraft than other wildlife incidents. Frequency and damage caused by these incidents vary by airport type and appear strongly associated with species' behavior and body mass. Management techniques, particularly fencing, can be used to reduce mammal presence at airports, and are most effective when combinations of techniques are implemented. Each airport should evaluate the hazardous mammal species inhabiting their properties and the relative efficacy of available techniques to reduce their use of airport properties. We suggest airport wildlife management officials evaluate mammal species present based on the aircraft hazard information we provided and consider management strategies that emphasize reducing their occurrence on airport property.

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