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ABSTRACT Despite a substantial amount of information available on bird and other wildlife strikes at large international airports, relatively few researchers have considered bird hazards at smaller general aviation (GA) airports and airfields. However, small airports often are located in rural areas, and the potential for wildlife strikes may be significant, especially because airworthiness standards related to bird strikes are much less stringent for GA aircraft compared to commercial aircraft. In this study, we conducted habitat assessments (onsite land-cover evaluations and Geographic Information System analyses) and seasonal bird surveys (walking transects) over a period of 1 year at 10 small airports in the state of Indiana, USA. Across all airports, the 3 most abundant habitat types were short (mowed) grass (mean = 40.2% of total airport area), soybean fields (10.3%), and corn fields (9.5%). At least 2 types of bird attractants (e.g., standing water, agricultural fields, woodlots) were present at each airport property, although most airports had 5 to 7 types. Seven species groups (American kestrel [*Falco sparverius*], blackbirds-starling, crows-ravens, mourning dove [*Zenaida macroura*], shorebirds, sparrows, and swallows) each were present at 9–10 of the airport properties during 1 or more seasons. The most numerous species group was blackbirds-starling, although the abundance of this and most other species groups varied widely across seasons and airports. Our results indicate that small airports in Indiana contain many bird attractants and harbor substantial numbers of birds hazardous to aviation. Management of wildlife hazards at small airports is especially challenging, given that many such airports have limited resources available for design and implementation of effective wildlife management programs. Future research should evaluate the suitability of alternative habitat types and agricultural crops that are cost-effective but compatible with effective management of wildlife hazards to aviation.

KEY WORDS airport, agriculture, aviation safety, birds, FAA, general aviation, GIS, habitat, wildlife strike

Wildlife strikes with aircraft are increasing in the USA and elsewhere (Allen and Orosz 2001, Dolbeer and Wright 2008). The number of wildlife strikes reported to the U.S. Federal Aviation Administration (FAA) increased steadily from 1,759 in 1990 to 7,666 in 2007 (Dolbeer and Wright 2008). Expanding wildlife populations, increases in number of aircraft movements, and a trend toward faster and quieter aircraft all have contributed to the observed increase in wildlife strikes (Dolbeer and Eschenfelder 2002, Dolbeer and Eschenfelder 2003, Dolbeer et al. 2008). Concomitant with the increase in wildlife strikes has been greater emphasis on strike-hazard research and airfield management. Our understanding of the causes of wildlife (primarily bird) strikes with aircraft has improved, both in the airport environment (e.g., Dolbeer et al. 1993, Dolbeer et al. 2000, MacKinnon et al. 2001, Cleary and Dolbeer 2005) and at higher altitudes (e.g., Larkin et al. 1975, DeVault et al. 2005, Blackwell and Wright 2006, Dolbeer 2006). Further, in the USA the number of airports that requested hazard-management assistance from the U.S. Department of Agriculture, Wildlife

Services, increased from 42 in 1990 to 714 in 2007 (Dolbeer and Begier 2008).

In the USA, most research has been limited to "certificated" airports (those approved by the FAA for scheduled flights of aircraft with more than 9 passenger seats or unscheduled flights of aircraft with more than 30 seats), which are required by the FAA to address wildlife hazard issues on their properties (FAA 2007). Few data are available concerning wildlife strike hazards at smaller, general aviation (GA) airports and airfields (DeVault et al. 2008), even though GA airports in the USA (n = 14,377) outnumber certificated airports (n = 570) by a ratio of approximately 26:1 (Dolbeer et al. 2008). Unlike certificated airports, GA airports in the USA generally are not required by the FAA to address wildlife hazard issues.

GA airports face considerable challenges in managing wildlife hazards. Such airports often are located in rural areas with high densities of birds and other wildlife, and many GA airports have inadequate funding and few, if any, trained personnel available for wildlife hazard management. Also, the general lack of government oversight concerning airfield land-cover types, bird and mammal attractants, deer-proof fencing, and other aspects of effective wildlife hazard management contributes to the risk of damaging wildlife strikes at GA airports (DeVault et al. 2008).

The FAA Wildlife Strike Database contains relatively few records from GA airports; only about 5% of the strikes in the database, 1990–2006, were from GA airports (Dolbeer et al. 2008). However, the percentage of strikes that reported damage to the aircraft (1990–2006) is greater for GA airports (39%) than for certificated airports (14%). Also, 24 of the 36 known hull losses in the USA from 1990 to 2006 involved GA aircraft ($\leq$ 27,000 kg at take-off) at GA airports (Dolbeer et al. 2008). Unquestionably, the potential for damaging wildlife strikes at GA airports warrants further investigation.

