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Bird Window Strikes on a College Campus: Mortality Estimates and Possible Mitigation

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BIRD WINDOW STRIKES ON A COLLEGE CAMPUS: MORTALITY ESTIMATES AND POSSIBLE MITIGATION

by

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(Under the Direction of C. Ray Chandler)

ABSTRACT

Understanding the impact that human development has on wildlife populations is essential to preserving biodiversity. Bird populations are a good indicator of anthropogenic threats because they are sensitive to environmental change. Window strikes are a major source of mortality for bird populations. Studies have begun to monitor factors that cause window strikes and estimate the amount of birds killed annually by strikes. However, these estimates can be greatly affected by site dependent variables and scavenging of carcasses. My study addresses this issue by answering four questions: First, how many birds are killed annually on campus? Second, what factors complicate making this estimate of bird mortality? Third, what building factors affect this mortality? Fourth, what is the best method to try for cost effective mitigation? I conducted my study on the Statesboro Campus of Georgia Southern University. Searches were completed on campus buildings to find any birds that had struck windows. Buildings were also measured for various environmental factors including total area (square footage), window area and surrounding tree area. Carcass removal rate was also determined by placing previously struck birds at buildings and monitoring daily for decomposition and scavenging. Once carcass searches concluded and a carcass removal rate was determined, an annual mortality estimate for the campus was calculated. I also evaluated three window strike prevention options based on cost. An estimated 2270 – 4604 birds die annually at Georgia Southern University. Carcass removal was considered high with 44% of carcasses being removed in 1 to 2 days. Window strikes increased with both building area and window area. However, the number of window strikes and surrounding tree-line did not have a significant relationship. High carcass removal rate can be responsible for the lack of carcass detection at buildings with factors that other studies found to have increased window strikes such as high vegetation cover. By consistently monitoring window strikes and thinking bird friendly while in the planning stages, the campus can greatly reduce the number of birds killed yearly and preserve bird biodiversity.

INDEX WORDS: Window strikes, Bird mortality, Migratory birds, Carcass scavenging, Decomposition

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TABLE OF CONTENTS

Page

ACKNOWLEDGMENTS.....3

LIST OF TABLES.....5

LIST OF FIGURES.....6

CHAPTER

1: INTRODUCTION.....8

Impact/Magnitude.....9

Window Strike Studies.....10

Carcass Removal Studies.....12

Prevention Solutions.....13

2: METHODS.....15

Study Area.....15

Carcass Searches.....17

Environmental Measures.....20

Carcass Removal and Decomposition.....20

Prevention Solutions.....21

Data Analysis.....21

3: RESULTS.....23

Species.....23

Strike Surveys.....23

Carcass Removal and Decomposition.....27

Environmental Factors.....31

Prevention Methods.....38

Mortality Estimates.....40

4: DISCUSSION……………..41

Cost Prevention Summary………………………………………………………..43

REFERENCES 46

APPENDICES……………………………………………………………………………....51

Appendix A: All Known Species that Have Been Killed by Windows at Georgia Southern University……………………………………………………...51

LIST OF TABLES

Page

Table 1. Species of birds killed by striking windows during this study, Statesboro campus, Georgia Southern University………………………….……...24

Table 2. Number of window-killed birds found by buildings on the Statesboro campus of Georgia Southern University……..25

Table 3. Estimated mortality rates for window-killed birds on the Statesboro campus of Georgia Southern University. ………………………………..…...26

Table 4. Fate of the 27 experimentally placed bird carcasses, Statesboro campus, Georgia Southern University...……………………….……...29

Table 5. Physical characteristics of 20 buildings used during this study, Statesboro campus, Georgia Southern University.……………………………...33

Table 6. The three best models based on multimodel inference using AICc for the predictors building area, window area, and treeline area……………………………………………..………37

Table 7. Cost to treat all the windows of 20 buildings on the Statesboro campus of Georgia Southern University………………………………………………………………………………...39

LIST OF FIGURES

Page

Figure 1. Variation in window design on buildings on the Statesboro campus of Georgia Southern University. ………………………………...16

Figure 2. Buildings searched for bird window kills on the Statesboro campus of Georgia Southern University during the first search period ……………………………………….............................18

Figure 3. Buildings searched for bird window kills on the Statesboro campus of Georgia Southern University during the second and third search periods ………………….......................................19

Figure 4. Buildings on the Statesboro campus of Georgia Southern University used during the studying of scavenging and decomposition rates ……………………………….………...................22

Figure 5. Percentage of experimentally placed bird carcasses remaining by day, Statesboro campus, Georgia Southern University……………………………………………………………………....28

Figure 6. Examples of mammals scavenging experimentally placed carcasses………………...….30

Figure 7. Number of window-killed birds increases with building area at 20 buildings on the Statesboro campus of Georgia Southern University……………………………………………….32

Figure 8. Number of window-killed birds increases with window area at 20 buildings on the Statesboro campus of Georgia Southern University……………………………………………32

Figure 9. Area of tree-line within a 40 meter radius does not have a significant effect on the number of window-killed birds at 20 buildings on the Statesboro campus of Georgia Southern University……………………………………………………………………………………..34

Figure 10. Number of window-killed birds decreases with age of buildings at 20 buildings on the Statesboro campus of Georgia Southern University……………………………………………35

Figure 11. Age of buildings does not have a significant relationship with window area at 20 buildings on the Statesboro Campus of Georgia Southern University……………………………35

Figure 12. Age of buildings does not have a significant relationship with buildings area at 20 buildings on the Statesboro campus of Georgia Southern……………………………………..36

CHAPTER 1

INTRODUCTION

Humans profoundly alter the global landscape. Understanding the impact that human development has on wildlife populations is essential to preserving biodiversity. Bird populations, in particular, are often good indicators of anthropogenic threats because they are sensitive to environmental change. Birds are also well monitored by various networks and monitoring groups such as the Christmas Bird Count (Dunn et al. 2005) and ebird (Sullivan et al. 2009). This sort of monitoring can document broad population change and reveal how environmental alterations affect bird populations and their distribution.

However, this monitoring needs to be paired alongside a finer scale analysis of anthropogenic threats. These threats can be indirect (habitat loss) or direct (hunting, pet trade, radio towers, powerlines and windows, etc). While some direct threats, such as hunting, are well documented, others such as radio towers, powerlines and window strikes still have a level of uncertainty due to the impact varying by locality (Calvert et al. 2013). Window collisions rank among the top direct sources of human-related bird mortality, only ranking behind cat predation (Loss, Marra and Will. 2015). Windows account for 25 to 50% of bird collision fatalities, while wind turbines account for 0.01 to 0.02 percent, and vehicle fatalities 15 to 30% (Erikson et al. 2010). Windows kill an estimated 365- 988 million birds annually in the United States alone (Loss et al. 2014). Fatal bird strikes occur independent of a bird’s age or sex and occur at both reflective and transparent windows (Klem 1989).

Studies, such as Horton et al. (2019), have found a relationship between artificial lights and the risk of window strikes. By quantifying the amount of growth in artificial light in urban areas, U.S cities have been ranked based on their threat to migrating birds. Urban centers, such as Chicago and Houston, contain high artificial light exposure, which means they have a higher risk of birds striking buildings (Horton et al. 2019). These types of studies have begun to quantify the impact of window strikes in urban and suburban areas, however there is still a need to evaluate which cost-effective solutions will reduce impact.

University campuses are a good place for a window strike study. Campuses have a variety of building types in an environment that has suburban to urban qualities and green space that attracts birds. Campuses also have accessible public space, and students and volunteers that can help monitor bird activity. University campuses have begun to adapt sustainable objectives, and administration may also have interests in implementing cost-effective solutions in order to preserve biodiversity. This implementation of preventive solutions can allow for the most effective solutions to be used at larger scales.

Thus, my study will address four questions about window strikes on a large campus of a state university. First, how many birds are killed annually on campus? Second, what factors complicate making this estimate of bird mortality? The first two objectives of this study will answer these questions through carcass searches and observing the rate at which carcasses are removed from the environment. Feral cats and other mesopredators may scavenge bird carcasses, complicating estimates of mortality. Third, what building factors affect this mortality? I will test the hypothesis that buildings that have bigger area (square footage), including more area of glass, and more surrounding vegetation cause higher amounts of window strikes. Understanding which factors contribute to window-related bird mortality can ensure the reduction in the amount of birds killed as new buildings are built. Fourth, what is the best method to try for cost-effective mitigation? I will evaluate three window strike prevention solution options based on information found on the manufacturer’s websites. By quantifying factors involved in bird strikes and evaluating prevention options associated with those factors, I aim to provide a cost-effective solution to reduce bird strike mortality.

Impact/Magnitude

There is uncertainty surrounding the impact of window strikes as window strikes numbers vary by site, however, efforts have been made to estimate mortality on a large-scale. In 1990, Klem estimated that about 1 to 10 birds fall victim to window strikes per building per year here in the United States. Assuming that every commercial building and school accounted for one building, Klem was able to use U.S census data to estimate the number of buildings in the United States. Then, using the number of buildings, he was able to estimate that the amount of birds killed by striking windows to be near 98 to 975 million (Klem 1990). However, Klem's estimate did not account for the buildings that kill more birds than average and is considered conservative.

