Patterns of bird-window collisions inform mitigation on a university campus

Natalia Ocampo-Peñuela, R Scott Winton, Charlene J Wu, Erika Zambello, Thomas Wittig, Nicolette L Cagle

Bird-window collisions cause an estimated one billion bird deaths annually in the United States. Building characteristics and surrounding habitat affect collision presence and frequency. Given the importance of collisions as a human-caused threat to birds, mitigation is essential. Patterned glass and UV-reflective films have been proven to prevent collisions. At Duke University's West campus in Durham, North Carolina, we set out to identify the buildings and building characteristics associated with the highest frequencies of collisions on campus in order to propose a mitigation strategy. We surveyed six buildings stratified by size and measured architectural characteristics and surrounding area variables. During 21 consecutive days in spring and fall 2014, and spring 2015, we conducted carcass surveys to document collisions. In addition, we collected collision data year-round using the app iNaturalist. Consistent with previous studies, we found a positive relationship between glass and collisions. Fitzpatrick, the building with the most window area, caused the most collisions. Schwartz and the Perk, the two small buildings with small window areas, had the lowest collision frequencies. Penn, the only building with bird deterrent pattern, caused just two collisions, despite being almost completely made out of glass. Unlike many research projects, our data collection led to mitigation action. A resolution backed up by the student government, plus news stories in the local media, resulted in the application of a bird deterrent film to the deadliest building: Fitzpatrick. We present our collision data and mitigation result to inspire other researchers and organizations to prevent bird-window collisions.

Patterns of bird-window collisions inform mitigation on a university campus

Natalia Ocampo-Peñuela[1*], R Scott Winton[1], Charlene Wu[1,2], Erika Zambello[1,3], Thomas Wittig[1], Nicolette Cagle[1]

[1] Nicholas School of the Environment, Duke University. Durham, NC, USA.

[2] Ecology & Environment Inc., Arlington, VA, USA

[3] Okaloosa County, Fort Walton Beach, FL, US

[*] Corresponding author: no19@duke.edu

Abstract

Bird-window collisions cause an estimated one billion bird deaths annually in the United States. Building characteristics and surrounding habitat affect collision presence and frequency. Given the importance of collisions as a human-caused threat to birds, mitigation is essential. Patterned glass and UV-reflective films have been proven to prevent collisions. At Duke University's West campus in Durham, North Carolina, we set out to identify the buildings and building characteristics associated with the highest frequencies of collisions on campus in order to propose a mitigation strategy. We surveyed six buildings stratified by size and measured architectural characteristics and surrounding area variables. During 21 consecutive days in spring and fall 2014, and spring 2015, we conducted carcass surveys to document collisions. In addition, we collected collision data year-round using the app iNaturalist. Consistent with previous studies, we found a positive relationship between glass and collisions. Fitzpatrick, the building with the most window area, caused the most collisions. Schwartz and the Perk, the two small buildings with small window areas, had the lowest collision frequencies. Penn, the only building with bird deterrent pattern, caused just two collisions, despite being almost completely made out of glass. Unlike many research projects, our data collection led to mitigation action. A resolution backed up by the student government, plus news stories in the local media, resulted in the application of a bird deterrent film to the deadliest building: Fitzpatrick. We present our collision data and mitigation result to inspire other researchers and organizations to prevent bird-window collisions.

Keywords: advocacy, building structure, carcass survey, collision prevention, surrounding area, window area

Introduction

General bird-window collisions

Bird-window collisions are an important source of human-caused bird mortality accounting for as many as one billion bird deaths annually in the United States (Klem Jr 1989; Loss et al. 2014). Among human caused bird fatalities, window collisions are second only to free ranging cats (Loss et al. 2015). Birds flying through urban or rural landscapes fail to recognize windows as barriers and often collide against them due to glass transparency or reflectivity (Klem Jr 1989). Window collisions are an additional threat for birds that already face natural dangers like predation, disease, starvation, inclement weather, and the cost of long distance migration (Klem Jr 2014). Although it is uncertain whether window collisions are a major cause of the declining trends in some North American bird populations (Arnold & Zink 2011; DeSante et al. 2015), mortality due to collisions accounts for an annual loss of 2-9% of the total estimated North American bird population (Loss et al. 2014).

Effects of buildings and surrounding area on collisions

All buildings do not pose an equal threat to birds. From previous studies, glass area of a building has been shown to be the most important feature explaining collisions (Borden et al. 2010; Cusa et al. 2015; Hager et al. 2013). Building height also plays a role. Low and medium-rise buildings, such as those found on a university campus, have the highest cumulative number of collisions with 44 and 56% of total collisions in the United States, respectively (Loss et al. 2014).

The area surrounding a building is also thought to influence the amount of bird-window collisions by attracting birds to adjacent vegetation or available water sources (Hager & Craig 2014; Klem Jr 1989; Klem Jr 2014). This finding may not apply in all contexts; for example, Borden et al. (2010) found that the presence of trees near buildings had no effects on collision presence and frequency.

Species vulnerability to collisions

While many bird species have been documented as window collision victims, differences in habits and behavior cause some to be far more susceptible than others. Studies in North America have found that 90% of collisions occur during spring and fall migration (Borden et al. 2010). Passerines that migrate at night, such as warblers and sparrows, collide with windows frequently (Arnold & Zink 2011; Gelb & Delacretaz 2006; Klem Jr 1989) because they must traverse many stepping stones of unfamiliar habitat in transit between breeding and wintering grounds. Among the migrants, forest understory species, accustomed to flying low and through restricted space between trees, such as Wood Thrush (*Hylocichla mustelina*), thrushes of the genus *Catharus*, Ovenbird (*Seiurus aurocapilla*) and hummingbirds, are among the most common collision victims (Blem & Willis 1998; Klem Jr 2014). The disproportionate effect of window-collisions on migratory species is particularly noteworthy given that 50% of North American migrants have declined by at least 50% over the past 50 years (Robbins et al. 1989).

