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BIRD DENSITY AND MORTALITY AT WINDOWS

STEPHEN B. HAGER,[1,7] HEIDI TRUDELL,[2,4] KELLY J. MCKAY,[3]
STEPHANIE M. CRANDALL,[1,5] AND LANCE MAYER[1,6]

ABSTRACT.—Little is known about impacts to birds from collisions with windows at commercial buildings. We monitored bird mortality from striking windows at five commercial buildings on two college campuses in northwestern and southwestern Illinois. Bird mortality at Augustana College (northwestern), which was evaluated from 2002 to 2006, totaled 215 individuals in 48 species for an average rate of 55 birds/building/year. We calculated a mortality rate of 24 birds/building/year for 2004–2005 from 142 individuals within 37 species at Principia College (southwestern). Mortality of North American migrant (NAM) and neotropical migrant (NTM) birds was higher during migration than during summer or winter. We tested the hypothesis at Augustana that density of birds at a given location will be positively correlated with numbers of birds that die due to strikes with windows. Bird density only partially explained strikes with windows since mortality was also a function of landscaped habitat that attracted birds. Annual bird mortality at commercial buildings may be about five times higher than previous estimates. These buildings may place bird populations at high risk of strikes at windows.
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Annual bird mortality from collisions with windows in North America could be as high as 1 billion (Klem 1990). Windows may be the most significant cause of mortality second only to habitat loss (Klem 2006). In an evolutionary sense, both the fit and unfit are at risk wherever birds exist in close proximity to windows (Klem 1990).

Experiments and systematic monitoring, mainly at residential structures (e.g., houses), suggest that mortality to birds from collisions with windows is highest in winter (Klem et al. 2004, Klem 2006) or migration and winter (Klem 1989), and disproportionately affects species that frequent bird feeders (Dunn 1993, Klem et al. 2004). It is thought that landscaping features in the vicinity of houses, which maintain bird feeders, provide habitat (shelter and fruiting trees and shrubs) for birds and, thus, increase their vulnerability to window collisions (Klem 1989). It is also known that mortality at skyscrapers in large cities, such as Toronto, Chicago, and New York is significant, but little has been published about the details of negative impacts. Internet reporting by monitoring programs has identified thousands of birds that die annually during spring and fall migration periods; the species most vulnerable are neotropical and North American migrants, and species of conservation concern (New York City Audubon Society 2004, Hunsinger 2005, Fatal Light Awareness Program 2006).

Less attention has been given to studying the impacts to birds at commercial buildings, which may be broadly defined as buildings (~600 m^2) used in service, office, education, and healthcare (Swenson 1997). Recent developments related to commercial building construction may be placing birds at a higher risk of collisions with windows than current estimates of annual bird mortality. We estimated that 5.58 million commercial buildings were in the United States in 2006 which is up 1.63 million since 1986 (Klem 1990, Environmental Protection Agency 2004).

Blem and Willis (1998) suggested that in the last 10–20 years, commercial building construction had increased in suburban areas and these buildings are surrounded by landscaping features that provide food and shelter for birds. We found support for this contention by examining city ordinances which mandate establishment of landscaping around commercial buildings (City of Rock Island, Illinois 2004; City of Wheaton, Illinois 2007). Furthermore, the American So-

[1] Department of Biology, Augustana College, Rock Island, IL 61201, USA.
[2] Principia College, Elsah, IL 62028, USA.
[3] BioEco Research and Monitoring Center, Hampton, IL 61256, USA.
[4] 2218 South 23rd Street, Abilene, TX 79605, USA.
[5] University of Illinois Extension, Rock Island County, 4550 Kennedy Drive, Suite 3, East Moline, IL 61244, USA.
[6] 1006 Oakcrest Street, Apartment 102, Iowa City, IA 52246, USA.
[7] Corresponding author;
e-mail: stevehager@augustana.edu

ciety of Landscape Architects expected that in 2007 the demand would be higher than ever for environmentally-friendly landscaping, which includes adding native plants and water resources in close proximity to commercial buildings (Owens 2006).

One published study detailing the systematic monitoring in suburban Virginia of bird mortality at commercial buildings found: (1) bird mortality was about three times higher than the estimated 1–10 dead birds/building/year, (2) North American and neotropical migrants died at higher proportions compared to permanent residents, and (3) mortality was highest during spring and fall migration and lowest in winter and summer (O'Connell 2001). Similar results were reported by Blem and Willis (1998), whose data came partly from office buildings in Virginia, and by Johnson and Hudson (1976) in an analysis of bird impacts related to a glassed-in walkway connecting two commercial buildings in Washington State.

It is critical that details of mortality due to collisions with windows at commercial buildings be identified given that relatively little is known about the interactions between birds and commercial buildings, and that more of these buildings are being constructed in areas that contain ''bird-friendly'' habitat. Moreover, little is known about the intrinsic factors affecting whether or not birds fly into windows aside from the contention that birds do not perceive clear and tinted glass as barriers (Klem 1989, Klem et al. 2004). Extrinsic factors thought to affect collision frequency include behavior, window characteristics, and the environment (season, time of day, and weather) (Klem 1989, Klem et al. 2004). In addition, Klem (1989, 2006) hypothesized the best predictor of collision rate at any one site is the density of birds in the vicinity of glass. This hypothesis—hereafter referred to as the bird density hypothesis—was generally supported for bird mortality observed at a house in southern Illinois (Klem 1989) and by Dunn (1993), who analyzed data from Project Feeder Watch (Cornell Laboratory of Ornithology 2006) for the winter months at houses where participants provided estimates of bird abundance only for species observed at feeders.

We present the results of two studies. In Study 1 we systematically monitored avian mortality from strikes at windows at five commercial buildings in northwestern and southwestern Illinois: Augustana College, Rock Island, and Principia College, Elsah, respectively. Our objectives were to: (1) document the abundance and richness of birds killed by buildings, and (2) assess the relationship between season and migratory class of birds killed by windows, and between window area and mortality within sections of a building and among buildings. We tested the bird density hypothesis in Study 2 for a commercial building at Augustana College in spring (Apr–May 2006) and winter (Dec 2006–Jan 2007). Our objective for this study was to evaluate the relationship between estimates of bird density using point counts and birds killed by strikes with windows.