Dunn (1993) found mortality estimates that agreed with Klem's. This study was able to take data from Project FeederWatch and estimate the number of birds killed by windows. Project FeederWatch was a survey that had volunteers from across North America record the number of birds at their home feeders and to optionally record any window strikes. Given that many of the volunteers lived in an area of high bird populations and attracted birds near their homes, it was that assumed that these homes may kill birds at an above-average rate. After correcting for this, Dunn found that homes kill about 0.65 to 7.70 birds per year.

Although Klem's estimate has been widely accepted, there is still a need to find more accurate estimates as strike rates can vary widely by area and spatial variables. Given that a range of 100 million to 1 billion is highly variable, the number given often depends on the study or region. For this reason, a more accurate estimate can be given by analyzing multiple studies and the factors that contribute to window strikes in the given environment. More studies on more variable sites are needed in order to gain precision over the span of many areas.

Window Strike Studies

It is widely believed that birds collide with windows because of reflection. However, there are many contributing factors that lead to window strikes. Klem (1989) concluded that window strike rates are affected by numerous factors interacting with each other. These different variables were placed into specific categories such as bird-related, window-related, and environmental factors. Bird-related factors are variables like bird behavior; Window-related factors are variables like window size and placement;

Environmental factors are variables such as season and time of day. Klem (1989) also determined that any factor that would increase bird density would also correlate to increased strike frequency. This includes variables that attract birds such as vegetation and feeders, but also includes seasons, locations, etc.

In a 2015 study, Cusa et al. used window strike data, collected by volunteers of The Fatal Light Awareness Program, to analyze the effect of environmental variables on bird-strikes in Canada. The researchers determined that bird window strikes were positively related to the percentage of glass cover. The study also found that the square footage of buildings and area covered by exposed habitat significantly affects window collisions. The more area a building occupied and the more area of exposed habitat, the greater the amount of window strikes. However, percent of the landscape covered by canopy does not seem to have any effect on the amount of window strikes (Cusa et al. 2015).

There have also been studies to test the best ways to prevent window strikes. In a follow up to his original study, Klem (1990) set out to find effective prevention methods for bird window strikes. For window properties, he suggested building windows at an angle that reflects the ground, instead of the sky or surrounding vegetation to help birds avoid strikes. He also determined that covering windows with netting or with evenly spaced clothed strips was the best way to eliminate bird strikes (Klem 1990). However, these options are not practical as this may ruin the aesthetic appeal of a building. Building owners, both commercial and residential, would want their buildings to appear as pleasing as possible for curb appeal. Klem (1990) also concluded that many of the available prevention options, such as falcon silhouettes and patterned decals, do not reduce window strikes significantly because they do not cover the entire surface of the window. Based on these findings, this study will aim to elucidate the factors affecting window strikes on a rural southern college campus in hopes of reducing the number of birds killed. Campuses are constrained by both financial and aesthetic reasons in terms of limiting bird strikes. On this campus, there is no widespread sticker use, and using nets to cover every window is impractical.

A window strike study was conducted on a campus in Bogota, Columbia. The campus, near the Olaya Herra National Park (283 hectares of forest and recreational areas), has 46 buildings of various ages. Six buildings were surveyed daily from 2006 to 2008. Three of the buildings were considered to have translucent glass, while the other three had reflective windows. When specimens were collected, the species, date, building, type of glass, and direction of strike were recorded. A total of 106 strikes were recorded. Seventy-three percent of those collisions were found to have occurred at translucent windows. The researchers discussed two limiting factors of their study. One, some birds struck the windows and did not land directly under the window or moved away before dying. Two, scavengers were observed moving a carcass before it could be discovered. Due to these limitations, the researchers believe their mortality estimates to be conservative (Agudelo-Alvarez 2010). To estimate the number of collisions, the researchers made the assumptions that every building on the campus has the same probability of causing a collision (due to no difference in characteristics such as height, amount of glass), that the rate of collisions stays the same throughout the year, all bird species have the same probability of striking, and that all collisions are found. They estimated that 271 – 659 birds are killed yearly at 46 buildings on their campus. There is a need to understand what factors increase the risk of window strikes. The factors that cause high strike rates will most likely vary by site and any quickly developing area hoping to reduce collisions (like a college campus) should look to gain further data.

Carcass removal studies

Estimates of strike mortality often assume all birds are found. However, if scavengers remove birds before they are recorded, mortality estimates may become overly conservative and underestimated (Agudelo – Alvarez 2010). Strike mortality is a major concern on wind turbine farms, but Villegas et al. (2012) raised the issue of scavenging biasing estimates. Studies such as Kostecke et al. (2010) have examined the impact of scavenging at wind farms but few have considered the effect of scavenging on window strike mortality estimates. Thus, there is still a need for further studies to understand the impact that scavenging has on window strike estimates in order for those estimates to become more accurate. Previous studies have shown that areas that have high strike rates also have higher scavenging occurrences (Kummer et al. 2016).

Not only is scavenging rate important for calculating accurate estimates, but a decomposition rate is also critical. Both factors reduce the accuracy of window strike mortality estimates.

Scavenging rates and decomposition rates are affected by several factors, including carcass size and age, the amount of cover and vegetation, temperature and latitude. Bracey et al. (2016) suggest that vegetation creates more cover for predators and scavengers, which allows them to access carcasses easier. Scavengers and predators also tend to return to areas where they were able to secure a meal. This leads to areas with higher window strikes also having higher scavenging events (Bracey et al. 2016).

Most carcass removal studies have been done on Wind-Turbine projects, and not in a suburban environment such as a college campus. In a 2010 bird fatality and carcass study (Smallwood 2010) carcasses were randomly placed at 20 locations within 60 meters of wind turbines. The carcasses were then monitored by a camera trap. Scavengers removed 79% of the carcasses from the study area. Thirteen percent of the carcasses had little remaining after scavenging. On average, carcasses were scavenged 4.45 days after being placed (Smallwood et al. 2010).

In 2015, a carcass removal study was conducted in Canada to determine removal rate by urban scavengers. Carcasses were placed at homes for randomized trials that lasted seven days (Kummer et al. 2016). During these trials, bird carcasses were placed on their back in front of a window. Time-lapse cameras were then placed at each carcass. The researchers found that carcasses remained for 3.46 days before being removed. Their top scavengers were Magpies and feral cats (Kummer et al. 2016). Over 30% percent of carcasses were removed within 24 hours, equaling a scavenging removal rate of 1.47. The number of carcasses found within 24 hours needs to be adjusted by the removal rate.

Prevention Solutions

While Klem (1990) suggested that things such as hawk silhouettes do not prevent window strikes, there are other solutions such as window films, glass and stickers that help reduce the number of strikes. The American Bird Conservancy (ABC) does extensive testing on various products and makes a recommendation on its website based on an assigned score. These products have been tested using a procedure that involves letting birds free fly in a 10-meter-long tunnel with glass panes at the end. The glass panes can be fitted with various films and glass, and the effectiveness of each product is recorded (American Bird Conservancy 2015). The tunnel has netting so that the birds do not hit any glass. There is a wide range of products including tape, UV reflective decals, and specially coated glass that reduces reflectance. For this study, three ABC suggested solutions were researched for cost-benefit analysis: ABC Bird Tape, Feather Friendly ™ Window Decals, and Solyx Bird Safety Film.

CHAPTER 2

METHODS

Study Area

My study was conducted on the Statesboro campus of Georgia Southern University [32.4205° N, 81.7865° W], 364.2-hectare campus located in a suburban portion of Statesboro, Georgia. Statesboro is a small city of 30,000 people. Georgia Southern dominates a large portion of Statesboro's land with 14.9% of it being used for institutional purposes. About 25% of the land is unused (natural habitat) and contains areas such as wetlands and mixed pine forests (City of Statesboro 2008). The university's student population is responsible for majority of the population within Bulloch County (Bulloch County 2009). To accommodate the growing student population, Georgia Southern is renovating and developing new buildings. Currently, Georgia Southern has 87 buildings on its Statesboro campus with more planned for development. The buildings range in age from 61 years to 4 years. There are a variety of window shapes, sizes and types found across the campus (Figure 1). Most of the buildings found on campus are multiple storied, often 2 to 3 stories. Georgia Southern also plans to expand onto 84.1 undeveloped hectares south of its main campus.

Figure 1. Variation in window design on buildings on the Statesboro campus of Georgia Southern University.

Carcass Searches

The first set of carcass searches began in February 2017 and lasted until April 2017. These months were chosen as they were previously documented as a period of high bird collisions on campus. The searches were performed by a group of three searchers. Eight buildings were searched every two to three days. Searchers walked a single loop around the building, looking for window strike victims wherever windows were present. Each search lasted between 5-15 minutes, depending on the building's size. When a carcass was found, the date, weather, building, GPS location, and species were all recorded. If a carcass was still intact, then it was placed in a Ziploc bag and labeled with the time, date, and building and returned to biology department collection freezers.

