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Composition and Diversity of Avian Communities Using a New Urban Habitat: Green Roofs

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Abstract Green roofs on buildings are becoming popular and represent a new component of the urban landscape. Public benefits of green roof projects include reduced stormwater runoff, improved air quality, reduced urban heat island effects, and aesthetic values. As part of a city-wide plan, several green roofs have been constructed at Chicago's O'Hare International Airport (ORD). Like some other landscaping features, green roofs on or near an airport might attract wildlife and thus increase the risk of bird–aircraft collisions. During 2007–2011, we conducted a series of studies to evaluate wildlife use of newly constructed green roofs and traditional (gravel) roofs on buildings at ORD. These green roofs were 0.04–1.62 ha in area and consisted of primarily stonecrop species for vegetation. A total of 188 birds were observed using roofs during this research. Of the birds using green roofs, 66, 23, and 4 % were Killdeer, European Starlings, and Mourning Doves, respectively. Killdeer nested on green roofs, whereas the other species perched, foraged, or loafed. Birds used green roofs almost exclusively between May and October. Overall, avian use of the green roofs was minimal and similar to that of buildings with traditional roofs. Although green roofs with other vegetation types might offer forage or cover to birds and thus attract potentially hazardous wildlife, the stonecrop-vegetated green roofs in this study did not increase the risk of bird–aircraft collisions.

Keywords Airport · Bird strike · Green roof · Habitat · Urban ecology · Wildlife

Introduction

Worldwide, urbanization results in an overall loss of biodiversity, with notable impacts on insect and bird communities (Chace and Walsh 2006; Grimm et al. 2008). Within highly urbanized areas, birds (and other wildlife) use a variety of seminatural and human-made habitats, including natural habitat fragments, parks, roadsides and railways, golf courses, gardens, and green roofs (Fernández-Juricic 2000; Fernández-Juricic and Jokimaki 2001; Hudson and Bird 2009; Vallejo et al. 2009; Meffert and Dziock 2012). Research examining the structure and composition of avian communities using urban habitats might provide insights into the effects of urbanization on birds and information needed to preserve or promote biodiversity in urban ecosystems (Sandström et al. 2006; Strohbach et al. 2013).

Green roofs (i.e., roofs with a vegetative surface and substrate) provide a variety of ecosystem and other services within urban areas, including extension of the longevity of roof membranes, increased sound insulation, mitigation of stormwater runoff, improved air quality, reduction of energy consumption and the urban heat island effect, and urban wildlife habitats (Dunnett and Kingsbury 2004; Getter and Rowe 2006; Oberndorfer et al. 2007; Cantor 2008; Dvorack and Volder 2010; Rowe et al. 2012). The aesthetic value of green roofs to the public is well documented (Cantor 2008; Jungels et al. 2013). Similar to green roofs, green walls and other living vegetation substrates provide these values and ecosystem services as well (Chiquet et al. 2012).

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In recent years, biological surveys have been conducted (primarily in Europe) that demonstrate green roofs can provide unique urban habitat for invertebrates (Kadas 2006; MacIvor and Lundholm 2011; Tonietto et al. 2011; Ksiazek et al. 2012), nesting sites for birds (Baumann 2006; Brenneisen 2006; Grant 2006; Fernández-Canero and Gonazlez-Redondo 2010), and refugia for native plants, including rare species and those of conservation concern (Brenneisen 2004; Moyle Studlar and Peck 2009). However, no comprehensive evaluations of wildlife using green roofs have been conducted, especially in North America (Dvorack and Volder 2010; Fernández-Canero and Gonzalez-Redondo 2010). To our knowledge, this study is the first to examine the composition and diversity of avian communities using green roofs throughout the year (i.e., across seasons).

Many airports around the world, including Chicago's O'Hare International Airport, are attempting to operate "greener" and use more environmentally sustainable practices (McAllister 2009; Chicago Department of Aviation 2012). Incorporation of green roofs, photovoltaic installations (Wybo 2013; DeVault et al. 2014), wind energy facilities (Infanger 2010; DeVault et al. 2012), biofuel production (DeVault et al. 2012), waste management systems (Washburn 2012), and other land-use practices are being incorporated into airport planning and operations.

