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Bird-Strike Risk Factors and Prevention in Atlanta

By

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Master of Science

Environmental Science

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Bird-Strike Risk Factors and Prevention in Atlanta

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Jack Galanek

B.S., The University of the South, 2021

Advisor: Dr. John Wegner, Doctor of Philosophy

An abstract of
A Thesis submitted to the Faculty of the James T. Laney School of Graduate Studies of Emory University in partial fulfillment of the requirements for the degree of Master of Science in Environmental Science
2023

Abstract

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By Jack Galanek

Many bird populations are declining rapidly because of anthropogenic activity. Collisions with man-made structures is among the largest causes of bird mortality, with estimates reaching over 1 billion collisions per year in North America. Birds collide with buildings because they do not recognize windows as physical barriers, but bird deterrent window treatments have been developed to alert birds to a window's presence. Prior research has identified overnight lighting, proximity to trees, window reflection of vegetation, window percentage, and total window area as potential risk factors influencing bird-window collisions. This study identified bird strikes on the campus of Emory University in Atlanta, Georgia, in Fall 2022 along with previously reported strikes in Fall 2019. The relative danger of the identified risk factors at strike locations was analyzed along with the proportions of bird-strikes by taxonomic families. Weather during migration was also analyzed for potential effects on collision likelihood. Bird deterrent tape was also applied to a known bird-collision hot spot to test its marketed efficacy. Distance to vegetation did not prove significant in explaining bird strike locations, and bird deterrent tape showed only anecdotal decrease in bird strikes. All analyzed facades had both tree reflections and overnight lighting, so no significant relationship with strikes could be recognized. Percent window coverage was strongly positively correlated with bird strike risk, while total window area was negatively correlated with strike risk. Average daily windspeed, minimum temperature, and precipitation did not significantly influence bird strikes in 2022, but both minimum temperature and precipitations showed significant correlation to bird strikes in 2019. These findings will hopefully influence building designers and managers to prioritize management of risk factors to reduce bird-collision risk most effectively and efficiently.

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Introduction

Bird populations have declined rapidly in North America since 1970 resulting in an estimated net loss of nearly 3 billion breeding birds. Migratory species bear the brunt of the population loss, as 2.5 billion individuals from 419 migratory species were lost, although the greatest proportional loss occurred in overwintering migratory species (Rosenberg et al. 2019). Collisions with man-made structures is the second largest threat to migratory birds in North America, behind only predation by domestic cats, resulting in an estimated 365 million to over 1 billion birds per year dying in collisions (Loss et al. 2015).

Bird-window collisions occur when a bird is unable to recognize the glass as a barrier or is confused by the reflection of habitat in the window (Klem 1989, USFWS 2016). The likelihood of bird-window collisions is impacted by environmental factors surrounding the collision site. Seasonality is an important component, as increases in the number of strikes correspond with migratory seasons, especially fall migration (Borden et al. 2010, Hager et al. 2008, Klem 1989). Another key factor is the amount of glass constituting a building's façade, as there is a significant positive correlation between percent glass cover and bird window collisions (Cusa et al. 2015). Similarly, buildings with high total glass cover have a higher risk for collisions (Ocampo-Pañuela 2016b) Nearby vegetation also increases the probability of collisions at a given window, as vegetation reflected in the window attracts birds, especially when vegetation reaches a height of at least five meters (Borden et al. 2010, Gelb & Delacretaz 2006, Loss et al. 2019). Artificial light at night (ALAN) influences bird mortality as well. These lights can kill birds directly by attracting them into collisions with structures, or indirectly by affecting their orientation ability and their selection of habitat and refueling sites (Evans Ogden 1996, Horten et al. 2019, Longcore & Rich 2004, Van Doren et al. 2017). Frequency of bird window collisions is also dependent on the building type. High rises account for less than 1% of bird strike mortalities in North America, while the vast majority of strikes occur at low rises and residences (Loss et al. 2015). Indoor vegetation visible through window and presence of nearby bird feeders also increase the risk of collisions, but these are uncommon traits on Emory's Campus, so they are not analyzed in this study (Gelb & Delacretaz 2009, Klem et al. 2004). Weather patterns may also affect bird collision timing by triggering migration with certain temperature, wind, and precipitation conditions (Haest et al. 2019).

Birds provide many ecosystem services that could be lost if populations continue to decline, including trophic regulation, seed dispersal, pest control, and both the economic and recreational benefits of birdwatching (Díaz-Siefer et al. 2022, Howe & Smallwood 1982, Hvebegaardnet al. 1989, Rogers et al. 2012). Fortunately, recovery of breeding North American wetland species, likely due to habitat restoration and management for waterfowl hunting, shows hope of recovery if similar measures are taken on behalf of birds from other habitats (Lees et al. 2022). One such management option for protection of migratory birds is the promotion of bird safe window treatments, which have been shown to successfully reduce bird-window collisions (De Groot et al. 2022, Klem 2009, Ocampo-Peñuela 2016b).

Incorporating bird friendly design elements, such as angled windows, fritted or tinted glass, bird safe landscaping, and lower glass percentage can also reduce the risk of bird window collisions (Brown et al. 2021, Borden et al. 2010, Evans Ogden 1996, Klem 2009, Klem et al. 2004).

Similar research has been done on bird window collisions on other college campuses in Ohio and Illinois and internationally in Colombia and Toronto (Borden et al. 2010, Cusa et. Al 2015, Hager et al. 2008, Ocampo-Peñuela et al. 2016b), but it is unclear whether similar results would be seen in Atlanta because of the differences in environmental factors in the study areas. In general, bird strikes in the eastern United States are of concern, as Eastern US bird biomass has declined significantly between 2007 and 2017 compared to central and western flyways, which saw no consistent change (Rosenberg 2019). Atlanta is of particular interest as it has the highest percentage of canopy cover of any major city in the United States, with 47.9% canopy cover (treesatlanta.org). Atlanta also has very high exposure to overnight lighting during the fall migration compared to other major cities in the United States (Horton et al. 2019), and it is situated within the Atlantic Flyway migration route (Audubon.org).

The purpose of this study is to analyze the factors influencing bird window collisions on Emory University's campus and to test the effectiveness of marketed bird deterrent window decals at a known hotspot for bird window collisions on campus. This analysis of the relative danger associated with each of these bird-collision risk factors and the associated cost, both in money and effort, to mitigate these efforts can inform decision makers about how to feasibly make their buildings as bird safe as possible.

Methods

Collision Surveys

Bird carcass surveys were conducted along a predetermined path throughout Emory University's campus (See Figure 1). The path was chosen to pass along windows that were either previously known hot spots, including the Mathematics & Science Center atrium window with applied BirdTape, or were suspected potential hotspots due to presence of risk factors, such as high window percentage, high total window area, overnight lighting, or proximity to trees. The full path was about 2.1 miles long and took about 75 minutes to complete. Surveys occurred five days per week, Monday through Friday, from August 24 through October 28, at which time surveys were terminated after two weeks of finding no carcasses, indicating that migratory birds had already passed through Atlanta. Surveys were conducted between 5:00 am and 6:30 am to reduce the likelihood of carcasses being collected by building maintenance crews arriving in the morning. Weekends were chosen as non-survey days because the maintenance staff did not usually work on weekends, so carcasses would be more likely to remain until Monday surveys. Dead birds found by windows had location noted and were identified to species except for when impossible due to weather damage or scavenging. In this case, birds were identified to the narrowest taxonomic level possible.

