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Carnivore incidents with U.S. civil aircraft

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ABSTRACT

Wildlife incidents with aircraft are of concern in the United States as they pose a risk to human safety and economic losses for the aviation industry. Most previous research on wildlife-aircraft incidents has emphasized birds, bats, and ungulates. We queried the Federal Aviation Administration's National Wildlife Strike Database from 1990 to 2012 to characterize carnivore incidents with U.S. civil aircraft. We found 1016 carnivore incidents with aircraft representing at least 16 species, with coyotes ($n = 404$) being the species most frequently struck. California and Texas had the most reported incidents and incidents were most likely to occur at night from August to November. Overall estimated damage to aircraft was US$ 7 million. Coinciding with the increase in air traffic, the rate of carnivore-aircraft incidents increased 13.1% annually from 1990 to 2012 whereas the rate of damaging incidents remained fairly constant. Due to the increase in carnivore-aircraft incidents from 1990 to 2012, we recommend further research on techniques to increase detection of carnivores and implementation and scheduled maintenance of perimeter high fences for exclusion. Additionally, we recommend increasing patrol of runways, especially during peak incident periods (July–November) and at night (2000–0600 h).

Introduction

Wildlife collisions with aircraft pose a threat to human safety and economic losses for the aviation industry (DeVault et al., 2013). From 1990 to 2009, wildlife incidents with U.S. civil aircraft resulted in more than US$ 1.4 billion in damages and substantial loss of revenue due to the cost of mitigation techniques (Biondi et al., 2011). From 1990 to 2010, more than 100,000 wildlife incidents with aircraft were reported using the Federal Aviation Administration's (FAA) National Wildlife Strike Database (Dolbeer et al., 2012). Birds are the primary group involved in incidents (97.2%), followed by mammals (2.7%) and reptiles (0.1%) (Dolbeer et al., 2012). Increases in wildlife populations and air traffic have contributed to the increased risk and severity of wildlife collisions with aircraft (Khalafallah and El-Rayes, 2006; DeVault et al., 2013).

Though most research on wildlife-aircraft incidents has emphasized birds (e.g., DeVault et al., 2009; Dolbeer, 2011; Blackwell et al., 2012), incidents involving mammals cause a greater proportion of damaging incidents with aircraft (e.g., Dolbeer et al., 2000; Biondi et al., 2011; DeVault et al., 2011). Previous research on mammal incidents with aircraft has focused on ungulates and bats (Parsons et al., 2008; Biondi et al., 2011, 2013); other mammalian taxa have not been studied

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in detail. Our objective was to summarize carnivore incidents with U.S. civil aircraft to estimate the frequency and timing of incidents and associated hazards to aircraft. Carnivores use airport runways and surrounding areas to acquire prey (e.g., small mammals), thus posing a threat to aircraft. We predicted overall similar numbers of carnivore incidents annually from 1990 to 2012 due to increased awareness of wildlife hazards at airports and associated reporting, but also consequent increases in management to reduce the frequency of such incidents. We also predicted that carnivore incidents would be greatest during autumn when abundance is greatest and juvenile dispersal typically occurs (e.g., Bekoff, 1977).

Methods

We queried the Federal Aviation Administration National Wildlife Strike Database (NWSD; http://wildlife.faa.gov/database.aspx) containing data from 1990 to 2012 for wildlife incidents involving species within the Order Carnivora and U.S. civil aircraft. We included only incidents reported within the 50 U.S. states and Washington, D.C. The National Wildlife Strike Database contains information reported to the FAA by pilots and airport personnel using FAA Form 5200-7 (Dolbeer et al., 2009). Reporting of wildlife incidents for U.S. civil aircraft is voluntary; therefore, some reports were incomplete which resulted in varying sample sizes.

