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ASSESSING OWL COLLISIONS WITH US CIVIL AND US AIR FORCE AIRCRAFT

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Abstract.—Collisions between wildlife and aircraft (wildlife strikes) pose notable risks. Previous research has found that a variety of birds and mammals are involved in wildlife strikes, but no comprehensive evaluation of collisions between owl and aircraft (owl strikes) has been conducted. We queried the Federal Aviation Administration's National Wildlife Strike Database (from 1 January 1990 to 30 June 2014) and the US Air Force's Birdstrike Database (from 1 January 1994 to 30 June 2014) to characterize owl strikes. We found 2531 owl strikes involving at least 20 species of owls. Barn Owls (*Tyto alba*) were the most frequently struck species, accounting for 42% of all reported owl strikes. Almost 75% of owl strikes occurred during the night. Owl strikes typically occurred within the airfield environment itself, and 86% of owl strikes occurred when the aircraft was at or below 30 m above ground level. Some mitigation tools and techniques (e.g., nonlethal hazing, translocation, lethal removal) can reduce the frequency of owl strikes, but the efficacy of these methods remains unevaluated. An important area of future research will involve the development and evaluation of effective, publicly acceptable methods of reducing human–owl conflicts.

Key Words: *Barn Owl*; Tyto alba; *Short-eared Owl*; Asio flammeus; *airport*; *bird strike*; *human-raptor conflict*; *owls*.

EVALUACIÓN DE COLISIONES DE BÚHOS CON AERONAVES CIVILES Y DE LA FUERZA AÉREA DE LOS ESTADOS UNIDOS

Resumen.—Las colisiones entre animales silvestres y aeronaves plantean riesgos importantes. Las investigaciones previas han registrado una variedad de aves y mamíferos que están involucrados en colisiones, pero no se ha realizado una evaluación completa de las colisiones entre búhos y aeronaves. Consultamos la base de datos de colisiones de animales silvestres de la Administración Nacional de Aviación Federal (desde el 1 de enero de 1990 hasta el 30 de junio de 2014) y la base de datos de colisiones de aves de la Fuerza Aérea de los Estados Unidos (desde el 1 de enero de 1994 hasta el 30 de junio de 2014) para caracterizar las colisiones de búhos. Encontramos 2531 colisiones que incluyen al menos 20 especies de búhos. *Tyto alba* fue la especie con mayor número de colisiones, representando el 42% de todas las colisiones de búhos reportadas. Casi el 75% de las colisiones de búhos ocurrió durante la noche. Las colisiones de búhos ocurrieron típicamente dentro del ámbito mismo de las bases aéreas y los aeropuertos, y el 86% de las colisiones de búhos ocurrieron cuando la aeronave se encontraba a una altura igual o menor a los 30 metros sobre el suelo. Existen herramientas y técnicas (v.g. arreo no letal, translocación, remoción letal) que pueden reducir la frecuencia de colisiones de búhos, pero la eficacia de estos métodos todavía no ha sido evaluada. Un área importante de investigación a futuro deberá involucrar el desarrollo y la evaluación de métodos efectivos y públicamente aceptables para reducir los conflictos entre los búhos y los humanos.

[Traducción del equipo editorial]

Collisions between aircraft and wildlife (hereafter, wildlife strikes) are a serious safety risk to all forms of aviation. Wildlife strikes almost always result in the deaths of the animals involved. The total cost to world commercial aviation has been estimated to be more than 1.5 billion US$ per year (Allan et al. 2016). Wildlife strike costs to civil aviation have conservatively been estimated to be at least $957

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million annually in the United States alone (Dolbeer et al. 2015), but the actual cost (incorporating aircraft down time and other indirect costs) is likely much higher (Anderson et al. 2015). Incidents of wildlife strikes occur with both fixed-wing (Dolbeer et al. 2015) and rotary-wing aircraft (Washburn et al. 2013). Wildlife strikes are also an important threat to military aircraft (Zakrajsek and Bisonette 2005, Washburn et al. 2014). Implementation of management actions to reduce wildlife numbers on and around airports is critical for safe airport operations (US Department of Agriculture 2005, DeVault et al. 2013).

