Investigating the effects of urban features on bird window collisions

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ABSTRACT

Migrant bird species stopping over in urban locations are threatened by a number of anthropogenic causes of mortality, including collisions into reflective glass windows. Annual avian mortality rate, surrounding landscaping, and building characteristics that can potentially predict mortality rate were evaluated on mid-rises on the York University Keele Campus. I predicted that frequency of collisions increases with (1) higher proportional vegetation and proximity of vegetation to buildings, and (2) increased window area. After accounting for surveyor bias and predator removal, the rate of collision was 7.7 ± 4 SD birds/building/year. A negative binomial GLM determined collision frequency to be significantly predicted by proportional vegetation area, distance to vegetation, window area and wall vegetation. Significant interactions occurred between proportional vegetation area and season, distance to vegetation and window type, and wall vegetation and window area. It is strongly recommended that mitigation measures be implemented on high mortality buildings through visual markers.

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INTRODUCTION

During fall and spring migration, vast numbers of North American birds stop over in urban locations where they are faced with several anthropogenic-induced causes of mortality. These threats include predation by domestic and feral cats (Mumme et al. 2000; Lepczyk et al. 2003; Loss et al. 2012a; Loss et al. 2012b; Blancher 2013), collisions with vehicles, power lines and wind turbines (Balogh et al. 2011; Bishop and Brogan 2013; May et al. 2015;) and disorientation due to ecological traps and sink habitats (Robertson and Hutto 2006; Robinson and Hoover 2011). Among these threats, migratory bird window collisions (BWC) and the ensuing impact on bird populations have become a growing concern over the past couple decades (Klem 1990a; Borden et al. 2010; Hager et al. 2013; Machtans et al. 2013; Loss et al. 2014).

Each year, five billion songbirds and over 400 species breed in Canada over a wide variety of habitats must pass through urban matrices to get to their wintering grounds (Codoner 1995; Blancher 2002). Illustrating the scale of this problem for bird conservation, mortality due to window collisions have been documented for 225 different species in North America (Klem 2006). The most recent estimates place the annual toll from bird-window collisions at 365 million to 988 million in the United States (Loss et al. 2014), and 16 million to 42 million per year in Canada (Machtans et al. 2013). This magnitude of mortality places BWCs behind only predation by free-ranging cats as the most important sources of anthropogenic-causes of bird mortality (Loss et al. 2013). These window strikes are a major conservation issue and many species, including vulnerable or declining species, are susceptible to collisions. According to the U.S. Fish and Wildlife Service (2008), several threatened species were glass casualties during migration, such as the Canada Warbler (*Cardellina canadensis*) and the Golden-winged Warbler

(*Vermivora chrysoptera*); however, it is not known if window collisions are frequent enough to be contributing to their population declines for these species.

The threat of window collisions has grown to the point that in Ontario building owners are now legally required to take actions to minimize bird collisions. In 2013, Cadillac Fairview was charged under 14(1) of the provincial Environmental Protection Act (EPA) and s. 32(1) of the federal Species at Risk Act (SARA). It is now an offense (1) under Ontario law for buildings to emit reflected light as it is radiation/contaminant which lures birds towards windows, and (2) under the SARA to harm or kill birds regardless of whether reflective windows were responsible. In addition, protection of migratory birds in Canada falls under the Migratory Birds Convention Act of 1994. This case effectively sets a precedent and provides legal protection through the expectation that building managers implement reasonable bird-safe practices for migratory birds flying through urban environments. In North America, bird-safe window practices have also been implemented in the cities of Minnesota, New York and Calgary (Audubon Minnesota 2010; Brown & Caputo 2007; City of Calgary 2011; City of Toronto 2007; Sheppard 2011). Therefore, there is urgent need to accurately identify which buildings are most in need of mitigation measures to reduce bird fatalities.

Some species appear to collide with windows more frequently than others based on their local abundance (Dunn 1993; Hager et al. 2013). In their natural habitat, birds that fly swiftly through passageways within dense vegetation become common window casualties due to the deceptive properties of windows as their high velocity aimed towards a supposed light gap makes it harder for the bird to stop or veer away even if it does detect the glass. These species include the Ruffed grouse (*Bonasa umbellus*), American woodcock (*Scolopax minor*), Accipiter hawks, hummingbirds, thrushes, and Ovenbird (*Seiurus aurocapilla*) (Ross 1946; Snyder 1946;

Klem 1989; Klem 2014). Species that exhibit trap-lining behavior, such as the tropical hermit hummingbirds (*Phaethornis spp.*) at La Selva biological station in Costa Rica, are thought to be especially susceptible to window collisions due to their repeated flight patterns and thus more opportunities for collision (Graham 1997). Based on collision records from previous literature, recent studies have found that North American migrants flying long distances or at night, tend to be victims of bird window collisions more often than diurnal migrants or non-migratory residents (Machtans et al 2013; Loss et al. 2014).

Studies show that birds are unable to recognize windows as invisible barriers to them, or lack the ability to distinguish between a reflection of habitat and real habitat (Klem 2009). As a result, birds often collide with clear and reflective surfaces at full speed. A bird in flight can gain enough velocity to create a fatal collision from a perch as far as a meter away (Klem 2010). Birds are thought to collide into windows during the daytime through two main mechanisms. The first being that birds flying through a breezeway or other narrow paths strike transparent panes at the end, because they can perceive that they can continue their flight through to the other side (Ross 1946; Klem et al. 2009). Second, birds can be deceived by reflective panes that mirror potential habitat or sky resulting in a collision (Banks 1976; Klem 2006; Klem 2007). In some cases, prey and predators in pursuit often become collision victims, as when raptors hunt near windows forcing the prey to perform erratic evasive movements (Klem 1989; Hager 2009). During the day, due to increased bird activity such as foraging, these collisions appear to occur more frequently on lower windows of a façade for foraging (Gelb 2009), but tall towers and skyscrapers threaten migrants moving at night (Longcore et al. 2013).

Incidence of mortality due to window collisions are higher during migration owing to the higher abundance of birds (Klem 1989; Drewitt & Langston 2008). During migration, birds that require rest and food to refuel, frequently select habitats that are characterized by forest cover and proximity to water. Furthermore, nocturnal migrants that rely on constellations and the moon for navigation, are often attracted to the light pollution or 'beacon effect' that is emitted from structures, such as communication towers and tall buildings (Avery et al. 1976; Larkin and Frase 1988; Manville 2000; Erickson et al. 2005). This is especially true on nights with fog or low cloud-ceilings (Newton 2008; Longcore et al. 2012). In most cases, this is a fatal attraction as birds may become disoriented and once inside a lighted area, and continue to fly in it as if trapped (Avery et al. 1976; Larkin and Frase 1988). Passerines that migrate at night, such as warblers and sparrows, collide with windows frequently (Klem 1989; Gelb & Delacretaz 2006). Once lured to a light source or trapped in a city, threats to birds include collisions with lighted structures, an increased risk of predation, and dropping to the ground due to exhaustion (Avery et al. 1976; Erickson et al. 2005). Birds which are not fatally injured are often stunned and are left vulnerable to other threats such as predation (Klem 1990b; Graham 1997; Klem et al. 2004).

