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Biondi, Kristen M.; Belant, Jerrold L.; Devault, Travis L.; Martin, James A.; and Wang, Guiming, "Bat incidents with U.S. civil aircraft" (2013). *USDA National Wildlife Research Center - Staff Publications*. 1452.
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Acta Chiropterologica, 15(1): 185–192, 2013
PL ISSN 1508-1109 © Museum and Institute of Zoology PAS
doi: 10.3161/150811013X667984

Bat incidents with U.S. civil aircraft

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Wildlife collisions with aircraft (hereafter incidents) threaten human safety and cause substantial economic loss. Although more than 97% of wildlife incidents with U.S. civil aircraft involve birds, damage is more than 4.5 times more likely to occur during a mammal incident (e.g., deer, canids). Bats are the only mammals with the potential to be struck by aircraft outside the airport environment (at least 152.4 m above ground). We examined the Federal Aviation Administration's (FAA) National Wildlife Strike Database from 1990 to 2010 to estimate the frequency of bat incidents with aircraft within the U.S. and the risk relative to other wildlife incidents. We summarized 417 bat incidents with U.S. civil aircraft. There were 10 bat species or species groups involved in these incidents; however, 68.9% were not identified to species. Most (85.7%) bat incidents occurred at Part 139 certificated airports that receive regularly-scheduled passenger flights with more than nine seats or unscheduled flights with more than 30 seats. More incidents occurred during August (28.3%) than any other month. Most bat incidents occurred at night (81.7%), but the greatest incident rate occurred at dusk (57.3%). More incidents occurred during aircraft landing (85.0%) than take-off (11.2%) or other phases of flight (3.7%). 'Minor' damage to aircraft occurred on only two occasions but no damage costs were reported. Incidents coincided with bat behavior, including diel activity, migration, hibernation, and juvenile recruitment. We conclude bat incidents are low risk to U.S. civil aircraft and have minimal economic effect on the U.S. civil aviation industry.

Key words: airport, airport management, aviation hazard, bats, United States, wildlife-aircraft incident, wildlife strike

Introduction

Wildlife collisions with aircraft (hereafter incidents) pose a risk to human safety and result in substantial economic loss. Wildlife incidents with aircraft cost the United States (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). Over 100,000 wildlife incidents were reported using the Federal Aviation Administration's (FAA) National Wildlife Strike Database from 1990–2010 (Dolbeer *et al.*, 2012). These incidents included primarily birds (97.2%), followed by mammals (2.7%), and reptiles (0.1%) (Dolbeer *et al.*, 2012). Although overall reported incidents have increased five-fold from 1990 to 2010, the total number of annual reported damaging incidents has declined (Dolbeer, 2011; Dolbeer *et al.*, 2012).

Most research on wildlife incidents with aircraft has emphasized birds; however, a greater proportion of mammal incidents cause damage to aircraft (Wright *et al.*, 1998; Dolbeer *et al.*, 2000; Biondi *et al.*, 2011). Although comparatively few (< 1%) wildlife incidents with U.S. civil aircraft involve bats (Dolbeer *et al.*, 2012), no detailed summary of timing and frequency of bat incidents or damage to U.S. civil aircraft from bat incidents has been reported. Parsons *et al.* (2008) used the Australian Transport Safety Bureau database of bat incidents with aircraft to examine flying altitudes of the flying-fox (Pteropodidae), which demonstrates that information from wildlife strike databases could be used to help determine bat behavior and provide more insight to bat incidents with aircraft. Damage occurred in 19% of bat incidents with Australian aircraft from 1996–2006; however, the bats involved in these incidents mostly were considered Pteropodidae (Parsons *et al*., 2009). In contrast, Zakrajsek and Bissonette (2005) considered bats a low risk to U.S. military aircraft, with a hazard ranking of 21/22 relative to other species or species groups. Additionally, < 1% of bat incidents with U.S. Air Force (USAF) aircraft during 1997–2007 caused damage (Peurach *et al*., 2009). However, these incidents incurred > US$ 825,000 of damage to USAF aircraft. The species reported struck most frequently by USAF aircraft was the Brazilian free-tailed bat (*Tadaria brasiliensis*), whereas the species reported to incur greatest damage costs was red bat (*Lasiurus* spp. — Peurach *et al*., 2009).