METHODS

Study 1.—We monitored bird mortalities at two geographic locations in Illinois: Augustana College in Rock Island and Principia College in Elsah. Monitoring at Augustana College was conducted at the Science Building (90° 33′ W, 41° 30′ N) from November 2002 to November 2006 (Fig. 1). The college is within the Dissected Hill Plains Physiographic Area (Ruth 2006) and at the edge of a terrace overlooking the Mississippi River (National Cooperative Soil Survey 1998). The slopes of the bluffs are composed of upland hardwood forest, whereas the flat areas are landscaped with a variety of deciduous and evergreen shrubs and trees. The Science Building is at the western edge of campus. The western and southern edges of the building are in close proximity to wooded terrace slopes, while the northern edge faces a parking lot and paved roadway. The eastern side faces the ''quad'', which is a mosaic of landscaped grasses and woody vegetation including ginkgo (*Ginkgo biloba*), sycamore (*Platanus* spp.), oaks (*Quercus* spp.), maples (*Acer* spp.), and crab apple (*Malus* spp.).

The Science Building is 74 m long, 25 m wide, and four stories in height. The main entry ways (2 along the eastern edge and 1 at the western edge), and the walls in which the entry ways are found, are almost completely glass. Much of the remainder of the eastern and western walls is composed of glass. We identified sections of the building that corre-

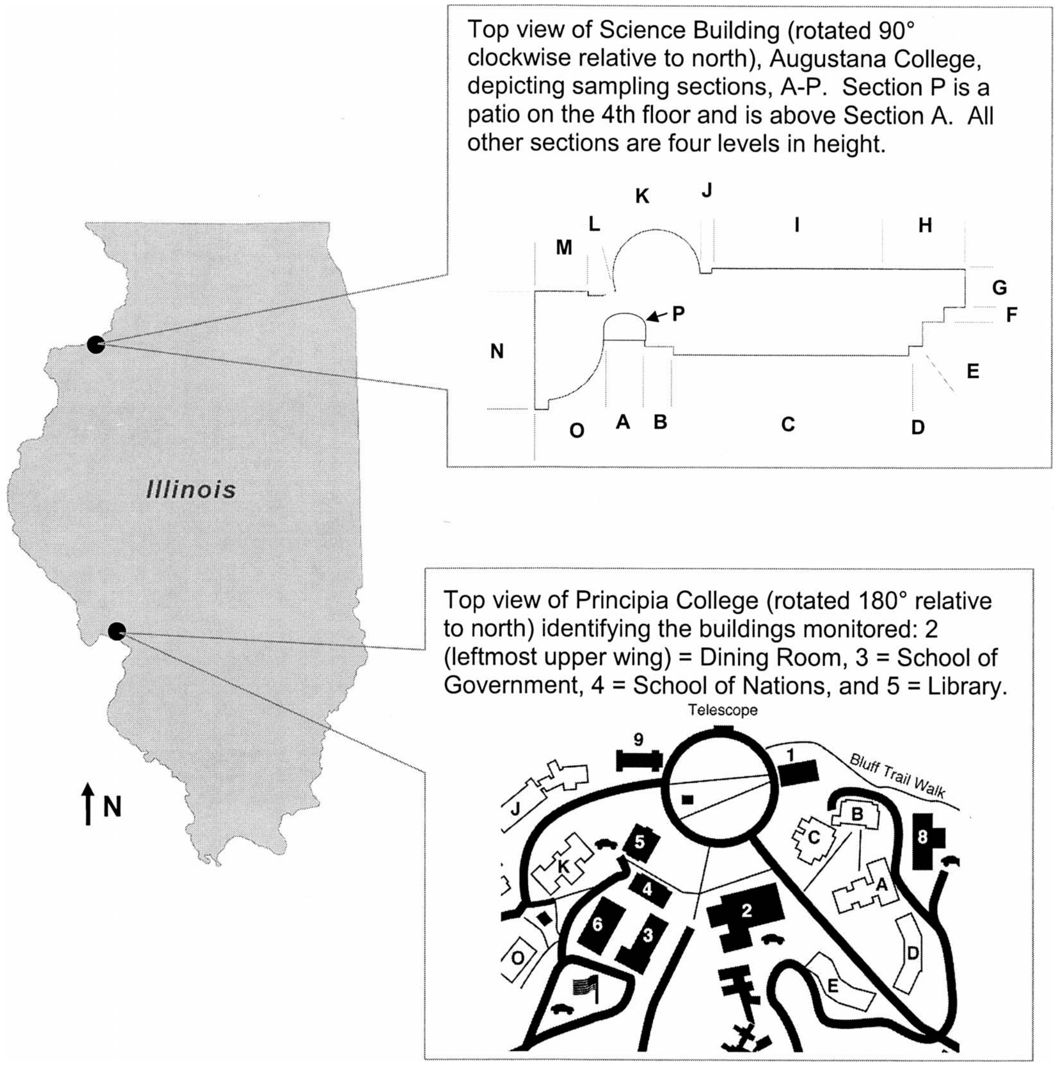

FIG. 1. Locations and building characteristics for studies at Augustana and Principia colleges, Illinois.

sponded to variation in wall characteristics and window size and shape. Each section was given a unique label ranging from ''A'' through ''P'' (Fig. 1) and we calculated window area. Little vegetation occurs at the immediate edge of the building and this made visual surveys for dead birds relatively unobstructed. Some ivy ground cover (*Hedera* spp.) occurs at the northeast corner of the building, but the remainder is either paved walkway or decorative stone ground cover.

We monitored avian mortality by completing about two surveys/week around the building. We focused on a 2-m wide transect surrounding the entire building that extended from the building's edge. An analysis of survey effort suggested that two surveys/week, rather than daily surveys, were sufficient to accurately estimate mortality rate. Bodies reported to us by others that were within 2 m of the building were also included in the data set. We assumed that all dead birds adjacent to the building resulted from window collisions.

We salvaged all bodies (including incidental findings exclusive of surveys), identified them to species whenever possible, and placed them in the Vertebrate Museum of Augustana College. Common and scientific names followed the American Ornithologists' Union (1998). We also recorded the date and section of the building at which each body was found. Scavengers, grounds workers, custodians, and students may have impacted detection probability. However, we believe that any effect was minimal since many of the faculty, staff, and students at the Science Building were informed of this project and reported bird bodies to us. Moreover, scavengers may have had little impact since some of the bodies found were fairly well decomposed (estimated to be 2–3 days old) and recent work found only 13% of experimental baits were taken or moved slightly from their location by scavengers (Klem et al. 2004).

