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Seasonal, Taxonomic, and Local Habitat Components of Bird-window Collisions on an Urban University Campus in Cleveland, OH

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Abstract. **Migrating birds congregate near the shores of Lake Erie during migration and may be funneled through small green spaces within the urban matrix of Great Lake coastal cities, where they are at risk of higher mortality from manmade structures. Bird deaths due to window collisions were assessed amongst a complex of low-rise buildings (<30 m) on a university campus in Cleveland, OH. A 1.8 km route was surveyed three times per week during a 12-month period. Deaths were tested against null hypotheses that season, taxonomy, and building attributes had no significant relationship with avian mortality. We recovered 271 dead birds of 50 species, all of which were consistent with regional bird lists and Neotropical-Nearctic and North American migrants through Ohio. Deaths occurred non-randomly by week, month, and migratory status with 90 percent of deaths occurring during spring and fall migrations. Consequently, migrants (warblers: 34 percent of species richness, 30 percent of deaths; sparrows: 14 percent of richness, 35 percent of deaths) were observed nine times more frequently than residents. Neotropical-Nearctic migrant species outnumbered North American migrant species. Although there was no statistical difference between the compass direction of a building facade and the number of deaths, deaths were not randomly distributed among campus buildings. Rather, significantly more deaths occurred at facades with higher percentages of glass. The presence of trees within 5 m of a window and the reflection of trees in windows were also associated with a greater risk of fatality. A better understanding of the factors associated with bird-window collisions is a pressing issue in the conservation of migratory birds.**

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INTRODUCTION

Collisions with man-made structures are a significant source of avian mortality (Johnston and Haines 1957, Crawford 1981, Kemper 1996, Morris and others 2003). In fact, bird-building collisions may be the second leading cause of human-induced avian mortality with a conservative estimate of 550 million deaths annually in the U.S. (Erickson and others 2005). The primary cause of these collisions is plate-glass windows (Johnson and Hudson 1976, Yanagawa and Shibuya 1989, O'Connell 2001, Klem and others 2004, Gelb and Delacretaz 2006, Hager and others 2008) due primarily to their properties of reflectivity and transparency (Klem 1989, 2006, Klem and others 2009).

Identifying and assessing the roles of intrinsic (bird discernment of windows, migration) and extrinsic (weather, habitat) factors leading to bird-window collisions is crucial to developing effective strategies of conservation. Studies evaluating bird-window collisions in urban habitats generally agree that birds often cannot detect glass (Klem 1989, 1990), most collisions result in death (67 percent in Gelb and Delacretaz 2009, 82 to 85 percent in Klem and others 2009), bird fatalities do not statistically vary between age or sex (Johnston and Haines 1957, Klem 1989), and more collisions occur during migration events (Klem 1989, Yanagawa and Shibuya 1998, O'Connell 2001, Hager and others 2008) of which Neotropical-Nearctic migrants are most frequently killed (O'Connell 2001, Hagar and others 2008, but see Klem 1989 regarding the role of resident status). Additionally, bird density is only a partial predictor of collision frequency (Hagar and others 2008). More collisions occur in the morning and almost always during daylight (Klem 1989); however, poor flying conditions caused by weather do not result in more deaths (Klem 1989). One exception to the latter is anomalous weather events during which reduced visibility and disorientation (Hebert 1970) are associated with large numbers of deaths at television towers (e.g. Crawford 1981, Morris and others 2003). Obviously, the topic of bird mortalities is very complex, and a simple relationship between cause and effect of bird-window collisions is not a realistic expectation. Rather, interactions among numerous characteristics of the local urban habitat (building attributes, extent of vegetation, presence of water) and bird density affect the frequency of bird-window collisions (Hagar and others 2008, Klem and others 2009).

Bird densities are high along migratory pathways and the coastlines of large bodies of water, such as the Great Lakes, which act as temporary barriers and affect the distribution of birds (Gauthreaux and Belser 1998, Bonter and others 2009). Migrating birds that stop to rest and feed, select habitats characterized by forest cover and proximity to water (Bonter and others 2009). Along the coasts of the Great Lakes, these stopover sites take the form of forests, residential, and urban habitats and are all positively associated with migratory bird densities (Bonter and others 2009). Stopover sites greatly influence reproductive fitness as they dictate migratory success (Schaub and Jenni 2001), allow for completion of prebasic molt (Winker and others 1991), and provide sanctuary and food (Smith and others 1998). Within cities that border the Great Lakes, often along migration flyways, stopover sites are fragmented and can take the form of green spaces within the urban matrix (e.g., Seewagen 2008) since they can meet the requirements of stopover habitat (Bonter and others 2009). Yet, the effects of an urban habitat adjacent to a large body of permanent water along an important flyway on bird-window collisions have not been addressed.