Various landscape characteristics have been implicated with increasing the number of collisions such as migratory corridors, surrounding landscape, habitat type, and weather conditions. Bonter et al. (2009) demonstrates that migrants are spatially focussed through the shoreline of the Great Lakes where humans prefer to build cities, to utilize stop over sites in the form of forests, residential, and urban fragmented habitats. Urban parks act as stopover habitat for birds migrating through cities (Seewagen and Slayton 2008; Seewagen et al. 2010). Factors in the design and size of buildings also play a role such as the reflectivity of windows, lighting used and height (Klem 2009; Hager et al. 2013). Building and landscape features can also influence the density of birds near windows, such as the locality of a home, the amount of glass exposed to the environment (Hager et al. 2008; Klem et al. 2009; Borden et al. 2010; Hager et al. 2013), the surrounding vegetation (Klem et al. 2009; Borden et al. 2010), presence of water as an attractant, and artificial lighting conditions (Drewitt and Langston 2008; Zink and Eckles 2010). Time of day is also implicated with window collisions as Hager and Craig (2014) determined that mortality occurred most frequently between sunrise and 1600h. Thus, to a great extent, building design, lighting, and landscaping can be modified to reduce the mortality rate for birds.

Research objectives:

In Canada, Machtans et al. (2013) concluded that while the kill rate of birds at mid-rise (0.4 to 55 deaths/building/year) and high-rise (376-8779 deaths/building/year) buildings is higher than at single homes (0.3 and 15.7 birds per year), they only make up a small fraction of the total number of BWCs nation-wide. This is due to the substantially larger number of single family residences and low-rise commercial buildings across the country and so overall most BWCs occur at individual houses rather than high-rises (Hager et al. 2013; Machtans et al. 2013; Loss et al. 2014). It was estimated that of the total number of bird deaths caused by buildings in Canada, low-rises are responsible for slightly less than 10%, high rises for 1% and the remainder to rural and urban single homes (Machtans et al. 2013).

The goal of this study was to obtain scientifically based estimates of annual avian mortality rate in a low-rise campus setting and to determine the landscaping and building features that can predict mortality rate. This is important for: (1) providing firm guidelines and recommendations for university campuses to make their buildings more bird friendly as part of larger efforts of sustainable practices, and (2) improving modelling of overall mortality across Canada. In their Canada-wide estimates of avian mortality from window collisions, Machtans et al. (2013) noted the paucity of systematic studies for low-rise commercial and campus buildings and that most estimates of mortality in this class had been for buildings or sites already known to have a high collision rate. This bias greatly complicates efforts to accurately model mortality rates across the country, especially given that this class of building accounts for some 10% of all mortality. Machtans et al. (2013) also noted the need for low-rise building studies that measure search efficiency and predator removal rate, in order to better estimate the actual number of birds killed vs found.

To fill this gap, I systematically searched the same set of buildings on the York University main campus in Toronto in fall and spring, for two different years. With a team of volunteers, I conducted daily searches for window collision victims and also conducted search efficiency and predator removal tests in both seasons. I tested the predictions that:

(1) The frequency of bird-window collisions will increase with higher amounts of vegetation near buildings and closer proximity of vegetation to buildings.
(2) The risk of collision increases with window area, all else being equal.

METHODS

Study Area

Data collection was conducted on the York University Keele campus in Toronto, Ontario, Canada (Figure S1) occupying 457 acres of land with 92 separate buildings. Toronto is estimated to contribute to 33% of national BWC from high-rise buildings but little is known about mortality rates at the more numerous mid-rise buildings within the city (Machtans et al. 2013). Furthermore, Toronto is found along the Atlantic migratory flyway and the Great Lakes, suggesting that mitigation of BWCs is especially important in this region

In a pilot study conducted in spring 2014 to test methodology, six study buildings were categorized by both building size (small, medium, large) and vegetation (high surrounding green space, low green space). Small buildings were one to two story single family residences less than 2,000 ft^2, medium buildings were two to four story office buildings ranging between 2,000 – 45,000 ft^2 and large buildings were greater than or equal to five stories in height or more than 45,000 ft^2. Buildings selected had variation in percent vegetation within ~30 m buffer. High surrounding green space was defined as any buildings with shrubs and trees surrounding the base of the building whereas low was where buildings had only a few dispersed trees and shrubs from a wall. Beginning in fall 2014, nine additional buildings across campus were included to increase sample size and variation between buildings.

Experimental Design

All 15 buildings were searched daily during migration. Surveys were conducted for four consecutive seasons from mid-September to mid-October 2014/2015, and late April to late May 2015/2016 during the peak periods of fall and spring migration. Building surveys were conducted daily for five weeks (35 continuous days), regardless of weather.

This study followed the survey protocol developed by Hager (2014). Full day sampling (Hager 2014) has shown that most collisions occur during the daytime, as birds move around locally to forage and refuel for their next migration flight. Surveys took place between (1400-1600h) and consisted of two passes around the base of the building at a two-metre distance (or just beyond the width of arms held out horizontal to the ground) from a building façade. A window strike was recorded for a façade when either dead or injured birds were found on the ground. Two passes are required in opposite directions (one person) or to have two individuals independently search in the same direction around the building. Surveyors recorded the building, direction of the buildings wall (north, south, east or west) on a provided data sheet and took photos of birds every time a bird was found.

Dead birds were collected, identified to species and then stored in a freezer. Unidentifiable birds due to decay and inaccessible carcasses found on ledges or on higher floors were categorized as Unknown Species (UNSP). Any injured or stunned birds found during a survey were transferred to the Toronto Animal Care Centre for rehabilitation, release or euthanasia. During the entirety of this study, no birds were intentionally harmed or disturbed. Collection of bird carcasses has been reviewed and approved by the Animal Care Committee at York University.

Search efficiency protocol

To determine the accuracy of surveyors in the field, search team members tested each other's search efficiency. At each building, one surveyor was randomly selected to implement the search test using one of three pre-selected carcasses. The carcass would then be placed along a random wall, and subsequently, the other search team member(s) conducted two normal sweeps of the building, using regular survey protocols. Carcasses that were not found on two sweeps were recorded as misses and an overall proportion for successful sweeps were calculated at the end of the search efficiency protocol week. This protocol yielded six search tests per day for one week at random locations for a total of 42 tests per season and was conducted once in the fall and once in the spring.

Predator removal protocol

Carcasses were placed in pre-determined locations in order to test scavenger activity on campus. This protocol was conducted after the second surveying week, one time per day for seven days, once in the fall and once in the spring. A bird was placed on specific sides of buildings on a given day of the week (Monday: North; Tuesday: East, Wednesday: South, Thursday: West and Friday: North side again). At 1000h am each morning, a bird carcass was placed on the designated side of each building, half way along the side. If there is a doorway or other obstruction at the half way point, carcasses were then placed on the right side, when facing the building. Surveyors were notified of predator test carcasses and during the normal search (1400-1600h) they determined if the placed carcass had disappeared. This yielded five predator tests per day for a week totalling of 35 tests per season and was conducted once in the fall and once in the spring.

Building and Landscaping Measurements

Floor and building plans obtained through York University's Planning and Renovations Department were processed in ImageJ (Schneider & Eliceiri 2012) to measure the total window area (m^2) of each wall or façade of a building (n=113). As songbird activity is confined to the ground and trees during the day time and the tallest height of a tree does not extend past the 3rd floor, window area was measured up no further than the 3rd floor.

