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RESEARCH ARTICLE

Use of citizen science to identify factors affecting bird–window collision risk at houses

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ABSTRACT

Bird–window collisions at houses have been identified as a significant source of mortality for North American birds, but which types of houses and windows are most problematic remains poorly understood. We assessed how neighborhood type, yard conditions, house attributes, and window type influenced collision rates. Data were collected from citizen scientists across Alberta, Canada, who surveyed their houses daily. In relation to the best-fitting model, the yard model explained 58.1% of the explained deviance, the neighborhood model 45.6%, and the house model 42.6%. The factors that had the largest effect for predicting collision risk included season and whether the house was in a rural or an urban area (rural areas in the fall had a 6.0× higher collision risk than urban areas in the winter), the height of vegetation in the front yard of the house (trees >2 stories high increased collision risk by 3.6× compared to houses with no trees), and the presence of a bird feeder (which increased collision risk by 1.7×). This suggests that multiple factors affect collision rates and that the suitability of a yard as bird habitat is likely a key driver. Given that few homeowners are likely to take an approach that reduces the number of birds in their yards, future focus needs to be given to bird-friendly urban design and developing the most effective window deterrents so that collisions can be reduced and birds enjoyed in urban environments.

Keywords: avian mortality, bird mortality, bird–window collisions, buildings, citizen science, glass, urban birds

Utilisation de la science citoyenne pour identifier les facteurs qui affectent le risque de collision entre les oiseaux et les fenêtres des maisons

RÉSUMÉ

Les collisions entre les oiseaux et les fenêtres des maisons ont été identifiées comme une source de mortalité importante des oiseaux d'Amérique du Nord. Toutefois, on comprend mal quels types de maisons et de fenêtres sont les plus problématiques. Nous avons évalué comment le type de quartier, l'état de la cour, les caractéristiques de la maison et le type de fenêtre influençaient les taux de collision. Les données ont été recueillies à l'aide de citoyens scientifiques de l'Alberta, au Canada, qui ont effectué des recherches quotidiennes autour de leur maison. Par rapport au meilleur modèle, le modèle sur la cour expliquait 58,1 % de la déviance expliquée, le quartier 45,6 % et la maison 42,6 %. Les facteurs qui avaient le plus d'effet pour prédire le risque de collision comprenaient la saison et si la maison était dans un milieu rural ou urbain (les milieux ruraux à l'automne avaient un taux de collision 6,0 fois plus élevé que les milieux urbains en hiver), la hauteur de la végétation dans la cour avant de la maison (les arbres d'une hauteur de plus de deux étages augmentaient le risque de collision de 3,6 fois comparativement aux maisons sans arbre), et la présence d'une mangeoire à oiseaux (la présence de mangeoires augmentait le risque de collision de 1,7 fois). Ceci suggère qu'il existe un certain nombre de facteurs affectant les taux de collision et que la qualité d'une cour comme habitat pour les oiseaux est possiblement un facteur clé. Puisque peu de propriétaires de maisons sont susceptibles d'adopter une approche qui réduit le nombre d'oiseaux dans leur cour, il faut concentrer les priorités futures sur une conception urbaine respectueuse des oiseaux et sur le développement de moyens dissuasifs près des fenêtres pour réduire les collisions et permettre d'apprécier les oiseaux dans les milieux urbains.

Mots-clés: collisions entre les oiseaux et les fenêtres, mortalité des oiseaux, mortalité aviaire, oiseaux urbains, bâtiments, science citoyenne, vitre

INTRODUCTION

Accidental bird mortality caused by human activities is increasing worldwide (Calvert et al. 2013). The results of recent studies demonstrate that large numbers of birds are colliding and dying at the windows of houses each year (Machtans et al. 2013, Loss et al. 2014). Such studies have focused on estimating the magnitude of bird–window

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collisions, which has increased awareness of the bird–window collision issue among the general public. This awareness has led to calls to determine which types of houses and windows are most problematic, because it is poorly understood why one house has more collisions than another (Machtans et al. 2013, Loss et al. 2014). Having such information would aid in the design of effective mitigation strategies for reducing bird–window collisions (Klem 1989, 2015, Dunn 1993, Klem et al. 2004, Bayne et al. 2012, Hager et al. 2013, Klem and Saenger 2013, Kummer et al. 2016).

To date, the 4 studies that have looked at bird–window collisions with houses have been focused on different aspects of window collision risk, which makes it difficult to generalize results (Klem 1989, Dunn 1993, Bayne et al. 2012, Hager et al. 2013). Klem (1989) conducted a review of anecdotal reports and concluded that bird feeders and the type, size, and placement of glass were the most important predictors of collisions. Dunn (1993) found that bird–window collisions occurred in proportion to the numbers of birds present at feeders. The most recent studies, by Bayne et al. (2012) and Hager et al. (2013), have shown that structural attributes of houses and environmental factors related to neighborhoods influenced window collision risk, but they didn't evaluate the relative effects of window type or yard attributes.

We propose that the factors influencing bird–window collisions can be categorized into 4 levels based on spatial scale: neighborhood type, yard conditions, house attributes, and window types. No single study has addressed the relative importance of these categories at once. Understanding the level that has the greatest impact on bird–window collisions has implications for prioritizing mitigation options. For example, if bird–window collisions are most strongly predicted by attributes of a neighborhood, mitigation efforts could be focused in particular areas through information campaigns. However, if window type (i.e. reflective vs. 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 how variables at each of the 4 levels influence bird–window collisions at houses. We predicted that the neighborhood and yard levels would have a greater effect on window collision risk than individual house or window attributes. Our logic was that birds are attracted to neighborhoods with appropriate vegetation first, because the yard of any given house is not large enough to support the needs of an individual bird. Birds should select houses with bird feeders and greater structural and compositional complexity of vegetation over those without such attributes. We also predicted that the factors that have the largest effect would differ between species that use feeders and those that do not. Species that use feeders were predicted to be more likely to collide with windows when a house had a feeder, whereas vegetative factors that attract all birds were predicted to have a greater influence on species that don't use feeders.

