The use of citizen science to identify the factors affecting bird-window collisions at residential houses

by

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A thesis submitted in partial fulfillment of the requirements for the degree of

Master of Science

In Ecology

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University of Alberta

ABSTRACT

Every year a large number of birds die when they collide with windows. The actual number however is difficult to ascertain. Previous attempts to estimate bird-window collision rates in Canada relied heavily on a citizen science study that used memory-based surveys which may have potential biases. Building upon this study and their recommendations for future research the Birds and Windows citizen science project was designed to have homeowners actively search for collision evidence at their houses and apartments for an extended period. The first objective of the Birds and Windows project was to see how a more standardized approach to citizen science data collection influenced bird-window collision estimates and to see if the same patterns observed by memory-based surveys were observed using different data collection methods. Comparing the results from the Birds and Windows standardized searches and memory-based surveys revealed differences in absolute values of collisions but similar relative rankings between residence types. This suggests that memory-based surveys may be a useful tool for understanding the relative importance of different risk factors causing bird-window collisions.

The second objective from the Birds and Windows project was to gain a better understanding of the factors affecting collisions at residential houses. It currently remains poorly understood which types of buildings and windows are most problematic. Understanding whether neighbourhood type, yard conditions, house attributes, or window types have the largest effect on collision rates is crucial for identifying which mitigation options might be most effective. Factors at the yard level had the best model fit for predicting bird-window collisions at residential houses. Efforts to reduce collisions should target variables at this level and those factors that

attract birds to an individual yard. As few homeowners are likely to take an approach that reduces the number of birds in their yards, focus should instead be given to bird-friendly urban design and developing the most effective window deterrents.

Finally, the effects of bird feeder presence and placement on bird-window collisions at residential homes was determined through a manipulative experiment. During the study there were 1.84 times more collisions when the bird feeder was present. However, there were no collisions at half of the study windows. High variance was observed in the number of collisions at different houses, indicating that effects of bird feeders are context dependent. Changing the occurrence, timing, and placement of feeders can alter collision rates but is only one of many factors that influence whether a residential house is likely to have a bird-window collision or not.

In conclusion, I provide recommendations for conducting future survey-based citizen science projects and outline the next steps for bird-window collision research in working towards stopping avian mortality from collisions with windows. I have thoroughly outlined a number of factors affecting bird-window collisions and believe the focus of future research should now shift towards reducing the number of collisions. The Birds and Windows project saw a number of successes as a citizen science project and citizen science remains the best method for collecting large scale data in real-world scenarios and should continue to be used in similar experiments.

PREFACE

The Birds and Windows survey and bird feeder experiment were conducted under permits Pro00041311 and AUP00001361 from the Research Ethics Board at the University of Alberta.

The Department of Biological Sciences at the University of Alberta and Environment Canada provided funding for this project.

Chapter 4 of this thesis has been published in *Avian Conservation and Ecology*:

Kummer, J. A. and E. M. Bayne. 2015. Bird feeders and their effects on bird-window collisions at residential houses. *Avian Conservation and Ecology* 10(2).

Chapters 2 was recently submitted to *Avian Conservation and Ecology*, with the author list as follows:

Kummer, J. A., E. M. Bayne and C. S. Machtans. *Submitted.* Comparing the results of recall-surveys and standardized searches in understanding bird-window collisions at residential houses.

Chapter 3 is being prepared for submission to the journal *The Condor*, with proposed author list as follows:

Kummer, J. A., E. M. Bayne and C. S. Machtans. *In prep.* The use of citizen science to identify the factors affecting bird-window collisions at residential houses

ACKNOWLEDGMENTS

Thank you to my supervisor Erin Bayne for taking me on as a volunteer all those years ago and continuing to work with and encourage me every day since. I greatly appreciate your advice and everything you've done to get me where I am today. Thank you as well to my committee members: Craig Machtans, thank you for your insight and advice since the beginning of the Birds and Windows project and Colleen St. Clair, thank you for your ideas and helping feedback throughout.

Thank you to Connor Charchuk for identifying the dead birds in all my photos, Kofi Garbrah for creating the Birds and Windows website, Corey Scobie for helping with preliminary analysis, and Lorne LeClair and Igor Sinelnikov for helping me understand how to use a raspberry pi.

Thank you to my undergraduate students, high school WISEST students and volunteers for their help with data collection and bird feeder set up. These excellent people are: Taylor Berry, Colina Collins, Elita Grinde, Courtney Heck, Judy Hyun-Joo Ko, Emilie Jutras, Abby Menzies, Casandra Tse, and Mulan Xia.

Thank you also to my fellow members of the Bayne and Boutin labs for your company and support over the years. You're always there to make me smile. I could not have done it without you.

I owe a special thank you to my friends and family for their encouragement and support. The Kristins for always finding amusement in my project and providing an escape when needed. My sister for constantly telling me she doesn't care about my project but being there to listen to me talk about it over and over again. My mom for always trying her hardest to understand what it is I do and continuously offering her support any way she could. And an extra thank you to my dad for participating in my project for almost two years, engineering my bird feeder design and being there whenever I needed help with bird feeder set up and take down, especially during the winter when the ground was frozen and I was too weak to remove them. Thank you all ☺

Finally, this project would not have been a success without the 1315 people who registered and participated in the Birds and Windows project and the 43 families who allowed me to place bird feeders at their home. Your dedication in searching for bird-window collision evidence was greatly appreciated. Thank you for your continued support.

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CHAPTER 1. INTRODUCTION

There are a number of human activities in Canada that kill wild birds. In Environment Canada's synthesis of human-related avian mortality in Canada, collisions with windows tied for second with collisions with power lines for the leading cause of human-related bird mortality (Calvert et al. 2013). The largest source of mortality was predation by domestic and feral cats. Despite the threat to bird populations from human induced mortality, little research has been done to understand the magnitude of these threats and what can be done to mitigate them.

The earliest account of a bird hitting a window in North America is from 1832 where a hawk is described as flying through the panes of a greenhouse (Nutthall 1832, Klem 1989). Townsend (1931) was the first to document a series of collisions as scientific observations and suggested some species may be more at risk of a collision than others. Prior to World War II there was little cause for concern as large picture windows were uncommon (Klem 1989). However, in the postwar years, with rapid expansion of the sheet glass industry, glass windows were incorporated into the designs of new and remodeled structures (Klem 1989). In today's urban landscape it is uncommon to find a building without glass. Since the late 1980's, there has been a rise in scientific studies researching bird-window collisions (Klem 1989, Klem 1990, Dunn 1993, Klem et al. 2004, Erickson et al. 2005, Hager et al. 2008, Gelb and Delacretaz 2009, Klem et al. 2009, Borden et al. 2010, Arnold and Zink 2011, Bracey 2011, Bayne et al. 2012, Hager et al. 2013, Klem and Saenger 2013, Machtans et al. 2013, Hager and Craig 2014, Loss et al. 2014).

The first estimate of bird-window collision mortality was Banks (1979). In developing his estimate of 3.5 million fatalities per year in the United States he used a low incidence of 1 bird fatality per square mile in the U.S. instead of any actual scientific data. Klem (1990) derived a new estimate based on a study at two houses in Illinois. This study estimated 1 to 10 birds were killed per building each year which was extrapolated to 97.6-975.6 million birds killed each year in the United States (Klem 1990). In conducting a continent wide survey through Project Feeder Watch, Dunn (1993) estimated 0.85 birds were killed per home each winter. While a number of assumptions were made with her data, her estimates were comparable to Klem (1990). This estimate, commonly rounded to 1 billion birds dying per year from hitting windows in North America, became to most cited bird-window collision mortality estimate for residential houses.

However, there remained a lot of uncertainty with these estimates. While the goal of past authors may have been to reflect the potential for bird-window collisions as a problem, there have been serious misuses of their estimates and the caveats associated with them. All of the estimates described above have been used to express the importance or lack of importance of bird-window collisions as a conservation issue, sometimes with perverse consequences. Best (2008) used the estimation of bird-window collisions as classic example of the poor numerical understanding of society and how "dubious data … enters policy debates". To ensure that avian collision issues are taken seriously and valid comparisons of risk to bird populations are made, a greater degree of certainty is required in estimating mortality risk caused by all anthropogenic sources.

In one of the first detailed samplings of bird-window collisions, Bayne et al. (2012) reported an average of 1.7 ± 4.6 collisions per homeowner from 1458 participants to an online survey. These numbers suggest the previous Klem (1990) estimate was high. This study was also one of the first to discuss the idea that collisions are not random and vary based on attributes of house type. The highest collision and mortality rates were seen at rural residences with bird feeders. A number of recent studies have continued to look at the factors affecting bird-window collisions at residential houses (Hager et al. 2013, Hager and Craig 2014). Hager et al. (2013) found very few collisions at houses and that distance to vegetation and development to be large factors in predicting collision risk.

The first Canadian bird-window collision estimate was developed by Machtans et al. (2013) using the data collected by Bayne et al. (2012) and other previous studies from different building classes. These results stated 24.9 million birds are killed each year in Canada from collisions with windows. As residential houses far outnumber the tall and commercial buildings on the landscape, 90% of all building-related mortality was estimated to occur at residences. Similar analysis has since been used to develop the new window collision mortality estimate of 365 to 988 million birds for the United States (Loss et al. 2014). These large estimates relied heavily upon the data collected by Bayne et al. (2012) and as there were a number of potential biases in their methods the Birds and Windows project was developed.

1.0 THESIS OUTLINE

The Birds and Windows citizen science project was developed from the previous Bayne et al. (2012) study to better understand bird-window collisions at residential houses. Chapters 2 and 3 are derived directly from the data collected in the recall-survey and standardized searches from this project. In Chapter 2 the main objective was to see how a more standardized approach to citizen science data collection influenced bird-window collision estimates and to see if the same patterns observed by Bayne et al. (2012) were observed using the same and different methods. Chapter 3 focused on understanding whether neighbourhood type, yard conditions, house attributes, or window types have the largest effect on collision rates to determine which level should be targeted in developing the most effective and economical strategies for reducing bird-window collisions. In Chapter 4, I focus on the results of an experiment where the placement of a bird feeder in front of a window was manipulated at residential homes. The main objective of this study was to determine if bird feeder presence and placement influenced bird-window collisions risk. In conclusion, in Chapter 5 I provide a series of recommendations for conducting survey based citizen science projects and discus potential ideas for future bird-window collision studies.

CHAPTER 2. COMPARING THE RESULTS OF RECALL-SURVEYS AND STANDARDIZED SEARCHES IN UNDERSTANDING BIRD-WINDOW COLLISIONS AT RESIDENTIAL HOUSES

2.0 SUMMARY

Every year a large number of birds die when they collide with windows. The actual number however is difficult to ascertain. Previous attempts to estimate bird-window collision rates in Canada relied heavily on a citizen science study that used memory-based surveys that have many potential biases. We built upon this study and their recommendations for future research by creating a citizen science program that actively searched for collision evidence at houses and apartments for an extended period with the objective to see how standardized approaches to data collection compared to memory recall. We compared absolute collision estimates as well as relative differences between residence types and found considerable differences in absolute values of collisions but similar rankings of collision rates between residence types. Collision rates based on memory recall in our study (56.5%) were very similar to Bayne et al. (2012) where 50.5% of participants remembered a bird colliding with a window at some time in the past. Fatality estimates however were 1.4 times higher in Bayne et al. (2012) than our study based on standardized searches. The types of houses with the highest number of collisions were similar between all studies and methods. This suggests that memory recall-surveys may be a useful tool for understanding the relative importance of different risk factors causing bird-window collisions which is essential for creating effective mitigation strategies.

2.1 INTRODUCTION

Bird-window collisions are an environmental issue that resonates with people when they are informed of it. In Canada, an estimated 16-42 million birds die each year from collisions with windows (Machtans et al. 2013). This estimate equals close to one bird killed per person in Canada every year (Government of Canada 2015). Many people can remember an instance where a bird collided with a window of their residence (Bayne et al. 2012). However, a large percentage of the population is unaware of the magnitude of the issue and the need for more research to properly estimate and mitigate the impacts of bird-window collisions (Arnold and Zink 2011, Sushinsky et al. 2013).

The field of citizen science, a form of public participation in scientific research, has grown in recent years as tools have become more available for dispersing information about projects and gathering data from the public (Bonney et al. 2014, Crain et al. 2014, Loss et al. 2015, Wiggins and Crowston 2015). The largest and some of the most successful citizen science programs, including eBird, the Christmas Bird Count, Project Feeder Watch and the Breeding Bird Survey are in the field of ornithology (Tulloch et al. 2013). Recently, citizen science projects have started collecting data on bird-window collisions. The majority of these bird-window collision projects have focused on large buildings in the downtown core of large cities (Loss et al. 2015). Often overlooked are the effects of windows in houses. Houses may represent a much greater potential threat to birds than tall commercial buildings because there are many more houses on the landscape than tall commercial buildings. Based on the best available science at the time, houses were estimated to cause 90% of all bird-window collision mortalities in Canada (Machtans et al. 2013).

The first attempt at using citizen science to study bird-window collisions at houses was conducted by Bayne et al. (2012). The project consisted of an online survey where homeowners were asked to recall whether they could remember a bird-window collision occurring at their home at any point in the past as well as more detailed questions about the number of collisions they remembered occurring in the past year. This has been cited as the most extensive study to date on the effects of bird-window collisions at houses and the results had a strong influence on recent estimates of Canadian and United States bird mortality caused by collisions with windows (Machtans et al. 2013, Loss et al. 2014).

The development of national estimates of mortality caused by bird-window collisions was quite successful in garnering media attention and raising public awareness about bird-window collisions (Machtans and Thogmartin 2014). However, the interest was primarily in the total number killed. The caveats and criticisms of the underlying data these estimates were based on were not discussed in the media despite being emphasized in the original papers (Best 2008, Machtans and Thogmartin 2014). For example, the data collected by Bayne et al. (2012) relied entirely on participant memory. This design may have led to recollection errors where respondents were unable to recall past collisions or might recall collisions that did not occur (Gaskell et al. 2000, Iarossi 2006). Participants also self-identified, potentially creating non-response errors or responses dominated by those who had observed a collision (Loss et al. 2012). Those participants with an interest in birds and a pre-established window collision problem at their home may have been more likely to answer a series of questions relating to bird-window collisions than those who have not previously observed such an event. Such biases could result in the data being skewed towards participants who have already observed collisions, resulting in collision and mortality estimates that are much higher than actually occurs.

Machtans and Thogmartin (2014) stressed that using data from studies like Bayne et al. (2012) to estimate bird-window mortality should be viewed as a catalyst to collect better data rather than the answer itself. Thus, we built on Bayne et al. (2012) by applying their recommendations for future research and more detailed monitoring. Specifically, we designed a citizen science program to actively search for collision evidence at houses and apartments for an extended period of time as well as evaluating what people remembered about collisions at their home. The objective was to see how a more standardized approach to citizen science data collection influenced bird-window collision estimates and to see if the same patterns observed by Bayne et al. (2012) were observed using the same and different methods of data collection.

2.2 METHODS

2.2.1 Data collection protocol

The Birds and Windows project (http://birdswindows.biology.ualberta.ca) was initiated in 2013 with two main components. First, we conducted a survey where people were asked to recall previous bird-window collisions similar to that of Bayne et al. (2012). This was done to determine whether consistent patterns in people's recollection of collisions were similar between the two studies. This survey was then used to recruit people to participate in systematic monitoring of their homes whereby they were asked to search the perimeter of their residence for evidence of a bird-window collision on a daily basis.

Forms of collision evidence that participants were asked to look for include a dead or injured bird, a body smudge, feathers or blood on the window, and hearing or seeing a collision occur. Participants were asked to record every day they searched for evidence. This was done to account for search effort and to ensure days with no collisions were recorded. In completing searches, homeowners were asked to search within a 2 m perimeter of their residence. Thus, birds that collided with a window, flew off and died elsewhere may not have been detected. Participants were asked to look on the ground, in and around vegetation, and on balconies and sidewalks. As well, all windows were to be checked for evidence of a collision. To reduce the chance of evidence being missed, a pace of one step per second was recommended. After searching the residence once, participants were asked to reverse their direction and walk around a second time.

Homeowners living in apartments were also encouraged to participate. These participants were expected to walk the perimeter of their entire building and check the balconies of their own unit. Homeowners living in homes attached to at least one other dwelling (row housing, duplexes, semi-detached and single-attached homes) were required to search the perimeter and exterior walls of their individual unit not the entire complex. Additionally, detached garages were to be monitored.

2.2.2 Birds and Windows website

Upon registering for the Birds and Windows project, homeowners completed a short survey on the past bird-window collision history at their home. Information was also collected on house and yard characteristics. The primary questions asked were: (1) How did you hear about the project; (2) What is your address; (3) What type of building do you live in (options and definitions provided); (4) Do you ever remember observing a bird-window collision in this residence; (5) Do you remember observing a bird-window collision in the past year at this residence; and (6) How many of each bird attractant (bird feeder, bird bath, bird house) can be found within the following distances from your home (<2m, 2-5m, >5-10m, >10m). Following completion of the recall-survey, participants were directed to the collision evidence search protocol and an onscreen calendar to be used in tracking the days they searched for evidence from the day of registration forward. Each day the homeowner searched for collision evidence they were asked to enter it into the calendar, whether or not evidence of a collision was found. If no collision evidence was observed there were no additional questions. When a collision was reported several questions were asked. In this paper, we only used information from the question: (1) Did the bird survive the initial collision? Using the addresses and/or postal codes provided by homeowners, Google Earth Pro was used to determine whether the location of each home was in an urban or rural setting. Homeowners were asked to email or upload photos of collision evidence to the Birds and Windows website to allow confirmation of each collision event and to identify species.