Wildlife–aircraft collisions (i.e., wildlife strikes) cause serious safety hazards to aircraft. Wildlife strikes cost civilian aviation at least $957 million annually in the USA (Dolbeer et al. 2013). Habitat management within and adjacent to airport environments is the most important long-term component of an integrated wildlife damage management approach to reduce the use of airfields by birds that pose hazards to aviation (Washburn et al. 2007; DeVault et al. 2013). Green roofs on or near airports could pose a hazard to safe aircraft operations if these types of urban habitats attract birds hazardous to aviation or result in birds making regular movements across an airfield or through critical airspace. If so, this type of wildlife habitat would not be recommended on or near airports (FAA 2007).

The objectives of our study were to: (1) quantify and compare avian use and bird community diversity of traditional and green roofs and (2) assess the wildlife hazard (severity) of birds using traditional roofs and green roofs on buildings at Chicago's O'Hare International Airport (ORD), one of the largest and busiest airports in the United States.

Methods

Study Areas

We selected three green roofs and two traditional (e.g., aggregate-based) flat, building roofs for study at Chicago's O'Hare International Airport (41°58′N, 87°54′W) located in Chicago, Illinois. The green roofs were studied following their installation on the airport, and the specific traditional roofs were selected because they were similar in size to one of the green roofs. Mean annual precipitation at the study area is 930 mm per year with 54 % falling as rain during April through September (Calsyn 2001). The average seasonal snowfall (total) is 914 mm per year. Average daily temperatures are 22.2 °C during summer and −4.1 °C during winter.

Aircraft Rescue and Fire Fighting Station #3 Green Roof

This green roof, 0.04 ha in size, is located on the Aircraft Rescue and Fire Fighting Station #3 building (ARFF#3). Constructed in 2006, the vegetation on this extensive green roof comprised five stonecrop species (Table 1) established from plant plugs arranged in trays (GreenGrid™ Green Roof System, Weston Solutions, Inc., West Chester, PA). Weeds (and other volunteer vegetation) were removed from all areas of the green roof in August 2007. We established a permanent bird survey point that allowed for a complete view of the green roof.

Aircraft Rescue and Fire Fighting Station #1 Traditional Roof and South Airfield Lighting Control Vault Green Roof

We established a pair of study roofs of similar size, one traditional (e.g., aggregate-based) roof and one green roof, located within 500 m of each other. The traditional roof was located on Aircraft Rescue and Fire Fighting Building #1 (ARFF#1), has no vegetation and is 0.15 ha in size. The South Airfield Lighting Control Vault (SALCV) green roof is 0.14 ha in size and was constructed in 2008. This extensive green roof comprised eight species of stonecrop (a total of 13 cultivars; Table 1) established by planting individual plants with 23-cm spacing. Maintenance to remove weeds was conducted during the first year. We established a permanent bird survey point on both the ARFF#1 traditional roof and the SALCV green roof that provided a complete unobstructed view.

Airline Cargo Building Traditional Roof and FedEx Cargo Main Sort Building Green Roof

We established a second pair of study roofs of similar size, one traditional and one green roof, located within 400 m of each other. The traditional (e.g., flat, aggregate-based) roof on an airline cargo building (CARGO) has no vegetation and is 1.22 ha in size. The FedEx Cargo Main Sort Building (FEDEX) green roof is 1.62 ha in size and was constructed in spring 2010. This extensive green roof comprised 10 stonecrop species (Table 1) established in

Table 1 Composition of plant communities established within green roofs on the Airport Rescue Fire Fighting Station #3 Building, the South Airfield Lighting Control Vault Building, and the FedEx Cargo Main Sort Building at Chicago's O'Hare International Airport, Chicago, IL, USA