METHODS

Data Collection Protocol

The Birds and Windows Project (http://birdswindows.biology.ualberta.ca) was initiated in 2013 with a survey that asked respondents to recall bird–window collisions they had observed in the past. That survey also recruited participants to systematically monitor the perimeter of their house daily for evidence of a bird–window collision. In these standardized searches, forms of collision evidence included dead or injured birds and/or body smudges, feathers, or blood on windows. If a participant saw or heard a collision outside of their daily perimeter search, that was included as well. Participants were asked to record every day they searched for evidence. This was done to account for searcher effort and to ensure that days with no collisions were recorded. Participants were asked to search within a 2 m perimeter of their home; 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, on balconies and sidewalks, and on all windows 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 house once, participants were asked to reverse their direction and walk around a second time.

People living in apartments were also encouraged to participate. These participants were asked to walk the perimeter of the entire building and check the balconies of their unit. Participants living in houses attached to at least one other dwelling (row housing, duplexes, semidetached, and single-attached houses) were required to search the perimeter and exterior walls of their individual unit only. Detached garages were also monitored. The building classes used were based on the types of households provided by Statistics Canada (Government of Canada 2005).

Registered participants who stopped reporting evidence of collisions were contacted after a few months to encourage them to continue. When registering with the survey, participants had the option of requesting a weekly email reminding them to participate. All observations were checked for consistency. Confirmation emails were sent to participants with suspicious entries (e.g., 30 observations entered at once, multiple collisions entered in one day, collisions entered for dates before the participant had registered with the project). If confirmation of observations was not provided, we excluded them from analysis.

Data Entry Protocol

When participants registered, information was collected on house and yard characteristics. The questions included in this analysis were as follows: (1) What is your address? (2) What type of building do you live in (row housing, duplex, semidetached, or single-attached) (BUILDINGTYPE)? (3) How many windows are in your house (WINDOWNUM)? (4) What is the square footage of your house (SQRFOOT)? (5) How many stories are in your house (NUMSTORIES)? (6) In what year was your house built (YRBUILT)? and (7) How many of each bird attractant (bird feeder, birdbath, birdhouse) can be found within the following distances from your house ($<$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 were further classified to answer these questions: (1) Do you have a bird feeder within 10 m of your house (FEEDYESNO)? and (2) How many bird feeders are within 10 m of your house (FEEDCOUNT)?

Following completion of the survey, participants were directed to the protocol for collecting data on collisions. An onscreen calendar was used to track the days they searched for evidence from the day of registration forward. Each day the participant searched their house, they were asked to enter evidence of whether or not a collision was found into a calendar. We assumed that participants walked around their house and searched once a day. If no collision evidence was observed on that day, there were no additional questions. When a collision was reported, we asked (1) What was the collision evidence? and (2) What species of bird was involved in the collision? Participants were also asked to email or upload photos of collision evidence to our 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 involved in the collision and an additional window selected by the homeowner. These included (1) What is the size of each window (AREA)? (2) What is the height of the bottom of each window from the ground (HEIGHT)? (3) What direction does each window face (DIRECTION)? (4) When you look into each window, can you see the reflection of vegetation (REFLECTION)? (5) What type of glass are the windows (clear dual- or tri-pane, low-E, "SunStop"/ultraviolet [UV] reflective) (GLASSTYPE)? (6) On what side of the house are the windows (front, back, or side) (SIDE)? (7) What is the distance from each window to the nearest bird attractant (bird feeder, birdbath, birdhouse) (ATTRACTTYPE)? and (8) What is the nearest bird attractant (ATTRACTDIST)?

Using the addresses and/or postal codes provided by participants, Google Earth Pro was used to determine (1) whether the location of each house was in an urban or rural setting (URBANRURAL), (2) the distance of the house from a natural treed area (DISTNAT), (3) the average height of vegetation in the front yard of each house (VEGHEIGHT), and (4) the main and second dominant landscape types estimated within 50 m of the house (LANDSCAPE and LANDSCAPE2). Houses were classified as urban or rural on the basis of definitions provided by Statistics Canada (Government of Canada 2011). An urban area was defined as having a population of $\geq$1,000 people and a density of $\geq$400 people km^{-2}. The 4 landscape types included (1) structures—houses and all additional buildings; (2) pavement—roads and sidewalks; (3) canopy—tree cover and forest; and (4) exposed habitat—open lawn, grass, and field. For this classification, we used the methods and land-cover types outlined in Hager et al. (2013). Because urban bird diversity and abundance are positively correlated with vegetation and negatively correlated with urban surfaces (Hager et al. 2013), we also included 2 broader categories: (1) undeveloped—canopy and exposed habitat; and (2) developed—structures and pavement (LEVELDEVEL).

Species-specific Details

Species-specific information was determined through participant answers on our website and from submitted photos. All photos were identified to the species level when possible, and this overrode classification by the participant when they differed. If the participant identified the bird as 1 of 2 species, it was classified as unknown (e.g., "chickadee or sparrow" became "unknown"). Many participants identified the bird to broader groupings. For most groupings, there was $>$1 species from that group that could be found in Alberta, Canada, and so the birds could not be accurately classified to species (e.g., "waxwing" became "waxwing sp."). A total of 80 birds that collided with a window were sparrow species but could not be identified further; they could have been from Emberizidae or Passeridae. Likewise, some birds identified as grosbeaks could have belonged to either Cardinalidae or Fringillidae.

We used the above rules and information from the Cornell Lab of Ornithology (2015) to divide birds into two categories: (1) "feeder birds" are species that frequent bird feeders, such as Black-capped Chickadee, Dark-eyed Junco, and House Sparrow; and (2) "nonfeeder birds" are species that do not frequent feeders, such as Cedar Waxwing, Bohemian Waxwing, and American Robin (scientific names of species are given in Appendix Table 4). When the bird could not be identified to species, the most likely classification for that group was used (e.g., "chickadee species" became "feeder bird" and "waxwing species" became "nonfeeder bird").