We calculated incident rates as the annual number of incidents/1 million U.S. civil aircraft movements using the FAA Terminal Area Forecast Summary Report (Federal Aviation Administration, 2012a). We also calculated monthly data on aircraft movements from 1996 to 2012 using the Research and Innovative Technology Administration (RITA) Bureau of Transportation Statistics (United States Department of Transportation, 2012). Additionally, we summarized incidents by states and species responsible for incidents. We defined an aircraft movement as a take-off or landing by the aircraft. We determined the time of day each incident took place based on the local time reported. Incidents occurring between 0800 to 1800 local time were categorized as 'day', and incidents occurring from 2000 to 0600 were categorized as 'night' (Washburn et al., 2013). 'Dawn' incidents occurred from 0600 to 0800 and 'dusk' from 1800 to 2000 (Washburn et al., 2013).

We summarized phase of flight using the classification of approach, climb, taxi, landing roll, and take-off run. Approach was defined as an aircraft engaged in landing with at least one wheel off the ground whereas climb was defined as an aircraft engaged in take-off with at least one wheel off the ground (Biondi et al., 2011). We defined taxi as an aircraft moving between the gate and runway (Biondi et al., 2011). Take-off run and landing roll were defined as an aircraft having all wheels on the ground during landing and take-off (Dolbeer and Wright, 2009). From the FAA National Wildlife Strike Database, we used the damage classes "none", "minor", "substantial", and "destroyed" to assess the overall extent of damage incurred on the aircraft (Dolbeer et al., 2009). None was defined as no damage to the aircraft. Minor damage required simple repairs and did not require extensive inspection. Damage defined as substantial could not be fixed by simple repairs and required extensive inspection as it affected flight, structural integrity of the aircraft, and overall performance. Damage categorized as destroyed was irreparable, resulting in decommissioning of the aircraft. The estimated damage cost of an aircraft deemed "destroyed" was the cost of replacement for the aircraft.

We estimated damage by averaging reported costs for each damage class, multiplying those averages by the total number of incidents within each respective damage class, and summing the estimates (Biondi et al., 2011). Additionally, we summarized damaged components of aircraft by analyzing damage reports provided by the FAA National Wildlife Strike Database to further assess extent of aircraft damage. The estimated damage cost was the cost of replacement for the component. We used simple linear regression to assess trends in the number of incidents across years and chi-square analyses to compare the number of incidents among months, phase of flight, and incident rates/hour by time of day (e.g., day, night) (program R version 2.13.1, The R Foundation for Statistical Computing, Vienna, Austria).

Results

Overall, 1016 carnivore–U.S. civil aircraft incidents were reported from 1990 to 2012. The number of incidents increased 13.1% annually ($y = 1.98 + 0.20x$; $r^2 = 0.94$; $P < 0.01$) from 1990 to 2012, with the greatest number of reported incidents/1 million movements ($n = 101$) in 2012 (Fig. 1). The number of reported incidents varied among months ($\chi^2_{11} = 158.5$, $P < 0.01$) and was greatest in October ($n = 142$) and lowest in April and May ($n = 41$) (Fig. 2).

At least 16 carnivore species were responsible for reported incidents (Table 1). Overall, canids accounted for 66.2% of all incidents with coyotes (*Canis latrans*), the most frequently reported species ($n = 404$), accounting for 39.8% of incidents. The second most frequently reported species, red fox (*Vulpes vulpes*) ($n = 120$), accounted for 11.8% of incidents. Incidents were reported in 48 of the 50 United States and Washington, D.C. California had the most reported incidents ($n = 88$) followed by Texas ($n = 85$) and Illinois ($n = 77$); South Dakota and Wyoming had no reported incidents.

Of the 509 incidents for which the time of day was reported, most ($\chi^2_3 = 507.7$, $P < 0.01$) incidents occurred at night ($n = 334$), followed by day ($n = 129$) (Fig. 3). Of the 537 reported incidents which included phase of flight when the incident occurred, landing roll ($n = 279$) was most common ($\chi^2_4 = 626.7$, $P < 0.01$), followed by take-off run ($n = 214$) (Fig. 4).

