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Breeding season bird mortality from window collisions: Comparing species-specific abundance with mortality rates

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Abstract:
The second largest anthropogenic cause of bird mortality in North America is bird-window collision, which kills 100s of millions of birds every year in the United States alone. Many studies have focused on documenting species-specific collision occurrences during the migration seasons, which are commonly thought to be the time of year with the highest rate of mortality. However, few studies have been conducted during periods when birds are sedentary. Similarly, only a small number of studies have attempted to compare collision occurrence to local abundance. To help fill these gaps, data on bird-window collisions was collected in a downtown business district including the collection of carcass (i.e. collisions) and local point counts (i.e. species frequency) during the summer breeding season. In total, 15 species were observed but only three species (house sparrow, house finch, and American robin) were observed both alive and dead. The other 12 species were either detected alive but not found dead or found dead but not detected alive. This finding suggests that there is a discrepancy in collision likelihood among species that should be further studied to determine which traits are shared among those that collide more or less often relative to their abundance. Some traits which could be studied include species origin (i.e. native or introduced), foraging style, nesting habits, mating patterns, flocking, age, or sex. With improved understanding of traits that make some species more prone to collisions than others, city planners and developers may be able to improve development strategies to decrease bird-window collisions.

From an analysis of 23 studies (>92,000 fatality records), Loss et al. (2014) estimated that approximately 365 to 988 million (median = 599 million) birds die from collisions with glass every year in the United States. Although Loss et al. (2014) completed a very thorough process of data collecting and cleaning to get the most accurate estimate of nation-wide bird-window collision mortality, there are a few possible reasons that this estimate may show discrepancy: 1) studies analyzed included collisions with a range of building types (i.e. low-rises, residences, and high-rises), 2) studies included collision data collected at one or many buildings (with no distinction in number of buildings that were part of each study), and 3) the author found that a large portion of uncertainty was explained by the correction factor parameter that was included to correct for two biases in the survey methods that could lead to underestimation of mortality (i.e. "removal of carcasses by scavengers prior to fatality surveys and imperfect detection of the carcasses remaining at the time of surveys") (13). This rate of human-caused bird mortality is second only to free-ranging domestic cats and is significantly larger than other high-profile causes such as oil spills (Loss et al., 2014). According to Hager et al. (2008), "bird density only partially explained strikes with commercial buildings", and annual bird-collision mortality with commercial buildings is likely increasing due to an increase in urban construction and commercial buildings.

Relative to estimated abundance, some species of birds have been found to collide with buildings more frequently than others (Arnold and Zink, 2011; Loss et al., 2014, Anderson, personal communication, 2017). Furthermore, some taxa such as warblers and hummingbirds are found to have high collision rates by more than one species within that taxa (Loss et al., 2014). Of the 25 most vulnerable species summarized by Loss et al. (2014), 10 were warblers. In another similar study of vulnerability, warblers and sparrows were found to be "super colliders" (i.e. collide at a high rate relative to their population size) while swallows and larks were found to be "super avoiders" (Arnold and Zink, 2011). However, Arnold and Zink (2011) concluded that species vulnerability did not have any effect on population dynamics. While this may be true, some concern has been raised regarding super colliders that are also listed as national Birds of Conservation Concern ("species likely to become candidates for listing under the U.S. Endangered Species Act without further action based on population trends, threats to populations, distribution, abundance, and relative density", Loss et al., 2014, p.19). For species that already have a declining population due to unrelated causes, the added pressure of building collisions can increase the rate at which their population declines. Loss et al (2014) found that three species of warblers and one species of bunting are at an increased risk of extinction because of high building collision rates. Therefore, it is important to have a broad range of collision and local abundance data not only when populations are spatially or temporally at highest risk but also to create a baseline of data with which we can compare the rate of population growth or decline.

To date, most bird-building collision research has focused on eastern North America during spring and fall migrations, while fewer resources have been dedicated to studying the breeding season (Loss et al., 2014). Multiple studies agree that summer has the lowest number of collisions while spring and fall have the highest (Hager et al., 2008; Klem, 1989). However, such a conclusion may depend on the location of the study (i.e. residential vs. urban core). Residential areas have been found to elicit high rates of collision during the winter likely because a number of seed-eating species are attracted to the birdfeeders hanging near windows (Dunn, 1993; Klem, 1989). Research in the urban core has strongly focused on migratory seasons because they are known to have higher rates of bird-window collision. In order to expand research and lessen this seasonal bias, it is important to study bird collision during the breeding seasons (i.e. summer and winter) as well. In Minneapolis, Minnesota a study is in progress to compare collision rates of species during the breeding season relative to local relative abundance of each species (Anderson, personal communication, 2017). Initial results from the study indicate that certain species collided more or less often than others relative to their abundance. However, the reason for the varying collision rates among the various species collected during the breeding season is still unclear.