TABLE 1. Predictor variables (defined in the text) for each model at the neighborhood, yard, house, and window levels for factors affecting bird–window collisions at houses in Alberta, Canada. 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.

Variable	Format
Neighborhood level	
URBANRURAL	Categorical
DISTNAT	Continuous
Yard level	
VEGHEIGHT	Categorical
LANDSCAPE	Categorical
LANDSCAPE2	Categorical
LEVELDEVEL	Categorical
FEEDYESNO	Categorical
FEEDCOUNT	Continuous
House level	
BUILDINGTYPE	Categorical
SQRFOOT	Categorical
NUMSTORIES	Categorical
WINDOWNUM	Categorical
YRBUILT	Categorical
Window level	
AREA	Categorical
HEIGHT	Categorical
GLASSTYPE	Categorical
DIRECTION	Categorical
SIDE	Categorical
REFLECTION	Categorical
ATTRACTTYPE	Categorical
ATTRACTDIST	Continuous

Data Analysis

Using the number of collisions (including zeros) reported by each participant for each day they searched their house, 3 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 neighborhood, yard, and house levels affecting the number of bird–window collisions each day. Participants were asked to collect data for a minimum of 28 days, but many did not attain this minimum. The random effect in these models was the individual house, and it accounted for the fact that we measured the number of collisions on a daily basis at the same house repeatedly. In theory, any amount of sampling (1 day, 1 wk, 1 mo, or 1 yr) could be analyzed by this approach without having to correct for differential sampling effort, given that the collision rate was estimated on a daily time interval. However, when we looked at sampling effort, there were 3 major groupings in the data: (1) participants who reported $\leq$3 days of sampling, (2) participants who entered 4–27 days of data, and (3) participants who collected data for 1 mo (28 days) or more. The number of days of monitoring per participant ranged from 1 to 610 and did not fit any statistical distribution particularly well. Inclusion of these categories as a fixed effect improved model fit considerably.

A fixed effect for season was included because we have previously shown seasonality to be the best individual predictor of bird–window collisions at houses in Alberta (Kummer and Bayne 2015). Seasons were defined as follows: winter = October 15–March 14; spring migration = March 15–May 14; summer breeding = May 15–August 14; and fall migration = August 15–October 14. The random effect for house identity, number of days searched, and season represented our baseline model.

A summary of the neighborhood, yard, and house variables analyzed at each level is provided in Table 1. Models were compared using Akaike's Information Criterion (AIC; Burnham and Anderson 2004). Forward stepwise selection using AIC determined the variables within each level that resulted in the best model fit. When deciding on variables for inclusion within each level, there were often variables with high collinearity. In these cases, the variable with the best fit in direct comparisons was selected. Specifically, the combinations of LEVELDEVEL vs. LANDSCAPE and FEEDYESNO vs. FEEDCOUNT were identified by AIC. Interactive effects for (1) URBANRURAL*SEASON, (2) LEVELDEVEL*SEASON, (3) FEEDYESNO*SEASON, (4) SQRFOOT*SEASON, and (5) YRBUILT*SEASON were also compared. We tried to evaluate the interactions (1) VEGHEIGHT*SEASON, (2) BUILDINGTYPE*SEASON, (3) NUMSTORIES*SEASON, and (4) WINDOWNUM*SEASON, but there were insufficient observations to achieve model convergence.

Once we had determined the best-fitting neighborhood, yard, and house models, we compared the fit via AIC and analysis of deviance (ANODEV; Harris et al. 2005) to determine which model explained the greatest amount of variation in the number of bird–window collisions. For the analysis of deviance, we compared the fit of each model to the baseline model. Each of the individual variables identified as being predictive in the best-fitting neighborhood, yard, and house models was used with backward stepwise selection based on AIC to determine the overall best-fitting model.

Bird feeders can increase bird–window collision risk (Klem et al. 2004, Bayne et al. 2012). We have previously shown that the impacts of bird feeders are greatest for species that frequently visit feeders (Kummer and Bayne 2015). As a result, the neighborhood and yard models were also run (1) using collisions from birds that frequent feeders only and (2) using collisions by those birds that do not frequent feeders. Insufficient collisions within feeder and nonfeeder birds were observed to run the house or window models.

A case-control logistic regression model (command "clogit" in Stata 13) was used to determine factors affecting collisions at the window level by pairing the collision and noncollision window information. The effect of AT-

TABLE 2. Akaike's Information Criterion (AIC) scores for each model at the baseline, neighborhood, yard, and house levels, and the overall best model for factors affecting bird–window collisions at houses in Alberta, Canada. Summary includes the relative difference between models and the best model (ΔAIC), Akaike weights (w_i), log-likelihood (L), number of parameters (K), and percentage of deviation explained vs. the simplest and fullest models (ANODEV). ANODEV is equal to the difference in model deviance ($-2L$) between the baseline model and the current model, divided by the difference between the baseline model and the most complex model. Only models with $w_i > 0.10$ are included.