Extent of damage was reported for 501 incidents. Damage reports indicating "none" were most frequent ($n = 440$), followed by "minor" ($n = 42$), "substantial" ($n = 12$), "destroyed" ($n = 2$), and "uncertain" ($n = 5$). Damaged components were

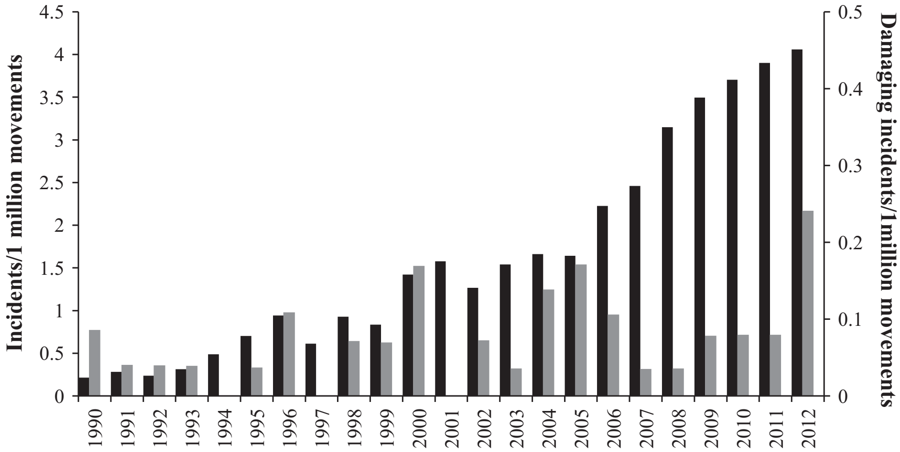

Fig. 1. Number of carnivore incidents/1 million aircraft movements (black bars) and number of damaging incidents/1 million aircraft movements (gray bars) involving U.S. civil aircraft ($n = 1016$) by year, 1990–2012 (FAA NWSD).

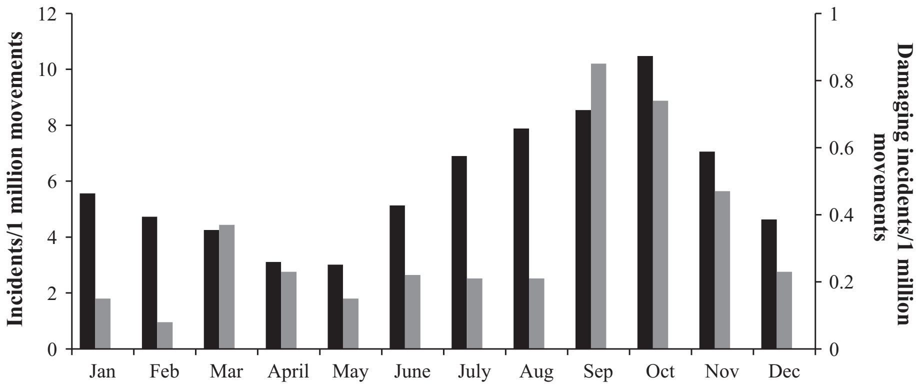

Fig. 2. Number of carnivore incidents/1 million aircraft movements (black bars) and number of damaging incidents/1 million aircraft movements (gray bars) involving U.S. civil aircraft ($n = 458$) by month, 1996–2012 (FAA NWSD).

Table 1
Percentage of reported incidents of carnivores with U.S. civil aircraft by species or species group, 1990–2012 (FAA NWSD).