Mitigation opportunities

Given the recognized importance of window collisions to bird conservation and its apparent ubiquity (Loss et al. 2015), mitigation options have been both gaining popularity and championed by urban conservationists and architects. Moral/ethical implications notwithstanding, the prevention of collision-caused bird deaths is arguably necessary in order to comply with the Migratory Bird Treaty Act of 1918 and the Endangered Species Act of 1973 (Klem Jr & Saenger 2013). There is a wide variety of bird deterrent techniques used on windows, including: glass with etched or sandblasted patterns, fritted glass displaying opaque patterns on the outer surface, and UV-reflective films. This last solution has the most potential for widespread application, but in order for it to be effective it must reflect 20-40% of incipient radiation between 300 and400 nm (Klem Jr 2009b), and to date this solution has yet to be systematically tested at the building scale.

Patterns that divide the clear space of windows have been proven effective at deterring window collisions when placed no more than 10cm apart (Klem Jr 1990; Klem Jr 2009b).

Purpose

The purpose of this study was to investigate the patterns of bird-window collisions at Duke University's campus in Durham, North Carolina. We set out to identify the buildings and building characteristics associated with the highest frequencies of bird-window collisions on campus.

Unlike many research projects, this one was carried out with advocacy in mind. A fundamental goal of this study was to generate an evidence-based foundation from which we could advise Duke University on the scope of bird death on campus, and how it might best be mitigated. Here, we present results on the bird-window collision data, and the resulting mitigation action.

Methods

Study area

The study site is Duke University's West Campus located in Durham, North Carolina, United States (Figure 1). Construction of the campus started in 1924 and buildings continue to be added to the 200 existing structures. The suburban campus spans 34 km^2, 29 km^2 of which are forested. West Campus has a predominantly gothic architecture, though newer buildings include elements of modern construction such as large windows for natural light, multiple wings, and as many as four stories. Starting in 2000, Duke University's administration decided that all new buildings and major renovations would be Leadership in Energy and Environment Design (LEED™) certified, with a goal of earning at least LEED™ Silver status for each (Campus Sustainability Committee 2015).

We selected 6 buildings for the study, stratifying by size: Fitzpatrick Center for Interdisciplinary Engineering Medicine and Applied Sciences (Fitzpatrick), French Family Science Center (French), Penn Pavilion (Penn), Schwartz-Butters Athletic Center (Schwartz), The Perk, and Law School extension (Law extension). Small buildings were <2500 m² (The Perk, Law extension), medium sized buildings were between 2500 m² and 4500 m² (Schwartz, Penn), and large buildings were between 25000 m² and 32000 m² (French, Fitzpatrick). All buildings except Schwartz are LEED™ certified.

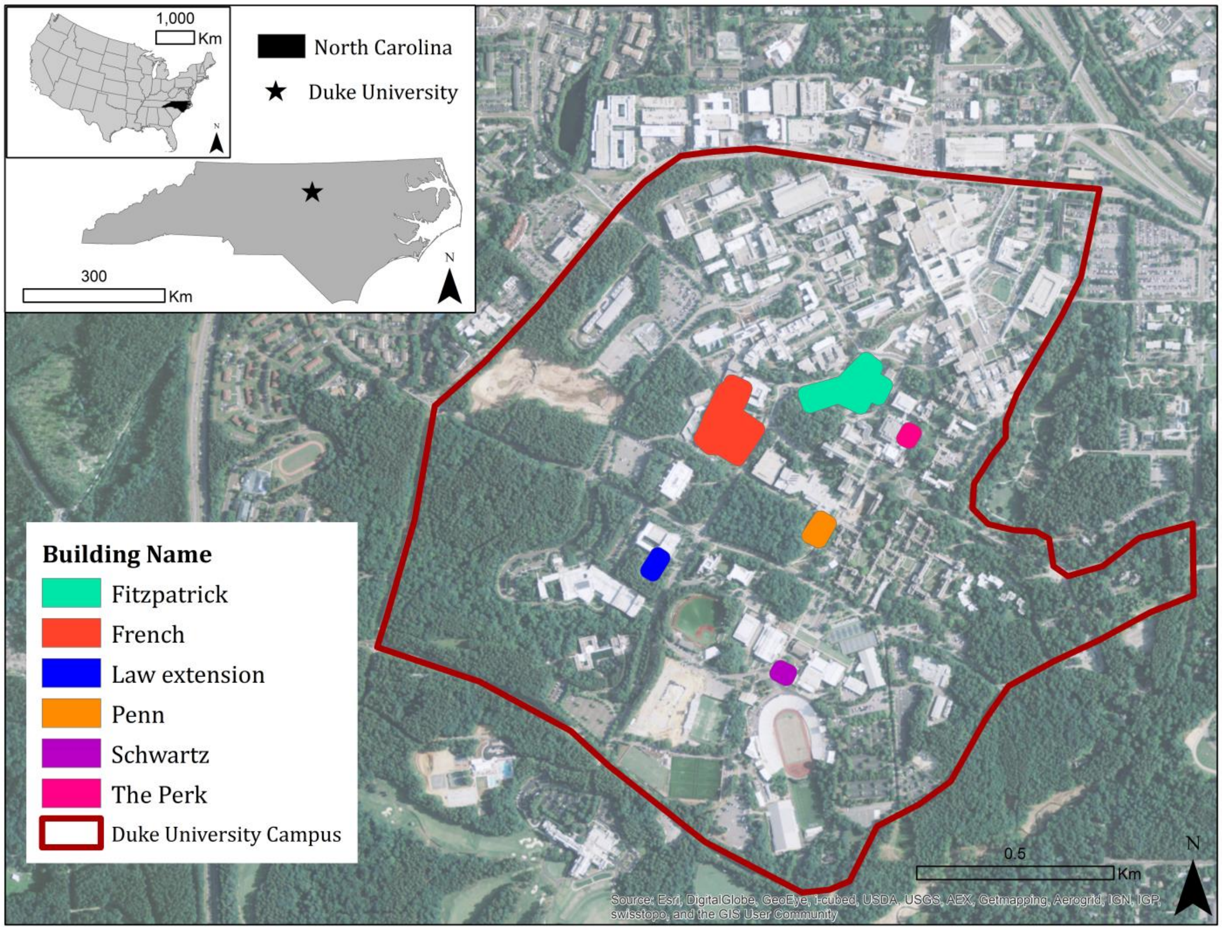

Figure 1. Study area. Upper left corner shows the location of the campus in the United States, and within the state of North Carolina. Main panel shows Duke University's West campus and the six study buildings. Background image source: Esri (2015).