Model	AIC	ΔAIC	w_i	L	K	ANODEV
Baseline						
EFFORT + SEASON + USER	7,239.51	0.00	1.00	−3,611.75	8	0%
Neighborhood						
URBANRURAL*SEASON	7,179.76	0.00	0.70	−3,576.88	13	45.64%
URBANRURAL*SEASON + DISTNAT	7,181.44	1.68	0.30	−3,575.72	15	47.15%
Yard						
LEVELDEVEL + FEEDYESNO*SEASON + VEGHEIGHT	7,170.70	0.00	0.65	−3,567.35	18	58.11%
LEVELDEVEL + FEEDYESNO + VEGHEIGHT	7,172.05	1.35	0.33	−3,571.02	15	53.30%
House						
WINDOWNUM + YRBUILT + BUILDINGTYPE	7,192.36	0.00	0.62	−3,579.18	17	42.63%
WINDOWNUM + YRBUILT	7,195.18	2.82	0.15	−3,582.59	15	38.16%
WINDOWNUM + YRBUILT + BUILDINGTYPE + NUMSTORIES	7,195.35	2.99	0.14	−3,575.67	22	47.22%
Overall						
URBANRURAL*SEASON + VEGHEIGHT + LEVELDEVEL + FEEDYESNO + WINDOWNUM	7,133.12	0.00	0.27	−3,542.56	24	90.55%
URBANRURAL*SEASON + VEGHEIGHT + LEVELDEVEL + FEEDYESNO + BUILDINGTYPE + WINDOWNUM	7,133.35	0.23	0.24	−3,540.67	26	93.02%
URBANRURAL*SEASON + VEGHEIGHT + FEEDYESNO + BUILDINGTYPE + WINDOWNUM	7,133.94	0.82	0.18	−3,542.97	24	90.01%
URBANRURAL*SEASON + VEGHEIGHT + LEVELDEVEL + FEEDYESNO + WINDOWNUM + YRBUILT	7,134.08	0.96	0.16	−3,540.04	27	93.85%
URBANRURAL*SEASON + VEGHEIGHT + LEVELDEVEL + FEEDYESNO + BUILDINGTYPE + WINDOWNUM + YRBUILT	7,134.38	1.26	0.14	−3,538.19	29	96.27%
URBAN*SEASON + VEGHEIGHT + UNDEVEL + FEEDYESNO + BUILDING + WINDOWS + YRBUILT + STORIES	7,138.68	5.56	0.02	−3,535.34	34	100%

TRACTTYPE was dropped because there was no within-group variation and is not discussed further. As a result of the design having a sample from windows where collisions were observed vs. windows without a collision in the same house, seasonality could not be tested at the window level.

RESULTS

Bird–Window Collisions

Since the launch of the project, there were 34,114 recorded days of monitoring from participants in Alberta. Within these observations, there were 930 collisions and 102 fatalities. It is unknown whether the bird survived in 219 of the collision events; 76 collisions were verified through photos. Only homeowners in Alberta were included in the analysis.

Bird–Window Collision Factors

A model based on negative binomial distribution provided a much better fit for daily collision rate than one based on a Poisson distribution ($\alpha = 7.88$, $\Delta\text{AIC} = 29.42$). Including the individual house as a random effect improved model fit in relation to standard negative binomial regression ($\chi^2 = 1{,}142.87$, $P < 0.001$). The addition of the categorical variable for participant effort improved model fit, with a ΔAIC value of 33.53 compared to the model with no participant effort. People who participated for <4 days were 3.4× more likely to report a collision than those who participated for >1 mo. Similar numbers of collisions were seen during fall migration and summer breeding. There were fewer collisions during spring migration, and the number decreased dramatically in the winter months. The inclusion of season improved model fit, with a ΔAIC value of 91.11 compared to the model without season.

Models at all 3 levels could predict the number of collisions. The yard variables explained more of the variation than the neighborhood ($\Delta\text{AIC} = 9.06$) and house ($\Delta\text{AIC} = 21.66$) variables (Table 2). For the overall model, there were several models within a ΔAIC value <2. While these models differed slightly, the best-fitting and more parsimonious models always included whether the house was located in an urban or a rural area (a neighborhood-level variable), the average height of vegetation in the front yard of the house (a yard-level variable), and bird-feeder presence (a yard-level variable) (Table 2). In relation to the best-fitting overall model, ANODEV indicated that the yard model explained 58.1% of the explained deviance, the neighborhood model 45.6%, and the house model 42.6%. This indicates that the overall model could explain considerably more variation than models at the other

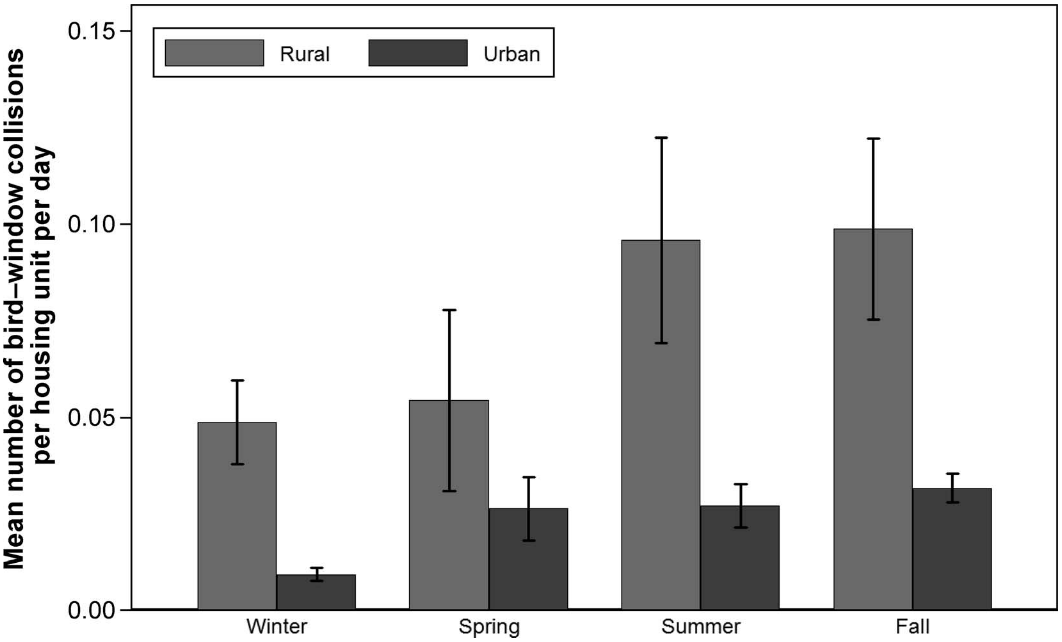

FIGURE 1. Mean number of bird–window collisions per housing unit for every day of each season (winter, spring migration, summer breeding, and fall migration), subdivided by whether the residence was in an urban or a rural location. Data were collected from citizen scientists across Alberta, Canada, who surveyed their houses daily. Error bars represent 95% confidence intervals.

levels. Model coefficients and incident-rate ratios for the best-fitting model are provided in Appendix Table 5.

