How does the landscape context of urban environments influence building and vehicle-caused bird mortality?

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Highlights:

- Collisions with anthropogenic structures are often fatal for birds and result in a loss of otherwise healthy birds from the population
- Within Vancouver, these collisions were mapped and analyzed to gain insight to both species and landscape-specific factors conducive with bird injuries and provide a starting point for prevention strategies and future research
- Young birds from the orders *perching birds* and *pigeons and doves* were the most commonly injured throughout the city, with *nightjars* and *shorebirds* showing a higher tendency of building collisions and vehicle collisions respectively
- Mid-rise buildings surrounded by <50% vegetative cover were also found to be the most problematic

Abstract

Anthropogenic structures present novel and unnatural threats to wildlife on a daily basis. Within cities, birds are of particular concern because they are highly mobile and thus extremely susceptible to colliding with structures such as buildings and cars. These collisions are problematic because they remove healthy, breeding individuals from the population which over time, can have population-level effects. Understanding the bird and landscape-specific factors that influence these collisions is a fundamental first step in implementing conservation strategies that effectively reduce these injuries, especially as cities continue to expand. To assess the landscape context surrounding bird-building and bird-vehicle collisions in Vancouver, four years of bird-specific data was collected from a local wildlife rehabilitation center. A map was created to show the exact locations of injuries throughout the city along with the bird and landscape-specific information associated with each injury. For each injury, the variables bird age, bird order, building height type, and amount of surrounding vegetation were quantified and each was tested using Chi-squared analyses. Young birds from the orders *perching birds* and *pigeons and doves* were found to be the most commonly injured throughout the city for both types of injuries. Additionally, mid-rise buildings surrounded by less than fifty percent vegetative cover proved to be the most problematic. These findings suggest that bird age, building height, and vegetative cover are important factors influencing bird injuries throughout Vancouver and efforts to reduce mortality from these sources should structure prevention strategies that focus on young birds and mid-rise buildings.

Key Words: birds, mortality, conservation, anthropogenic, structures, collisions

Introduction

Urban expansion drives habitat loss and fragmentation

Urban expansion has occurred rapidly in the last century as a direct result of the growing global population (Seto et al. 2011). Habitat loss and fragmentation are two of the most detrimental effects of urban expansion on wildlife populations and are the leading causes of the current biodiversity loss crisis. There are few parts of Earth that remain truly unaltered by people and as we continue to expand we directly and indirectly threaten the persistence of ecosystems and species. In the southeastern United States for example, urban development in many areas has removed almost all natural habitat from the landscape and as a result, the number of resident and migratory nesting birds within the region has steadily declined (Valiela & Martinetto, 2018). Similarly, urban expansion indirectly causes habitat loss and degradation through processes such as soil compaction, pollution, and climate change which are more difficult to observe and quantify. As urban populations continue to expand we make survival increasingly difficult and give little option for wildlife but to try survive within our urban landscapes. Conservation efforts therefore face the challenge of maintaining safe and suitable habitats within urban environments to ensure the persistence of wildlife populations into the future.

Urban areas are hotspots for wildlife mortality

Cities are highly fragmented and fast-paced environments that pose novel and unnatural threats to wildlife. Of these novel threats, anthropogenic objects such as buildings and vehicles rank among the top risks. Interactions between buildings, vehicles and wildlife are significant because they result in high mortality that has the potential to be prevented. In terms of negative building-wildlife interactions, perhaps the easiest animals to observe are birds because they are highly mobile and unable to detect glass structures. Thus, birds are prone to window strikes and in Canada alone it is estimated that 22.4 million birds are killed in collisions with residential buildings every year (Machtan et al. 2013, Calvert et al. 2013). This is a substantial number that could be prevented by the use of UV-absorbing films, blinds, and tilting windows that make windows detectable to the avian eye (Klem 2009, Klem 1990). Similarly, birds are highly susceptible to vehicle collisions because roads that intersect habitat patches pose threats to birds flying between habitats. Such causalities are preventable if certain mitigation efforts are enforced, such as planting certain shrubs next to roads and constructing roads away from critical habitat (Ramsden 2003). In light of this, understanding the trends in building and vehicle-caused avian mortalities and injuries could facilitate more effective conservation approaches.

Spatially assessing avian mortality

Avian success in urban areas is largely dependent on the availability of quality habitat and the degree of collision threats within the urban environment. Understanding the relationship between avian collisions and certain urban and bird characteristics can highlight areas of focus for conservation efforts. Habitat characteristics such as quantity, structure, and spatial pattern are often analyzed in isolation from other factors that influence bird survival. Models based solely on habitat characteristics could overestimate the survival potential of certain habitats. Although the quantity, structure, and pattern of habitat within urban environments has shown positive correlation with bird species richness and evenness, understanding the characteristics of urban habitats that cause avian injuries should be incorporated for a more detailed understanding (Donnelly & Marzluff, 2006). Since building and road collisions can remove healthy and breeding individuals from populations, certain species may be at risk of population-level effects due to these interactions. Therefore, bird survival within urban environments will depend upon a combination of both bird and landscape-level characteristics.

Utilizing wildlife data from the Wildlife Rescue Association of British Columbia (WRA) including the locations of bird-building and bird-vehicle collisions, and supplementary geospatial data including building and landcover information, this study evaluates how specific characteristics of both urban environments and birds influence bird injuries. More specifically, this paper investigates how building height, amount of surrounding vegetation, bird age class, and bird order influence the number of birds that collide with windows or vehicles by utilizing a variety of geo-processing techniques. In doing so, trends between these variables are highlighted to provide insight to the most influential factors and specific areas of concern within the study area.