Carcass surveys

We conducted three carcass surveys during peak migration periods in spring and fall 2014, and spring 2015 following methods described by Hager & Cosentino (2014). We surveyed the 6 study buildings between 1400 and 1600 hrs every day for 21 consecutive days. Before the 21-day survey, we picked up all the accumulated carcasses at each building during a clean-up survey, so all buildings started the survey period with zero carcasses. Spring surveys were between April 1st and 21st (clean up March 31st) and the fall survey ran from September 22nd to October 12th (clean-up September 21st). We conducted surveys daily to minimize imperfect detection due to carcass removal by scavengers (Hager et al. 2012).

During each survey, two observers walked the entire perimeter of each building twice, at a constant speed, looking for carcasses in a 2 m search swath from the building wall. All carcasses or feather piles were recorded, collected, and deposited in a freezer for identification confirmation. Some carcasses from the surveys were used for teaching purposes at Duke University, while most of the carcasses were given to the North Carolina Museum of Natural Sciences in Raleigh, NC. We identified all complete carcasses to species, but we left some feather piles unidentified due to uncertainty. Following the data collection protocol proposed by Hager & Cosentino (2014), we filled data forms for all surveys, including those in which no birds were found.

Although we only conducted standardized surveys during peak migration times, we collected incidental collision data year-round using the smartphone app and webpage iNaturalist (Ueda et al. 2015). Since these data are not standardized, we only used these incidental reports for documenting species richness in bird-window collisions at Duke University. We only used standardized survey data for all analyses of abundance.

All carcasses from surveys and random reports were collected and stored in on-campus facilities in pursuance of Federal Fish and Wildlife Permit MB49165B-0.

Buildings and surrounding area

We collected the following data on building traits: floor space (m^2), building height (m), total window area (m^2), percentage of window area to wall surface (%), LEED™ certification, and presence of a pattern on the glass that could act as bird deterrent.

We used the high resolution (1m) land cover map for Durham produced by the US Environmental Protection Agency (2013) to classify the buildings' surrounding area into three main classes: grass, forest, and impervious. We created land cover thresholds based on percent cover within a 25m radius. We defined forest and impervious surface as those areas with at least 80% coverage in the 25m range. Grass had a lower threshold of 25%. With the classified landcover map, we calculated the percentage of area covered by grass, forest, and impervious surfaces within a 50m buffer around the study buildings.

Because of a small sample size of just six buildings and because two of the sampled buildings proved to be outliers, conventional statistical tests were not appropriate for our building attribute data. Instead, we discuss qualitatively the factors that appear to be associated with collision frequency and drive the outliers.

Resolution and media coverage

Resolutions are an advocacy tool that allows a community to call attention to an issue and suggest action from the administration. At Duke, the Graduate and Professional Student Council (GPSC) is an important organization for communicating student needs to University administrators. After two seasons of surveys, we wrote a resolution accounting for the documented bird-window collisions on campus to date, and asking Duke University administrators to take action to mitigate bird-window collisions on campus. We presented the resolution to the GPSC General Assembly, which represents more than 8000 students. The resolution passed unanimously and was sent to all Duke University high level administrators, trustees and academic deans.

We also agreed to interviews with journalists from the Duke Chronicle, the Raleigh News and Observer, WNCN (local NBC news affiliate), and WRAL (local CBS news affiliate). In addition to the extensive local media coverage, the story of bird-window collisions was the subject of blogs hosted by the Nicholas School of the Environment, the American Birding Association, and Glass Magazine (Supplementary data 1).

Results

The buildings with the most glass area, highest percent glass area, and high surrounding forest cover tended to kill the most birds (Table 1, Figure 2). The building with the largest glass area, 57% glass cover and 33% surrounding forest cover, Fitzpatrick, caused 61 of the 86 (71%) collisions detected during standardized surveys (Figure 2, Figure 3A-B). A building with similar amount of glass area but with just 27% of its façade made of glass and little forest cover, French, yielded just 10 collisions (11%), making it the second-most-deadly building of the survey (which it shares with the much smaller Law Extension). The only building in the study with bird deterrent glass, Penn, caused just two window collisions and was the least deadly building in terms of collisions per glass area despite being similar to a glass box (97% glass cover), and in a heavily forested setting (76% surrounded by forest) (Figure 3C-D). Other buildings that caused two or fewer collisions were the two buildings with smallest amount of glass coverage and low surrounding forest cover, Schwartz and The Perk. Schwartz is the only building in the study that is not LEED™ certified.

Table 1. Building traits, surrounding area characteristics and collisions results for six buildings at Duke University's West campus. Percentage impervious, grass, and forest are based on a 50m buffer around the building. Days with collisions and total collisions are based on collisions detected during 63 days of standardized surveys in the fall and spring of 2014 and spring of 2015. LEED™: Leadership in Energy and Environmental Design Certification.