Researchers have studied wildlife strikes involving numerous wildlife taxa, including but not limited to bats (Biondi et al. 2013), eagles (Washburn et al. 2015), mammalian carnivores (Crain et al. 2015), and white-tailed deer (*Odocoileus virginianus*; Biondi et al. 2011). Birds account for approximately 97% of wildlife strikes to US civil aircraft (Dolbeer et al. 2015). Bird species currently causing the most concern at airports include gulls (Laridae), waterfowl (Anatidae), blackbirds (Icteridae) and European Starlings (*Sturnus vulgaris*), and raptors (hawks [Falconiformes] and owls [Strigiformes]; Dolbeer et al. 2000, Dolbeer and Wright 2009, DeVault et al. 2011). However, there has not been a comprehensive review of owl strikes involving civil or military aircraft.

Many known owl mortalities are related to human activity; major contemporary challenges faced by owl populations include collisions with vehicles (e.g., automobiles, aircraft), wind energy development, secondary effects of pesticides, and habitat loss (Duncan 2003, Hager 2009, Boves and Belthoff 2012, Booms et al. 2014). A better understanding of these human-owl conflicts is needed to allow for effective resolutions. The objective of our study was to quantify the number and characteristics of owl strikes reported to have occurred with US civil and US Air Force (USAF) aircraft. We characterized trends and patterns of owl-aircraft collisions to provide insight for airport and wildlife managers attempting to reduce the frequency of and damage associated with owl strikes.

Methods

We used data from the Federal Aviation Administration's National Wildlife Strike Database (Dolbeer et al. 2015) for a 24.5-yr period (1 January 1990–30 June 2014) for civil and joint-use airports and from the USAF Birdstrike Database (Zakrajsek and Bissonette 2005) for a 20.5-yr period (1 January 1994–30 June 2014). We queried these databases and selected only those records that reported a strike involving a species of owl or an "unknown/unidentified" owl. We removed 12 identical records of owl strikes with military aircraft that were found in both databases from the FAA database prior to analyses. We found approximately 80% of the owl strike reports were incomplete; specific fields of information were missing or unknown, and we were unable to effectively obtain the information from report narratives. Consequently, sample sizes varied for individual variables and among specific analyses.

We determined the time of day each owl strike 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, we defined "dawn" 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.

We defined the phase of flight for each strike event as the aircraft's operational phase of flight at the time the strike occurred (Federal Aviation Administration 2004). Aircraft in the "en route" phase of flight were flying at an altitude $>$ 305 m above ground level (AGL). Aircraft in the "descent" phase of flight were decreasing in altitude and in the early stages of preparing to land ($\leq$305 m AGL and $>$30.5 m AGL). Aircraft on "final approach" were in early stages of the landing process ($\leq$30.5 m AGL), typically on or over an airfield. "Landing" aircraft were in the final stages of landing and had one or more wheels on the ground. Aircraft in the "takeoff" phase were rolling along the runway and had one or more wheels in contact with it or were in the process of ascending upward ($\leq$30.5 m AGL). Aircraft in the "climb" phase were in the latter stages of taking off ($>$30.5 m AGL), typically on or over the airfield. We used the altitude of the aircraft (m AGL) at the time of an owl strike to categorize each strike into one of seven altitude categories: (1) 0–30 m AGL, (2) 31–152 m AGL, (3) 153–305 m AGL, (4) 306–610 m AGL, (5) 611–915 m AGL, and (6) $>$915 m AGL (Washburn et al. 2015).

An owl strike was defined as a "damaging strike" if there was any amount of damage to the aircraft (reported). Damaging strikes varied greatly in the amount of actual damage sustained by the aircraft, ranging from minor abrasions on the airframe or aircraft component to the complete destruction of the aircraft.