Here we assess the impact of and relationship between low-rise buildings and adjacent green spaces on bird mortality at a small university campus in Cleveland, OH. The campus comprises a dense array of relatively low-rise buildings (< 30 m tall) with the exception of two structures (Rhodes Tower, 111m; Fenn Tower, 81m). The campus lies on the southern edge of Lake Erie, a location known to concentrate birds in nearshore mix-cover habitats within 10 km

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of the coastline (Diehl and others 2003, Bonter and others 2009). In addition, the southern coast of Lake Erie lies along multiple migration routes (Rappole and others 1979) and encompasses regionally important historical and contemporary (Williams 1950, Peterjohn 2001, Diehl and others 2003, Rosche 2004, Bonter and others 2009) stopover habitat. Several urban centers are found along the southern shore of Lake Erie, including the city of Cleveland as the anchor of a larger metropolis (population > 2.1 million, U.S. Census Bureau 2000). This study is an initial step to quantify the impact of low-rise buildings in an urban setting situated along known bird migration routes. Our objectives were to: (1) document the species richness and relative frequencies of birds killed due to building collisions, and (2) identify fatality patterns association with season, taxonomy, and building attributes. These findings are crucial to initiate effective local conservation measures particularly among fragmented habitats in an urban matrix.

MATERIALS AND METHODS

We conducted a 12-month study on the campus of Cleveland State University (CSU) from 2007 February through 2008 February. CSU (41°30'N, 81°41'W) is located in downtown Cleveland, Cuyahoga County, OH, approximately 1.5 km from the nearest point on the southern shore of Lake Erie and stretches in an east-west direction (Fig. 1). The study area is approximately 0.15 km^2 and includes buildings of various ages, heights and materials with green spaces between buildings (Fig. 2). Green spaces within the campus included open lawns, lawns with manicured vegetation beds, beds with a single or few trees, and areas with a denser cluster of trees. Green spaces extended between adjacent buildings and abutted building facades. Many of the buildings are connected by walkways that are enclosed by transparent or reflective glass, have interior lighting, and are elevated from the ground at the second or third floor. No bird deterrent mechanisms to reduce the number of bird-window collisions were in place during this study. Several buildings or facades were intermittently inaccessible due to construction or had ledges preventing birds from falling onto the survey route; these sites were excluded from study.

A standardized survey route (approximately 1.8 km) through the campus sampled a diversity of structures, compass directions of building facades, and green spaces on the campus. This route was walked three days per week (typically Monday, Wednesday and Friday) during morning or late morning hours (daylight to 10 a.m.) to maximize recovery rates of fresh specimens (Klem 1989, Gelb and Delacretaz 2006). A total of 23 building faces plus 10 elevated walkways were surveyed (Fig. 1). The survey zone was an area within 5 m of buildings and consisted of sidewalks, concrete