	Building traits				Surrounding area				Collision results			
Building name	Floorspace (m^2)	Glass area (m^2)	Glass coverage (%)	LEED™	Impervious surface (%)	Grass (%)	Forest (%)	Distance to forest patch (m)	Clean-up survey	Days with collisions	Collisions/ $100m^2$ glass	Total collisions
Fitzpatrick	30860	1883	57	Silver	20	47	33	34	19	25	3.24	61
French	27282	1716	27	Silver	60	39	1	102	2	8	0.58	10
Schwartz	4040	148	12	-	95	5	0	166	0	2	1.35	2
Penn*	2322	437	98	Silver	18	6	76	0	0	1	0.46	2
Law extension	604	199	56	Green	41	21	39	0	3	2	5.03	10
The Perk	416	42	18	Green	74	13	14	218	0	1	2.38	1
	* Building with pattern on glass											

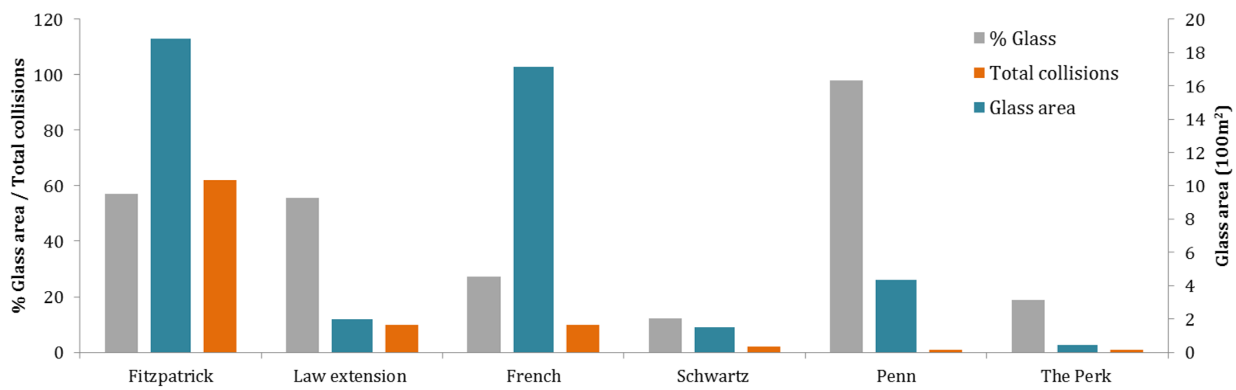

Figure 2. Glass metrics and bird-window collisions detected during 3 seasons of 21-day surveys of six buildings at Duke University's West campus in Durham, NC. Penn is the only building in the study fritted glass known to deter birds.

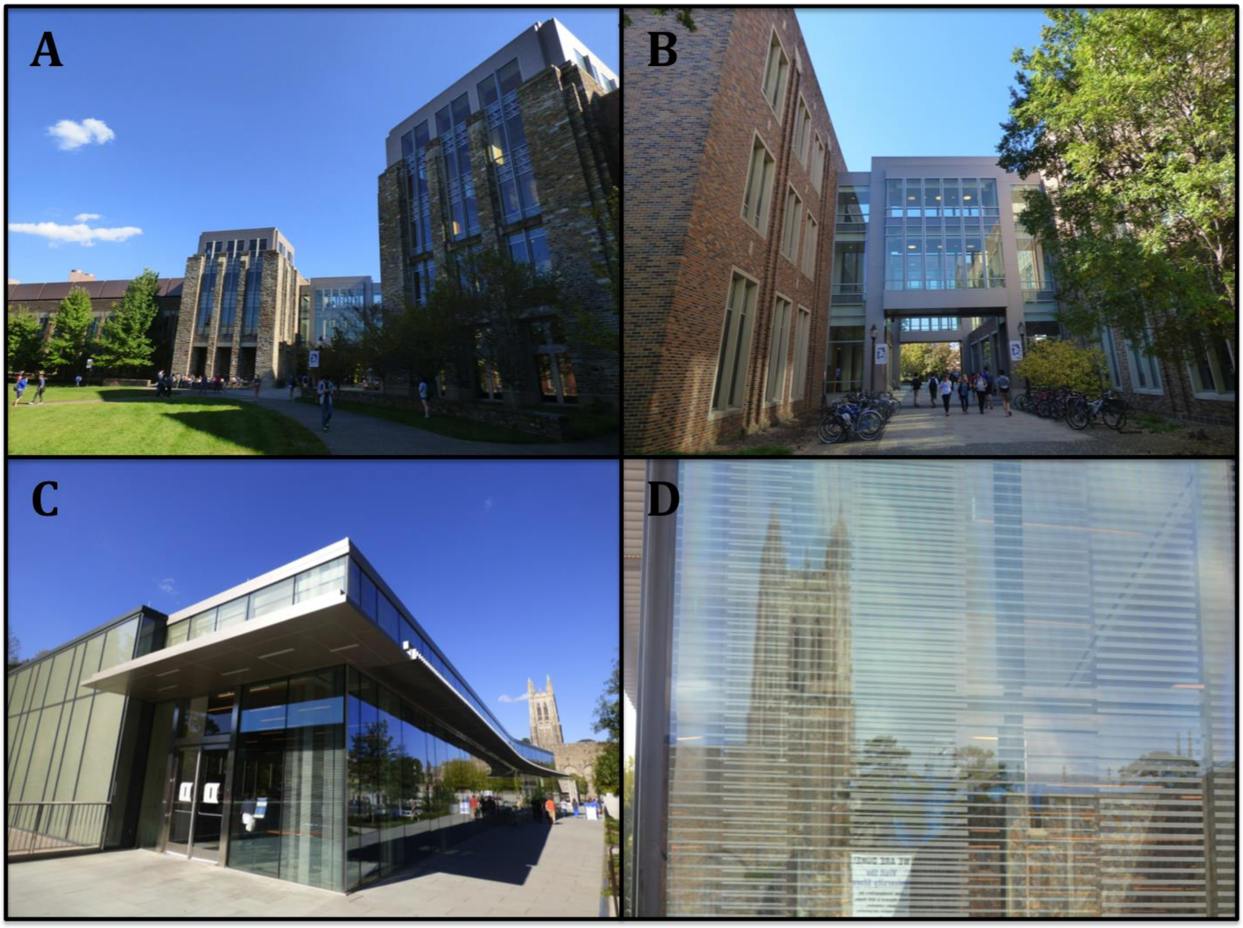

Figure 3. A-B: Fitzpatrick, the buildings with the highest bird-window collision frequency at Duke University. C-D Penn, the only building with bird deterrence patterns at Duke University.