Statistical Analyses. We investigated temporal and spatial trends in owl strikes with civil and military aircraft separately, because there are important differences in reporting requirements, aircraft flight patterns and localities, and other factors associated with the two databases. We used linear regression analyses and polynomial regression analyses to examine potential trends in the number of reported owl strikes with civil aircraft (1 January 1990–31 December 2013) as well as USAF aircraft (1 January 1994–31 December 2013) among yr (Neter et al. 1990). We compared the frequency of owl strikes with aircraft (US civil and USAF combined) among aircraft phases of flight using *G*-test for goodness-of-fit analysis (Zar 1996). We based our expected values on the relative distribution of hr among times of day (e.g., dawn and dusk were 2 hr; day and night were 8 hr) or an estimate of the distribution of time aircraft spent in each phase of flight. We used descriptive statistics to quantify the frequency of owl strikes that occurred among geographic locations and aircraft altitude classes. Differences were considered to be significant at $P \leq 0.05$ and we conducted all analyses using SAS statistical software version 9.1 (SAS Institute, Cary, NC, USA). Data are presented as mean ± 1 SE.

We conducted some separate analyses on the most frequently struck owl species. We used linear regression analyses and polynomial regression analyses to examine potential trends in the number of reported Barn Owl (*Tyto alba*) strikes and Short-eared Owl (*Asio flammeus*) strikes (US civil and USAF combined) among years (Neter et al. 1990). We used *G*-test for goodness-of-fit analysis (Zar 1996) to compare owl strikes involving four species of owl among times of day, as well as the number of Barn Owl strikes, Snowy Owl (*Bubo scandiacus*) strikes, and owl strikes (all species combined) among months.

RESULTS

We found 2531 reported owl strikes involving one or more owls. Of these owl strikes, 2201 were with civil aircraft and 330 with USAF military aircraft. Although the fate of the owls involved in these incidents is not known, it is very likely that all the birds involved in the owl strikes died from their injuries.

Species Involved. Owl strikes involved 20 owl species (Table 1). Barn Owls, Short-eared Owls, and Great Horned Owls (*Bubo virginianus*) were the most frequently struck owl species, accounting for 42.0%, 19.4%, and 10.3% of all reported owl strikes, respectively (Table 1). There were only 24 owl strike events that involved more than one owl; half of these ($n = 12$) affected Barn Owls, whereas Short-eared Owls, and Burrowing Owls (*Athene cunicularia*) were each involved in three strike events with more than one owl.

Temporal Patterns. The number of owl strikes with civil aircraft averaged 88.3 ± 12.9 annually during 1990–2013 (Fig. 1A). During this 24-yr time period, owl strikes with US civil aircraft increased ($R^2 = 0.95$, $F_{2,23} = 192.88$, $P < 0.0001$) by 995%. Similarly, reported Barn Owl strikes increased ($R^2 = 0.77$; $F_{1,23} = 74.51$, $P < 0.0001$) by 1700% and reported Short-eared Owl strikes increased ($R^2 = 0.86$; $F_{2,23} = 70.05$, $P < 0.0001$) by 700%.

The number of owl strikes with USAF aircraft (worldwide) averaged 17.0 ± 2.0 annually during 1994–2013 (Fig. 1B). During this 19-yr time period, owl strikes increased ($R^2 = 0.63$; $F_{2,18} = 13.43$, $P = 0.0004$) by 633%. Reported Barn Owl strikes remained relatively constant ($R^2 = 0.09$, $F_{1,18} = 1.70$; $P = 0.21$), whereas reported Short-eared Owl strikes increased ($R^2 = 0.36$; $F_{1,18} = 9.71$, $P = 0.006$) by 300% during this time period.

An average of 210.9 ± 10.5 owl strikes (US civil and military aircraft combined) were reported during each month of the year (Fig. 2). Across all owl species, the frequency of owl strikes varied ($G_{11} = 72.1$, $P < 0.0001$) among months. Strikes with some owl species (e.g., Barn Owls) occurred fairly consistently throughout the year, whereas strikes with other owls (e.g., Snowy Owls) exhibited a seasonal pattern (Fig. 2).