A variety of ecological differences exist among bird species which breed in downtown metropolitan areas, including but not limited to differences in traits such as feeding, nesting, foraging style, and typical habitat requirements, which could possibly explain the variability in collision rates per species (Blair, 1996; Blair, personal communication, 2017).With limited studies on the topic, a consensus has yet to be reached as to whether certain traits might be strong indicators of collision likelihood. Klem (1989) compared both age and sex differences among 225 species that had collided in the United States and Mexico and found neither to be a good indicator of collision likelihood. Kahle et al. (2016), however, found a higher proportion of male collisions than female throughout the year. Furthermore, Hager and Craig (2014) found that bird-window collisions during the breeding season are more positively correlated to species and age than to abundance. While the reason for this is still unknown, they suggest that the variable collision rates may have more to do with reproductive behavior, flight speed, distant movements, and dispersal patterns. Furthermore, it is important to consider the variability of bird-window collisions within a 24-hour day that might be related to variable species traits. McNamara, Mace, and Houston (1987) suggest that variation in feeding and behavioral interactions could play an important role in understanding collisions during the morning when activity levels are increased. Understanding which species collide more than others and what traits may increase collisions could allow us to provide new, efficient mitigation practices for commercial building owners in downtown business districts.

Reduction of vegetation near windows, closely placed decals, and lights out at night are all mitigation practices that are successful in reducing bird mortality due to collision with glass (Klem, 2009; Loss et al., 2014). By determining which species collide more frequently with windows in a downtown setting, we can study both the different traits of the species as well as the variation in building architecture and window design to determine if specific interventions can be made that will lower the rate of bird mortality. Today, there are many examples of bird-safe glass, window decals, and invisible films that allow birds to see the window as an obstruction, but don't take away from the use of windows for humans (Chaisson, 2014). While providing new collision mitigation strategies and building adaptations is an important outcome of bird-window collision research, the goal of this study is to provide much needed data relating to bird-window collisions during the breeding season.

Following the same methods as Anderson (Anderson, personal communication, 2017), this study analyzed bird-window collision rates among species during the breeding season in the business district of St. Paul, Minnesota. During the summer breeding season, carcasses of bird-window collision incidents were collected along a specified route. Additionally, point counts along the route were conducted throughout the season in order to create a local abundance estimate for each species. Any birds detected visually or audibly within a 50-meter radius of the selected corner (Figure 1) were counted by species. By comparing collision rates of each species relative to their abundance, it can be determined whether abundance is the main driver of variability among species-specific collision rates, as is suggested by Arnold and Zink (2014) or if there are other traits that play a more important role in species-specific collision rates (i.e. age, flight speed, reproductive behavior, etc.) as is suggested by Hager and Craig (2014).

There are three unique goals of this project. First, it will provide much-needed quantitative data regarding species-specific bird-window collision rates during the breeding season. Second, it will be analyzed which, if any, species are more or less likely (based on relative abundance) to collide with windows in a downtown business district zone. Lastly, if possible, the results will be used to make mitigation suggestions for city planners to lower the number of collisions.

Methods

Data Collection

During the breeding season of 2017, bird carcasses and point counts were collected from a two-mile route in downtown St. Paul. The route was established as part of the Project BirdSafe study and was monitored as part of a larger project from 2007-2016 (Eckles, personal communication). Along the route, there were 29 intersections (labeled A-CC) from which 16 were randomly selected that were not within 100 meters of another chosen intersection (Figure 1). Then at each of those 16 intersections, either the east, west, north, or south corner was randomly assigned so that each direction would only be used four times. From June 1, 2017 through July 5, 2017, the route