In a previous study, DeVault et al. (2008) examined perimeter fences and the occurrence of hazardous mammals (i.e., white-tailed deer [*Odocoileus virginianus*] and coyotes [*Canis latrans*]) at 10 small airports in Indiana, USA. They concluded that fences were generally inadequate to exclude hazardous mammals, a conclusion which was supported by frequent observations of white-tailed deer and coyotes within airport properties and near air-operations areas. In the present study, we investigated land cover (i.e., habitat types) and bird communities at the same 10 airports. Our objectives were to: 1) quantify habitat types within airport boundaries, 2) document the type and number of bird attractants, and 3) determine presence and relative abundance of bird communities at the airports, with emphasis on hazardous species. Information about these airport characteristics will be important for the recognition and remediation of avian hazards at small airports in the midwestern U.S. and elsewhere where similar circumstances exist.

METHODS

Study Area

Indiana (94,321 km^2) is located within the midwestern region of the USA and within the Mississippi flyway corridor. Ten airports in Indiana were chosen for study (Table 1). Nine of these were classified as GA airports, whereas 1 carried regularly scheduled commercial air traffic. Our study sites were not a random sample of all small airports in Indiana, but we attempted to represent the entire spectrum of aircraft traffic, proximity to urban development, and extent of wildlife hazard management programs of small airports in the region. Additionally, our study airports were distributed equally

Table 1. Characteristics of 10 airports chosen as study sites for an investigation of habitat and bird populations at small airports in Indiana, USA, 2005–2006.

Airport	Area (ha)	Runway length (m)	Civil aircraft movements [a]	Based aircraft [b]	Bird transect length (m)
1	202	5400	74	81	1133
2	170	3899	264	135	1478
3	243	5000	56	56	1532
4	60	4300	89	107	1009
5	194	5000	33	33	1323
6	202	6600	315	105	1848
7	78	5000	81	25	790
8	284	5500	95	32	1086
9	627	4300	149	58	788
10	225	6000	66	49	1139

[a] Mean number of civil aircraft movements per day in 2006.
[b] Total number of aircraft (single engine, multi-engine, jet) permanently based at airport in 2006.

among northern, central, and southern regions of the state to account for possible regional differences in the composition of wildlife communities.

Habitat Analyses

We conducted onsite assessments of habitat types at each airport in June 2005 and created field maps of major habitat types that could be expected to influence presence or abundance of wildlife on airport properties (Cleary and Dolbeer 2005). Habitats were classified into 1 of 26 types based on general habitat niches occupied by various wildlife taxa and for potential to serve as bird attractants (Table 2). We consulted aerial photographs (obtained by downloading geographic raster data generated in 2003 by the USDA National Agricultural Imagery Program [NAIP], provided by the Indiana Geological Survey [IGS; http://129.79.145.5/arcims/statewide/index.html]) to aid our interpretation of the spatial extent and location of habitat patches. If a given airport had a completely fenced airfield, we mapped habitat types within the fence line only. For airports that lacked complete fencing or other obvious boundary markers (e.g., roads), we mapped habitat types within official property boundaries as indicated by airport personnel.

In addition to identifying and mapping habitat types, we noted presence of potential bird attractants (Cleary and Dolbeer 2005) during onsite assessments. Specifically, we recorded presence of crop fields (alfalfa, corn, soybean, sorghum, wheat), woodlots, standing water (permanent or ephemeral), open streams (permanent or ephemeral, flowing above ground), open refuse containers, open buildings (e.g., hangars without closing doors), open culverts (i.e., those without grating), brush piles, and gravel piles on airport properties.

After we recorded presence and location of individual habitat types at each airport, we used ArcMap (ArcGIS 9) to create digital habitat maps, including specific bird attractants. First, we downloaded geographic raster data of Indiana counties where study airports were located (generated in 2003 by the USDA NAIP, provided by the IGS [http://129.79.145.5/arcims/statewide/index.html]). The .sid file for each raster download was added to an ArcMap project and served as a base map for digitizing habitat types. We created an individual feature class for each habitat type, and then digitized features

Table 2. Composition of 10 small airports by 26 habitat types in Indiana, USA, in 2005–2006. Data represent the mean percentage of the total airport area in each habitat.