At the neighborhood level, the most parsimonious model included the URBANRURAL*SEASON model, with ΔAIC = 1.68 compared to the next-best model, which contained more parameters (Table 2 and Appendix Table 5). Rural houses during fall had a daily collision risk 10.8× greater than that of urban houses in winter. Rural houses consistently had a higher risk of a collision than urban houses in all seasons, and collision risk during fall was 1.2× to 1.4× greater than that of the next closest season (Figure 1).

At the yard level, the level of development was a better predictor than the dominant landscape type (ΔAIC = 3.32) and bird-feeder presence was a better predictor than the number of feeders present (ΔAIC = 12.89). The model that provided the best fit for the yard level was VEGHEIGHT + LEVELDEVEL + FEEDYESNO*SEASON, with ΔAIC = 1.35 compared to the next-best model (Table 2 and Appendix Table 5), which included LEVELDEVEL + FEEDYESNO + VEGHEIGHT only. The interactive model indicated that houses with a bird feeder present during fall had a 6.0× greater collision risk per day than houses without a feeder during winter (Figure 2). Spring and fall consistently had greater collision rates than the other seasons. Houses with an undeveloped landscape were 2.2× more likely to have a collision than houses with a developed landscape, and houses with vegetation in their front yards that was 2–3 stories high had a collision risk 4.3× greater than houses with no trees or shrubs.

The model that provided the best fit at the house level included WINDOWNUM + YRBUILT + BUILDINGTYPE, with ΔAIC = 2.82 compared to the next-best model (Table 2 and Appendix Table 5). The next-best model did not include the type of building. Compared to apartments, single-attached houses were 2.3× more likely to have a collision, and row housing and duplexes were 1.6× more likely to have a collision. Houses built before 1970 had a collision risk 1.7× greater than houses built after 1990, and houses with >10 windows were 2.1× more likely to have a collision than houses with ≤ 5 windows.

For the window level, 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 ΔAIC = 1.95 compared to the next-best model, which included all these variables as well as the height of the window from the ground (Table 3 and Appendix Table 5). The collision window was 1.9× more likely to be on the front of the house than on the back of the house, and 5.6× more likely to reflect vegetation than to not reflect vegetation. Windows where vegetation was only sometimes reflected were 3.0× more likely to be the collision window than windows that did not reflect vegetation. The collision window was 1.7× more likely to be low-E glass and 1.5× more likely to be UV glass, compared to regular glass. The collision window was only slightly more likely to face south than to face the other directions. A direct comparison could not be made between the window level and the other

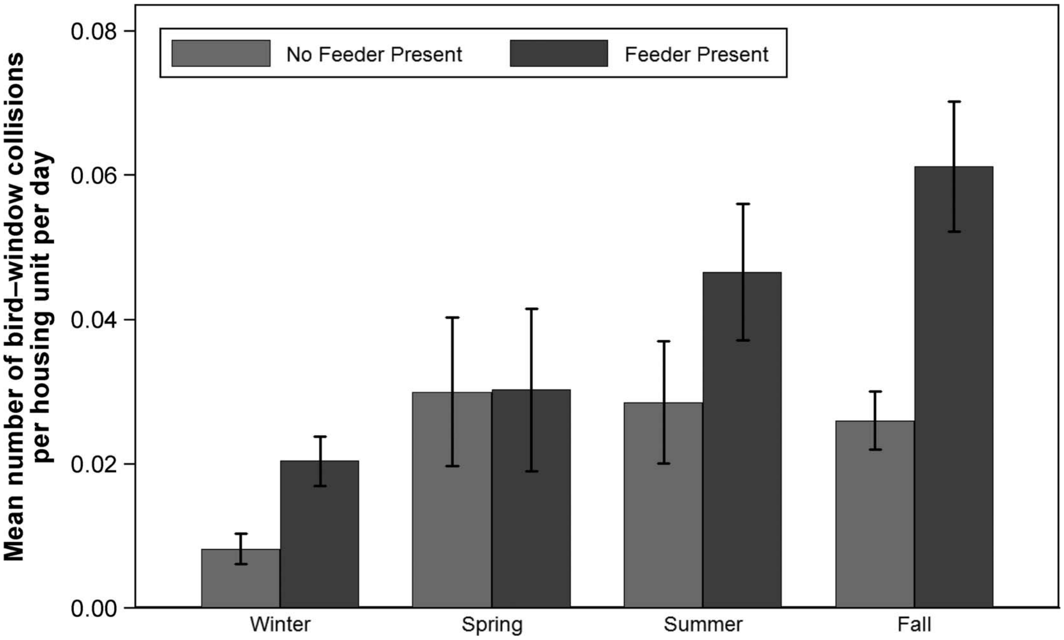

FIGURE 2. Mean number of bird–window collisions per housing unit for every day of each season (winter, spring migration, summer breeding, and fall migration), subdivided by whether there was a bird feeder present at each residence. Data were collected from citizen scientists across Alberta, Canada, who surveyed their houses daily. Error bars represent 95% confidence intervals.

3 levels because we were not able to track collisions at individual windows over time.

Feeder and Nonfeeder Birds

For birds that frequent feeders, the variables at the yard level explained more of the variation in the number of collisions than the neighborhood model (ΔAIC = 34.92). The best model for nonfeeder birds was the neighborhood model (ΔAIC = 0.64), although model fit at the yard level was similar (Appendix Table 6). There were several models for nonfeeder birds at the yard level that did not achieve model convergence because of the smaller number of collisions in this group.