2.2.3 Survey distribution

The Birds and Windows website launched in September 2013 and data was collected through May 2015. Requests to participate in the survey were distributed using multiple approaches. In promoting the project, posters and pamphlets were distributed throughout neighbourhoods in Edmonton and outlying areas. Across Alberta, the project was presented to local bird stores, nature and bird groups, and small newspapers. Social media sites, including Facebook and Twitter, were set up allowing the project to be accessible to a larger audience. Various universities and established organizations, which promote citizen science programs relating to bird conservation across North America were contacted electronically. Additionally, the Conservation Biology class at the University of Alberta participated for class credit during the Fall 2013 and 2014 semesters. Four radio interviews were conducted with Canadian Broadcasting Corporation (CBC) Radio to promote the project. An additional CBC News article was published and a segment aired on CBC Alberta Late Night News. A number of scientific outreach opportunities were taken to promote the project to children and the general public. Through personal contact with Environment Canada, Nature Alberta, the Alberta Conservation Association, the Alberta Biodiversity Monitoring Institute and the Alberta Chapter of the

Wildlife Society, the Birds and Windows project reached a number of potential participants and organizations with an established interest in bird conservation and citizen science. Registered participants who had stopped searching for evidence were contacted again after a few months to encourage them to continue. As well, in registering with the survey, participants had the option of requesting a weekly email reminding them to participate.

2.2.4 Data analysis

All homeowner observations were checked for consistency. Confirmation emails were sent to participants with suspicious entries (entered 30 observations at once, multiple collisions entered in 1 day, and collisions entered for the time period before the participant had initially signed up for the project). If confirmation of these observations was not provided, they were excluded from our analysis.

Each residence was divided into one of the five major residence classes outlined by Bayne et al. (2012): (1) rural residences with a bird feeder; (2) rural residences without a bird feeder; (3) urban residences with a bird feeder; (4) urban residences without a bird feeder; and (5) apartments and condo complexes.

Five response variables were calculated for each homeowner: (1) CollisionEver – was derived from the recall-survey question – “Do you ever remember observing a bird-window collision in this residence?”; (2) CollisionYear – was derived from the recall-survey question – “Do you remember observing a bird-window collision in the past year at this residence?”; (3) CollisionSearch – whether or not a collision was ever entered during the homeowner’s standardized searches; (4) CollisionNumber – the predicted number of collisions at each residence in one year based on standardized search data; and (5) FatalityNumber – the predicted number of collisions that resulted in a fatality in one year based on standardized search data.

As not all participants collected data for the same length of time we had to adjust for differential effort when estimating CollisionNumber and FatalityNumber. Two options were explored for correcting for differential effort. First, we calculated the proportion of the year a person reported collecting data by taking the total number of days of observations and dividing by 365. Second, we evaluated the proportion of the year a person participated by taking the numbers of days between when they registered and the last date when they entered data and dividing by 365. These proportions were ln-transformed and then applied as either a statistical offset or fixed effect in our statistical models. Model fit was compared via Akaike Information Criteria (AIC) (Burnham and Anderson 2004) and the approach that provided the best model fit was chosen when reporting results. Both approaches model count data as a rate which allows us to report CollisionNumber and FatalityNumber on an annual basis. CollisionNumber and FatalityNumber were modelled using negative binomial regression because of overdispersion in the raw count data. Models were created in STATA 13 (StataCorp, College Station, Texas, USA, http://www.stata.com/). Only homeowners who completed a minimum of 1 month of observations (28 days) outlined in the protocol were included in these analyses.

2.3 RESULTS

2.3.1 Participant recruitment

There were 1315 participants registered with the project. Of those, 981 homeowners completed bird-window collision observations. The two most successful survey distribution methods were word of mouth (474 homeowners recruited) and email (353). 161 people heard about the project through students in the Biology 367 Conservation Biology class. 104 participants heard about the project through pamphlet distribution and 99 through the Birds and

Windows Facebook and Twitter accounts. Another 57 people first heard about the project through media outreach, including newspaper articles and radio and TV interviews.

1226 participants were from Canada, 56 from the United States and 8 from the United Kingdom. There were additional participants from Australia, India and some European countries. In Canada, 995 homeowners from Alberta registered with the project. The next two highest provinces were British Columbia (101 homeowners) and Ontario (56). There were participants from each of the remaining provinces and the Yukon and Northwest Territories. 768 homeowners in Alberta who registered with the project then went on to enter observations. Figure 1 shows the number of participants by the nearest city or town in Alberta. Only homeowners from Alberta were included in our analysis as the majority of our participants were from Alberta and we did not have a representative sample for all of Canada.

2.3.2 Recollection of past bird-window collisions from survey questions

Upon registering for the Birds and Windows project, participants were asked about collisions that they remembered occurring in the past. CollisionEver was 56.5% for participants in Alberta who participated for at least one month, while CollisionYear was 43.8%.

The rank order for CollisionYear using the 5 main residence classes was: rural residence with a feeder (95.7% of homeowners reported a collision) > urban residence with a feeder (56.2%) > rural residence without a feeder (53.8%) > urban residence without a feeder (36.9%) > apartments (11.6%). Overall, 70% of the homeowners who reported a collision in the previous year at their home observed a collision while conducting the standardized searches around their home.

2.3.3 Observed collisions from standardized searches

There was a 12.2% drop off rate from homeowners after entering one observation. A total of 381 participants reached the minimum 28 days of standardized searches required by the project protocol. The average length of participation was 44.42 ± 76.51 (SD) days. There were a number of participants who exceeded the minimum and participated for an extended period. The top 5 number of observations was 610, 554, 527, 526, and 511 days.

Based on AIC in our best model, negative binomial distribution (AIC = 1105.82) provided a much better fit than Poisson (AIC = 2041.68). We found that model fit was better when we used the proportion of the year a person participated in the project rather than the proportion of the year they made actual observations (ΔAIC = 25.02). Treating this variable as an offset with the coefficient set to 1 provided a better fit than a fixed effect model (ΔAIC = 1.81). All of the results are reported using this approach to correct for differential effort (Table 1).

Alberta homeowners entered 34 114 observations in the Birds and Windows project database. Of these observations, there were 930 collisions and 102 fatalities recorded. 76 collisions were verified through photos. CollisionSearch was 42.3% for homeowners who participated for at least 1 month. The top 5 residences reported 68, 44, 36, 30, and 27 collisions and 9, 9, 4, 4, and 3 fatalities. Based on our model, correcting for differential sampling effort, we found the mean number of collisions occurring annually to be 5.55 (4.61 – 6.70: 95% CI), while fatalities per year were estimated to be 0.48 (0.32 – 0.72: 95% CI). These estimates are based on data collected from all residence types and pooled together (Table 2).

Based on standardized searches, the rank order for CollisionSearch was: rural residences with a feeder (91.7% probability of a collision occurring) > rural residences without a feeder (69.2%) > urban residences with a feeder (50.5%) > urban residences without a feeder (33.9%) > apartments (25.0%). CollisionNumber followed the same pattern (Table 3). For all building classes, rural residences were predicted to have more collisions than urban residences. The presence of a bird feeder at a residence typically resulted in more collisions than when there was no bird feeder present. The pattern for FatalityNumber was similar apart for an unexpectedly low number of fatalities at rural houses without feeders. Except for the fatality rate at these houses, apartments had the lowest number of collisions and lower fatality rates than the other residence classes (Table 3).

2.4 DISCUSSION

2.4.1 Are surveys based on recall of past events comparable to standardized searches?

Comparing the results from our standardized searches to our recall-survey data and the recall-survey data in Bayne et al. (2012) revealed larger differences in absolute values of collisions but similar relative rankings between residence types.

Bayne et al. (2012) reported five collision metrics based on participants ability to recall past events: 1) CollisionEver - probability of a participant reporting a bird colliding with a window at any point since they moved into their current residence; 2) CollisonYear - probability of a participant reporting a bird colliding with a window within the year previous to taking the survey; 3) DiedYear - probability of a participant reporting a bird dying after colliding with a window within the previous year; 4) #CollisionYear – mean number of birds reported as colliding with a window within the year previous to taking the survey; and 5) #DiedYear - mean number of birds reported as dying after colliding with a window within the year previous to taking the survey. In our study, CollisionEver and CollisionYear are directly equivalent to these metrics in Bayne et al. (2012). Our recall-survey questions did not ask about the number of collisions and whether or not a dead bird was observed. This was done to limit participant fatigue. Instead, these variables were measured directly through the standardized searches.

Comparing CollisionEver and CollisionYear, which used the same questions and methods as Bayne et al. (2012), we found very similar results. Overall, 56.5% of participants remembered a bird colliding with a window at some time in the past while Bayne et al. (2012) found it was 50.5%. Within the previous year, 43.9% remembered a collision while Bayne et al. (2012) found 39.0%. Overlapping binomial confidence intervals for both studies indicates no significant difference between studies when the same techniques were used. This suggests that potential biases that may have existed in Bayne et al. (2012) were similar to those in our recall-survey. If survey methods based on past recall were a completely unreliable way of determining the likelihood of a bird-window collision occurring, we would have expected high variability over the four years of surveys which does not seem to be the case indicating that the results of Bayne et al. (2012) were robust.

The relative ranking of the 5 types of residences was also generally consistent when systematic surveys and past recall were compared. The relative ranking for CollisionEver between the 5 types of residences was identical between studies. CollisionYear was similar to Bayne et al. (2012) except for one year where participants at rural residences without a bird feeder had a higher probability of remembering a collision than at rural residences with a bird feeder (Table 3). In our study, rural residences with a bird feeder always had the highest collision rate regardless of whether the data was collected based on past recall or standardized searches. Absolute values did vary between the two studies for the same metrics although in most cases the 95% confidence intervals overlapped (Table 3).

The similar relative ranking of residence types between our study and Bayne et al. (2012) increases confidence of these patterns being robust. However, there were differences in absolute values. We suggest participants in the standardized searches were more likely to take note of things like body smudges, collision noises, and feathers or blood on the window once they were told this was evidence of a bird-window collision. Remembering this type of evidence as asked for in the survey questions is likely more difficult to recall than finding a dead or injured bird and may explain the differences.

Fatality estimates were 1.4 times higher in Bayne et al. (2012) than our study which is somewhat surprising. Somewhat different rankings in which residence types had the highest fatality rate were also observed across studies but different rankings were also observed between collisions and fatalities within our study. The small number of fatalities relative to collisions resulted in much wider confidence intervals for fatalities. Add this to the small sample size for rural residences without feeders in the systematic survey and it is not surprising that there are some differences in the relative ranking of fatality estimates for different residence types between studies. We argue rural residences, even without feeders are more likely to have collisions and fatalities than urban residences simply because of the larger number of birds that typically exist in rural areas. This has previously been argued by Dunn (1993) and Klem (1990) who stated bird-window collisions occur in proportion to the number of birds present in a yard and those factors that increase the density of birds in a yard will increase collision risk. However, concerning rural homes, the definition of rural may influence this result as residences on rural acreages where native vegetation might still be common may have very different bird abundances than those on rural farms where native vegetation has been removed.

Perhaps more important, is the fact that the magnitude of difference in fatalities was influenced by the approach used to adjust for differential sampling effort. The maximum fatality rate was 2.3 times greater than the minimum rate depending on method of correction. Importantly, the fatality estimate from Bayne et al. (2012) fell in the middle of this range suggesting that past efforts to estimate the total number of birds killed by window collisions is starting from a reasonable baseline.

2.4.2 Improving citizen science – what works and what does not

That most of the metrics used in our study and Bayne et al. (2012) were similar in the relative ranking between residence types, suggests that recall-surveys may be a useful tool for understanding the relative importance of different risk factors causing bird-window collisions. Estimating absolute collision rates however remains very challenging, as is measuring the absolute value of any ecological phenomena. Whether to correct for differential effort using a statistical approach versus only using data from observers who participate for a fixed number of days is a good example of the challenges involved in getting a precise and accurate estimate of collisions and mortality, even when systematic surveys are employed.

We argue that reducing these sources of potential error will be difficult using citizen science and uncertainty in absolute collision and mortality rates will likely persist using such an approach to data collection. At this point in our scientific understanding of bird-window collisions however, perhaps it is time to move away from worrying about precision and accuracy in the absolute number of birds killed. Instead, we should start considering questions like: (1) What role can citizen scientists play in helping determine how to reduce bird-window collisions?; (2) Are relative comparisons sufficient to understand the efficacy of different mitigation options?; (3) Is past recall sufficiently accurate that we can understand the drivers that make one house more likely to suffer collisions than another when seeking mitigation solutions; and (4) How important is it to conduct such studies in other cities?

To effectively reduce bird-window collisions, far more research is needed to test effective mitigation options that are cost effective. For example, many homeowners place cut-outs of hawks in their windows under the premise that they prevent smaller birds from hitting windows; when to the best of our knowledge there has never been a rigorous test at residential houses with sufficient statistical power to demonstrate the efficacy of this approach. While there have been a number of successful localized studies as new mitigation options are developed the effectiveness of these approaches has not been scientifically tested at residential houses (American Bird Conservancy BirdTape 2015, Feather Friendly Bird Deterrent Window Films 2015, Ornilux Bird Protection Glass 2015, Window Alert 2015). We are currently comparing past recall data to the standardized searches to determine if consistent patterns can be observed in local variation in vegetation, window type, and window size. Identifying the factors that lead to increased risk will be particularly helpful in identifying mitigation options for certain types of houses rather than trying to fix houses where collision and mortality are less of an issue.

Citizen scientists can play a key role in this type of research. For example, we recently completed a bird feeder study where the presence and placement of bird feeders was manipulated at residential houses by citizen scientists (Kummer and Bayne 2015) to identify bird-safe feeding practices. This study found a dedicated group of citizen scientists who searched for window collision evidence at their homes for multiple months. We attempted to remove the need for citizen scientists in this study by using remote cameras to photograph collisions at each of the study windows. The cameras were not fast enough to detect collision events and get a high quality photo. As well, the costs of this approach were prohibitive to get the desired sample size. The design of our experiment did not require we know the absolute reduction in bird-window collisions, and until a technological solution to record absolute numbers of collisions are possible (i.e. window vibration sensors) we argue that using citizen scientists to collect data that provide relative comparisons between various mitigation options is the only cost-effective option for achieving the sample sizes required in real-world scenarios.

Biased sampling is still a major concern for estimating the absolute magnitude of bird-window collisions. Our intention when we originally started this project was to obtain estimates of bird-window collisions from an area larger than Alberta. We spent considerable time trying to elicit other universities and agencies to participate with limited success. We have recently been able to recruit additional participation in the city of Vancouver, British Columbia through Bird Studies Canada. However, if we desire national estimates of bird-window collisions then a far greater number of cities and homes would have to be sampled as the Edmonton and Vancouver area are not likely representative of all of Canada. As well, a number of our homeowners had a pre-established interest in bird-window collisions and cannot be considered a random sample. The participation of undergraduate classes in both our study and in Bayne et al. (2012) show how approximately 360 students over four years helped recruit over 3000 participants. This model should be encouraged across Canada for two reasons. First, only by having dedicated personnel in each city is participation likely to occur as personal relationships play a large roll in getting homeowners to participate. Second, the simple act of teaching students about bird-window collisions who inform their friends and families, increases awareness about the issue and in our experience encourages people to try different mitigation options. A centralized agency that is able to provide resources to advertise, encourage participation through some type of reward system, and provide the data collection materials is sorely needed.

Overall, we suggest that our research and that of Bayne et al. (2012) demonstrate that bird-window collisions at houses are an issue in the Edmonton area. We were able to observe the same bird-window collision patterns as Bayne et al. (2012) using both the same and different methods of data collection. Regardless of how data were collected these studies have identified that a large number of birds are colliding and dying at windows. Having a bird feeder increases this risk. If these patterns hold elsewhere in most cities where birds occur in reasonable abundance then the magnitude of the number of birds colliding with windows in Canada is reasonably correct. Shifting our scientific objective from estimating the magnitude to using citizen scientists to help solve bird-window collisions should become a focus of future research.

2.5 TABLES

Table 2-1. Akaike information criterion (AIC) scores and collision and fatality estimates when correcting for participant effort. Summary also includes the relative difference between models and the best model (ΔAIC), Akaike weights (AICw), log-likelihood (*L*) and number of parameters (K). The model highlighted in bold has the best fit, based on the lowest AIC score.

	Model	Estimate	AIC	ΔAIC	AICw	*L*	K
	Offset						
Fatality	Proportion of year with participation	0.48	**278.22**	0.00	0.74	-137.11	2
	Proportion of year where data collected	0.68	280.32	2.10	0.26	-138.16	2
	Fixed Effect						
	Proportion of year with participation	1.11	279.61	0.00	0.56	-136.81	3
	Proportion of year where data collected	0.57	280.09	0.48	0.44	-137.04	3
	Offset						
Collision	Proportion of year with participation	5.55	**1105.82**	0.00	1.00	-550.91	2
	Proportion of year where data collected	7.95	1130.84	25.02	0.00	-563.42	2
	Fixed Effect						
	Proportion of year with participation	9.88	1107.63	0.00	1.00	-550.82	3
	Proportion of year where data collected	5.89	1131.84	24.21	0.00	-562.92	3

Table 2-2. Comparative statistics between survey questions and standardized searches from the Birds and Windows project and the results presented in Bayne et al. (2012). The results from Kummer et al. (2015) are presented as mean probabilities and counts. Only homeowners from Alberta who completed the 1 month of observations (28 days) outlined in the protocol were included in analysis. The results presented from Bayne et al. (2012) were taken directly from that paper. As a result of different study designs there is no result for CollisionSearch from Bayne et al. (2012).

	Kummer et al. (2015)	Bayne et al. (2012)
Participants	381	1458
CollisionEver	56.5%	50.5%
CollisionYear	43.9%	39.0%
CollisionSearch	42.3%	~
CollisionNumber	5.55	1.7
FatalityNumber	0.48	0.7
Top 5 Fatalities Reported	9, 9, 4, 4, 3	43, 32, 17, 17, 16
Top 5 Collisions Reported	68, 44, 36, 30, 27	84, 55, 43, 34, 32

Table 2-3. Rates of bird-window collisions and fatalities reported and predicted from survey questions and standardized searches from the Birds and Windows project for five residence types in the province of Alberta, Canada compared to the previous rates predicted for the years 2009 and 2010 in Bayne et al. (2012). The results from Kummer et al. (2015) are presented as mean probabilities and counts. Only homeowners from Alberta who completed the 1 month of observations (28 days) outlined in the protocol were included in analysis. Numbers in brackets are the lower and upper bounds of 95% confidence intervals. The results presented from Bayne et al. (2012) were taken directly from that paper.