Bird strike data for Fall 2022 was supplemented by individuals found by other Emory community members or by me outside of the designated surveys. Bird strike data was also collected on Emory's campus in Fall 2019 by Emory community members. Many of these had incomplete or missing location data, so this data was not included in façade analysis, but was used for family proportion and weather effect analysis.

Risk Factors

For each facade, presence of overnight lighting was noted as yes or no. Distance to the nearest tree was measured. Tree proximity measurements were rounded to the nearest meter because the measurement extended to the closest appendage of the tree, which was often well out of reach overhead, so more precise measurements were not possible. Google Earth 9.185.0.0 measurement was used for one site because hand measurement was not possible. Comparisons of Google Earth measurements to known hand measurements confirmed Google Earth measure tool is accurate to at least the nearest meter. Window percentage and total window area were measured using ImageJ 1.53, an open-source image analysis software, using known measurements of windowpanes to determine length of pixels in photographs, similarly to Cusa et al. 2015. Many of the buildings had ledges high up on the façade, where bird carcasses may lay outside of vision. In this case, only the façade area below the ledge was analyzed.

Bird Deterrent Application

CollidEscape™ 2" x 164' white High-Performance BirdTape™, marketed as an Ultraviolet (UV) absorbing window tape for bird strike prevention, was applied on the exterior of the southward facing window to Emory University's Mathematics & Science Center atrium, which was a previously known hotspot for bird strikes, having accumulated 40 known strikes over a 19-day monitoring period in September 2002 (Davis 2002). Although CollidEscape™ claims both horizontal and vertical patterns are effective, prior research has shown that vertical stripe patterns are more effective for bird strike prevention than horizontal stripes at the same level of spacing (Rössler et al. 2015). Therefore, the bird deterrent tape was cut and applied in the window in vertical strips with 2 inches of spacing between strips, creating a repeating pattern of 2 inches of tape followed by 2 inches of uncovered window, as directed by CollidEscape™ for optimum bird strike prevention. All exposed window for the full length of the façade was treated with the bird tape up to 10 feet from the ground, as was the maximum height permitted by the university.

Analysis

Data were analyzed and plotted in Microsoft Excel 16.66., RStudio 2022.12.0+353, and R 4.2.2 with packages base, car, utils, graphics, methods, readxl, and stats, each of which were included in R 4.2.2. Due to small sample size, a Shapiro-Wilk normality test showed that the number of strikes by location was not normally distributed, so linear regression could not be used. Instead, binomial logistic regression was used to analyze the relationship between supposed risk factors (distance to nearest tree, total glass area, and percentage glass area) and whether a strike occurred at a surveyed façade. Poisson regression was used to analyze the relationship these risk factors and the number of strikes at each façade. Binomial logistic regression and Poisson regression were then run while including facades with bird strikes reported outside of the surveys. These analyses were then run again while excluding the data from the MSC atrium to account for possible effects of the applied bird deterrent tape. The model of best fit was identified using Akaike information criterion (AIC) where lower AIC indicates better fit.

Pearson's Chi-square tests were used to analyze the difference between family proportions of strikes both within and between 2022 and 2019 data. Carcasses that could not be identified to family level were excluded from the family proportion analyses.

To analyze possible weather effects, daily measurements for temperature, wind speed, and precipitation were retrieved from the Hartsfield Jackson International Airport Station via WeatherUnderground.com. T-test were run to analyze differences in daily minimum temperature, daily average windspeed, and daily precipitation between fall 2019 and 2022. Binary logistic regression analyses were run to investigate the relationship between occurrence of a bird strike and these weather factors. Poisson regressions were run to determine the relationship between these weather factors and the number of daily strikes.

Results

Bird Strikes

During 2022 morning surveys, Twenty-two bird carcasses spanning were found. These spanned four families, 10 genera, and 13 species. Two individuals could not be confidently identified due to weather damage or scavenging. Parulidae, the new world warbler family, was the most represented family, followed by Turidiae, the thrush family. The Tennessee warbler, *Leiothypis peregrina*, was the most common species found, followed by Swainson's thrush, *Catharus ustulatus*. When externally reported strikes were added the survey individuals, a total of 35 carcasses were found spanning seven families, 13 genera, and 19 species along with four individuals that could not be identified to the family level. The most common families represented remained Parulidae and Turdidae, respectively, but Swainson's thrush was the most common species, followed by the Tennessee warbler.

Of the 28 fully identifiable carcasses, only four (Pine Warbler, Song Sparrow, and Two Brown Thrashers) had year-round residency in Atlanta, and 16 of the 28 were strictly migratory species, thus highlighting how migrating birds are at increased risk for collisions.

Family	Common Name	Scientific Name	No.
Mimidae	Gray Catbird	*Dumatella carolinensis*	1
	Brown Thrasher	*Toxostoma rufum*	2
Parulidae	Wilson's Warbler	*Cardellina Pusilla*	1
	Tennessee Warbler	*Leiothypis peregrina*	4
	Ovenbird	*Seiurua aurocapilla*	1
	Yellow-throated	*Setophaga dominica*	1
	Chestnut-sided	*Setophaga pensylvanica*	1
	American Redstart	*Setophaga ruticulla*	1
	Orange-crowned	*Vermivora celata*	1
	Unidentified warbler	*Parulidae G. sp.*	1
Trochilidae	Ruby-throated	*Archilochus colubris*	1
Turdidae	Gray-cheeked	*Catharus minimus*	1
	Swainson's Thrush	*Catharus ustulatus*	3
	Wood Thrush	*Hylocichla mustelina*	1
Unidentifiable			2

Table 1: Bird carcasses found during morning surveys.

Family	Common Name	Scientific Name	No. Observations
Bombycillidae	Cedar Waxwing	*Bombycilla cedrorum*	1
Mimidae	Gray Catbird	*Dumatella carolinensis*	1
	Brown Thrasher	*Toxostoma rufum*	2
Parulidae	Wilson's Warbler	*Cardellina Pusilla*	1
	Tennessee Warbler	*Leiothypis peregrina*	4
	Worm-eating Warbler	*Helmitheros*	1
	Ovenbird	*Seiurua aurocapilla*	1
	Yellow-throated	*Setophaga dominica*	1
	Chestnut-sided Warbler	*Setophaga*	1
	Pine Warbler	*Setophaga pinus*	1
	American Redstart	*Setophaga ruticulla*	1
	Orange-crowned	*Vermivora celata*	1
	Unidentified warbler	*Parulidae G. sp.*	2
Passerelidae	Song Sparrow	*Melospiza melodia*	1
Picidae	Unidentified	*Picidae G. sp.*	1
Trochilidae	Ruby-throated	*Archilochus colubris*	1
Turdidae	Veery	*Catharus Fuscenscens*	1
	Hermit Thrush	*Catharus guttatus*	1
	Gray-cheeked Thrush	*Catharus minimus*	2
	Swainson's Thrush	*Catharus ustulatus*	5
	Wood Thrush	*Hylocichla mustelina*	1
Unidentifiable			4

Table 2: All reported bird carcasses from Fall, 2022.