The second set of carcass searches were conducted from April 2018 to May 2018 by a single searcher. Twenty academic buildings were selected, using a random number generator, to be searched every one to two days (Figure 2). Residential halls and maintenance buildings were excluded from the list of the buildings that could be chosen. When a carcass was found, the same data were collected as above with a few extra points recorded. For every carcass found, a picture was taken of the carcass, window, and environment. The species were also identified for the carcasses found during this trial. If a specimen was too decomposed to be collected, then a picture was still taken and saved with proper labeling.

A third set of searches began in September 2018 and continued until May 2019. During these searches, the previously chosen 20 buildings were checked opportunistically near a rate of every three days. When a carcass was found, the same procedure occurred as the previous carcass searches. Window strikes found by volunteers between February 2017 through May 2019 were also added into the data collection with both the date and location recorded.

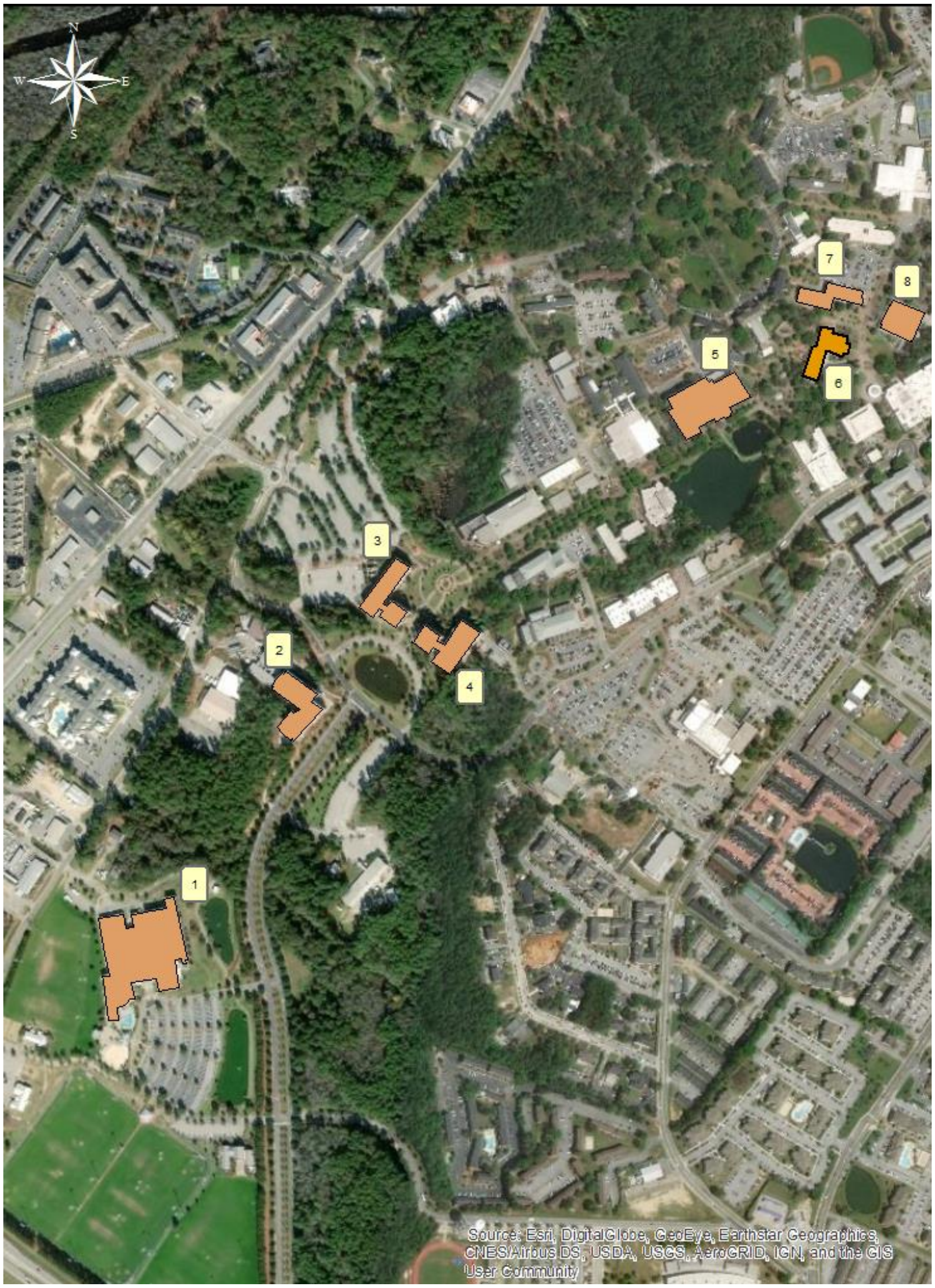

Figure 2. Buildings searched for bird window kills on the Statesboro campus of Georgia Southern University during the first search period (2/20/17 to 4/24/17): (1) Recreational Activity Center, (2) Biological Sciences Building, (3) Education building, (4) Chemistry building, (5) Henderson Library, (6) Williams Center, (7) Herty, (8) Natural Sciences Building.

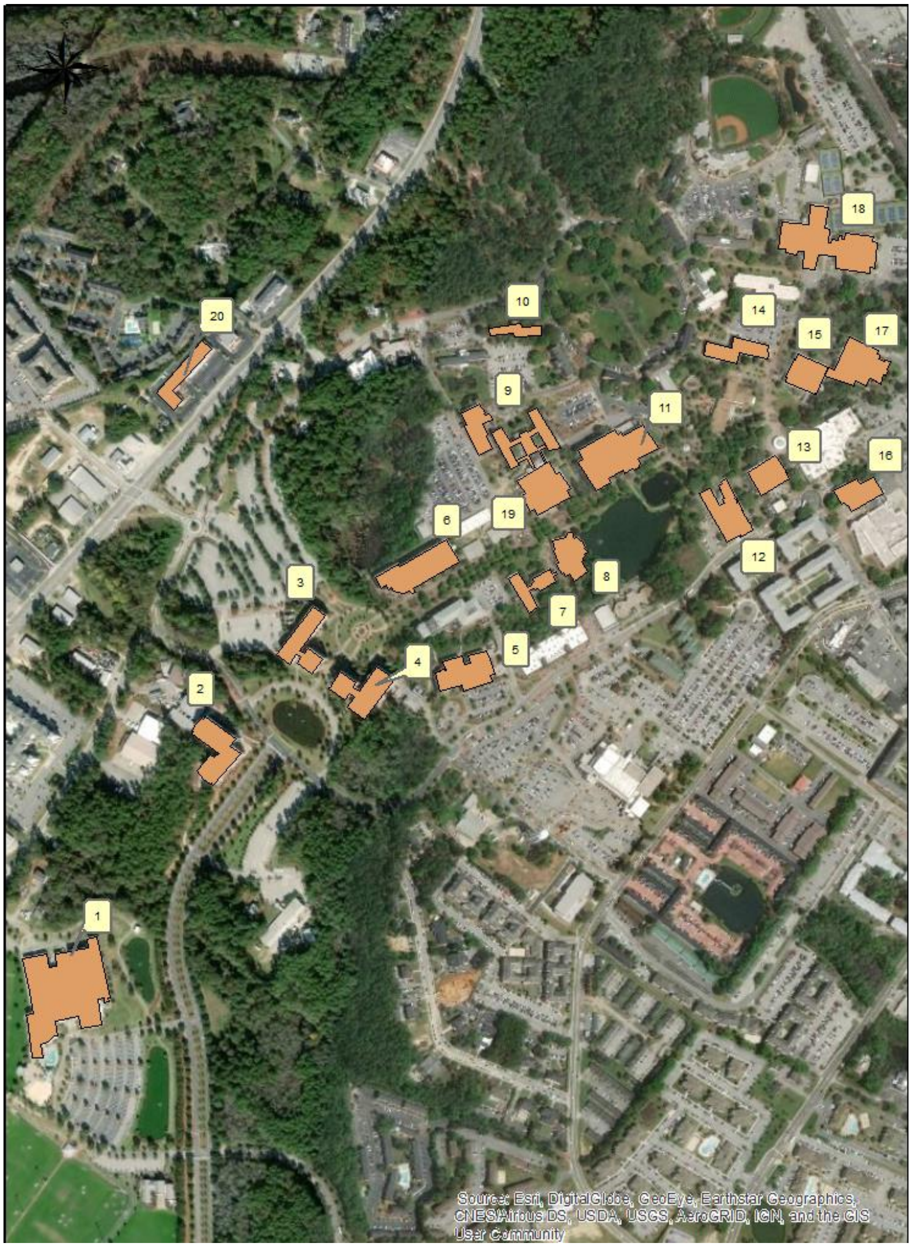

Figure 3**.** Buildings searched for bird window kills on the Statesboro campus of Georgia Southern University during the second (4/6/18 to 5/11/18) and third (9/30/18 to 5/6/19) search periods: (1) Recreational Activity Center, (2) Biological Sciences building, (3) Education building, (4) Chemistry building, (5) Engineering building, (6) Information Technology, (7) Newton, (8) Lakeside Dining, (9) Center for Art & Theatre, (10) Veazy, (11) Henderson Library, (12) Carruth Building, (13) Foy, (14) Herty, (15) Natural Sciences Building, (16) University Store, (17) Math & Physics building, (18) Hanner Fieldhouse, (19) Carroll, (20) Military Sciences Building.

