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ABSTRACT.—Most known fatalities for both Bald Eagles (*Haliaeetus leucocephalus*) and Golden Eagles (*Aquila chrysaetos*) are associated with humans (e.g., collisions with vehicles and artificial structures). Notably, the risk of collisions between eagles and aircraft is an increasing problem at civil airports and military airfields. Of the 234 eagle collisions with civil and military aircraft reported to the Federal Aviation Administration, the U.S. Air Force, and the U.S. Navy during 1990–2013, 52% caused damage to the aircraft. During this 23-yr time period, Bald Eagle–aircraft collisions increased by 2200% and Golden Eagle–aircraft collisions increased by 400%. Eagle–aircraft collisions occur primarily during daylight hours (88%) and typically within the vicinity of the airfield itself; 82.6% of the Bald Eagle–aircraft collisions and 81.0% of Golden Eagle strikes occurred when the aircraft was at or below 305 m aboveground level. Although collision with aircraft is a very minor source of mortality for Golden Eagles, increasing and expanding Bald Eagle populations will likely result in more eagle–aircraft collisions. Currently, there are few mitigation tools and techniques available to reduce eagle–aircraft collisions. Development and evaluation of effective, publically acceptable methods of reducing eagle–human conflicts represent important areas for future research.

KEY WORDS: *Bald Eagle*; Haliaeetus leucocephalus; *Golden Eagle*; Aquila chrysaetos; *airport*; *bird strike*; *human–raptor conflicts*.

COLISIONES ENTRE ÁGUILAS Y AERONAVES: UN PROBLEMA CRECIENTE EN EL AMBIENTE AEROPORTUARIO

RESUMEN.—La mayoría de las muertes conocidas de *Haliaeetus leucocephalus* y *Aquila chrysaetos* están asociadas a causas antropogénicas (e.g., colisiones con vehículos y estructuras artificiales). Sorprendentemente, el riesgo de colisiones entre águilas y aeronaves es un problema creciente en aeropuertos civiles y bases militares. De las 234 colisiones de águilas con aeronaves civiles y militares declaradas a la Administración Federal de Aviación, la Fuerza Aérea de los Estados Unidos y la Armada de los Estados Unidos durante el periodo 1990–2013, el 52% causó daños a la aeronave. Durante este periodo de 23 años, las colisiones con individuos de *H. leucocephalus* aumentaron en un 2200% y las colisiones con individuos de *A. chrysaetos* aumentaron en un 400%. Las colisiones entre águilas y aeronaves ocurren principalmente durante las horas de luz (88%) y típicamente en las inmediaciones de la misma base militar; 82.6% de las colisiones de *H. leucocephalus* con aeronaves y el 81% de los golpes de *A. chrysaetos* tuvieron lugar cuando la aeronave en cuestión se encontraba a una altura sobre el suelo igual o menor a 305 m. Aunque las colisiones con aeronaves son una fuente menor de mortalidad para *A. chrysaetos*, el crecimiento y la expansión de las poblaciones de esta especie probablemente tenga como consecuencia una mayor frecuencia de colisión de águilas con aeronaves. Actualmente existen pocas herramientas de mitigación y técnicas disponibles para reducir las colisiones entre águilas y aeronaves. Deben llevarse a cabo investigaciones sobre el desarrollo y la

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evaluación de métodos efectivos y aceptados públicamente con objeto de reducir los conflictos entre humanos y águilas en el futuro.

[Traducción del equipo editorial]

Wildlife–aircraft collisions (wildlife strikes) cause serious safety hazards to aircraft and their occupants. Wildlife strikes cost civil aviation approximately $957 million annually in the United States (Dolbeer et al. 2013). Gulls (*Larus* spp.), waterfowl such as Canada Geese (*Branta canadensis*), raptors [hawks (Falconiformes) and owls (Strigiformes)], and blackbirds (Icteridae) and European Starlings (*Sturnus vulgaris*) are the bird species presently causing the most concern at airports (Dolbeer et al. 2000, Dolbeer and Wright 2009, DeVault et al. 2011). Sound management techniques that reduce bird and mammal (e.g., deer, bats) numbers on and around airports are therefore critical for safe airport operations (U.S.D.A. 2005, DeVault et al. 2013).