In 2019, 60 bird carcasses were found from August through October. These carcasses spanned 9 families, 16 genera, and 24 species. The most common families represented were Parulidae and Trochilidae, the hummingbird family, respectively. The most of common bird found was the Ruby-throated Hummingbird, *Archilochus colubris*, with 12 individuals, followed by the Common Yellowthroat, *Geothlypis trichas*, and the Northern Cardinal, *Cardinalis cardinalis*, each with five found carcasses.

There were significantly fewer strikes per day in fall 2022 than 2019, with 0.289 and 0.492 average daily strikes respectively (One tailed t-test, p = 0.026). The proportions of families record between 2019 and 2022 bird strikes differed significantly (X^2= 39.875, df = 24, p = 0.022). Both 2019 and 2022 also showed significant difference in family proportions within the respective year (2019: X^2 = 87.3, df = 8, p = 1.641e-15; 2022: X^2 = 38.774, df = 6, p = 7.925e-7).

Family	Common Name	Scientific Name	Observatinon
Cardinalidae	Northern Cardinal	*Cardinalis cardinalis*	5
Columbidae	Mourning Dove	*Zenaida macroura*	1
Fringillidae	House Finch	*Haemorhous mexicanus*	1
Mimidae	Grey Catbird	*Dumetella carolinensis*	2
	Northern Mockingbird	*Mimus polyglottos*	1
Parulidae	American Redstart	*Setophaga ruticulla*	3
	Black-and-White Warbler	*Mniotilta varia*	2
	Canada Warbler	*Cardellina canadensis*	1
	Common Yellowthroat	*Geothlypis trichas*	5
	Kentucky Warbler	*Geothlypis formosa*	1
	Magnolia Warbler	*Setophaga magnolia*	1
	Setophaga magnolia	*Setophaga magnolia*	1
	Nashville Warbler	*Leiothlypis ruficapilla*	3
	Orange-crowned warbler	*Leiothlypis celata*	1
	Ovenbird	*Seiurus aurocapilla*	3
	Pine Warbler	*Setophaga pinus*	1
	Prarie Warbler	*Setophaga discolor*	1
	Tennessee Warbler	*Leiothlypis peregrina*	1
	Warbler Sp.	*Unidentifiable Warbler*	3
Passerelidae	Grasshopper Sparrow	*Ammodramus savannarum*	1
Trochilidae	Ruby-throated Hummingbird	*Archilochus colubris*	12
Troglodytidae	Winter Wren	*Troglodytes hiemalis*	1
Turdidae	Swainson's Thrush	*Catharus ustulatus*	3
	Veery	*Catharus fuscescens*	2
	Wood Thrush	*Hylocichla mustelina*	2
Unidentified			2

Table 3: All reported bird carcasses from Fall, 2019.

Bird carcasses were found at 10 locations during the morning surveys. The greatest number of carcasses were found at Math & Science Center (MSC) stairwell and Emerson Connector, with five individuals each, followed by MSC atrium and MSC front entrance, with three and two respectively. Only one bird was found at each of the other six locations. At these 10 collision sites, the distance to the nearest tree ranged from 0 to 26 meters an averaged 10.5 meters. The total glass area ranged from 35 to 146 square meters and averaged 104 square meters. Percentage of glass cover at collision sites ranged from 28% to 96% and averaged 64% of the façade. Every collision site had reflection of trees in the window and overnight indoor lighting.

Figure 1: All survey strikes by location signified by proportionally sized symbols. The red line indicates the survey route, and green lines indicated daily surveyed facades.

Bird carcasses were found at a total of 16 locations when community-found strikes are considered as well. Emerson connector had the greatest number of strikes, with seven, followed by the MSC atrium and MSC back stairwell, each with six. Three other sites had two carcasses, and the remaining 10 sites each had one. Among these 16 collision sites, the distance to the nearest tree ranged from 0 to 26 meters and averaged 10.5 meters. The total glass area ranged from 10 to 324 square meters with an average of 102 square meters. Percentage glass constituting the façade ranged from 9% to 96% with an average of 58% glass coverage. All sites still had tree reflections in the glass and overnight lighting.

Figure 2: All reported strikes by location signified by proportionally sized symbols. The red line indicates the survey route, and green lines indicated daily surveyed facades.

When including façades without reported strikes, the distance to nearest tree ranged from 0 to 26 meters and averaged 8.7 meters. The total glass area ranged from 10 to 1418 square meters and averaged 216.7 square meters. Percent glass coverage ranged from 9% to 96% and averaged 50% glass coverage.

Location	Distance To Nearest Tree (m)	Tree Reflection? (0=No, 1=Yes)	Strikes Occurred? (0=No, 1=Yes)	Total Glass (Square Meters)	Percent Glass Cover	No. Strikes	Survey Only Strikes
Library Lower Patio	1	1	1	109.42	27.9708	2	1
Library Stacks	26	1	1	196.95	36.6693	1	1
Library Side Patio	8	1	1	122.03	82.6786	1	1
White Hall	9	1	1	42.291	49.3354	1	1
Candler Theology	14	1	1	122.32	80.434	1	1
Chemistry Back Door	7	1	1	34.768	59.3487	1	1
MSC Front	11	1	1	104.48	71.4021	2	2
MSC Atrium	13	1	1	145.54	68.708	6	3
MSC Back Stairwell	0	1	1	99.611	95.7329	6	5
Emerson Connector	16	1	1	67.506	71.1301	7	5
PAIS Alley	6	1	0	1418.3	75.6678	0	0
LGS Building	6	1	0	190.57	8.9093	0	0
Convocation Front	3	1	0	82.961	15.0564	0	0
Hospital Front	5	1	0	1029.1	60.6262	0	0
Chemistry Front	17	1	0	69.26	64.729	0	0
Goizueta	2	1	0	275.4	18.7402	0	0
MCC Hall	4	1	0	229.27	37.0089	0	0
Convocation	2	1	0	85.97	13.0021	0	0
MSC W Face	5	1	0	444.77	48.6751	0	0
MSC E Face	7	1	0	171.1	21.8854	0	0
Cox Dining Hall Stairs	7	1	1	23.886	70.4395	1	N/a
Woodruff Mem. Research	9	1	1	324.5	80.1997	1	N/A
Dorm Building	6	1	1	38.785	36.906	1	N/A
Parking Garage	8	1	1	9.9218	9.46225	1	N/A
Emerson Backside	11	1	1	169.05	51.2871	1	N/A
MSC Balcony	22	1	1	25.177	32.8834	2	N/A

Table 4: All analyzed locations in Fall, 2022 with measurements for distance to nearest tree, tree reflection, whether a strike occurred, total glass area, percent glass cover, all reported strikes by location, and survey only strikes by location.