ArcGIS was used to determine the surrounding vegetation area and the nearest distance to vegetation (ESRI 2011). Vegetation was defined as any trees, shrubs or possible leafy habitat for birds to perch or fly from. Shapefiles of York University were gathered from the GAIA request system and a base layer was composed of orthophotos taken from the Esri Toronto Orthophoto 2013 index. The area of vegetation within 30m of a buildings wall was calculated and extending 45º from each façades corner. Thirty meters was selected as this was the minimum distance between the corridors of adjacent buildings. Grass or open fields were not included in this measurement. To determine the accuracy of these measurements, ground truthing was conducted for proportional vegetation area and distance to vegetation. Ground validation of proportional vegetation area was determined for a random façade for each building by measuring the green footprint of any trees, shrubs or vegetation within the sampled area of 30m (Figure S2A).

Distance to vegetation was measured as the mean distance from a wall to the edge of the nearest vegetation within 30m. Validation of distance to vegetation was measured through the use of an open roll measuring tape from a random building façade for each building to the nearest vegetation for each building (Figure S2B). Measurements for the amount of wall vegetation cover up to the 3rd floor on the wall itself were also collected. A photo was taken from 30m away from a façade. Following this, the photo was processed in ImageJ (Schneider & Eliceiri 2012) and wall vegetation cover was measured as the proportion of ivy or wall creeping plants that grew on the side of the wall.

Window reflection was categorized into three groups: translucent, transparent and very reflective, each designated by numbers 1 to 3 respectively. No windows on study buildings contained any window film, predator stickers or fritted glass.

Data analyses

A generalized linear model (GLM) using a negative binomial distribution was developed to examine the relationship between urban landscape features such window area, proportional vegetation area, distance to vegetation, wall vegetation cover, window reflection and bird window collisions in R Statistics (R Development Core Team 2012) using the statistical package "MASS" (Venables and Ripley 2002). The negative binomial GLM is a model used for describing variation in count data in the presence of over-dispersion (Boyce et al. 2001). Subsequently, model selection was carried out using stepwise AIC (Akaike information criterion; Burnham and Anderson 1998). A type II ANOVA was performed on the model using the "car" package (Fox and Weisberg 2011) to interpret interactions of mixed effects for any complex scenarios between the predictor variables and frequency of collisions.

RESULTS

Annual Mortality

A total of 231 individuals from 43 different species were documented as bird-window collisions during the cumulative 20-week fall/spring survey periods (Supplementary Table S1). Five of these collisions were stunned birds, whereas the remaining documented collisions (98%) were fatal. The total number of collisions per building ($N_B = 15$), cumulative over all four sampling periods, ranged from 1 to 34 with a mean value of 7.7 ± 4 SD birds/building/year (2014-2016 fall and spring). In the fall there was an average of 5.3 ± 1.3 SD collisions per building, while there were 2.4 ± 1.9 SD in the spring. Over 133 sampling days, there was an average daily collision rate of 1.7 ± 2.1 SD birds/day across all 15 buildings.

The search efficiency test in the fall yielded a 100% recovery rate and 95% (38 of 42) of carcasses were found on the first pass (Table 1). However, in the spring, the search efficiency test yielded a 73.8% (30 of 42) recovery rate. Overall search efficiency was therefore 86%. During the fall migration, a predator removed 11.4% (4 of 35) pre-placed carcasses, and 8.6% (3 of 35) in the spring (overall removal rate of 10%). An adjusted daily collision rate over 133 sampling days was determined to be 2.01 ± 2.1 SD birds/day across all 15 buildings. However, for all subsequent analyses, the observed (uncorrected) rate was used.

Species Occurrences

Species most commonly documented in order of number of collisions were White-throated Sparrow (*Zonotrichia albicollis*) (16.5%), Ovenbird (*Seiurus aurocapilla*) (10.4%), Nashville Warbler (*Oreothlypis ruficapilla*) (6%), Tennessee Warbler (*Oreothlypis peregrina*) (5.2%), and Swainson's Thrush (*Catharus ustulatus*) (5.2%) (Supplementary Table S1). The most numerous collisions were from the Parulidae family (warblers: 31.2%) followed by Emberizidae (sparrows: 24.7%), unknown species due to decay or predation (19%) then Troglodytidae (wrens: 9.1%), and both Picidae (woodpeckers) and Regulidae (kinglets: 3%). All other families were each less than 2% of the total number of collisions.

Predicting Mortality Risk

Buildings with the highest bird mortality were Lumbers (14.7% of total collisions), Founders Residence and Chemistry (12.5% each), Life Science Building (12.1%), Osgoode Hall Law School (10.3%), Atkinson (9.5%) and Executive Learning Centre (9.1%). The remaining buildings each made up less than 5% of the total number of collisions.

In both fall and spring, a simple bivariate comparison revealed no correlation with proportional vegetation area or distance to vegetation with number bird window collisions in the fall and spring (Figure 1 and 2). Similarly, no correlation was found between the amount of window area up to the 3rd floor and number of collisions. Results from the negative binomial GLM (Table 2) indicate that proportional vegetation area (GLM: $\chi2(1)= 17.6$, $p<0.01$), distance to vegetation (GLM: $\chi^2(1)= 0.074$, $p=0.785$) and window area (GLM: $\chi2(1)= 10.5$, $p<0.01$) were significant predictors of bird window collisions. The model also determined that other significant predictors of BWCs were the spring season (GLM: $\chi2\ (1) = 17.4$, $p<0.01$), wall vegetation (GLM: $\chi^2(1)= 7.23$, $p<0.01$) and window reflection (GLM: $\chi^2(2)= 16.9$, $p<0.01$) (Table 2)

Comparison of mixed effects between predictor variables revealed significant interactions between the predictor variables and frequency of collisions (Table 3). An interaction effect was present between window area and wall vegetation on BWCs (GLM: $\chi^2(1)= 8.92$, $p<0.01$)(Figure 3a), where walls with more vegetation and increasing window area created a greater number of collisions. In addition, significant mixed effects were found between spring season and percentage of vegetation area, where vegetation is more predictive in the spring (GLM: $\chi2(1)= 4.93$, $p= 0.026$) (Figure 3b). The ANOVA also revealed that when windows on a façade are either transparent or reflective, we find distance to vegetation as a significant predictor of bird window collisions (GLM: $\chi^2(2)= 6.12$, $p= 0.047$) (Figure 3c). Translucent windows and increasing vegetation area had a negative impact on the frequency of collisions.

DISCUSSION

Predicting Bird Window Collisions

The mortality rate of mid-rise buildings varies across studies depending on density and type of buildings, the landscape, and the abundance of migrants passing through (Somerlot 2003; Borden et al. 2010; Hager et al. 2013; Ocampo-Peñuela et al. 2016; Sabo et al. 2016). A study documented a collision rate of 54.8 birds/building/year at in Augustana College in Illinois and 24.0 birds/building/year at Principia College in Elsah (Hager et al. 2008), whereas over two years (fall and spring) the overall frequency of collisions at the Keele campus of York University in Toronto was far lower at 7.7 ± 4 SD birds/building/year. Augustana College and York University share common landscape features such as woodlots, gardens, and a high amount of exterior glass on buildings. However, a higher number of bird collisions at Augustana College may be attributed to a differing location along migration routes and also structure and connectivity of surrounding landscapes (Longcore et al. 2012).York University is within an industrial zone of one of the largest cities in Canada whereas Augustana College is located in a small town along the Mississippi River flyway and is surrounded by a rural landscape.