Most Barn Owl strikes (82.1%) occurred during night ($n = 375$ strike events with time of day reported; $G_3 = 299.8$, $P < 0.0001$; Fig. 3), as did most Great Horned Owl strikes (86.1%) ($n = 115$; $G_3 = 105.73$, $P < 0.0001$). More Short-eared Owl strikes occurred during the night, with fewer during the day than expected ($n = 169$; $G = 45.9$, df = 3, $P < 0.0001$; Fig. 3). In contrast, Snowy Owl strikes occurred with the expected frequency ($n = 59$; $G_3 = 3.2$, $P = 0.37$, Fig. 3) among all times of day.

Geographic Location, Phase of Flight, and Altitude. Owl strikes were reported in all 50 US states, the District of Columbia, Puerto Rico, and 23 foreign countries. Among the 2375 owl strikes with civil and USAF aircraft that occurred within the USA for which the specific geographic location could be determined, states with the most reported strikes

Table 1. Number of owl strikes with US civil (1 January 1990–30 June 2014) and US Air Force (USAF) aircraft (1 January 1994–30 June 2014), by species, within the USA (civil and USAF aircraft combined) and within foreign countries (USAF aircraft only). The symbol —— indicates that the species does not occur in the USA.

Species	USA		Foreign Countries	
	Number of Strikes with Aircraft	% of Total	Number of Strikes with Aircraft	% of Total
Barn Owl (*Tyto alba*)	1043	42.5	19	25.3
Short-eared Owl (*Asio flammeus*)	467	19.0	23	30.7
Long-eared Owl (*Asio otus*)	20	0.8	6	8.0
Snowy Owl (*Bubo scandiacus*)	114	4.6	1	1.3
Great Horned Owl (*Bubo virginianus*)	261	10.6	0	0
Eurasian Eagle Owl (*Bubo bubo*)	——	——	1	1.3
Flammulated Owl (*Psiloscops flammeolus*)	4	0.2	0	0
Barred Owl (*Strix varia*)	26	1.1	0	0
Great Gray Owl (*Strix nebulosa*)	1	0.1	0	0
Eurasian Tawny Owl (*Strix aluco*)	——	——	1	1.3
Northern Hawk Owl (*Surnia ulula*)	1	0.1	0	0
Brown Hawk Owl (*Ninox scutulata*)	——	——	1	1.3
Pallid Scops Owl (*Otus brucei*)	——	——	2	2.7
Eurasian Scops Owl (*Otus scops*)	——	——	4	5.4
Southern White-faced Owl (*Ptilopsis granti*)	——	——	1	1.3
Burrowing Owl (*Athene cunicularia*)	192	7.8	1	1.3
Little Owl (*Athene noctua*)	——	——	8	10.8
Eastern Screech Owl (*Megascops asio*)	8	0.3	0	0
Western Screech Owl (*Megascops kennicottii*)	3	0.1	0	0
Northern Saw-whet Owl (*Aegolius acadicus*)	8	0.3	0	0
Owls (not identified to species)	308	12.5	7	9.3
Total	**2456**		**75**	

were California (19.8%), Hawaii (16.0%), New York (6.9%), Oregon (6.7%), and Illinois (4.8%).

Owl strikes occurred during all phases of (aircraft) flight. The frequency of owl strikes varied ($n = 1037$ records where phase of flight was reported; $G_5 = 551.0$, $P < 0.0001$) among aircraft phases of flight. Overall, the proportion of owl strikes that occurred with civil and USAF aircraft during the enroute phase of flight was 4.9%, descent was 18.1%, approach was 8.1%, landing was 40.4%, take-off was 22.9%, and climb was 5.6%.

Owl strikes occurred at a variety of (aircraft) altitudes (Table 2). However, 86.0% and 97.3% of the owl–aircraft collisions took place at or below 30 m AGL and 305 m AGL, respectively. Very few (i.e., <1%) of the owl strikes occurred over 610 m AGL.