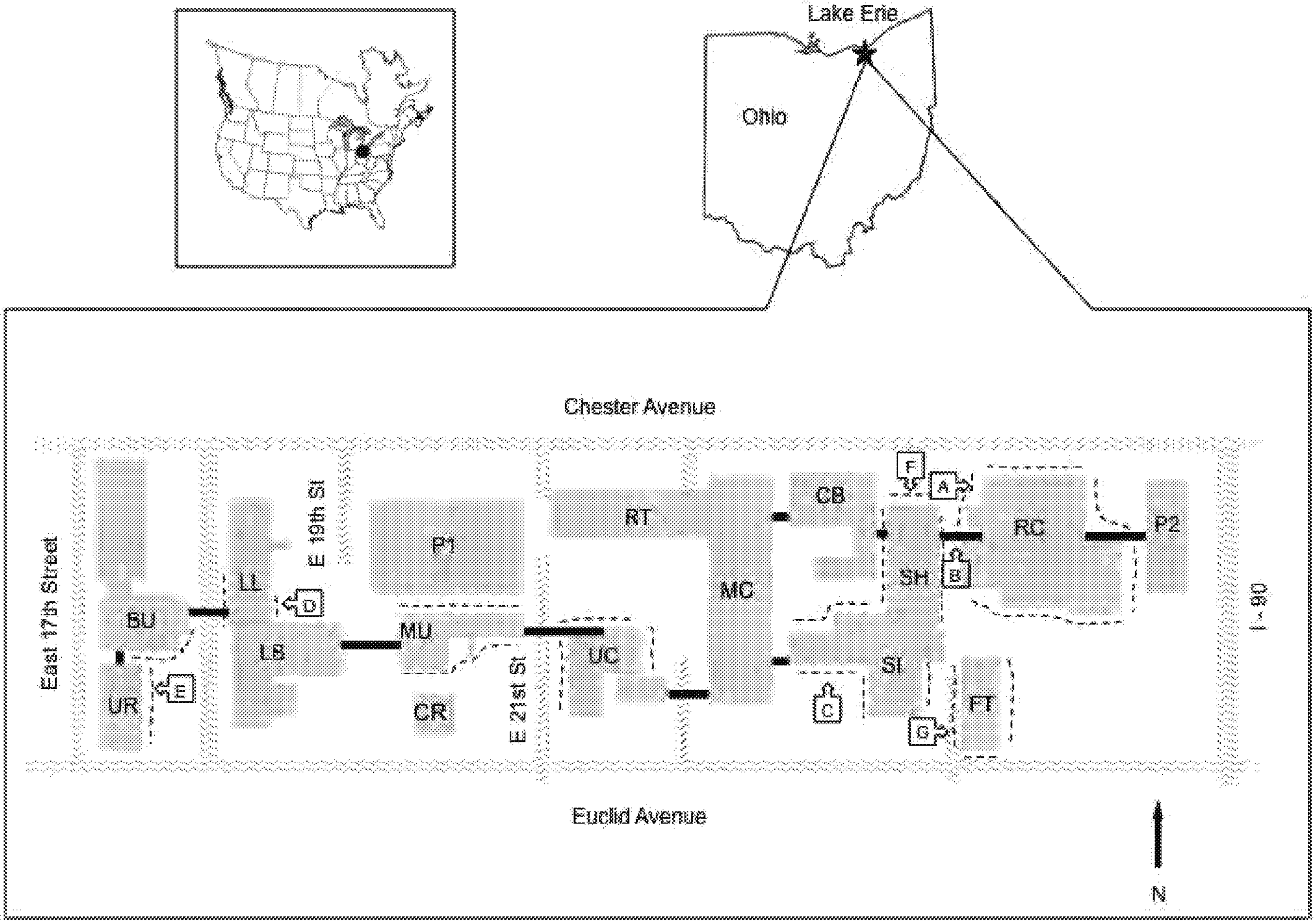

FIGURE 1. Study site on the campus of Cleveland State University, Cleveland, OH. Inset maps highlight the location of Ohio relative to North America and the Great Lakes (filled circle) and Cleveland (filled star) relative to Ohio and Lake Erie. Dashed lines indicate the surfaces surveyed. Solid black bars indicate 10 elevated and glassed-in walkways. Only odd numbered streets are labeled. East 21st and E 22nd Streets continue underneath the northern border of campus. Boxed letters indicate the locations and orientations of photographs in Fig. 2. Buildings are shaded and identified with a two-letter abbreviation that is consistent with those used in the text: BU, Business Bldg; CB, Chester Bldg; CR, Corlene Bldg; FT, Fenn Tower; LB, Law Bldg; LL, Law Library; MC, Main Classroom; MU, Music Bldg; P1, parking structure 1; P2, parking structure 2; RC, Recreation Center; RT, Rhodes Tower; SH, Stilwell Hall; SI, Science Bldg; UC, University Center; UR, Urban Bldg.

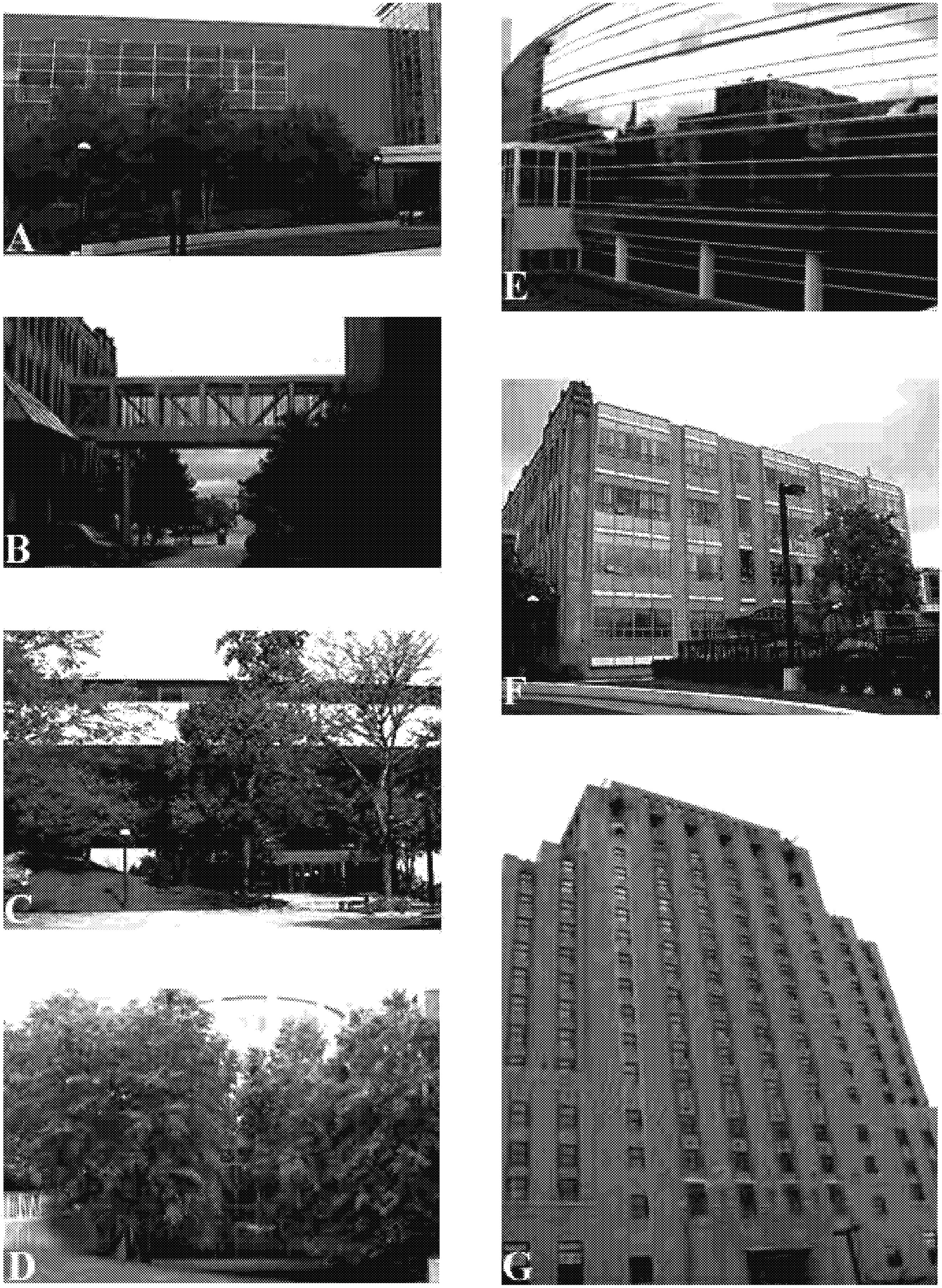

Figure 2. Photographs depicting the diversity in structural characteristics and in vegetation of buildings on the CSU campus. (A) West side of RC. (B) South face of walkway RC-SH. Lake Erie is visible on the distant horizon. (C) South side of SI. (D) East face of LL. LB is to the left. (E) East side of UR. (F) North face of SH. (G) West side of FT. All photos by O. Lockhart.