In addition to the carcasses discovered during our 21-day surveys, we documented 102 incidental collisions throughout the study period across the entire Duke University campus, as well as 33 collisions found during carcass cleanups prior to each survey period. Incidental collisions were most frequently documented during important months for bird migration (September, October, April) (Figure 4).

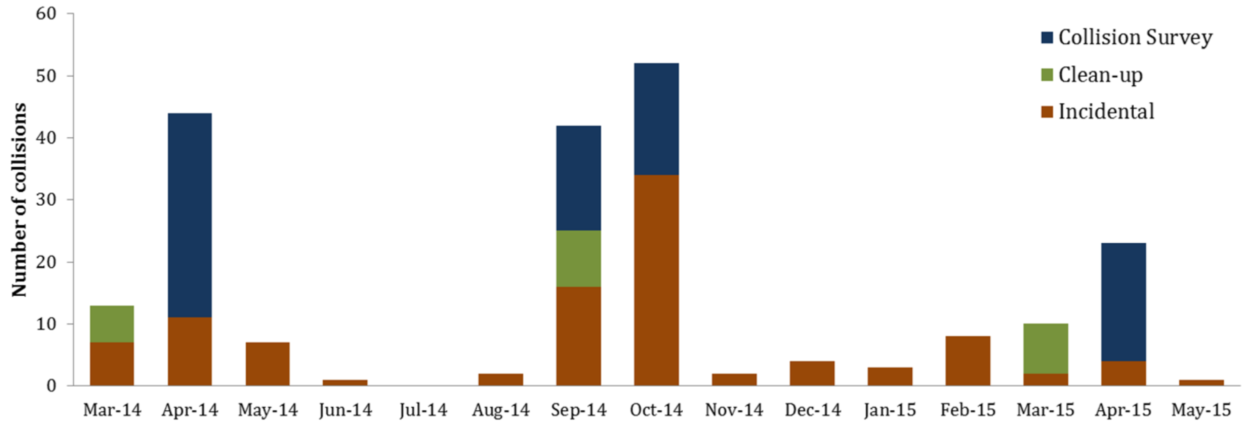

Figure 4. Seasonal distribution of bird-window collisions binned by month at Duke University's West campus in Durham, NC.

We documented 41 species as collision victims, 31 of which (76%) were migratory. Five species collided with windows five or more times during the standardized carcass surveys: Cedar Waxwing (11), Ovenbird (7), American Goldfinch (7), Northern Cardinal (6), and Tufted Titmouse (5). Incidental collisions showed a slightly different set of species with the most collisions: Ruby-throated Hummingbird (9), American Goldfinch (8), Yellow-bellied Sapsucker (6), and Hermit Thrush (6) (Table 2).

Table 2. List of species observed as window collision victims at Duke University's West campus during 2014 and 2015. Migratory status from Cornell Lab of Ornithology (2015), complemented with local observations.

Order	Family	Common Name	Scientific Name	Migrant*	# Incidental Collisions	2014				2015		Survey total
						Clean-up Spring	Survey Spring	Clean-up Fall	Survey Fall	Clean-up Spring	Survey Spring	
Columbiformes	Columbidae	Mourning Dove	*Zenaida macroura*		1		1					1
Apodiformes	Trochilidae	Ruby-throated Hummingbird	*Archilochus colubris*	x	9				1		2	3
Piciformes	Picidae	Downy Woodpecker	*Picoides pubescens*		1							0
Piciformes	Picidae	Northern Flicker	*Colaptes auratus*		1					1		0
Piciformes	Picidae	Yellow-bellied Sapsucker	*Sphyrapicus varius*	x	6				1			1
Piciformes	Picidae	Red-bellied Woodpecker	*Melanerpes carolinus*		3							0
Passeriformes	Vireonidae	Red-eyed Vireo	*Vireo olivaceus*	x	2				3			3
Passeriformes	Paridae	Tufted Titmouse	*Baeolophus bicolor*		1	1	5					5
Passeriformes	Sittidae	White-breasted Nuthatch	*Sitta carolinensis*	x			1					1
Passeriformes	Troglodytidae	Carolina Wren	*Thryothorus ludovicianus*		1							0
Passeriformes	Regulidae	Golden-crowned Kinglet	*Regulus satrapa*	x	3							0
Passeriformes	Regulidae	Ruby-crowned Kinglet	*Regulus calendula*	x			1				1	2
Passeriformes	Turdidae	American Robin	*Turdus migratorius*	x	1	1	1			2	2	3
Passeriformes	Turdidae	Veery	*Catharus fuscescens*	x				1				0
Passeriformes	Turdidae	Gray-cheeked Thrush	*Catharus minimus*	x	1				1			1
Passeriformes	Turdidae	Hermit Thrush	*Catharus guttatus*	x	6					1		0
Passeriformes	Turdidae	Wood Thrush	*Hylocichla mustelina*	x	1			1	3			3
Passeriformes	Turdidae	Swainson's Thrush	*Catharus ustulatus*	x				1				0
Passeriformes	Mimidae	Brown Thrasher	*Toxostoma rufum*			1			2			2
Passeriformes	Mimidae	Northern Mockingbird	*Mimus polyglottos*						2			2
Passeriformes	Mimidae	Gray Catbird	*Dumetella carolinensis*	x	4			2	3			3
Passeriformes	Bombycillidae	Cedar Waxwing	*Bombycilla cedorum*	x	2	1	11					11
Passeriformes	Parulidae	American Redstart	*Setophaga ruticilla*	x	2				1		2	3
Passeriformes	Parulidae	Black-throated Blue Warbler	*Dendroica caerulescens*	x					1			1
Passeriformes	Parulidae	Black-throated Green Warbler	*Dendroica virens*	x					1			1
Passeriformes	Parulidae	Cape May Warbler	*Dendroica tigrina*	x	2							0
Passeriformes	Parulidae	Chestnut-sided Warbler	*Dendroica pensylvanica*	x	1							0
Passeriformes	Parulidae	Common Yellowthroat	*Geothlypis trichas*	x	4			1				0
Passeriformes	Parulidae	Ovenbird	*Seiurus aurocapilla*	x	1			1	2		4	6
Passeriformes	Parulidae	Yellow-rumped Warbler	*Dendroica coronata*	x	4		1					1
Passeriformes	Emberizidae	White-throated Sparrow	*Zonotrichia albicollis*	x	2		1					1
Passeriformes	Emberizidae	Eastern Towhee	*Pipilo erythrophthalmus*		3							0
Passeriformes	Emberizidae	Song Sparrow	*Melospiza melodia*	x	4						1	1
Passeriformes	Emberizidae	Swamp Sparrow	*Melospiza georgiana*	x	3						1	1
Passeriformes	Emberizidae	Dark-eyed Junco	*Junco hyemalis*	x	3						1	1
Passeriformes	Emberizidae	Fox Sparrow	*Passerella iliaca*	x	1							0
Passeriformes	Cardinalidae	Indigo Bunting	*Passerina cyanea*	x	1							0
Passeriformes	Cardinalidae	Northern Cardinal	*Cardinalis cardinalis*		2		2		2	1	2	6
Passeriformes	Cardinalidae	Rose-breasted Grosbeak	*Pheucticus ludovicianus*	x	1			1				0
Passeriformes	Cardinalidae	Scarlet Tanager	*Piranga olivacea*	x	1							0
Passeriformes	Fringillidae	American Goldfinch	*Carduelis tristis*	x	8				6	1	1	7
		Unidentified	Unidentified		12	2	7	1	6	2	3	16
			Total	31	98	6	31	9	35	8	20	86