URBANRURAL*SEASON was included in the best model at the neighborhood level when all birds were included and for feeder birds alone (ΔAIC = 3.92 compared to the next-best model). The interactive effect of URBANRURAL*SEASON did not improve model fit for nonfeeder birds, and the best model included only whether the house was in an urban or a rural location, with ΔAIC = 2.22 compared to the next-best model (Appendix Table 6).

The best model at the yard level 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 by 6.1× for feeder species. The best model for nonfeeder birds at the yard level was FEEDYESNO, with ΔAIC = 1.10 compared to the next-best model (Appendix Table 6). The presence of a bird feeder was predicted to result in a 3.0× increase in collision risk for nonfeeder birds.

Species-specific Susceptibilities

Ideally, we wanted to build models of collision risk for individual species. However, this was not possible given our sample sizes. Only 497 collisions could be identified to species or family. There were collisions from 53 different species. Species that frequent feeders accounted for 295 of the identified collisions, and birds that do not visit feeders

TABLE 3. Akaike's Information Criterion (AIC) scores for each model of factors affecting bird–window collisions at houses in Alberta, Canada, at the window level. Summary includes the relative difference between models and the best model (ΔAIC), Akaike weights (w_i), log-likelihood (L), and number of parameters (K). Only models with $w_i > 0.0$ are included.

Model	AIC	ΔAIC	w_i	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

accounted for 202. The most common families were Paridae (8.78% of birds collided), Bombycillidae (7.07%), Turdidae (4.93%), Emberizidae (4.71%), and Corvidae (3.96%). The total number of collisions in each family was often dominated by a large number of collisions for a single species within the group. Collisions within Paridae were predominantly by Black-capped Chickadees ($n = 50$), and those within Emberizidae were predominantly by Dark-eyed Juncos ($n = 31$). Collisions within Bombycillidae were evenly split between Bohemian Waxwings ($n = 30$) and Cedar Waxwings ($n = 24$). The Turdidae were all American Robins ($n = 40$). Within Corvidae the greatest numbers of collisions were by Blue Jays ($n = 12$) and Black-billed Magpies ($n = 22$). The total number for each species and their survival rates are provided in Appendix Table 4. Because the birds categorized as "sparrow sp.," "chickadee sp.," and "waxwing sp." could not be identified further, the numbers for Black-capped Chickadees, House Sparrows, and both waxwing species are likely higher than the values reported.

DISCUSSION

Factors Affecting Bird–Window Collisions

The yard model explained more of the variation in bird–window collision rates than the neighborhood or house models. However, all 3 of these models were predictive and each of the parameters in the best-fitting individual models had a large influence on collision rates. The presence of a bird feeder, whether the house was in an urban or a rural location, and the height of vegetation in the front yard were the most important and consistent predictors of bird–window collisions across categories. These results are comparable with those of other studies that have focused on a single level of our 4 categories. Many of the variables at the house level no longer improved model fit when we controlled for neighborhood and yard attributes, yet they had coefficient estimates with 95% confidence intervals that did not overlap zero.

Consistent across studies is the fact that bird-feeder presence and complex vegetation within yards 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 increases, so does the likelihood of a bird–window collision (Dunn 1993). In current estimates of bird–window collision rates (Machtans et al. 2013, Loss et al. 2014), the strata used to obtain North American estimates relied primarily on whether the house was in an urban or a rural location. This suggests that more refined and accurate estimates of total numbers of collisions might be possible if feeder presence and the state of vegetation within yards could be measured.

In all seasons except spring, there were more collisions when a feeder was present than when there was not a feeder. We expected that there would be fewer species present in winter but that these resident species would be more reliant on seeds and more likely to visit a bird feeder. As a result, we expected to see a greater relative increase in collisions between houses with and without feeders during the winter. This pattern did exist but was not sufficiently large to claim that it was different compared to fall and summer. The interactive effect of feeder and season was primarily driven by the lack of difference between feeder and nonfeeder houses during the spring. One possible reason may be that the resident species present in the winter are more aware that windows are a risk, whether or not a bird feeder is present. An additional explanation may be that deciduous vegetation with no leaves, as would occur in winter, does not create a reflective situation that results in birds flying toward windows.

For nonfeeder birds, the presence of a bird feeder still increased collision rates. It is possible that houses that have bird feeders also have more complex vegetation, creating bird-friendly yards that attract nonfeeder birds. Bird-feeder presence may also be correlated with other bird attractants, such as birdhouses and birdbaths, that were not considered but could attract nonfeeder birds. Alternatively, our citizen scientists who had feeders may have been more engaged than those without feeders and, therefore, may have put more effort into searching for collisions.

The birds identified as colliding with windows represented 53 of the 421 bird species that can be found in Alberta (Royal Alberta Museum 2014) and are consistent with the results of other bird–window collision studies at 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 or colliding and dying; birds generally died in proportion to the number of collisions that occurred for that species (Arnold and Zink 2011: supplemental analyses). Machtans and Thogmartin (2014) discuss the benefit of shifting the focus away from grand totals and toward individual species in developing conservation strategies. Although we had sufficient data to thoroughly outline collision risk for feeder and nonfeeder birds, we were unable to develop species-specific collision-risk models. This suggests that research on this topic will have to remain focused on larger groups, instead of developing species-specific models, simply because of the small sample sizes most studies are able to achieve. To be able to model the effects of window collisions on species, in order to reduce bird–window collisions for species of greater concern, a collation of all bird–window studies is likely needed to achieve adequate statistical power. Only half of all collisions reported in our study could be identified to species. Our participants were looking for multiple types of window-collision evidence and, as a result, relatively fewer collisions were confirmed by the presence of a dead bird. Additionally, only a handful of homeowners submitted photographic evidence of collisions. Future studies should focus more attention on the importance of species identification when submitting observations, which may have been unknown to many of our participants.