Because of their large body size, eagles are capable of causing significant damage to aircraft. For example, Bald Eagles (*Haliaeetus leucocephalus*; average mass of males = 4.2 kg; females = 5.4 kg; Buehler 2000) and Golden Eagles (*Aquila chrysaetos*; average mass of males = 3.5 kg; females = 4.9 kg; Kochert et al. 2002) far exceed the airworthiness standards for airframes, windshields, and engines set by the Federal Aviation Administration (FAA). Consequently, eagles pose a high risk of damage to aircraft and passenger or aircrew safety when eagle–aircraft collisions occur (Dolbeer and Eschenfelder 2003, Dolbeer and Wright 2009).

Though once endangered, Bald Eagle (*Haliaeetus leucocephalus*) populations in the conterminous 48 states have increased considerably in recent years (Buehler 2000, Suckling and Hodges 2007). Regional Bald Eagle populations in the Pacific Northwest, Great Lakes, Chesapeake Bay, and Florida have increased five-fold during the past 20 yr (Watts et al. 2008, Elliott et al. 2011). Bald Eagles are now repopulating much of this species' historical range. In 2007, there were more than 11 000 nesting pairs of Bald Eagles in the conterminous 48 states (Suckling and Hodges 2007). Concurrent with increases in Bald Eagle populations, conflicts between humans and eagles have increased as well (Stauber et al. 2010, Pagel et al. 2013).

In North America, Golden Eagles (*Aquila chrysaetos*) occur primarily in the western U.S.A., although a much smaller eastern population does exist (Kochert et al. 2002, Katzner et al. 2012). Although the status and trends of these Golden Eagle populations have been debated in recent years, overall Golden Eagle populations in the western U.S.A. are apparently relatively stable (Millsap et al. 2013). As with Bald Eagles, most Golden Eagle mortality is anthropogenic and land-use issues, such as wind energy development and urbanization, are important contemporary challenges in the conservation and management of eagle populations (Kochert and Steenhof 2002, Katzner et al. 2012, Pagel et al. 2013).

To our knowledge, there has not been a comprehensive review of eagle–aircraft strikes for civil or military aircraft. The objective of this study was to quantify the number and characteristics of Bald Eagle, Golden Eagle, and ''unidentified eagle'' strikes reported to have occurred with U.S. civil and military (i.e., U.S. Air Force [U.S.A.F.] and U.S. Navy/U.S. Marine Corps [NAVY]) aircraft. We here report trends and patterns of eagle–aircraft collisions to provide potential insight for the effective management of eagles within airport environments and to reduce the frequency and severity of eagle collisions with aircraft.

Methods

We used data from the FAA National Wildlife Strike Database (Dolbeer et al. 2013) for a 24-yr period (1990–2013) for civilian and joint-use airports (Dolbeer et al. 2013), from the U.S.A.F. Birdstrike Database (Zakrajsek and Bissonette 2005) for a 21-yr period (1993–2013), and from the NAVY Web Enabled Safety System (WESS) for a 20-yr period (1994–2013). We queried these three databases and selected only those strike records that were reported to have occurred within North America (primarily the United States), for which the species struck was identified as a Bald Eagle, a Golden Eagle, or an ''unknown/unidentified'' eagle. Three identical records of eagle–military aircraft strikes were found in both the FAA National Wildlife Strike Database and the U.S.A.F. Birdstrike Database; consequently, we removed those three records from the FAA database prior to analyses. Many wildlife strike reports were incomplete. Either specific fields of information were missing or unknown, or we were unable to effectively obtain the information for report narratives. Thus, sample sizes varied for individual variables and among specific analyses.