We tested for differences in average weekly mortality by bird season using Kruskal-Wallis tests. Seasons were defined according to the seasonal movements of passerine birds in the region of northwest and southwest Illinois: (1) North American Migrant (NAM): Fall Migration = 2nd half of September–November, Winter = December–February, Spring Migration = March–1st half of May, Summer Breeding = 2nd half of May–1st half of September; (2) neotropical migrant (NTM): Fall Migration = 2nd half of August–1st half of October, Winter = 2nd half of October–March, Spring Migration = April–May, Summer Breeding = June–1st half of August; and (3) permanent resident (PER): Non-Breeding Season = October–April, Breeding Season = May–September. Differentiating each migratory class in this manner allowed us to more precisely assess the timing of mortality relative to seasonal movements of individuals. We used the log likelihood ratio and examined whether the proportion of birds separated by migratory class was different relative to known proportions (total species = 99; NAM = 45.5%; NTM = 36.4%; PER = 18.1%; S. B. Hager, unpubl. data) at the campus. We conducted simple linear regression to assess the relationship between window area (i.e., building section) and mortality. Normality was examined using the Shapiro Wilk Test (Zar 1984) and all statistical tests were completed using JMP 6 (SAS Institute Inc. 2006).

We monitored bird collisions at Principia College at windows at four commercial buildings (90° 21′ W, 38° 56′ N) between January 2004 and November 2005 (Fig. 1); however, in 2004 we could not monitor from 4 June to 4 September and 20 November to 29 December, nor for July 2005. The college is within the Prairie Peninsula Physiographic Area (Ruth 2006) and is on the bluffs of the Mississippi River (National Cooperative Soil Survey 1999). The general character of campus vegetation is similar in landscaping design and plant species to Augustana.

Standardized surveys for mortality were conducted at the Library, School of Nations, School of Government, and Dining Room (Fig. 1). The Library (Lib) is roughly square in shape and three stories in height. Relatively more vegetation surrounded this building than the others, although this did not impact visual surveys. School of Nations (SN) is two stories in height, roughly rectangular, and contains an irregularly shaped main entrance at the northeast edge of the building. This building was the most difficult at which to conduct surveys due to the presence of creeping vegetation (e.g., *Hedera* spp.) that surrounded most windows. This may have prevented us from retrieving all bodies. School of Government (SG), three stories in height, is "L" shaped from top view. The Dining Room (DR), two stories tall, comprises the eastern section of Howard Center and contains only three sides. No measurements were taken for each building. Qualitatively speaking, we ranked the following for relative size of buildings: SG > Lib > SN > DR; and for window area: Lib > SN > SG > DR.

Survey methods and documentation for salvaging bird bodies followed those used for Augustana, except that daily surveys were completed around each building and all bodies were deposited in the Museum of Natural History, University of California, Santa Cruz. Incidental mortality is reported as the number of bodies opportunistically encountered on campus exclusive of Lib, SN, SG, and DR; these are not included in any statistical analysis.

Kruskal/Wallis Ranked Sums test was used to evaluate differences in mortality for migratory class and bird seasons. We used the log likelihood ratio to examine whether the proportion of birds separated by migratory class was different relative to known proportions (total species = 147; NAM = 36.7%; NTM = 49.0%; PER = 14.3%; M. J. Hoff, unpubl. data) at the campus. Differences in mortality by building (i.e., estimated window area) were examined using the log likelihood ratio.

Study 2.—We tested the bird density hypothesis at the Augustana College Science Building during spring migration (Apr–May 2006) and winter (Dec 2006–Jan 2007). We chose spring migration since species detection via singing males, including non-breeding migrants, could be maximized relative to fall, when male singing is rare for most species. A winter analysis was used so that comparisons could be made with spring since other studies speculated that window-caused mortality is low in winter as fewer birds may be present at a site (Johnson and Hudson 1976, Klem 1989, Blem and Willis 1998).

We assessed avian richness and abundance in spring with fixed radius (50 m) point counts, which were 10 min in duration (Bibby et al. 2000). The Science Building is disproportionately long along a north-south axis and we established one point count station each on the west facing (Augie Point #1) and east facing (Augie Point #2) sides of the building. One point count survey was completed on Saturdays of each week between 0700–0800 hrs CDT (surveys on 28 Apr and 5 May were completed on Friday). Data from both point count stations were combined for each survey date. We followed the weather protocol for the North American Breeding Bird Survey (Pardieck 2001). Weekly point count data were compared to the number of dead birds discovered 3 days prior to and 3 days following the point count (surveys completed on a Friday were compared to mortality 2 days prior and 4 days after this day). We assumed for this comparison that (1) migration for a species at a specific location may be several weeks in duration (Devore et al. 2004), and (2) within individuals, average stopover times would be ~1 week in duration given data for White-crowned Sparrow (*Zonotrichia leucophrys*) and Wood Thrush (*Hylocichla mustelina*) (Chilton et al. 1995, Wang and Moore 1997), and recent mathematical models (Schaub et al. 2001, Efford 2005).

We used the same point count survey methodology for winter as in spring to estimate species abundance and richness except that surveys were completed between 0700 and 0800 hrs CST. We believe these methods were appropriate for winter since bird populations are generally stable during this season, as was found for winter home ranges in the Northern Cardinal (*Cardinalis cardinalis*) (Halkin and Linville 1999).

Bird mortality due to collisions with windows reported by others was highest in the spring and fall at commercial buildings (Johnson and Hudson 1976, Blem and Willis 1998, O'Connell 2001). Thus, based on the bird density hypothesis, we predicted the following at the Science Building: (1) in spring, a time of high mortality, bird abundance would be relatively high; (2) in winter, a time of low mortality, bird abundance would be relatively low; and (3) the abundance and richness of species killed at windows will be proportional to the abundance and richness of birds living in the vicinity of the building.