Building	Scientific name	Common name
Airport Rescue Fire Fighting Station #3	*Sedum album*	White stonecrop
	Phedimus hybridum 'Immergunchen'	Immergunchen stonecrop
	Sedum rupestre	Jenny's stonecrop
	Sedum sexangulare	Tasteless stonecrop
	Phedimus spurius 'Fuldaglut'	Fuldaglut stonecrop
South Airfield Lighting Control Vault	*Sedum acre* 'Aureum'	Goldmoss stonecrop
	Hylotelephium cauticola	Bertram Anderson sedum
	Phedimus kamtschaticum 'Weihensterphaner gold'	Weihensterphaner gold stonecrop
	Sedum rupestre 'Angelina'	Angelina stonecrop
	Sedum rupestre 'Blue spruce'	Blue spruce stonecrop
	Sedum sexangulare	Tasteless stonecrop
	Phedimus spurius 'Bronze carpet'	Bronze carpet stonecrop
	Phedimus spurius 'Dragon's blood'	Dragon's blood stonecrop
	Phedimus spurius 'John Creech'	John Creech stonecrop
	Phedimus spurius 'Tricolor'	Tricolor stonecrop
	Phedimus spurius 'Voodoo'	Voodoo stonecrop
	Sedum stefco	
	Phedimus hyridum 'Rosy Glow'	Rosy glow stonecrop
FedEx Cargo Main Sort	*Sedum acre* 'Aureum'	Goldmoss stonecrop
	Sedum album	White stonecrop
	Phedimus aizoon	Orpin aizoon
	Phedimus hybridum 'Czar's gold'	Czar's gold stonecrop
	Sedum oreganum	Oregon stonecrop
	Sedum pulchellum	Widow's cross
	Sedum rupestre	Jenny's stonecrop
	Sedum sexangulare	Tasteless stonecrop
	Phedimus spurius 'Dragon's blood'	Dragon's blood stonecrop
	Sedum stenopetalum	Wormleaf stonecrop

vegetative mats (Xero Flor XF301™, Xero Flor America, LLC, Durham, NC). Maintenance to remove weeds was conducted during the first year following establishment. On these larger roofs, we established three permanent survey points that allowed for a complete view of approximately one-third (each) of the CARGO traditional roof or the FEDEX green roof.

Avian Surveys

We conducted four 3-min avian point-count surveys each month (averaging one survey per week) at random start times (e.g., two during sunrise to noon, two during noon to sunset) at each of the traditional and green roof survey points (Bibby et al. 2000). We identified all birds observed to the lowest possible taxonomic level and recorded the number and activity of all birds in or flying over the survey area (i.e., on or just above the traditional or green roof). We are highly confident that we were able to detect all of the birds present on the roofs during surveys due to the short vegetation height or lack of vegetation (Buckland et al. 2001). Although birds that only used the observational space as a movement corridor were recorded, we did not use these data in our analyses (Buckland et al. 2001).

We conducted a 55 3-min bird surveys on the ARFF#3 green roof during January 2007–March 2008. During November 2008–November 2009, 50 bird surveys were conducted on the ARFF#1 traditional roof and 50 bird surveys on the SALCV green roof. We conducted 47 bird surveys (across three replicated plots) on the CARGO traditional roof and 47 bird surveys (across three replicated plots) on the FEDEX green roof during September 2010–August 2011.

Wildlife Hazard (Severity)

Using the avian point-count data from ORD (i.e., pooled bird observations from each individual roof) for all birds, we assigned each species to one of six hazard (severity) levels (i.e., 'very low,' 'low,' 'moderate,' 'high,' 'very high,' 'extremely high') as defined by Dolbeer and Wright (2009).

Data Analyses

Using pertinent avian literature (e.g., Cabe 1993; Jackson and Jackson 2000; Otis et al. 2008) as a guide, we defined three biological periods: (1) breeding = April, May, June, and July; (2) migration = March, August, September, and October; and (3) wintering = November, December, January, and February. We assessed bird use of each roof type by comparing avian point-count surveys of all and each bird species among these three biological periods.

We compared bird use of the ARFF#3 green roof by bird species across biological periods using one way analysis of variance (ANOVA) and Fisher's protected Least Squared Difference (LSD) tests for means comparisons (Zar 1996). Bird use of the ARRF#1 traditional roof and the SALCV green roof were compared by bird species and among biological periods using two-way ANOVA and Fisher's protected LSD tests (Zar 1996). We compared bird use of the CARGO traditional roof and the FEDEX green roof by bird species and among biological periods by treating the 'replicate' plots on each roof as a random variable within an ANOVA and used Fisher's protected LSD tests for means comparisons (Zar 1996). Differences were considered significant at $P \leq 0.05$, and all analyses were conducted using SAS statistical software version 9.1 (SAS Institute, Cary, NC).