We determined the time of day each eagle strike event occurred based on the reported local time of the event or this information was obtained directly from the strike records. We examined each strike event and categorized the time of day as ''dawn,'' ''day,'' ''dusk,'' or ''night.'' For our analyses, ''dawn'' was defined as 1 hr before sunrise to 1 hr after sunrise and ''dusk'' as 1 hr before sunset to 1 hr after sunset for that specific date and location.

Phase of flight was defined as the phase of flight the aircraft was in at the time the eagle strike occurred (FAA 2004). Aircraft ''en route'' were flying at an altitude >305 m above ground level (AGL). Aircraft in ''descent'' were decreasing in altitude and in the early stages of preparing to land (≤305 m AGL and >30.5 m AGL). Aircraft on ''final approach'' were in early stages of the landing process (≤30.5 m AGL), typically on or over an airfield. ''Landing'' aircraft were in the final stages of landing and had one or more wheels on the ground. Aircraft in the ''take-off'' phase were rolling along the runway (with one or more wheels in contact with it) or were in the process of ascending upward (≤30.5 m AGL). Aircraft in the ''climbout'' phase were in the latter stages of taking off (>30.5 m AGL), typically on or over the airfield.

The impact location was defined as the area(s) of the airframe that the eagle struck. If one or more eagles struck more than one component on the aircraft (e.g., windscreen and tail), the impact location was categorized as ''multiple impact.''

We defined a wildlife strike event as a damaging strike if there was any amount of damage to the aircraft. Damaging strikes varied greatly in the amount of actual damage the aircraft incurred; damage ranged from minor abrasions on the airframe or aircraft component to the complete destruction of the aircraft.

The altitude of the aircraft (m above ground level; m AGL) at the time of an eagle collision was used to categorize each strike event into one of seven altitude categories: (1) 0 to 30 m AGL, (2) 31 to 152 m AGL, (3) 153 to 305 m AGL, (4) 306 to 610 m AGL, (5) 611 to 915 m AGL, and (6) >915 m AGL.

Statistical Analyses. Our investigation included identification of temporal and spatial trends in eagle strikes with civilian and military aircraft. We used chi-square analysis (Zar 1996) to compare the frequency of eagle collisions with aircraft among times of day, aircraft phases of flight, impact location, and damaged aircraft components. Expected chi-square values were based on the relative distribution of hours among times of day (e.g., dawn and dusk were 2 hr each; day and night were 8 hr each) or an estimate of the distribution of time aircraft spent in each phase of flight. Descriptive statistics were used to quantify the financial costs of eagle strikes (in US$). We considered differences to be significant at $P \leq 0.05$ and conducted all analyses using SAS statistical software version 9.1 (SAS Institute, Cary, North Carolina, U.S.A.). Data are presented as mean ±1 S.E.M.

We conducted some analyses on Bald Eagle strikes and Golden Eagle strikes independently. We used linear regression analyses and two-sample *t*-tests to examine potential trends in the number of reported Bald Eagle strikes and reported Golden Eagle strikes to aircraft among years (Zar 1996). We used chi-square analysis (Zar 1996) to compare the number of Bald Eagle strikes and Golden Eagle strikes with aircraft among months. Descriptive statistics were used to quantify the frequency of Bald Eagle strikes and Golden Eagle strike events that occurred among geographic locations and (aircraft) altitude classes.

RESULTS

We found a total of 234 eagle–aircraft collisions involving one or more eagles in the time periods we studied. Of these, 197 were with civil aircraft, 26 with U.S.A.F. military aircraft, and 11 with NAVY military aircraft. Most eagle strikes (88%) occurred during day ($\chi^2 = 96.6$, df = 3, $P < 0.0001$; $n = 194$ strike events with time of day reported), and relatively few strike events occurred during dawn, dusk, or night (Fig. 1).