Study Site

The city of Vancouver is well-suited for this project because it is a bustling urban environment that harbors a large variety of wildlife and is well-represented within the bird injury data obtained from WRA. Encompassing one hundred and fifteen square kilometers (Figure 1), Vancouver is home to more than 631,000 residents (Statistics Canada 2016). Naturally, the high population density resulted in increased urban development and the dominant land covers within the city are currently urban (buildings and paved areas) and deciduous trees (derived from Williams, D.A.R et al. 2018). Although highly urban, Vancouver continues to maintain healthy vegetation within the city which harbors a diverse array of bird species. As a whole, metro-Vancouver (all 21 municipalities) regularly observe more than 250 species of birds on an annual basis and the City of Vancouver alone contains half of all Important Bird Areas (IBA's) in the region (MetroVancouver, 2015). Additionally, metro-Vancouver has derived a "Vancouver Bird Strategy" within the "Greenest City Action Plan" to mitigate the negative effects of urban development on birds. With active measures being taken to support bird habitat, reduce threats, enhance access to habitat, increase public awareness, and increase bird-related tourism, understanding the trends of bird injuries that occur within the city can provide a more diverse understanding and may help structure conservation plans aiming to protect urban-dwelling birds.

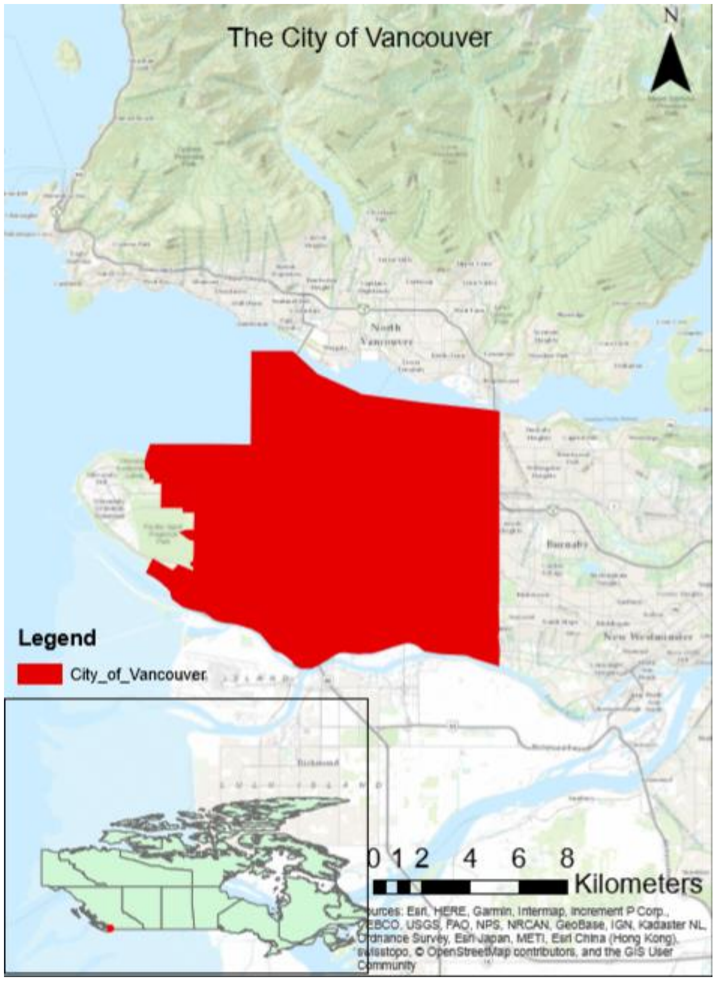

Figure 1. Vancouver, BC, highlighted in red to indicate the geographical extent of the study site for this project.

Methods

Summary

This project utilized three main datasets to gain information relating to bird injuries within Vancouver. The primary dataset was injury-specific information collected by WRA and the secondary datasets were land-cover and building information available from UBC and the City of Vancouver respectively. The locations of each injury were mapped to spatially visualize the distribution of injuries throughout the city (Figure 3). Once visualized in ArcMap, the 5-m spatial resolution land-cover map and the building data could be associated with each bird injury. Five key attributes were associated with each injury: the height class of the building hit, the amount of vegetation within a 50m radius of the location of injury, the bird's age class, and the bird's order. These attributes were then tested for independence using Chi square tests (X^2).

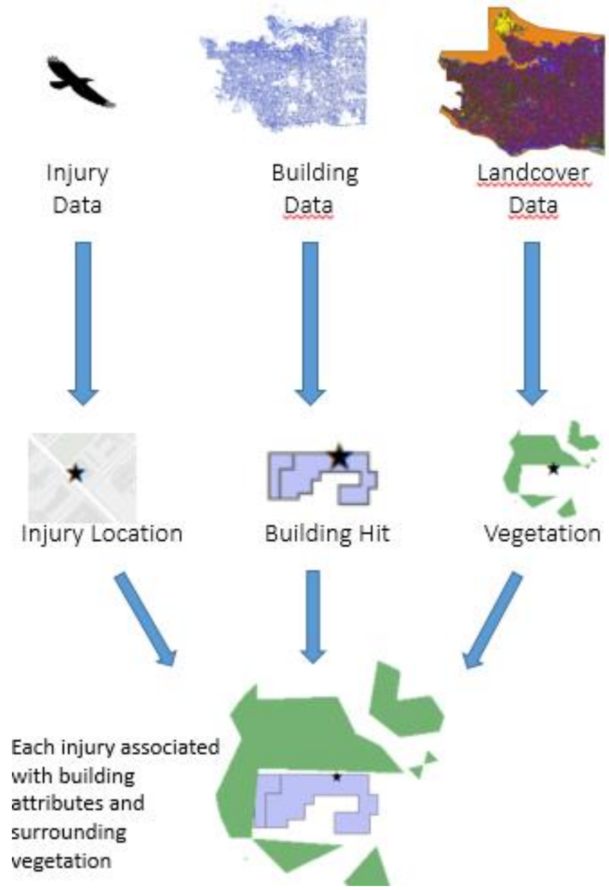

Figure 2. Generalized flow chart of the methods used to associate each bird injury with supplementary information including vegetation and building attributes

Data Acquisition

Bird injury data was collected from WRA for the years 2014, 2016, 2017, and 2018 (Wildlife Rescue Association of British Columbia, 2018). Specific information for each injury was collected including the location found (address and city), species name (common and scientific), cause of injury, disposition, age, class, order, family, genus and species. Using Google Sheets the latitude and longitude of each injury were extracted from the address where the animal was found.