We used simple linear regression to analyze the relationship between the abundance of mortalities and living birds, as well as the richness of mortalities and living birds within season. The Kruskal-Wallis Ranked Sums test was used to evaluate the abundance of mortalities to the abundance of living birds for each species. Differences in abundance and richness of living birds for spring and winter were assessed using ANOVA.

RESULTS

Study 1.—We documented 215 window-killed birds within 48 species at Augustana College (Fig. 2, Appendix 1). Average mortality was 54.8 birds/building/year. Species with ≥10 dead individuals (this level appeared to be a natural break in the data) included White-throated Sparrow (*Zonotrichia albicollis*), Ovenbird (*Seiurus aurocapilla*), American Robin (*Turdus migratorius*), Swainson's Thrush (*Catharus ustulatus*), Dark-eyed Junco (*Junco hyemalis*), Ruby-throated Hummingbird (*Archilochus colubris*), and Northern Cardinal. These represented 44.2% of the total mortality at the Science Building. Nine to 12 new species were added each year after an initial species total of 23 in 2003 (including 8 weeks in 2002).

The mean weekly rate of mortality for each migratory class (Fig. 3) differed among bird-defined seasons (NAM: $H = 35.9$, $P < 0.0001$; NTM: $H = 72.9$, $P < 0.0001$; PER: $H = 6.33$, $P = 0.012$). The proportions of window-killed NAMs (39.9%), NTMs (54.2%)

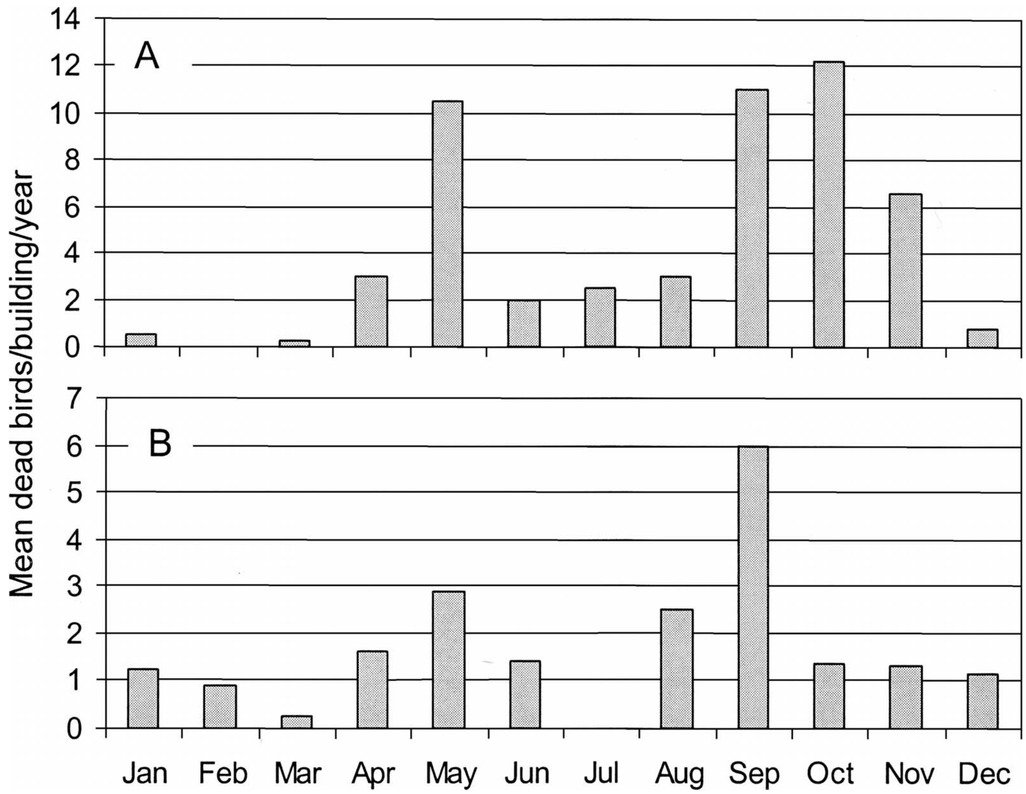

FIG. 2. Detections of dead birds/building/year, (A) 2002–2006 at Augustana College and (B) 2004–2005 at Principia College, Illinois.

and PERs (6.3%) differed from proportions known to occur on campus (G = 9.06, df = 2, P = 0.011). There was a significant positive relationship between window area and mortality for each building section (n = 16, r^2 = 0.54, P = 0.0012).

We documented 142 window-killed individuals of 37 species at Principia College (Fig. 2, Appendix 1). Average mortality was 24.0 birds/building/year. Species killed most often (≥8 individuals; natural break in the data) included Ruby-throated Hummingbird, American Robin, White-throated Sparrow, and Ovenbird. These species represented 56.3% of the total mortality. Twelve new species were found in 2005 relative to those found in 2004. Incidental mortality totaled 58 individuals, which were dominated by the same species recorded during standardized surveys, except for Ovenbirds (Appendix 1).

The mean weekly rate of mortality (Fig. 3) differed among seasons for NTMs (H = 34.3, $P < 0.0001$), but not for NAMs (H = 3.24, P = 0.36) or PERs (H = 0.69, P = 0.41). The proportions of window-killed NAMs (29.7%), NTMs (54.1%), and PERs (16.2%) was not different from proportions known to occur on campus (G = 0.81, df = 2, P = 0.67). Significantly more birds died from collisions with windows at Lib (71.1%) than at SG (11.3%), SN (11.3%), and DR (6.30%) (G = 135.5, df = 3, $P < 0.0001$); this corresponded to qualitative estimates of window area by building. This may also be explained by the finding that all dead Ruby-throated Hummingbirds, which had the highest mortality at Principia, were at Lib; however, significantly more birds died at Lib than at the other buildings (G = 56.1, df = 3, $P < 0.0001$) even if hummingbirds are excluded from the data set.