Eagle strikes were reported during all phases of aircraft flight. The frequency of eagle–aircraft collisions varied among aircraft phases of flight ($\chi^2 = 37.3$, df = 5, $P < 0.0001$; $n = 203$ records where phase of flight was reported). Overall, the proportion of eagle strikes that occurred with civilian and military aircraft during the ''enroute'' phase of flight was 13.8%, ''descent'' was 2.5%, ''approach'' was 32.5%, ''landing'' was 24.6%, ''take-off'' was 15.3%, and ''climbout'' was 11.3%.

Eagles collided with all sections of civil and military aircraft, but specific areas were struck by eagles with a much higher frequency than others ($\chi^2 = 50.6$, df = 9, $P < 0.0001$). The wings and rotors and ''multiple'' components were the most common impact locations on the aircraft (Table 1).

The frequency of aircraft components damaged during eagle–aircraft collisions varied among various

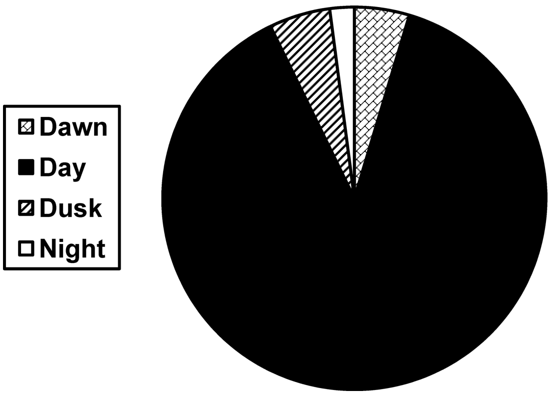

Figure 1. Distribution of the time of day for eagle–aircraft collisions ($n = 194$) with U.S. civilian or military (U.S. Air Force, U.S. Navy, and U.S. Marine Corps) aircraft within the U.S.A. during 1990–2013.

Table 1. Percent of impact locations and damaged areas of aircraft resulting from eagle strikes with U.S. civilian and military (U.S. Air Force, U.S. Navy, and U.S. Marine Corps) aircraft during 1990–2013.

AIRCRAFT COMPONENT	IMPACT LOCATION (%)	DAMAGED (%)
Engine	11.0	16.8
Fuselage	3.1	1.0
Landing gear	8.9	6.3
Nose/radome	6.8	7.4
Propeller	2.6	3.2
Tail	4.2	7.4
Windshield	3.1	3.2
Wing/rotor	26.2	28.4
Other	11.6	9.5
Multiple[a]	22.5	16.8

[a] More than one aircraft component was struck or damaged during the same eagle strike event.

sections of the aircraft ($\chi^2 = 50.6$, df = 9, $P < 0.0001$). Wings and rotors, engines, and multiple components were the most frequently damaged aircraft parts due to eagle–aircraft collisions (Table 1). The average reported cost to repair damages to aircraft from Bald Eagle strikes was \$425 945 (median = \$10 000; range = \$50 to \$14 000 000; $n = 43$) per strike event. Golden Eagle strikes caused an average of \$103 242 (median = \$25 255; range = \$40 to \$800 000; $n = 13$) in aircraft damage per reported strike.

Eighty-three of 197 (42.1%) reported eagle strikes to civil aircraft caused damage (including the destruction of an entire aircraft), whereas 19 of 26 (73.1%) of U.S.A.F. military aircraft sustained damage during collisions with eagles. In addition to physical damage to aircraft, nine people were injured during five eagle strike events.

Bald Eagle Collisions with Aircraft. There were 200 reported Bald Eagle strikes, including 173 strikes with civil aircraft and 27 strikes with military (U.S.A.F. and NAVY) aircraft. An average of 8.3 ± 1.15 (SE) Bald Eagle strikes was reported annually during 1990–2013 (Fig. 2). During this 23-yr time period, Bald Eagle–aircraft collisions increased ($y = 0.67x - 1326.58$; $R^2 = 0.70$, $F_{1,23} = 50.3$, $P < 0.0001$) by 2200%. Furthermore, the average number of reported Bald Eagle–aircraft collisions per year was higher ($t_{22} = -7.62$, $P < 0.0001$) during 2006–2013 (15.0 ± 1.40 eagle strike events per year) than in earlier years (1990–2005; 5.0 ± 0.62 events per year).