Aircraft Damage and Economic Losses. Among the 1206 owl strikes where damage to the aircraft (or no damage) was reported, 166 (13.8%) of these events caused damage to an aircraft. Across species, only 134 of 940 (14.3%) reported owl strikes that caused aircraft damage included an identification of the owl species. Of these owl strike incidents, the damaging strike rates (i.e., proportion of strikes that caused damage) involving Barn Owls, Short-eared Owls, Great Horned Owls, and Snowy Owls were 11.8%, 9.7%, 28.1%, and 23.7%, respectively. In addition to physical damage to aircraft, one person was injured during an owl strike event.

The average reported cost to repair damages to aircraft from owl strikes was US$113,292 (range = $150 to $1,267,326) per damaging strike event. Damaging owl strikes involving Barn Owls, Short-eared Owls, Great Horned Owls, and Snowy Owls caused an average of $135,498, $155,010, $160,719, and $209,536 in aircraft damage per reported owl strike, respectively.

Discussion

The large magnitude of the increases in owl (all species), Barn Owl, and Short-eared Owl strikes with US aircraft (both civil and military) documented in our study strongly suggests that the frequency of owl strikes is increasing and represents a significant economic and aviation safety issue. Like owl–aircraft strikes, the overall number of wildlife strikes with US

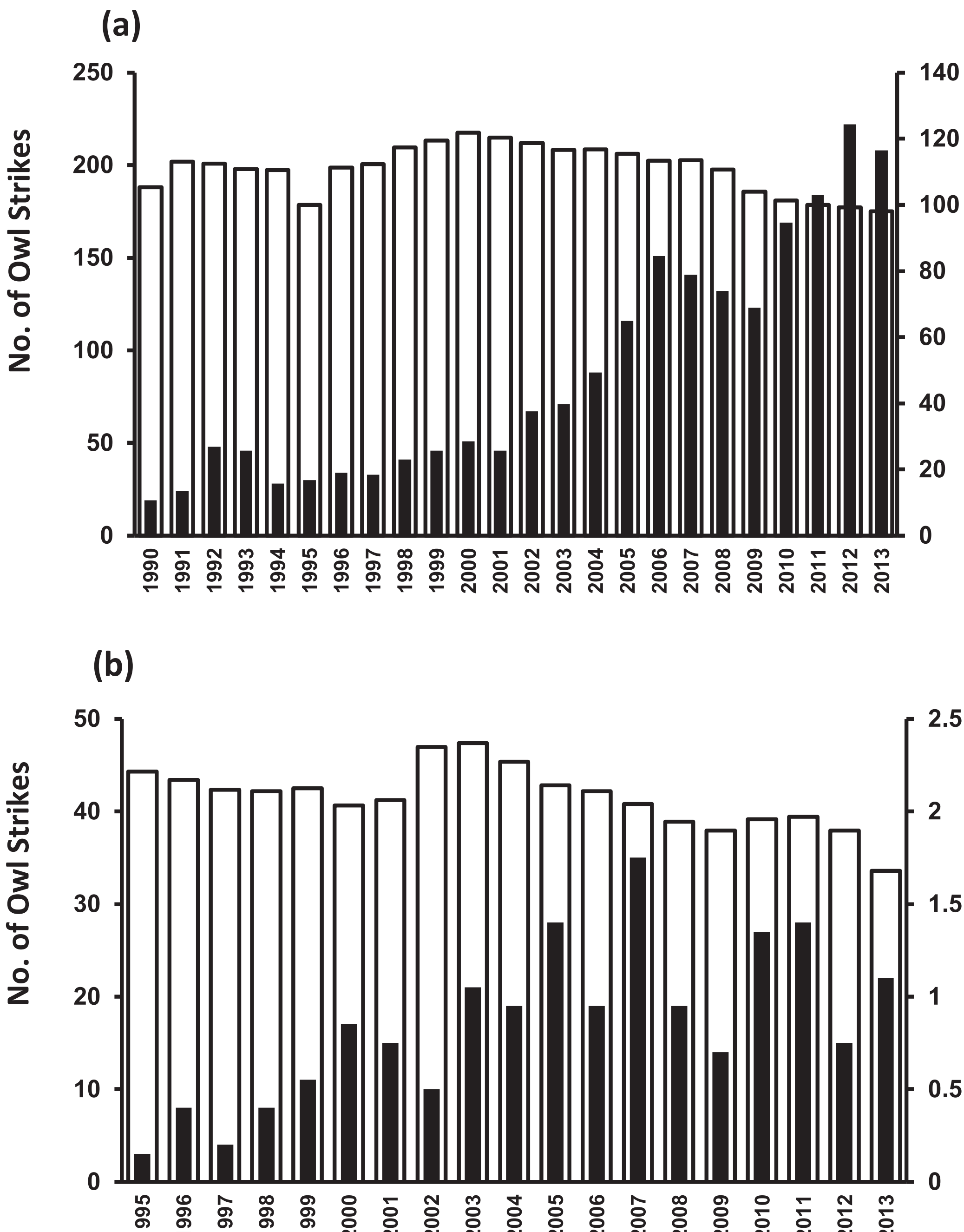

Figure 1. (a) Annual total number of owl strikes with US civil aircraft (shaded bars) and total number of US civil aircraft operations in the USA (open bars) during 1 January 1990–31 December 2013. (b) Annual total number of owl strikes with US Air Force aircraft (shaded bars) and total number of annual flight hours (world-wide) for US Air Force aircraft (open bars) during 1 January 1995–31 December 2013.

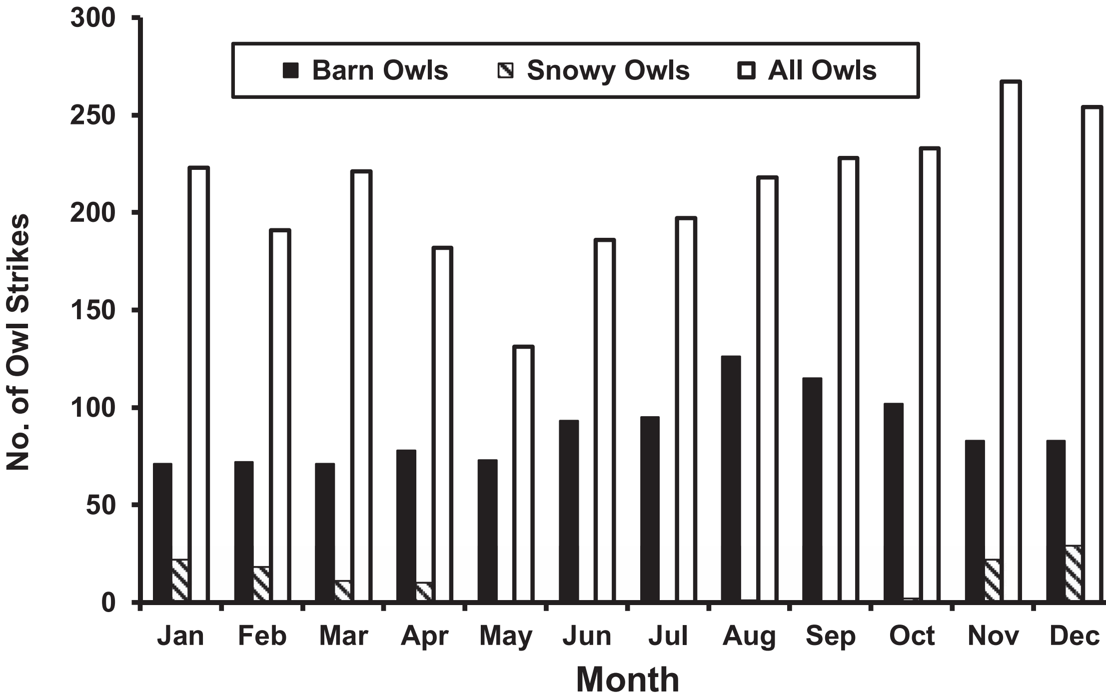

Figure 2. Monthly total number of Barn Owl strikes, Snowy Owl strikes, and all owl species (combined) strikes with US civil (1 January 1990–30 June 2014) and US Air Force aircraft (1 January 1994–30 June 2014).

civil aircraft has increased during 1990–2014 (Dolbeer et al. 2015). Part of this increase can likely be attributed to increases in voluntary reporting of wildlife strikes to US civil aircraft (Dolbeer 2009). In contrast, wildlife strike reporting has been mandatory for incidents with USAF aircraft throughout the period. Consequently, other factors are likely responsible for the observed increases in owl strikes.