Sampling protocols based on those used in Hager et al. (2003), were implemented to reduce the biases associated with imperfect detection of carcasses or if carcasses were removed by scavengers or surveyor error (Hager & Cosentino 2014). The high variability in collision rate suggests that additional studies on mid-rise buildings are needed to better model national collision rates and to understand where mitigation is urgently needed. The search efficiency and predator removal protocols in this study suggest bird carcasses from window strikes may be underestimated from actual observations of window kills. Both these protocols suggest that the fatality rate of 7.7 ± 4 SD birds/building/year on the Keele campus is a conservative estimate due to the surveyor error or removal of predators. Our study found an overall search efficiency test yielded 86% recovery rate whereas birds were removed at an overall rate of 10%. Thus, before birds were removed or missed, our estimate total number of collisions over 133 sampling days (fall and spring) was 9.5 ± 4.9 SD birds/building/year. Our predator removal rate of 10% is half than that at West-Coast Urban Park Museum at Golden Gate Park, San Francisco with a rate of 20% (Kahle et al. 2016) and 1.58 times less than at small communication towers at towers within aggregated Bird Conservation Regions (Longcore et al. 2013). Consequently for all bird-window collision studies, to be useful in modelling risk of specific building types, search efficiency and predator removal must be measured.

The most frequent BWCs at mid-rise buildings in this study were the species White-throated Sparrow (*Zonotrichia albicollis*), *S. aurocapilla*, Nashville Warbler (*Oreothlypis ruficapilla*), Tennessee Warbler (*Oreothlypis peregrina*), and Swainson Thrush (*Catharus ustulatus*) (Supplementary Table 1). These species are also among the top ranked victims at high-rise buildings (Hager et al. 2013; Machtans et al. 2013; Loss et al. 2014). Sparrows, warblers, thrushes and Brown Creepers (*Certhia Americana*) comprise the most commonly observed fatalities in our study and echo the taxonomic distribution of fatalities reported by other studies during migration in north eastern United States and Canada (Klem 1989; Dunn 1993; O'Connell 2001; Gelb and Delacretaz 2009).

Mortality rates during fall migration (2.52 ± 4.48 SD) were consistently greater than that during spring migration (1.03 ± 2.87). The increased abundance of birds flying through stop over sites in fall due to the presence of juveniles presumably leads to a greater risk of window collisions because more birds are present in fall than spring (Dunn 1993; Hager et al. 2013; Drewitt and Langston 2008) and are consistent with observations documented across North America (Johnson and Hudson 1976; Hager et al. 2008; Gelb and Delacretaz 2009).

Effect of Landscape Predictors

BWCs are dependent upon several related building and landscape variables such as surrounding vegetation in the immediate area (Klem et al. 2009; Borden et al. 2010) and amount of glass exposed to the environment (Hager et al. 2008; Klem et al. 2009; Borden et al. 2010; Hager et al. 2013). A significant predictor of bird window collisions in this study was proportional vegetation area. Prior literature has found that patchy greenery in an urban environment act as natural habitat providing resources such as food and refuge thus potentially luring in migrant birds, increasing bird density and diversity near buildings (Klem 1989; Pennington et al. 2008; Bonter et al. 2009; Matthews & Rodewald 2010; Hager & Craig 2014; Klem 2014). Similarly, Borden et al. (2010) found that along with compass direction of a building façade and the presence of trees within 5 m of a building at an urban university campus in Cleveland, OH, had no effects on collision frequency and collisions occurred at façades with higher percentages of glass and not randomly distributed across campus. At single homes, Sheppard (2011) and Erikson et al. (2005) found that more birds were attracted to the vicinity of a home when more vegetation such as trees and shrubs was present, resulting in an increased exposure to windows and thus a risk of collisions. Expanding on this relationship, this study revealed that an interaction effect occurred with season and proportional vegetation area, where the spring season and lower vegetation area predicted fewer window fatalities.

This study found that the distance of trees, shrubs of leafy plants within 30 meters of a façade was a significant predictor of BWC during the spring and fall. These results suggest that migrant species that move to green spaces in the vicinity of a building are at risk of collisions the greater distances are between trees and buildings. However, other studies (Klem et al. 2009; Hager et al. 2013) found that distance to vegetated lots did not predict frequency of window collisions, and that lethal collisions could occur only 1 m away causing to head trauma (Klem 1990a; Klem et al. 2004; Veltri and Klem 2005). Despite this, the model also found that frequency of BWCs can be predicted by façades with transparent or reflective windows, and having a greater distance to vegetation (Figure 3c). A higher frequency of BWCs occurs at buildings which contain highly reflective windows and highly vegetated surroundings (Klem et al. 2009; Ocampo-Peñuela et al. 2016), suggesting that distance to vegetation as well as its varying visible reflection could have an effect on predicting collisions. This is supported by a study that found an increased likelihood of window collisions when the reflection of vegetation increase, or the vegetation seen behind the transparent glass in windows increased (Gelb and Delecretaz 2006). Furthermore, depending on the time of day, transparent glass can become reflective, appearing as an unobstructed flyway (Sheppard 2011).

My results support the current literature that sheet glass consisting of small windows to entire walls of buildings are a greater lethal hazard for birds (Hager et al. 2013; Kahle et al. 2016). Greater window area on a building façade saw an increased risk of bird-window collisions, allowing more exposed area for a bird to collide into. This is supported by Borden et al. (2010) and Hager et al. (2013) who demonstrated that risk of collision was predicted by percentage of window area. In addition, increasing wall vegetation cover such as ivy (*Hedera spp.*) was a significant predictor of BWCs in this study, and in conjunction with high amounts of window area, this mixed effect predicted greater window collisions. Wall vegetation can play a role similar to greater proportional vegetation area where window collisions occur with greater frequency in areas with high canopy cover and window area (O'Connell 2001; Hager et al. 2008, Klem et al. 2009). The food provided by wall vegetation, such as invertebrates or fruits (Jacobs et al. 2010), lure in birds much like surrounding vegetation patches (Hinsley and Bellamy 2000).

Campus management recommendations

My study can help inform future building design and landscape management to reduce the rate of bird window collisions on university campuses. Window collisions were associated with greater vegetation area suggesting that reducing vegetation near buildings could reduce bird mortality. But the benefits that urban greenery can provide through social, physical or psychological means to humans, birds, and other wildlife and cannot be overlooked (Fuller et al. 2007). Similarly, while the removal of ivy could be an effective mitigation effort, green walls aid in several processes such as protecting walls by ameliorating temperature and relative humidity extremes (Sternberg et al. 2010), diminish acoustic (Kotzen 2004; Wong et al. 2010) and light pollution (Perez et al. 2011), influence local climate (Holm 1989), provide building insulation and protection (Viles and Wood 2007; Jin et al. 2009) and reducing storm-water flows (Roehr and Laurenz 2008). Thus alternative solutions would be to mitigate BWCs at buildings of high mortality rather than reducing the overall surrounding vegetation across campus as the benefits of green walls and spaces cannot be overlooked (Flather and Sauer 1996) and humans (Vries et al. 2003).

An effective solution would be to develop mitigation measures for the high-mortality buildings rather than target all buildings. Specific buildings, such as the Life Science Building, Lumbers, and Executive Learning Centre (Supplementary Figure 4) had a higher collision rate ranging from 20-31 birds per building per year. A simple recommendation is the closing of any interior window covering such as shutters or blinds during the day to prevent mirrored reflections caused by the contrast of bright sunlight from the outside and low light from the inside of a window (Hager 2014). This suggestion can also extend to the night to decrease the light emissions from buildings, thus reducing the number of night migrants that are lured in. Alternatively, indoor building light can be turned off at night to reduce the number of nocturnal migrants from colliding or being lured onto the campus (Brown and Caputo 2007; Sheppard 2011).