Risk Factors

Both overnight lighting and tree reflections were present at all analyzed facades, so they could not be statistically analyzed as binary data. Future research should focus on quantifying the and tree reflection of a façade for further analysis of these risk factors. Model selection using AIC criterion showed that the best fit model excluded the risk factor “distance to nearest tree” for all analyses.

Figure 3: Images of Candler Theology (left) and MCC Hall (right). Both have overnight lighting, but display the difference in lighting level that could be analyzed in future research.

When only survey data is considered, binary logistic regression showed significant positive correlation between whether a bird strike occurred at a façade and percent window coverage (β=0.070310, p=0.0365). Total glass area showed no significant correlation in binomial logistic regression analysis. Poisson regression showed that percent glass cover and the number of bird strikes at a given façade were significant positive correlation (β=0.038020, p=0.000669). When including externally reported strikes, binomial regression showed a significant correlation between percent glass cover and whether a strike occurred (β=0.073992, p=0.0232), and Poisson regression showed significant positive correlation between percent glass cover (β=0.029968, p=0.0000974) and significant negative correlation with total glass area (β=-0.004545, p=0.0399). Excluding MSC atrium from the analysis changed the survey only binomial logistic correlation of percent window coverage to insignificant (β=0.065701, p=0.0507). This exclusion did not cause other results changed from significant to insignificant or vice versa (see Tables 7 and 10).

MSC Atrium Included		MSC Atrium Excluded	
SURVEY ONLY	**AIC**	**SURVEY ONLY**	**AIC**
TWC + PWC	18.988	TWC + PWC	18.69
DNT + TWC + PWC	20.691	DNT + TWC + PWC	20.402
TWC + DNT	23.988	Total Window Coverage	22.8
Total Window Coverage	24.156	TWC + DNT	23.073
Percent Window Coverage	25.246	Percent Window Coverage	24.541
PWC + DNT	25.788	PWC + DNT	25.27
Distance to Nearest Tree	28.496	Distance to Nearest Tree	27.691
ALL REPORTED STRIKES		**ALL REPORTED STRIKES**	
TWC + PWC	23.12	TWC + PWC	22.987
DNT + TWC + PWC	24.556	DNT + TWC + PWC	24.432
TWC + DNT	29.58	TWC + DNT	29.112
Total Window Coverage	30.303	Total Window Coverage	29.41
PWC + DNT	33.152	PWC + DNT	32.843
Percent Window Coverage	34.058	Percent Window Coverage	33.542
Distance to Nearest Tree	34.168	Distance to Nearest Tree	33.711

Table 5: Model selection AIC values for binomial logistic regression analyses of total window coverage (TWC), percent window coverage (PWC), and distance to the nearest tree. Lower AIC values signify better model fit.

Risk Factor	Coefficient	Standard Error	Z-Value	P-Value
SURVEY ONLY				
Percent Window Coverage	0.070310	0.033628	2.091	**0.0365**
Total Window Area	-0.009108	0.007621	-1.195	0.2321
ALL REPORTED STRIKES				
Percent Window Coverage	0.073992	0.032590	2.270	**0.0232**
Total Window Area	-0.013128	0.006979	-1.881	0.0600

Table 6: Risk factor binomial logistic regression statistics (Bold=Significant, Alpha=0.05)

Risk Factor	Coefficient	Standard Error	Z-Value	P-Value
SURVEY ONLY				
Percent Window Coverage	0.065701	0.033627	1.954	0.0507
Total Window Area	-0.009241	0.007863	-1.175	0.2399
ALL REPORTED STRIKES				
Percent Window Coverage	0.071652	0.032780	2.186	**0.0288**
Total Window Area	-0.012913	0.006896	-1.872	0.0611

Table 7: Risk factor binomial logistic regression statistics when MSC atrium with bird deterrent tape is excluded (Bold=Significant, Alpha=0.05)

MSC Atrium Included		MSC Atrium Excluded	
SURVEY ONLY	**AIC**	**SURVEY ONLY**	**AIC**
TWC + PWC	45.6	TWC + PWC	40.05
DNT + TWC + PWC	46.5	DNT + TWC + PWC	41.84
Percent Window Coverage	50.83	Percent Window Coverage	46.22
PWC + DNT	51.29	PWC + DNT	47.2
Total Window Coverage	57.65	Total Window Coverage	51.43
TWC + DNT	58.91	TWC + DNT	53.11
Distance to Nearest Tree	66.66	Distance to Nearest Tree	61.64
ALL SRIKES		**ALL SRIKES**	
TWC + PWC	75.38	TWC + PWC	64.66
DNT + TWC + PWC	76.05	DNT + TWC + PWC	66.2
PWC + DNT	84.51	Percent Window Coverage	75.09
Percent Window Coverage	85.25	PWC + DNT	75.68
Total Window Coverage	91.1	Total Window Coverage	77.42
TWC + DNT	91.94	TWC + DNT	79.06
Distance to Nearest Tree	98.25	Distance to Nearest Tree	86.51

Table 8: Model selection AIC values for Poisson regression analyses of total window coverage (TWC), percent window coverage (PWC), and distance to the nearest tree. Lower AIC values signify better model fit.

Risk Factor	Coefficient	Standard Error	Z-Value	P-Value
SURVEY ONLY				
Percent Window Coverage	0.038020	0.011175	3.402	**0.000669**
Total Window Area	-0.005733	0.004429	1.294	0.195531
ALL REPORTED STRIKES				
Percent Window Coverage	0.029968	0.007690	3.897	**0.0000974**
Total Window Area	-0.004545	0.002212	-2.055	**0.0399**

Table 9: Risk factor Poisson regression statistics (Bold=Significant, Alpha=0.05)

Risk Factor	Coefficient	Standard Error	Z-Value	P-Value
SURVEY ONLY				
Percent Window Coverage	0.039173	0.012179	3.216	**0.0013**
Total Window Area	-0.008125	0.005918	-1.373	0.1698
ALL REPORTED STRIKES				
Percent Window Coverage	0.029519	0.008269	3.570	**0.000357**
Total Window Area	0.005881	0.002791	-2.107	**0.035085**

Table 10: Risk factor Poisson regression statistics when MSC atrium with bird deterrent tape is excluded (Bold=Significant, Alpha=0.05).

Weather Effects

Fall (August-November) 2022 average minimum daily temperature was 14.4 degrees Celsius, which was significantly lower than 2019, 17.2 degrees Celsius (Two sample t-Test, $p<0.01$). There was no significant difference in average daily wind speed or average daily precipitation between 2022 and 2019. Neither binary logistic regression nor poisson regression showed significant relationship between strikes and 2022 daily minimum temperature, wind speed average, and precipitation total, but both daily minimum temperature and precipitation total showed significant correlation with strike occurrence in 2019 (DMT: $\beta=0.10792$, $p=0.00511$; Precipitation: $\beta=3.50138$, $p=0.01491$). Poisson regressions on 2019 daily minimum temperature and precipitation also showed significant correlation with the number of daily bird strikes (DMT: $\beta= 0.07154$, $p=0.002304$; Precipitation: $\beta=1.3311$**,** $p=0.00336$).