*Resident populations on Duke University campus may be augmented by migrants from more northerly latitudes, so it is impossible to determine whether residents and/or migrants of these species are colliding with windows

After collecting these collision data and observing Fitzpatrick's dominant contribution to bird-window collisions, our group, supported by the Graduate and Professional Student Council, led an effort to retrofit Fitzpatrick with bird deterrent patterns. Duke University facilities management department installed a bird deterrent film on several sections of glass façade at Fitzpatrick. Two glass passageways (Figure 5A) and other windows we identified as dangerous for birds, were retrofitted with a 2'x2' dotted pattern film called Feather Friendly® which is produced by the Canadian-based company Convinience Group Inc (2015) (Figure 5B). Installation was completed in September 2015.

Figure 5. Bird deterrence dotted patterns in Fitzpatrick building at Duke University. A: Glass passageways. B: Close up of dotted pattern. Photos: Casey Collins.

Discussion

Building traits, glass, and surrounding area

Our results are consistent with those of previous studies documenting a positive relationship between glass area and window collisions (Borden et al. 2010; Hager et al. 2013). Buildings on Duke University's campus with more glass tended to cause more bird-window collisions. Fitzpatrick, the building with the most window area, caused the most collisions. Schwartz and the Perk, the two small buildings with small window areas, had the lowest collision frequencies.

The main exception to the correlation between glass area and collision frequency was at Penn, the only building with fritted glass incorporated into the façade. Fritted glass is a feature known to deter bird collisions (Klem Jr 1990). Vertical frit lines cover approximately 30% of Penn's windows (Figure 3D), which likely helps birds recognize the glass as a barrier mitigating collision incidence.

In addition to glass area, the habitat cover of areas surrounding buildings is also thought to have an impact on the collision susceptibility (Hager et al. 2013). We found some anecdotal evidence that surrounding area may be interacting with the glass effects we observed at Duke University's campus. For example, Schwartz and the Perk not only have small glass area, but are also surrounded by a high proportion of impervious cover and relatively removed from wooded green spaces, which may have further reduced their susceptibility to collisions. In contrast, Law Extension had a relatively high percentage (39%) of forested surrounding, which may have contributed to a high rate of collisions per glass area. If surrounding forest is an important risk factor for bird-window collisions, then it makes the relative scarcity of collisions detected at Penn particularly compelling. Not only is the façade of Penn nearly completely made of glass, but the building is partially surrounded by old growth (100+ year-old) forest, which may further indicate the effectiveness of glass fritting in this case.

While the deadliest building, Fitzpatrick, has a moderate amount of surrounding forest cover (33%), we attribute the high total number of collisions it caused to two second-story transparent glass passageways that connect wings of the building (Figure 5A). While we did not specifically keep track of collision victims collected from beneath the glass passageways we began to notice that they were a likely site for finding carcasses as we conducted surveys. This observation is consistent with other studies that have implicated glass tunnels as architectural features associated with high incidence of window-collisions (Agudelo-Álvarez et al. 2010; Klem Jr 1989).

We noticed a dominance of glass in buildings that are LEED™ certified which could make these "green" buildings especially deadly to birds. Fitzpatrick is certified at the Silver level and has significant amounts of glass, but the same was true for Penn (Table 2). Although LEED™ certified buildings have the potential to be more dangerous for birds (due to high glass area), collision prevention solutions could also be incorporated to these "green" structures. American Bird Conservancy has already advocated for a LEED credit to prevent window collisions (US Green

Buildings Council 2011) but we encourage more research on the impact of the certification on collisions, and recommend this issue be weighted more heavily in the certification scheme.