Visual markers in the form of an image or pattern can be applied on to glass surfaces. Glass treatments include ceramic frit, acid-etched finish or sandblasted glass to achieve various patterns or images on the outer surface (Klem et al. 2004; Klem 2006; Klem 2009). Patterns can be made to the requirements of manufacturers and building management allowing them the opportunity to create translucent or opaque images of varying sizes to project enough visual cues to be perceived by birds or reducing reflectivity of the exterior surface (Klem 2009). In addition to potentially reducing BWCs, ceramic frit and acid-etched patterns aid in the reducing transmission of light and heat, providing privacy or advertising branding. AviProtek, a product of Walker Textures is an example of a company that produces bird-friendly glass with acid-etched markers on the outside surface. In existing situations where replacement of glass is cost prohibitive, external films or decals can act as visual on the outside surface of a window, reducing the risk of window collisions by 59% (Klem 2009; Klem 2013). Patterned decals and films spaced no further than 10 cm apart that serve to break apart larger clear spaces on glass surfaces are an effective deterrent for BWCs (Klem 1990; Klem 2009b). These treatments can be applied up to the third floor of a building or to the height of the top of the surrounding tree canopy at maturity.

While maintaining the same separation pattern of 10 cm, ultraviolet (UV) signals implemented into film are another external alternative. These external films have been recommended to reflect 20-40% of UV light (Klem and Saenger 2013). However, 50% UV reflectance or absorption were shown through simulation models depicting the reflections of natural skylines on window glass to be effective for UV sensitive species (Hastad and Odeen 2014). In some songbirds (Passeriformes), the peak sensitivity of UV cones is approximately 365 nm (Rossler et al. 2009), 25 nm shorter than what humans use. Thus a UV signal range emitting or reflecting 300-400 nm wavelength should be used for avian deterrence (Klem 2009; Klem and Saenger 2013). Four companies which have adopted the UV concept are ORNILUX Mikado, GlasPro-Bird Safe Glass, WindowAlert and Bird's Eye View, where the former two offer UV-treated panes and the latter two offer UV decal kits. However, a study by Klem and Saenger (2013) concluded that the UV-treated panes offered by ORNILUX Mikado to be ineffective at alerting birds to the presence of windows as it reflected a lower level of UV that can be perceived by birds. This glass pane reflected 7-22% UV from 300-400 nm reaching above 20% reflection only at 397 nm.

Limitations and Future Studies

More research of mortality rates at mid-rises will contribute greatly to improving mortality estimates and be able to further influence the decisions of building designers. Future research should sample a variety of mid-rise types, including residential, commercial, and industrial buildings and also with varying amounts of vegetation around the buildings. Further investigation into bird deterring products including window types and UV films and their effect on avian mortality is suggested. Controlled experiments should be conducted in isolated wind tunnels with light gaps behind differing glass treatments to simulate the flight paths of birds while removing other predictor variables such as proportional vegetation and window area to control for predictors that have an effect on BWCs. Assessing window reflection and its effects on BWCs could aid in pinpointing the exact predictors and improving overall window collision modelling in North America.

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TABLES

Table 1: Results of predator removal (n=35 each season) and search efficiency (n=42 each season) protocols during the fall 2014-15 and spring 2015-16 season.

Season	Predator Removal (%)	Search Efficiency (%)
Fall	11.4	94.3
Spring	8.6	71.4
Total	10	82.9

Table 2: Fitted negative binomial GLM coefficients and p-values for predictor variables of BWCs.

	Dependent variable:	
	Frequency of Collisions	
	Coefficient	*P-value*
Spring season	-1.474	0.00001***
Window area	0.002	0.011**
Vegetation area	0.001	0.077*
Distance to vegetation	-0.224	0.092*
Wall vegetation	-0.045	0.058*
Transparent windows	-0.108	0.905
Reflective windows	0.393	0.753
Window area + wall vegetation	0.0004	0.013 **
Spring season + vegetation area	0.002	0.009 ***
Distance to vegetation + transparent windows	0.235	0.080*
Distance to vegetation + reflective windows	0.253	0.084*
Observations (# of Façades)		452
Log Likelihood		-361.192
theta		0.469*** (0.092)
Akaike Information Criterion		746.385

Table 3: ANOVA of GLM. Table indicates interactions between BWCs and predictor variables.

Analysis of Deviance Table (Type II tests)

Response: Frequency of Collisions	**Likelihood Ratio χ^2**	**Df**	**Pr(> χ^2)**
Season	17.4118	1	3.01E-05 ***
Window area	10.5164	1	0.001183 **
Vegetation area	17.6432	1	2.67E-05 ***
Distance to vegetation	0.0747	1	0.784614
Wall vegetation	7.229	1	0.007173 **
Window reflection	16.9117	2	0.000213 ***
Window area + wall vegetation	8.9234	1	0.002815 **
Season + vegetation area	4.9281	1	0.026423 *
Distance to vegetation + window reflection	6.1189	2	0.046914 *

FIGURES

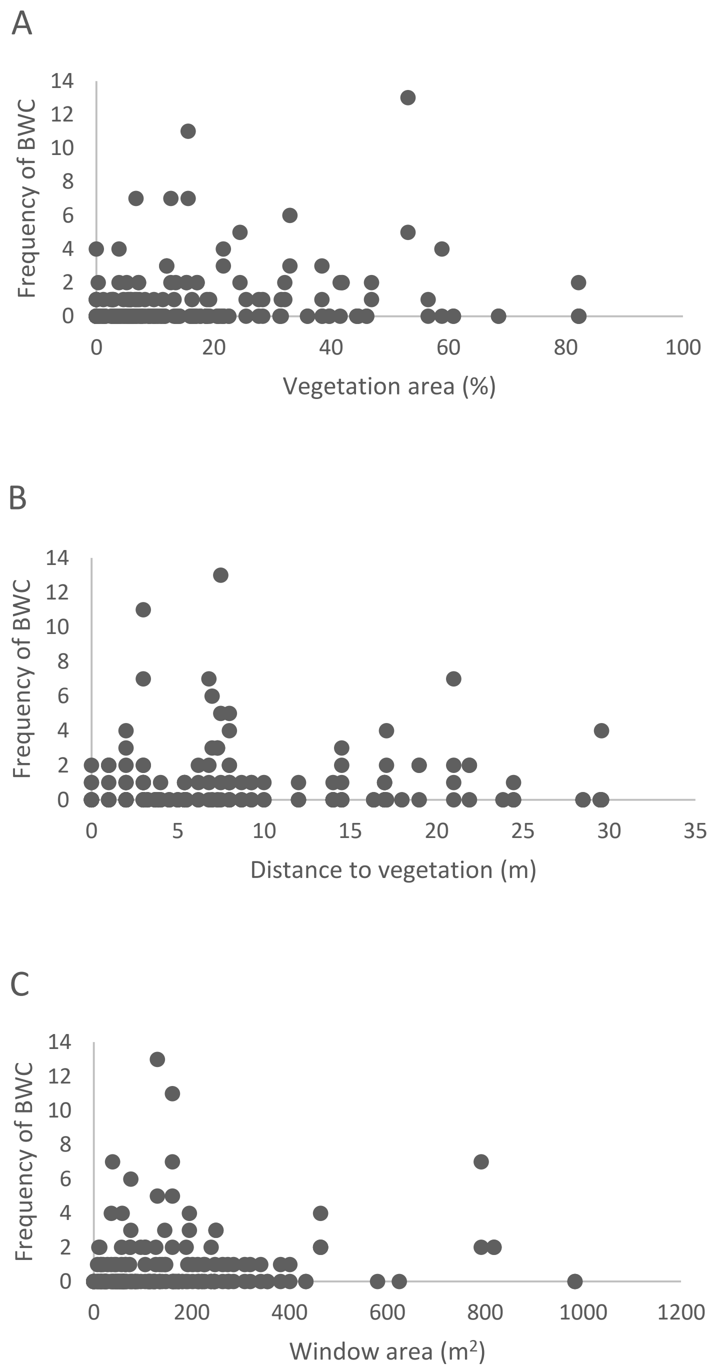


Figure 1: The relationship between frequency (# per wall cumulative) of bird-window collisions and A) vegetation area (m^2) within 30m of a building B) distance to vegetation and C) window area during fall 2014-2015 survey periods. Each point is one wall of a building (n=113).