Study 2.—We documented 55 and 22 live species during spring and winter, respectively (Table 1, Appendix 2). Simple linear regression revealed no relationship between dead

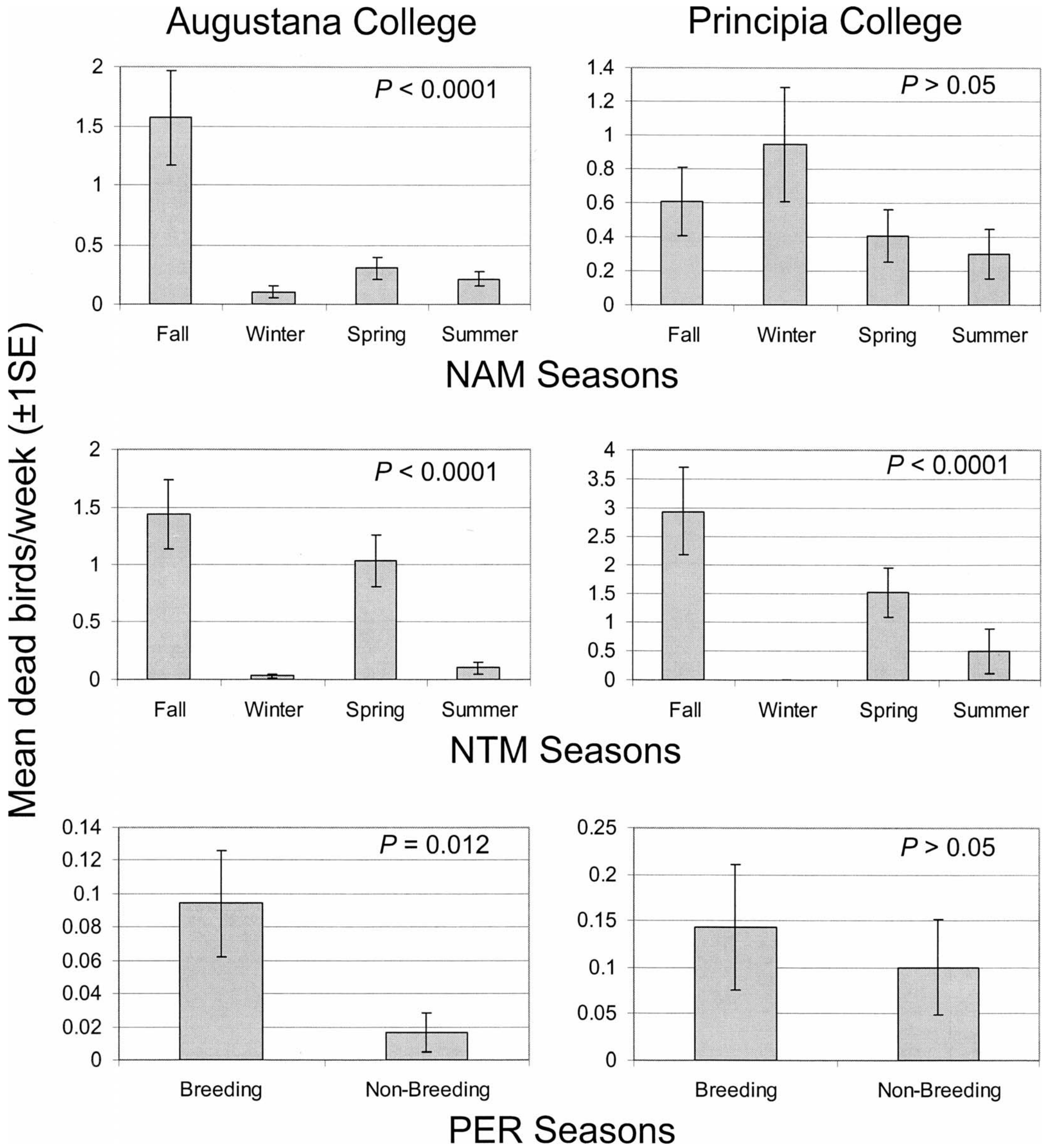

FIG. 3. Detections of dead birds/week for bird-defined seasons separated by campus and migratory class, Augustana and Principia colleges, Illinois.

and living birds for abundance (n = 8, r^2 = 0.014, P = 0.79) and richness (n = 8, r^2 = 0.18, P = 0.29) in spring. We found no relationship in spring between species of living birds observed around the Science Building and those that were killed, all surveys combined (H = 23.1, P = 0.57). In spring, only 8 of 55 (14.5%) species observed during point count surveys were recorded as window-killed. We found no window-killed birds in winter despite relatively abundant species (defined as >5 individuals/survey), such as American Crow (*Corvus brachyrhynchos*), American Robin, European Starling (*Sturnus vulgaris*), Cedar Waxwing (*Bombycilla cedrorum*), Dark-eyed Junco, Northern Cardinal, and House Sparrow (*Passer domesticus*). We found no differences in the abundances of living birds between spring and winter (F = 2.81, P = 0.12); however, richness in living

TABLE 1. Abundance of birds at point counts and birds found dead near windows at Augustana College, Illinois in Study 2.

Season Observation date[a]	# Live birds		# Birds found dead	
	Abundance	Richness	Abundance	Richness
Spring				
8 Apr 2006	113	25	2	1
15 Apr 2006	98	25	0	0
22 Apr 2006	101	20	0	0
28 Apr 2006	107	17	1	1
5 May 2006	70	22	4	3
13 May 2006	76	22	1	1
20 May 2006	127	32	3	3
27 May 2006	85	22	2	2
Mean ± SE	97.1 ± 6.80	23.13 ± 1.56	1.63 ± 0.50	1.38 ± 0.42
Winter				
6 Dec 2006	128	16	0	0
12 Dec 2006	86	14	0	0
20 Dec 2006	87	12	0	0
27 Dec 2006	68	14	0	0
3 Jan 2007	68	16	0	0
10 Jan 2007	71	13	0	0
19 Jan 2007	73	14	0	0
25 Jan 2007	59	10	0	0
Mean ± SE	80.0 ± 7.62	13.6 ± 0.71		

[a] Weekly point count data were compared to bird kills discovered ± 3 days relative to the date on which a point count survey was conducted.

birds differed between these seasons (F = 30.7, $P < 0.0001$). Relatively abundant species observed during point counts in both spring and winter experienced no mortality from window collisions, including American Robin, Northern Cardinal, and House Sparrow. The monitoring data revealed no differences among years for mortality in spring (H = 1.81, P = 0.61) and winter (H = 4.59, P = 0.33). Thus, the mortality we documented in spring 2006 and winter 2006–2007 was not different than the mortality observed for these same seasons in previous years.