Environmental Measures

All 20 buildings from the 2nd and 3rd carcass searches were measured for various environmental factors. The total surface area of buildings was taken from Georgia Southern's online database. Using Image J (Schneider 2012), the total surface area of windows was calculated. Photos were taken of each side of every building and lengths of bottom level windows. The photos were placed inside of ImageJ and the spatial scale was set using the known measured length. Once the spatial scale was set, the area of the window was measured. The surface area of the windows was grouped by nearest cardinal direction and then added together to get the total size of the window area. The ages of the buildings were determined using Georgia Southern's building directory. If a building had been renovated, then the date of the renovation was used instead of the original date that is was built.

Shapefiles of each building were made inside of ArcMap 10 (ESRI 2011). A 40-meter buffer was placed around each building and the area of the tree line within the buffer was calculated in order to measure the amount of tree line surrounding each building.

Carcass Removal and Decomposition

Twenty-seven bird carcasses were placed at 14 buildings. The carcasses were of birds that had hit windows in previous years and were all various sizes and species. All carcasses were salvaged under USFWS permit (#MB21850B-0). Each carcass was placed on its back within a 1-meter radius of a window. On the first day that the carcass was placed, the location of the carcass was recorded via GPS. The date, time, species and nearby vegetation (shrubs or trees) were also documented. The specimens were monitored daily, and photos were also taken. For nineteen carcasses, trail cams were placed facing the carcasses. The trail cams were set to record photos whenever there was motion detected nearby. To avoid human interference, many of the carcasses were placed away from areas of high campus activity such as walkways and building entrances. Each carcass trial lasted until the carcasses were missing/scavenged or decomposed. A carcass was considered missing or scavenged when it appeared that most of its flesh was missing (more than 50%) or the carcass could not be found at all. If a carcass had been scavenged, but most of it remained intact, then it was left to be further monitored. Each building had at least 1 - 3 trials but carcasses were never placed in the same exact spot. For each carcass that had a trail cam, the footage was used to identify the scavengers at a species level. Insects were considered a scavenger when the carcass was completely covered by them.

Prevention Solutions

Using the recommended list of window strike products found on the American Bird Conservancy (ABC) website, three options were chosen for comparison. These products were chosen based on the practicality of them being applied on Georgia Southern's campus. Solyx Bird Safety Film, Feather Friendly™, and ABC Bird Tape were compared by their pricing and feasibility based on information found on each company's site. No experiments were performed with these products only cost-benefit analysis.

Data Analysis

Correction factor of carcasses was based on Kummer 2016 in which removal rate equaled 1/ (1 - percentage of carcasses missing in amount of time).

To estimate the number of birds killed per year, the following equations were used:

$$\left(\frac{\#\ of\ birds\ found}{\#\ of\ days\ searched}\right)/(\#\ of\ buildings\ searched) = \#\ birds\ per\ day\ per\ building$$

$$(\#Birds\ per\ day\ per\ building) \times \left((\#total\ buildings\ on\ study\ site)\right)$$

$$= \#number\ of\ birds\ per\ day * correction\ factor$$

Data were analyzed in JMP 13.1 (SAS Institute Inc., 1989). Linear Regressions were performed under the assumptions that data were normally distributed and have normal variance. Normal Distribution was tested for using Shapiro-Wilk W test. Strikes found by volunteers and the first search were omitted from analysis to avoid any bias.

Figure 4. Buildings on the Statesboro campus of Georgia Southern University used during the studying of scavenging and decomposition rates: (1) Recreational Activity Center, (2) Biological Sciences building, (3) Education Building, (4) Chemistry Building, (5) Engineering Building, (6) Newton, (7) Carroll, (8) Center for Art & Theatre, (9) Veazy Hall, (10) Henderson Library, (11) Carruth, (12) Natural Sciences Building, (13) Herty, (14) Math & Physics building.

CHAPTER 3

RESULTS

Species

I documented a total of 28 species as window kills during this study (Table 1). Existing Records show that 42 species have been recorded as strikes on campus (C.R. Chandler, unpublished data). (Appendix A)

Strike Surveys

During the first search, 5 out of 8 buildings had any observed window strikes. Twenty total window strikes were recorded. Chemistry Building had the most collisions with 6 birds being found (Table 2; Table 3).

The second search lasted for 26 days. Twenty-five window strikes were discovered. Of the 20 buildings that were searched, only 8 had any carcasses discovered at them. Biological Sciences Building had the most discovered strikes (Table 2; Table 3).

The third search had 31 search days. Twenty-eight window strikes were discovered at 11 of the 20 buildings. Information Technology Building had the most strikes (Table 2; Table 3).

A volunteer found strike is any strike observed by a non-searcher or found outside of search times. Forty-five carcasses were found by volunteers and 10 species were identified (Table 1).

Table 1. Species of birds killed by striking windows during this study 02/2017 – 05/2019, Statesboro campus, Georgia Southern University.

Common Name	Scientific Name	1st Search (2/2017-4/24/17)	2nd Search (4/6/18 – 5/11/18)	3rd Search (9/30/18 – 5/6/19)	Volunteer	Total
Cedar waxwing	*Bombycilla cedrorum*	-	4	-	13	17
Common Yellowthroat	*Geothypis trichas*	2	3	1	5	11
Ovenbird	*Seiurus aurocapilla*	-	5	1	2	8
Gray Catbird	*Dumetella carolinesis*	1	1	6	-	8
House Finch	*Haemorhous mexicanus*	3	3	-	2	8
Chipping Sparrow	*Spizella passerina*	3	-	1	3	7
Yellow Rumped Warbler	*Setophaga coronta*	4	-	2	1	7
Mourning Dove	*Zenaida macroura*	1	3	1	2	7
Northern Cardinal	*Cardinalis cardinalis*	2	1	2	1	6
House wren	*Troglodytes aedon*		1	1	1	3
Northern Parula	*Setophaga Americana*	-	1	-	2	3
Indigo Bunting	*Passerina cyanea*	-	-	1	2	3
Unknown	-	-	3	-	-	3
Ruby- throated hummingbird	*Archilochus colubris*	-	1	-	1	2
Swamp Sparrow	*Melospiza georgiana*	-	-	1	1	2
Hermit Thrush	*Catharus guttatus*	1	-	-	1	2
American Redstart	*Setophaga ruticilla*	-	-	-	1	1
Black-throated Blue Warbler	*Setophaga caerulescens*	-	-	1	-	1
White-throated Sparrow		-	1	-	-	1
Painted Bunting	*Passerina ciris*	-	-	-	1	1
Blue-headed Vireo	*Vireo solitarius*	-	-	-	1	1
Dark-eyed Junco		-	1	-	-	1
Louisiana Water Thrush	*Parkesia motacilla*	-	-	-	1	1
American Robin	*Turdus migratorius*	-	-	-	1	1
Palm Warbler		-	1	-	-	1
Red-eye Vireo	*Vireo olivaceus*	-	-	-	1	1
Savannah Sparrow	*Passerculus sandwhichensis*	-	-	-	1	1
Yellow-billed Cuckoo	*Coccyzus americanus*	-	-	1	-	1
Yellow-bellied Sapsucker	*Sphyrapicus varius*	-	-	1	-	1
Brown Thrasher	*Toxostoma rufum*	-	-	-	1	1
Tufted Titmouse	*Baeolophus bicolor*	-	-	1	-	1
Scarlet Tanager	*Piranga olivacea*	-	-	1	-	1

Table 2. Number of window-killed birds found by buildings on the Statesboro campus of Georgia Southern University.

Building	**Search 1 (2/20/17 – 4/24/17)**	**Search 2 (4/6/18 – 5/11/18)**	**Search 3 (9/30/18 – 5/6/19)**
Art/ Center for Arts & Theatre	-	0	1
Biological Sciences	2	8	3
Carroll	-	0	0
Carruth	-	0	0
Chemistry	6	5	4
Education	5	0	2
Engineering	-	0	1
Foy	-	0	0
Hanner Fieldhouse	-	0	0
Henderson Library	2	1	2
Herty	-	0	0
Information Technology	-	3	8
Lakeside Dining	-	1	2
Math/Physics	-	0	0
Natural Sciences	-	0	1
New military sciences	-	1	1
Newton	-	0	0
Recreational Activity Center (RAC)	5	4	3
University Store	-	0	0
Veazy	-	2	0

Table 3. Estimated mortality rates for window-killed birds on the Statesboro campus of Georgia Southern University.