We determined the species richness, Shannon diversity index, and Simpson dominance index (Magurran 2004) for the bird communities recorded using each traditional and green roof. The Shannon diversity index emphasizes the richness component of diversity and is more sensitive to the presence of species, whereas the Simpson dominance index emphasizes the evenness component of diversity and is more responsive to the most abundant species present (Magurran 2004; Tuomisto 2012). Lastly, we compared the proportion of total birds within the hazard (severity) levels using traditional and green roofs using comparison of proportion tests (Zar 1996).

Results

A total of 188 individual birds representing 11 species were observed using a traditional flat or green roof during this research at ORD. Killdeer (*Charadrius vociferus*), European Starling (*Sturnus vulgaris*), and Mourning Dove (*Zenaida macroura*) were the most abundant species during the studies, accounting for 59.6, 24.5, and 8.5 % of the total bird observations, respectively.

ARFF#3 Green Roof

Bird use of the ARFF#3 green roof varied among biological periods for all species combined ($F_{2, 54} = 15.96$, $P < 0.0001$), Killdeer ($F_{2, 54} = 11.72$, $P < 0.0001$), and Mourning Dove ($F_{2, 54} = 3.82$, $P = 0.03$). Bird use was highest during the breeding season and lowest during the wintering period (Fig. 1). Killdeer were the most frequently observed bird during surveys of the ARFF#3 green roof (Table 3). Species richness, Shannon diversity index, and Simpson dominance index were 6, 0.953, and 0.554, respectively, for avian communities observed using the ARFF#3 green roof (Table 4).

SALCV Green Roof and ARFF#1 Traditional Roof

We found a significant interaction between roof type and biological period ($F_{2, 99} = 9.85$, $P = 0.006$) for Killdeer. Killdeer abundance was highest on the SALCV green roof during the breeding season, whereas this species was absent from this green roof during the wintering period and was never observed on the ARFF#1 traditional roof (Figs. 1, 2). The mean numbers of European Starling, Mourning Dove, American Kestrel (*Falco sparverius*), Barn Swallow (*Hirundo rustica*), Red-tailed Hawk (*Buteo jamaicensis*), Field Sparrow (*Spizella pusilla*), and all species combined were similar (all $P > 0.11$) between the two roofs (Table 2) and did not differ among biological periods (all $P > 0.20$; Figs. 1, 2). Mourning Doves were present in 10 % of the surveys of the traditional roof (ARFF#1), whereas Killdeer were found in almost one-third of the green roof surveys (Table 3). Although species richness and the Simpson dominance index for the ARFF#1 traditional roof were lower than that of the SALCV green roof, the Shannon diversity index was similar between these roof types (Table 4).

FEDEX Green Roof and CARGO Traditional Roof

We found significant interactions between roof type and biological period for all species combined ($F_{2, 281} = 9.99$, $P < 0.0001$) and for Killdeer ($F_{2, 281} = 8.85$, $P = 0.0002$). Species-specific variation occurred in bird use between the CARGO traditional roof and the FEDEX green roof. Killdeer used the green roof exclusively and most use occurred primarily during the breeding season, whereas there were no differences (all $P > 0.25$) in use of the two roofs (Table 2) or among biological periods (all $P > 0.23$) by other species (e.g., European Starling, Mourning Dove; Figs. 1, 2). European Starlings were found in <2 % of the