An average of 16.7 ± 1.74 (SE) Bald Eagle strikes occurred during each month of the year (Fig. 3). The frequency of Bald Eagle–aircraft collisions did not vary among months ($\chi^2 = 11.6$, df = 11, $P = 0.39$).

Among the 195 Bald Eagle strikes with civilian and military aircraft for which the specific geographic location could be determined, most were reported from Alaska (31.3%), Florida (27.2%), the Chesapeake Bay region (13.3%), and the Great Lakes region (10.8%; Table 2). Bald Eagle strikes were reported in 26 U.S. states and the District of Columbia.

Collisions between Bald Eagles and aircraft occurred at a variety of (aircraft) altitudes (Table 3). However, 62.7% of Bald Eagle–aircraft collisions occurred at or below 30 m AGL, and 82.6% occurred at or below 305 m AGL. Fewer than 2% of Bald Eagle strikes occurred over 915 m AGL.

Golden Eagle Collisions with Aircraft. There were 27 Golden Eagle strikes, including 17 strikes with civil aircraft and 10 strikes with military (U.S.A.F. and NAVY) aircraft. An average of 1.1 ± 0.26 (SE) Golden Eagle strikes was reported annually during 1990–2013 (Fig. 2). During this 23-yr period, Golden Eagle–aircraft collisions increased by 400% ($y = 7.63x - 15 223.5$; $R^2 = 0.67$, $F_{1,23} = 9.2$, $P = 0.006$). As with Bald Eagles, the average number of reported Golden Eagle–aircraft collisions per year was higher ($t_{22} = -3.78$, $P = 0.001$) during 2006–2013 (2.3 ± 0.53 events per year) than in earlier years (1990–2005; 0.6 ± 0.18 events per year).

An average of 2.3 ± 0.39 Golden Eagle strikes occurred each month of the year (Fig. 3). As with