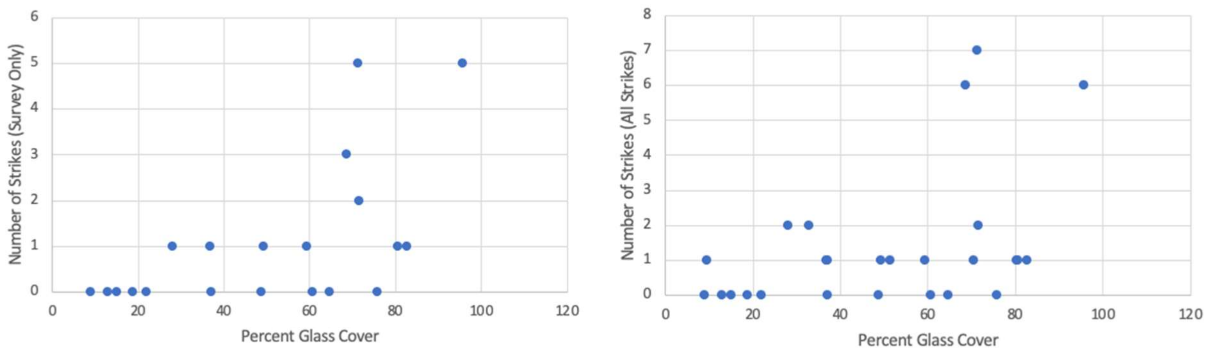

Figure 4: Number of Fall 2022 bird strikes versus percent glass cover: survey only (left) and all reported strikes (right).

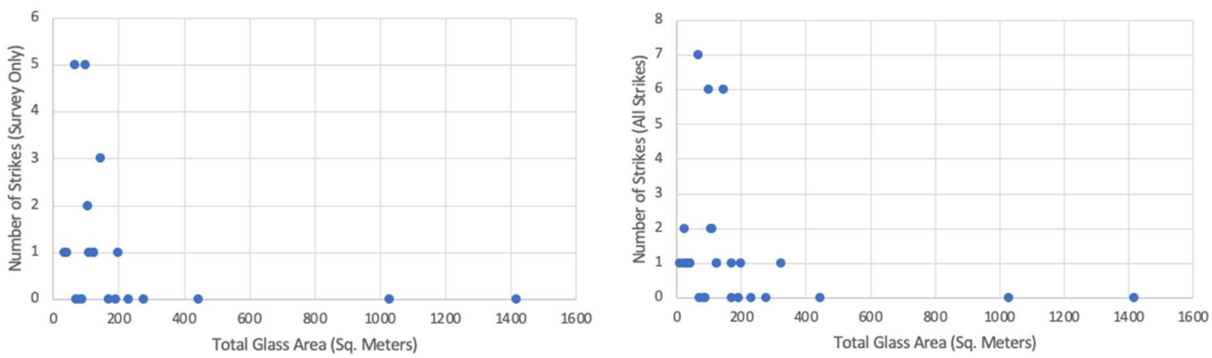

Figure 5: Bird Strikes versus total glass area: survey only (left) and all reported strikes (right).

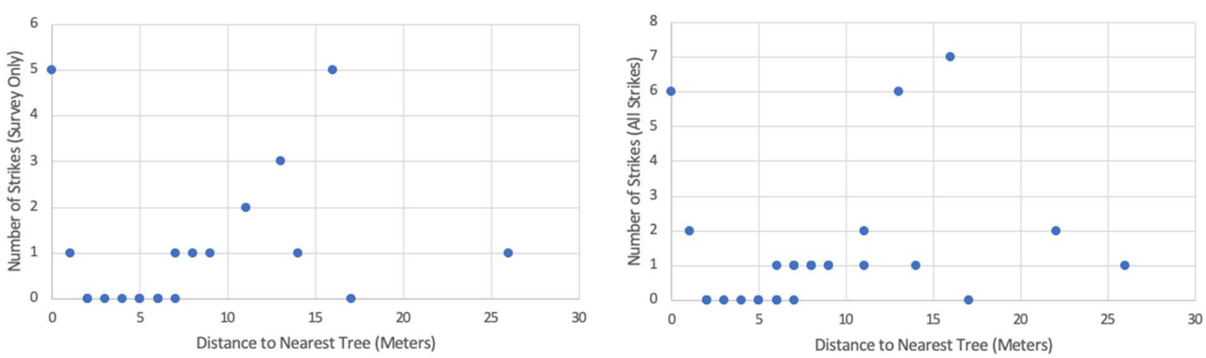

Figure 6: Distance to nearest tree versus strikes: survey only (left) and all reported strikes (right).

Weather Factor	Coefficient	Standard Error	Z-Value	P-Value
2022				
Daily Minimum Temperature	0.03031	0.038209	0.793	0.4276
Daily Average Wind Speed	-0.006504	0.079479	-0.082	0.9348
Daily Precipitation	-1.014164	1.171373	-0.866	0.3866
2019				
Daily Minimum Temperature	0.10792	0.03854	2.8	**0.00511**
Daily Average Wind Speed	0.03345	0.08563	0.391	0.69612
Daily Precipitation	3.50138	1.43825	2.434	**0.01491**

Table 11: Weather effects binomial logistic regression statistics (Bold=Significant, Alpha=0.05).

Weather Factor	Coefficient	Standard Error	Z-Value	P-Value
2022				
Daily Minimum Temperature	-0.01959	0.02699	0.726	0.468
Daily Average Wind Speed	0.01192	0.05703	-0.209	0.8344
Daily Precipitation	-1.3971	1.07552	-1.299	0.1939
2019				
Daily Minimum Temperature	0.07154	0.02347	3.048	**0.002304**
Daily Average Wind Speed	0.03983	0.05118	0.778	0.436501
Daily Precipitation	1.3311	0.45388	2.933	**0.00336**

Table 12: Weather effects Poisson regression statistics (Bold=Significant, Alpha=0.05).