Seasonality

From our year-round campus-wide incidental collision data, we observed a trend of higher bird-window collisions during spring and fall migration, especially during September and October (Figure 3). In a campus in Ohio, where similar research took place, 90% of deaths by collisions also occurred during migration (Borden et al. 2010). We confirm that standardized surveys during peak migration, as proposed by Hager & Cosentino (2014), is an efficient way of gathering collision data. We recommend augmentation of their survey method by adding a spring survey to the protocol because it improves chances to detect some species that may be missed in the fall.

Species vulnerability

Although collisions occur year-round and can impact a wide range of bird species, studies show a prominence of migratory species as collision victims (Blem & Willis 1998; Borden et al. 2010; Klem Jr 2009a). Our data supports the idea that migratory birds are especially susceptible to window-collision mortality, as we found that 76% of the species recorded during carcass surveys were migratory and an additional 9% were partially migratory. One migratory species, Cedar Waxwing (*Bombycilla cedrorum*), was involved in more collisions than any other species, accounting for 17% of the total collisions detected during surveys. Cedar Waxwing is a gregarious species during migration (Sibley 2003) and when collisions occurred, we found several individuals simultaneously. This species may be particularly vulnerable to collisions because of the consumption of fermented berries that can cause ethanol toxicosis affecting the bird's flight and sense of orientation (Fitzgerald et al. 1990). The second most common collision victim on Duke University campus, the Ovenbird (*Seiurus aurocapilla)*, is listed by many studies of bird-window collisions as one of the most frequently encountered species (Blem & Willis 1998; Borden et al.

2010; Cusa et al. 2015; Hager et al. 2008) . The Ovenbird is an understory specialist, a guild which has been identified as highly vulnerable to collisions (Blem & Willis 1998).

The non-migratory species we most frequently observed as collision victims were Northern Cardinal and Tufted Titmouse. Other studies have noted the pattern that migrants collide most frequently during migration, whereas permanent residents are at risk of collision year-round (Blem & Willis 1998).

Retrofitting of Fitzpatrick

The combination of sound scientific data, media coverage, and a resolution backed up by representatives of more than 8000 students (approximately half of the total student body), led Duke University to take action to mitigate bird deaths on campus (Figure 5). Scientific data allowed us to identify problem buildings and prioritize. Media coverage helped communicate a local problem to a wider audience, and put pressure on the school's reputation. The GPSC resolution helped us reach high level administrators which may have otherwise been insulated from this issue. An additional research project we participated in allowed us to put Duke University's collision data in context. A collaboration led by Hager and Cosentino aimed to evaluate the drivers of bird-window collisions in North America in 40 university campuses. Duke University was the campus with the highest collision frequency (unpublished data) which contributed to our call to action.

Conservation biology is described as a 'crisis science' (Soulé 1985), but all too often biological research ends for the scientist at the publication stage and crises remain unsolved. Here, we have presented a rare example of conservation research that progressed almost immediately from data collection to mitigation. We caution that action did not happen serendipitously, but rather we engaged with decision makers and reached out to the media. This required effort beyond the scope of the standard research life cycle, but we encourage other researchers, particularly those in conservation biology, to follow our example and engage media, peers and decision-makers to resolve the crises being studied.

Recommendations

Bird-window collision studies have looked at patterns of presence and frequency of collisions as a snap-shot, but research that compares time of collision, different seasons, years, or even decades are still lacking. We recommend collision surveys that collect data over migratory and non-migratory seasons, and for consecutive years. Another factor that has been overlooked in the analysis of collisions patterns is the weather. From studies about migration, we know that bird movements can be affected by the weather, yet we still ignore how it can affect the frequency of bird-window collisions. At our site, we looked into this relationship and found some interesting trends that we would like to confirm with a larger dataset.

Monitoring the effectiveness of bird deterrent materials is fundamental for the management of current buildings, and the planning of future structures. Additionally, testing these materials at the building scale and evaluating the effectiveness of UV-reflective materials is still needed. When available, placing camera traps near windows might help with document the timing of collisions, as well as mapping exact locations of collision events to better inform prevention.

Acknowledgements

We thank the many Duke University masters and undergraduate students who assisted with data collection for this project, especially the Wildlife Surveys class at the Nicholas School of the Environment. We also thank the many volunteers around campus who have collected data for the collision project since 2013, especially Anna Wilson. John Gerwin of the North Carolina Museum of Natural Sciences assisted by receiving all bird carcasses we collected. We thank the 2014-2015 General Assembly of the Graduate and Professional Student Council for unanimously passing our bird-window collisions resolution. Duke University Facilities and Management Department deserves credit for its willingness to understand our study and take action on behalf of campus birds by retrofitting Fitzpatrick.

Data availability

All data used for this publication can be made available, upon reasonable request, by the corresponding author.

Literature Cited

Agudelo-Álvarez L, Moreno-Velasquez J, and Ocampo-Peñuela N. 2010. Colisiones de aves contra ventanales en un campus universitario de Bogotá, Colombia. *Ornitología Colombiana* 10:3-10.
Arnold TW, and Zink RM. 2011. Collision mortality has no discernible effect on population trends of North American birds.
Blem C, and Willis B. 1998. Seasonal variation of human-caused mortality of birds in the Richmond area. *The Raven* 69:3-8.
Borden WC, Lockhart OM, Jones AW, and Lyons MS. 2010. Seasonal, taxonomic, and local habitat components of bird-window collisions on an urban university campus in Cleveland, OH. *The Ohio Journal of Science* 110:44-52.
Campus Sustainability Committee. 2015. Buildings, Duke sustainability. *Available at* https://sustainability.duke.edu/campus_initiatives/buildings/ (accessed 6/15/2015.
Convinience Group Inc. 2015. Feather Firendly Bird Deterrent Technology (accessed 9/25 2015).
Cornell Lab of Ornithology. 2015. All about birds: species factsheets (accessed 6/24 2015).
Cusa M, Jackson DA, and Mesure M. 2015. Window collisions by migratory bird species: urban geographical patterns and habitat associations. *Urban Ecosystems*:1-20.
DeSante DF, D. R. Kaschube, and Saracco JF. 2015. Vital Rates of North American Landbirds.
Esri D, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community. 2015. World Satellite Imagery. In: ESRI Arc Map 10.3, editor.
Fitzgerald S, Sullivan J, and Everson R. 1990. Suspected ethanol toxicosis in two wild cedar waxwings. *Avian diseases*:488-490.
Gelb Y, and Delacretaz N. 2006. Avian window strike mortality at an urban office building. *The Kingbird* 56:190-198.
Hager SB, and Cosentino BJ. 2014. Surveying for bird carcasses resulting from window collisions: a standardized protocol. *PeerJ PrePrints* 2:e406v401.
Hager SB, Cosentino BJ, and McKay KJ. 2012. Scavenging affects persistence of avian carcasses resulting from window collisions in an urban landscape. *Journal of Field Ornithology* 83:203-211.
Hager SB, Cosentino BJ, McKay KJ, Monson C, Zuurdeeg W, and Blevins B. 2013. Window Area and Development Drive Spatial Variation in Bird-Window Collisions in an Urban Landscape. *PLoS ONE* 8:e53371.
Hager SB, and Craig ME. 2014. Bird-window collisions in the summer breeding season. *PeerJ* 2:e460.