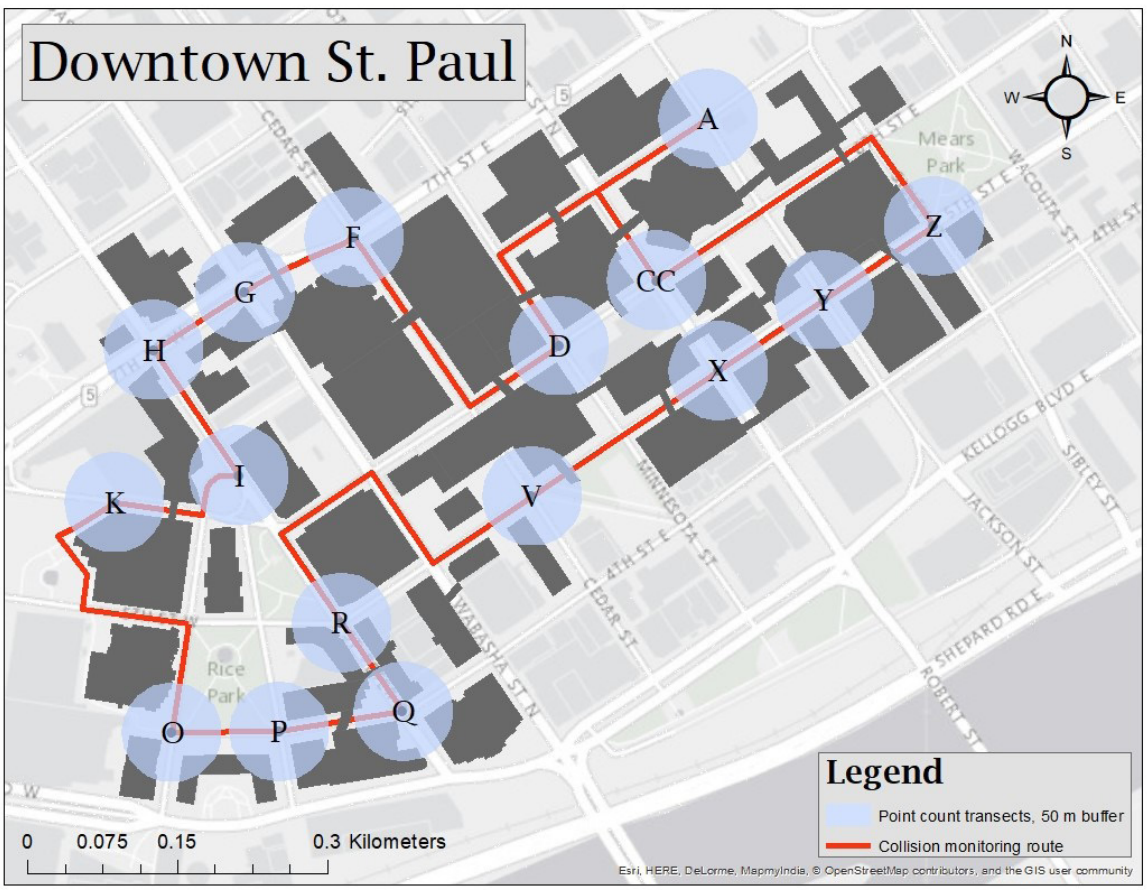

Figure 1. Map of St. Paul Monitoring Route. A collision monitoring route (in red) of 3.32 km was established as part of a larger monitoring project from 2007-2016 with Project BirdSafe (Eckles, personal communication, 2017). Corners chosen randomly for point counts are marked by transect buffers of 50 m and lettered. Buildings which include a facade along the route and skyways that cross the route are shaded dark gray. Starting point 1 was at the corner between points "I" and "K" while starting point 2 was at the corner labeled "Z".

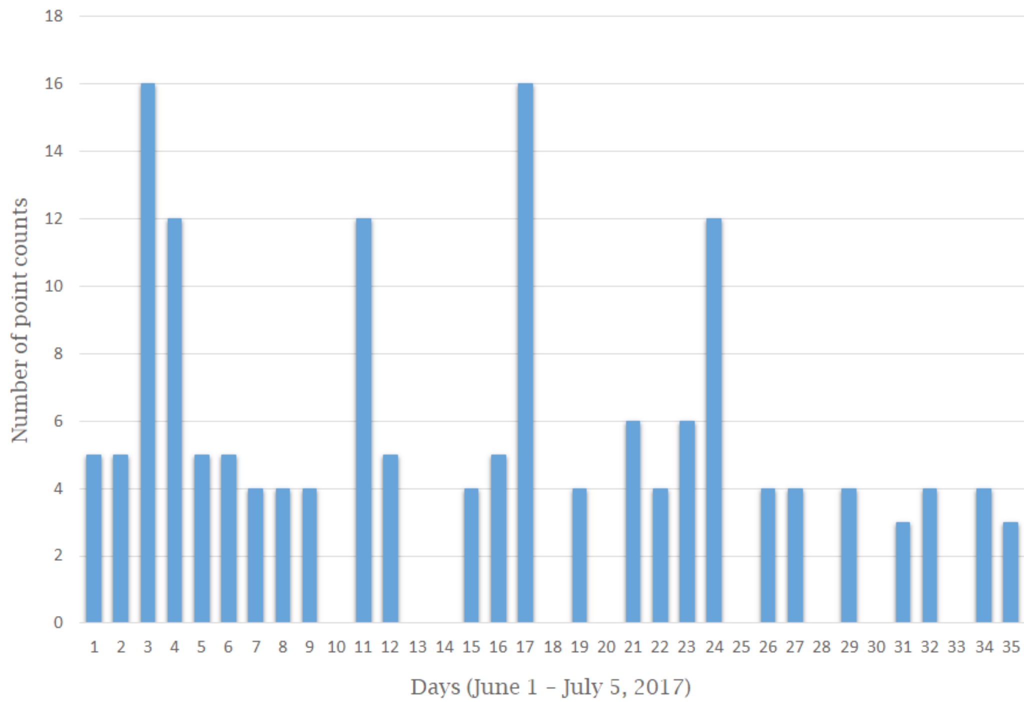

Figure 2. Number of point counts completed per day throughout the breeding season (June 1 - July 5, 2017) in downtown St. Paul. Days with high numbers of point counts (i.e. day 3, 4, 11, 17, and 24) were weekend days when less traffic noise made detection easier.