Our objective was to summarize bat incidents with U.S. civil aircraft to estimate the magnitude of incidents and the hazard bats pose to civil aircraft. We characterized trends and patterns of bat incidents to provide potential insight for management of bats at airports and to reduce bat incidents. We expected bats to pose a low relative hazard to civil aircraft, similar to USAF aircraft (Peurach *et al*., 2009). We also expected a higher frequency of incidents during summer through fall and at night corresponding with typical bat behavior (Villa-R. and Cockrum, 1962; Erkert, 1982; Cryan, 2003; Fleming and Eby, 2003; Keeley and Keeley, 2004; Reichard *et al*., 2009).

Materials and Methods

Following Biondi *et al*. (2011), we queried the Federal Aviation Administration National Wildlife Strike Database containing data from 1990–2010 for incidents involving bats and U.S. civil aircraft within the U.S. We excluded any incidents reported outside the 50 U.S. states or Washington, D.C., as well as any incidents reported as involving 'unknown bird or bat.' The National Wildlife Strike Database contains information reported to the FAA by pilots and airports using FAA Form 5200-7 (Dolbeer, 2009). Because reporting incidents is voluntary, many reports were incomplete; therefore, only incidents that reported the variable of interest were used in analysis of that variable. Incidents information may also be misleading as animal remains may not be recovered during the flight the incident may have occurred, or the remains were found on the runway with no other signs of an incident. Consequently, sample sizes varied among comparisons. We used the FAA Airport Facilities Data Report (Federal Aviation Administration, 2010), which includes all airports eligible for federal funding and that submit FAA Form 5200-7 for the FAA National Wildlife Strike Database, to compare frequency of bat incidents at general aviation (GA) and Part 139 (certificated) airports. Certificated airports are those which receive regularly-scheduled passenger flights with > nine seats or unscheduled flights with > 30 seats, or are otherwise required by the FAA Administrator to hold a certificate (Federal Aviation Administration, 2012*b*). General aviation airports are generally smaller and have fewer aircraft movements than certificated airports (Dolbeer *et al*., 2008; Federal Aviation Administration, 2012*b*).

We summarized the number of bat incidents reported annually and calculated annual bat incident rates/1 million U.S. civil aircraft movements using the FAA Terminal Area Forecast Summary Report (Federal Aviation Administration, 2012*c*). The 2010 flight data were presented as estimates in the report and are not definitive movements. We determined the number of bat incidents reported monthly and calculated monthly bat incident rates/1 million U.S. civil aircraft movements using the FAA Air Traffic Activity System (Federal Aviation Administration, 2012*a*). We also calculated the number of incidents/hr by time of day for a 24-hour period, as categorized in the FAA National Wildlife Strike Database. Dawn and dusk represented 0.75 hrs each, whereas night and day represented 11.25 hrs each (Wright *et al*., 1998; Biondi *et al*., 2011). We summarized incidents by time of day within month. We calculated the number of incidents by U.S. state. We calculated the number of occasions multiple bats (> 1) were observed by pilots during incidents and struck by aircraft as reported within the FAA National Wildlife Strike Database.

To assess frequency of bat incidents by aircraft phase of flight, 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 (> 22,500 ft) above ground. Approach was defined as an aircraft engaged in landing from ≤ 6,858 m (≤ 22,500 ft) above ground with at least one wheel off the ground. 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 as reported in the FAA National Wildlife Strike Database.

We used damage classes ('none', 'minor', 'substantial', and 'destroyed') from the FAA National Wildlife Strike Database to assess the amount of damage incurred (Dolbeer *et al*., 2000) by bats. '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. We summarized effect on flight and aircraft out of service 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.

Because visual inspection of incident rates suggested a non-linear trend across years, we used quadratic regression (program R version 2.13.1, The R Foundation for Statistical Computing, Vienna, Austria) with incident rate as the dependent variable and year as the independent variable to model the trend in annual incident rates across years. We used chi-square analyses (program SAS, version 9.3 — SAS Institute, Cary, North Carolina) to compare the number of incidents by month, phase of flight, and incidents/hour by time of day (e.g., day, night) as reported on FAA Form 5200-7. We accepted statistical significance at $\alpha < 0.05$.