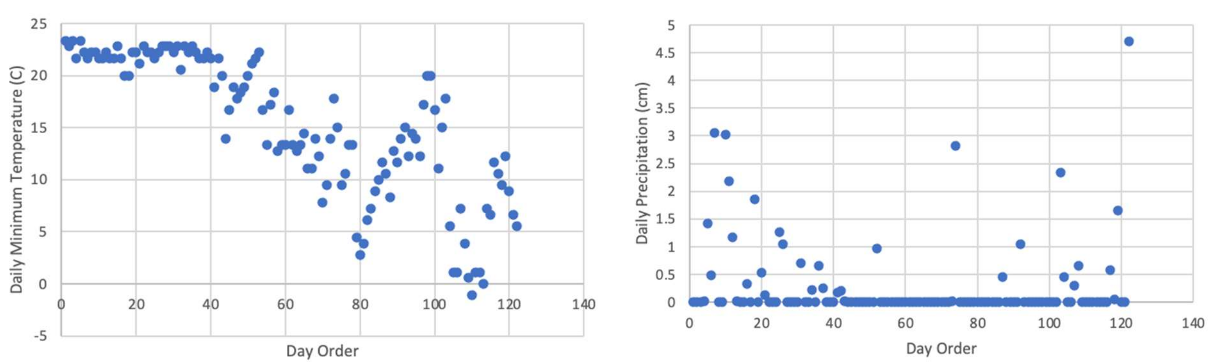

Figure 7: Minimum temperature 2022 by day (left) and daily precipitation (right).

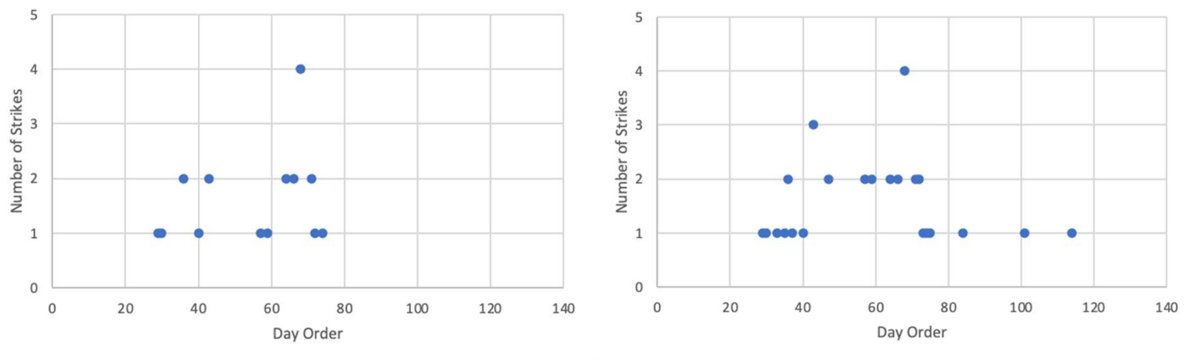

Figure 8: 2022 chronological strikes versus number of strikes by day (survey only on left; all reported strikes on right).

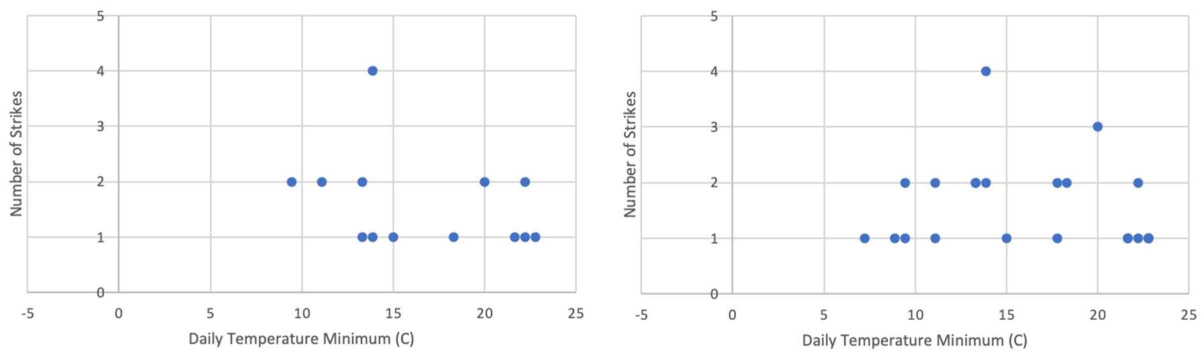

Figure 9: Survey only strikes vs minimum temperature (left), all reported strikes 2022 vs daily minimum temperature (right).

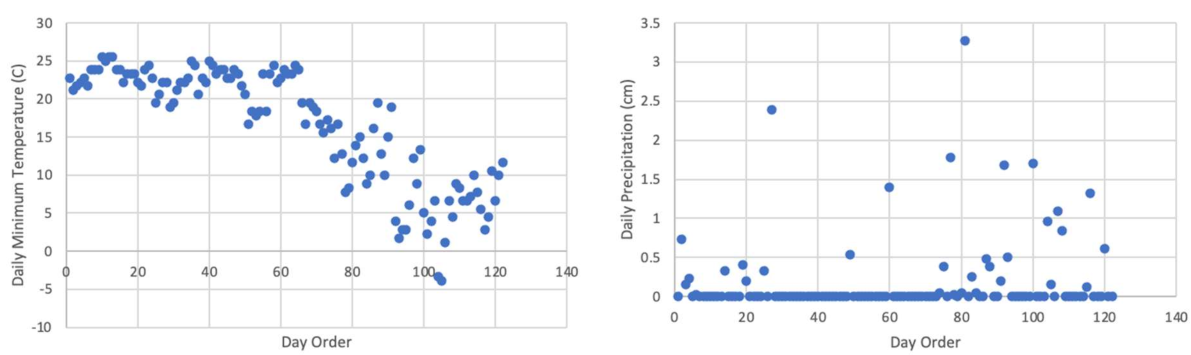

Figure 10: 2019 daily chronological temperature minimum (left) and daily precipitation (right).

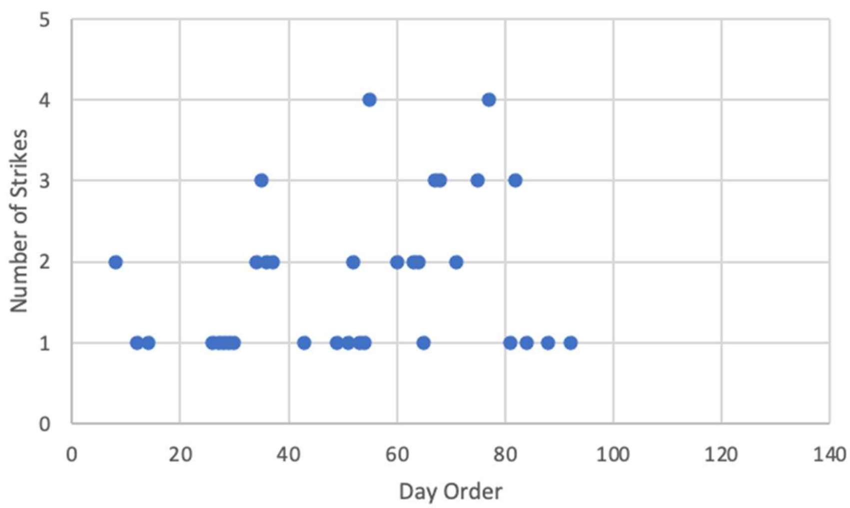

Figure 11: 2019 chronological strikes by day.