was surveyed 26 times. At sunrise, the survey would begin at one of two starting points on opposite sides of the route (which were chosen based on proximity to bus routes) and then continue either clockwise or counterclockwise so that each quarter of the route would be rotated through earliest to latest surveyed in a day. The longest time to complete a route was just under three hours after sunrise, but the average completion time was 93 minutes after sunrise. The discrepancy in time is mostly due to the number of point counts that were completed in any given day (Figure 2), which itself was due mostly to weather and traffic noise.

Every morning that the route was surveyed, bird carcasses that were underneath windows on either side of the street and those that were underneath skyways in the middle of the street were collected. Information for each specimen was recorded regarding the building or skyway it collided with, the cardinal direction which the window was facing, the time and date found, and the species (Appendix, Table 1).

While surveying for bird collisions, six-minute point counts were also conducted at a selection of the 16 chosen points (Figure 1) along the route. The number of point counts conducted each morning depended mostly on weather conditions and noise pollution from traffic. Of the 26 mornings on which data were collected, there was a median of four point counts conducted with a maximum of 16 and a minimum of three (Figure 2). The higher counts per day (i.e. 16 and 12) are attributed to the lack of traffic-related noise pollution on weekends, which creates an ideal time to detect birds in locations that otherwise might not be detected. The specific corners that were selected each day, were chosen depending on the route start point and direction to ensure that the average start time of the 10 points conducted at each corner was relatively similar. Average start time for the point counts at each corner ranged from 51.1 to 56.9 minutes after sunrise.

Data Analysis

Using Program R and the lme4 package, three generalized linear mixed models were compared to determine which was most appropriate for this dataset (Bates et al., 2014). All three models had a fixed effect of abundance but varied with random effect. Model 1 had no random effects, model 2 had a random effect of species, and model 3 had a random effect of week nested within species. The degrees of freedom for each model were 1, 2, and 3, respectively. The Akaike Information Criterion (AIC), which is used to compare the relative quality of statistical models for a given data set, suggests that model 1 is preferable as it has the lowest value. Due to the fact that the difference between AIC was small (≤ 2) and that theoretically model 3 best explains the random effect of species within week, model 3 was used to test the significance and strength of abundance as an explanatory factor of collisions among bird species. Species origin (i.e. native or introduced) was then added as a second fixed effect to test with abundance. Finally, because there were only three species out of the 15 which were detected in the survey that did not fall on an

Species	Live Detections	Live Proportion	Collision Detections	Collision Proportion
House sparrow	875	0.5916	3	0.1765
Rock pigeon	320	0.2164	0	0
House finch	179	0.1210	3	0.1765
European starling	49	0.0331	0	0
American robin	44	0.0297	1	0.0588
Mourning dove	8	0.0054	0	0
Black-capped chickadee	3	0.0020	0	0
Peregrine falcon	1	0.0007	0	0
Indigo bunting	0	0	2	0.1176
Mourning warbler	0	0	1	0.0588
Cedar waxwing	0	0	2	0.1176
Yellow warbler	0	0	1	0.0588
Common yellowthroat	0	0	2	0.1176
Red-eyed vireo	0	0	1	0.0588
Northern cardinal	0	0	1	0.0588

Table 1. 1,551 birds were detected alive during point counts and 21 were detected dead as carcasses along the route in downtown St. Paul during the survey. Of the 21 dead specimens, 4 were dropped from the analysis because they were unidentifiable, leaving 17 counts of collision (Appendix, Table 1 has full list). Live detections are the number detected alive visibly or audibly during the survey, and the collision detections are the number of each species found dead along the survey route. The live proportion and collision proportion are relative to the total number of live detections and collision detections, respectively.

axis (Figure 4), and upon first glance, house sparrow appeared to skew the results, it was removed from the data set to determine its effect on the results. Although house sparrow made up a large proportion of the total live counts, its removal as an outlier was justified because house sparrows are an unusually synanthropic species unlike anything else in the data set.