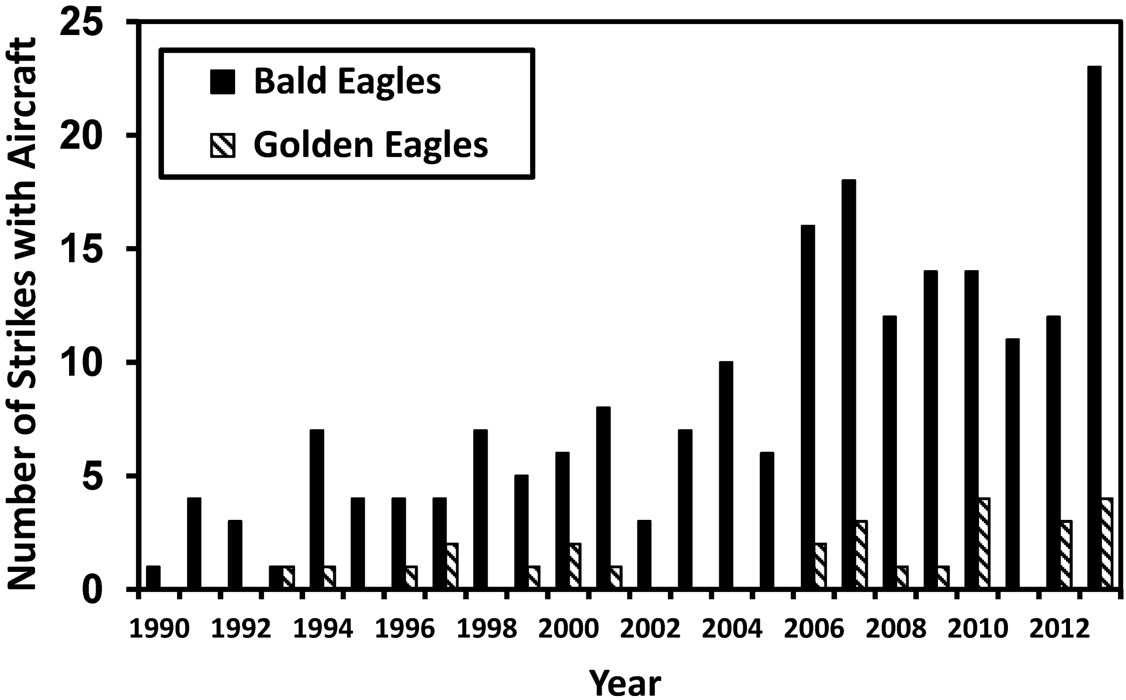

Figure 2. Number of Bald Eagle and Golden Eagle strikes (annually) with U.S. civilian or military (U.S. Air Force, U.S. Navy, and U.S. Marine Corps) aircraft within the U.S.A. from 1990 to 2013.

Bald Eagles, the number of Golden Eagle–aircraft collisions was similar among months ($\chi^2 = 4.9$, df = 11, $P = 0.94$; Fig. 3).

All 24 Golden Eagle strike events for which a specific geographic location was reported occurred in the western United States (Table 2). Golden Eagle–aircraft collisions were reported in California (41.6%), Colorado (25.0%), New Mexico (8.3%), Utah (8.3%), Arizona (4.2%), Idaho (4.2%), Montana (4.2%), and Nevada (4.2%).

Collisions between Golden Eagles and aircraft occurred at a variety of (aircraft) altitudes (Table 3). However, 38.1% of the Golden Eagle–aircraft collisions occurred at or below 30 m AGL and 81.0% occurred at or below 305 m. No Golden Eagle strikes were reported to have occurred over 915 m AGL.

DISCUSSION

The frequency of eagle–human conflicts associated with both Bald Eagles and Golden Eagles within the U.S.A. has been increasing. Most known eagle fatalities are anthropogenic; major contemporary challenges faced by eagle populations include wind energy development, electrocutions, collisions with vehicles (e.g., automobiles, aircraft), secondary effects of pesticides, and lead exposure and poisoning (Stauber et al. 2010, Millsap et al. 2013, Pagel et al. 2013). However, we note that eagles killed by human-related causes are more likely to be discovered than eagles that die of natural causes far from human development (McIntyre 2012).

Eagles pose a higher risk of damage to aircraft and human safety relative to many other bird species due to their relatively large body mass. More than 40% of reported eagle strikes in this study caused physical damage to aircraft compared to 9% of all reported bird strike events (i.e., all species combined) with U.S. civil aircraft (Dolbeer et al. 2013). In addition to direct costs associated with aircraft damage, eagle–aircraft collisions can result in other significant economic losses and injuries to humans. Airports face corporate liability, and airport managers and operators have been personally sued, following bird (including Bald Eagle) strike events when inappropriate or no actions were taken to mitigate the risk posed by hazardous wildlife (Dale 2009).

Bald Eagles colliding with civilian and military aircraft is a contemporary and growing aviation safety issue within the United States. Increased