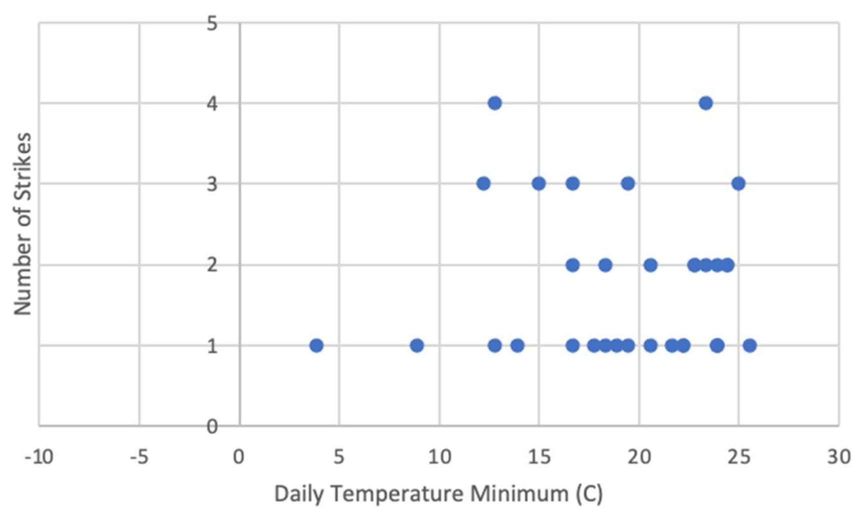

Figure 12: 2019 strikes versus minimum temperature.

Bird Deterrent Tape

No statistics were applied to the MSC atrium, the site with bird deterrent tape, to compare to previous years' data because university administration delayed application until the data collection period had already begun, fewer overall birds were found in 2022 than 2019 regardless of specific site, and a large tent was erected in front of the window during the data collection period. Any of these confounding variables would make statistics unreliable.

However, only one individual was found at the MSC atrium after bird deterrent tape was finished being fully applied on September 28. Prior to full taping, two birds were found at the site during surveys, and three others were found outside of the surveys. Comparatively, 40 individuals were found at this façade in 19 days in September 2002, suggesting there was more at play in reducing bird strikes during this migration season than just the bird deterrent tape (Davis 2002).

Discussion

Limitations

The limitations of the study all stem from the setup as a natural experiment rather than a lab experiment, as many external elements could not be manipulated or completely controlled for. Notably, the relatively small sample size of birds found during 2022 surveys could be due to many external ecological or meteorological factors.

Time was a major limitation in this study, as only one field season was available for this survey route, so temporal comparisons had to be made against data found by others either following a slightly different route or by community members who were not conducting surveys at all. The surveys were also constricted by the arrival of morning maintenance staff, as surveys had to be short enough to complete before their arrival to avoid any potential unwanted carcass removal from collision sites.

Only pre-existing structures were monitored, so there was no manipulation of potential risk factors to provide for more simple analysis. Also, factors such as indoor overnight lighting were subject to daily change depending on the action of the inhabitants of the buildings. The only measure of vegetation as a risk factor was the distance to the nearest tree, which did not account for potential impact of different species of trees or vegetation density.

Possible Confounding Factors

Most of the recorded strikes were recorded on the western side of the campus, at either the MSC or the Chemistry Building. This is problematic for two reasons. First, most of the Emory Community members that reported strikes outside of the survey time were other Environmental Science students or faculty who heard about this research through word of mouth. These environmental science personnel likely spent more time in or around the MSC and Chemistry buildings than other parts of campus, so it's possible more birds were reported in this area simply due to greater overall search effort.

Second, several outdoor cats were spotted on the eastern side of the campus during the morning surveys. It is possible that birds died at buildings in this area but were scavenged by cats before they could be found, so these buildings' bird strike risk is underestimated.

Mitigation

Overnight Lighting

Limiting overnight lighting should be a primary form of bird strike mitigation because it is relatively easy, inexpensive, effective, and helps other organisms affected by light pollution as well. Not only can ALAN increase bird strike risk, it also decreases bird survival by delaying migration and increasing predation risk, and it impacts other species by influencing movement of species, predator-prey interactions, and ecosystems as a whole (Sanders & Gaston 2018). ALAN disrupts daily and seasonal natural light cycles, thus impacting the phenology of many organisms (Gaston et al. 2017).

Ecological light pollution can confuse and trap nocturnally migrating birds, causing them to collide with buildings, exhaust them, or increase predation risk (Longcore & Rich). Some birds orient during nocturnal using a combination of stellar and geomagnetic cues (Wiltschko & Wiltschko 1978). Since artificial light sources can reduce star visibility (Longcore & Rich 2004), it is possible that birds may be further disoriented because there are no visible stars to use as landmarks. Raptors are known to take advantage of prey species disoriented by night lighting, and two owl species, *Asio flammeus* and *Asio otus*, have been observed trying to take advantage of migratory birds specifically (Canário et al. 2012, Fleming & Bateman 2018).

Light reduction has shown to be effective, as birds behavioral disruptions disappeared when lights were turned off (Van Doren et al. 2017). ALAN reduction can be achieved focusing light downward rather than horizontally or upward, lighting only necessary areas, and reducing turning off lights when not in use (Falchi et al. 2011). The Audubon Society's Lights Out program is aimed at spreading awareness about the threat ALAN poses to migratory birds. These kinds of public outreach programs must be implemented to convince the public that reducing unnecessary overnight lighting is a win-win because it protects birds while also reducing energy cost (Audubon.org).

Tree Reflections

The reflection of vegetation could be a more important risk factor than the distance to the nearest vegetation, as reflections were present in every strike location, whereas distance to nearest tree showed no significant correlation to strikes. Since they do not recognize that reflections are not real trees, birds see these reflections as oases of food. During migration, birds must stop and forage intensively to refuel (Alerstam 2003). These stopover foraging periods constitute 2/3 of total energy and 7/8 of total time spent during migration (Hedenström & Alerstam 1997).

Birds also may view tree reflections as sources of protection. Raptorial predation is a threat for migrants at stopover sites (Aborn 1994), and migratory birds have been shown to retreat into vegetation in response to raptor presence (Cimprich et al. 2004). The combination of protection and refueling opportunities trees provide can be seen in migratory bramblings, *Fringilla montifringilla,* which reduce predation risk by migrating through forests, where still able to forage on mast yields, thus increasing their predation risk to energy intake rate (Lindström 1990). Because birds must stopover to forage during migration, they likely see the reflections in these trees as both potential food sources and protection from predation, so they fly towards them and collide with the window.

Reducing reflections of trees in windows is a more difficult task. Natural vegetation in the area may be out of a building designer's control, and removing pre-existing trees may do more ecological harm than is justifiable for bird safety's sake. However, vegetation reflection risk could be minimized by using bird safe treated glass in highly vegetated areas and avoiding planting of ornamental vegetation in locations where their reflection will be show in the window.