Results

During surveys, 1,551 live birds and 21 collision mortalities were counted. However, four collision specimens were removed from the data set because identification was uncertain leaving a collision count of n=17 (Table 1). In three cases, the carcasses were too mangled to reliably identify. The fourth specimen which was omitted from the data set was found without a head, which did not allow for certain identification. In addition, if identifiable parts (i.e. a wing, leg, head, or pile of feathers) were found, they were not included in data collection as there was no conclusive way to rule the cause of death a collision. The live counts consisted of eight species with house sparrow accounting for ~59% (n=875) and rock pigeon for ~22% (n=320) (Table 1). Of the 10 species found dead, house sparrow and house finch had 3 mortalities each, indigo bunting, cedar waxwing, and common yellowthroat had 2 mortalities each, and the last five species (American robin, mourning warbler, yellow warbler, red-eyed vireo, and northern cardinal) each had one mortality. Of the 15 species identified in downtown St. Paul, three were both detected alive and found dead: house sparrow, house finch, and American robin (Figure 3). Even though house sparrow makes up 59% (n=875) of all the live counts, it only accounts for 18% of the collision counts (n=3). Nevertheless, house finch and American robin collision proportions are relatively more comparable to their alive proportions. House finch makes up 12% (n=179) of live counts and 18% (n=3) of collision counts while American robin makes up 3% (n=44) of live counts and 6% (n=1) of collision counts. Furthermore, there were 12 species that were recorded either only alive (i.e. rock pigeon, European starling, mourning dove, black-capped chickadee, and peregrine falcon) or only dead (i.e. indigo bunting, cedar waxwing, common yellowthroat, mourning warbler, yellow warbler, red-eyed vireo, and northern cardinal). Rock pigeons, by themselves, made up a considerably large portion, ~22%, of the live counts while indigo bunting, cedar waxwing, and common yellowthroat together made up ~35% of collision counts.

When comparing the relative number of collisions per species to the relative frequency of each species, it is possible to see which species collide at a relatively higher or lower rate than they are seen alive (Figure 4). Species that fall along the one-to-one line (American robin and house finch) collide relatively proportional to their frequency. However, the species that fall above the line (indigo bunting, cedar waxwing, common yellowthroat, mourning warbler, and yellow warbler), have a higher collision rate relative to their frequency, and the species that fall below the line (house sparrow, rock pigeon, European starling, mourning dove, black-capped chickadee, and peregrine falcon), have a lower collision rate relative to their frequency.

According to the best supported model, species collision vulnerability is positively associated with abundance ($\Delta AIC = 1.72$; $\beta = 0.1867$; p-value = 0.101). However, adding origin of the species to the model as a fixed effect does not help explain collision vulnerability (for origin, $\beta = 0.211$ and p-value = 0.783 while for abundance, $\beta = 0.222$ and p-value = 0.190). Because house sparrow is an outlier, the same tests were repeated without house sparrow. When house sparrow is removed from the data set, the estimate coefficient drops but the statistical significance is completely lost ($\beta = -0.136$ and p-value = 0.814).

Discussion

Bird-window collisions have been studied for nearly a century with one of the earliest studies to acknowledge a difference in species-specific collision rates being Townsend (1931). Nevertheless, there is still a strong need for research on bird-window collisions, especially regarding specific species and the breeding season. Kahle et al. (2016) found that active migration might not be as important of an indicator of collision as previously thought, and that other traits such as sex and age might play a larger role. Unlike past studies which found that summer had the lowest collision rate of the year (Hager et al., 2008; Klem, 1989), Kahle et al. (2016) found that collisions increased along with abundance from April to October. This lack of understanding around the issue of bird-window collisions has created a need for more research. Furthermore, in Minnesota, there are requirements through Buildings, Benchmarks & Beyond (n.d.) to prevent bird-window collisions, which apply to state-bond funded new construction or major renovation. The requirements help reduce high-risk surfaces and light pollution at night which attracts birds in and around source areas that contain increased glass hazards. In addition to Minnesota's requirements, Leadership in Energy and Environmental Design (LEED, n.d.), a global certification program for sustainable development, similarly incentivizes designs which reduce surfaces known to increase risk to birds. Both programs have important roles in decreasing human-caused