Hager SB, Trudell H, McKay KJ, Crandall SM, and Mayer L. 2008. Bird density and mortality at windows. *The Wilson Journal of Ornithology* 120:550-564.
Klem Jr D. 1989. Bird Window Collisions. *The Wilson Bulletin* 101:606-620.
Klem Jr D. 1990. Collisions between Birds and Windows: Mortality and Prevention *Journal of Field Ornithology* 61:120-128.
Klem Jr D. 2009a. Avian mortality at windows: The second largest human source of bird mortality on earth. In: T. D. Rich CA, D. Demarest, and C. Thompson, editor. Tundra to Tropics: Proceedings of the Fourth International Partners in Flight Conference. McAllen, Texas, USA: Partners in Flight. p 244–251.
Klem Jr D. 2009b. Preventing bird-window collisions. *The Wilson Journal of Ornithology* 121:314-321.
Klem Jr D. 2014. Landscape, Legal, and Biodiversity Threats that Windows Pose to Birds: A Review of an Important Conservation Issue. *Land* 3:351-361.
Klem Jr D, and Saenger PG. 2013. Evaluating the effectiveness of select visual signals to prevent bird-window collisions. *The Wilson Journal of Ornithology* 125:406-411.
Loss SR, Marra PP, and Will T. 2015. Direct Mortality of Birds from Anthropogenic Causes. *Annual Review of Ecology, Evolution, and Systematics* 46.
Loss SR, Will T, Loss SS, and Marra PP. 2014. Bird-building collisions in the United States: Estimates of annual mortality and species vulnerability. *The Condor* 116:8-23.
Robbins CS, Sauer JR, Greenberg RS, and Droege S. 1989. Population declines in North American birds that migrate to the Neotropics. *Proceedings of the National Academy of Sciences* 86:7658-7662.
Sibley D. 2003. *The Sibley field guide to birds of eastern North America*: Chanticleer Press and Alfred A. Knopf, Inc.
Soulé ME. 1985. What is conservation biology? A new synthetic discipline addresses the dynamics and problems of perturbed species, communities, and ecosystems. *BioScience* 35:727-734.
Ueda K, Belmonte J, Shepard A, Leary P, and Loarie S. 2015. iNaturalist (accessed 9/2014 2014).
US Environmental Protection Agency. 2013. EnviroAtlas – Meter Resolution Urban Area Land Cover Map for Durham, NC (2010). In: Laboratory UEOoRaDNER, editor. Research Triangle Park, NC.
US Green Buildings Council. 2011. Pilot Credit 55: Bird collisions deterrence. LEED Pilot Credit Library. United States.

Supplementary data 1. Newspaper and TV stories about bird-window collisions at Duke University.

Date	Media	Title	Link
23/5/2013	The Chronicle (Duke University's newspaper)	Grad student advocates for bird-friendly windows	http://www.dukechronicle.com/article/2013/05/grad-student-advocates-bird-friendly-windows
16/4/2015	American Birding Association Blog	Open Mic: Bird-window collisions and "green" buildings on Duke's campus	http://blog.aba.org/2015/04/open-mic-bird-window-collisions-and-green-buildings-on-dukes-campus.html
22/5/2015	The Chronicle (Duke University's newspaper)	Duke's bird safety one of worst in nation according to Bird Window Collision Project	http://www.dukechronicle.com/article/2015/05/dukes-bird-safety-one-worst-nation-according-bird-window-collision-project#.VV8ubFVViko
15/6/2015	WNCN (local associate of	Duke University's bird collision problem	http://wncn.com/2015/06/15/duke-universitys-bird-collision-problem/
6/17/2015	The News & Observer	Duke 'green' building blamed for bird deaths	http://www.newsobserver.com/news/local/community/durham-news/article24691264.html
6/21/2015	Glass Magazine Blog	Birds and glass	http://fromthefabricator.blogspot.com/2015/06/birds-and-glass.html
6/24/2015	WRAL	Duke researchers hope to make campus building more bird-friendly	http://www.wral.com/duke-researchers-hope-to-make-campus-building-more-bird-friendly/14735932/
7/3/2015	The News & Observer	Bob Wilson: Duke's bird killer and the law of unintended consequences	http://www.newsobserver.com/news/local/community/durham-news/dn-opinion/article25831687.html
8/25/2015	The Chronicle (Duke University's newspaper)	Birds fly free at Duke: CIEMAS adds patterned film	http://www.dukechronicle.com/article/2015/08/birds-fly-free-at-duke-ciemas-adds-patterned-film
9/15/2015	WRAL	Duke adds design to keep birds from flying into building	http://www.wral.com/duke-adds-design-to-keep-birds-from-flying-into-building/14901036/