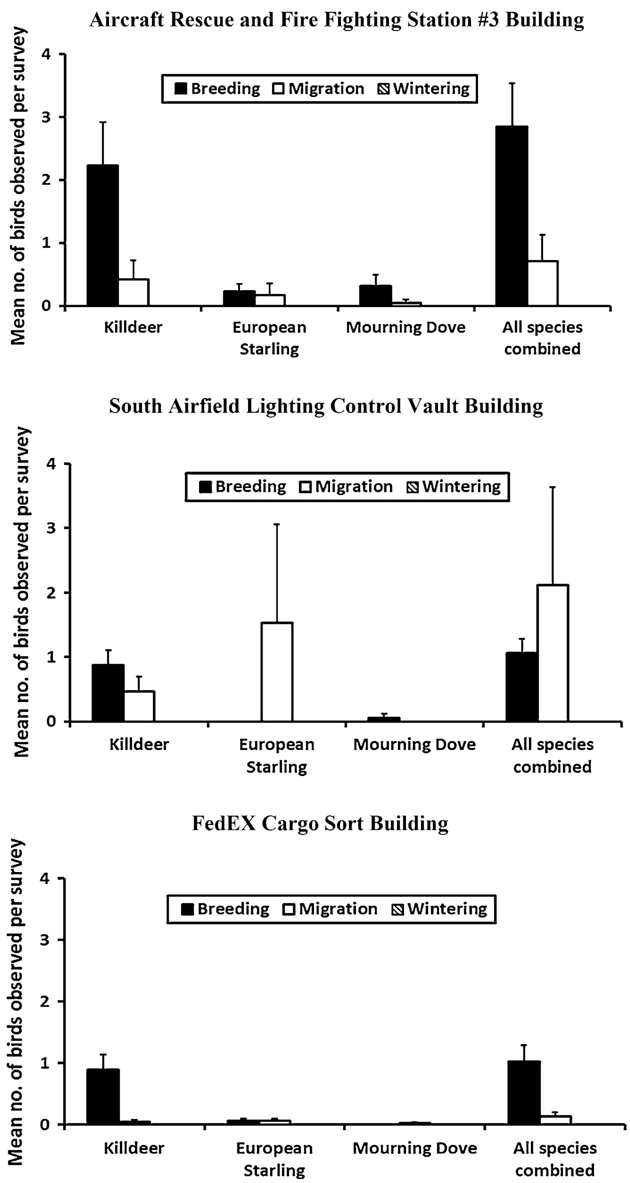

Fig. 1 Mean (±SE) number of birds observed during 3-min avian point-count surveys conducted on three green roofs [Aircraft Rescue and Fire Fighting Station #3 Building (ARFF#3), the South Airfield Lighting Control Vault Building (SALCV), and the FedEx Cargo Main Sort Building (FEDEX)] during three biological periods at Chicago's O'Hare International Airport, Chicago, IL, USA, Jan 2007–Aug 2011

surveys of the CARGO traditional roof, whereas Killdeer were found in approximately 9 % the FEDEX green roof surveys (Table 3). Although species richness and the Shannon diversity index for the CARGO traditional roof were lower than that of the FEDEX green roof, the Simpson dominance index was similar between these roof types (Table 4). Overall, the largest-sized roofs (CARGO and FEDEX) had lower Shannon and Simpson indices compared to the other three (smaller) roofs (Table 4).

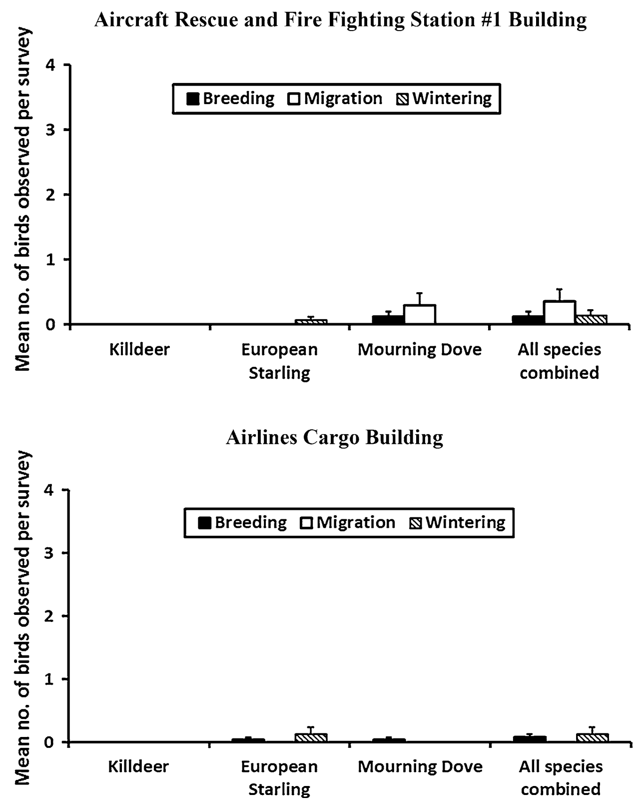

Fig. 2 Mean (±SE) number of birds observed during 3-min avian point-count surveys conducted on two traditional roofs [(Aircraft Rescue and Fire Fighting Station #1 Building (ARFF#1) and an airline cargo building (CARGO)] during three biological periods at Chicago's O'Hare International Airport, Chicago, IL, USA, Nov 2008–Aug 2011

Strike Hazard Severity

Overall, the distribution of birds within hazard levels (as defined in Dolbeer and Wright 2009) varied between the two roof types (Fig. 3). Birds in the 'low' and 'very low' hazard levels (combined) accounted for 5.6 % of birds using the traditional roofs and 72.4 % of the birds using green roofs ($z = -5.69$, $P < 0.001$). The proportion of 'moderate' hazard-level birds using traditional roofs (88.8 %) was over three times higher ($z = -5.23$, $P < 0.001$) than for green roofs (27.6 %).