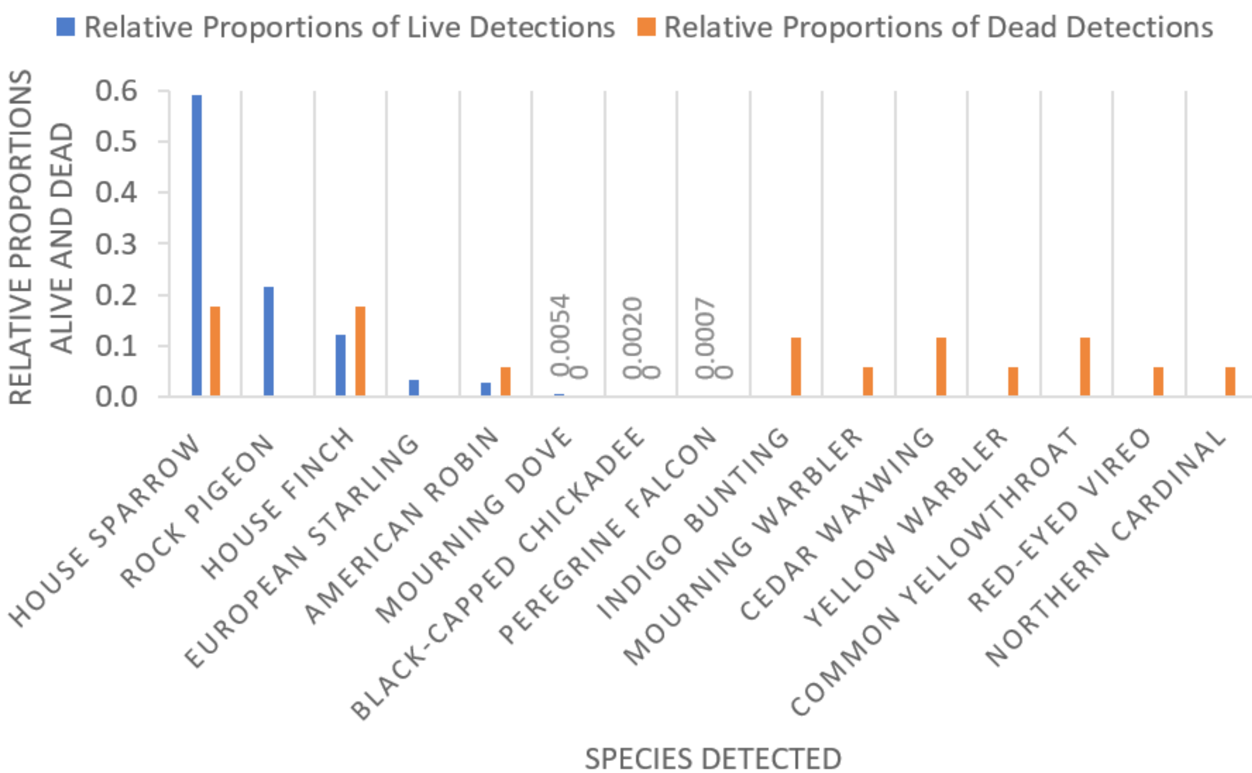

Figure 3. Relative proportions of species detected alive during point counts are depicted by blue bars. Likewise, relative proportions of species detected dead (i.e. found as carcasses along route) are depicted by orange bars. If a bar cannot be seen, it is because there were no detections in that category, except with mourning dove, black-capped chickadee, and peregrine falcon where the relative detections were so low that they cannot be seen. In downtown St. Paul during the 2017 breeding season, 1,551 birds were detected alive, including 8 species. Two of those species (house sparrow (n=875) and rock pigeon (n=320)) made up 81%. The remaining 19% consisted of house finch (n=179), European starling (n=49), American robin (n=44), mourning dove (n=8), black-capped chickadee (n=3), and peregrine falcon (n=1). Furthermore, 17 birds were found dead next to a window or under a skyway. Of the 10 species found dead, house sparrow (n=3) and house finch (n=3) made up 35%, indigo bunting (n=2), cedar waxwing (n=2), and common yellowthroat (n=2) made up another 35%, and the last 5 species (American robin (n=1), mourning warbler (n=1), yellow warbler (n=1), red-eyed vireo (n=1), and northern cardinal (n=1)) each accounted for approximately 6%. Of the 15 species identified in downtown St. Paul, three were both detected alive and found dead: house sparrow, house finch, and American robin. While the alive proportion of house sparrow is noticeably larger than the dead proportion, the same is not true for house finch and American robin. The proportions of house finches and American robins detected alive and found dead are relatively similar for both.

bird mortality via collisions with glass. However, they need robust data and analysis in order to justify their guidelines. Therefore, more research is needed in order to understand bird-window collisions better and to continue to improve mitigation strategies.

In order to help fill the knowledge gap, this study gathered data on window collisions in a downtown setting along with locally collected species frequency data. Due to the limited time allowed for the study, the analysis only includes data from the summer breeding season of one year. The data set is therefore rather small (n=1,551 alive and n=17 dead), which has hindered the strength of the statistical analysis. With house sparrow included in the data set, the correlation between abundance and species-specific collision rates had a weak statistical significance (p=0.101). However, it is clear by observing figure 4 that of the three species which appeared both alive and dead, house sparrow is strongly skewing the statistical relationship. If house sparrow is removed from the data set, house finch and American robin fall almost precisely on the one-to-one line in figure 4. However, because there are only two species left that were seen both alive and dead once house sparrow is removed, the data set becomes too small to hold any statistical significance. Removing house sparrow should have made the correlation between abundance and species-specific collision more statistically significant; however, due to the small data set, the p-value became very weak (0.814).