Land cover information was obtained from a 5m spatial resolution map of Metro-Vancouver produced by Williams et al. (2018). When visualized in ArcMap this shows various land cover types including: barren, buildings, clouds/ice, coniferous, deciduous, modified grass-herb, natural grass-herb, non-photosynthetic vegetation, other built, paved, shadow, shrub, soil and water.

Data for the City of Vancouver was obtained from the City of Vancouver's Open Data Catalog website (https://data.vancouver.ca/datacatalogue/index.htm). The *AdminBoundaries* shapefile was used to visualize the boundaries of each municipality. Information pertaining to building heights was obtained from the attribute table of the *building_heights_2009* shapefile, where the maximum height of the building is given in meters.

Geospatial Analyses

The address of each injury, obtained from the WRA injury data, were georeferenced using Google Sheets to obtain the latitude and longitude of each injury. For both bird-window and bird-vehicle collisions, a layer was created to visualize the injuries as points throughout the city. Each point was associated with information specific to that injury including common name, class, family, order, species, age, and cause of injury. In addition, the *AdminBoundaries* layer was clipped to show only the municipal boundary of the City of Vancouver. This was done to ensure that future work was done solely within the study area.

With each injury visualized in ArcMap, each injury could be associated with additional information from the supplementary datasets. From the *buildings* layer, the buildings associated with each injury were selected and the height (m) of each building was recorded. Bird-window collisions that had a single address were assumed to have hit the building where the bird was found. In cases where birds were found at road intersections, averages of the buildings on the surrounding corners were used for height estimates. For bird-vehicle collisions, a similar approach was taken for birds found at road-intersections. For birds that were hit by a car *and* found at a single address, an average of buildings on both sides of the road was used. This was done because it is unfair to assume that the building where a bird was found was exactly where it was hit by a car. Once quantified, the building heights were categorized as Low-rise, Med-rise, and High-rise (Appendix 1).

Using the *land-cover* layer, each injury could be associated with surrounding vegetation (considered to be bird habitat) compared to uninhabitable land-cover types. Initially, the 5-m spatial resolution land-cover raster was representative of the entire of Metro-Vancouver. Using the tool extract by mask, the map was cropped to show land-cover types within the City of Vancouver only. This map was re-classified to show only vegetation land-cover classes including coniferous, deciduous, shrub, modified grass-herb, natural grass-herb, and non-photosynthetic vegetation. The vegetation raster was then converted to a shapefile to show vegetation as polygons throughout the city. Using a 50m radius buffer around each injury, the amount of vegetation was quantified and categorized to represent the amount of habitat within a 50m radius of each injury. Vegetation categories were defined based on what proportion of buffered area was occupied with vegetation (e.g. <25%, 25-50%, 51-75%, >75%).

Statistical Analyses

All of the variables collected for this analyses were categorical (or transformed to categorical) so a series of Chi squared (X^2) tests were performed to see if certain variables were associated with each other. Eight X^2 tests were performed to assess the independence of the five key variables. Each test was run using an alpha level of 0.05 and the following null and alternative hypotheses:

H0: Variable 1 and Variable 2 are independent of each other (are not associated)

H1: Variable 1 and Variable 2 are not independent of each other (are associated)

Results

Using the address where each injured bird was found, the locations of each injury were viewed in ArcMap to show the spatial distribution of injuries throughout the city (Figure 3). Bird vehicle-collisions occurred all throughout the city but are clustered around the downtown core. Bird-window collisions are sparser than vehicle collisions, and most of these injuries occurred near the center of the municipality.