Discussion

We documented a variety of bird species using the traditional- and green-roof habitats during this study. All of the bird species we found using rooftop habitats are common, especially in urban areas (DeGraaf et al. 1991; Melles 2005; Washburn 2012). We did not find any rare or threatened/endangered species using the rooftop habitats; however, Brenneisen (2006) documented use of green

Table 2 Mean (±SE) number of birds observed during 3-min avian point-count surveys conducted on two traditional roofs [(Aircraft Rescue and Fire Fighting Station #1 Building (ARFF#1) and an airline cargo building (CARGO)] and three green roofs [Aircraft Rescue and Fire Fighting Station #3 Building (ARFF#3), the South Airfield Lighting Control Vault Building (SALCV), and the FedEx Cargo Main Sort Building (FEDEX)] at Chicago's O'Hare International Airport, Chicago, IL, USA, Jan 2007–Aug 2011

Species	Hazard (severity) Classification[a]	Mean no. of birds per 3-min point count (±SE)				
		Traditional roof		Green roof		
		ARFF#1	CARGO[b]	ARFF#3	SALCV	FEDEX[b]
Killdeer *Charadrius vociferus*	Low	–[b]	–	0.71 ± 0.22	0.46 ± 0.12	0.35 ± 0.10
European starling *Sturnus vulgaris*	Moderate	0.02 ± 0.02	0.04 ± 0.03	0.13 ± 0.06	0.52 ± 0.52	0.04 ± 0.02
Mourning dove *Zenaida macroura*	Moderate	0.14 ± 0.07	0.02 ± 0.02	0.09 ± 0.05	0.02 ± 0.02	0.01 ± 0.01
Barn swallow *Hirundo rustica*	Very low	–	–	–	0.02 ± 0.02	0.02 ± 0.02
American kestrel *Falco sparverius*	Very low	0.02 ± 0.02	–	0.02 ± 0.02	0.04 ± 0.04	–
Red-tailed hawk *Buteo jamaicensis*	High	0.02 ± 0.02	–	–	–	–
Cliff swallow *Petrochelidon pyrrhonota*	Very low	–	–	–	–	0.001 ± 0.001
Common grackle *Quiscalus quiscalus*	Moderate	–	–	0.02 ± 0.02	–	–
House sparrow *Passer domesticus*	Low	–	–	–	–	0.001 ± 0.001
Field sparrow *Spizella pusilla*	Very low	–	–	–	0.02 ± 0.02	–
Unknown songbird	Very low	–	–	0.02 ± 0.02	–	–
All species combined		0.20 ± 0.08	0.06 ± 0.03	0.98 ± 0.25	1.08 ± 0.52	0.44 ± 0.11
No. of surveys		50	141	55	50	141

[a] Hazard (severity) classification according to Dolbeer and Wright (2009)

[b] These roofs were divided into three replicate sections and each section was surveyed during each visit

[c] No birds were observed

roofs in the United Kingdom for nesting by an endangered songbird, the Black Redstart (*Phoenicurus ochruros*). The geographic location of an individual green roof would have strong influence on the specific composition of the avian community using that rooftop habitat. This is an important factor to be considered when assessing the overall ecological value of a green roof.

The amount of bird use of traditional and green roofs varied considerably among seasons during this study. Bird use of rooftop habitats was primarily during the summer (i.e., breeding season), whereas there was no bird use of green rooftops during the winter months. This trend was evident for all birds (and species). Many species (e.g., Killdeer) that used the rooftop habitats during summer migrate to more southern areas and thus were not present on the airport during winter. The green-roof vegetation likely provided no thermal cover or viable food sources for resident birds during the winter months.