Results

From 1990–2010 there were 417 bat incidents with U.S. civil aircraft reported through the FAA National Wildlife Strike Database. Average annual number of incidents was 20 (SD = 24, range = 0–91 — Fig. 1). Generally, annual incident rates increased (incident rates = 0.177– 0.061(year) + 0.005(year^2); adjusted r^2 = 0.91, $P < 0.001$) from 1990–2010. The greatest number of incidents (*n* = 91) and annual incident rate (1.26 incidents/year/1 million operations occurred in 2010.

There were 10 known bat species or groups involved in incidents (Table 1). Brazilian free-tailed bat *Tadarida brasiliensis* (*n* = 39) and little brown bat *Myotis lucifugus* (*n* = 31) were the species reported most frequently. However, most incidents (68.9%) were reported with species unknown. More than one bat was struck in 32 incidents. Incidents occurred in 38 of 50 states and in Washington, D.C. (Fig. 2); states with most frequent bat incidents reported were Texas (*n* = 128), Arizona (*n* = 41), and Florida (*n* = 20). More bat incidents were reported at certificated airports (*n* = 409) than GA airports (*n* = 5) and unknown (*n* = 5).

Brazilian free-tailed bat incidents (*n* =39) were reported in Arizona (*n* = 18) from February to November, in California (*n* = 8) during May–October, in Texas (*n* = 6) during November–January (*n* = 5) with one incident in August, in Utah (*n* = 4) during August–September, in Florida (*n* = 1) in May, and in New Mexico (*n* = 1) in February. All little brown bat incidents (*n* = 31) were reported from June–September, and were reported most frequently in Colorado (*n* = 6) and Nebraska (*n* = 6).

Number of incidents varied across months (*n* = 417; χ^2_{11} = 336.4, $P < 0.001$) with most incidents in August (*n* = 117) (Fig. 3). Incidents varied by time of day (*n* = 104; χ^2_3 = 78.3, $P < 0.001$ — Fig. 4). Of incidents reporting time of day (*n* = 104), most occurred at night (81.7%). However, the highest incident rate (*n* = 26) occurred at dusk (57.3%; 14.7 incidents/hr). At least 63.6% of bat incidents (*n* = 104) occurred at night each month excluding December for which no times of day were reported (Fig. 5). November had the highest proportion of incidents occurring during day (33.3%), however only three incidents were reported

TABLE 1. Species or groups of bats and number of incidents (*n* = 417) with U.S. civil aircraft occurring in the U.S, 1990–2010

Species or group	Incidents	
	n	%
Unknown	287	68.8
Tadarida brasiliensis	39	9.4
Myotis lucifugus	31	7.4
Lasiurus spp.	25	6.0
Molossidae	13	3.1
Eptesicus fuscus	7	1.7
Lasiurus cinereus	6	1.4
Lasionycteris noctivagans	5	1.2
Nyctinomops femorosacca	2	0.5
Lasiurus intermedius	1	0.2
Lasiurus seminolus	1	0.2