Search	**Dates**	**Search Rate**	**Correction Rate**	**Number of days searched**	**Number of buildings Searched**	**Number of Strikes Observed**	**Number of strikes observed corrected**	**Birds/building/ day**	**Bids/building/ day corrected**	**Birds/Building/Year**	**Birds/ building/ year corrected**
1	2/20/17 – 4/24/17	2 – 3 days	1.78	46	8	20	35.6	.053	.094	19.34	35.31
2	4/6/18 – 5/11/18	Daily	1.49	26	20	25	37.25	.048	.071	17.52	26.104
3	9/30/18 – 5/6/19	Opportunistically	3.22	31	20	28	90.16	.045	.145	16.425	52.88

Carcass Removal and Decomposition

I placed twenty-seven birds at 14 buildings. Of the 27 carcasses placed, 19 were placed with a trail cam. To adjust for outliers, the geometric mean was used to calculate carcass survival time. On average, carcasses decomposed or were removed within 2.46 days. Thirty-three percent of the carcasses were removed in one day, while another 11% were removed by Day 2. Thirty-three percent of carcasses were removed in 3-4 days, and 22% of carcasses lasted 5 or more days. Three (15%) of the 19 carcasses placed with cameras showed no scavenger despite the carcasses being removed. Of the recorded scavengers, cats, possums and raccoons were responsible for 73.6% of removal (14 carcasses). Two of the carcasses were completed covered by insects (Table 4).

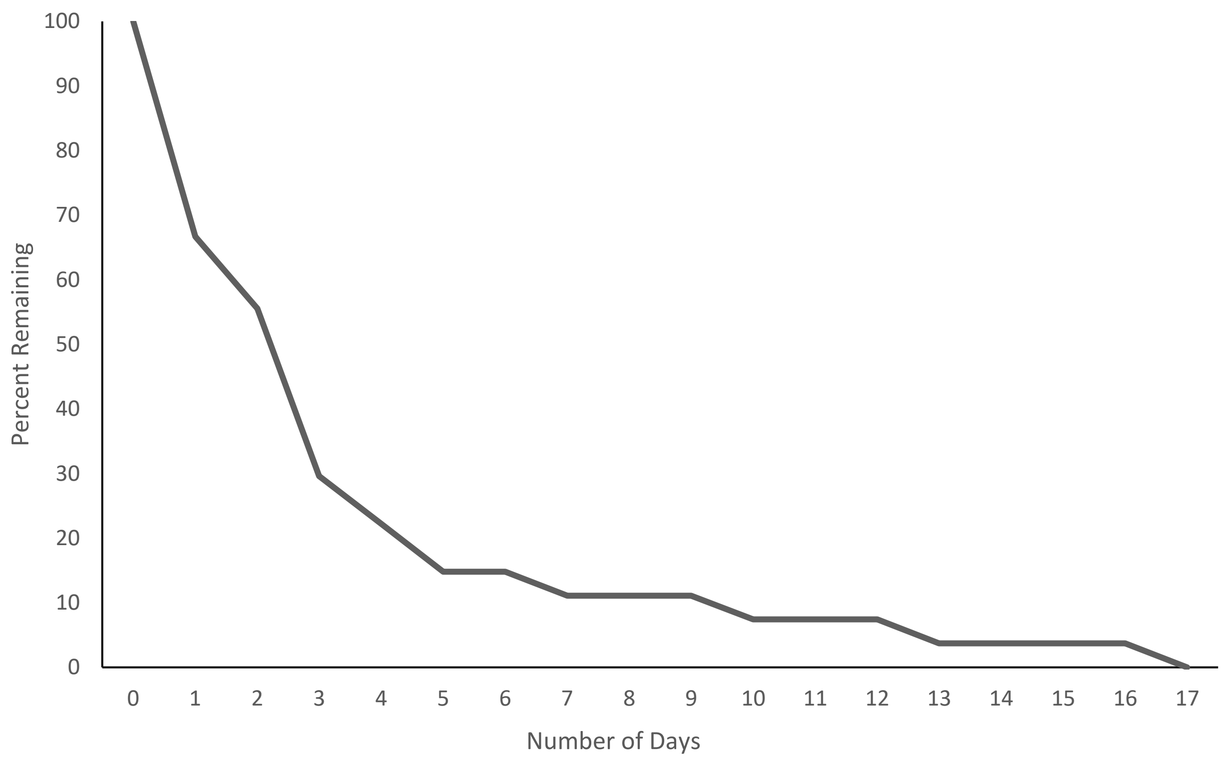

Figure 5. Percentage of experimentally placed bird carcasses (n=27) remaining by day, Statesboro campus, Georgia Southern University.

Table 4. Fate of the 27 experimentally placed bird carcasses, Statesboro campus, Georgia Southern University.

Building Placed	*Species*	*Date Placed*	*Date Missing*	*Number of Days*	*Trail Cam*	*Scavenger(s) Recorded*
Biology	Cedar waxwing	3/28/2018	4/2/2018	5	No	N/A
Natural Sciences	Cedar waxwing	3/28/2018	3/29/2018	1	No	N/A
Veazy	Cedar waxwing	3/28/2018	4/1/2018	4	No	N/A
Biology	Cedar waxwing	4/5/2018	4/22/2018	17	No	N/A
RAC	Cedar waxwing	4/5/2018	4/15/2018	10	No	N/A
Biology	Cedar waxwing	4/16/2018	4/23/2018	7	Yes	Cat
Chemistry	Yellow-Rumped Warbler	4/25/2018	4/27/2018	2	Yes	Racoon
Veazy	Yellow-Rumped Warbler	4/26/2018	4/28/2018	3	No	N/A
Art	Northern Cardinal	4/26/2018	5/8/2018	13	No	N/A
Math/Physics	American Goldfinch	4/26/2018	4/28/2018	2	No	N/A
Math/Physics	White-Throated Sparrow	5/7/2018	5/8/2018	1	Yes	Cat
Education	Palm warbler	5/7/2018	5/8/2018	1	Yes	Raccoon
Natural Sciences	White-Throated Sparrow	7/25/2018	7/26/2018	1	Yes	Cat
Math/Phys	American Goldfinch	7/25/2018	7/27/2018	2	Yes	Cat
Henderson	Yellow Rumped Warbler	7/27/2018	7/28/2018	1	Yes	Cat
Veazy	Pine Warbler	7/30/2018	8/2/2018	3	Yes	None
Art	Yellow Rumped Warbler	7/30/2018	8/1/2018	3	Yes	None
RAC	Yellow Rumped Warbler	8/3/2018	8/8/2018	5	Yes	None
Education	Cedar waxwing	8/3/2018	8/8/2018	3	Yes	Armadillo/Raccoon
Chemistry	Common Yellow-throat	8/6/2018	8/7/2018	1	Yes	Opossum
Natural Sciences	Ovenbird	8/18/2018	8/21/2018	3	Yes	Insects
Education	Common Yellow-throat	8/18/2018	8/21/2018	3	Yes	Insects
Carruth	Cedar waxwing	9/29/2018	9/30/2018	1	Yes	Opossum & Cat
Engineering	Cedar waxwing	9/29/2018	10/3/2018	4	Yes	Possum
Herty	Northern Cardinal	9/29/2018	9/30/2018	1	Yes	Racoon
Caroll	Cedar waxwing	10/13/2018	10/16/2018	3	Yes	Opossum
Newton	Cedar waxwing	10/13/2018	10/14/2018	1	Yes	Raccoon and Opossum

Figure 6. Examples of mammals scavenging experimentally placed carcasses: Feral cat (*Felis catus*) (top left), Raccoon (*Procyon lotor*) (top right), Virginia opossum (*Didelphis virginiana*) (bottom).

Environmental Factors

The square footage of buildings ranged from 14,375 (Lakeside Dining) to 245,888 (Henderson Library). The relationship between building area and the number of observed strikes is significant (Figure 7). Seven of the 20 buildings (35%) were composed of 10% or more by window area. Another 7 buildings (35%) were 5-9% composed of windows. Six of the buildings were 4% or less window surface area (Table 5). There is also a significant relationship between the total window area of a building and the number of window strikes observed at that building (Figure 8).

Math and Physics building had the greatest amount of surrounding tree-line (9,256.4 square meters). Military sciences building had the least amount of surrounding vegetation with 1,939.8 square meters of tree-line (Table 5). There is no significant relationship between the tree area within 40 meters and the number of window strikes (Figure 9.)

Building ages ranged from three years to sixty years, with the average building being 29.15 years old (Table 5). Age of the building and number of window strikes do have a significant relationship (Figure 10). The age of buildings and the amount of building area and window area do not have a significant relationship (Figure 11; Figure 12).

Of the possible multivariate linear models using the predictors building area, window area, and tree-line area, a model including window area and tree-line area was best (Table 6). However, a model including only window area had approximately the same explanatory power ($G = 3.7$, $P = 0.052$). However, sample size ($n = 20$ buildings) was small to rigorously evaluate multivariate models.