The diversity of avian communities using traditional and green roofs in this study was relatively low compared to natural and anthropogenic grassland habitats found on airports (e.g., Washburn and Begier 2011; Schmidt et al. 2013). This finding is likely due to the short height and low botanical diversity of stonecrop-based vegetation (essentially a monoculture) on the green roofs in this study. Stonecrop-dominated habitats do not mimic grassland communities in regard to vegetation structure. In addition, some bird species will not nest on or use elevated habitats provided by rooftops. Green-roof habitats comprising taller and more diverse plant communities (e.g., native warm-season grasses, woody plants) might result in use by a more diverse avian community. Although this study is an

Table 3 Frequency of occurrence (%) of birds observed during 3-min avian point-count surveys conducted on two traditional roofs [(Aircraft Rescue and Fire Fighting Station #1 Building (ARFF#1) and an airline cargo building (CARGO)] and three green roofs [Aircraft Rescue and Fire Fighting Station #3 Building (ARFF#3), the South Airfield Lighting Control Vault Building (SALCV), and the FedEx Cargo Main Sort Building (FEDEX)] at Chicago's O'Hare International Airport, Chicago, IL, USA, Jan 2007–Aug 2011

Species	Frequency of occurrence (%)				
	Traditional roof		Green roof		
	ARFF#1	CARGO[a]	ARFF#3	SALCV	FEDEX[a]
Killdeer *Charadrius vociferous*	–[b]	–	21.8 %	28.0 %	8.5 %
European starling *Sturnus vulgaris*	2.0 %	1.4 %	9.1 %	2.0 %	2.8 %
Mourning dove *Zenaida macroura*	10.0 %	0.7 %	7.3 %	2.0 %	0.7 %
Barn swallow *Hirundo rustica*	–	0.7 %	–	2.0 %	1.4 %
American kestrel *Falco sparverius*	2.0 %	–	1.8 %	2.0 %	–
Red-tailed hawk *Buteo jamaicensis*	2.0 %	–	–	–	–
Cliff swallow *Petrochelidon pyrrhonota*	–	–	–	–	0.7 %
Common grackle *Quiscalus quiscalus*	–	–	1.8 %	–	–
House sparrow *Passer domesticus*	–	–	–	–	0.7 %
Field sparrow *Spizella pusilla*	–	–	–	2.0 %	–
Unknown songbird	–	–	1.8 %	–	–
All species combined	16.0 %	2.1 %	30.9 %	38.0 %	12.1 %
No. of surveys	50	141	55	50	141

[a] These roofs were divided into three replicate sections and each section was surveyed during each visit

[b] No birds were observed

Table 4 Species richness, Shannon diversity index, and Simpson dominance index for bird communities observed during 3-min avian point-count surveys conducted on two traditional gravel roofs [(Aircraft Rescue and Fire Fighting Station #1 Building (ARFF#1) and an airline cargo building (CARGO)] and three green roofs [Aircraft Rescue and Fire Fighting Station #3 Building (ARFF#3), the South Airfield Lighting Control Vault Building (SALCV), and the FedEx Cargo Main Sort Building (FEDEX)] at Chicago's O'Hare International Airport, Chicago, IL, USA, Jan 2007–Aug 2011

	Species richness	Shannon index	Simpson index
Traditional roofs			
ARRF#1	4	0.940	0.480
CARGO	3	0.562	0.375
Green roofs			
ARFF#3	4	0.953	0.554
SALCV	6	0.976	0.563
FEDEX	6	0.772	0.347

important first step, more research is needed to better understand the ecological value of green roofs for birds during the breeding, migration, and wintering periods (Oberndorfer et al. 2007).

Killdeer was the most commonly observed species using green-roof habitats. Further, this was the only species documented to nest on traditional or green roofs during our study. During the breeding season, Killdeer typically use