Habitat type	Comments	No. airports (n=10) with habitat present	Mean (range)
Short grass	<10 cm tall, mowed weekly or bi-weekly	10	40.2 (9.3–75.5)
Soybean field		6	10.3 (0–37.7)
Corn field		5	9.5 (0–31.8)
Runway system	active runways and taxiways	10	8.1 (2.8–14.5)
Developed	buildings, paved roads and parking lots	10	6.6 (1.4–12.1)
Woodlot		5	5.2 (0–20.2)
Medium grass	10–45 cm tall, mowed several times/year	7	4.8 (0–16.0)
Tall grass	>75 cm tall, not mowed more than once/year	7	4.6 (0–29.7)
Hayfield		4	3.2 (0–17.6)
Old field habitat	tall, uncut grass and forbs	2	1.3 (0–11.6)
Alfalfa		1	1.1 (0–10.5)
Bare earth/construction		6	1.1 (0–6.7)
Sorghum field		1	1.0 (0–10.2)
Scrub-shrub	mix of shrubs, young trees, and tall grass	8	0.8 (0–3.3)
Gravel road		5	0.6 (0–4.0)
Weedy ditch		6	0.5 (0–1.9)
Wheat field		2	0.5 (0–3.6)
Permanent water		4	0.4 (0–2.3)
Cattail marsh	*Typha* spp.	1	0.1 (0–0.6)
Ephemeral pool		4	0.1 (0–0.4)
Fencerow		2	0.1 (0–0.3)
Grassy swamp		1	0.1 (0–0.6)
Ornamental/shade tree		2	0.1 (0–0.5)
Savanna		1	0.1 (0–0.9)
Dirt/gravel pile	bare or covered with weeds	2	0.0 (0–0.1)
Stone swale		1	0.0 (0–0.1)

(including the airport property as a whole) based on data we recorded on our field maps. We attempted to achieve a minimum of 5-m accuracy for all features. Following completion of the maps, we used the Calculate Area tool in ArcMap to determine the area (m^2) of each polygon. Polygon areas were summed for each habitat type and converted to a percentage of the total airport area.

Bird Surveys

We used walking line-transect surveys (Bibby et al. 1992) to sample bird populations at each airport. We conducted 2 surveys during each season (spring 2005, summer 2005, fall 2005, winter 2006) at each airport, for a total of 8 bird surveys per airport. Transect lengths ranged from 0.79–1.89 km (Table 1), and were established based on: 1) ability to survey a representative sample of habitat types available to birds within the airport property, 2) topography (in terms of our ability to view as much of the airport property as possible), and 3) accessibility. A team of 1–3 observers walked at a pace of ~2 km/hr and paused frequently to listen and look for birds. We were careful not to double-count individuals at corners on L- or U-shaped transects. During spring and summer seasons, counts were confined to a 5-hr period beginning 30 min before sunrise on days with little wind and no rain. During fall and winter (non-breeding season when birds do not sing), counts were not restricted to morning hours. For each bird detected, the observer recorded species, mode of detection (song, call, or visual), and distance to transect. Many birds that were counted were singing and, therefore, adult males. However, detections by sight or call note likely included some females, especially for visually conspicuous species such as red-winged blackbird (*Agelaius phoeniceus*) and eastern meadowlark (*Sturnella magna*), so we report count data as "individuals" per km. We categorize species into groups following Dolbeer et al. (2000).

RESULTS

Habitat types present at all airport properties were short grass, runway systems, and developed areas (Table 2). The next most commonly occurring habitat types were scrub-shrub (n = 8 airports), tall grass (n = 7), medium grass (n = 7), weedy ditches (n = 6), bare earth/construction (n = 6), and soybean fields (n = 6). Corn fields, gravel roads, and woodlots each were present at 5 airports (Table 2). On average, airport habitats consisted of short grass (40.2% of total airport area), soybean fields (10.3%), corn fields (9.5%), runway systems (8.1%), development (6.6%), woodlots (5.2%), medium grass (4.8%), tall grass (4.6%), and hayfields (3.2%); however, the average for tall grass habitat was skewed by a large value at 1 airport. All other habitat types averaged ≤1.3% of total airport area, although alfalfa and sorghum fields each represented ~10% at airports where they occurred.

At least 1 type of bird attractant was present on each airport property, but most airports had 5 to 7 types (Table 3). The most common attractant was standing water (ephemeral), which was present at 8 airports (Table 3). Other common attractants were crop fields, woodlots, and gravel piles.