	Response Variable	Apartment	Urban, no feeder	Urban, with feeder	Rural, no feeder	Rural, with feeder
Collision Ever	Kummer et al. (2015)	0.09 (0.01–0.18)	0.50 (0.43–0.58)	0.72 (0.63–0.81)	0.92 (0.76–1.00)	1.00 (1.00–1.00)
	Bayne et al. (2012)					
	2009	0.27 (0.14–0.39)	0.59 (0.53–0.64)	0.70 (0.63–0.77)	0.82 (0.62–1.00)	0.86 (0.68–1.00)
	2010	0.20 (0.10–0.30)	0.45 (0.39–0.51)	0.71 (0.65–0.77)	0.88 (0.77–0.99)	0.93 (0.85–1.00)
Collision Year	Kummer et al. (2015)	0.12 (0.02–0.22)	0.37 (0.30–0.44)	0.56 (0.47–0.66)	0.54 (0.22–0.85)	0.96 (0.87–1.00)
	Bayne et al. (2012)					
	2009	0.20 (0.10–0.30)	0.37 (0.32–0.42)	0.53 (0.46–0.60)	0.61 (0.38–0.84)	0.68 (0.45–0.91)
	2010	0.13 (0.06–0.20)	0.25 (0.20–0.29)	0.44 (0.38–0.51)	0.84 (0.70–0.97)	0.67 (0.54–0.81)
Collision Search	Kummer et al. (2015)	0.25 (0.12–0.38)	0.34 (0.27–0.41)	0.50 (0.41–0.60)	0.69 (0.40–0.98)	0.92 (0.80–1.00)
Collision Number	Kummer et al. (2015)	2.57 (1.36–4.85)	4.25 (1.13–15.98)	5.40 (1.41–20.73)	5.79 (0.99–33.89)	19.7 (4.37–88.81)
	Bayne et al. (2012)					
	2009	0.85 (0.45–1.26)	1.11 (0.87–1.35)	2.03 (1.49–2.56)	5.87 (0.93–10.8)	3.67 (0.54–6.81)
	2010	0.22 (0.09–0.35)	0.69 (0.53–0.85)	1.81 (1.37–2.25)	5.10 (1.76–8.44)	4.29 (2.17–6.43)
Fatality Number	Kummer et al. (2015)	0.31 (0.07–1.43)	0.33 (0.01–8.34)	0.44 (0.02–10.93)	0.24 (0.01–20.0)	1.82 (0.06–55.2)
	Bayne et al. (2012)					
	2009	0.22 (0.06–0.37)	0.50 (0.36–0.64)	0.65 (0.43–0.87)	1.62 (0.00–3.29)	2.16 (0.00–4.37)
	2010	0.06 (0.01–0.13)	0.20 (0.13–0.26)	0.71 (0.49–0.93)	2.12 (0.44–3.81)	1.38 (0.54–2.24)
Sample Size	Kummer et al. (2015)					
	CollisionEver	n=43	n=177	n=104	n=13	n=24
	CollisionYear	n=43	n=176	n=105	n=13	n=23
	CollisionSearch, CollisionNumber & FatalityNumber	n=48	n=189	n=107	n=13	n=24
	Bayne et al. (2012)					
	2009	n=117	n=404	n=219	n=22	n=18
	2010	n=173	n=433	n=272	n=35	n=54

2.6 FIGURES

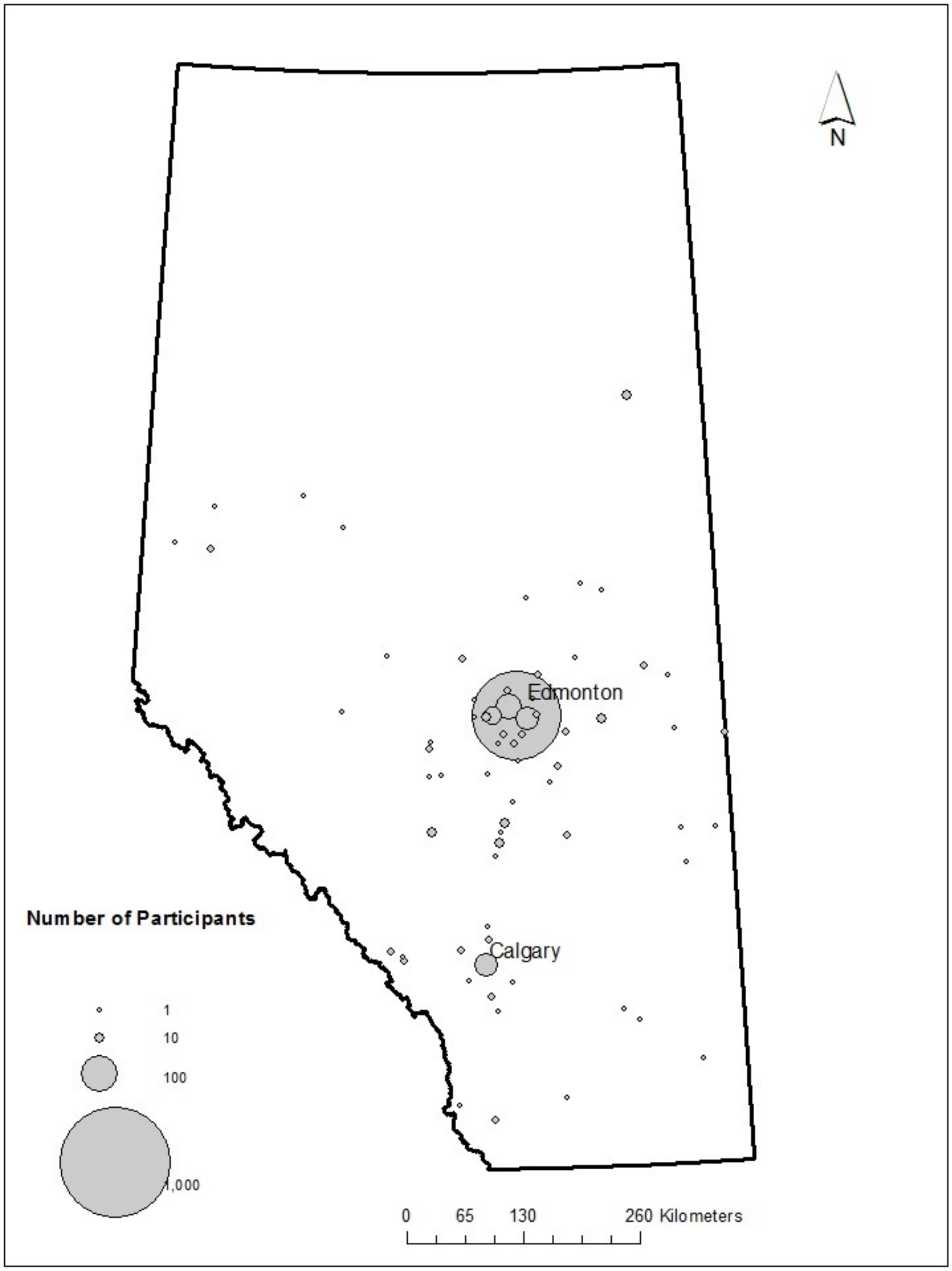

Figure 2-1. Map of the province of Alberta, showing location of participants. Size of symbol indicates the number of participants in that community.

CHAPTER 3. THE USE OF CITIZEN SCIENCE TO IDENTIFY THE FACTORS AFFECTING BIRD-WINDOW COLLISION RISK AT RESIDENTIAL HOUSES

3.0 SUMMARY

Bird-window collisions have been identified as a large source of mortality for North American birds. However, it remains poorly understood which types of buildings and windows are most problematic. Understanding whether neighbourhood type, yard conditions, house attributes, or window types have the largest effect on collision rates is crucial for identifying which mitigation options might be most effective. A citizen science project was developed to gain a better understanding of the factors affecting collisions at residential houses. Factors at the yard level had the best model fit for predicting bird-window collision risk. Efforts to reduce collisions should target variables at this level and those factors that attract birds to an individual yard. As few homeowners are likely to take an approach that reduces the number of birds in their yards, focus should instead be given to bird-friendly urban design and developing the most effective window deterrents.

3.1 INTRODUCTION

Accidental bird mortality caused by human activities is increasing worldwide (Calvert et al. 2013). Past studies have demonstrated a large number of birds are colliding and dying at the windows of residential buildings each year (Machtans et al. 2013, Loss et al. 2014). Such studies have focused on estimating the magnitude of bird-window collisions, which has helped increase awareness of the issue with the general public. Establishing the magnitude has led to increased calls to determine which types of residences and windows are most problematic in an effort to design the most effective mitigation strategies to reduce bird-window collisions (Klem 1989, Dunn 1993, Klem et al. 2004, Bayne et al. 2012, Hager et al. 2013, Klem and Saenger 2013, Klem 2015, Kummer et al. *Submitted*).

The four studies that have looked at why one house has more collisions than another each focused on different aspects of window collision risk (Klem 1989, Dunn 1993, Bayne et al. 2012, Hager et al. 2013). For example, Klem (1989) conducted a review of mostly anecdotal reports and concluded bird feeders as well as the type, size and placement of glass were the most important predictors of collisions. Dunn (1993) built upon these findings and found bird-window collisions occurred in proportion to the numbers of each species present at feeders. In her study, focus was solely given to bird feeders and no other factors were evaluated. The most recent studies by Bayne et al. (2012) and Hager et al. (2013) have shown structural attributes of houses and environmental factors related to neighbourhoods most strongly influence window collision risk but did not evaluate the relative impacts of window type or yard attributes of individual houses at the same time.

We propose the factors that influence bird-window collision rates be categorized based on scale into four levels: neighbourhood type, yard conditions, house attributes, and window types. Previous studies have identified factors affecting bird-window collision rates but no single study has addressed the relative importance of these categories at once as other projects have generally focused on variables within one or two levels. Understanding the level that has the greatest impact on bird-window collision rates has implications for prioritizing mitigation options. For example, if bird-window collision rates are most strongly predicted by attributes of a neighbourhood, mitigation efforts might be focused in particular areas through information campaigns about the best deterrents. However, if window type (i.e. reflective versus clear glass) is a more important driver then efforts focused on window manufacturers changing their designs might be more effective and cost-efficient.

A citizen science project was developed to gain a better understanding of the factors affecting collisions at residential houses at all four levels. Specifically, we focused on understanding the relative importance of variables at each of our four levels. We predicted those factors at a larger scale, including those at the neighbourhood and yard level, would have a greater effect on window collision risk than attributes of an individual house and window. Presumably birds are attracted to neighbourhoods with appropriate vegetation because the yard of a house is unlikely to be large enough to support the needs of an individual bird. Within a neighbourhood however, houses with bird feeders and greater structural and compositional complexity of vegetation are more likely to be selected by birds than houses without in the same neighbourhood. At each house there is likely an increased risk from different house and window attributes like number, size, and type of windows. It was additionally predicted that the factors having the largest effect would differ between birds that use feeders and those that do not. The presence of a bird feeder in a yard will have a larger effect on feeder birds but the vegetative factors that attract a bird to an individual yard will be similar between groups. As well, a more consistent and complete analysis of the factors influencing collisions at each of the four levels will allow for comparison between our study and previous and future work on bird-window collisions.

3.2 METHODS

3.2.1 Birds and Windows website

The Birds and Windows project (http://birdswindows.biology.ualberta.ca) was initiated in 2013 with two main components. First, a survey was conducted where people were asked to recall previous bird-window collisions similar to that of Bayne et al. (2012). The survey was then used to recruit people to participate in systematic monitoring of their homes whereby they were asked to search the perimeter of their residence for evidence of a bird-window collision on a daily basis. A detailed description of the data collection protocol and survey distribution can be found in Kummer et al. (*Submitted*).

Upon registering for the Birds and Windows project, homeowners completed a short survey on the past bird-window collision history at their home. Information was also collected on house and yard characteristics. The questions included in this analysis were: (1) What is your address; (2) What type of building do you live in (options and definitions provided); (3) How many windows are in your home; (4) What is the square footage of your home; (5) How many storeys are in your home; (6) In what year was your home built; and (7) How many of each bird attractant (bird feeder, bird bath, bird house) can be found within the following distances from your home (<2 m, 2-5 m, >5-10 m, >10 m). Information on square footage and year built was collected using City of Edmonton, City of St. Albert and Sherwood Park websites when needed. Data collected on bird attractants was further classified to answer: (1) Do you have a bird feeder within 10 m of your home; and (2) How many bird feeders are within 10 m of your home.

Following completion of the survey, participants were directed to the collision evidence search protocol and an onscreen calendar to be used in tracking the days they searched for evidence from the day of registration forward. Each day the homeowner searched for collision evidence they were asked to enter it into the calendar, whether or not evidence of a collision was found. If no collision evidence was observed there were no additional questions. When a collision was reported several questions were asked. Here, we only used information from the questions: (1) In what form was the collision evidence; and (2) If possible, what is the species of bird from the collision? Homeowners were also asked to email or upload photos of collision evidence to the Birds and Windows website to allow confirmation of each collision event and to identify species.

Participants had the option of completing an additional set of questions directly related to each reported collision event. These questions were specific to the window from the collision and a random window in the house. These included: (1) What is the size of each window; (2) What is the height of the bottom of both the collision and random windows from the ground; (3) What direction does each window face; (4) When you look into the collision and random windows can you see the reflection of vegetation; (5) What type of glass are the two windows (options and descriptions provided); (6) On what side of the house are the windows (front, back, and side); (7) What is the distance from each window to the nearest bird attractant (bird feeder, bird bath, bird feeder); and (8) What is the nearest bird attractant?

Using the addresses and/or postal codes provided by homeowners, Google Earth Pro was used to determine: (1) whether the location of each home was in an urban or rural setting; (2) the distance of the house from a natural treed area; (3) the average height of vegetation in the front yard of each home; and (4) the main and second dominant landscape type estimated within 50 m of the home. The four landscape types included: (1) Structures - houses and all additional buildings; (2) Pavement – roads and sidewalks; (3) Canopy – tree covered and forest; and (4) Exposed habitat – open lawn, grass and field. For this classification we used the methods and four land cover types outlined in Hager et al. (2013). As outlined by Hager et al. (2013), urban bird diversity and abundance are positively correlated with vegetation and negatively correlated with urban surfaces. Thus two broader categories were formed: (1) Undeveloped – canopy and exposed habitat; and (2) Developed – structures and pavement.

3.2.2 Species-specific details

Species-specific information was determined through homeowner responses to the above questions and from photos submitted by the homeowner. All photos were identified to the species level when possible and this overrode classification by the homeowner when they differed. If the homeowner identified the bird as one of two species it became an unknown (i.e. 'chickadee or sparrow' became unknown). In a number of cases the homeowner only identified the bird to a broader grouping. For many of these groupings there were a number of species from that group that can be found in Alberta and as a result, they could not be classified further (i.e. waxwing became waxwing sp.).

All birds were identified to both species and family when possible. There were a number of instances where the bird was not identified to the species level and their family could not be determined. A total of 80 birds were sparrow species but could not be identified further as it was unknown whether these were Emberizidae or Passeridae. Another bird was identified as a grosbeak species and could belong to either the Cardinalidae or Fringillidae family.

Birds were further divided into: (1) birds that frequent bird feeders (i.e. Black-capped chickadees (*Poecile atricapillus*), Dark-eyed juncos (*Junco hyemalis*) and House sparrows (*Passer domesticus*)), and (2) birds that do not frequent feeders (i.e. Cedar waxwings (*Bombycilla cedrorum*), Bohemian waxwings (*Bombycilla garrulus*) and American robins (*Turdus migratorius*)). All species were classified based on information provided by the Cornell Lab of Ornithology (2015). When the bird could not be identified to species the most likely classification for that group was used (i.e. chickadee species became a feeder bird and waxwing species a non-feeder bird).

3.2.3 Data analysis

All homeowner observations were checked for consistency. Confirmation emails were sent to participants with suspicious entries (entered 30 observations at once, multiple collisions entered in 1 day, and collisions entered for the time period before the participant had initially signed up for the project). If confirmation of these observations was not provided, they were excluded from our analysis.

COLLISIONNUM was determined as the number of collisions (including zeros) reported by each homeowner during standardized searches for each day of the project. To account for differential effort in all models, we included a fixed effect with 3 classes, where: 1 - represented homeowners who reported 3 or less observations; 2 – homeowners who entered between 4 and 27 observations; and 3 – homeowners who participated for 1 month (28 days) or more. These three levels were based on observed trends where the majority of homeowners did not participate for the 28 days outlined in the project protocol and the number of observations per homeowner ranged from 1 to 610. A fixed effect for season was added to all models as we have previously shown seasonality to be the best individual predictor of a bird-window collision at houses in Alberta (Kummer and Bayne 2015). Based on personal experience related to migration of birds in Edmonton, our seasons were defined as winter being the period between 15 October and 14 March, spring migration being 15 March to 14 May, summer breeding being 15 May to 14 August, and fall migration being 15 August to 14 October.

Using COLLISONNUM, three multilevel mixed effects count models (command menbreg in STATA 13; StataCorp, College Station, Texas, USA, http://www.stata.com) were used to determine the factors at the neighbourhood (hereafter NEIGHBOUR), yard (hereafter YARD), and house (hereafter HOUSE) level, affecting the number of bird-window collisions for each day of the project, while controlling for the number of observations entered by each homeowner. A detailed summary of the variables analyzed in each level is provided in Table 1. All models were compared using Akaike's information criterion (AIC) (Burnham and Anderson 2004) and forward stepwise selection was used to determine the best fitting model for each level.

The best fit from LEVELDEVEL and MAINLAND, and FEEDYESNO and FEEDCOUNT was identified based on AIC and only one of each pair was used in developing the best fitting model. Additionally, interactive effects for: (1) URBANRURAL*SEASON; (2) LEVELDEVEL*SEASON; (3) FEEDYESNO*SEASON; (4) SQRFOOT*SEASON; and (5) YRBUILT*SEASON were compared. We also tried to evaluate the interaction between (1) VEGHEIGHT*SEASON; (2) BUILDINGTYPE*SEASON; (3) NUMSTOREYS*SEASON; and (4) WINDOWNUM*SEASON but there were an insufficient number of entries in some categories to achieve model convergence.