patios, driveways, mowed lawns, and manicured garden beds of shrubs and trees (Fig. 2). Thus, the recovery rate of specimens was minimally impacted by obstructions to viewing the search area.

During six weeks of the autumn migration additional surveys were performed that may have biased mortality counts. Hence, we corrected the number of bird deaths in a given week by the number of surveys conducted in that week and used those values in statistical analyses. We recorded the species, specimen condition, location, date, building attributes, and local habitat for dead birds. Dead birds were salvaged and accessioned into the ornithology collection at the Cleveland Museum of Natural History. Injured birds were placed in shrubbery beyond the survey area.

Several biases can lead to an underestimation of mortality including variation in searching efficiency and scavenger removal rates (Erickson and others 2005). We believe searching efficiencies were minimally impacted by bird size, bird color, or surrounding vegetation since the survey zone consisted of manicured beds and pavement. Scavenger removal rates vary widely in the published literature (summarized in Erickson and others 2005). Urban scavengers [e.g., feral cats (*Felis catus*), striped skunks (*Mephitis mephitis*), rats (*Rattus* spp.)] and human interference (e.g., pedestrians and university grounds crews) were observed during our surveys. While we did not quantify the effect of scavengers, we frequently recovered decomposing and weather-damaged birds throughout the year. Based on this and focused observations since the end of the study, we suggest that scavenger removal rates were minimal. Finally, we did not estimate the number of birds that collided and then moved away from the survey zone only to die later. Therefore, our data are a conservative estimate of bird deaths.

Chi-square tests were applied to the null hypotheses that deaths were randomly distributed with respect to week, month, species, family, migratory class, and 'migrants' versus 'residents'. Species of dead birds were categorized as residents (RES), North American migrants (NAM), or Neotropical-Nearctic migrants (NNM) using Peterjohn (2001) and Hager and others (2008). Categorizing birds in this manner ignored population-level differences that may, for example, identify NAM individuals as residents.

Patterns of avian fatality were evaluated against building attributes, presence of trees, and the interaction between the amount of glass and trees. Because all but one building (Fenn Tower, 81 m) was shorter than 30 m, we elected not to investigate the effect of building height on avian fatality. Klem and others (2009) found no statistically significant pattern between the number of deaths and building height. Given that 90 percent of the deaths occurred during spring and autumn migrations (23 weeks cumulative), we chose not to investigate the temporal role of building attributes on bird deaths.

We determined the compass direction of each building facade to test the hypothesis that facade orientation was independent of bird strike incident. Facades were categorized as north or south facing (hereafter N-S) and east or west facing (hereafter E-W), because deaths at elevated walkways could not be assigned to a single direction (e.g., if a bird is lying directly underneath a walkway, did it strike the north or south face?). Relatively small sample sizes (N-S = 19 faces, E-W = 13 faces) also warranted the grouping of facade orientation for the sake of statistical analysis. Since birds were assumed to be striking buildings during descent, ascent, or foraging, we hypothesized that they would be approaching green spaces from the best angle of approach regardless of their overall migration direction. Hence, we used a t-test to test the null hypothesis that the mean number of deaths per face in each category would not differ.

We also predicted that the greatest number of deaths would occur at glass facades with adjacent trees. The percentage of glass was calculated from digital photographs and ranged from 2.5 to 95 percent. These data were bimodally distributed and could not be transformed to conform to a normal distribution. This was due to building facades having either "high" (>45 percent) or "low" (<31 percent) percentages of glass, with no buildings between these two values. We evaluated the association between percentage of glass and proximity of trees on deaths using a two-way ANOVA with glass coverage and tree presence/absence as the main factors. Fatalities were assigned to one of four categories based on the percentage glass (high: ≥ 47 percent, low: ≤ 31 percent) and trees (present, absent). The number of deaths was log-transformed [$\log_{10}$(# of deaths + 1)] to meet the parametric assumptions of homoscedasticity and normality. Three data points fell beyond ±5 standard errors of the mean of their respective groups, so analyses were performed with and without these values for heuristic purposes. All test statistics were computed with SPSS software (SPSS 16.0 for Windows, release 16.0.1, SPSS Inc., Chicago, IL) and evaluated at $\alpha = 0.05$. Deviations from normal distributions were assessed using Kolmogorov-Smirnov tests.