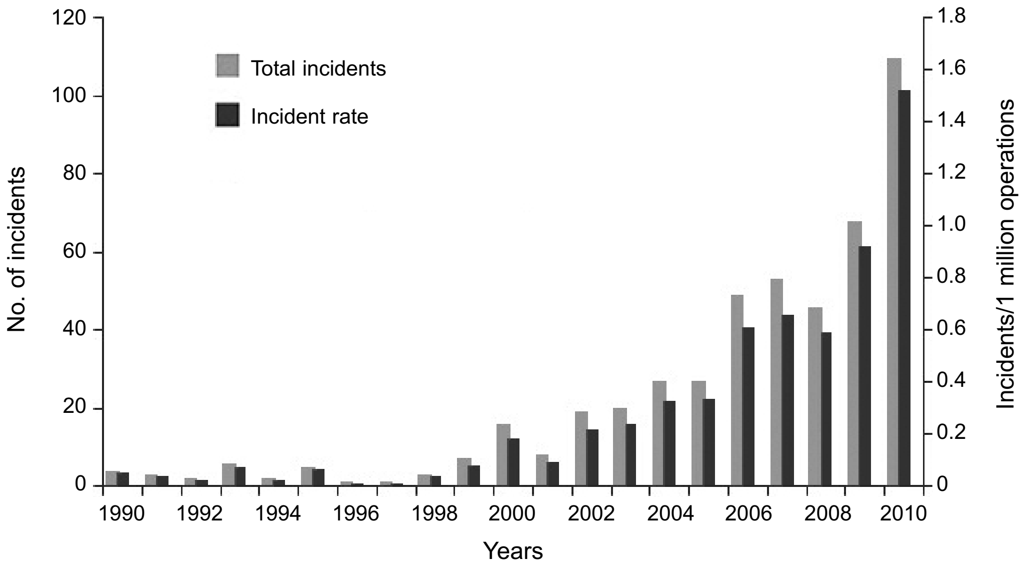

FIG. 1. Number of bat incidents (*n* = 417) and incident rate (incidents/1 million operations) with U.S. civil aircraft in the U.S. by year, 1990–2010

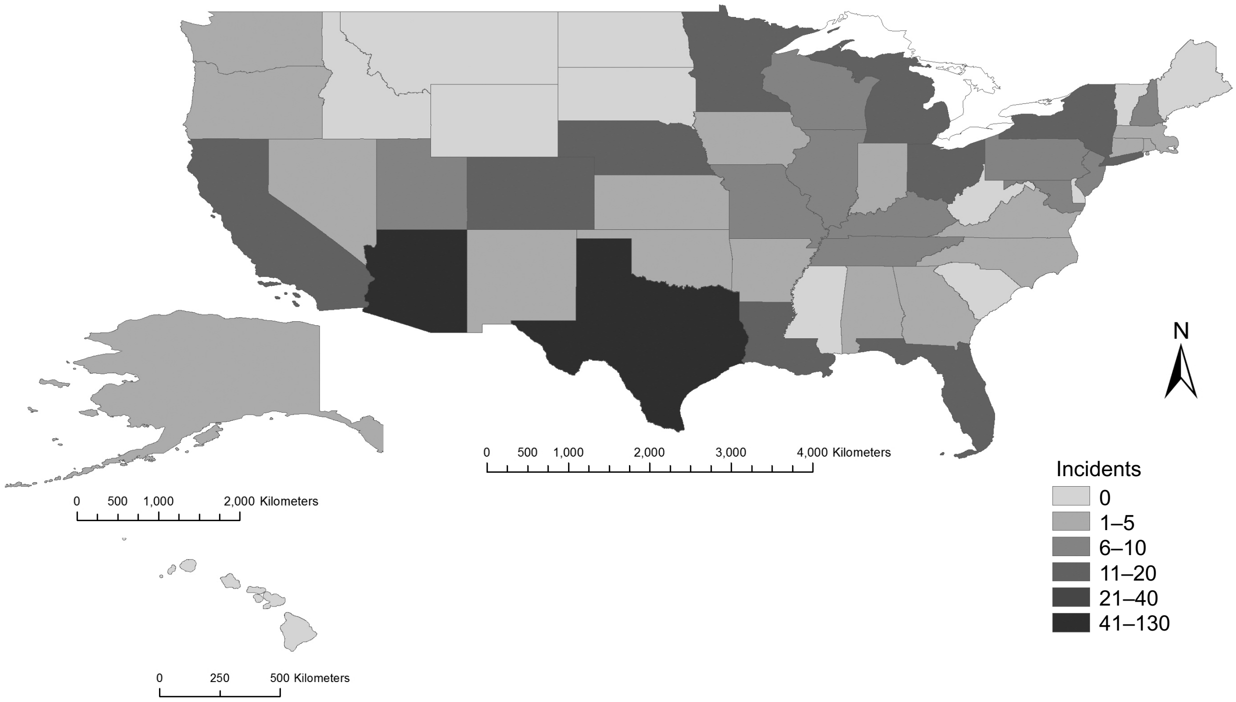

FIG. 2. Number of incidents (n = 417) with U.S. civil aircraft by state, 1990–2010

during November with one incident occurring during day.