The top model for NEIGHBOUR, YARD and HOUSE were compared to determine which level had the largest effect on the number of reported bird-window collisions. Each of the individual variables identified in the top NEIGHBOUR, YARD and HOUSE models were used, along with backwards stepwise selection, to determine the best fitting model for identifying the factors affecting bird-window collision risk when all levels were considered (OVERALL).

Bird feeders are often shown to increase bird-window collision risk (Klem et al. 2004, Bayne et al. 2012) and we have previously shown the effect of bird feeders to be specific to those species that frequently visit feeders (Kummer and Bayne 2015). As a result the NEIGHBOUR and YARD models were also run: (1) only using collisions from birds that frequent bird feeders; and (2) only using collisions by those birds that do not frequent feeders.

A case-control logistic regression model (command clogit in Stata 13) was used to determine the factors affecting collisions at the WINDOW level while pairing the random and collision window information provided by the homeowner. The effect of ATTRACTTYPE was later dropped as a result of no within-group variation and is not discussed further. As a result of the paired design and only having a sample from windows where a collision was observed versus a random window in the same house, seasonality could not be tested at this level.

3.3 RESULTS

3.3.1 Bird-window collisions

Since the launch of the Birds and Windows project there have been 34114 recorded days of monitoring from homeowners in Alberta. Only homeowners from Alberta were included in our analysis as the majority of our participants were from Alberta and we did not have a representative sample for all of Canada. Within these observations there were 930 collisions and 102 fatalities. It is unknown whether or not the bird survived in 219 of the collision events. 76 collisions were verified through photos.

3.3.2 Species-specific susceptibilities

Of the collisions in Alberta, 497 could be identified to species or family. There were collisions from 53 different species. Birds that frequent feeders accounted for 295 of the identified collisions and 202 collisions were by those birds that do not visit feeders.

The most common families were Paridae (8.78% of birds collided), Bombycillidae (7.07%), Turdidae (4.93%), Emberizidae (4.71%) and Corvidae (3.96%) (Table 2). The total number of collisions in each family was often dominated by a large number of collisions for one species within the group. The high number of collisions for Paridae was dominated by collisions by Black-capped chickadees (*Poecile atricapillus*) (n=50). Bombycillidae saw a relatively even split between Bohemian (*Bombycilla garrulus*) (n=30) and Cedar (n=24) waxwings (*Bombycilla cedrorum*). The Emberizidae family was largely dominated by collisions by Dark-eyed juncos

(*Junco hyemalis*) (n=31) and the Turdidae family by American robins (*Turdus migratorius*) (n=40). Within the Corvidae family the greatest number of collisions was by Blue jays (*Cyanocitta cristata*) (n=12) and Black-billed magpies (*Pica hudsonia*) (n=22). The total number for each species can be found in Table 3. The birds categorized as sparrows, chickadees, or waxwings could not be identified further and as a result the numbers for Black-capped chickadees, House sparrows (*Passer domesticus*) and both waxwing species are likely higher than what we report.

Black-capped chickadees accounted for 5.4% of all species that collided and survived but only 1.9% of the birds that collided and died. 92.0% of the Black-capped chickadees collided and survived. The largest difference between collided and survived and collided and died was seen in Cedar waxwings. Cedar waxwings made up only 1.5% of the birds that collided and survived but 8.7% of the birds that collided and died. Bohemian waxwings and Dark-eyed juncos saw the next largest difference with a larger number of each species colliding and dying. Table 3 lists the remaining species and the percentages of survival.

3.3.3 Bird-window collision factors

Based on AIC, a model based on negative binomial distribution (AIC = 7179.75) provided a much better fit than one based on a Poisson distribution to describe COLLISIONNUM, (AIC = 7209.17). Including the house as a random effect resulted in significant model improvement relative to standard negative binomial regression (χ^2 = 1142.87, P < 0.001). The addition of a dummy variable for participant effort improved model fit, with a ΔAIC of 33.53 relative to the model with no participant effort. Homeowners who participated for less than 4 days were 3.42 times more likely to report a collision than those homeowners who participated for at least 1 month. A similar average number of collisions was seen during fall migration and summer breeding. There were fewer collisions during spring migration and the number decreased again in the winter months (Figure 1). The inclusion of SEASON improved model fit, with a ΔAIC of 91.11.

Factors related to YARD better explained the number of collisions than factors related to either NEIGHBOUR (ΔAIC = 9.06) or HOUSE (ΔAIC = 21.66). In determining the best OVERALL model for identifying the factors affecting bird-window collision risk, there were a number of models within a ΔAIC of < 2. While these models differed slightly, the best models always contained the effect of URBANRURAL, VEGHEIGHT and FEEDYESNO (Table 4). Coefficients and incident rate ratios for the best fitting model are provided in Table 5.

At the NEIGHBOUR level, the most parsimonious model was the URBANRURAL*SEASON interactive effect with a ΔAIC of 1.68 compared to the next best model (Table 4, Table 5). Rural homes during the fall had a daily collision risk 10.84 times greater than urban houses in the winter. These homes consistently have a higher risk of a collision than urban houses and collision risk during the fall season is 1.24 to 1.44 times greater than the next closest season.

At the YARD level, LEVELDEVEL was a better predictor than MAINLAND (ΔAIC = 3.32) and FEEDYESNO a better predictor than FEEDCOUNT (ΔAIC = 12.89). The model that provided the best fit for YARD was VEGHEIGHT + LEVELDEVEL + FEEDYESNO*SEASON with a ΔAIC of 1.35 compared to the next best fitting model (Table 4, Table 5) which included LEVELDEVEL + FEEDYESNO + VEGHEIGHT. Based on the interactive model, homes with a bird feeder present during the fall months saw a 5.96 times greater collision risk per day than homes without a feeder during the winter. Spring and fall consistently saw the greatest collision rate compared to the other seasons. Homes with an undeveloped landscape were 2.19 times more likely to have a collision than houses with a developed landscape and homes with vegetation in their front yards that was 2-3 storeys high had a collision risk that was 4.26 times greater than houses with no vegetation.

The model that provided the best fit at the HOUSE level included WINDOWNUM + YRBUILT + BUILDINGTYPE with a ΔAIC of 2.82 relative to the next best fitting model (Table 4, Table 5). Compared to apartments, single-attached homes were 2.32 times more likely to have a collision and homes in the other (including row housing and duplexes) building class were 1.64 times more likely. Homes built before 1970 had a collision risk 1.74 times greater than more modern homes built after 1990 and houses with greater than 10 windows were 2.07 times more likely to have a collision than homes with 5 windows or less.

For WINDOW, the case-control model improved fit by ΔAIC = 458.71, compared to regular logistic regression. The model that provided the best fit was REFLECTION + SIDE + DIRECTION + GLASSTYPE with a ΔAIC of 1.95 compared to the next best fitting model, which also included HEIGHT (Table 6). The odds of the collision window being on the front of a house was 1.91 times more likely than it being on the back. The odds of the collision window reflecting vegetation was 5.64 times more likely compared to windows that did not reflect vegetation. Windows where vegetation was only sometimes reflected were 3.02 times more likely to be the collision window. The odds of the collision window having Low-E or UV glass was 1.69 and 1.54 times more likely, respectively, compared to regular glass and there was only slightly better odds of the collision window facing south compared to the other directions. Direct comparison could not be made between WINDOW and the other three levels because we did not track collisions at each window.

3.3.4 Bird feeder and non-feeder birds

For birds that frequent feeders, the variables at the YARD level explained more of the variation in COLLISIONNUM compared to NEIGHBOUR (ΔAIC = 34.92). The best model for non-feeder birds was NEIGHBOUR (ΔAIC = 0.64), but model fit at the YARD level was similar (Table 7). There were a number of models for non-feeder birds at the YARD level that did not achieve model convergence because of the smaller number of collisions in this group.

URBANRURAL*SEASON was the best model at the NEIGHBOUR level when all birds were included and for feeder birds (ΔAIC = 3.92 compared to the next best model). The interactive effect of URBANRURAL*SEASON was lost for non-feeder birds and the best model became URBANRURAL with a ΔAIC of 2.22 compared to the next best model (Table 7).

The best model for YARD for feeder birds was the same as when all birds were included (ΔAIC = 5.28 compared to the next best model). The presence of a bird feeder increased collision risk 6.13 times for feeder species. Based on a ΔAIC of 1.10 compared to the next highest ranked model, the best fit for non-feeder birds at the YARD level was FEEDYESNO (Table 7). The presence of a bird feeder still led to a 2.96 increase in collision risk for non-feeder birds.

3.4 DISCUSSION

3.4.1 Factors affecting bird-window collisions

In determining the best overall model, the presence of the bird feeder, whether the house was in an urban or rural location and the height of vegetation in the front yard were always included. These factors are having the largest effect on collision risk at residential houses and should be focused on in determining strategies to reduce bird-window collisions.

The yard model generally explained more of the variation in bird-window collision rates than variables at the neighbourhood or house level. In current estimates of bird-window collision rates, the strata that has been used to obtain the North American estimates has relied on the neighbourhood variable URBANRURAL suggesting that a more refined and accurate strata may be possible. Our results are consistent with most other studies that have focused on a single level of our four categories in terms of the direction of the various effects. Consistent across studies is the fact that bird feeder presence and ample vegetation are linked to bird-window collision rates. This is presumably because these attributes increase the number of birds utilizing a particular yard (Goddard et al. 2010, Hager et al. 2013) and as the number of birds in a yard increase, they are expected to experience a greater likelihood of a bird-window collision (Dunn 1993). However, the overall model selected variables from across all scales indicating that a multitude of factors are increasing bird-window collision risk at residential houses.

Factors at the neighbourhood and yard level had the largest effect on bird-window collision risk and these factors were similar between feeder and non-feeder birds. In an experiment where we manipulated the placement of a bird feeder at residential houses (Kummer and Bayne 2015), we lacked the data necessary to test if there was an interactive effect between bird feeder presence and the time of the year. With a larger sample size, this study was able to identify this effect both when all birds were included and for just feeder birds. During the winter months there may be fewer species present but these species are more reliant on seeds and likely to visit a bird feeder at this time. This interactive effect could not be run for non-feeder birds but the presence of the bird feeder still increased collision risk. It is likely these homes are the same that have increased the number of birds in their yard by embracing urban gardens and creating bird-friendly regions. The waxwing and robin species are being attracted to these neighbourhoods and yards because of the abundant vegetation they present. These yards are additionally more likely to provide the fruit and berries waxwing species are reliant on year round. This rise in urban gardens and homeowners taking pride in creating a natural area in their yard may be an example of the unintended consequences of creating bird-friendly regions in urban areas (Bayne et al. 2012). The relationship between bird feeder presence and urban gardens likely drove the number of collisions by non-feeder birds at those yards with bird feeders. As well, bird feeder presence may also be correlated with other bird attractants, such as bird houses and bird baths.

During the winter months, Black-capped chickadees are commonly found at bird feeders and throughout this study were one of the species experiencing the greatest collision risk. However, there were few collisions during the winter months when Black-capped chickadees and other residents are most reliant on a bird feeder. The presence of the bird feeder during the winter did not lead to an increased collision risk. Instead this was seen during the spring and fall months when migratory species are more common. It is possible those residents that commonly frequent a yard and bird feeder have learned the nearby windows present a risk. In Black-capped chickadees there are a number of benefits to their winter flocking (Barash 1974), yet one advantage that has not been looked at is how flocking could be beneficial in identifying windows and glass surfaces that pose a collision risk. Migratory species passing through and stopping in a yard are less aware of their surroundings and as a result may be more at risk of a collision.

To the best of our knowledge, this is the first study to highlight the interactive effect between urban and rural houses and different times of the year on bird-window collisions. Seasonality was the highest during times when the most birds are present in an area (i.e. fall migration). For non-feeder birds this interactive effect was not the strongest model and instead there was a larger increase in the number of collisions expected at rural homes than when all birds were included.

In rerunning the models with only feeder and non-feeder birds, we considerably reduced our sample size. For these models there were over 400 collisions removed where we did not know the species that collided. The species that were identified could be biased by those homeowners who attract birds to their yard and have prior knowledge of the bird species that can be found there. The homeowners who were unable to identify species may represent different house types and include those residences less actively trying to attract birds to their yard.

The identified birds that collided with windows represented 53 of the 421 bird species that can be found in Alberta (Royal Alberta Museum 2014) and are consistent with other bird-window collision studies at residential houses (Klem 1989, Dunn 1993, Bayne et al. 2012). For the majority of species there was little difference in the likelihood of colliding and surviving and colliding and dying, birds generally died in proportion to the number of collisions that occurred for that species. Machtans and Thogmartin (2014) discuss the benefit of shifting the focus away from grand totals and towards individual species in developing conservation strategies. While we had sufficient data to thoroughly outline collision risk for feeder and non-feeder birds, we were unable to develop species-specific collision risk models and suggest that our focus may have to remain on larger groups instead of developing multiple species-specific models simply due to the small sample size most studies achieve. To be able to model the impacts of window collisions on species, a collation of all bird-window studies is likely needed to achieve the statistical power required to reduce bird-window collisions for species of greater concern.

Those species identified as most vulnerable to a bird-window collision by Loss et al. (2014) and Machtans et al. (2013) were based on studies that largely consisted of building classes not addressed in our study and only a few of these species collided with residential windows in our study. A number of the species identified by Loss et al. (2014) and Machtans et al. (2013) are listed as Birds of Conservation Concern (U.S. Fish and Wildlife Service 2008) but these species may be more vulnerable at low-rise and high-rise buildings than houses during migration. None of the birds identified as colliding with windows in our study are currently listed as Species at Risk in Alberta (Alberta Environment and Parks 2015). Instead, the majority of birds that collided are urban adapters or exploiters (McKinney 2002) and these populations are more tolerant to a broader environmental range and are generally common in an urban environment (Bonier et al. 2007).

There were a number of difficulties in conducting our analysis from homeowners who participated for less than the 1 month outlined in the project protocol. In a number of instances, these homeowners only entered a handful of observations; almost always collisions. The homeowner also did not report the days they searched but did not find collision evidence. As a result, the homeowners who entered less than 4 observations were more than 3 times likely to report a collision than homeowners that participated for at least a month. We suspect that these participants may have monitored their houses for bird-window collisions and simply forgot or chose not to enter the days when they did not observe a collision.

The best model for the window level could not be directly compared to the other three. Homeowners had the option of completing these additional questions and as a result we only have a subsample of all entered collisions and there are multiple entries for some homeowners and none for others. There was one house that provided information on the collision and random window after 26 separate collisions. The paired design accounted for within house variation when there was only one entry per house, but this did not fully account for a house effect when there were multiple entries from the same house. In having more than one entry per house, it is possible some windows switched from being random or collision windows between different collision events. Ideally, to complete a thorough analysis, we would have information on all the windows of each home and information on the numbers of collisions occurring at each window.

3.4.2 Reducing bird-window collision risk

The factors at the yard level associated with vegetation and increasing bird abundance were identified as having the largest effect on bird-window collisions. Recent studies have attempted to look at this issue from the level of urban design. Sushinsky et al. (2013) suggest cities with high residential density, large natural green spaces and small backyards will minimize the per capita ecological impact of a city. However, they also identify the trade-off that exists between promoting species diversity and reducing homeowner access to interactions with nature in their backyard. Maintaining large natural areas and reducing the size of yards has potential ecological value in promoting future urban conservation, while reducing bird-window collision risk at residential homes. This idea could be beneficial in future developments. However, established urban areas are already dominated by developed neighbourhoods and abundant vegetation. Recently, these areas are experiencing an influx of new development as older homes are being replaced and newer designs are leading to larger homes (Wilson and Boehland 2005).

In these areas, mature vegetation and canopy cover are naturally attracting birds to residential yards. If the homeowner additionally places a bird feeder in their yard, both feeder and non-feeder birds will likely choose that yard over a neighbouring one. Bird feeders consistently lead to an increase in the number of bird-window collisions (Bayne et al. 2012, Klem et al. 2004, Kummer and Bayne 2015, Kummer et al. *Submitted*), and we have shown this is not entirely dependent on whether or not the bird frequents the feeder. Eliminating bird feeders may appear to be an easy fix, however, alone this will not solve bird-window collisions. Plus there are a number of accepted benefits to feeding birds (Robb et al. 2008).

At the yard level, those factors increasing bird abundance are having the largest effect on bird-window collision risk. Bird feeders are only one of these attractants, reductions to vegetation cover and abundance might reduce collisions but would presumably reduce bird habitat quality in urban areas. This is a very difficult trade-off and we do not know whether the overall effect on avian population growth rate of feeding and natural vegetation in yards compensates for the loss caused by windows. While the yard level was the best model in determining bird-window collision risk, additional house and window factors had an effect. While these factors are not as predictive as those at the yard level, there may be an increased collision risk if these factors are seen in conjunction with the abundant and mature vegetation that may be found in an established neighbourhood. As well, our sample size was not large enough to test for a seasonal interactive effect with a number of house and yard level covariates. With an increased number of houses these interactions may have an effect on collision risk.

Whether or not the window reflected vegetation and the type of glass were strong predictors at the window level. The coatings on Low-E and UV glass create a more reflective surface and if this is found in combination with abundant vegetation outside the window, it could lead to an increased number of collisions. With abundant vegetation clear, non-reflective windows will help reduce collision risk. The number of windows in a home and the side of the house the window was on were additional strong predictors. Collision risk will likely increase as the amount of glass in a house increases and if this is seen in conjunction with abundant vegetation, there will be a greater risk of a bird-window collision. As newer homes are seeing an increase in exterior glass (Wilson and Boehland 2005), a reduction of, or strategic placement of windows in new homes can only be beneficial. Previous studies have reported collisions only occur at large windows and when there is abundant sheet glass on a building (Klem 1989, Hager et al. 2013), but in our models, window size was not a strong predictor and as such we cannot refute these results.