FIGURES

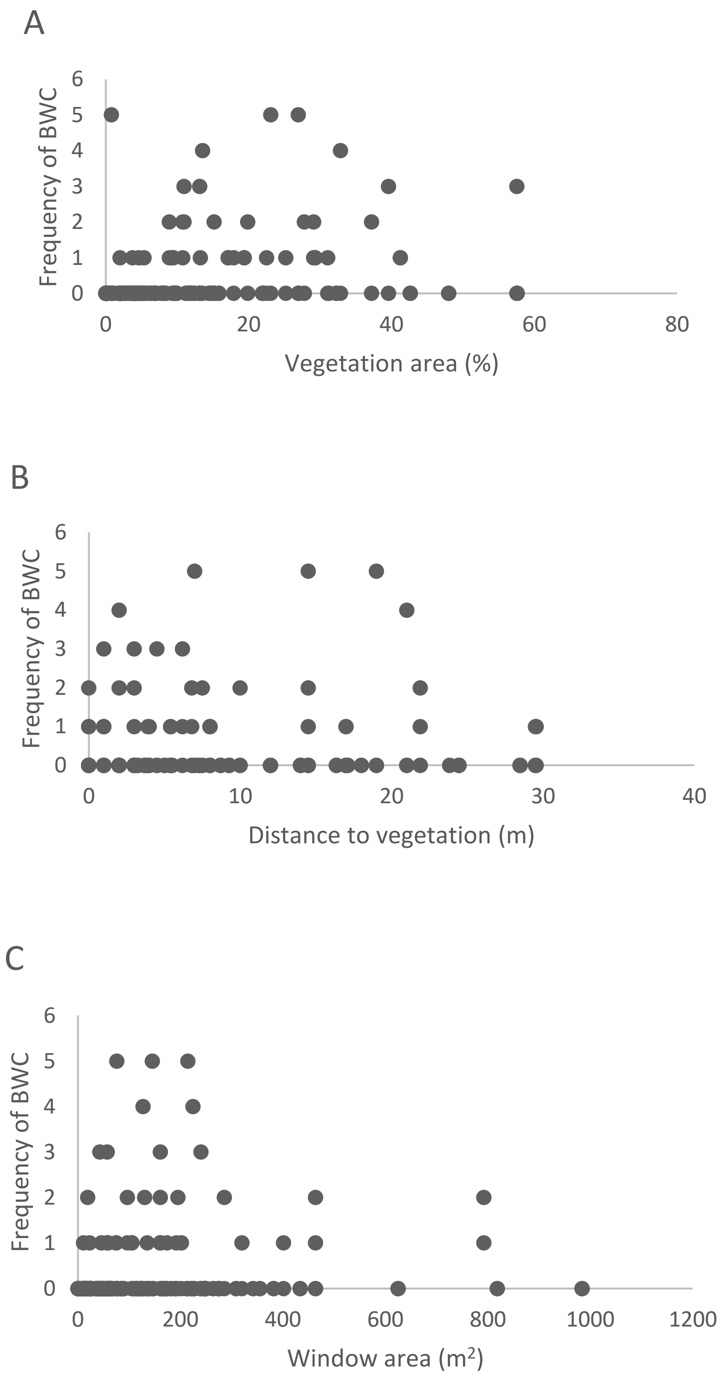


Figure 2: The relationship between frequency of collisions (# per wall cumulative) and A) vegetation area (m^2) within 30m of a building B) distance to vegetation and C) window area during spring 2015-2016 survey periods. Each point is one wall of a building (n=113).