Number of incidents varied by aircraft movement type (n = 107; χ^2_5 = 216.3, P < 0.001). Twice as many incidents (n = 107) occurred during approach (72.5%) than all other phases of flight (Fig. 6). Similarly, > 5.5 times more incidents (n = 107, χ^2_2 = 129.7, P < 0.001) occurred during landing (85.0%) than take-off (11.2%) and other (3.7%).

Of all parts of the aircraft struck (n = 138), the windshield (n = 32), nose (n = 22), radiator (n = 17), and wing rotor (n = 17) were reported most frequently. 'Minor' damage was sustained in two incidents and both aircraft incurred damage to the wing rotor. No damage costs were reported. Only 1 incident was reported to have an effect on flight (n = 95).

DISCUSSION

The increase in annual numbers of bat incidents and incident rates since 1990 generally corresponded

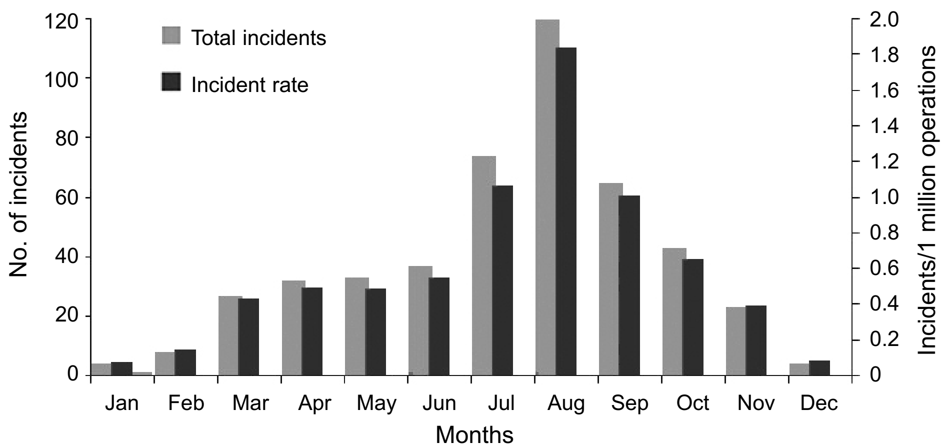

FIG. 3. Number of bat incidents (n = 417) and incident rate (incidents/1 million operations) with U.S. civil aircraft in the U.S. by month, 1990–2010

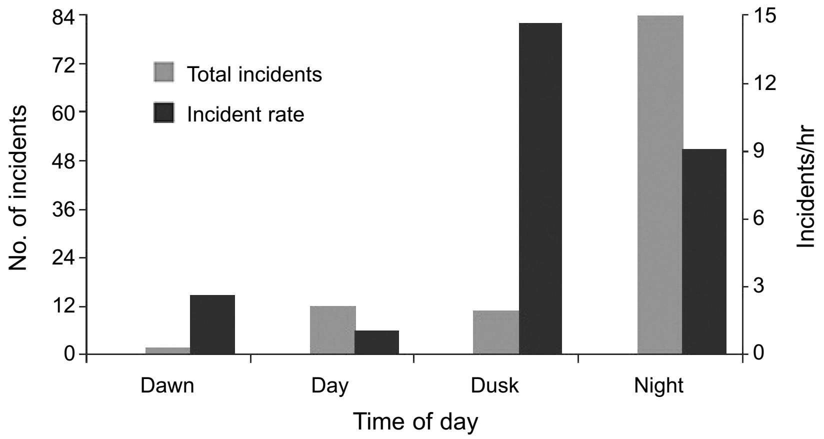

FIG. 4 Number of bat incidents (n = 104) and incident rate (incidents/1 hour) with U.S. civil aircraft in the U.S. by time of day, 1990–2010

with increases in all wildlife incidents (Dolbeer, 2011; Dolbeer *et al*., 2012). The annual number of bat incidents reported doubled from 2002 to 2008, then again doubled from 2008 to 2010. Reporting rates for all wildlife incidents increased 5-fold from 2004–2008 then increased 25% after 2008, presumably due to the publicized incident with US Airways Flight 1549 (Marra *et al*., 2009; Dolbeer *et al*., 2012).