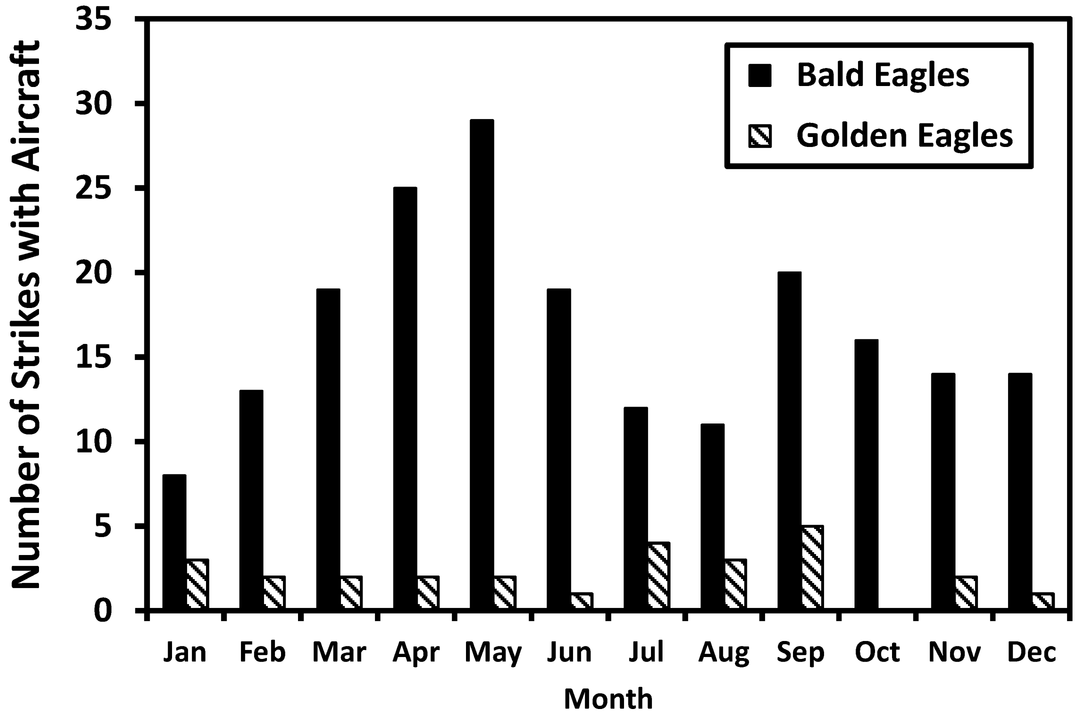

Figure 3. Monthly total number of Bald Eagle and Golden Eagle strikes with U.S. civilian or military (U.S. Air Force, U.S. Navy, and U.S. Marine Corps) aircraft within the U.S.A. during 1990–2013.

frequency of Bald Eagle strike events during the last decade reflects the exponential growth of Bald Eagle populations in the conterminous U.S.A. during the same time period, as well as the concomitant increase in air traffic (Dolbeer 2009). Not unexpectedly, the highest numbers of Bald Eagle–aircraft collisions occurred in the geographic areas with the highest densities of Bald Eagles (e.g., Alaska, Florida, and Chesapeake Bay).

Collision with aircraft represents a very minor source of mortality for Golden Eagles (i.e., approximately one fatality per year; this study) compared to other anthropogenic sources of mortality. For example, an estimated 67 to 75 Golden Eagles are killed each year at the Altamont Pass Wind Resource Area in California (Smallwood and Thelander 2008). Given the relatively low incidence rate of Golden Eagle–aircraft collisions, we suggest Golden Eagles pose a low risk to civil and military aircraft relative to Bald Eagles and many other wildlife species (Dolbeer and Wright 2009, DeVault et al. 2011, Dolbeer et al. 2013). Although Golden Eagle strikes are very infrequent, proper management actions to decrease Golden Eagle presence in airport environments is warranted due to the high rate of damage to aircraft and eagle mortality associated with these events. All reported Golden Eagle–aircraft collisions occurred in the western U.S.A. within the range of most Golden Eagle populations within the U.S.A. (Kochert et al. 2002). In the western U.S.A., Golden Eagles likely forage within airport habitats, and nests are often located on or near military airfields. No Golden Eagle strikes were reported within the range of the eastern Golden Eagle populations (Katzner et al. 2012), likely because the abundance of Golden Eagles is much lower in the East, and eastern Golden Eagles typically use remote habitats located far from airports and military airfields.

Most eagle–aircraft collisions occurred at altitudes below 305 m AGL (1000 feet AGL), when aircraft were in the final stages of landing or taking off, near an airport or military airfield. A clear understanding of how and why eagles of varying age classes use airport environments is needed to develop effective tools and techniques to reduce eagle–aircraft collisions (and thus this source of eagle mortality).