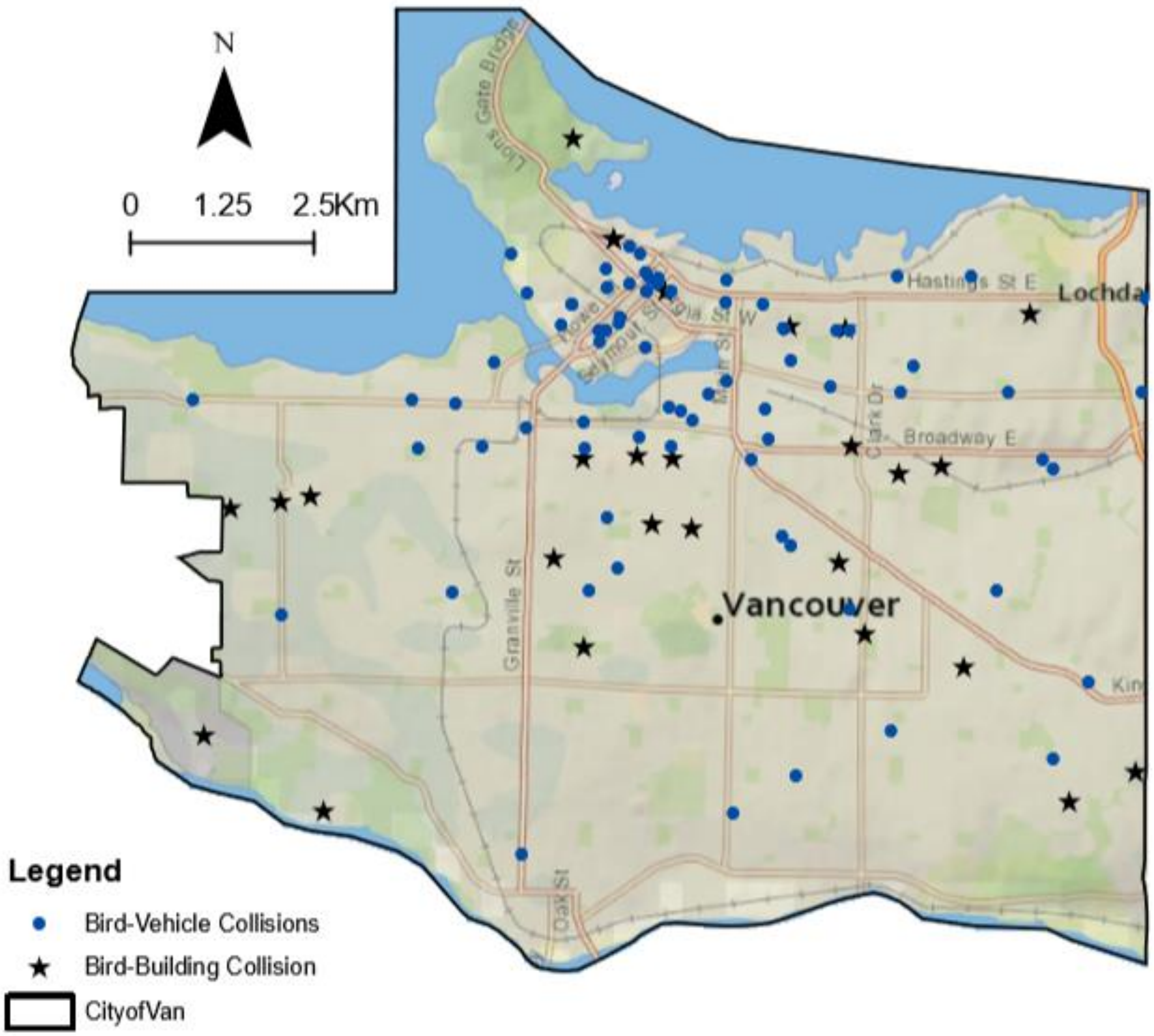

Figure 3. Map of Vancouver showing the locations of bird-building collisions (black stars) and bird-vehicle collisions (blue dots), and the municipal border outlined in black

X^2 tests were performed on eight different combinations of variables to assess for association or independence. Each test yielded a p-value greater than alpha (0.05) suggesting that each set of variables are likely independent of each other (Table 1). Descriptions of each test are listed below:

Test 1: Compares bird age class and building height type

Test 2: Compares bird order and building height type

Test 3: Compares bird age class and % surrounding vegetation

Test 4: Compares bird order and % surrounding vegetation

Test 5: Compares bird age class and % surrounding vegetation

Test 6: Compares bird order and % surrounding vegetation

Test 7: Compares bird age class and building height type

Test 8: Compares bird order and building height type

Table 1. Results of Each X^2 Test to Assess Independence between the Key Variables.

Test #	**X^2**	**df**	**p-value**
1	9.225	6	0.1613
2	13.476	10	0.1982
3	10.306	6	0.1123
4	8.5206	10	0.5781
5	11.328	21	0.956
6	14.634	15	0.4781
7	5.5295	14	0.977
8	8.9704	10	0.5349

In addition to statistical analyses, the injury data provides further insights into the patterns of bird injuries within the City of Vancouver. For bird-window strikes, most injuries occurred within vegetation classes 1 and 2 (Figures 4 & 5). These classes represent less than 50% vegetative cover within a 5m radius of each injury. Additionally, age classes AHY and HY and the orders Passeriformes and Columbiformes were the most commonly injured within these vegetation classes. These indicate that birds of hatching year and after hatching year, and perching birds and pigeons/doves are injured most frequently by colliding with windows. Less than 3 injuries occurred where there was more than 50% vegetative cover (vegetation classes 4 & 5). Similarly, most bird-window collisions occurred at low-rise and mid-rise buildings (Figures 6 & 7). Age classes AHY and HY, and orders *Passeriformes*, C*olumbiformes*, and *Caprimulgiformes* (nightjars) were the most commonly injured by low and mid-rise buildings.

For bird-vehicle collisions, most injuries occurred within vegetation classes 1 and 2 (Figures 8 & 9). Of these injuries most birds were within the age classes AHY, HY, and LG, and the orders *Columbiformes,* *Charadriiformes, and Passeriformes.* These represent after hatchling year, hatchling year, local, nightjars, pigeons/doves, and shorebirds respectively. Less than 5 injuries occurred in areas with greater than 50% vegetative cover. In addition, most bird-vehicle collisions occurred on roads surrounded by mid-rise buildings (Figures 10 & 11). Age classes AHY, HY, and LG were the most commonly hit by vehicles and orders *Columbiformes, Charadriiformes, and Passeriformes* were also the most commonly injured.

Figures

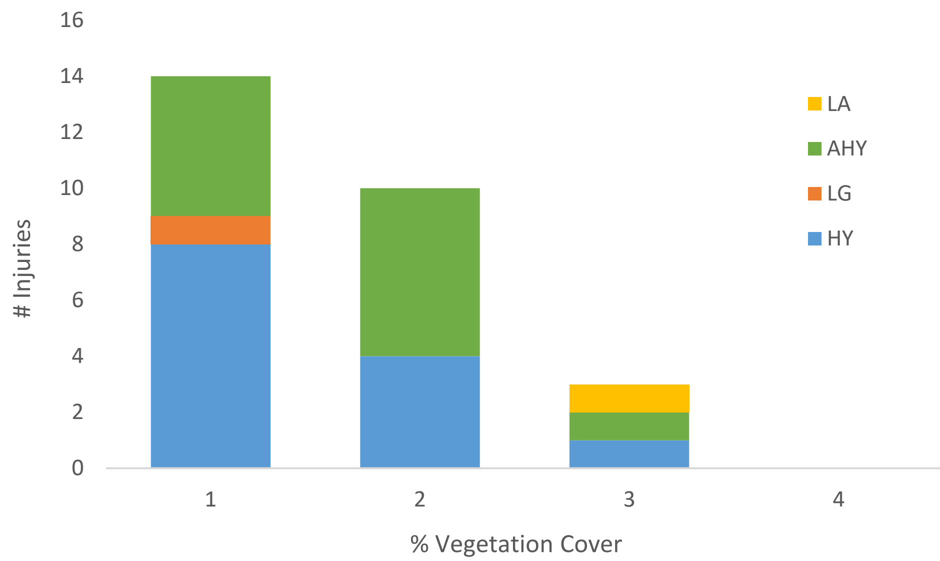

Figure 4. Distribution of Bird-Window Strikes across Vegetation Class and Bird Age Class