Although the statistical tests did not provide strong results due to the small data set, there are some clear takeaways that can be observed from the data. As shown in figure 3, of the 15 species that were detected during the survey, only three species (house sparrow, house finch, and American robin) were recorded both alive (i.e. detected during point counts) and dead (i.e. detected as carcasses along route). In addition to those three species, another five species were detected alive but never found dead, and another seven species were found dead but never detected alive. Rock pigeon made up approximately 23% of the alive detections but 0% of the dead detections, and three species (indigo bunting, cedar waxwing, and common yellowthroat) made up approximately 35% of the dead

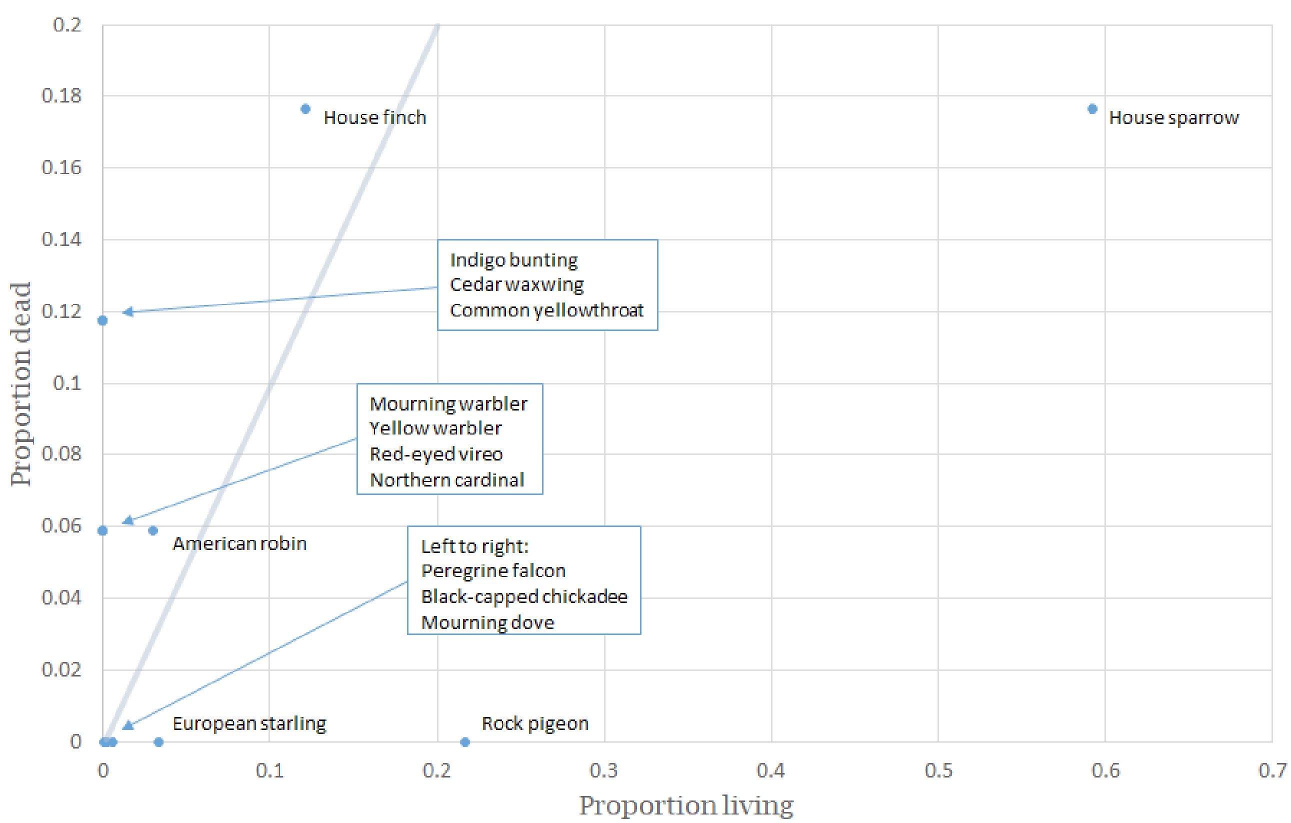

Figure 4. Relative number of collisions per species are depicted as a function of relative frequency of each species. Species that fall along the one-to-one line (American robin and house finch) collide relatively proportional to their frequency. However, the species that fall above the line (in this case on the vertical axis), have a higher collision rate relative to their frequency, and the species that fall below the line (house sparrow and those on the horizontal axis), have a lower collision rate relative to their frequency.

dead detections but 0% of the alive detections. This suggests that there is a distinction between species which are more or less likely to collide because the relative collision counts do not line up with the relative frequency of each species. Furthermore, house sparrow appears to be a "super avoider" as it falls very far below the line in figure 4 to the point that it is affecting the model substantially because it has a much larger relative proportion of live detections than collision counts.