FIGURES

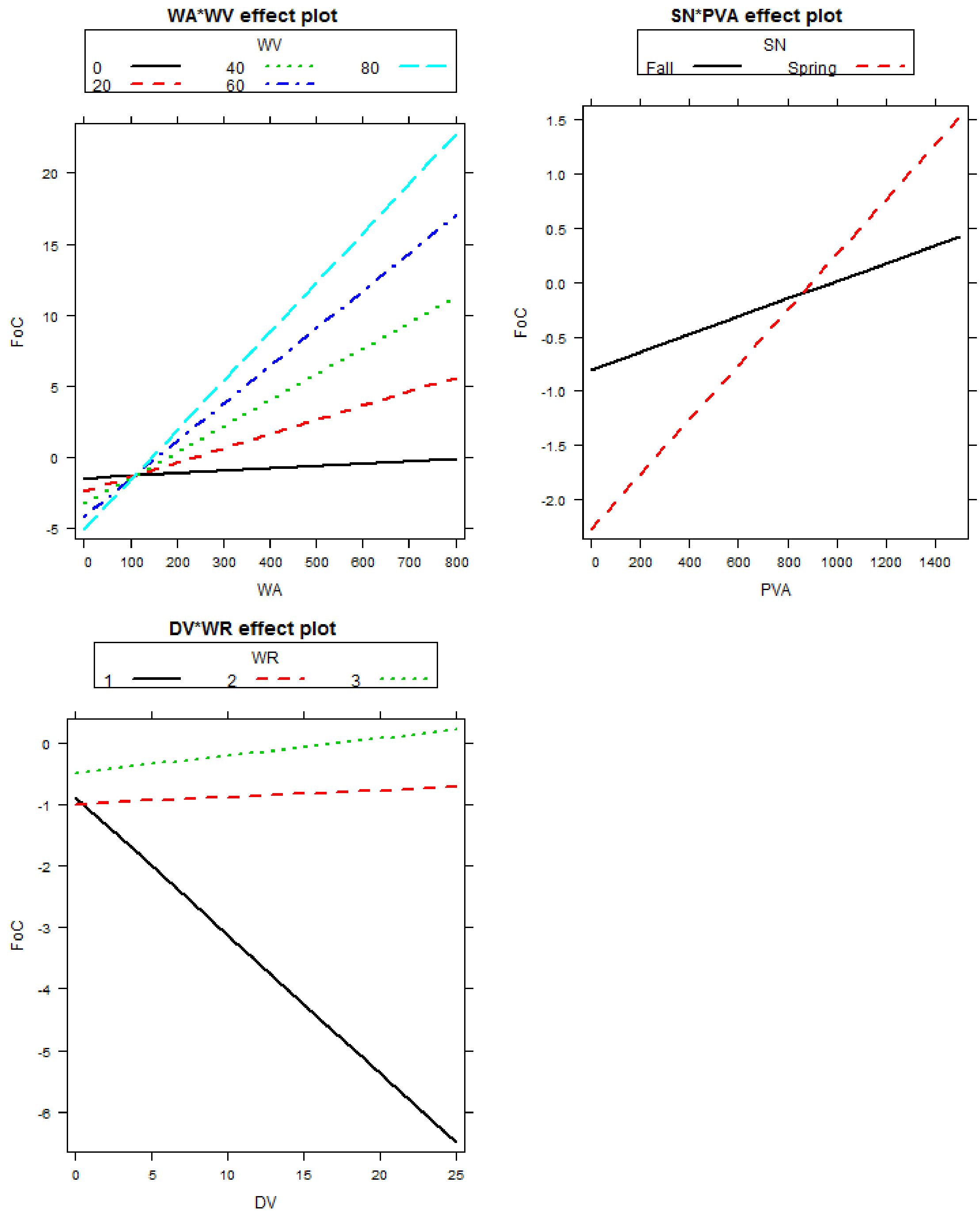


Figure 3: Mixed interaction effects of A) increasing window area (WA) and wall vegetation (WV), B) season (SN) and increasing proportional vegetation area (PVA), and C) increasing distance to vegetation (DV) and type of window (WR) on frequency of collisions.

SUPPORTING INFORMATION

Table S1: Defined list of landscape predictor variables of frequency of bird window collisions used in negative binomial GLM over fall and spring 2014-2016.

Predictor Variable	**Variable Type**	**Data Code**	**Definition**
Building height	Continuous	Variable	Height of building up to 3rd floor (m)
Direction	Categorical	1 2 3 4	North East South West
Distance to vegetation	Continuous	Variable	Distance to nearest shrub, bush, or tree (m)
Reflection	Categorical	1 2 3	Translucent or tinted glass Transparent glass Reflective mirror-like Glass
Season	Categorical	1 2	Fall Spring
Surrounding vegetation area	Continuous	Variable	Percentage of vegetation within sampled area (%)
Wall vegetation cover	Continuous	Variable	Amount of vegetation growth along a wall (m^2)
Window area	Continuous	Variable	Amount of window area (m^2)

SUPPORTING INFORMATION

Table S2: Total number of BWC carcasses collected or observed during fall 2014 and spring/fall 2015 and spring 2016 building surveys over the York University Keele campus for 20 weeks.

Family	Species	Fall 2014	Spring 2015	Fall 2015	Spring 2016	Total Number of Collisions
Pigeons and Doves (Columbidae)	Mourning Dove (*Zenaida macroura*)	1				1
Cuckoo (Cuculidae)	Black-Billed Cuckoo (*Coccyzus erythropthalmus*)		1			1
Hummingbird (Trochilidae)	Ruby-Throated Hummingbird (*Archilochus colubris*)			1		1
Woodpeckers (Picidae)	Northern Flicker (*Colaptes auratus*)	1				1
	Yellow-Bellied Sapsucker (*Sphyrapicus varius*)	2	1	2		5
Flycatchers (Empidonax)	Yellow-Bellied Flycatcher (*Empidonax flaviventris*)	2				2
Jays (Corvidae)	Blue Jay (*Cyanocitta cristata*)	1				1
Creepers (Certhiidae)	Brown Creeper (*Certhia americana*)	1		2	1	3
Kinglets (Regulidae)	Ruby-crowned Kinglet (*Regulus calendula*)				1	1
	Golden-crowned Kinglet (*Regulus satrapa*)			2	3	5

Family	**Species**	**Fall 2014**	**Spring 2015**	**Fall 2015**	**Spring 2016**	**Total Number of Collisions**
Tanagers (Tharupidae)	Scarlet Tanager (*Piranga olivacea*)	1				1
Thrushes (Troglodytidae)	Hermit Thrush (*Catharus guttatus*)				2	2
	Gray-Cheeked Thrush (*Catharus minimus*)	1		1		2
	Swainson Thrush (*Catharus ustulatus*)	5	2	3	2	12
	Winter Wren (*Troglodytes hiemalis*)				1	1
	American Robin (*Turdus migratorius*)	1				1
Catbird (Mimidae)	Gray Catbird (*Dumetella carolinensis*)		2		1	3
Starlings (Sturnidae)	European Starling (*Sturnus vulgaris*)	1	3		1	5
Waxwings (Bombycillidae)	Cedar Waxwing (*Bombycilla cedrorum*)		1	1		2
Warblers (Parulidae)	Common Yellowthroat (*Geothlypis trichas*)	1	1	1		3
	Black and White Warbler (*Mniotilta varia*)		2	1	1	4
	Tennessee Warbler (*Oreothlypis peregrina*)	5	3	4		12
	Nashville Warbler (*Oreothlypis ruficapilla*)	11	1	1	1	14
	Ovenbird (*Seiurus aurocapilla*)	10	4	7	3	24
	Northern Parula (*Setophaga americana)*			1		1

Family	Species	Fall 2014	Spring 2015	Fall 2015	Spring 2016	Total Number of Collisions
	Black-throated Blue Warbler (*Setophaga caerulescens*)			1	1	2
	Yellow-Rumped Warbler (*Setophaga coronata*)	1				1
	Magnolia Warbler (*Setophaga magnolia*)	1	2	1		4
	Chestnut Sided Warbler (*Setophaga pensylvanica*)				1	1
	Blackpoll Warbler (*Setophaga striata*)	1		1	1	3
	Black-throated Green Warbler (*Setophaga virens*)	2		1		3
Vireos	Red-Eyed Vireo (*Vireo olivaceus*)			1	1	2
Sparrows (Emberizidae)	Dark Eyed Junco (*Junco hyemalis*)		2	3	2	7
	House Sparrow (*Passer domesticus*)		1	4		5
	Fox Sparrow (*Passerella iliaca*)			1		1
	Swamp Sparrow (*Melospiza georgiana*)	1				1
	Lincolns Sparrow (*Melospiza lincolnii*)	1		1		2
	White-throated Sparrow (*Zonotrichia albicollis*)	10	4	19	5	38
	White Crowned Sparrow (*Zonotrichia leucophrys*)	1		2		3
Cardinal (Cardinalidae)	Northern Cardinal (*Cardinalis cardinalis)*				1	1
	Indigo Bunting (*Passerina cyanea*)		1			1

Family	Species	Fall 2014	Spring 2015	Fall 2015	Spring 2016	Total Number of Collisions
Blackbirds (Icteridae)	Common Grackle (*Quiscalus quiscula*)	1	1			2
Finches (Fringillidae)	American Goldfinch (*Spinus tristis*)	2				2
Unknown Species (UNSP)		12	3	20	9	44
Total	43	77	35	82	38	231