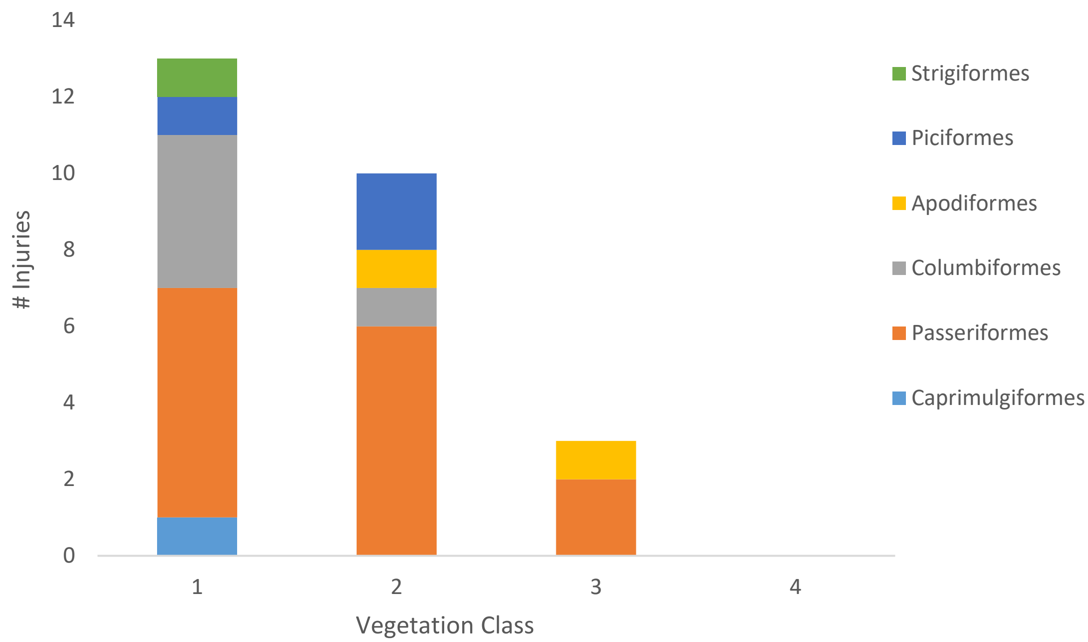

Figure 5. Distribution of Bird-Window Strikes across Vegetation Class and Bird Order

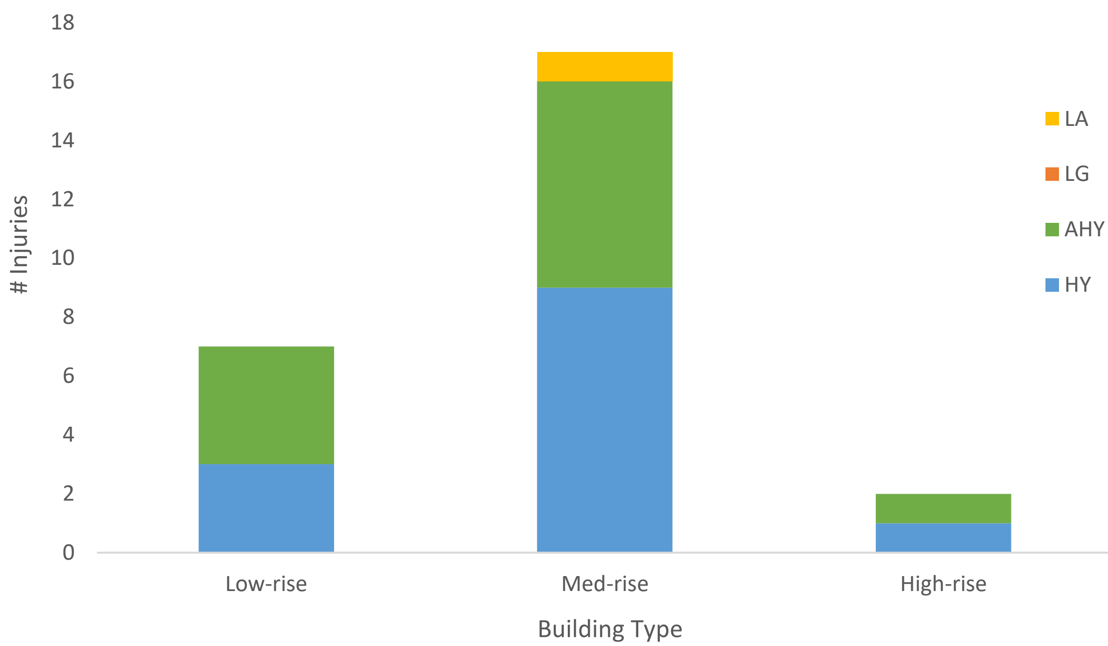

Figure 6. Distribution of Bird-Window Strikes across Building Types and Age Class