RESULTS

Surveys were conducted on 137 days (mean 2.6 ± 0.8 sd surveys/week), and ranged from one (two weeks in December) to five (one week in September) days per week. A total of 271 dead birds was recovered, representing 50 species in 17 families (Table 1). Species identifications were consistent with published regional bird lists (Rosche 2004) and known Neotropical-Nearctic migrants in the Great Lakes basin. Deaths were not distributed uniformly across either species or family (Table 1, Kolmogorov-Smirnov $Z = 4.70$, $P < 0.001$ and $Z = 2.80$, $P < 0.001$, respectively). Warblers (family Parulidae) comprised 34 percent of the species richness and 30 percent of the deaths. Sparrows and their relatives (family Emberizidae) were the most frequently killed (35 percent) but comprised only 14 percent of the species richness (Table 1). American Woodcock (*Scolopax minor*) was the only shorebird species encountered.

A non-random distribution of deaths occurred by month (Kolmogorov-Smirnov $Z = 1.96$, $P = 0.001$; range: 0.0 to 7.1, mean: 1.6 ± 0.6) and week (Kolmogorov-Smirnov $Z = 4.87$, $P < 0.001$; range: 0.0 to 10.5, mean: 1.6 ± 0.3) and clearly reflected increased fatality during spring and fall migrations (Fig. 3). Consistent with that pattern, migrant species (NAM + NNM, Table 1) were nine times more frequently observed dead than resident species ($\chi^2 = 14.7$, df = 2, $P < 0.001$). The species richness of dead NNM individuals (n = 27) outnumbered dead NAM individuals (n = 8) even though fewer NNM individuals (n = 112) were killed (NAM=127 individuals). In northeastern Ohio, spring and fall migrations respectively correspond to mid-March into early June (12 weeks) and mid-August through October (11 weeks) (Rosche 2004). Spring and fall migrations collectively accounted for 44 percent of the calendar year (23 weeks), but 90 percent of the dead birds (n = 245) were collected during these two periods. The spring migration (23 percent of the calendar year) resulted in 52 individuals (19 percent of fatalities) of 24 species, and the fall migration (21 percent of the year) resulted in 193 individuals (71 percent of fatalities) of 41 species. The most frequently observed

TABLE 1

Bird deaths from bird-building strikes on the campus of Cleveland State University from 2007 February to 2008 February. Taxa are listed according to the American Ornithologists' Union (www.aou.org). The superscript "RES" indicates a year-round resident, "NAM" indicates a North American migrant, and "NNM" is a Neotropical-Nearctic migrant.

Order	Family	Species	N
Apodiformes	Trochilidae	Ruby-throated Hummingbird (*Archilochus colubris*)$^{\text{NNM}}$	2
Charadriiformes	Scolopacidae	American Woodcock (*Scolopax minor*)$^{\text{NAM}}$	1
Columbiformes	Columbidae	Rock Pigeon (*Columba livia*)$^{\text{RES}}$	1
		Mourning Dove (*Zenaida macroura*)$^{\text{NAM}}$	2
Cuculiformes	Cuculidae	Yellow-billed Cuckoo (*Coccyzus americanus*)$^{\text{NNM}}$	1
Passeriformes	Bombycillidae	Cedar Waxwing (*Bombycilla cedrorum*)$^{\text{NAM}}$	1
	Cardinalidae	Northern Cardinal (*Cardinalis cardinalis*)$^{\text{RES}}$	1
		Indigo Bunting (*Passerina cyanea*)$^{\text{NNM}}$	1
		Rose-breasted Grosbeak (*Pheucticus ludovicianus*)$^{\text{NNM}}$	6
	Certhiidae	Brown Creeper (*Certhia americana*)$^{\text{NAM}}$	18
	Emberizidae	Grasshopper Sparrow (*Ammodramus savannarum*)$^{\text{NNM}}$	1
		Dark-eyed Junco (*Junco hyemalis*)$^{\text{NAM}}$	5
		Swamp Sparrow (*Melospiza georgiana*)$^{\text{NAM}}$	14
		Lincoln's Sparrow (*Melospiza lincolnii*)$^{\text{NNM}}$	12
		Song Sparrow (*Melospiza melodia*)$^{\text{NAM}}$	6
		White-throated Sparrow (*Zonotrichia albicollis*)$^{\text{NAM}}$	38
		White-crowned Sparrow (*Zonotrichia leucophrys*)$^{\text{NAM}}$	2
		unidentified sparrow	17
	Mimidae	Gray Catbird (*Dumetella carolinensis*)$^{\text{NNM}}$	1
	Paridae	Black-capped Chickadee (*Poecile atricapillus*)$^{\text{RES}}$	1
	Parulidae	Black-throated Blue Warbler (*Dendroica caerulescens*)$^{\text{NNM}}$	1
		Yellow-rumped Warbler (*Dendroica coronata*)$^{\text{NAM}}$	2
		Blackburnian Warbler (*Dendroica fusca*)$^{\text{NNM}}$	1
		Magnolia Warbler (*Dendroica magnolia*)$^{\text{NNM}}$	4
		Palm Warbler (*Dendroica palmarum*)$^{\text{NNM}}$	1
		Chestnut-sided Warbler (*Dendroica pensylvanica*)$^{\text{NNM}}$	4
		Blackpoll Warbler (*Dendroica striata*)$^{\text{NNM}}$	2
		Cape May Warbler (*Dendroica tigrina*)$^{\text{NNM}}$	4
		Common Yellowthroat (*Geothlypis trichas*)$^{\text{NNM}}$	14
		Black-and-white Warbler (*Mniotilta varia*)$^{\text{NNM}}$	4
		Mourning Warbler (*Oporornis philadelphia*)$^{\text{NNM}}$	6

species during the spring migration were the White-throated Sparrow (n = 5, *Zonotrichia albicollis*), Common Yellowthroat (n = 5, *Geothlypis trichas*), and Ovenbird (n = 5, *Seiurus aurocapillus*). During the fall migration, the White-throated Sparrow (n = 32), Nashville Warbler (n = 14, *Oreothlypis ruficapilla*), Swamp Sparrow (n = 14, *Melospiza georgiana*), and Brown Creeper (n = 14, *Certhia americana*) were the most frequently observed fatalities.