Architecture

Percentage window coverage proved to be positively correlated to bird strike risk on Emory's campus, which is consistent with prior bird collision research (Borden et al. 2010, Cusa et al. 2015). Future building design should include lower window percentage, especially in areas with other potential risk factors, such as Atlanta's high urban green index of urban areas with high overnight lighting. Pre-existing buildings with high window percentage should be prioritized as targets for bird-safe retrofitting. Total window area was significantly negatively correlated with number of bird strikes, which was likely due to a some very large facades that carry a high total glass area despite a middling percentage, such as the Hospital Front and the MSC West faces, with no observed strikes. While significant, this correlation was not nearly as strong as the correlation between strikes and window percentage, so reducing window percentage should be prioritized.

Other architectural design elements can be incorporated in the design phase to make windows more bird friendly. Fritted or frosted glass and bird deterrent decals create a visual signal on windowpanes that can alert birds to the presence of a barrier that would otherwise go unnoticed. UV treated glass and UV absorbing decals can further deter bird collisions while offering minimal obstruction to human view because UV light is beyond the human visual spectrum but can be seen by many bird species (De Groot et al. 2022, Klem 2009, Sheppard 2019). However, UV treatments cannot be expected to completely deter birds alone because not all birds can see UV light and nocturnal migrants often collide overnight when there is little, if any, UV light (Ödeen & Håstad 2013, Sheppard 2019). Alcoves in buildings can act as trapping mechanisms that lead to more bird strikes than flat or convex facades (Riding et al. 2020), as was evident at the MSC atrium and Emerson Connector, which were two of the three top collision sites.

Weather Effects

One reason that fewer birds may have been found 2022 than in 2019 was the difference in weather patterns, as fall 2022 was significantly colder in Atlanta than fall 2019. This difference Is most notable in October, especially around October 17-20 of 2022, where a cold front minimum temperature dove below five degrees Celsius before jumping back up to around 10 degrees Celsius the next week. Contrastingly, 2019 daily minimum temperatures did not drop below 5 degrees Celsius until October 31st, when it sharply dropped from 19 to 4 degrees Celsius in one day. No birds were found after this drop below 5 degrees in 2022, and only one bird was found after the 2019 drop below 5 degrees. This constitutes a two-week difference in cold fronts reaching below 5 degrees between Fall 2019 and Fall 2022. During this two-week period from October 17-31, four more individuals were found in 2019 than in 2022.

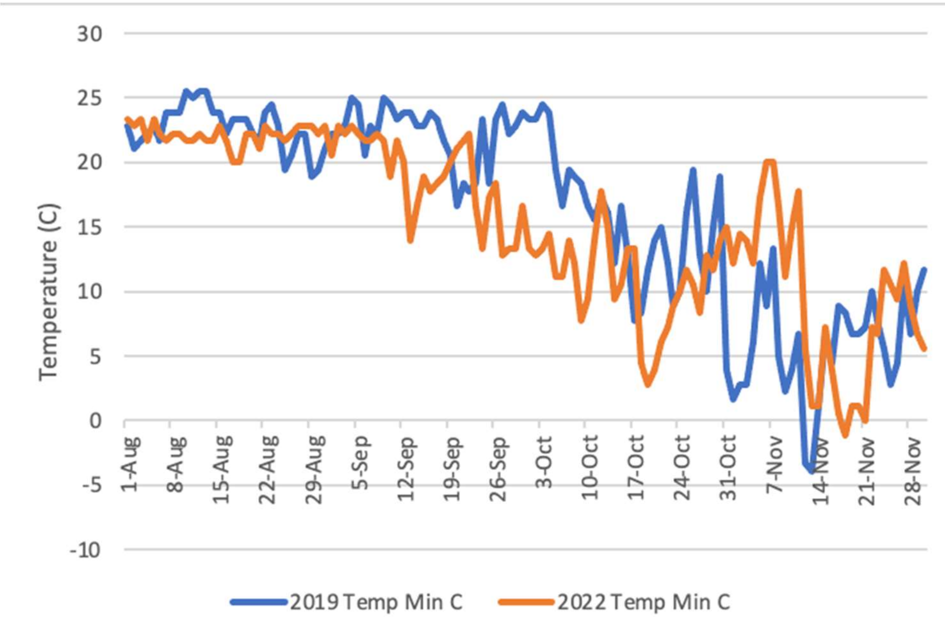

Figure 13: 2019 (blue) and 2022 (orange) daily minimum temperature.

It is possible that the colder weather triggered the birds to continue migrating, as cold fronts have been shown to correlate to increased volume of nocturnal migrants (Hassler et al. 1963). If this is the case, then the lack of bird strikes after the cold front could be due to migratory birds having already passed through Atlanta, especially since migratory birds are more prone to collision than urban residents (Cusa et al 2015), as was represented in this study, as 88.9% and 81.8% of fully identifiable carcasses in 2022 and 2019, respectively, have migratory populations in Georgia (allaboutbirds.org).

Weather effects may offer short term migratory season measures for bird strike protection. Real time predictive bird modeling can use weather radar to predict bird migration patterns up to a week in advance (Van Doren &. Horton 2018). These models are probably not as useful for long term bird strike mitigation but could be used to influence “lights out” compliance and reduction of certain other easily adjustable risk factors, such as taking down bird feeders near windows, using blinds or nets over windows, and removing indoor plants from window areas, during high intensity migration periods.

Bird Deterrent Effectiveness

Bird deterrent tape was originally intended to reach up to 25 feet of the MSC atrium, but this was disallowed by university administration. For safety precaution, only an 8-foot ladder was allowed, thus limiting the height of bird tape coverage to the first 10 feet from ground level. Although this left uncovered window area higher from the ground, this offered the opportunity to test for effectiveness while only covering the first story windows. No statistics were used to evaluated effectiveness of the bird tape, but anecdotal reduction of window strikes occurred despite the uncovered window area, which supports the notion that bird strike risk does not increase with the height of windows, as high rises make up a much smaller percentage of bird strike locations than buildings with much lower windows (Loss et al. 2015). Future research should be aimed toward studying the relative effectiveness of bird deterrents at lower areas of coverage. If shown to be effective with less than complete coverage, this could encourage more widespread use of deterrents. Lower cost of materials and effort of application would make parties more likely to use bird collision deterrents, especially since treated bird-friendly glass is not readily available for smaller scale residential construction, so bird tape and retroactive treatments are the most realistic option for homeowners without corporate budgets (abcbirds.org).

Conclusion

Bird-window collisions remain an issue on Emory University's campus. The most important collision risk factor identified in this study is percent window coverage, which showed significant risk for bird strikes. Overnight lighting and reflection of vegetation in windows are also notable potential risk factors, as they occurred at every strike location. Distance to nearest tree did not prove to be a major bird strike risk factor. There was some anecdotal reduction in bird strikes due to bird deterrent decals, but delays in the application process made statistical analysis inappropriate. More research needs to be done on the use of bird deterrent decals in Atlanta, especially research into the relative efficacy of differing level of percent façade coverage. Future research should also try to identify possible synergistic effects of multiple combined risk factors. Hopefully, future stakeholders for bird safety and the built environment can use this research to create buildings that are both bird safe and economically feasible.

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