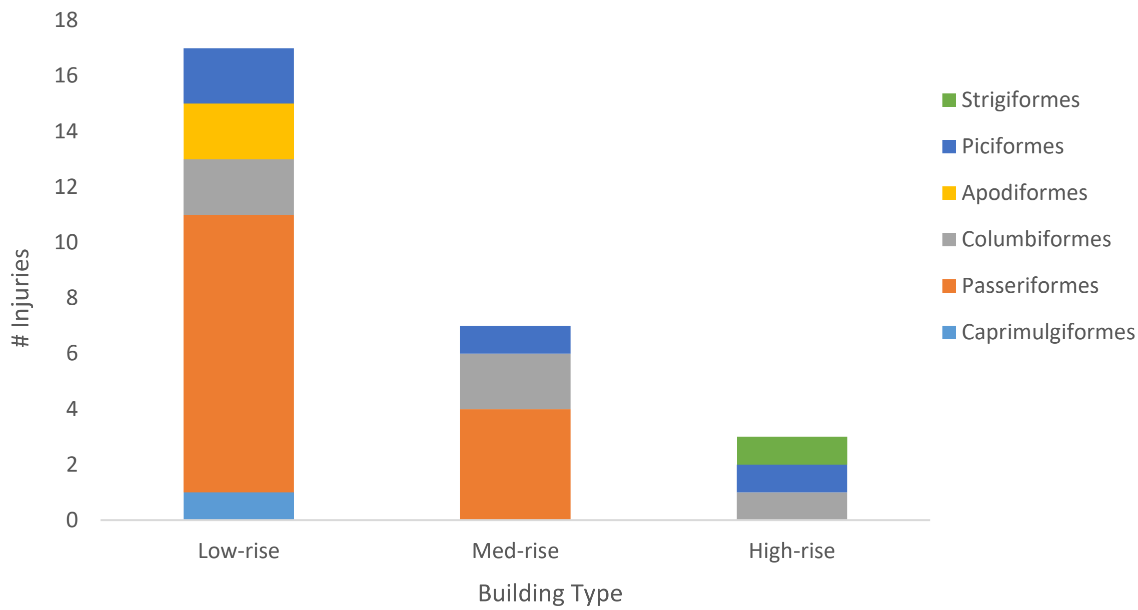

Figure 7. Distribution of Bird-Window Strikes across Building Type and Bird Order

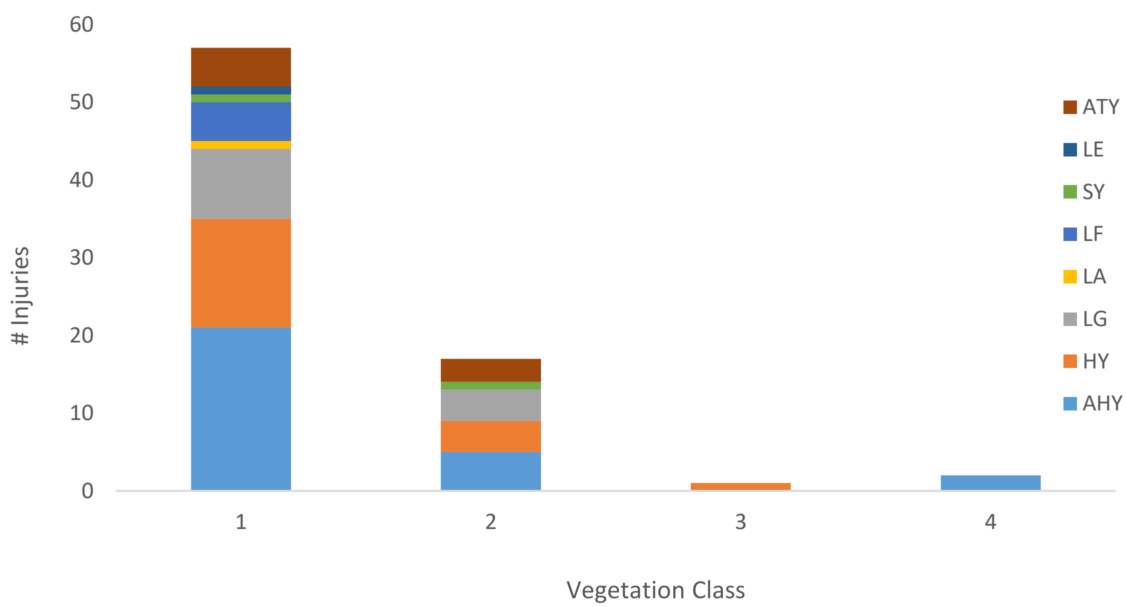

Figure 8. Distribution of Bird-Vehicle Collisions across Vegetation Class and Bird Age Class