Habitat and building parameters variably affected bird fatalities. No bird deaths were observed at the tallest building in the study (81 m, FT, Fig. 2G). There was no statistical difference in mean deaths per face (t = -0.03, P = 0.91) between north-south (n = 147, mean: 7.74 ± 9.97) and east-west (n = 116, mean: 8.29 ± 15.38) facing facades over the course of the year. During each migration, more deaths occurred at N-S than E-W facades. In subsequent analyses, facade orientation was not considered.

More glass in a building's facade was positively associated with more bird fatalities ($F_{1,29}$ = 13.165, P = 0.001). But deaths did not significantly increase in the presence of trees ($F_{1,29}$ = 0.236, P = 0.631) or due to the interaction (i.e., reflections) between glass and trees ($F_{1,29}$ = 1.310, P = 0.262) (Fig. 4A). Further analysis revealed that three sites were five or more standard errors from their respective means. One site, the north side of RC (low glass – no trees) had deaths (n=38) characteristic of facades having more than 47 percent glass ("high glass" category). Though this facade had a relatively

TABLE 1 (cont.)

Bird deaths from bird-building strikes on the campus of Cleveland State University from 2007 February to 2008 February. Taxa are listed according to the American Ornithologists' Union (www.aou.org). The superscript "RES" indicates a year-round resident, "NAM" indicates a North American migrant, and "NNM" is a Neotropical-Nearctic migrant.

Order	Family	Species	N
		Northern Waterthrush (*Parkesia noveboracensis*)$^{\mathrm{NNM}}$	1
		Tennessee Warbler (*Oreothlypis peregrina*)$^{\mathrm{NNM}}$	3
		Nashville Warbler (*Oreothlypis ruficapilla*)$^{\mathrm{NNM}}$	15
		Ovenbird (*Seiurus aurocapilla*)$^{\mathrm{NNM}}$	10
		American Redstart (*Setophaga ruticilla*)$^{\mathrm{NNM}}$	5
		Wilson's Warbler (*Wilsonia pusilla*)$^{\mathrm{NNM}}$	1
		unidentified warbler	4
	Passeridae	House Sparrow (*Passer domesticus*)$^{\mathrm{RES}}$	3
	Regulidae	Golden-crowned Kinglet (*Regulus satrapa*)$^{\mathrm{NAM}}$	6
		Ruby-crowned Kinglet (*Regulus calendula*)$^{\mathrm{NAM}}$	2
	Sittidae	Red-breasted Nuthatch (*Sitta canadensis*)$^{\mathrm{NAM}}$	8
		White-breasted Nuthatch (*Sitta carolinensis*)$^{\mathrm{RES}}$	1
	Troglodytidae	Marsh Wren (*Cistothorus palustris*)$^{\mathrm{NAM}}$	2
		House Wren (*Troglodytes aedon*)$^{\mathrm{NNM}}$	1
		Winter Wren (*Troglodytes troglodytes*)$^{\mathrm{NAM}}$	2
	Turdidae	Gray-cheeked Thrush (*Catharus minimus*)$^{\mathrm{NNM}}$	1
		Swainson's Thrush (*Catharus ustulatus*)$^{\mathrm{NNM}}$	8
		Wood Thrush (*Hylocichla mustelina*)$^{\mathrm{NNM}}$	2
		American Robin (*Turdus migratorius*)$^{\mathrm{NAM}}$	11
		unidentified thrush (*Catharus* spp.)	1
Piciformes	Picidae	Northern Flicker (*Colaptes auratus*)$^{\mathrm{NAM}}$	1
		Yellow-bellied Sapsucker (*Sphyrapicus varius*)$^{\mathrm{NAM}}$	6
unidentified bird			3
Total			271

small percentage of glass, essentially all the glass formed a single pane under which most fatalities were recovered. The remaining two sites were unusually short walkways MC-SI and BU-UR with treated glass that muted reflections. Despite these walkways being 95 percent glass, we did not observe any fatalities associated with these structures. When these three data points were excluded from the ANOVA, larger glass surfaces ($F_{1,26} = 67.25$, $P < 0.001$), the presence of trees ($F_{1,26} = 8.70$, $P = 0.007$), and the reflection of trees by windows ($F_{1,26} = 7.089$, $P = 0.013$) were statistically associated with significantly more bird deaths (Fig. 4B). Trees had no statistical effect on deaths when the percentage of glass was less than 47 percent (Fig. 4A, B).