Seven bird species groups (American kestrel [*Falco sparverius*], blackbirds-starling, crows-ravens, mourning dove [*Zenaida macroura*], shorebirds, sparrows, and swallows) each were present at 9–10 of the airport properties at some point during the year. Geese, hawks (buteos), and vultures each were present at 7–8 of the airport properties, and ducks, herons, and rock doves (*Columba livia)* each were present at 5–6. Gulls, eagles, and cranes each were present at only 1 airport property. Bird abundances also varied widely depending on species group and season (Table 4). Among all airports, the most numerous species group was blackbirds-starling (including red-winged blackbirds, eastern meadowlarks, brown-headed cowbirds [*Molothrus ater*], common grackles [*Quiscalus quiscula*], and European starlings [*Sturnus vulgaris*]), although the totals were skewed somewhat by a flock of blackbirds (over 2,000 individuals) that was observed during 1 of the fall surveys at 1 airport.

DISCUSSION

Our bird surveys indicated that many hazardous species were regularly present at our sample of small airports in Indiana, USA. Of the 19 bird species groups considered by Dolbeer et al. (2000) in their rankings of wildlife most hazardous to aircraft (those species groups for which there were ≥ 17 strike reports between January 1991 and May 1998), 16 (84%) were present (and in many cases, abundant) at Indiana airports. Only osprey (*Pandion haliaetus*) and pelicans (*Pelecanus erythrorhynchos* and *P. occidentalis*), which are uncommon in Indiana, and owls (nocturnal and thus not active during our

Table 3. Presence of hazardous bird attractants at 10 small airports in Indiana, USA, in 2005–2006.

Airport	Crop field	Woodlot	Standing water (p) [a]	Standing water (e) [b]	Open stream (p)	Open stream (e)	Open refuse container	Open building	Brush pile	Gravel pile
1	X	X			X	X			X	
2		X		X	X	X	X			
3	X	X	X	X					X	X
4	X	X		X	X			X		
5	X	X	X	X						X
6			X	X						X
7	X	X		X		X	X			X
8	X			X						X
9		X	X	X					X	
10	X									

[a] Permanent.
[b] Ephemeral.

surveys) were not observed. Furthermore, the 2 most hazardous groups, vultures and geese, were observed at 7 and 8 airports, respectively.

The abundance of hazardous birds observed at our study airports likely resulted from: 1) recent population increases for hazardous species in general (Dolbeer and Eschenfelder 2002) and 2) the composition of habitat types. Unlike certificated airports, which are regulated by the FAA and ostensibly contain relatively few wildlife attractants compared to GA airports, our study airports contained a wide variety of habitat types, many of which are considered bird attractants (FAA 2007). Airports in this study were composed of grasslands, crop fields, and to a lesser extent, developed areas and woodlots. Many facultative grassland species, such as red-winged blackbirds, often occupy such areas in large numbers, where preferential breeding, roosting, and loafing areas are available locally (e.g., Herkert 1994, Patterson and Best 1996, Blackwell and Dolbeer 2001).

The most effective wildlife hazard management plans at airports usually follow an integrated approach, combining limited lethal take, nonlethal harassment, exclusion (i.e., fencing), and habitat management (Cleary and Dolbeer 2005). However, lethal take is often controversial, birds can habituate quickly to many forms of nonlethal harassment (e.g., pyrotechnics and other noisemakers), and standard fencing does not exclude birds (Conover 2002). As such, successful management of hazardous birds at airports often relies foremost on habitat management, with the overall goal of reducing the availability or quality of food, water, cover, and loafing sites for hazardous species or both (Cleary and Dolbeer 2005).

Some wildlife hazard management practices at airports are well accepted and commonly used (e.g., covering trash receptacles, keeping hangar doors closed), but there is no clear consensus concerning airfield habitat management, because no single vegetation type is unattractive to all species (Barras and Seamans 2002, Washburn and Seamans 2004). For example, opinions differ concerning proper grass height and stand density for airport infields. Airports commonly maintain grass height from 5–45 cm, but until recently few data were available to support recommendations

Table 4. Birds observed during 8 walking transect surveys at each of 10 small airports in Indiana, USA, 2005–2006. Species groups follow Dolbeer et al. (2000). Values represent the mean number of individuals observed per km, across 10 airports ± SD. We report only birds observed within airport properties. For each species, the high count for each season (of 2 counts at each airport) was used to calculate means.