Bird strike events and wildlife damage management activities at airports involving socially and

Table 2. Number of Bald Eagle and Golden Eagle strikes with U.S. civilian or military (U.S. Air Force, U.S. Navy, and U.S. Marine Corps) aircraft among various states or regions within the U.S.A. during 1990–2013.

State/Region	Number of Strikes with Aircraft	
	Bald Eagles[a]	Golden Eagles
Alaska	61	0
Florida	53	0
Chesapeake Bay[b]	26	0
New England[c]	8	0
Carolinas[d]	4	0
Gulf Coast[e]	3	0
Great Lakes[f]	21	0
Great Plains[g]	3	0
Intermountain West[h]	6	14
California	1	10
Pacific Northwest[i]	9	0
Total	**195**	**24**

[a] One additional Bald Eagle strike occurred in the Canadian province of British Columbia, but was reported in the U.S.A. database.
[b] Includes the District of Columbia and the states of Delaware, Maryland, New Jersey, and Virginia.
[c] Includes the states of Connecticut, Maine, New York, and Pennsylvania.
[d] Includes the states of North Carolina and South Carolina.
[e] Includes the states of Louisiana and Mississippi.
[f] Includes the states of Illinois, Michigan, Minnesota, Ohio, and Wisconsin.
[g] Includes the states of Nebraska and Texas.
[h] Includes the states of Arizona, Colorado, Idaho, Montana, Nevada, New Mexico, Utah, and Wyoming.
[i] Includes the state of Washington.

Table 3. Number of Bald Eagle and Golden Eagle strikes with U.S. civilian and military (U.S. Air Force, U.S. Navy, and U.S. Marine Corps) aircraft occurring at various altitudes (in m above ground level) within the U.S.A. during 1990–2013.

Altitude (m Above Ground Level)	Number of Strikes with Aircraft	
	Bald Eagles	Golden Eagles
0 to 30	101	8
31 to 152	21	4
153 to 305	11	5
306 to 610	16	2
611 to 915	10	2
>915	2	0
Total	**161**	**21**

politically sensitive species like Bald Eagles and Golden Eagles can result in significant adverse media attention and concern among members of the public (Graham et al. 2005, Dale 2009). These issues might become more frequent and intense due to the popularity of social media (e.g., webcams at eagle nests) and instant transfer of information via the internet (Cushing and Washburn 2014). Given the current widespread public interest in eagles and a strong concern for eagle protection, managers need to use effective, publically accepted methods to reduce the hazards posed by eagles using airport environments.

Recent changes in federal legislation, most importantly revision of the Bald and Golden Eagle Protection Act (16 United States Code 668-668d), has allowed for the availability of more management actions and new permits associated with ''purposeful'' and ''nonpurposeful'' take [take is defined as ''pursue, shoot, shoot at, poison, wound, kill, capture, trap, collect, destroy, molest, or disturb''; U.S.F.W.S. 2009] associated with eagle damage management actions (including eagle–aircraft collisions). The U.S. Fish and Wildlife Service has the authority to issue nonlethal hazing permits to alleviate human and health concerns associated with eagles and permits to allow for removal of eagle nests and nest trees in areas that pose issues to human health and safety (e.g., eagle nests within or near airports).

Few mitigation tools and techniques are available to reduce eagle–aircraft collisions. Nonlethal hazing (e.g., use of pyrotechnics), live-capture and translocation of problem individuals, nest removals, habitat modification, and other methods have the potential to reduce eagle use of airports and thus decrease the risk of eagle strikes (Washburn et al. 2011, DeVault et al. 2013, Guerrant et al. 2013). Management actions to reduce eagle use of airports and adjacent habitats would be effective in reducing the risk of eagle–aircraft collisions. Development and evaluation of effective, publically acceptable methods of reducing eagle–human conflicts (e.g., eagle strikes to civilian and military aircraft) represent important areas for future research.

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