DISCUSSION

Based on the number of deaths, taxonomic richness, and temporal patterns, our results suggest that complexes of low-rise commercial buildings pose significant hazards to migrating birds. Thus, the discussion of bird-building strikes should not be limited to tall buildings (e.g., Gelb and Delacretaz 2009) and other tall structures (e.g., Kemper 1996, television towers) previously known to cause large numbers of deaths. The seasonal patterns of increased deaths during migration events are consistent with a growing list of observations across North America (Johnson and Hudson 1976, Blem and Willis 1998, Crawford and Engstrom 2001, Hager and others 2008, Gelb and Delacretaz 2009) and in Japan (Yanagawa and Shibuys 1998). Sparrows, warblers, Brown Creepers and thrushes are the most commonly observed fatalities in our study and echo the taxonomic distribution of deaths tallied by Gelb and Delacretaz (2009) in NY during migrations. We observed 3.7 times more deaths during autumn than spring migration, consistent with expected migration numbers (immature birds in the fall augment total migration numbers compared to spring) and previous studies (Klem 1989, Crawford and Engstrom 2001, O'Connell 2001, Hager and others 2008, Gelb and Delacretaz 2009).

We did not contrast mortality in nocturnal versus diurnal migrants. It is tempting to assume that the percentage glass should have no bearing on deaths of nocturnal migrants such as passerines. Yet, nocturnal migrants (warblers, sparrows) are the two most commonly observed groups of dead birds, and most collisions occur in the hours following dawn (Klem 1989, DeCandido 2005, Gelb and Delacretaz 2006, 2009). Nocturnal migrants reorient toward land and descend at dawn into protective cover where they rest and forage. This pattern is consistent with conclusions drawn from radar ornithology over Lake Erie (Diehl and others 2003). During early

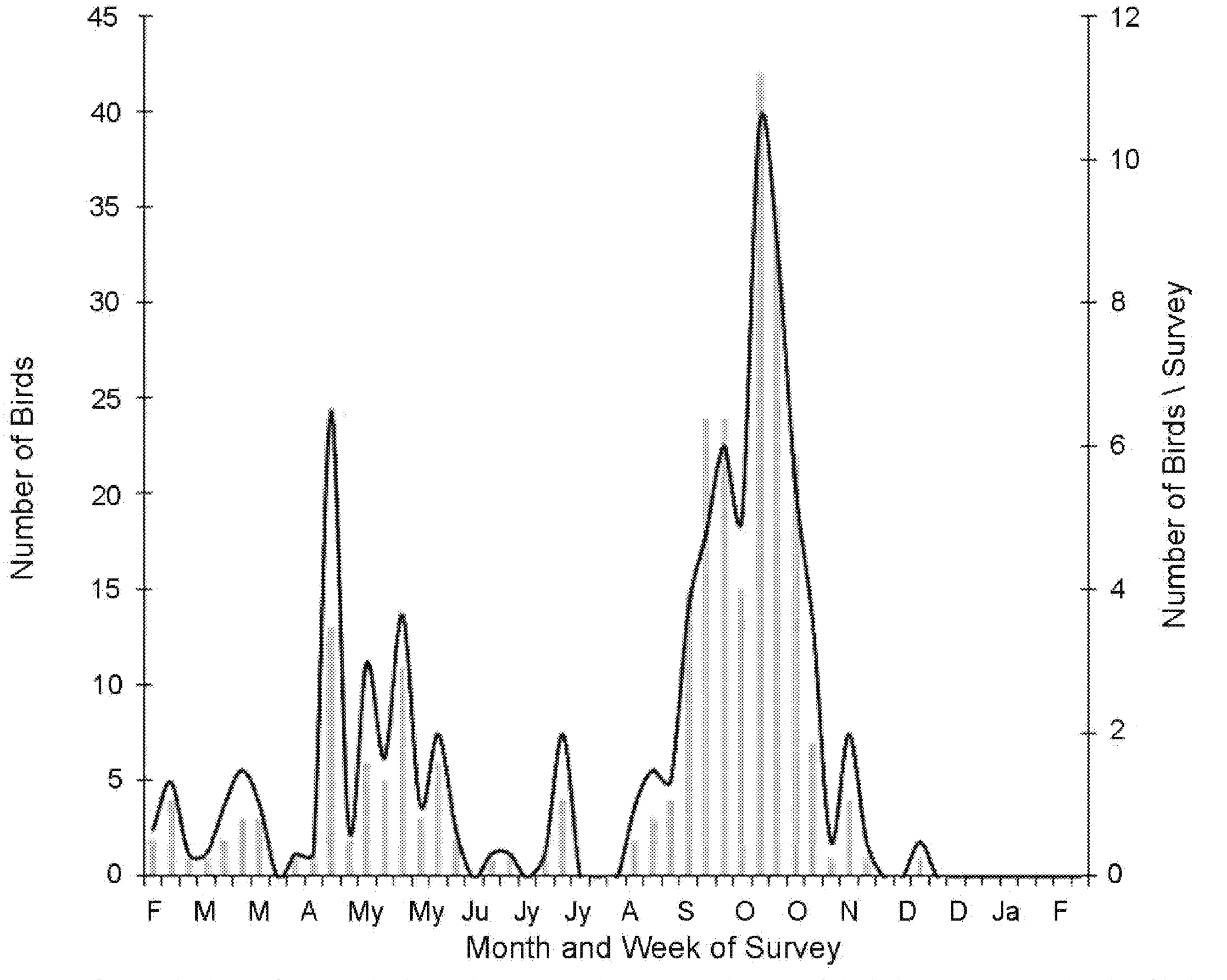

FIGURE 3. A frequency distribution of avian mortality during February 2007 – February 2008 on the campus of Cleveland State University. Total number of deaths by week is indicated by shaded bars (right ordinate) whereas the line represents deaths corrected by the number of surveys (left ordinate) during a particular week. Peaks correspond to the spring (mid-March to early June) and autumn (mid-August through October) migrations in northeastern Ohio. Months are abbreviated and the first bar corresponds to week 1 of the study.

morning descent birds appear most susceptible to collisions. This scenario may also suggest why building height is a poor predictor of bird mortality (DeCandido 2005, Klem and others 2009).