We have identified the factors at the yard level to be having the largest effect on bird-window collisions at residential houses. As few homeowners want to stop having birds in their yards, we believe our focus will need to shift towards developing the most effective window deterrents for reducing collisions. A localized study where window deterrents are added or removed over time from the windows of a home would be helpful to determine the most effective deterrent design. To date, only a handful of studies have looked at bird-window collision deterrents (Klem 1990, Klem et al. 2009, Klem and Saenger 2013, Rossler et al. 2015) and none of these have been conducted in an actual residential setting. As new products are developed, there have been independent studies producing supporting evidence for new window deterrent methods (Window Alert 2015, ABC BirdTape 2015, Ornilux 2015, Feather Friendly Bird Deterrent Window Films 2015) and while a number of these methods have succeeded in independent studies, to the best of our knowledge, no scientific study has been conducted where window deterrents are tested at houses already experiencing bird-window collisions. Moving forward, effort should be focused on finding the best technique for reducing window collisions while being cost effective and socially acceptable. A number of current deterrent methods have not been embraced by homeowners because they are not esthetically pleasing. As a result, products are now being developed that maintain a transparent appearance for the homeowner while transforming the pane into an obstacle that is visible to the bird.

Recently there has been a large movement towards bird safe buildings and eco-friendly design (New York City Audubon 2007, City of Toronto Green Development Standard 2007, Sheppard 2011, San Francisco Planning Department 2011). However, these established guidelines are largely focused on mid and high-rise buildngs and there currently exist few strategies for bird-safe residential buildings. While a large number of birds are colliding with the windows of our houses and a large number of birds are dying as a result, the impact these collisions are having on populations of backyard birds remains unknown. Bird-window collisions at houses may not be a conservation issue in the context of creating declining species but, homeowners take pride in their home and enjoy having a large number of birds in their yard. Both esthetically and emotionally, bird-window collisions are having an effect on homeowners. We have identified a number of factors affecting bird-window collisions at houses and broken them into four levels based on scale to determine where conservation efforts should be focused. A large number of birds are colliding with the windows of residential homes and focus in the future should be given to bird-friendly urban design and developing the most effective window deterrents.

3.5 TABLES

Table 3-1. Predictor variables for each model at the neighbourhood, yard, house and window level looking at the factors affecting bird-window collisions at residential houses. Summary includes the shortened code identifying each variable, a description of each effect and whether or not each was analyzed as continuous or categorical data. Each variable was derived from answers provided by homeowners when completing the Birds and Windows survey on previous bird-window collision history at their home or through Google Earth Pro and the addresses and/or postal codes provided by the homeowners.

Level	Code	Description	Format
NEIGH-BOUR	URBANRURAL	Whether the location of each home was in an urban or rural setting	Categorical
	DISTNAT	The distance of the house from a natural treed area	Continuous
YARD	VEGHEIGHT	The average height of vegetation in the front yard	Categorical
	MAINLAND	The dominant landscape type estimated within 50 m of the home	Categorical
	SECNDLAND	The second dominant landscape type estimated within 50 m of the home	Categorical
	LEVELDEVEL	Broader category formed from MAINLAND	Categorical
	FEEDYESNO	Do you have a bird feeder within 10 m of your home?	Categorical
	FEEDCOUNT	How many bird feeders are within 10 m of your home	Continuous
HOUSE	BUILDINGTYPE	What type of building do you live in?	Categorical
	SQRFOOT	What is the square footage of your home?	Categorical
	NUMSTOREYS	How many storeys are in your home?	Categorical
	WINDOWNUM	How many windows are in your home?	Categorical
	YRBUILT	In what year was your home built?	Categorical
WINDOW	AREA	What is the size of each window?	Categorical
	HEIGHT	What is the height of the bottom of both windows from the ground?	Categorical
	GLASSTYPE	What type of glass are the two windows?	Categorical
	DIRECTION	What direction does each window face?	Categorical
	SIDE	On what side of the house are the windows (front, back, and side)?	Categorical
	REFLECTION	When you look into the windows can you see the reflection of vegetation?	Categorical
	ATTRACTTYPE	What is the nearest bird attractant (bird feeder, bird bath, bird feeder)?	Categorical
	ATTRACTDIST	What is the distance from each window to the nearest bird attractant (bird feeder, bird bath, bird feeder)?	Continuous

Table 3-2. Percentage of reported collisions and the sample size for each bird that collided, grouped by family.

Family	% Collided	Sample size (*n* =)
Accipitridae	0.21	2
Bombycillidae	7.07	66
Cardinalidae	0.96	9
Cardinalidae or Fringillidae	0.11	1
Certhiidae	0.21	2
Columbidae	0.54	5
Corvidae	3.96	37
Emberizidae	4.71	44
Emberizidae or Passeridae	6.75	63
Falconidae	0.75	7
Fringillidae	3.85	36
Hirundinidae	0.32	3
Icteridae	0.96	9
Laridae	0.11	1
Paridae	8.78	82
Parulidae	2.03	19
Passeridae	1.93	18
Phasianidae	0.64	6
Picidae	2.25	21
Regulidae	0.11	1
Sittidae	1.18	11
Strigidae	0.11	1
Sturnidae	0.11	1
Trochilidae	0.32	3
Troglodytidae	0.32	3
Turdidae	4.93	46
Tyrannidae	0.11	1
Unknown	46.57	435
Vireonidae	0.11	1

Table 3-3. Percentage of reported collisions and sample sizes by species that collided with windows and died and collided and survived the collision. Summary also includes the overall percentage of collisions and sample size for each species and the number of birds for each species where survival was unknown.

Species	#	%	# Survived	% Survived Total	# Died	% Died Total	Survival Unknown
American Crow (*Corvus brachyrhynchos*)	2	0.21	2	0.33	0	0.00	0
American Goldfinch (*Spinus tristis*)	3	0.32	2	0.33	1	0.97	0
American Kestral (*Falco sparverius*)	1	0.11	0	0.00	0	0.00	1
American Robin (*Turdus migratorius*)	40	4.28	28	4.58	4	3.88	8
American Tree Sparrow (*Spizella arborea*)	1	0.11	1	0.16	0	0.00	0
Black-billed Magpie (*Pica hudsonia*)	22	2.36	16	2.61	1	0.97	5
Blackbird sp.	4	0.43	2	0.33	0	0.00	2
Black-capped Chickadee (*Poecile atricapillus*)	50	5.35	46	7.52	2	1.94	2
Blue Jay (*Cyanocitta cristata*)	12	1.28	10	1.63	0	0.00	2
Bohemian Waxwing (*Bombycilla garrulus*)	30	3.21	20	3.27	9	8.74	1
Brown Creeper (*Certhia americana*)	2	0.21	1	0.16	1	0.97	0
Cedar Waxwing (*Bombycilla cedrorum*)	24	2.57	9	1.47	9	8.74	6
Chickadee sp.	31	3.32	27	4.41	1	0.97	3
Common Grackle (*Quiscalus quiscula*)	1	0.11	1	0.16	0	0.00	0
Common Redpoll (*Acanthis flammea*)	8	0.86	7	1.14	0	0.00	1
Corvus sp.	1	0.11	1	0.16	0	0.00	0
Dark-eyed Junco (*Junco hyemalis*)	31	3.32	21	3.43	8	7.77	2
Downy Woodpecker (*Picoides pubescens*)	13	1.39	11	1.80	1	0.97	1
Eurasian Collared-Dove (*Streptopelia decaocto*)	1	0.11	1	0.16	0	0.00	0
European Starling (*Sturnus vulgaris*)	1	0.11	0	0.00	1	0.97	0
Evening Grosbeak (*Coccothraustes vespertinus*)	4	0.43	1	0.16	3	2.91	0
Finch sp.	1	0.11	1	0.16	0	0.00	0
Grosbeak sp.	1	0.11	1	0.16	0	0.00	0

Grouse sp.	1	0.11	1	0.16	0	0.00	0
Hairy Woodpecker (*Picoides villosus*)	3	0.32	3	0.49	0	0.00	0
Hawk sp.	1	0.11	1	0.16	0	0.00	0
Hermit Thrush (*Catharus guttatus*)	1	0.11	1	0.16	0	0.00	0
House Finch (*Haemorhous mexicanus*)	6	0.64	6	0.98	0	0.00	0
House Sparrow (*Passer domesticus*)	18	1.93	13	2.12	4	3.88	1
Hummingbird sp.	2	0.21	1	0.16	1	0.97	0
Least Flycatcher (*Empidonax minimus*)	1	0.11	1	0.16	0	0.00	0
Lincoln's Sparrow (*Melospiza lincolnii*)	1	0.11	1	0.16	0	0.00	0
Merlin (*Falco columbarius*)	6	0.64	3	0.49	2	1.94	1
Mountain Chickadee (*Poecile gambeli*)	1	0.11	1	0.16	0	0.00	0
Mourning Dove (*Zenaida macroura*)	1	0.11	0	0.00	1	0.97	0
Northern Flicker (*Colaptes auratus*)	4	0.43	3	0.49	1	0.97	0
Northern Saw-whet Owl (*Aegolius acadicus*)	1	0.11	1	0.16	0	0.00	0
Nuthatch sp.	4	0.43	3	0.49	0	0.00	1
Pigeon sp.	2	0.21	1	0.16	1	0.97	0
Pine Grosbeak (*Pinicola enucleator*)	2	0.21	1	0.16	0	0.00	1
Pine Siskin (*Spinus pinus*)	11	1.18	8	1.31	2	1.94	1
Purple Finch (*Haemorhous purpureus*)	1	0.11	1	0.16	0	0.00	0
Purple Martin (*Progne subis*)	1	0.11	1	0.16	0	0.00	0
Red-breasted Nuthatch (*Sitta canadensis*)	4	0.43	4	0.65	0	0.00	0
Red-winged Blackbird (*Agelaius phoeniceus*)	4	0.43	4	0.65	0	0.00	0
Ring-billed Gull (*Larus delawarensis*)	1	0.11	0	0.00	0	0.00	1
Rock Pigeon (*Columba livia*)	1	0.11	1	0.16	0	0.00	0
Rose-breasted Grosbeak (*Pheucticus*	7	0.75	7	1.14	0	0.00	0
Ruby-crowned Kinglet (*Regulus calendula*)	1	0.11	0	0.00	1	0.97	0
Ruffed Grouse (*Bonasa umbellus*)	5	0.54	1	0.16	4	3.88	0
Rufous Hummingbird (*Selasphorus rufus*)	1	0.11	0	0.00	0	0.00	1
Sharp-shinned Hawk (*Accipiter striatus*)	1	0.11	0	0.00	1	0.97	0

Sparrow sp.	63	6.75	53	8.66	4	3.88	6
Swainson's Thrush (*Catharus ustulatus*)	4	0.43	1	0.16	3	2.91	0
Swallow sp.	1	0.11	0	0.00	0	0.00	1
Tennessee Warbler (*Oreothlypis peregrina*)	2	0.21	1	0.16	0	0.00	1
Thrush sp.	1	0.11	1	0.16	0	0.00	0
Tree Swallow (*Tachycineta bicolor*)	1	0.11	1	0.16	0	0.00	0
Warbler sp.	5	0.54	2	0.33	1	0.97	2
Warbling Vireo (*Vireo gilvus*)	1	0.11	1	0.16	0	0.00	0
Waxwing sp.	12	1.28	9	1.47	2	1.94	1
Western Tanager (*Piranga ludoviciana*)	2	0.21	0	0.00	2	1.94	0
White-breasted Nuthatch (*Sitta carolinensis*)	3	0.32	3	0.49	0	0.00	0
White-crowned Sparrow (*Zonotrichia*	4	0.43	4	0.65	0	0.00	0
White-throated Sparrow (*Zonotrichia albicollis*)	7	0.75	3	0.49	4	3.88	0
Wilson's Warbler (*Cardellina pusilla*)	1	0.11	1	0.16	0	0.00	0
Woodpecker sp.	1	0.11	1	0.16	0	0.00	0
Wren sp.	3	0.32	3	0.49	0	0.00	0
Yellow Warbler (*Setophaga petechia*)	8	0.86	3	0.49	3	2.91	2
Yellow-rumped Warbler (*Setophaga coronata*)	3	0.32	0	0.00	1	0.97	2
Unknown	435	46.57	248	40.52	24	23.30	163

Table 3-4. Akaike information criterion (AIC) scores for each model at the neighbourhood, yard, house and the overall best model looking at the factors affecting bird-window collisions at residential houses. Summary also includes the relative difference between models and the best model (ΔAIC), Akaike weights (AICw), log-likelihood (*L*) and number of parameters (K). Only those models with an AICw > 0.0 have been included for all models.

Level	Model	AIC	ΔAIC	AICw	*L*	K
NEIGH - BOUR	URBANRURAL*SEASON	7179.76	0.00	0.70	-3576.88	13
	URBANRURAL*SEASON + DISTNAT	7181.44	1.68	0.30	-3575.72	15
YARD	LEVELDEVEL + FEEDYESNO*SEASON + VEGHEIGHT	7170.70	0.00	0.65	-3567.35	18
	LEVELDEVEL + FEEDYESNO + VEGHEIGHT	7172.05	1.35	0.33	-3571.02	15
	LEVELDEVEL + FEEDYESNO*SEASON	7178.74	8.04	0.01	-3575.37	14
	LEVELDEVEL + FEEDYESNO	7179.99	9.29	0.01	-3579.00	11
HOUSE	WINDOWNUM + YRBUILT + BUILDINGTYPE	7192.36	0.00	0.62	-3579.18	17
	WINDOWNUM + YRBUILT	7195.18	2.82	0.15	-3582.59	15
	WINDOWNUM + YRBUILT + BUILDINGTYPE + NUMSTOREYS	7195.35	2.99	0.14	-3575.67	22
	WINDOWNUM + YRBUILT + NUMSTOREYS	7196.34	3.98	0.09	-3578.17	20
OVERALL	URBANRURAL*SEASON + VEGHEIGHT + LEVELDEVEL + FEEDYESNO + WINDOWNUM	7133.12	0.00	0.27	-3542.56	24
	URBANRURAL*SEASON + VEGHEIGHT + LEVELDEVEL + FEEDYESNO + BUILDINGTYPE + WINDOWNUM	7133.35	0.23	0.24	-3540.67	26
	URBANRURAL*SEASON + VEGHEIGHT + FEEDYESNO + BUILDINGTYPE + WINDOWNUM	7133.94	0.82	0.18	-3542.97	24
	URBANRURAL*SEASON + VEGHEIGHT + LEVELDEVEL + FEEDYESNO + WINDOWNUM + YRBUILT	7134.08	0.96	0.16	-3540.04	27
	URBANRURAL*SEASON + VEGHEIGHT + LEVELDEVEL + FEEDYESNO + BUILDINGTYPE + WINDOWNUM + YRBUILT	7134.38	1.26	0.14	-3538.19	29
	URBAN*SEASON + VEGHEIGHT + UNDEVEL + FEEDYESNO + BUILDING + WINDOWS + YRBUILT + STOREYS	7138.68	5.56	0.02	-3535.34	34
	URBAN*SEASON + VEGHEIGHT + UNDEVEL + FEEDYESNO + BUILDING	7140.39	7.27	0.01	-3548.19	22

Table 3-5. Model and coefficients for the best fitting neighbour, yard and house model and the best fitting overall model for all birds that collided with windows. Summary also includes the standard error (SE) for each coefficient, the P value to illustrate the significance of each term and the incident rate ratio for each term of the neighbour, yard, house and overall model and the odds ratio for each term of the window model.

Level	Model	Coefficient	SE	P>z	Ratio
NEIGHBOUR	URBANRURAL*SEASON				
	Rural, Fall	2.383	0.254	0.000	10.841
	Rural, Spring	1.925	0.328	0.000	6.852
	Rural, Summer	2.168	0.283	0.000	8.743
	Rural, Winter	2.152	0.263	0.000	8.605
	Unknown	2.887	0.982	0.003	17.945
	Urban, Fall	1.202	0.118	0.000	3.329
	Urban, Spring	0.837	0.158	0.000	2.310
	Urban, Summer	0.525	0.153	0.001	1.689
	PARTICIPANT EFFORT				
	2	-0.299	0.739	0.686	0.742
	3	-1.280	0.735	0.081	0.278
	INTERCEPT	-4.523	0.741	0.000	~
	USER	2.131	0.274	~	~
YARD	FEEDYESNO*SEASON				
	No Feeder, Fall	1.108	0.156	0.000	3.029
	No Feeder, Spring	0.924	0.218	0.000	2.521
	No Feeder, Summer	0.729	0.219	0.001	2.073
	Feeder, Fall	1.785	0.205	0.000	5.960
	Feeder, Spring	1.196	0.244	0.000	3.306
	Feeder, Summer	1.130	0.225	0.000	3.096
	Feeder, Winter	0.945	0.213	0.000	2.574
	VEGHEIGHT				
	Ground Level + 1 Storey	0.595	0.831	0.474	1.813
	2 – 3 Storeys	1.450	0.822	0.078	4.264
	Greater than 3 Storeys	1.338	0.820	0.103	3.811
	Unknown	0.916	0.949	0.334	2.499
	LEVELDEVEL				
	Undeveloped	0.785	0.193	0.000	2.192

YARD	Unknown	1.546	0.590	0.009	4.693
	PARTICIPANT EFFORT				
	2	-0.505	0.728	0.488	0.603
	3	-1.439	0.725	0.047	0.237
	INTERCEPT	-5.802	1.096	0.000	~
	USER	1.884	0.247	~	~
HOUSE	WINDOWNUM				
	6-10	0.756	0.478	0.113	2.130
	11-20	0.728	0.495	0.142	2.071
	> 10 Apartment	1.292	0.512	0.012	3.641
	Unknown	-0.277	0.597	0.642	0.758
	YRBUILT				
	1970 – 1989	-0.388	0.279	0.164	0.678
	1990 - Present	-0.555	0.283	0.050	0.574
	Unknown	0.418	0.214	0.051	1.520
	BUILDINGTYPE				
	Apartment	-0.494	0.491	0.314	0.610
	Single-attached House	0.348	0.444	0.434	1.416
	SEASON				
	Spring	-0.439	0.132	0.001	0.644
	Summer	-0.548	0.113	0.000	0.578
	Winter	-0.968	0.099	0.000	0.380
	PARTICIPANT EFFORT				
	2	-0.384	0.749	0.608	0.681
	3	-1.356	0.745	0.069	0.258
	INTERCEPT	-4.048	0.836	0.000	~
	USER	2.030	0.261	~	~
WINDOW	REFLECTION				
	Sometimes	1.105	0.415	0.008	3.020
	Unknown	-0.212	0.661	0.749	0.809
	Yes	1.730	0.399	0.000	5.639
	SIDE				
	Front	0.646	0.271	0.017	1.909
	Side	-0.286	0.388	0.462	0.751
	Unknown	0.237	3117.948	1.000	1.268
	DIRECTION				
	North	0.126	0.355	0.722	1.134
	South	0.179	0.347	0.605	1.196
	Unknown	19.067	2555.38	0.994	1.91E08