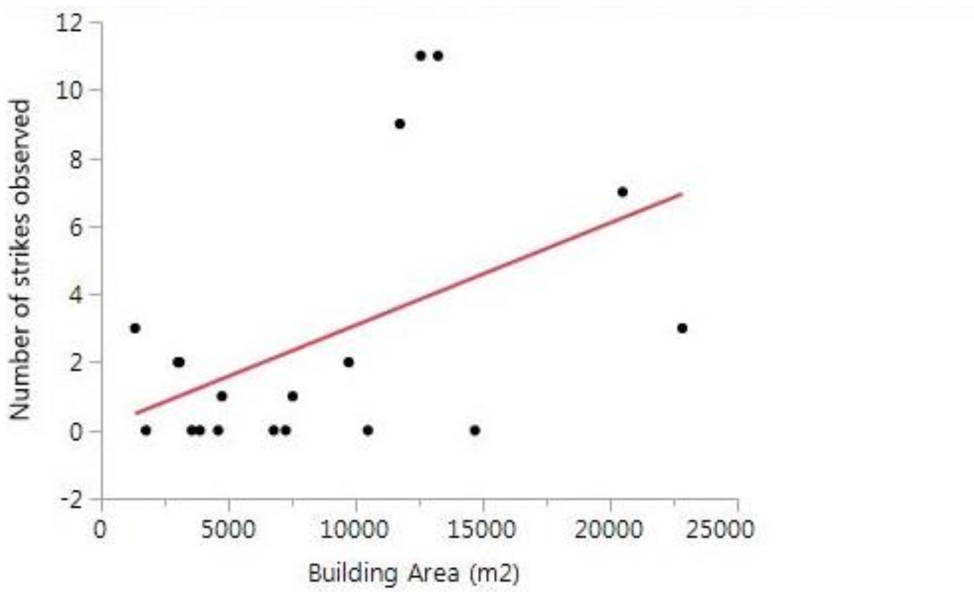

Figure 7. Number of window-killed birds increases with building area at 20 buildings on the Statesboro campus of Georgia Southern University (m^2). (Rsquare =.23; Df=19; F-ratio= 5.42; P=.03; n=20)

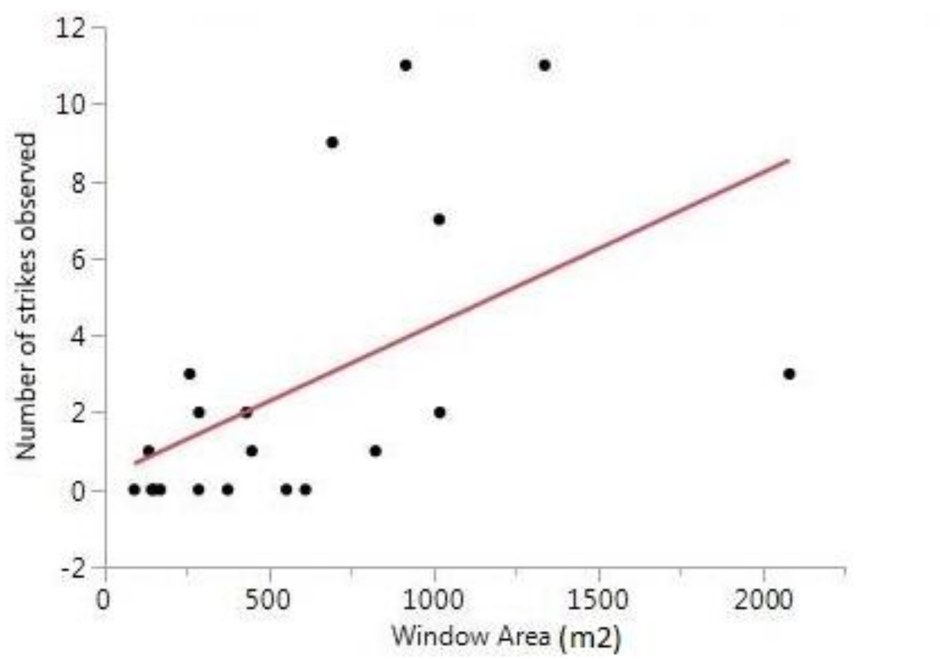

Figure 8. Number of window-killed birds increases with window area at 20 buildings on the Statesboro campus of Georgia Southern University (m^2). (Rsquare=.27; df=19; F-ratio = 6.97; P=.016; n=20)

Table 5. Physical characteristics of 20 buildings used during this study, Statesboro campus, Georgia Southern University.

Building	Year Built	Year Renovated	Area (m^2)	Window Area (m^2)	Percent Windows	Canopy Area (m2)
Arts & CAT	1937	2008	7530.28	823.572	10.93	2553
Biological Sciences	2013	-	12567.35	915.885	7.28	7649.28
Carroll	1971	-	7258.73	168.61	2.32	3657.16
Carruth	1959	-	3567.26	373.917	10.48	5723.74
Chemistry	2003	-	11742.93	692.401	5.89	6158
Education	2000	-	9732.44	1019.547	10.47	2924.54
Engineering	1995	-	7511.70	447.124	5.95	3510.65
Foy	1967	-	6783.53	552.525	8.14	4302.92
Hanner Field House	1969	2014	14693.703	150	1.02	4816.44
Henderson	1975	-	22843.55	2083.264	9.11	3150.9
Herty	1958	-	4604.23	610.58	13.26	2402.69
Information Technology	2004	-	13245.63	1338.397	10.10	7551
Lakeside Dining	1,991	2015	1335.47	258.295	19.34	3379.57
Math and Physics	1971	-	10485.32	285.351	2.72	9256.4
Natural Sciences	1968	2002	4750.27	133.503	2.81	1939.8
Military Sciences	2016	-	3091.78	286.533	9.26	4303.8
Newton	1972	-	3883.87	89.6	2.30	8021.23
RAC	1968	2006	20500.55	1017.451	4.73	3136.87
University Store	1989	-	1763.19	142.67	8.09	3087.66
Veazy	1959	-	3021.73	430.88	14.25	8317.84

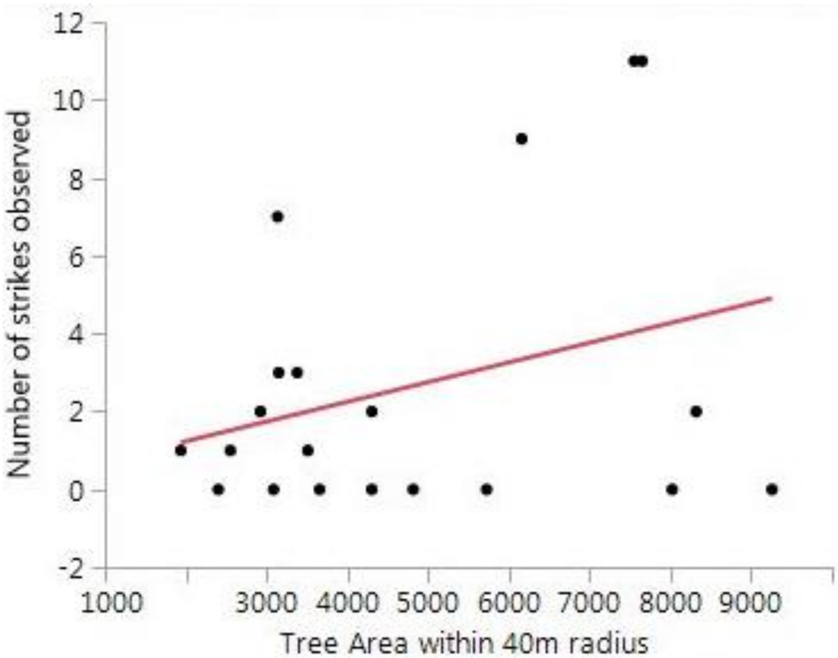

Figure 9. Area of tree-line within a 40-meter radius does not have a significant effect on the number of window-killed birds at 20 buildings on the Statesboro campus of Georgia Southern University. (Rsquare=.09; df=19; F-ratio= 1.87; P=.18; n=20)

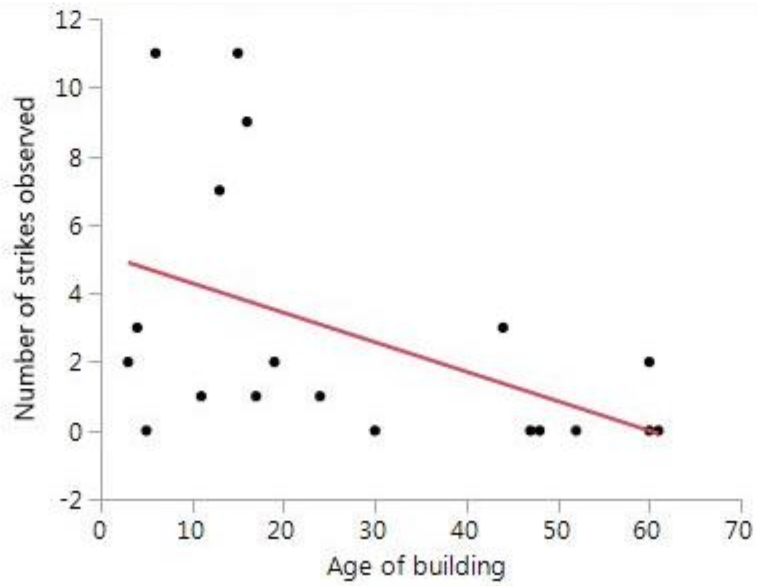

Figure 10. Number of window-killed birds decreases with age of buildings at 20 buildings on the Statesboro campus of Georgia Southern University. (Rsquare=.23; df=19; F-ratio = 5.4; P=.03; n=20)