DISCUSSION

The results of systematic monitoring of window strikes at commercial buildings in northwestern and southwestern Illinois (Study 1) demonstrate that bird mortality was high. We calculated a mortality rate of almost 55 dead birds/building/year at Augustana (northwestern Illinois); this is about twice as high as Principia in southwestern Illinois (24 birds/building/year) and relative to an office park (29 birds/building/year) in Richmond, Virginia (O'Connell 2001). Bird mortality was highest among sections of the Science Building with the most window area and corresponded to buildings at Principia with the highest estimated window area. Species richness of bird mortality was higher at Augustana (n = 48) than at Principia (n = 37) and in Virginia (n = 40; O'Connell 2001). Differences among sites in numbers and species of birds dying may be a consequence of factors related to behavior, environment, and window area. We found that 9 to 12 new species died each year at both Augustana and Principia. Thus, multi-year studies may observe a larger range of species dying from collisions with windows than monitoring projects of relatively short duration (O'Connell 2001).

Mortality for Study 1 at Augustana and Principia was high for particular species: Ruby-throated Hummingbird, American Robin, White-throated Sparrow, and Ovenbird. Swainson's Thrush, Northern Cardinal, and Dark-eyed Junco also died at high rates at Augustana. Deaths of Ruby-throated Hummingbirds at Principia were more than twice as high as other species; about half of these deaths occurred in September, which includes the peak of fall migration in this region (Robinson et al. 1996). Robinson et al. (1996) identified Ruby-throated Hummingbirds as being possibly vulnerable to window strikes and Graham (1997) suggested that traplining (foraging for nectar over great distances of undefended plants) of hummingbirds may make them vulnerable to collisions. High abundance of this species in southwestern Illinois (K. J. McKay, pers. obs.) coupled with fall flowering honeysuckle (*Lonicera* spp.) on the Principia campus (M. J. Hoff, pers. obs.) may attract high numbers during fall migration. White-throated Sparrows at Augustana were killed more often than other species. Most individuals (72%) died in the fall, a time during which migration for this sparrow is more prolonged than during spring (Borror 1948). We found individuals from September through November, whereas spring mortality was restricted to May.

Our work contributes toward a better understanding of those species commonly killed at windows of different building structures. Regular fatalities at commercial buildings include Ruby-throated Hummingbird, Yellow-bellied Sapsucker (*Sphyrapicus varius*), Brown Creeper (*Certhia americana*), thrushes, waxwings, and wood-warblers (Klem 1989, Blem and Willis 1998, O'Connell 2001), whereas at houses they are grosbeaks, chickadees, and woodpeckers (Klem 1989, Dunn 1993). Some species are common at both structures: kinglets, American Robin, Northern Cardinal, White-throated Sparrow, Dark-eyed Junco, finches, and House Sparrow (Klem 1989, Dunn 1993, Blem and Willis 1998, O'Connell 2001).

To our knowledge, this is the first study to examine mortality of migratory classes against proportions known from a site and across specific bird-defined seasons for each migratory class. These analyses allowed us to more precisely understand bird mortality related to seasons. Generally, migrating species tended to die relatively more during spring and fall migration, although patterns of seasonal mortality were different between campuses. We believe the lack of monitoring surveys conducted in summer and December at Principia resulting in less than a full year of monitoring data, explains part of these differences. In addition, differences may be attributed to variation in the composition of bird populations among seasons at each site.

We tested the bird density hypothesis in Study 2 at the Science Building of Augustana. We predicted the following at this building: (1) in spring, a time of high mortality, bird abundance would be relatively high, (2) in winter, a time of low mortality, bird abundance would be relatively low, and (3) the abundance and richness of species killed at windows will be proportional to the abundance and richness of birds living in the vicinity of the building. Only the first of these predictions was supported by the data. Thus, our work does not support the bird density hypothesis *per se*. Our data suggest that in addition to bird density, window-related factors and bird behavior (Klem 1989) explain the patterns of collisions at windows observed at the Science Building. The hypothesis of window-related factors indicates that habitat variables attract particular avian species to the vicinity of windows which results in these species being more vulnerable to dying at windows than birds not found near windows. Factors in this explanation include: size and location of windows in a building relative to ground level; suburban and urban habitats; and habitat surrounding buildings that contains bird feeding stations, fruiting trees, water supplies, and nesting and perching sites (Klem 1989). The bird behavior hypothesis suggests that collisions with windows occur due to intra- and interspecific interactions (e.g., male-male chasing and escape flights due to sudden presence of a potential predator) and physiological effects to the body during migration, e.g., migratory restlessness and aggression (Klem 1989, Berthold 2001).

The results of Study 2 are consistent with these hypotheses because: (1) mortality was documented in spring and not in winter despite the observation during point counts of no significant differences in abundance between these two time periods; (2) there was no relationship for species richness between birds found living near the building and those that died; (3) for birds that did not die from collisions with windows, abundances were similar between spring and winter (e.g., Mourning Dove [*Zenaida macroura*], Downy Woodpecker [*Picoides pubescens*], and House Finch [*Carpodacus mexicanus*]) or the species was more abundant in one season or another (e.g., American Crow and Cedar Waxwing); (4) abundance was higher in winter for some birds that died in spring (e.g., European Starling); and (5) relatively abundant birds did not die at windows during Study 2 (e.g., Northern Cardinal and House Sparrow) (Table 1, Appendix 2). Only one season each for spring and winter was examined for this work, but the mortality data were not statistically different among years for these seasons; several bird surveys completed on the Augustana campus in previous years in winter and spring suggest that abundance and diversity were similar among years (S. B. Hager, unpubl. data).