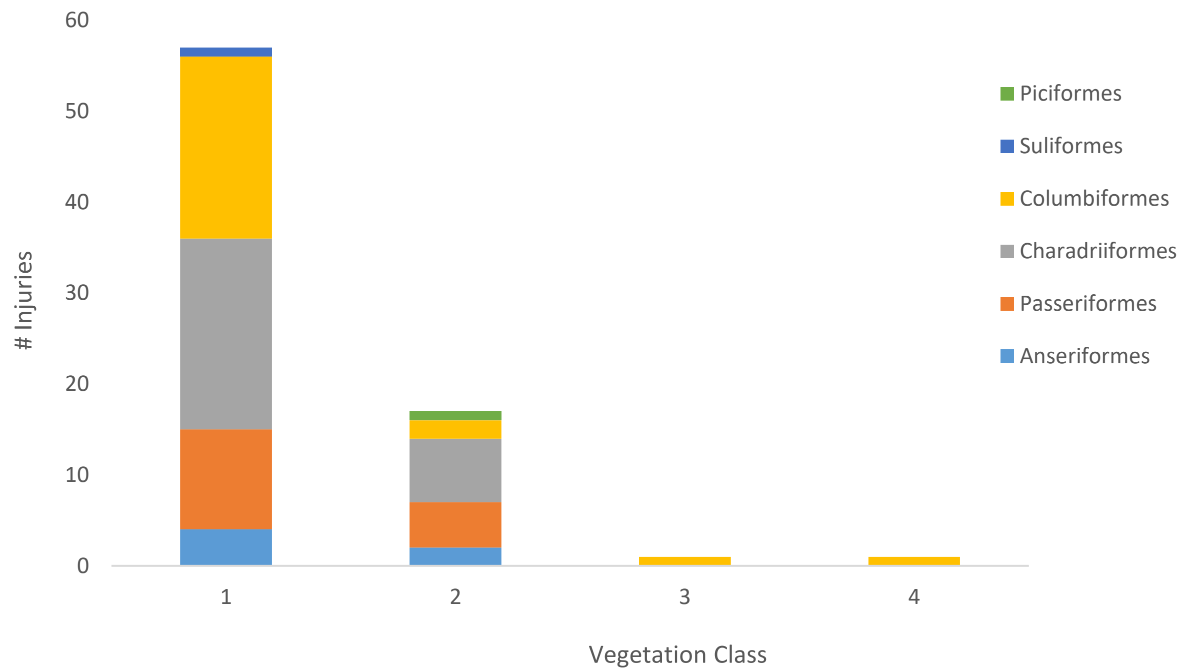

Figure 9.Distribution of Bird-Vehicle Collisions across Vegetation Class and Bird Order

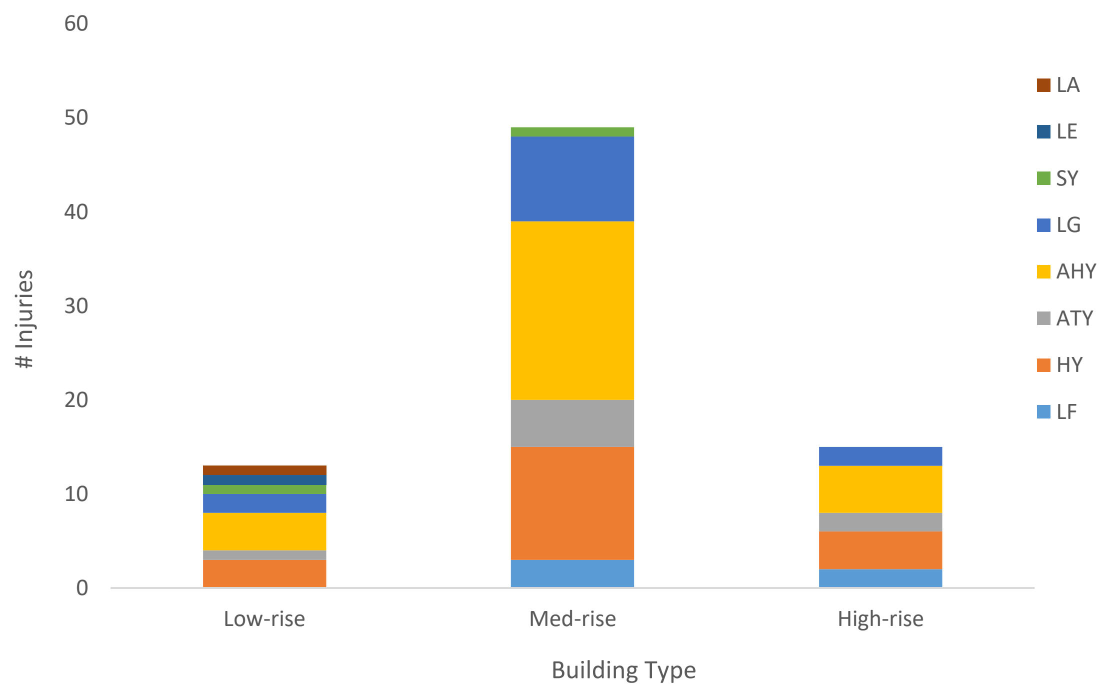

Figure 10. Distribution of Bird-Vehicle Collisions across Building Type and Bird Age Class

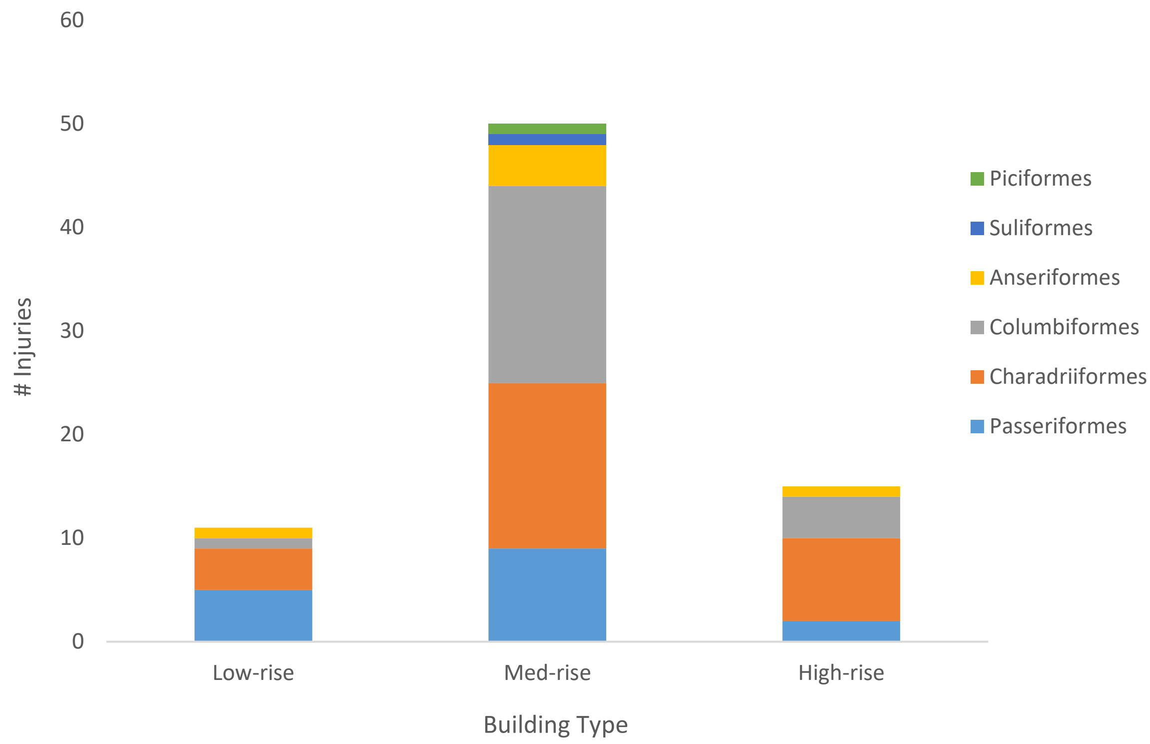

Figure 11. Distribution of Bird-Vehicle Collisions across Building Type and Bird Order