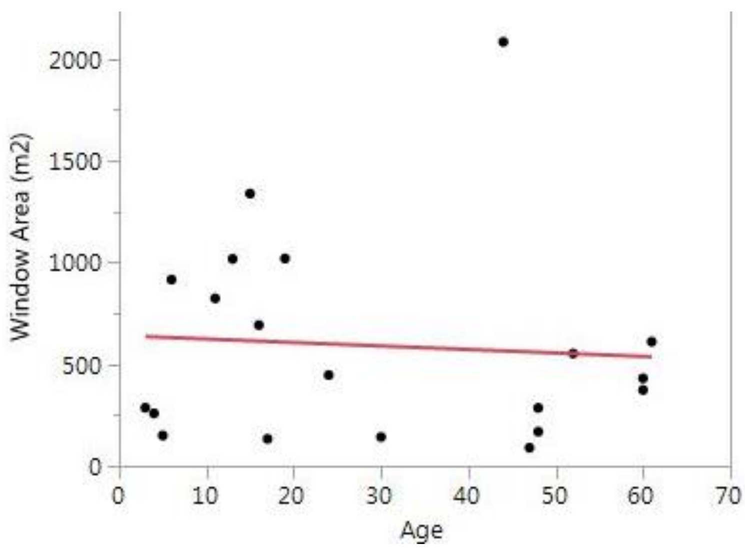

Figure 11. Age of buildings does not have a significant relationship with window area at 20 buildings on the Statesboro Campus of Georgia Southern University. (Rsquare= .005; df= 19; P= 0.76; F-ratio=.094; n=20)

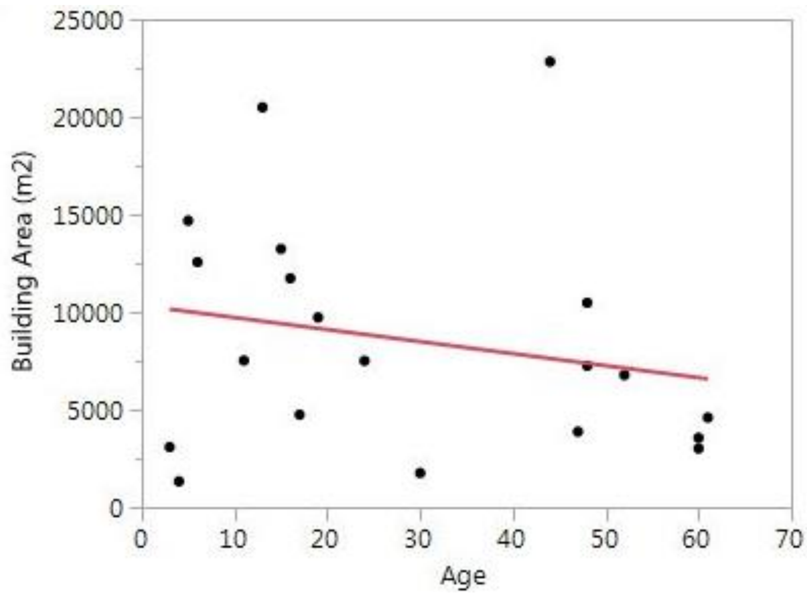

Figure 12. Age of buildings does not have a significant relationship with buildings area at 20 buildings on the Statesboro campus of Georgia Southern. (Rsquare= .046; df= 19; P= 0.36; F-ratio = .8817; n = 20)

Table 6. The three best models based on multimodel inference using AICc for the predictors building area, window area, and tree line area.

Model	**-Loglikelihood**	**AICc**
Window + Tree	49.038	108.746
Window	50.926	109.352
Building	51.565	110.631

Prevention methods

I evaluated three different commercial window strike prevention methods based on the values given on the American Bird Conservancy (ABC) website and manufacturing websites. The ABC Bird Tape costs about $0.56 per sqft. Using the calculated average window area of our monitored buildings, then it will be an average cost of $3,548.00 to apply to windows. Feather Friendly ™ costs around $1.87 per square foot and will cost around $11,850.00 to apply to windows. Solyx Bird Safety Film costs about $5.18 per square foot and will cost on average $36,817.61 to apply to windows (Table 7). The ABC Bird Tape has a lifespan up to 4 years before replacement, while Feather Friendly™ lasts eight years and Solyx last seven years.

Table 7. Cost to treat all the windows of 20 buildings on the Statesboro campus of Georgia Southern University.

Building	Total Window sqft	Solyx Bird Safety ($5.81 per sqft)	Bird Tape ($.56 per sqft)	Feather Friendly ($1.87 per sqft)
Hanner	1,614.6	$9,380.82	$904.17	3,019.30
Math/Phys	3,071.51	$17,845.52	$1720.05	5,743.73
Natural Sciences	1,437.02	$8,349.12	$804.73	2,687.23
Herty	6,572.28	$38,184.96	$3,680.47	12,290.16
Foy	5,947.37	$34,554.27	$3,330.53	11,121.59
University Store	1,535.69	$8,922.41	$859.99	2,871.75
Carruth	4,024.84	$23,384.33	$2,253.91	7,526.45
Veazy	4,637.99	$26,946.73	$2,597.27	8,673.04
Henderson	22,424.25	$130,284.91	$12,557.58	41,933.35
Carroll	1,814.91	$10,544.673	$1,016.35	3,393.89
Arts & Center for Theatre	8,864.92	$51,505.23	$4,964.36	16,577.41
Lakeside Dining	2,780.28	$16,153.46	$1,556.96	5,199.13
Newton	964.45	$5,603.48	$540.09	1,803.52
Information Technology	14,406.50	$83,701.79	$8,067.64	26,940.16
Engineering	4,812.84	$27,962.61	$2,695.19	9,000.01
Education	10,974.40	$63,761.28	$6,145.66	20,522.13
Chemistry	7,453.00	$43,301.95	$4,173.68	13,937.11
Biological Sciences	9,858.58	$57,278.38	$5,520.80	18,435.55
Recreational Activity Center	10,459.00	$60,766.80	$5,857.041	19,558.33
New Military Sciences	3,084.24	$17,919.44	$1,727.17	5,767.53
Average Building	6,336.93	$36,817.61	$3,548.68	11,850.07

Mortality Estimates

Estimate with no removal rate:

1st search:

$$\frac{\left(\frac{20}{46}\right)}{8} = .053\ birds\ per\ \frac{day}{building} = (.053)(87) = 4.611\ per\ day$$
$$= 424.11\ per\ spring\ or\ 1683.01\ per\ year$$

2nd search:

$$\frac{\left(\frac{25}{26}\right)}{20} = .048\ birds\ per\ day\ per\ building = (.048)(87) = 4.17\ per\ day$$
$$= 383.64\ per\ spring\ or\ 1522.05\ per\ year$$

3rd search:

$$\frac{\left(\frac{28}{31}\right)}{20} = .045\ birds\ per\ day\ per\ building = (.045)(87) = 3.915\ per\ day = 1428.975\ per\ year$$

Estimate with removal rate correction:

1st search:

$$\frac{\left(\frac{20}{46}\right)}{8} * 1.78 = .094\ birds\ per\ \frac{day}{building} = (.094)(87) = 8.207\ per\ day$$
$$= 754.72\ per\ spring\ or\ 2507.68\ per\ year$$

2nd search:

$$\frac{\left(\frac{25}{26}\right)}{20} * 1.49 = .71\ birds\ per\ day\ per\ building = (.071)(87) = 6.22\ per\ day$$
$$= 572\ per\ spring\ or\ 2270\ per\ year$$

3rd search:

$$\frac{\left(\frac{28}{31}\right)}{20} * 3.225 = .145\ birds\ per\ day\ per\ building = (.145)(87) = 12.615\ per\ day$$
$$= 4604\ per\ year$$

CHAPTER 4

DISCUSSION

I estimate that 2270 – 4604 (95% CI = 1086 - 3585) birds die annually here at Georgia Southern from window strikes. Buildings kill about 26 – 52 (95% CI = 13.12 – 42.73) birds a year. This rate is higher than Klem (1990), who estimated that building in the United States kill 1- 10 birds a year. However, this rate falls within the range of Loss et al. (2014), where low-rise buildings kill 5.9 – 55 birds a year. Window strike searches during my study were conducted mostly during times of high bird activity (spring migration), and the few search months during late fall into winter saw a decrease in the rate that strikes were being discovered. It is even suggested that every building has its own window strike signature based on a combination of building characteristics and environmental variables (Hager et al. 2013). For this reason, it is important to take into consideration multiple studies and sites when estimating a continental total. However, single site estimates, like the ones done in this study, are essential to conserving and protecting species in constantly developing environments. Window strike estimates should be used and closely monitored when it comes to management of environments as urbanization continues to expand on unaltered land.