Frequency of bat incidents with aircraft across months appeared to reflect broad aspects of bat behavior. The low percentage of incidents (< 1%) during December–February is consistent with Peurach *et al*. (2009) who reported < 2% of bat incidents with USAF aircraft during December–February. This decrease in incidents coincides with bat hibernation or torpor in the northern hemisphere, where bat activity is comparatively low (Fleming and Eby, 2003) and therefore would provide less opportunity for an incident to occur. The increase in incidents during March–June coincides with bat migration (Keeley and Keeley, 2004). For example, Brazilian free-tailed bats in Texas migrate from March to May (Keeley and Keeley, 2004). The high frequency of incidents from August to October (≥ 30 incidents/month) agrees with Peurach *et al*. (2009) who documented bat incidents with USAF aircraft occurred most frequently during August–October. Bat parturition occurs in early summer and young begin to emerge from roosts in July (Reichard *et al*., 2009). Thus, the greater number of incidents reported in August may be explained by the greater number of juvenile bats. Brazilian free-tailed (Villa-R. and Cockrum, 1962) and silver-haired bats *Lasionycteris noctivagans* (Cryan, 2003) migrate southward in the fall, which also may increase population abundance as well as an increase of bats in sustained flights in winter ranges and increase risk of an incident.

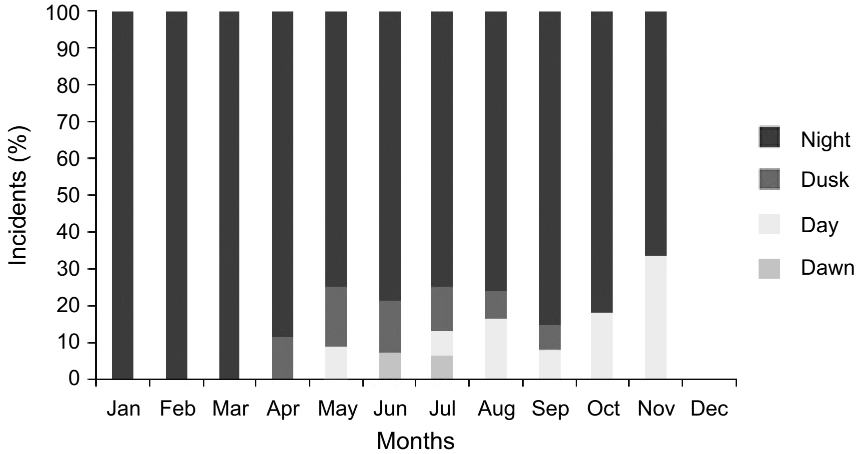

FIG. 5. Percent of bat incidents (n = 104) with U.S. civil aircraft in the U.S. by time of day within month, 1990–2010

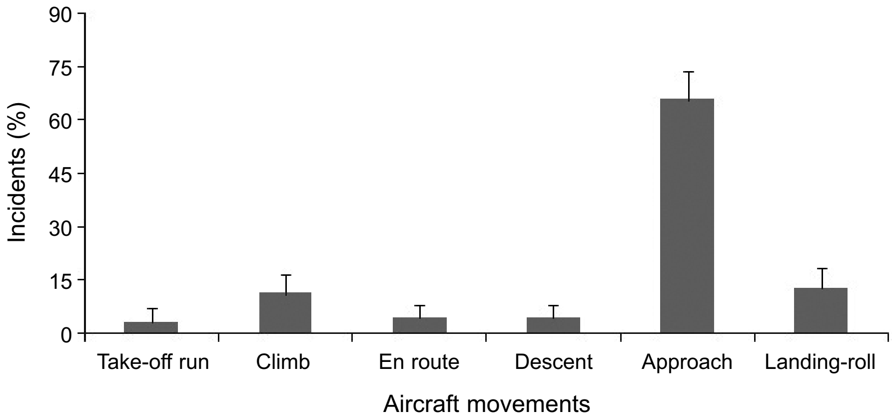

FIG. 6. Percent (± 95% CI) of bat incidents (n = 107) with U.S. civil aircraft in the U.S. by aircraft movement, 1990–2010

The high frequency of bat incidents at night is similar to results reported by Parsons *et al*. (2009) and Peurach *et al*. (2009), who found that incidents occurred most frequently from 17:00–02:00 and 19:00–02:00, respectively. Also, the greater incident rate at dusk is similar to that reported by Peurach *et al*. (2009) for USAF aircraft. The high incident rate at dusk and number of incidents at night is consistent with bat activity, in that many species of bat emerge in groups from roosts at dusk to forage at night (Erkert, 1982). The standardized risk for bat incidents appears greatest at dusk, however, the high frequency of incidents at night, suggest that both dusk and night have increased risk for bat incidents.