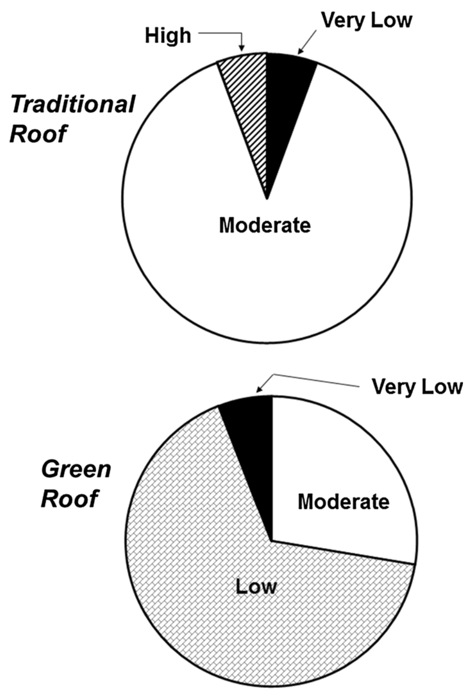

Fig. 3 Distribution of birds categorized by species into six strike hazard categories (as defined by Dolbeer and Wright 2009) and observed using traditional and green roofs at Chicago's O'Hare International Airport, Chicago, IL, USA, Jan 2007–Aug 2011

open, sparsely vegetated areas as habitats (e.g., sandbars, heavily grazed pastures, gravel parking lots, gravel rooftops) and select nest sites that are slightly elevated, often in graveled road shoulders and in parking lots (Jackson and Jackson 2000). Stonecrop-based green roofs apparently provide nesting areas and foraging habitats with appropriate structural characteristics (i.e., short vegetation). Although green-roof habitats appear to meet the life-history needs of Killdeer (as indicated by their presence and nesting attempts on green roofs in this study), it is possible that such habitats could represent a population sink for this species. Future research specifically examining the reproductive success and juvenile survival of Killdeer (and other birds) nesting on green roofs is clearly needed.

Roof top nesting is a common occurrence with *Larid* gulls, such as Herring Gulls (*Larus argentatus*) and Ring-billed Gulls (*Larus delawarensis*; Belant 1997; Belant et al. 1998). The Jardine Water Purification Plant is located on the shoreline of Lake Michigan, adjacent to Navy Pier in downtown Chicago. Although not formally part of this study, we believe it is important to note that during 2011 we documented a large Ring-billed Gull nesting colony (over 1700 nests) on the stonecrop-based green roof portion of this facility (0.74 ha in size). There are several large gull nesting colonies (primarily ring-billed gulls) with the immediate area (Beckerman et al. 2010). This provides an important example that the installation of green roofs has the potential to attract birds that present a 'moderate' to 'high' hazard to aviation safety. We acknowledge that integrated wildlife damage management activities (e.g., use of pyrotechnics, relocation of problematic birds) to reduce the frequency and severity of wildlife–aircraft collisions at ORD occurring during our study. However, we do not believe these management actions had a large influence on our study, as the activities did not involve the rooftop habitats directly and the fact that any influences (e.g., harassment of bird near runways) would have impacted both the traditional and green roofs equally.

Overall, only a small proportion of species that are considered to be of a 'moderate' to 'high' hazard (severity) level (based on the classification of Dolbeer and Wright 2009) used green roofs. Although some species from these categories were observed using both roof types (e.g., mourning doves), most of the species (e.g., killdeer, sparrows) observed using the green roofs during this study pose a 'low' or 'very low' hazard to aviation safety due to their body size or behavioral patterns (Dolbeer and Wright 2009; DeVault et al. 2011). Consequently, we found little evidence to suggest that the presence of stonecrop-based green roofs within an airport environment increases the risk of wildlife strikes.

Site-specific monitoring efforts should be conducted when green roofs are present on or near airfields to ensure these areas do not increase the risk of bird strikes. Regardless, our findings suggest that stonecrop-based green roofs might be considered as viable for use on airports, thereby potentially providing habitat for birds that present minimal hazards to safe aircraft operations.

Conclusions

Green roofs represent a new urban habitat that might be used by a variety of species. A few studies have been conducted that document the presence of invertebrates and birds found on green roofs (Baumann 2006; Brenneisen 2006; Kadas 2006; MacIvor and Lundholm 2011). Although such work is an important first step, ecological studies of green roofs must go beyond taxonomic surveys conducted in a single season or biological period. Long-term studies are needed that examine the ecological processes involved and how these relate to this new frontier of urban landscapes. We believe this study provides an early step in that direction.

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Compliance with Ethical Standards

Conflict of Interest The authors declare they have no conflict of interest.

Ethical Approval All applicable international, national, and/or institutional guidelines for the care and use of animals were followed. All procedures performed in this study involving animals were in accordance with the ethical standards of the National Wildlife Research Center of the U.S. Department of Agriculture, Animal Plant Health Inspection Service, Wildlife Services.

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