Carcass removal rates were similar to other window strike studies, with carcasses lasting on average 2.46 days. Kummer et al. (2016) had carcasses lasting on average 3.46 days. Window strike studies tend to have quicker carcass removal when compared with wind turbine farms. Erikson et al. (2014) had a carcass removal range of 1.64 to 27.8 days based on 70 wind turbine studies. A building having no recorded strikes during carcass search periods does not equate to no birds being killed at a building (Huso et al. 2015). Carcass removal is considered high when 10% to 50% of carcasses are removed in 1 day (Kostecke 2001). For this study, 44% of carcasses were removed between 1-2 day and only 22% lasting more 5 or more days (Table 4). For my study, it is important to note that scavenging rates were only measured mostly in spring and summer. Scavengers are most likely to be active in hotter temperatures and Kummer et al. (2016) discovered that scavenging events are 7.6 times more likely to occur in spring/summer than winter scavenging events. High scavenging rates add high variability into my mortality estimate. Also, high carcass removal rate can be responsible for the lack of carcass detection at buildings with factors that other studies found to have increased window strikes such as high vegetation cover. There were also buildings that had scavenging instances that occurred within a few hours of a bird being placed. Kummer (2016) found that buildings that have higher strikes occur also have higher scavenging rates. However, for my study, the buildings that had highest scavenging rates also tended to have zero strikes. Buildings such as Natural Sciences and Math/Physics that had quick scavenging rates and large amounts of vegetation may be also causing high rates of window strikes despite having little or no strikes found by searchers. Having high vegetation cover also provides more cover for scavengers to roam and find carcasses and scavengers also tend to return to areas where they have secured a meal (Bracey 2016). While raccoons and possums may roam around buildings that commonly have bird strike victims, it is feral cats that are a special case. People on campus will often provide cat food and cafeteria scraps to stray cats. This may cause groups of feral cats to live around buildings where they can secure bird carcasses and food from people.

My study indicates that window strikes are significantly related to both building area and window area. This consistent with other studies (Cusa et al. 2015; Hager et al. 2013; Ocamp-Penuela et al. 2016; Schneider et al. 2018). However, my study lacked a significant relationship between the number of window strikes and surrounding tree area of buildings. This seems to contradict with Klem (1990), who suggested that buildings that have more bird attractants will have higher rates of strikes due to having higher bird densities. Bird abundance also directly relates to vegetation cover (Hager et al. 2013). Hager (2013) and Mactans (2013) provided further evidence to support Klem's claim by finding that buildings that are in undeveloped areas (rural) and have high window area have higher window Collison rates. Schneider et al. (2018) also determined that the amount of lawn reduced the number of strikes at buildings. Age of buildings also had significant negative relationship with window strikes. The older the buildings are the less strikes they will have. This relationship may be caused by the design standards and aesthetic appeal at the time of the buildings constructed. While window area did not significantly vary by age of buildings, older buildings tend to have smaller frequent windows, while newer buildings tend to have big areas of glass on portions of the building. My study focused on variables local to buildings, but Cusa et al. (2015) determined that large-scale variables within a 500-meter radius of buildings affect both bird density and variables near the buildings. The relationship between age and number of strikes can be due to bird density. New buildings may be being built in places where there are higher abundance of individuals. Another possible explanation is that migrating and native species may learn the landscape over time and learn the best ways to navigate and avoid any hazards.

Behavioral responses may be responsible for species that strike windows at higher rates. Many of the species that collided with windows during this study are ground active species, suggesting that species that have high activity at lower levels are more susceptible to window strikes. Common yellowthroat, ovenbirds, chipping sparrows, and mourning doves are all species that forage on the ground or flutter in lower shrubbery (Bull & Farrand 1994). Species, such as cedar waxwings, are social and tend to forage in flocks. Cedar waxwings were often found to have struck windows in groups. Species like ovenbirds and gray catbirds are night migrants (Bull & Farrand. 1994). Borden et al. (2010) suggested that night migrants are susceptible to strikes as they descend early morning into cover. Since no population numbers were collected during my study, it is not possible to determine which species are striking at higher proportions given their abundance. Determining which species are striking at large numbers does not determine whether window strikes are an additive source of mortality, meaning that windows kill individuals that would have otherwise survived, therefore it is important to monitor for any species that may be already threatened or in decline (Arnold & Zink 2011).

Cost and Prevention Summary

Since completely replacing windows at buildings would be a costly, timely and not practical solution, one practical course of action would be to retrofit windows to prevent strikes.

The first and cheapest option is the ABC Bird Tape. The Bird Tape is a translucent tape that allows light to pass through while giving birds a visual cue. The Bird Tape costs about $.56 per square foot and does not require professional application. Using the calculated average square footage of our monitored buildings, then it will be an average cost of $3,548.00 to apply to buildings. While this very cost-effective, this method may not be practical since the tape obscures the view and affects the aesthetic of the buildings. Bird tape also has the shortest lifespan (4 years) of all the options.

The next option is the Feather Friendly™ window decals. These are circular markers that are placed on the outside of the window to create a pattern in hopes of reducing the level of reflection. The decals are spaced evenly on strips that you cut and apply to windows. This product is more expensive than the ABC Bird Tape, and costs around $1.87 per square foot. Using the "average-sized" building calculation, it will cost around $11,850.00 to apply to buildings. The decals also obscure the view of the window, but the symmetrical pattern may be more aesthetically pleasing than the Bird Tape. This product also has the longest lifespan of 8 years.

The third and most expensive option is the Solyx Bird Safety film. This is a polyester film with 1/8-inch horizontal stripes that are spaced 1 inch apart. A film is a whole sheet of material that covers a window pane. This method costs about 45.18 per square foot, which would be on average $36,817.61 to apply to buildings. It is also suggested that the film be professionally applied to windows (additional cost). While this is most expensive method, it is also the most practical as it barely obscures the view of the window. However, Solyx's lifespan is shorter than that of Feather Friendly™.

While finding funding and manpower to retrofit every window would be difficult and probably not in the university's interest, a better solution would be to focus on buildings that have high strike occurrences. By focusing on troublesome areas, it may be possible to reduce the impact of window strikes on bird's population while also being cost and time effective. Narrowing down the most problematic areas will allow for the costliest method to be applied at lower costs and without hurting the looks of the building. While these options are very practical, they will only reduce the number of strikes. The best method to lower impact as the campus develops further would be to build with the environmental impact in mind. By consistently monitoring window strikes and thinking bird-friendly while in the planning stages, the campus can greatly reduce the number of birds killed yearly and preserve bird biodiversity.

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APPENDIX A

All known species that have been killed by windows at Georgia Southern University

Species	Scientific Name	Alpha Code
American Redstart	*Setophaga ruticilla*	AMRE
American Robin	*Turdus migratorius*	AMRO
Belted Kingfisher	*Megaceryle alcyon*	BEKI
Blue-headed Vireo	*Vireo solitarius*	BHVI
Blackburnian Warbler	*Setophaga fusca*	BLBW
Brown Thrasher	*Toxostoma rufum*	BRTH
Black-throated Blue Warbler	*Setophaga caerulescens*	BTBW
Cedar waxwing	*Bombycilla cedrorum*	CEDW
Chipping Sparrow	*Spizella passerina*	CHSP
Common Yellowthroat	*Geothlypis trichas*	COYE
Dark-eyed Junco	*Junco hyemalis*	DEJU
Gray Catbird	*Dumetella carolinensis*	GRCA
Grasshopper Sparrow	*Ammondramus savannarum*	GRSP
Hermit Thrush	*Catharus guttatus*	HETH
Hermit Thrush	*Catharus guttatus*	HETH
House Finch	*Haemorhous mexicanus*	HOFI
House wren	*Troglodytes aedon*	HOWR
Indigo Bunting	*Passerina cyanea*	INBU
Louisiana Water Thrush	*Parkesia motacilla*	LOWA
Mourning Dove	*Zenaida macroura*	MODO
Northern Cardinal	*Cardinalis cardinalis*	NOCA
Northern Parula	*Setophaga americana*	NOPA
Ovenbird	*Seiurus aurocapilla*	OVEN
Painted Bunting	*Passerina ciris*	PABU
Palm Warbler	*Setophaga palmarum*	PAWA
Red-bellied Woodpecker	*Melanerpes carolinus*	RBWO
Red-eye Vireo	*Vireo olivaceus*	REVI
Ruby- throated hummingbird	*Archilochus colubris*	RTHU
Savannah Sparrow	*Passerculus sandwhichensis*	SAVS
Scarlet Tanager	*Piranga olivacea*	SCTA
Sharp-shinned Hawk	*Accipiter striatus*	SSHA
Summer Tanager	*Piranga rubra*	SUTA
Swamp Sparrow	*Melospiza georgina*	SWSP
Swainson's Thrush	*Catharus ustulatus*	SWTH
Tufted Titmouse	*Baeolophus bicolor*	TUTI
Worm-eating Warbler	*Helmitheros vermivorum*	WEWA
Wood Thrush	*Hylocichla mustelina*	WOTH
White-throated Sparrow	*Zonotrichia albicollis*	WTRS
Yellow-billed Cuckoo	*Coccyzus americanus*	YBCU
Yellow-bellied Sapsucker	*Sphyrapicus varius*	YBSA
Yellow Rumped Warbler	*Setophaga coronata*	YRWA