WINDOW	West	0.0912	0.342	0.789	1.096
	GLASSTYPE				
	Low-E Glass	0.525	0.713	0.461	1.690
	Other	-0.060	0.821	0.942	0.942
	SunStop/UV Glass	0.431	0.931	0.643	1.538
	Unknown	16.617	1163.948	0.989	1.65E07
OVERALL	URBANRURAL*SEASON				
	Rural, Fall	1.784	0.310	0.000	5.955
	Rural, Spring	1.301	0.368	0.000	3.671
	Rural, Summer	1.554	0.330	0.000	4.729
	Rural, Winter	1.546	0.314	0.000	4.694
	Unknown	2.403	0.999	0.016	11.054
	Urban, Fall	1.230	0.118	0.000	3.421
	Urban, Spring	0.778	0.157	0.000	2.177
	Urban, Summer	0.439	0.153	0.004	1.552
	VEGHEIGHT				
	Ground Level + 1 Storey	0.329	0.823	0.689	1.389
	2 – 3 Storeys	1.281	0.811	0.114	3.599
	Greater than 3 Storeys	1.120	0.808	0.166	3.064
	Unknown	0.461	0.949	0.627	1.586
	LEVELDEVEL				
	Undeveloped	0.455	0.207	0.028	1.575
	Unknown	0.830	0.618	0.179	2.293
	FEEDYESNO	0.558	0.165	0.001	1.747
	WINDOWNUM				
	6-10	0.962	0.360	0.008	2.616
	11-20	0.891	0.356	0.012	2.438
	> 10 Apartment	1.372	0.386	0.000	3.942
	Unknown	0.011	0.482	0.982	1.011
	PARTICIPANT EFFORT				
	2	-0.489	0.726	0.501	0.614
	3	-1.462	0.723	0.043	0.232
	INTERCEPT	-6.399	1.114	0.000	~
	USER	-1.774	0.235	~	~

Table 3-6. Akaike information criterion (AIC) scores for each model looking at the factors affecting bird-window collisions at residential houses at the window level. Summary also includes the relative difference between models and the best model (ΔAIC), Akaike weights (AICw), log-likelihood (*L*) and number of parameters (K). Only those models with an AICw > 0.0 have been included.

Model	AIC	ΔAIC	AICw	L	K
SIDE + REFLECTION + DIRECTION + GLASSTYPE	390.83	0.00	0.53	-181.41	14
SIDE + REFLECTION + DIRECTION + GLASSTYPE + HEIGHT	392.78	1.95	0.20	-179.39	17
SIDE + REFLECTION + DIRECTION	393.29	2.46	0.16	-186.64	10
SIDE + REFLECTION + DIRECTION + HEIGHT	393.94	3.11	0.11	-183.97	13

Table 3-7. Akaike information criterion (AIC) scores comparing the neighbourhood and yard models looking at the factors affecting bird-window collisions at residential houses. All models were run: (1) with all reported collisions; (2) with collisions by birds that do not visit feeders; and (3) with collisions from birds that visit feeders. Summary also includes the relative difference between models and the best model (ΔAIC), Akaike weights (AICw), log-likelihood (*L*) and number of parameters (K). A number of models for non-feeder birds at the yard level could not achieve model convergence and have not been included. Only those models with an AICw > 0.0 for each group of birds has been included for each level.

Level	Model	AIC	ΔAIC	AICw	AIC	ΔAIC	AICw	AIC	ΔAIC	AICw
		All Birds			Non-Feeder Birds			Feeder Birds		
NEIGHBOUR	URBANRURAL*SEASON	7179.76	0.00	0.70	2007.14	2.22	0.21	2825.65	0.00	0.87
	URBANRURAL*SEASON + DISTNAT	7181.44	1.68	0.30	2010.25	5.33	0.04	2829.57	3.92	0.12
	URBANRURAL	7196.66	16.9	0.00	2004.92	0.00	0.63	2837.9	12.25	0.00
	URBANRURAL + DISTNAT	7198.15	18.39	0.00	2008.24	3.32	0.12	2841.75	16.1	0.00
YARD	LEVELDEVEL + FEEDYESNO*SEASON + VEGHEIGHT	7170.70	0.00	0.65	~	~	~	2790.73	0.00	0.90
	LEVELDEVEL + FEEDYESNO + VEGHEIGHT	7172.05	1.35	0.33	~	~	~	2797.58	6.85	0.03
	LEVELDEVEL + FEEDYESNO*SEASON	7178.74	8.04	0.01	~	~	~	2796.01	5.28	0.06
	LEVELDEVEL + FEEDYESNO	7179.99	9.29	0.01	~	~	~	2802.80	12.07	0.00
	LEVELDEVEL + VEGHEIGHT	7188.87	18.17	0.00	2006.66	1.10	0.31	2830.40	39.67	0.00
	LEVELDEVEL	7196.45	25.75	0.00	2009.06	3.50	0.09	2835.57	44.84	0.00
	FEEDYESNO	7211.41	40.71	0.00	2005.56	0.00	0.54	2828.41	37.68	0.00
	VEGHEIGHT	7214.37	43.67	0.00	2010.29	4.73	0.05	2849.40	58.67	0.00

3.6 FIGURES

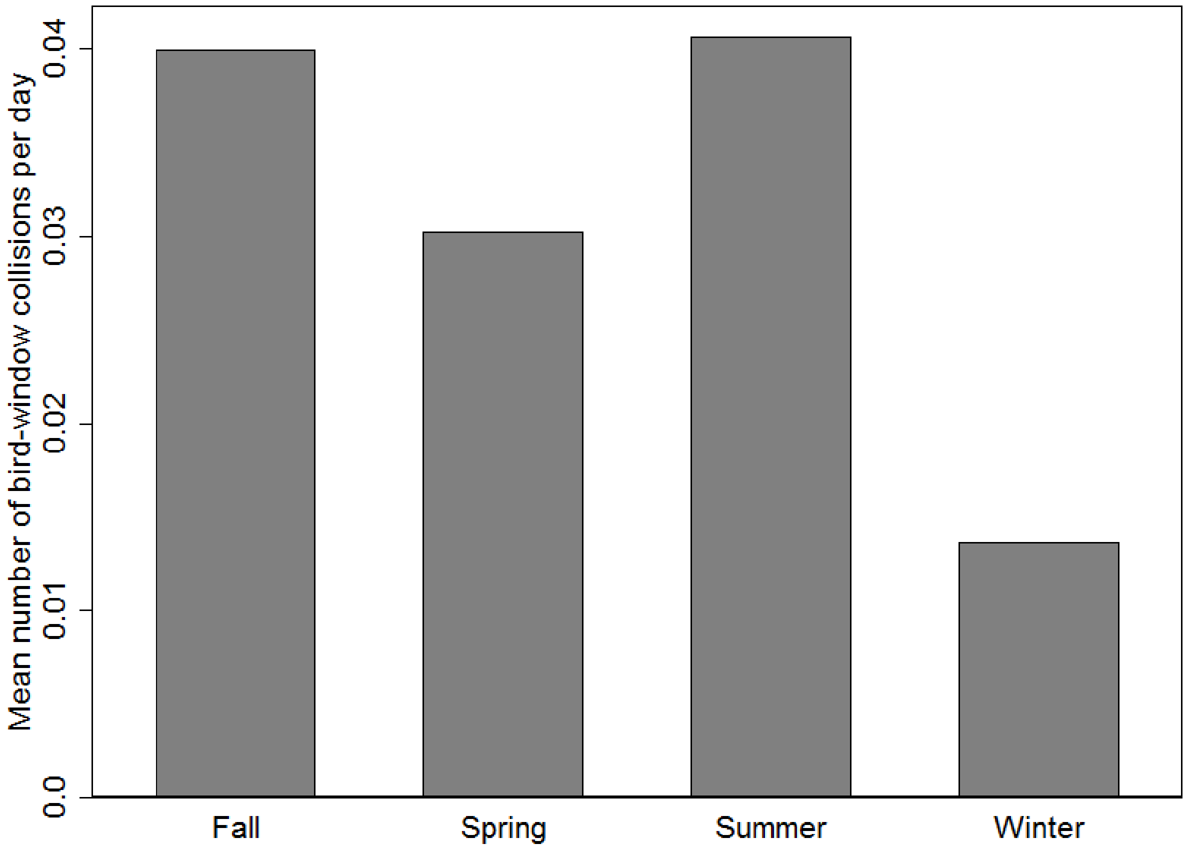

Figure 3-1. Bar graph showing the mean number of bird-window collisions for every day of each season: winter (n=16209), spring migration (n=3510), summer breeding (n=4628) and fall migration (n=10473).

CHAPTER 4. BIRD FEEDERS AND THEIR EFFECTS ON BIRD-WINDOW COLLISIONS AT RESIDENTIAL HOUSES

4.0 SUMMARY

Feeding wild birds creates an important link between homeowners and conservation. The effects of bird feeders and year-round feeding on birds have not been well studied, however, particularly in relationship to bird-window collisions. We determined effects of bird feeder presence and placement on bird-window collisions at residential homes. Paired month-long trials where a feeder was either present or absent for one month and then removed or added for the second month were completed at 55 windows at 43 houses. In each trial, homeowners were asked to search their study window daily for evidence of a bird-window collision. During the study there were 51 collisions when there was no bird feeder and 94 when the feeder was present. The season when each trial was set up was the best individual predictor of bird-window collisions. The largest number of collisions was observed during fall migration and the lowest during the winter months. There were no collisions at 26 of the study windows. High variance was observed in the number of collisions at different houses, indicating that effects of bird feeders are context dependent. Changing the occurrence, timing, and placement of feeders can alter collision rates but is only one of many factors that influence whether a residential house is likely to have a bird-window collision or not.

4.1 INTRODUCTION

In an increasingly urbanized world, feeding birds creates a simple way for people to interact with wildlife (Goddard et al. 2013). The popularity of wild-bird feeding has increased considerably in the past few decades as homeowners have become progressively motivated to connect to the natural world as part of their daily lives (Fuller et al. 2008, Jones and Reynolds

2008, Robb et al. 2008, Goddard et al. 2013). In the United States, an estimated 43-50% of households feed birds and up to $3.5 billion U.S. is being spent annually on bird food and supplies (Jones and Reynolds 2008, Fuller et al. 2012). Despite the popularity of bird feeding, there has been little research to evaluate how it influences the ecology of wild birds at the individual, population, or community level (Jones 2011, Goddard et al. 2013).

Feeding wild birds has traditionally been encouraged to prevent malnourishment during harsh winters, thereby increasing over-winter survival (Brittingham 1990, Jones and Reynolds 2008). Organizations such as the British Trust for Ornithology, the Royal Society for the Protection of Birds, and the Cornell Lab of Ornithology have actively encouraged wild-bird feeding as an activity to promote conservation. More recently, many of these groups have endorsed year-round feeding as both appropriate and beneficial under the assumption that it enhances breeding success (Robb et al. 2008). However, the overall benefit of feeding has not been evaluated relative to potential liabilities. Concerns about behavioural changes caused by feeder-dependency as well as reduced survival caused by increased predator attraction, disease spread, and collisions with human infrastructure have been raised (Jones 2011, Davies et al. 2012).

In the most recent bird-window collision estimate for Canada, 90% of all window collision mortality was estimated to occur with residential windows (Machtans et al. 2013). Considerable variation exists between different types of residences in collision rates (Bayne et al. 2012), and a growing number of researchers are trying to identify what makes one home more or less likely to incur a bird-window collision (Dunn 1993, Klem et al. 2004, Bayne et al. 2012, Hager et al. 2013). The use of bird feeders and where feeders are placed relative to windows is an area of increasing focus. Dunn (1993) conducted a North American wide survey of homes with bird feeders and found the abundance of species that commonly use feeders increased with bird feeding, and that abundance of these species was a good predictor of bird-window collisions. As a result, those species most likely to be window collision victims were those that frequented bird feeders. Bayne et al. (2012) found a similar pattern, whereby bird-window collisions were reported as being more common when a bird feeder was present. However, there was no relationship drawn between reported collisions and the species of birds that frequent feeders. In contrast, Hager et al. (2013) found a strong positive relationship between bird feeder presence and abundance of common bird feeder species, but not between bird feeders and bird-window collisions. Based on these somewhat conflicting results, more work is needed to better understand the relationship between bird-window collisions and bird feeders.

The window collision mitigation strategies most commonly recommended when using bird feeders are based on the results of one study which manipulated the distance of feeders relative to windows (Klem et al. 2004). This study, along with the majority of past studies exploring effects of bird feeders, have been done in woodlands and at scientific field stations (Orros and Fellowes 2012). For example, Klem et al. (2004) placed a series of window panes and bird feeders along the edge of a mixed deciduous forest and open field. There was an increase in the number of bird-window collisions when feeders were placed 2-10 m from a window. Within 1 m, birds were drawn to the feeder but due to its proximity to the window pane, fewer birds hit windows and fewer mortalities occurred as birds were unable to build up enough momentum to sustain serious injury if they hit the glass upon departure (Klem et al. 2004). These results are frequently used as evidence that placing bird feeders close to a window is a safe urban bird feeding practice. There have been no scientific studies, however, that look at effects of bird feeders at different distances on bird-window collisions in actual residential settings.

Our objective was to determine if bird feeder presence and placement influenced bird-window collisions at residential homes. We predicted that when feeders were present more birds would collide with windows because birds would be attracted to those residences. Fewer collisions were expected when feeders were placed close to versus far from windows based on flight speed and awareness of the window when leaving a feeder that was closer to the window. The general public are unlikely to stop feeding birds and there are a number of accepted benefits in them continuing. Thus, continuing to learn about the relationship between bird feeders and bird-window collisions is important in identifying ways homeowners can safely feed birds, while reducing bird-window collision risk at their home.

4.2 METHODS

4.2.1 Site selection

Houses for this experiment were identified using a variety of methods. Homeowners who had previously registered for our Birds and Windows project (http://birdswindows.biology.ualberta.ca/) were contacted and asked to participate in the study. Homeowners were also recruited through personal contact, social media (Facebook and Twitter accounts), and by delivering pamphlets and putting up posters in residential neighbourhoods in Edmonton. The bird feeder experiment was a focus of three Canadian Broadcasting Corporation Radio interviews and was featured on Canadian Broadcasting Corporation Alberta Late Night News. Emails were sent across Edmonton to community leagues, schools, and established nature and bird organizations. In total, 43 houses were recruited within Edmonton, Alberta and the surrounding area for our bird feeder experiment.

In selecting a window at each house, we allowed homeowners to indicate their preference and the one they felt was most likely to receive a collision. Other factors we considered when selecting a window included window size, presence of an already existing bird feeder, and nearby vegetation. Large windows with a bird feeder already present, shrubs or trees in close proximity, and a history of collisions were preferred but not essential in choosing a window. At 12 houses, two different windows were evaluated during different trials. A greenhouse and two clear deck railings were chosen instead of a window at 3 houses. The experiment was completed at a total of 55 windows at 43 houses.

One bird feeder was placed 1 m (n = 103) or 5 m (n = 39) in front of the selected window at each home during a trial (see Experimental Design). The presence of trees or large vegetation sometimes limited feeder placement and both distances could not be evaluated at each house. Additionally, some homeowners requested the bird feeder remain off their lawn, limiting the distances that could be tested at each home.

Bird feeders sat atop wooden stands that were anchored into the ground. They were placed at a height approximately in the middle of each window. Each bird feeder was gazebo style with a perch and attached roof. Feeders were filled with black oil sunflower seeds. Homeowners were instructed to keep the feeder full and when requested they were provided with their own seed or we visited and refilled the feeder.

4.2.2 Experimental design

The study was conducted from April 2014 – May 2015. The basic design consisted of a series of paired month long trials. In the first month, a feeder was either present or absent for that month and then removed or added for the second month. The order of each month was randomized and each trial lasted approximately 31 days. In total there were 284 completed trials. After each pair of trials, homeowners were given a break lasting at least 1 week (length varied amongst homeowners) before another set of trials began. At each window one (n = 11), two (n =

15), three (n = 15) or four (n = 14) paired trials were completed by the homeowner over the study period.

Homeowners searched their study window every day for evidence of a window collision. Forms of evidence included a dead or injured bird, a body smudge, feathers or blood on the window, and hearing or seeing a collision occur. If the homeowner reported any one form of evidence it was counted as a collision. Participants had the option of entering their observations into the Birds and Windows online database (http://birdswindows.biology.ualberta.ca/) or to fill out paper data sheets.

4.2.3 Data analysis

After each trial, homeowners were asked to confirm each window collision recorded and all observations were checked for consistency. From homeowner observations we calculated the total number of collisions with and without a feeder pooled for all houses (hereafter POOLED), the total number of collisions with and without a feeder occurring at each house pooled across all trials at that house (hereafter HOUSE), and the total number of collisions occurring per trial at each window (hereafter TRIAL).

A chi-square test was used to determine if there was a difference in the total number of collisions POOLED when a bird feeder was present and when a bird feeder was absent. A multilevel mixed effects count model was used to determine if the total number of collisions at each HOUSE differed when the feeder was present and absent while controlling for the number of trials done at each house (command menbreg in STATA 13; StataCorp, College Station, Texas, USA, http://www.stata.com/) and compared using Akaike's information criterion (AIC) (Burnham and Anderson 2004)). Finally, a multilevel mixed effects count model was used to determine the rate of bird-window collisions accounting for seasonal, house, and window attributes based on each TRIAL. Each analysis was run using all species and again after removing collisions by species that do not eat seeds and do not regularly frequent bird feeders (i.e. Cedar waxwings (*Bombycilla cedrorum*), Bohemian waxwings (*Bombycilla garrulus*) and American robins (*Turdus migratorius*)).