The bird density hypothesis was previously supported for houses during winter, and landscaping features and bird behavior (related to anti-predation) were found to contribute to collisions at windows (Dunn 1993). Our results for a commercial building suggest that birds are vulnerable to collisions with windows for different reasons. The presence of bird feeding stations at houses may best explain these differences. Dunn (1993) noted that houses maintaining feeders attracted a minimum of 84 birds during a count period, which tends to confine high densities to a relatively small area near a house. Mortality at houses is known to occur from the sudden presence of a potential predator that forced birds to abruptly take flight, but fail to recognize windows of a house as a barrier (Dunn 1993). Klem et al. (2004) found a significant positive relationship between increasing distance of feeders from houses and the rate of bird-window collisions. Thus, it seems that window strikes by birds occur when densities per unit area are high and birds are congregated some distance from the structure. We observed similar abundances at the Science Building as those reported by Dunn (1993) and suggest the density of birds was relatively lower when compared to the area available to birds at a house. In addition, birds known to frequent feeders in winter, such as Dark-eyed Junco, Northern Cardinal, and House Sparrow, were common at the Science Building, but experienced no mortality during Study 2. Houses with feeder stations may increase bird density beyond some threshold value that significantly increases their vulnerability to windows strikes. Conversely, at commercial buildings without feeding stations, bird density per unit area and vulnerability to colliding with windows are relatively low.

We suggest that birds in the United States and Canada are vulnerable to window collisions because: (1) increasing numbers of commercial buildings each year, zoning laws for and societal interest in increased naturalized habitat around houses and businesses, and that each of these is more common in suburban contexts (Blem and Willis 1998; Owens 2006; C. G. Mahaffey, pers. comm.); (2) bird mortality due to window collisions at commercial buildings disproportionately affects neotropical and North American migrants mostly during spring and fall migration; and (3) the reported annual mortality at commercial buildings is at least 3–5 times higher than estimated by Klem (1990). We recommend implementing measures directed at disrupting factors which place birds at high risk of striking windows. The most practical in the context of heightened interest by the public in naturalized landscaping are external window screening that covers windows and angled window mounting in buildings (Klem 2006). These significantly reduce mortality by migratory and non-migratory species (Klem et al. 2004, Klem 2006). Proper placement of bird feeders, if present in the vicinity of a building, appears to be effective in reducing mortality to species that frequent feeding stations (Klem et al. 2004).

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APPENDIX 1. Species of window-killed birds (n = 69) documented for Study 1 at both campuses, including Principia incidentals (n = 22), which were opportunistically collected on the Principia campus exclusive of the locations of standardized building surveys.

Common name	Scientific name	Migration status	Augustana College	Principia College	Principia incidentals	Totals
Sharp-shinned Hawk	*Accipiter striatus*	NAM			1	1
Mourning Dove	*Zenaida macroura*	NAM	4	3	2	9
Yellow-billed Cuckoo	*Coccyzus americanus*	NTM			1	1
Chimney Swift	*Chaetura pelagica*	NTM		1		1
Ruby-throated Hummingbird	*Archilochus colubris*	NTM	11	41	10	62
Yellow-bellied Sapsucker	*Sphyrapicus varius*	NAM	8	2		10
Downy Woodpecker	*Picoides pubescens*	PER		1		1
Northern Flicker	*Colaptes auratus*	NAM		1		1
Empidonax flycatcher	*Empidonax* spp.	NTM	1			1
Eastern Phoebe	*Sayornis phoebe*	NAM	1			1
Red-eyed Vireo	*Vireo olivaceus*	NTM	1	1		2
American Crow	*Corvus brachyrhynchos*	PER		1		1
Black-capped Chickadee	*Poecile atricapillus*	PER		1		1
Tufted Titmouse	*Baeolophus bicolor*	PER		1	1	2
White-breasted Nuthatch	*Sitta carolinensis*	PER	2			2
Brown Creeper	*Certhia americana*	NAM	4			4
Carolina Wren	*Thryothorus ludovicianus*	PER			1	1
House Wren	*Troglodytes aedon*	NTM	1			1
Marsh Wren	*Cistothorus palustris*	NAM	1			1
Golden-crowned Kinglet	*Regulus satrapa*	NAM	1	2		3
Blue-gray Gnatcatcher	*Polioptila caerulea*	NTM			1	1
Veery	*Catharus fuscescens*	NTM	1			1
Gray-cheeked Thrush	*C. minimus*	NTM	1	1		2
Swainson's Thrush	*C. ustulatus*	NTM	13	3		16
Hermit Thrush	*C. guttatus*	NAM	5			5
Wood Thrush	*Hylocichla mustelina*	NTM		7		7
American Robin	*Turdus migratorius*	NAM	14	18	3	35
Gray Catbird	*Dumetella carolinensis*	NTM	4			4
Brown Thrasher	*Toxostoma rufum*	NAM	1			1
European Starling	*Sturnus vulgaris*	PER	1			1
Cedar Waxwing	*Bombycilla cedrorum*	NAM	9	4	1	14
Tennessee Warbler	*Vermivora peregrina*	NTM	6	5	1	12
Orange-crowned Warbler	*V. celata*	NTM	1			1
Nashville Warbler	*V. ruficapilla*	NTM	7			7
Yellow Warbler	*Dendroica petechia*	NTM	1			1
Chestnut-sided Warbler	*D. pensylvanica*	NTM	1			1

APPENDIX 1. Continued.

Common name	Scientific name	Migration status	Augustana College	Principia College	Principia incidentals	Totals
Magnolia Warbler	*D. magnolia*	NTM	2	1		3
Cape May Warbler	*D. tigrina*	NTM		1		1
Yellow-rumped Warbler	*D. coronata*	NAM	1		2	3
Black-throated Green Warbler	*D. virens*	NTM		1		1
Yellow-throated Warbler	*D. dominica*	NTM		1		1
Black-and-white Warbler	*Mniotilta varia*	NTM	3	1		4
American Redstart	*Setophaga ruticilla*	NTM	2			2
Ovenbird	*Seiurus aurocapilla*	NTM	16	8	1	25
Northern Waterthrush	*S. noveboracensis*	NTM		1		1
Louisiana Waterthrush	*S. motacilla*	NTM		1		1
Kentucky Warbler	*Oporornis formosus*	NTM	1	1	1	3
Connecticut Warbler	*O. agilis*	NTM	1			1
Mourning Warbler	*O. philadelphia*	NTM	2			2
Common Yellowthroat	*Geothlypis trichas*	NTM	3			3
Canada Warbler	*Wilsonia canadensis*	NTM	2	1	1	4
Summer Tanager	*Piranga rubra*	NTM		2		2
American Tree Sparrow	*Spizella arborea*	NAM		1		1
Chipping Sparrow	*S. passerina*	NTM	1	1	2	4
Fox Sparrow	*Passerella iliaca*	NAM	3			3
Song Sparrow	*Melospiza melodia*	NAM	3			3
Lincoln's Sparrow	*M. lincolnii*	NTM	1			1
Swamp Sparrow	*M. georgiana*	NAM	4			4
White-throated Sparrow	*Zonotrichia albicollis*	NAM	25	13	8	46
Dark-eyed Junco	*Junco hyemalis*	NAM	12	3	4	19
Northern Cardinal	*Cardinalis cardinalis*	PER	10	5	5	20
Rose-breasted Grosbeak	*Pheucticus ludovicianus*	NTM	5			5
Indigo Bunting	*Passerina cyanea*	NTM	4	1	1	6
Common Grackle	*Quiscalus quiscula*	NAM	1	1		2
Brown-headed Cowbird	*Molothrus ater*	NAM	1			1
House Finch	*Carpodacus mexicanus*	PER			2	2
Pine Siskin	*Carduelis pinus*	NAM		2		2
American Goldfinch	*C. tristis*	NAM	4	3	2	9
House Sparrow	*Passer domesticus*	PER			7	7
Unidentified species			8			8
Totals			215	142	58	415