SUPPORTING INFORMATION

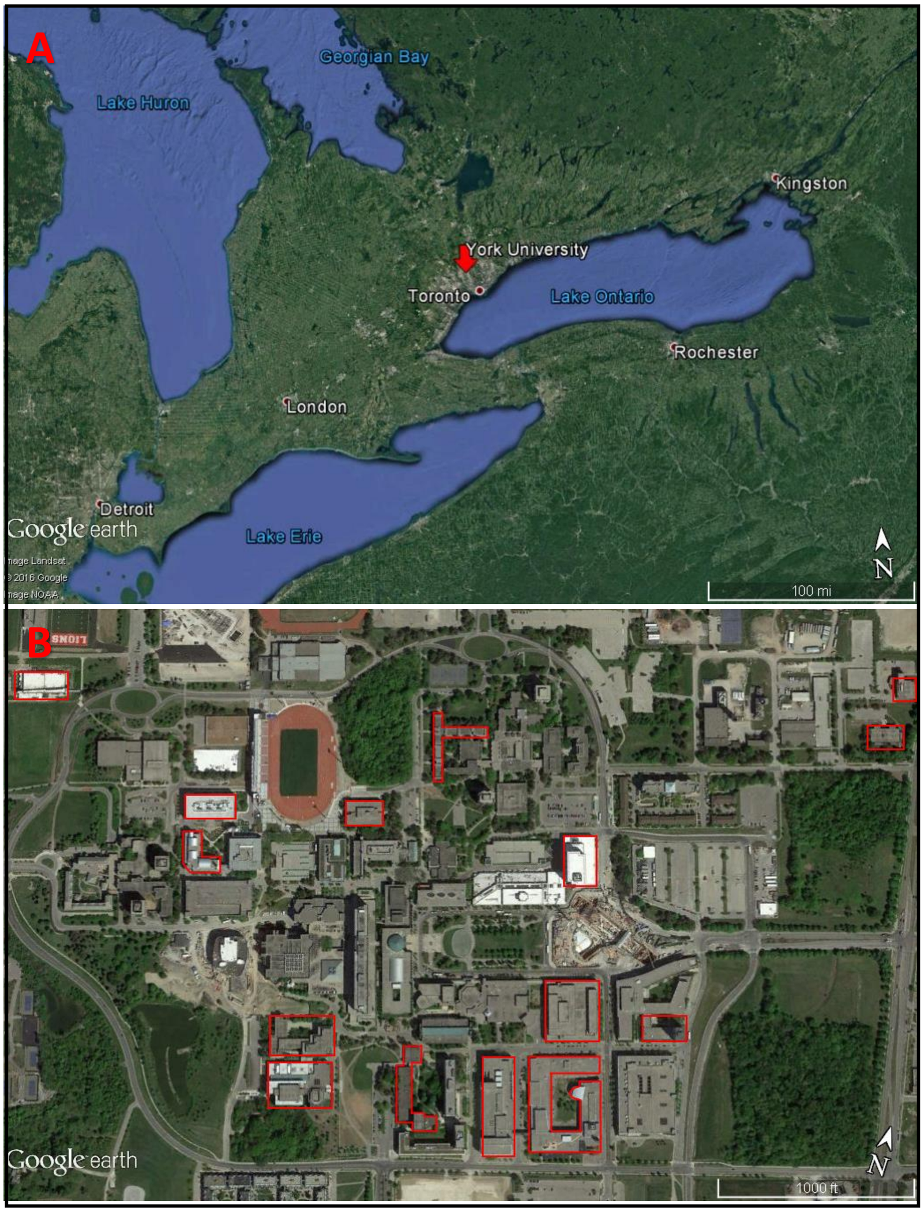
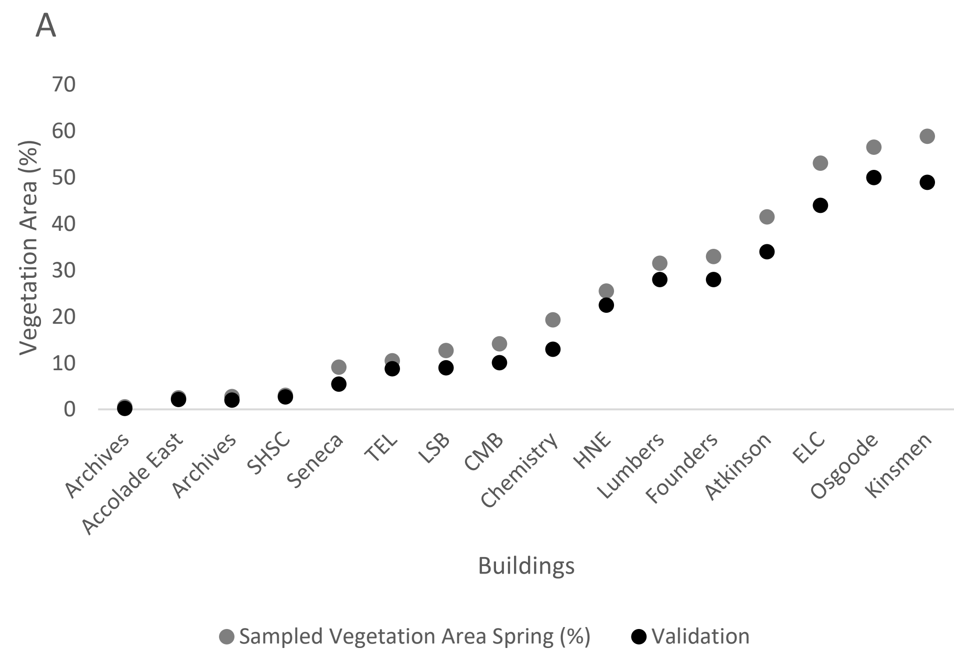


Figure S1: Study Area on Google Earth (2016) (A) shows the location of the York University Keele campus within Ontario; (B) map of campus with study buildings highlighted in red.



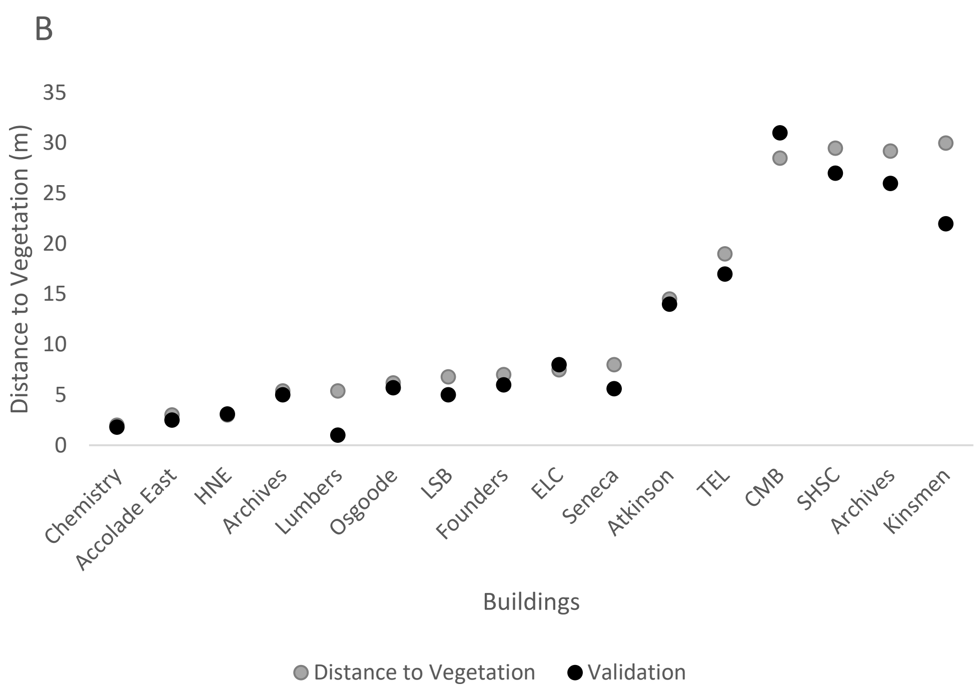


Figure S2: Ground validation of A) proportional vegetation area (t(30)= 0.413, p=0.682) and B) Ground validation of distance to vegetation (t(30)= 0.617, p=0.542).