Increases in owl strike frequency could be due to increases in owl populations (i.e., more owls on the landscape), changes in owl habitat use patterns (i.e., a re-distribution of owls on the landscape), or a combination of these factors. During this time period, the number of civil and military flights remained relatively constant or decreased slightly. Populations of Barn Owls and Short-eared Owls have reportedly declined during recent decades (Marti et al. 2005, Booms et al. 2014), whereas Barn Owl and Short-eared Owl strikes with US aircraft have actually increased. An increase in owl strikes could be the consequence of Barn and Short-eared Owls becoming more "urbanized" (Boal and Dykstra 2018) and using habitats within urban environments. Many airports are located in large urban population centers and provide the only grassland habitats within those environments (Kutschbach-Brohl et al. 2010).

More than 90% of owl strikes occurred at altitudes below 152 m AGL, when aircraft were in the final stages of landing or taking-off. Consequently, most owl strikes occurred at or near an airport or military airfield. Thus, owls using airfield environments in particular pose the greatest risk to safe aircraft operations. A clear understanding of how and why owls use airport environments is needed to allow for the development of effective tools and techniques to reduce owl strikes.

Some owl species 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 28% of reported Great Horned Owl and Snowy Owl strikes caused physical damage to aircraft compared to 9% of all reported bird strikes (i.e., all species combined) with US civil aircraft (Dolbeer et al. 2015).

The Barn Owl was the species of owl most frequently involved in collisions with aircraft, both within the USA and in foreign countries. This

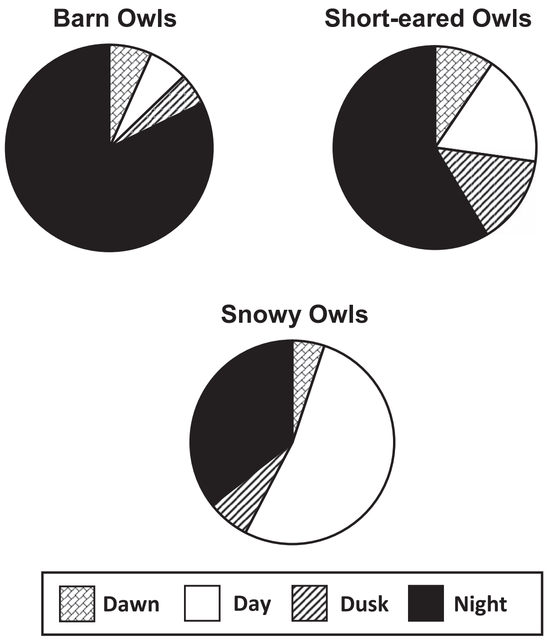

Figure 3. Distribution of the time of day for Barn Owl ($n =$ 375), Short-eared Owl ($n = 169$), and Snowy Owl ($n = 59$) strikes with US civil (1 January 1990–30 June 2014) and US Air Force aircraft (1 January 1994–30 June 2014).

species has a global range, is one of the most widely distributed land birds, and can use a wide variety of human-modified habitats (Marti et al. 2005). Barn Owls are nonmigratory and are active during nocturnal periods; thus they present a risk to safe aircraft operations mostly during the night and throughout the year. Wildlife surveys and mitigation activities conducted within airport environments typically occur only during daylight hours; thus, in situations where nocturnally active owl species, such as Barn Owls, are believed to be an important issue, wildlife biologists and airport managers will need to identify and use alternative survey and mitigation methods that are effective during nighttime periods.