It was hypothesized that species which are native to southeastern Minnesota would be more likely to collide than those which are introduced (i.e. European starling, house finch, house sparrow, and rock pigeon) because introduced species are often more well adapted to human-dominated environments (Shochat et al. 2010); however, species origin did not correlate to collision rate. It is likely due to the small data set because of the four species in this study that are non-native, three (European starling, rock pigeon, and house sparrow) suggest the hypothesis is correct. European starling and rock pigeon were present in relatively high numbers but were not detected dead. House sparrow, although it did collide, it had a proportion of collisions relative to other species that was substantially lower than its relative frequency, supporting the theory that introduced species are less likely to collide based on abundance. Had there been more data so that house finch and house sparrow did not make up two-thirds of the overlapping data, it is possible that species origin might have been a significant indicator of species-specific collision as data from other studies show low to average mortality risk relative to abundance for these non-native species (Loss et al., 2014; Hager and Craig, 2014).

Although the data set was small, it is apparent from the anecdotal results that there are species which collide more or less than others relative to their abundance. Based on the analysis, it would appear that species origin is not a good indicator of collision rates, but it is possible that that is due to the small data set and that it needs to be studied further. There are many other variable traits (i.e. age, sex, feeding and nesting habits, foraging style, etc.) that need to be tested as possible indicators of collision likelihood. Kahle et al. (2016) suggested that birds which fly in flocks may be less likely to collide because just one bird needs to see the glass for the entire flock to turn away. This is fitting with the lack of European starlings from the collision data. However, cedar waxwings, another flock species, had been found to collide as a pair in this survey. It is possible that alternative to the flock theory suggested by Kahle et al. (2016), some flock species may collide as a group because the small flock tries to fly through a window. Unfortunately, these traits could not be tested here due to the small sample size.

Conclusion

This study had three distinct goals: 1) to provide quantitative data regarding species-specific bird-window collision rates, 2) to analyze which species, if any, are more or less likely to collide with windows in a downtown area, and 3) to possibly create mitigation suggestions for city planners which could lower collision rates.

Ultimately, this study includes 26 days of collision data (n=17 documented collisions) and 160 corresponding point-count collections (n=1,551 live birds). This data also includes information which was not used in this study but can be used in the future, such as weather, time after sunrise, cardinal direction of each facade, and detection time of each bird after starting the point-count. The study does not provide statistically significant data regarding species-specific collision rates of birds in downtown St. Paul. It does, however, suggest that collisions during the breeding season are not proportional to abundance of a given species and that further data collection and additional research is needed. If future studies can analyze a larger data set and provide statistically significant results detailing super colliders and super avoiders, it might lend support to city planners and legislators in favor of new practices which decrease the rate of bird-window collisions.

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Appendix

Date	Time	Species	Side of Building or Street	Notes
06-01-2017	07:06	Mourning warbler	West	
06-02-2017	05:32	Indigo bunting	North	
06-02-2017	06:11	Unknown	St. Peter	Smashed by car under skyway
06-02-2017	06:33	Indigo bunting	Northeast	
06-04-2017	06:02	House sparrow	Northeast	Young of year
06-05-2017	06:15	Uncertain	Southwest	Missing head; possible Nashville warbler
06-06-2017	05:28	Cedar waxwing	West	Found with other cedar waxwing
06-06-2017	05:29	Cedar waxwing	West	Found with other cedar waxwing
06-08-2017	05:33	Unknown	Sibley St.	Smashed by car under skyway
06-15-2017	06:18	Yellow warbler	West	
06-16-2017	06:00	Unknown	Sibley St.	Ran over by car after hitting skyway
06-16-2017	06:01	American robin	Sibley St.	Ran over by car after hitting skyway
06-17-2017	06:41	Common yellowthroat	West	
06-21-2017	06:18	House sparrow	West	
06-21-2017	06:31	House finch	Southwest	Young of year
06-26-2017	05:34	House finch	West	
07-01-2017	05:28	Red-eyed vireo	West	
07-04-2017	06:18	House finch	Southwest	
07-04-2017	06:38	Northern cardinal	North	
07-05-2017	05:50	Common yellowthroat	West	
07-05-2017	05:51	House sparrow	West	

Table 1. Complete list of collisions (n=21) encountered including unidentified. For each encounter, the date and time were recorded, side of building or street where it was found, and any additional notes.