Machtans et al. (2013) and Loss et al. (2014) based their identification of species most vulnerable to a bird–window collision on studies that consisted largely of building classes not included in the present study, and only a few of those species collided with windows of houses in our study. Some of the species those authors identified are listed as birds of conservation concern (U.S. Fish and Wildlife Service 2008), but they may be more vulnerable at low-rise and high-rise buildings than at houses. 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 with windows in our sample were urban adapters or exploiters (McKinney 2002)—populations that tolerate a broader environmental range and are generally common in an urban environment (Bonier et al. 2007).

In modeling the daily collision rate, we assumed that it had no relationship to the number of days monitored. However, participants who entered observations for less than the 1 mo outlined in the project protocol had homes with higher collision rates. In particular, participants who entered <4 observations were more than 3× as likely to report a collision, compared to those who participated for ≥ 1 mo. We suspect that the former group may simply have forgotten or chose not to enter the days when they didn't observe a collision, given that these participants entered only a few observations, which were almost always collisions.

The random effect for individual house was very large in our baseline model. Including variables that describe variation between houses should have reduced this effect. The random effect was smaller in the overall model, but there remained a significant random effect of house when all other covariates were included. Two possible explanations for this effect are that (1) homeowners differed in their ability to find bird–window collision evidence and (2) there are additional factors affecting collision risk at individual houses that have not been accounted for. Future work that compares homeowners' observations to some type of "gold standard" of evidence (e.g., cameras at windows) is needed to better understand this effect.

The best model for the window level could not be directly compared to those for the other 3 levels because we have only a subsample of all entered collisions and there are multiple entries for some participants and none for others. One homeowner provided information on the collision and noncollision windows after 26 separate collisions. The paired design accounted for within-house variation when there was only 1 entry house^{-1}, but this did not fully account for a house effect when there were multiple entries from the same house. In having >1 entry house^{-1}, it is possible that some windows switched from being collision to noncollision windows between different events. Ideally, to complete a thorough analysis, we would have information on all the windows of each house and information on the numbers of collisions occurring at each window. This was not tenable with citizen scientists.

Reducing Bird–Window Collision Risk

Recent studies have attempted to look at bird–window collisions from the level of urban design. Sushinsky et al. (2013) suggest that 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 backyards. Maintaining large natural areas and reducing the size of yards may offer ecological value in promoting future urban conservation while reducing bird–window collision risk at houses. This idea could be beneficial in future developments. However, established urban areas are already dominated by developed neighborhoods and abundant vegetation. Recently, these areas are experiencing an influx of new development as older houses are being replaced by larger houses (Wilson and Boehland 2005) that often have more windows. In these areas, mature vegetation and canopy cover are naturally attracting birds to yards. If homeowners place a bird feeder in their yard, both feeder and nonfeeder birds will likely choose that yard over a neighboring one. Bird feeders consistently lead to an increase in the number of bird–window collisions (Klem et al. 2004, Bayne et al. 2012, Kummer and Bayne 2015, Kummer et al. 2016), and we have shown that this is not entirely dependent on whether the bird is actually feeding at the feeder. Eliminating bird feeders may appear to be an easy fix, but this alone will not solve the problem of bird–window collisions.

Factors that increase bird abundance have the largest effect on bird–window collisions, and feeders are only one of these attractants. Reduced vegetation cover and abundance might reduce collisions but would presumably reduce bird habitat quality in urban areas. This is a difficult trade-off, and we don't know whether the overall effect on bird population growth rates created by feeding opportunities and natural vegetation for nesting in yards compensates for the reduced survival caused by windows. While the yard-level model was slightly better in determining bird–window collision risk, house and window factors also have an effect. Although the latter factors are not as predictive, overall, as the yard-level factors, there may be an increased collision risk if they occur in conjunction with the abundant and mature vegetation often found in an established neighborhood. Also, our sample size was not large enough to test for a seasonal interactive effect with some house- and yard-level variables. With a larger sample of houses, these interactions might be shown to have a greater influence on collision risk.

Whether a 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 might lead to an increased number of collisions. With abundant vegetation present, it seems likely that clear, nonreflective windows will help reduce collision risk, but more explicit tests are required. At the house level, the number of windows in a house was a reasonable predictor. However, this was not an important predictor once yard and neighborhood variables were included. It seems logical that collision risk increases as the amount of glass in a house increases. However, we suspect that this relationship likely occurs only if there is an interaction with abundant vegetation. Many of the houses with a large number of windows are newer and, as such, have not developed complex vegetation structure. In the future, as these houses age and the vegetation matures, it is likely that collisions will increase. In general, newer houses have more exterior glass (Wilson and Boehland 2005) than older ones, which means that bird collisions may increase in the future. Previous studies have reported that collisions occur mainly at large windows and when there is abundant sheet glass on a building (Klem 1989, Hager et al. 2013). However, window size was not a strong predictor in our models, so we cannot refute or support those results.

Given that few homeowners want to stop having birds in their yards, we believe that the scientific research on bird–window collisions needs to shift toward developing the most effective deterrents at the widow level for reducing collisions. A localized study in which deterrents are added to or removed from the windows of a house over time would be helpful in determining the most effective deterrent designs for different types of neighborhoods and yards. To date, only a handful of studies have looked at bird–window collision deterrents (Klem 1990, Klem et al. 2009, Klem and Saenger 2013, Rössler et al. 2015), none of which were conducted in an actual residential setting. As new products are developed, lab-type studies are producing supporting evidence for their efficacy (e.g., WindowAlert, http://windowalert.com; American Bird Conservancy BirdTape, http://www.abcbirdtape.org/; Ornilux Bird Protection Glass, http://www.ornilux.com/; Feather Friendly Bird Deterrent Window Films, http://www.conveniencegroup.com/featherfriendly/feather-friendly). However, to our knowledge, no scientific study has tested window deterrents at houses already experiencing bird–window collisions. Moving forward, effort should be focused on finding the best technique for reducing window collisions that is also cost effective and socially acceptable. Some current deterrent methods have not been embraced by homeowners because they are not aesthetically pleasing. Products are needed that maintain a transparent appearance for the homeowner while transforming the pane into an obstacle that is visible to the bird.