APPENDIX 2. Species observed in Study 2 at Augustana College during point count surveys (n = 16) and monitoring surveys for window-killed birds. No dead birds were found in winter 2006–7.

			Spring 2006		Winter 2006–7
Common name	Scientific name	Migration status	# live/survey	# dead[a]	# live/survey
Canada Goose	*Branta canadensis*	NAM	0.3		
Wood Duck	*Aix sponsa*	NAM	0.3		
Mallard	*Anas platyrhynchos*	NAM			0.4
Bald Eagle	*Haliaeetus leucocephalus*	NAM			0.1
Sharp-shinned Hawk	*Accipiter striatus*	NAM	0.1		
Ring-billed Gull	*Larus delawarensis*	NAM			0.1
Rock Pigeon	*Columba livia*	PER	1.4		1.1
Mourning Dove	*Zenaida macroura*	NAM	2.5		2.9
Chimney Swift	*Chaetura pelagica*	NTM	2.6		
Ruby-throated Hummingbird	*Archilochus colubris*	NTM	0.3		
Red-bellied Woodpecker	*Melanerpes carolinus*	PER	0.1		0.1
Yellow-bellied Sapsucker	*Sphyrapicus varius*	NAM	0.6	2	
Downy Woodpecker	*Picoides pubescens*	PER	1.0		1.1
Northern Flicker	*Colaptes auratus*	NAM	0.8		
Eastern Wood-Pewee	*Contopus virens*	NTM	0.3		
Yellow-bellied Flycatcher	*Empidonax flaviventris*	NTM	0.1		
Least Flycatcher	*E. minimus*	NTM	0.4		
Blue-headed Vireo	*Vireo solitarius*	NTM	0.1		
Warbling Vireo	*V. gilvus*	NTM	0.1		
Red-eyed Vireo	*V. olivaceus*	NTM	0.3		
Blue Jay	*Cyanocitta cristata*	PER	4.8		0.4
American Crow	*Corvus brachyrhynchos*	PER	0.9		5.4
Black-capped Chickadee	*Poecile atricapillus*	PER	2.3		1.5
Tufted Titmouse	*Baeolophus bicolor*	PER	0.5		
White-breasted Nuthatch	*Sitta carolinensis*	PER	0.4		0.8
Brown Creeper	*Certhia americana*	NAM	0.1		
Carolina Wren	*Thryothorus ludovicianus*	PER	0.3		
House Wren	*Troglodytes aedon*	NTM	1.1		
Golden-crowned Kinglet	*Regulus satrapa*	NAM	0.6		
Ruby-crowned Kinglet	*R. calendula*	NAM	2.5		
Veery	*Catharus fuscescens*	NTM	0.1		
Gray-cheeked Thrush	*C. minimus*	NTM	0.3		
Swainson's Thrush	*C. ustulatus*	NTM	1.0	2	
Hermit Thrush	*C. guttatus*	NAM	0.9		
Wood Thrush	*Hylocichla mustelina*	NTM	0.1		
American Robin	*Turdus migratorius*	NAM	6.8		6.5
Gray Catbird	*Dumetella carolinensis*	NTM	0.3		
European Starling	*Sturnus vulgaris*	PER	5.4	1	8.8
Cedar Waxwing	*Bombycilla cedrorum*	NAM	2.9		8.4
Tennessee Warbler	*Vermivora peregrina*	NTM	0.9		
Nashville Warbler	*V. ruficapilla*	NTM	0.1		
Northern Parula	*Parula americana*	NTM	0.1		
Yellow Warbler	*Dendroica petechia*	NTM	0.1		
Yellow-rumped Warbler	*D. coronata*	NAM	1.0		
American Redstart	*Setophaga ruticilla*	NTM	0.5		
Ovenbird	*Seiurus aurocapilla*	NTM	0.4	2	
Chipping Sparrow	*Spizella passerina*	NTM	6.1	1	
Fox Sparrow	*Passerella iliaca*	NAM	0.1		
Song Sparrow	*Melospiza melodia*	NAM	0.1		
White-throated Sparrow	*Zonotrichia albicollis*	NAM	0.8	1	0.4
Dark-eyed Junco	*Junco hyemalis*	NAM	0.6		10.4
Northern Cardinal	*Cardinalis cardinalis*	PER	12.3		6.4
Rose-breasted Grosbeak	*Pheucticus ludovicianus*	NTM	0.8	2	
Indigo Bunting	*Passerina cyanea*	NTM	0.4	2	

APPENDIX 2. Continued.

Common name	Scientific name	Migration status	Spring 2006 # live/survey	Spring 2006 # dead[a]	Winter 2006–7 # live/survey
Red-winged Blackbird	*Agelaius phoeniceus*	NAM	1.3		
Common Grackle	*Quiscalus quiscula*	NAM	2.4		
Brown-headed Cowbird	*Molothrus ater*	NAM	5.4		
House Finch	*Carpodacus mexicanus*	PER	4.1		3.9
American Goldfinch	*Carduelis tristis*	NAM	6.3		3.5
House Sparrow	*Passer domesticus*	PER	11.8		17.6

[a] Represents the absolute number of individuals.