For the multilevel mixed effects count model at the TRIAL level, various fixed and random effects were added and compared using Akaike's information criterion (AIC) (Burnham and Anderson 2004) as well as likelihood ratio tests to determine the best model structure, evaluate how bird feeder presence, and feeder location influenced the number of collisions. We compared how model fit changed when we included fixed effects for: (1) presence/absence of a feeder as a categorical variable (hereafter FEEDER); (2) absence of a feeder or whether a feeder was present at 1 m or 5 m from the window as a categorical variable (hereafter DISTANCE); (3) time of year the trial started as a categorical variable with four levels: spring migration, summer breeding, fall migration and winter (hereafter SEASON); (4) SEASON + FEEDER; (5) SEASON + DISTANCE; and (6) SEASON * FEEDER. Based on personal experience related to migration of birds in Edmonton, we defined our seasons as winter being the period between 15 October and 14 March, spring migration being 15 March to 14 May, summer breeding being 15 May to 14 August, and fall migration being 15 August to 14 October. In preliminary analyses, we looked at the month of the year the trial began as an alternative variable for season but there were no reported collisions in December and February so we could not achieve model convergence. We also tried to evaluate the interaction between SEASON * DISTANCE but there was an insufficient number of collisions in the winter to allow model convergence.

4.3 RESULTS

Throughout the experiment there were 145 bird-window collisions. The mean number of collisions per trial was 0.51 ± 1.47 (SD). There were no collisions reported in 223 of the 284 trials. There were 5 collisions at one clear deck railing but no collisions at the other deck railing or the greenhouse.

Of the 145 birds that collided, 89 survived the event. There were only 11 reported fatalities and the fate of 45 birds was unknown. When the bird feeder was present there were only 7 (7.5%) fatalities while 55 (58.5%) birds survived the collision. These percentages are comparable to when there was no bird feeder present (7.8% died and 66.7% survived). Species could be identified in 35 of the observed bird-window collisions by our citizen scientists (Table 1). Another 15 birds were identified to broader groupings. Based on personal experience with the urban bird community and educated guesses, we identified the 5 chickadees as Black-capped chickadees (*Poecile atricapillus)* and the woodpecker and 2 waxwings as a Downy woodpecker (*Picoides pubescens*) and Cedar waxwings, respectively. There are several different sparrow species in the Edmonton area and as a result the 7 sparrows could not be classified further. Together, Black-capped chickadees (12), House sparrows (*Passer domesticus*) (7), and Dark-eyed juncos (*Junco hyemalis)* (4) composed almost half of the identified species colliding with windows. Other prominent species included non-feeder species such as American robins (6) and Cedar and Bohemian waxwings (8).

There were 51 collisions, with a mean of 0.36 ± 0.93 per trial when there was no bird feeder present. When a feeder was added the number of collisions increased to 94 with a mean of 0.66 ± 1.86 per trial (Figure 1). There were significantly more POOLED collisions when there was a bird feeder present ($\chi^2 = 12.2$, df = 1, P = 0.005). The presence of a bird feeder increased collision rate 1.84 times. Excluding collisions by waxwings and robins dropped the number of collisions when there was a feeder to 90 and when there was not a feeder to 41. There were again significantly more collisions when there was a feeder present ($\chi^2 = 17.6$, df = 1, P <0.001) and collision rate was increased 2.20 times when a feeder was present versus absent.

Based on AIC in our most complex model, a model based on a negative binomial distribution provided a much better fit than one based on a Poisson distribution for HOUSE level collisions (Poisson AIC = 288.26, Negative Binomial AIC = 276.40). Including house as a random effect resulted in significant model improvement relative to a standard negative binomial regression ($\chi^2 = 14.5$ P < 0.001). For the number of collisions at the HOUSE level, bird feeder presence increased collision rate 1.57 times ($\chi^2 = 2.4$, P = 0.12). Collision rate increased 1.81 times ($\chi^2 = 4.0$, P = 0.05) when robin and waxwing collisions were removed.

Comparing each house in its back-to-back trials (feeder vs. no feeder) at each window, we found 10 houses had a greater number of reported collisions when there was no feeder present while 14 houses had more collisions when there was a bird feeder (t = 1.3, df = 84, P = 0.19). There were no collisions reported at 18 houses and 1 house had the same number of collisions reported both when a feeder was present and absent. The top 5 houses reported 25, 19, 17, 15, and 9 collisions while participating in the project.

Based on AIC in our most complex model, negative binomial distribution (AIC = 463.37) provided a much better fit than Poisson (AIC = 495.66) for TRIAL level collisions. With no fixed effects in the model, we evaluated if individual house and study window within each house treated as nested or individual random effects provided a better fit. Including the individual window as a single random effect provided a better fit than treating house as a random effect or nesting window within house based on AIC (ΔAIC of more than 2 with window providing a better fit relative to nested model or the model with house identity as random effect). Including window as a random effect resulted in significant model improvement relative to a standard negative binomial regression (χ^2 = 15.7, P < 0.001).

In predicting TRIAL level collision rate, bird feeder presence was a better predictor than bird feeder distance from the window when included as a single fixed effect (Table 2). When the feeder was 1 m from the window the total number of collisions was 66, with a mean of 0.64 ± 1.82 (SD) per trial. At 5 m there were fewer trials so the total number of collisions was only 28, but the mean number of collisions was higher at 0.72 ± 1.99 (SD) per trial.

Based on AIC, the best model with a single fixed effect was SEASON with far fewer collisions occurring in the winter. There was a mean of 0.11 ± 0.40 (SD) collisions in the winter and this increased to 0.79 ± 1.52 (SD) during spring migration, 0.54 ± 1.36 (SD) in the summer breeding months, and 1.08 ± 2.66 (SD) through fall migration (Table 2, Figure 2).

The best fitting model was SEASON + FEEDER. Adding FEEDER to the SEASON model improved model fit only slightly, with a ΔAIC of 0.67. SEASON + FEEDER had more support than SEASON + DISTANCE and SEASON * FEEDER (Table 2). When FEEDER was modelled as a single fixed effect, the increase in number of collisions was 1.69 times higher (χ^2 = 3.1, P = 0.08) when a feeder was present. After accounting for SEASON, collision rate was 1.59 times higher when feeders were present (χ^2 = 3.3, P = 0.07). When the species that do not frequent feeders were removed, SEASON + FEEDER remained the best model based on AIC (Table 2). Collision rate with FEEDER as a single fixed effect was 1.96 (χ^2 = 4.9, P = 0.03) in the presence of a bird feeder. When SEASON was included, the increase in the number of collisions was 1.83 times (χ^2 = 5.3, P = 0.02).

4.4 DISCUSSION

This is the first manipulative experiment to look at the relationship between bird feeders and bird-window collisions in a residential setting. In our study, bird feeder presence increased collision risk 1.57 to 2.20 times, depending on the model, relative to not having a feeder. Admittedly, our mixed model results using all reported collisions were not statistically significant at $P = 0.05$ or at $\Delta AIC > 2$, suggesting that bird feeder presence was a weak predictor of collision rate after accounting for house and window attributes. However, effect size in our manipulative experiment was similar to other correlative studies that demonstrated statistically significant results because of larger sample sizes. For example, Bayne et al. (2012) found that people with feeders remembered 1.82 and 2.62 times more collisions occurring at their homes in two different years than people who did not have feeders. In a comparable study, where homeowners actively searched around their home for collisions, urban houses with a feeder had 1.98 more collisions than houses without (Kummer et al. *Submitted*). Overall, houses with bird feeders consistently report more bird-window collisions that those without, regardless of how collision data has been collected (Bayne et al. 2012, Klem et al. 2004, Kummer et al. *Submitted*).

All our models were improved and became statistically significant at $P = 0.05$ once collisions by non-feeder bird species were removed. Across our models there was an increased risk of a collision for feeder species in the presence of a bird feeder. This suggests that effects of bird feeder presence on collision risk are specific to species that frequently visit bird feeders. However, this was not seen in our comparable study where homeowners actively searched around their home for collision evidence (Kummer et al. *In Prep*). Future studies should attempt to determine which species of birds using feeders are at greatest risk of collisions but this will require far larger sample sizes than we were able to achieve.

While the average collision rate we observed was consistent with previous studies, we found very high variance in the number of collisions between different houses. This variance between houses drives the differences between the cumulative total and mixed effects results. Almost half of the houses reported no collisions, yet there was one window at one house where bird feeder presence increased collision rate by over 11 times. This trend was not seen at each of the homes reporting high collision numbers. The house where 15 collisions were reported saw almost 3 times as many collisions when there was no feeder than when there was a feeder present. A similar number of collisions for each treatment was also observed at some houses that reported a high number of collisions. This suggests that the effects of a bird feeder are dependent on the house and window. Overall, some houses have a much higher risk than others suggesting that impacts of feeding birds may be context dependent.

Klem et al. (2004) recommend placing bird feeders closer to windows to reduce collisions and/or their severity for birds. Similar to Klem et al. (2004), we had a slightly higher collision rate when feeder distance was 5 m compared to 1 m, but there was not strong statistical support for this difference being important. Admittedly, there were fewer trials in the 5 m distance class because of constraints on our design related to homeowner preferences and yard configuration. It is likely variability in bird-window collisions limits our ability to detect subtle differences as a result of bird feeder distance from a window. Thus, while we cannot dismiss the recommendation that placing feeders closer to windows will reduce collisions and/or their severity, our results do not strongly support this.

Seasonality was the most important driver of bird-window collision rate. Bird-window collisions are affected by seasonality, yet prior to this study there was no complete continuous data set that looked at bird-window collision trends over an entire year (Klem 1989, Codoner

1995, Bayne et al. 2012, Hager et al. 2013). The few collisions observed during the winter months is not surprising for Alberta as more than 80% of the bird species in Alberta are migratory (Bayne et al. 2012, Hager et al. 2013). There was an additional decline in the number of collisions during the early summer months. This is comparable to Klem (1989), who reported fewer collisions at this time because breeding birds seem to be moving less. The collision spikes that occurred during the spring and late summer and early fall coincide with migration. Edmonton is located within three migratory flyways and as a result, a large number of birds fly through and stop in the region during their spring and fall migration (City of Edmonton 2008). The increased abundance of birds at these times presumably leads to a greater risk of window collisions as more birds are being drawn towards windows (Dunn 1993, Hager et al. 2013). We had insufficient data to explicitly test if feeders have a differential effect at certain times of the year and this is an area that warrants further investigation.

It has previously been shown that there is an increase in the abundance of birds that frequent feeders when a bird feeder is present (Dunn 1993, Fuller et al. 2008). If this increased abundance increases collision risk as suggested by Dunn (1993), it is not surprising the majority of species we saw collide with windows were those that use feeders. However, there were a number of non-feeder species that collided. A number of houses that participated had a bird feeder in their yard before the study and as proposed by Dunn (1993), these homes are often characterized by abundant green space and are attractive to both feeder and non-feeder species. There were few fatalities during the study and it is possible the resident species that frequent feeders year round may be more aware of windows. As well, while resident species increase their feeder use in the winter (Chamberlain et al. 2005), they may no longer have green vegetation reflected in windows to the same degree at this time, reducing their collision risk relative to migrant species. Year-round feeding has been promoted and encouraged to promote conservation, but depending on the home and feeder placement, feeding only during the winter months might be more beneficial to populations and help reduce collisions. Ultimately, detailed demographic studies at appropriate scales are required to assess the benefits that feeding has for birds to determine if the benefits to individual health and reproductive success compensates for increased mortality associated with window collisions.

In conducting our study, we were unable to validate homeowner observations. Bird-window collisions are a quick event. Thus, it is possible that more collisions occurred than were recorded throughout the experiment (Smallwood 2007, Hager et al. 2012, Machtans et al. 2013, Loss et al. 2014). At the start of the study we attempted to use remote cameras and motion capture to photograph collisions at all of the windows used in this study. This was not effective as our cameras were not fast enough to detect collision events and get a high quality photo. Future work in this area should use high-speed video that runs continuously to validate homeowner observations and confirm that collision rates estimated by a single visit per day are in fact accurate. Alternatively, there are now security devices available that can sense vibrations when they occur at windows. This could be particularly important for collisions occurring when the feeder is placed 1 m from the window as birds may not gather enough momentum to leave visible evidence of a collision. Given the magnitude of bird-window collisions in North America and the potential effects this is having on bird populations (Machtans et al. 2013, Loss et al. 2014) more investment in monitoring technology that will allow us to accurately test the efficacy of mitigation approaches for bird-window collisions is needed.

By conducting this study at actual houses, our results suggest homeowners can mitigate some bird-window collisions by removing bird feeders. Feeders are one of many factors that influence whether a residence is likely to have a large number of collisions (Bayne et al. 2012). Types of glass, proximity to high quality bird habitat, window decals, and local vegetation are other factors that need to be tested more fully to assess what the most cost-effective way is to mitigate bird-window collisions. We cannot refute the argument made by Klem et al. (2004) that if a feeder is going to be placed in front of a window it should be placed close to that window. Trials testing the placement of bird feeders at different angles from windows should also be completed to see how eliminating the direct line of sight to the window affects the number of collisions.

Eliminating bird feeders will not solve the bird-window collision issue. Bird feeders do play a role in collisions but they are context dependent. In working towards eliminating bird-window collisions a combination of factors will need to be considered (Robb et al. 2008). Homeowners are not particularly interested in getting better estimates of the severity of bird-window collisions. Instead, they take pride in their yard and the birds in it. They want to know how to feed the birds in their yard safely. Feeding wild birds creates an important link between the general public and nature and improving this relationship will continue to promote biodiversity and conservation. In conducting this study a number of participants provided updates on the activity at their bird feeder and at the end of the project a handful kept their feeder. Homeowners enjoy having birds in their yards and being able to feed them. Finding successful ways for them to do so could be beneficial to both birds and the millions of people who feed them. More effort is required by ornithologists to assess how this might be done.

4.5 TABLES

Table 4-1. Percentage of reported collisions and the sample size for each species that collided.

Species	% Collided	Sample size (*n* =)
American Robin (*Turdus migratorius)*	4.14	6
Black-capped Chickadee (*Poecile atricapillus)*	8.28	12
Blue Jay (*Cyanocitta cristata)*	0.69	1
Bohemian Waxwing (*Bombycilla garrulus)*	0.69	1
Cedar Waxwing (*Bombycilla cedrorum)*	4.83	7
Dark-eyed Junco (*Junco hyemalis)*	2.76	4
Downy Woodpecker (*Picoides pubescens)*	1.38	2
House Sparrow (*Passer domesticus)*	4.83	7
Purple Finch (*Haemorhous purpureus)*	0.69	1
Red-breasted Nuthatch (*Sitta canadensis)*	0.69	1
Sparrow sp.	4.83	7
Swainson's Thrush (*Catharus ustulatus)*	0.69	1
Unknown	65.5	94

Table 4-2. Akaike information criterion (AIC) scores for each model looking at the factors affecting bird-window collisions at residential houses. Summary also includes the relative difference between models and the best model (ΔAIC), Akaike weights (AICw), log-likelihood (*L*) and number of parameters (K). All tests were run twice: once with all reported collisions, and again after removing collisions from Cedar and Bohemian Waxwings and American Robins.

	Model	AIC	ΔAIC	AICw	*L*	K
All birds	SEASON + FEEDER	463.37	0.00	0.44	-224.69	7
	SEASON	464.04	0.67	0.32	-226.02	6
	SEASON + DISTANCE	465.30	1.93	0.17	-224.65	8
	SEASON * FEEDER	467.00	3.63	0.07	-223.50	10
	FEEDER	478.68	15.31	0.00	-235.34	4
	DISTANCE	480.66	17.29	0.00	-235.33	5
	WINDOW	479.70	16.33	0.00	-236.85	3
	NULL	493.40	30.03	0.00	-244.70	2
Feeder birds only	SEASON + FEEDER	435.18	0.00	0.55	-210.59	7
	SEASON + DISTANCE	436.84	1.66	0.24	-210.42	8
	SEASON	437.51	2.33	0.17	-212.76	6
	SEASON * FEEDER	440.53	5.35	0.04	-210.27	10
	FEEDER	447.14	11.96	0.00	-219.57	4
	DISTANCE	448.93	13.75	0.00	-219.47	5
	WINDOW	449.95	14.77	0.00	-221.97	3
	NULL	464.94	29.76	0.00	-230.47	2

4.6 FIGURES

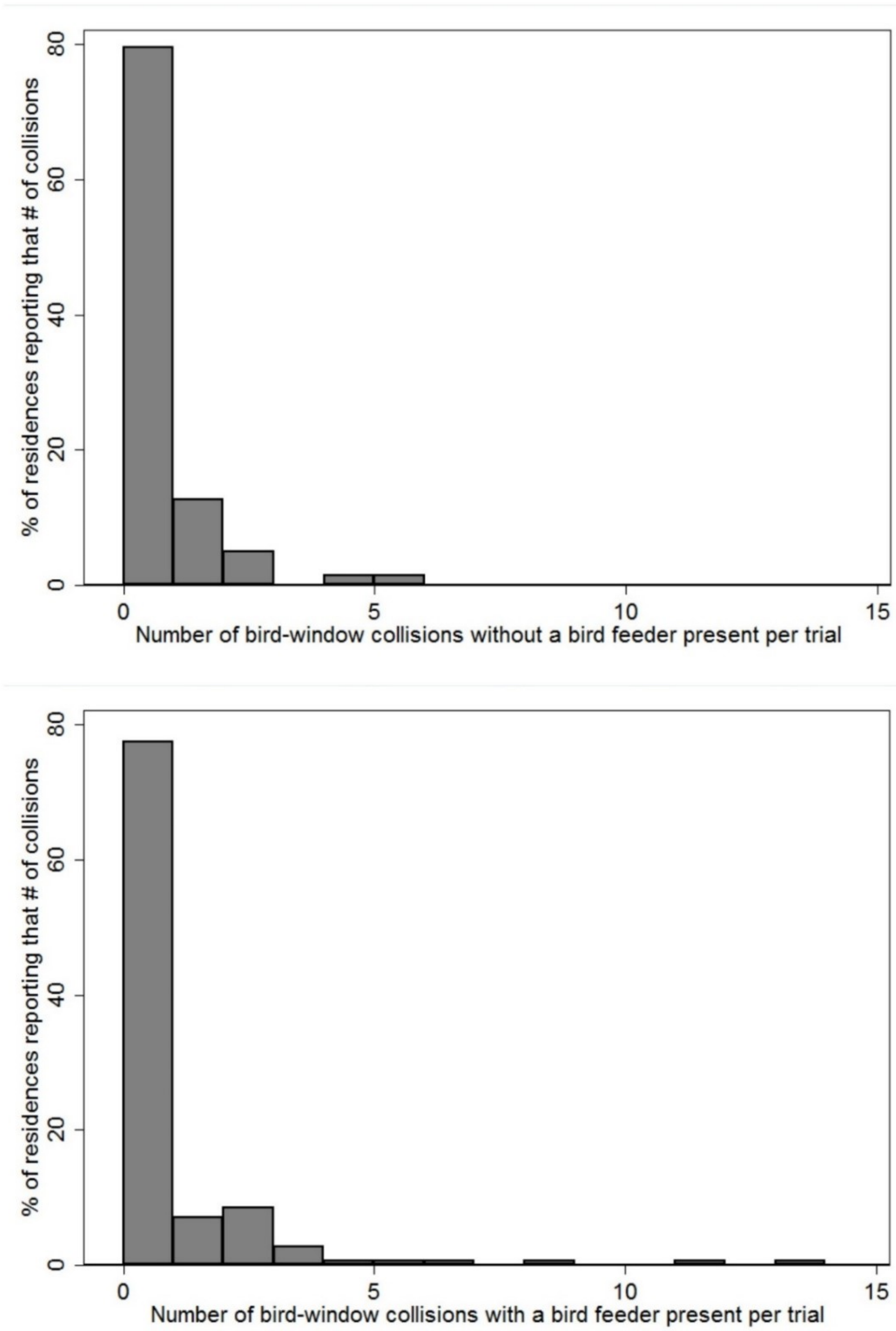

Figure 4-1. Histogram showing percentage of residences reporting a particular number of bird-window collisions during trials with no feeder and trials where the bird feeder was present in front of the window.