In urban and suburban areas such as metropolises bordering the Great Lakes, stopover sites increasingly take the form of residential neighborhoods, parks, and landscaped green spaces. Bird fatalities at CSU are clustered into a few hot spots (i.e., green spaces), characterized by large areas of sheet glass windows and adjacent vegetation taller than five meters. Sites where vegetation, glass windows, and permanent water converge and cause disproportionately high numbers of bird deaths are "migrant traps" (O'Connell 2001). These traits are consistent with campus hotspots (e.g., Fig. 2A, 2D) and help explain the variability of bird deaths among buildings. Our results support the tenet that local habitat characteristics can greatly exacerbate the prevalence of bird-window collisions (Klem 1990, O'Connell 2001, Klem and others 2004, 2009, Gelb and Delacretaz 2006, 2009, Hager and others 2008). Finally, the three extreme data points are informative and hint that building attributes not measured in this study (e.g., glass treatments, the area of contiguous glass surface rather than strictly the percentage of total glass) may be relevant parameters when assessing causative factors leading to bird-window collisions. For example, reflective glass yields more collisions (Klem and others 2009).

This year-long study is the first to investigate the association between local habitat and building factors with bird fatalities among a suite of low-rise buildings aligned within an important migratory pathway. Our results support many of the published temporal, taxonomic, and habitat patterns in deaths from bird-window collisions. More importantly, we demonstrate that low-rise buildings with adjacent green spaces are significant hazards to migrating birds, even when such buildings occur within a highly urbanized environment. The large number of dead migrants highlights their abilities to find small green spaces hidden within a city and emphasizes the biological value of fragmented green spaces to migrating birds. It also reinforces the urgency to mitigate the impact of architecture on the number of bird-window collisions. Additional studies that contrast urban coastal and urban inland sites and quantify the effect of site proximity to migration routes are needed.

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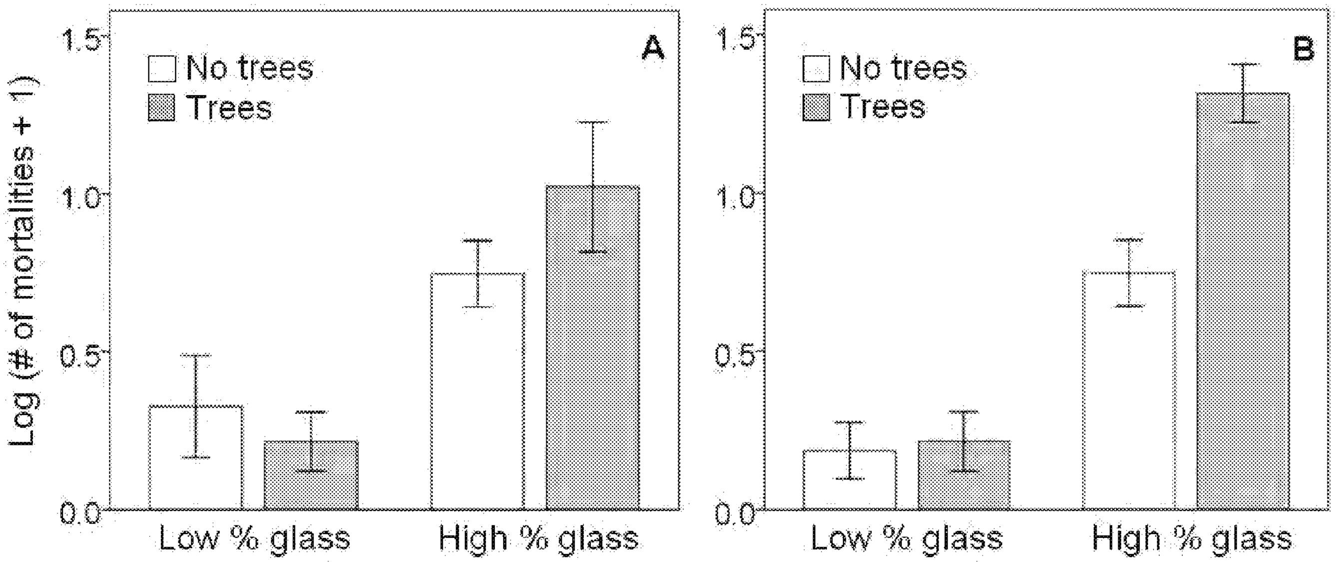

Figure 4. Effect of glass surface area and tree proximity on the frequency of bird mortality with the (A) inclusion and (B) exclusion of three data points greater than 5 SE from the mean (see text). Larger glass surfaces ($F_{1,26} = 67.25$, $P < 0.001$), trees ($F_{1,26} = 8.70$, $P = 0.007$), and the interaction between trees and glass ($F_{1,26} = 7.089$, $P = 0.013$) were associated with statistically more bird deaths following the removal of three extreme outliers. Bars represent the mean number of deaths per building surface (log-transformed values) ± 1 SE.

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