Species group	Spring	Summer	Fall	Winter	All seasons	Hazard ranking [a]
Blackbirds-starling	65.1 ± 49.1	98.8 ± 97.4	276.2 ± 405.0	35.5 ± 38.5	118.9 ± 95.4	19
Mourning dove	3.4 ± 5.3	22.2 ± 32.4	24.4 ± 33.0	12.6 ± 34.5	15.7 ± 13.7	13
Sparrows	16.2 ± 10.5	18.1 ± 9.5	6.8 ± 3.7	1.6 ± 1.7	10.7 ± 4.8	20
Crows-ravens	2.7 ± 2.0	3.7 ± 4.1	1.7 ± 1.9	33.2 ± 112.6	10.3 ± 24.6	18
Shorebirds	6.8 ± 8.3	20.5 ± 14.8	4.9 ± 3.6	1.4 ± 1.9	8.4 ± 4.8	17
Swallows	3.7 ± 4.6	11.3 ± 7.3	9.4 ± 28.0	0	6.1 ± 5.6	21
Geese	2.6 ± 2.6	4.3 ± 7.1	3.7 ± 2.3	5.0 ± 7.8	3.9 ± 3.1	3
Cranes	0	0	0	5.6 ± 0.0	1.4 ± 0.0	4
Rock dove	0.5 ± 0.9	4.0 ± 6.0	0.4 ± 0.0	0.3 ± 0.0	1.3 ± 1.6	10
Vultures	1.2 ± 2.9	1.2 ± 7.5	1.4 ± 4.7	0.5 ± 1.5	1.1 ± 2.5	2
American kestrel	0.5 ± 0.6	2.3 ± 3.3	0.1 ± 0.0	0.4 ± 0.3	0.8 ± 0.9	16
Hawks (buteos)	0.6 ± 0.3	0.9 ± 1.2	0.8 ± 0.4	0.9 ± 0.5	0.8 ± 0.6	8
Ducks	1.5 ± 2.1	0.2 ± 1.3	0.5 ± 1.9	0.6 ± 0.0	0.7 ± 0.9	7
Herons	0.9 ± 1.4	0.5 ± 0.7	0.1 ± 0.0	0	0.4 ± 0.4	12
Gulls	0.2 ± 0.0	0.1 ± 0.4	0	0	0.1 ± 0.2	11
Eagles	0	0	0	0.1 ± 0.0	0.0 ± 0.0	9

[a] Based on ranking of 21 species groups of birds and mammals (1 = most hazardous; 21 = least hazardous) compiled by Dolbeer et al. (2000).

that propose various turfgrass management strategies. Fortunately, recent and ongoing research concerning turfgrass management at airports has provided useful information (Seamans et al. 2007, Washburn and Seamans 2007, Washburn et al. 2007a, Washburn et al. 2007b), although more work is needed to refine recommendations for management.

The relationship between effective habitat management, economic viability of airports, and the presence of various forms of agriculture on airport properties is complex. Undoubtedly, agricultural crops such as corn and wheat can attract hazardous birds and other wildlife to airport properties at various times of the year, but few data are available concerning the relative strike risk associated with agricultural crops as opposed to turfgrass or other habitat types. The FAA recommends against using airport properties for agricultural production at certificated airports, unless "the airport has no financial alternative to agricultural crops to produce income necessary to maintain the viability of the airport…" (FAA 2007: page 9). General aviation airports, however, usually are not regulated in that way. Many small airports operate on limited budgets and rely on revenue generated from leasing out portions of their properties for agricultural production to remain solvent. Six of our 10 study airports contained agricultural fields (corn, soybeans, wheat, or sorghum), and soybean fields and corn fields were the second and third overall most abundant habitat types, respectively, behind only short grass. Furthermore, by leasing out land for agricultural production, airports avoid maintenance costs (i.e., cutting grass) that otherwise would be associated with the leased property.

Clearly there is a need for further research and guidance pertaining to airport land use, especially at GA airports where regulations are lacking and funding for wildlife hazard management is limited or nonexistent. Wildlife strikes at GA airports can be catastrophic (e.g., Dove et al. 2009), and the need for effective wildlife hazard management at GA airports will become more pronounced in future years as air traffic at such facilities increases (Dolbeer et al. 2008). Ideally, habitat management at airports should move toward creating habitats that are unattractive to hazardous wildlife but still can generate revenue. Research evaluating the suitability of various types of agriculture at airports would be especially beneficial.

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