Species	*n*	% of incidents
Coyote (*Canis latrans*)	404	39.8
Red fox (*Vulpes vulpes*)	120	11.8
Common gray fox (*Urocyron cinereoargenteus*)	7	0.7
Unknown foxes (*Vulpes spp.*)	61	6.0
Domestic dog (*Canis lupus familiaris*)	38	3.7
Unknown canids (*Canis spp.*)	2	0.2
Striped skunk (*Mephitis mephitis*)	207	20.4
Unknown skunks (*Mephitidae*)	52	5.1
Raccoon (*Procyon lotor*)	83	8.2
Ringtail (*Bassariscus astutus*)	1	0.1
White-nosed coati (*Nasua narica*)	1	0.1
Domestic cat (*Felis catus*)	28	2.8
Badger (*Taxidea taxus*)	4	0.4
Mink (*Neovison vison*)	4	0.4
River otter (*Lontra canadensis*)	2	0.2
American black bear (*Ursus americanus*)	1	0.1

reported for 107 incidents, with damage to the landing gear ($n = 43$) most frequent, followed by damage to the propeller ($n = 17$) (Fig. 5). Of these, multiple components were damaged in 17 incidents.

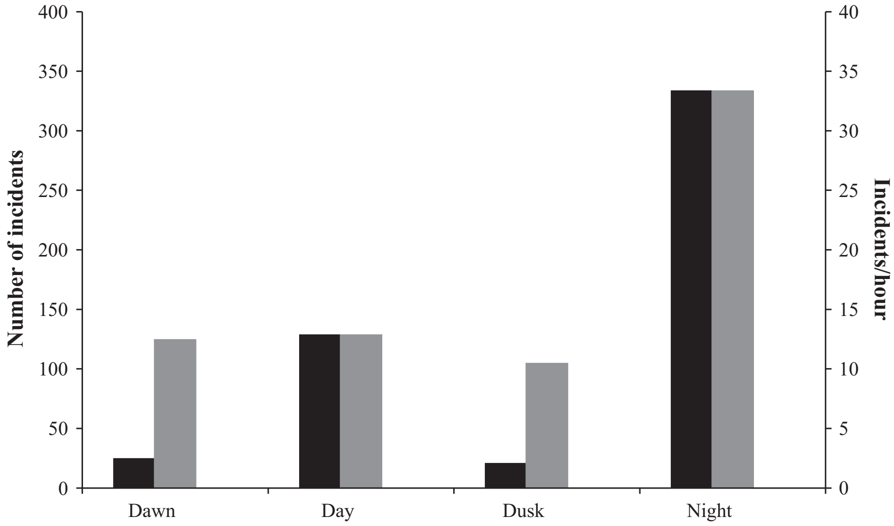

Fig. 3. Reported carnivore incidents with U.S. civil aircraft ($n = 509$) by time of day, 1990–2012 (FAA NWSD).

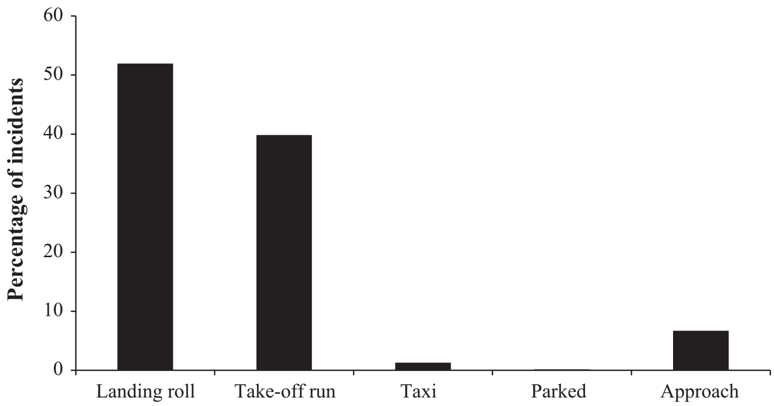

Fig. 4. Reported number of carnivore incidents ($n = 537$) (black bars) and incidents/hour (gray bars) with U.S. civil aircraft by phase of flight, 1990–2012 (FAA NWSD).