Discussion

Bird Specific Characteristics Do Influence Injury

The results of this study show that within Vancouver, there are certain birds that are subject to window and vehicle collisions more often than others. For both injury types, the most commonly injured age of bird was juniors and young adults (see appendix). Likely due to their inexperience, young birds are more susceptible to these injuries especially as they learn to fly and begin navigating through unfamiliar environments. Studies investigating the effects of collisions on birds also suggest that younger birds are more susceptible to and experience worse injury from colliding with manmade structures due to their lack of development (Veltri & Klem, 2005). These findings are important to understand because if young birds are being killed before they can reach sexual maturity and reproduce, there could be population-level effects if breeding numbers become too low. In addition to bird age class, commonalities were also observed between the bird *orders* injured for both window and vehicle strikes. Perching birds (*Passeriformes)* and Pigeons and Doves (*Columbiformes)* were the most frequently injured. This is likely because the order Passeriformes encompasses over half of all bird species and because pigeons are a very common urban dwelling species, so it is expected that these orders would represent a larger portion of bird injuries throughout the city. Interestingly, Nightjars or nighthawks (*Caprimulgiformes)* also had a high number of window collisions and Shorebirds (*Charadriformes)* were also commonly struck by vehicles. These findings suggest that there may be species-specific trends in these injuries and that some species are more susceptible than others. This is to be expected as some species are more accustomed to living within cities compared to others. For example, species that primarily reside within forested areas or grasslands are more likely to collide with buildings compared to species that reside in other habitats such as water environments (Jackson & Mesure, 2015). Additionally, migrating species are more likely to be injured when previously intact habitats are destroyed for development purposes. Knowing the bird orders and species that are most frequently injured by building and vehicle collisions is an important step in understanding why these injuries occur and provides a basis for investigating other potentially influential factors such as landscape characteristics.

Landscape-level Characteristics Also Influence Bird Injury

The landscape-level variables analyzed in this study also showed some notable trends. In total, 89% of window strikes and 96% of vehicle strikes occurred in areas with less than 50% vegetative cover (habitat). This suggests that buildings surrounded by more vegetation (> 50%) are less likely to be associated with bird injuries which is likely because there is more available habitat and less need for birds to travel between patches. However, these findings contrast those from similar studies wherein buildings surrounded by little vegetation were found to have fewer collisions associated with them (Jackson & Mesure, 2015). These differences likely arise because compared to other studies, the study site, Vancouver, is relatively small and contains few patches of large continuous vegetation. Expanding the study area to encompass more municipalities would allow for larger patches of vegetation to be included and enhance the quality of the analyses. As a result, the influence of vegetative cover on bird injuries is difficult to observe because the study site is dominated by small patches of vegetation. Lastly, the variable *building type* was studied to investigate which buildings are the most problematic for birds. For both injury types, mid-rise buildings were associated with the most injuries followed by low-rise buildings. This is likely because the study site is dominated by mid-rise buildings, however, these results corroborate findings from another study suggesting that buildings less than 12 stories tall are particularly problematic for birds (Machtans et al. 2013).

How Does This Contribute to the Big Picture?

Although the X^2 tests suggest that the tested variables are independent of each other, overall, the underlying trends shown throughout this analysis provide a starting point for understanding the dynamic nature of bird injures throughout Vancouver. In turn, incorporating this understanding into management plans may successfully reduce the number of birds that collide with both windows and vehicles in the future as urban areas continue to expand. Conservation strategies aiming to mitigate these unnecessary threats to birds should focus their strategies towards young birds, specifically for perching birds and pigeons and doves. Such strategies could include enlarging and enhancing specific types of habitat (e.g. forest and grass fields) to reduce the need for birds to travel between small habitat patches and thus reduce their chances of injury. In addition, numerous mitigation efforts have proven effective for preventing bird window collisions. Specifically, constructing buildings with angled windows such that they reflect the ground instead of the sky and using textured shades or blinds have shown to significantly reduce bird window collisions (Klem, 1990). Similarly, planting tall hedges along major roads has shown to be the most effective at preventing bird vehicle collisions because it forces birds to fly up and over the roads and away from cars.

Looking Forward

This project has demonstrated that the wildlife injury data has high potential for use within analyses and potentially even conservation strategies. Due to the time-frame of this project and the amount of manual data cleaning and processing required, the scope of this project was limited in terms of statistical analyses. Future studies regarding this topic should expand the study area to encompass more than just one city and thus enlarge the sample size for each injury type. This would enable large-scale trends to be detected and visualized over time. Additional bird and landscape characteristics should also be incorporated to fully understand the plethora of factors that influence bird injuries. Further data manipulation should also be done so that the data can be used for more advanced statistical analyses such as regressions to test significance of individual variables. Lastly, the results of this study suggest that analyzing species-specific trends in injury throughout the entirety of metro-Vancouver could be an interesting next step in analyzing this data.

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Appendix

Quantitative Data Review

Table 2. Bird age codes descriptions

Age Code	**Meaning**
LA	Local, blue band
LE	Local, yellow band
SY	Second Year
L	Local, no band
AHY	After Hatching Year
ATY	After Third Year
LG	Local, green band
HY	Hatching Year
LF	Local, red band

Table 3. Vegetation classes and their descriptions

Vegetation Class	**Meaning**
1	0-25 % vegetative cover
2	25.01-50 % vegetative cover
3	50.01-75 % vegetative cover
4	75.01- 100 % vegetative cover