Improved understanding and management of bat-aircraft incidents requires knowledge of bat species involved. In our study, almost 70% of bat incidents involved individuals not identified to species. Condition of carcasses and limited remains from bat incidents can make identification difficult (Parsons *et al*., 2009). Variable timing of migration across the geographic ranges of species (Fleming and Eby, 2003) can also cause difficulties with species identification. Peurach *et al*. (2009) used DNA analyses for species-level identification of bat remains obtained from incidents with aircraft with about 50% success. Increased use of DNA analysis could potentially increase species identification of bat incidents with U.S. civil aircraft to 65% if the success rate of Peurach *et al*. (2009) can be achieved.

In our study, < 2.0% of incidents caused damage, similar to the percentage of damaging incidents with USAF aircraft (Peurach *et al*., 2009), and only 1% had an effect on flight. As 59% of terrestrial mammal incidents and 13% of bird incidents cause damage to U.S. civil aircraft, and 51% of terrestrial mammal incidents and 11% of bird incidents had an effect on flight (Dolbeer *et al*., 2012), we suggest bats are a low risk to U.S. civil aircraft compared to other wildlife. In contrast, Parsons *et al*. (2009) reported 19% of bat incidents caused damage. Although Parsons *et al*. (2009) did not report bat species involved in incidents, all but three incidents occurred in areas where flying foxes occur. Flying foxes are the largest bats in Australia, weighing up to 1 kg (Hall and Richards, 2000) and similar to the median body mass of birds causing damage to U.S. civil aircraft (1.1 kg — DeVault *et al*., 2011). In contrast, the largest bat species in the U.S. is the greater western mastiff bat (*Eumops perotis*) which averages 61.5 g (Reid, 2006). As bats that potentially pose the greatest risk to aircraft in Australia are 16 times heavier than the heaviest bat in the U.S., the greater percentage of bat incidents causing damage to aircraft in Australia is not surprising. However, since some information from the database is unreliable or incomplete, particularly species identification, more accurate reports in the future may provide greater insight on the potential risk of bat incidents to U.S. civil aircraft.

Although bats are low risk to civil aircraft, small efforts to reduce bat use of airports should be considered. Bats often fly in groups, particularly at dusk (Erkert, 1982); therefore, adjusting aircraft flight schedules during dusk may reduce potential for damaging incidents. As many bat species roost in cavities (Lacki *et al*., 2007) and human-made structures (Wilson and Ruff, 1999; Kunz and Reynolds, 2003), removing trees (Barras and Seamans, 2002) and limiting other areas where bats can roost (i.e. behind shutters, holes in structures — Kunz and

Reynolds, 2003) using exclusion techniques may reduce bat use of areas. Some bats also forage in riparian forests and near streams or standing water (Fukui *et al*., 2006). Eliminating water sources (e.g., standing stormwater, wetlands, artificial basins — Barras and Seamans, 2002; Blackwell *et al*., 2008) at airports through stormwater management (Blackwell *et al*., 2008), and proper grading and drainage (Barras and Seamans, 2002) on airports may further reduce bat use. We suggest that all bat strike remains be sent to the feather identification laboratory at the Smithsonian Institution for identification so that further understanding of incidents can be obtained. We recommend continued monitoring of bat incidents with U.S. civil aircraft to help ensure number of incidents and relative risk remains low.

Acknowledgements

Our work was supported by the Department of Wildlife, Fisheries, and Aquaculture and Forest and Wildlife Research Center at Mississippi State University; United States Department of Agriculture; and the FAA under agreement DTFACT-04-X-90003. We thank B.F. Blackwell for reviewing a draft of this manuscript. Opinions expressed in this study do not necessarily reflect current FAA policy decisions regarding the control of wildlife on or near airports.

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Received 24 October 2012, accepted 08 April 2013