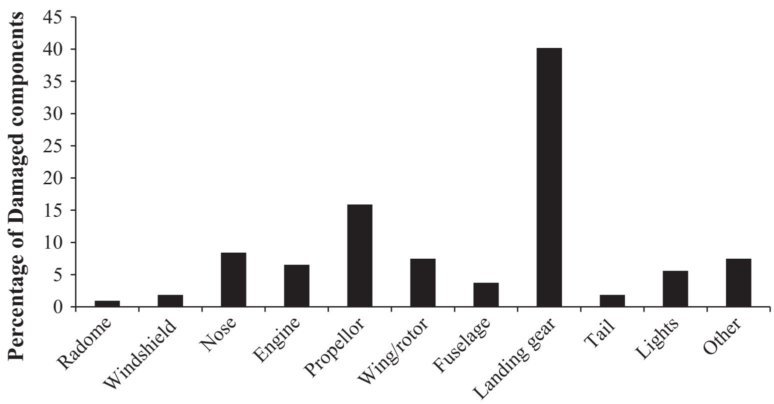

Fig. 5. Reported U.S. civil aircraft components damaged by incidents with carnivores ($n = 107$), 1990–2012 (FAA NWSD).

Assessment of reported costs to aircraft indicated that ''minor'' incidents were responsible for US $518,528 (mean per incident = US $12,345) in damage to US civil aircraft from 1990 to 2012. For incidents deemed ''substantial'', costs were

US $2,758,951 in damages (mean per incident = US $229,912), and "destroyed" damage classes accounted for US $3,704,278 (mean per incident = US $1,852,139). Damage classes deemed "uncertain" indicated a total cost of US $21,610 (mean per incident = US $4322). Summation of all damage classes indicated a total cost of US $7,003,367 in repairs to US civil aircraft.

Discussion

Carnivore incidents with aircraft have increased substantially from 1990 to 2012, not supporting our primary prediction. However, the FAA National Wildlife Strike Database was developed from incidents reported by pilots and other airport personnel upon occurrence of the incident. Reporting of incidents is voluntary (Dolbeer et al., 2009) and the importance of reporting incidents may not have been emphasized during early implementation of the database. Consequently, voluntary reporting may underestimate the number of incidents, especially if there was no damage to the aircraft. As the FAA NWSD is dependent on the quality and quantity of information submitted in incident reports, future studies should be conducted to evaluate the quality of data reported and determine the rate of underreporting to quantify potential biases. Awareness of the economic and safety risks due to wildlife-aircraft incidents has become more prevalent in the aviation industry as more recent studies using information from the FAA National Wildlife Strike Database have become available (e.g., DeVault et al., 2011; Biondi et al., 2013; Blackwell et al., 2013; Washburn et al., 2013). Public awareness also increased greatly after the highly publicized incident involving a Canada goose (*Branta canadensis*) and US Airways Flight 1549 which resulted in the aircraft being forced to land in the Hudson River in January 2009 (Marra et al., 2009). The overall increased awareness of these risks also has resulted in numerous recent efforts to mitigate incidents (Washburn et al., 2007; Blackwell et al., 2008, 2009; DeVault et al., 2008, 2013).

The greatest carnivore-aircraft incident rates occurred during autumn, supporting our second prediction. Several factors could explain the timing of these incidents. Most incidents involved canids, with coyotes and red foxes responsible for about 50% of all reported incidents. Coyotes, being the largest of the carnivores analyzed, are also the most likely to cause to damage to aircraft due to their body size (DeVault et al., 2011) Coyote breeding season occurs from mid-January through late March and litters usually consisting of 3–7 pups which are born from March to May (Mengel, 1971; Carlson and Gese, 2008). Juvenile dispersal takes place from October to January (Gese et al., 1989), coinciding with the greatest incident rates by month. The increase in population size due to production of young could be an important contributing factor to the autumn incident rates observed. Also, the broad geographic distribution of coyotes, their generalist behavior (Bekoff, 1977), and large body size (DeVault et al., 2011) could explain why more coyotes were reported than other species.