Short-eared Owls have one of the largest geographic ranges of owls in the world (Wiggins et al. 2006). This species favors grassland habitats for nesting, roosting, and foraging; thus the large expanses of such habitats at an airport can be attractive to these birds. Other than island endemic populations, such as the Pueo (*Asio flammeus sandwichensis*), Short-eared Owls are migratory and thus might use airport habitats only during part of the year (e.g., during winter months in the Upper

Table 2. Number of owl strikes with US civil (1 January 1990–30 June 2014) and US Air Force aircraft (1 January 1994–30 June 2014) occurring at various altitudes (m Above Ground Level [AGL]).

ALTITUDE (m AGL)	NUMBER OF STRIKES WITH AIRCRAFT	% OF TOTAL
0–30	810	86.0
31–152	73	7.8
153–305	34	3.6
306–610	19	2.0
611–915	5	0.5
>915	1	0.1
Total	**942**	

Great Lakes Region of the USA). Like many species of wildlife, Short-eared Owls select and use habitat in relation to prey availability and abundance (Clark 1975, Wiggins et al. 2006), and therefore management actions to reduce the abundance of small mammals and other prey resources might be effective in reducing the presence of Short-eared Owls on airports and consequently reduce the risk of owl strikes.

The Great Horned Owl has the widest geographic range of owls in North America (Artuso et al. 2013). Great Horned Owls are nonmigratory and are nocturnal predators, presenting a risk to safe aircraft operations at an airport or military airbase mostly during the night and throughout the year. This species uses a perch-and-pounce hunting strategy and likely forages for prey in the grassland areas on airfields. Airports provide for many of this bird's needs, such as grasslands for foraging and structures that provide nest sites.

Of the 20 owl species identified in owl strikes in this report, none are listed by the United States Fish and Wildlife Service (USFWS) as threatened or endangered (USFWS 2017) or are considered to be of global conservation concern according to the International Union for Conservation of Nature (IUCN 2017). All of the owl species occurring in North America are protected by the Migratory Bird Treaty Act (16 USC 703–712). In addition, a few owl species are listed as threatened or endangered at the state level in part of their geographic range (e.g., Burrowing Owls in Florida and California; Short-eared Owls in Pennsylvania, Michigan, and other states). Proper management actions to decrease owl presence on or near airports and military airbases, in particular larger-bodied species (e.g., Great Horned Owls, Snowy Owls) is warranted due to the high rate of damage to aircraft and owl mortality associated with these events.

Owl strike events and wildlife damage management activities at airports involving owl species that the public greatly appreciates, such as the Snowy Owl, can result in significant adverse media attention and public concern (Graham et al. 2005, Dale 2009). These issues might become more frequent and intense due to the popularity of social media and instant transfer of information via the internet (Cushing and Washburn 2014). Given the current widespread public interest in owls with a strong concern for owl protection, effective, publicly accepted methods to reduce the hazards posed by owls using airport environments are needed.

An integrated wildlife damage management program, which might include nonlethal hazing (e.g., pyrotechnics), live-capture and translocation, killing of problematic individuals, habitat modification, and other methods, is commonly used to reduce the risk of raptor strikes at airports (Washburn et al. 2011, DeVault et al. 2013, Schafer and Washburn 2016, Pullins et al. 2018). These management techniques might also be useful to reduce the risk of owl strikes; however, there has been no research or formal evaluation conducted to determine the efficacy of these methods (individually or in combination). Future research efforts focused on the development and evaluation of effective species-specific methods of reducing owl strikes are critically needed.

In summary, owl strikes with US civil and USAF aircraft are a common event during flight operations within the USA and throughout the world. These events cause owl mortality and can result in significant damage to aircraft. Barn Owls, Short-eared Owls, and Great Horned Owls are the species that most frequently collide with aircraft. The majority of owl strikes occurred within the airfield environment, and thus we suggest that management actions to reduce the frequency and damage associated with these events should be focused on the airfield itself.

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