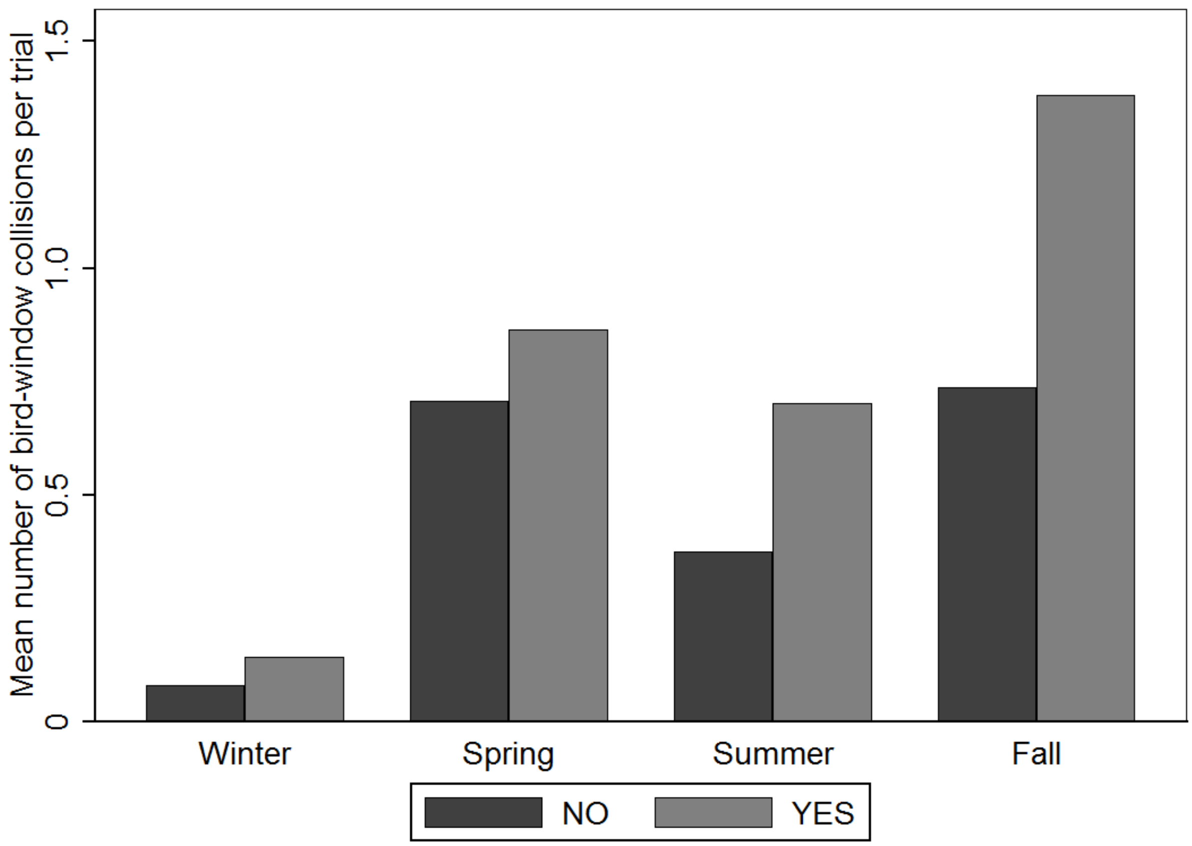

Figure 4-2. Bar graph showing the mean number of bird-window collisions for each season: winter (n=92), spring migration (n=39), summer breeding (n=40) and fall migration (n=40). The mean number of collisions was calculated for each season and subdivided for trials where there was no bird feeder (NO) and trials where the feeder was present (YES).

CHAPTER 5. CONCLUSION

The main objective of this thesis was to use citizen science to better understand bird-window collisions at residential houses. The Birds and Windows project was successful at accomplishing this goal. Over 1300 homeowners registered and participated in the project over the year and a half of its duration. Chapters 2 and 3 were directly derived from this project and the data collected by dedicated homeowners. Chapter 4 used a smaller set of citizen scientists who manipulated the presence and placement of a bird feeder outside their home for a year. The total number of participants in both aspects of the Birds and Windows project is an example of how successfully citizen science can be used in studying bird-window collisions. With the help of some undergraduate students I am also currently working on a scavenger removal project where a dead bird and a camera are being placed outside of residential homes for a week. We are currently finishing a year of data collection and working towards determining a scavenger removal rate that can be applied to residential areas to account for scavenger bias. Throughout this project a lot was learned about citizen science and interacting with the public on a conservation project. In conclusion, I provide a series of recommendations for conducting future survey based citizen science projects and discus potential ideas for future bird-window collision studies.

A number of distribution methods were used to reach the public and gain participants in conducting this project. For the majority of these methods it was easy to garner interest. The general public was genuinely interested in the project but while there was interest, it was sometimes difficult to get these people to participate in the project for an extended time period. A large number of attempts to attract participants went unanswered. The project was the focus of four Canadian Broadcasting Corporation (CBC) radio interviews, a print article and a segment on the Alberta Late Night News and while each of these methods was successful in getting a handful of participants, I was unable to get a proper estimate of how many homeowners heard about the project from each one. Future citizen science projects should attempt to provide a better account of the audience size for each media type (Cameron et al. 2013) to better understand how successful each recruitment method was.

The social media accounts were also successful at enticing participants. On both Facebook and Twitter it was easy to reach people and have them interact with our posts. Updating regularly helps increase followers on both social media platforms (Fauville et al. 2015), however it was difficult to get those interested to become good citizen scientists. This was seen with the Birds and Windows project where the project successfully accumulated 883 followers on Twitter and the Facebook page received 194 likes, but only 99 total participants came from these methods. There has been a push for scientists to communicate their research by embracing social media and recently citizen science and social media have become interwoven in a number of studies (Bik and Goldstein 2013, Ambrose-Oji et al. 2014, van Vliet et al. 2014). There is value in using social media to conduct citizen science, but for social media to be effective in achieving project goals a large amount of time and effort needs to be dedicated to each method (Ambrose-Oji et al. 2014, Fauville et al. 2015). Both the Birds and Windows social media accounts were used sparingly throughout the project. At the beginning, I worked hard to recruit homeowners through these methods and as the project progressed they were used to provide updates and links to media articles. When Chapter 4 was published a link to the article was shared on both platforms. On Facebook this post reached 746 people, received 10 likes and 2 shares. Another post a month prior that linked to a blog post summarizing the same results reached 702 people, received 9 likes, 2 shares and 3 comments. The same blog post received 6 retweets and 3 likes on Twitter while the published article saw 1 retweet. People consistently engaged with our Facebook and Twitter posts, however there were times when posts were far and in between. At least weekly posts on each platform should be encouraged moving forward.

In embracing citizen science the Birds and Windows project was given numerous opportunities to raise public awareness on the issue of bird-window collisions. Public outreach is an easy way to expand the reach of a project and interact with people who otherwise may not have heard about the project or the importance of an issue (Groffman et al. 2010, van der Wal et al. 2013, Varner 2014). At each event, the public was often interested as homeowners were given information on the project while children completed window deterrent crafts or colouring pages. However, it was then difficult to measure the success of these outings. It was often unknown if the interested homeowners registered and participated or used the information provided at the event to make changes at their home. Perhaps instead the focus of these outreach events should be on education and less on participant recruitment. One of the overarching objectives of the project was to educate homeowners on the issue of bird-window collisions and public outreach is an excellent way this can be accomplished.

While the Birds and Windows project succeeded at attracting a dedicated set of citizen scientists, there were a handful of difficulties encountered. The nature of the project made it challenging to validate homeowner observations. Only a handful of participants uploaded photos of their collision evidence. It is possible homeowners were unaware of this request, there was no collision evidence left behind or the technology was unfamiliar to the homeowner (Lye et al. 2012). As a result, these collisions cannot be confirmed and validated as I had originally hoped. Previous studies have found only ~70% of citizen science observations were plausible, and many successful citizen science projects monitor the quality of the data collected by volunteers (Jordan et al. 2011, Bonter and Cooper 2012, Fowler et al. 2013). Lewandowski and Specht (2015) offer recommendations including; improvements to project structure and survey protocol, and participant training, to improve data quality. In conducting the Birds and Windows project the survey was designed to be simple and easy to follow. Homeowners were given a detailed protocol and required to answer the minimum number of questions each time an observation was entered. In an attempt to improve data quality, online tutorials or videos could have been made available to homeowners prior to participating (Bonney et al. 2009, Newman et al. 2011, Moyer-Horner et al. 2012). An additional option to improve data quality, engage a broader audience and increase motivation and access to training videos is a mobile app for easy upload of photo evidence (Newman et al. 2012, Starr et al. 2014). Another tool that could be utilized is interactive maps. This has recently been used in downtown Toronto by the Fatal Light Awareness Program, where participants can enter the exact location collision evidence was found (FLAP Canada 2015). A number of these methods were suggested early on, but were never pursued. Moving forward, these are tactics that should be considered to improve data quality.

In future studies, more emphasis should be given to participant retention as recent studies have shown focusing efforts here may also lead to higher quality data (Lewandowski and Specht 2015). One way to accomplish this is by interacting more and reaching out to participants through the use of blogs, newsletters and social networking groups (Dickinson et al. 2012). The Birds and Windows website was the main platform available to interact with participants and keep them up to date on the project, and it has been shown that the more websites are updated and the more data summaries are provided, the more likely participants will continue with the project (Hochachka et al. 2012, Marshall et al. 2012). At the end of the project, as Chapter 4 was finished and there were results to share, the published article and blog post on the topic was posted on the Birds and Windows website. As of November 19, 2015, the blog post has received 452 views and the short post on the published article has received 113. Additionally, the blog post summarizing Chapter 4 was published on the Wild 49 (http://wild49.biology.ualberta.ca/) Bayne and Boutin lab website where it has received 88 views. Both the blog post and published articles were additionally sent to each of the homeowners who participated. 13 homeowners responded to the news of the published article and the blog, stating congratulations and appreciation for sharing the results. Additionally, a recent blog post summarizing the results of Chapter 2 was published on the Birds and Windows website on November 17, 2015 and after only two days had received 424 views. If preliminary results or emails with the total number of participants had been distributed throughout the project there may have been higher participant retention and I may have been able to develop a stronger relationship with some of the homeowners. The idea of writing blog posts was not explored till the end of the project but could have been very beneficial at attracting participants if this method had been utilized from the start. Developing strong relationships with homeowners would encourage homeowners to participate for longer periods as participants are motivated by contributing to scientific research and the enjoyment, social interaction and sense of belonging it provides (Newman et al. 2012, Crain et al. 2014, Nov et al. 2014). A participant rewards system was discussed early in the development of the Birds and Windows project but was never successfully implemented. In the future, a rewards system encouraging homeowners to participate for more than one month or during the winter months should be considered to increase response rate and response quality (Deutskens et al. 2004).

There were a number of difficulties encountered throughout the project: 25% of those homeowners who registered never entered an observation and only 50% of homeowners in Alberta who entered observations completed the 28 days outlined in the protocol. Importantly, there were a number of participants who far exceeded expectations. The greatest number of observations came from students who were required to participate for class credit. While these participants were forced to participate they provided a solid number of citizen scientists that could be trusted to complete observations for a set time period. There were additionally a large number of family and friends who supported the project throughout and participated each day of the project. As well, there were a large number of homeowners who participated because they had a previous interest in the birds in their yard or a long standing history of bird-window collisions at their home. It is because of these people that the project was a success.

Using citizen science to conduct the Birds and Windows project allowed the project to have a larger geographic and temporal spread than could have been achieved using traditional methods (Dickinson et al. 2010). Multiple homeowners collected data at private properties across Alberta each day of the project. The cost and manpower that would have been needed to conduct this project another way and collect the same amount of data would have been astronomical (De Coster et al. 2015). Successfully collecting data of this scale in under two years could not have been achieved without citizen science.

Most importantly, using citizen science allowed the project to be accessible to the general public. On an almost daily basis I was able to interact with homeowners, hear their stories, provide recommendations and encourage them to participate. I received a number of emails from these homeowners containing photos and little anecdotes about the bird population in their yards. It was very rewarding to see these homeowners excited about the project and contributing to scientific research. In turn, I greatly enjoyed having results that I could directly relay back to the homeowners who helped collect it and provide recommendations they can now apply to their houses and yards.

This project began with the objective to determine a new bird-window collision estimate for residential houses in Canada. As over 80% of all Canadian homeowners who registered with the project were from Alberta I did not have the data to produce an accurate estimate for the entire country. When this project began funding agencies did not believe it would be a success and I was told I would only be able to recruit a handful of homeowners. I have shown how this project did succeed, however, without support from these agencies, the reach of the project may have been limited. Until a project studying bird-window collisions receives the proper funding to promote the project and provide incentives and rewards to those homeowners participating, it will remain difficult to collect the data necessary to create a new national bird-window collision estimate for residential houses.

As well, there is still untapped citizen science potential in studying bird-window collisions. I have shown that recollection surveys are capable of helping us understand the relative importance of different window collision risk factors. It is also easier to recruit participants for recollection surveys as they are less of a commitment than projects that require ongoing participation. This method worked for Bayne et al. (2012) and again with the Birds and Windows project and I believe could be effectively applied on a larger scale. In having university classes participate in both projects, a dedicated set of citizen scientists were recruited. Using a similar framework, these methods could be applied across the country. To be most effective, recruiting university students should be completed in conjunction with a series of project leaders, like myself, promoting the project. In having project leaders throughout the country, there will be increased participation as a result of personal relationships and asking family and friends to participate.

While I have suggested the focus on future research should shift to reducing and eventually stopping bird-window collisions there remain a number of benefits for determining a Canadian-wide estimate. In conducting similar studies across Canada we will be able to better identify species-specific, seasonal and geographic trends. As well, only in having a more accurate estimate and representation of collisions across the country will steps be taken at a provincial or national level to reduce the number of collisions.

In shifting the focus of bird-window collisions away from determining large estimates, future studies will be able to focus on bird-window collisions at a more personal level with the homeowners who are participating in the project. Bird-window collisions at houses may not be a large conservation issue; the birds that collided throughout this study are not currently listed as species at risk, however these collisions are still occurring at our homes. Moving forward the focus of a similar project should shift away from the idea of a larger conservation issue and instead look at what is happening in our own backyards. It is here homeowners have an emotional connection and want to make a difference.

The first step in finding ways to reduce the number of bird-window collisions is a manipulative experiment, similar to the bird feeder experiment in Chapter 4, to determine the best window deterrent methods. There have been a number of localized studies but there remains no scientific study conducted at actual residential homes. For example, WindowAlert decals were scientifically tested in Klem (2009), however this study and the American Bird Conservancy follow up study was not conducted at actually homes (Window Alert 2015). Similarly, ORNILUX products have only been tested in localized tunnel experiments and ABC

BirdTape simply states the product has been tested in a special bird science facility (American Bird Conservancy BirdTape 2015, Ornilux Bird Protection Glass 2015). Each of these products have been tested and are promoted as effective deterrent methods but to the best of my knowledge, these products have yet to be compared in the same study at actual residences.

In the bird feeder experiment in Chapter 4, citizen science was used to collect information at each home. Motion capture cameras were initially used in this project and in future studies this approach should be reconsidered except with a continuous video stream at each window. As well, the use of window vibration sensors was discussed early on, and in the future they could provide a cost-effective option for measuring absolute collision numbers. However, until a more technological solution is tested, citizen science remains the best method for collecting this large scale data in real-world scenarios and should continue to be used in similar experiments.

The Birds and Windows project saw a number of successes. Over 1300 homeowners registered and provided information on the collisions at their homes and 43 families allowed me to place a bird feeder in their yard for multiple months. Through citizen science I have outlined a number of factors affecting bird-window collisions and identified those factors having the largest effect at residential homes. In conclusion, I have discussed the success of my work as a citizen science project and provided recommendations for conducting future survey-based citizen science projects. As well, as a result of the Birds and Windows project, I have outlined the next steps for bird-window collision research in working towards stopping avian mortality from collisions with windows.

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