Incident rates varied by time of day, with species responsible for most incidents (e.g., coyote) being most active during nocturnal and crepuscular periods (Bekoff and Wells, 1980; Thornton et al., 2004). Crepuscular and nocturnal activity further increases the risk of an incident occurring as pilot visibility is reduced (Biondi et al., 2011). Additionally, airport staff monitoring of runways may also be limited, and exacerbated by reduced visibility when incidents are most likely to occur.

California and Texas had the greatest number of reported incidents. The difference in number of reported incidents among states is undoubtedly related to the number of airports located in these states. For example, of the 3354 U.S. airports in the National Plan of Integrated Airport Systems (Federal Aviation Administration, 2012b), California ($n = 191$) and Texas ($n = 209$) account for 12%.

Of the carnivore species reportedly involved with incidents, none are of federal or global conservation concern according to the United States Fish and Wildlife Service (USFWS; http://ecos.fws.gov/tess_public/pub/listedAnimals.jsp) and the International Union for Conservation of Nature (http://www.iucnredlist.org/). However, carnivore incidents with aircraft do represent economic and human safety concerns. Since there is no conservation concern involving these species, a wider variety of control techniques (e.g., lethal control) could be applied to mitigate incidents. In addition, we recommend an increase in runway patrols during peak incident periods (July–November), especially during active hunting periods for carnivores (i.e., evening and dusk). An increase in staffing of runways during peak incident periods could also aid in mitigation of other species with peak activity periods that coincide with those of carnivores (e.g., white-tailed deer (*Odocoileus virginianus*)) (Schwarz et al., 2014).

Constructing perimeter fences should also be considered to prevent carnivores and potential prey from entering air operation areas (Biondi et al., 2011; VerCauteren et al., 2013). To effectively exclude carnivores, galvanized fences should be at least 2.4 m high (Cleary and Dolbeer, 2005; VerCauteren et al., 2006, 2010)), although recommended height is at least 3.0 m with barbed wire outriggers to discourage climbing carnivores (Federal Aviation Administration, 2004; Cleary and Dolbeer, 2005). Due to the ability of some carnivore species (e.g., canids) to burrow, we recommend the perimeter fences be buried 1.2 m deep (Cleary and Dolbeer, 2005; DeVault et al., 2008; Biondi et al., 2011; VerCauteren et al., 2013). With the implementation of perimeter fences, regular inspection and maintenance should be conducted to ensure maximum effectiveness (DeVault et al., 2008). Permanent openings (e.g., gates and entrances) should have deer/cattle guards (Belant et al., 1998; Cleary and Dolbeer, 2005) or electrified mats (Seamans and Helon, 2008) to mitigate carnivore entry. Habitat manipulation can also be an essential part of mitigating potential risks to airport safety. Dense, young vegetation can be highly suitable for coyotes, possibly due in part to prey abundance (Chamberlain et al., 2000). By eliminating habitat in and around airports that is suitable to carnivores and their prey, potential risks could likely be reduced. However, careful consideration should be taken when manipulating habitat to ensure the habitat is not made more suitable for other wildlife species that could pose a risk to aircraft. The implementation of predator control programs in and around airports, when possible, could reduce incident risk.

Mitigation techniques to reduce incidents can also be implemented through the use of technology at airports. Increasing runway lighting at night could increase visibility for pilots. Use of thermal cameras on runways might also aid in the detection of potential risks during landing and takeoff phases, further assisting pilots and flight crew to avert incidents. However, use of thermal cameras on runways requires further research to examine costs and benefits. Due to the increase in carnivore-aircraft incidents, additional studies to develop mitigation strategies to reduce incidents and enhance human safety are warranted. Implementing multiple techniques will likely be most successful in reducing carnivore incidents with U.S. civil aircraft.

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