There is a growing movement toward bird-safe buildings and eco-friendly design, but the guidelines that have been established (e.g., City of Toronto Green Development Standard 2007, New York City Audubon 2007, San Francisco Planning Department 2011, Sheppard 2011) are largely focused on mid- and high-rise buildings, and few strategies currently exist for bird-safe residential buildings. While many birds are colliding with the windows of houses and many birds are dying as a result, the effect of these collisions on populations of backyard birds remains unknown. Without knowing the individual risk per yard, it remains difficult to understand the effect of bird-friendly yards on collision risk. Bird–window collisions at houses may or may not be a conservation issue in the context of declining species, but homeowners take pride in their houses and often enjoy having a large number of birds in their yards. These homeowners are likely to be at the forefront in determining ways to reduce collision risk. Both aesthetically and emotionally, bird–window collisions are having an effect on homeowners (Belaire et al. 2015). A large number of birds are colliding with the windows of houses, and scientific focus in the future needs to be given to bird-friendly urban design and developing the most effective window deterrents that still allow homeowners to enjoy urban birds in their yards.

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APPENDIX

APPENDIX TABLE 4. Sample size (*n*) and percentage of all reported bird–window collisions by species, with number and percentage of total that collided with windows and died, number and percentage of total that collided and survived the collision, and number for which survival was unknown. Data were collected from citizen scientists across Alberta, Canada, who surveyed their houses daily.

Species	*n*	Percentage of total reported collisions	Survived (*n*)	Survived (percentage of total)	Died (*n*)	Died (percentage of total)	Survival unknown (*n*)
Unknown	435	46.57	248	40.52	24	23.30	163
Sparrow sp.	63	6.75	53	8.66	4	3.88	6
Black-capped Chickadee (*Poecile atricapillus*)	50	5.35	46	7.52	2	1.94	2
American Robin (*Turdus migratorius*)	40	4.28	28	4.58	4	3.88	8
Chickadee sp.	31	3.32	27	4.41	1	0.97	3
Dark-eyed Junco (*Junco hyemalis*)	31	3.32	21	3.43	8	7.77	2
Bohemian Waxwing (*Bombycilla garrulus*)	30	3.21	20	3.27	9	8.74	1
Cedar Waxwing (*Bombycilla cedrorum*)	24	2.57	9	1.47	9	8.74	6
Black-billed Magpie (*Pica hudsonia*)	22	2.36	16	2.61	1	0.97	5
House Sparrow (*Passer domesticus*)	18	1.93	13	2.12	4	3.88	1
Downy Woodpecker (*Picoides pubescens*)	13	1.39	11	1.80	1	0.97	1
Blue Jay (*Cyanocitta cristata*)	12	1.28	10	1.63	0	0.00	2
Waxwing sp.	12	1.28	9	1.47	2	1.94	1
Pine Siskin (*Spinus pinus*)	11	1.18	8	1.31	2	1.94	1
Common Redpoll (*Acanthis flammea*)	8	0.86	7	1.14	0	0.00	1
Yellow Warbler (*Setophaga petechia*)	8	0.86	3	0.49	3	2.91	2
Rose-breasted Grosbeak (*Pheucticus ludovicianus*)	7	0.75	7	1.14	0	0.00	0
White-throated Sparrow (*Zonotrichia albicollis*)	7	0.75	3	0.49	4	3.88	0
House Finch (*Haemorhous mexicanus*)	6	0.64	6	0.98	0	0.00	0
Merlin (*Falco columbarius*)	6	0.64	3	0.49	2	1.94	1
Ruffed Grouse (*Bonasa umbellus*)	5	0.54	1	0.16	4	3.88	0
Warbler sp.	5	0.54	2	0.33	1	0.97	2
Blackbird sp.	4	0.43	2	0.33	0	0.00	2
Evening Grosbeak (*Coccothraustes vespertinus*)	4	0.43	1	0.16	3	2.91	0
Northern Flicker (*Colaptes auratus*)	4	0.43	3	0.49	1	0.97	0
Nuthatch sp.	4	0.43	3	0.49	0	0.00	1
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
Swainson's Thrush (*Catharus ustulatus*)	4	0.43	1	0.16	3	2.91	0
White-crowned Sparrow (*Zonotrichia leucophrys*)	4	0.43	4	0.65	0	0.00	0
American Goldfinch (*Spinus tristis*)	3	0.32	2	0.33	1	0.97	0
Hairy Woodpecker (*Picoides villosus*)	3	0.32	3	0.49	0	0.00	0
White-breasted Nuthatch (*Sitta carolinensis*)	3	0.32	3	0.49	0	0.00	0
Wren sp.	3	0.32	3	0.49	0	0.00	0
Yellow-rumped Warbler (*Setophaga coronata*)	3	0.32	0	0.00	1	0.97	2
American Crow (*Corvus brachyrhynchos*)	2	0.21	2	0.33	0	0.00	0
Brown Creeper (*Certhia americana*)	2	0.21	1	0.16	1	0.97	0
Hummingbird sp.	2	0.21	1	0.16	1	0.97	0
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
Tennessee Warbler (*Oreothlypis peregrina*)	2	0.21	1	0.16	0	0.00	1
Western Tanager (*Piranga ludoviciana*)	2	0.21	0	0.00	2	1.94	0
American Kestrel (*Falco sparverius*)	1	0.11	0	0.00	0	0.00	1
American Tree Sparrow (*Spizelloides arborea*)	1	0.11	1	0.16	0	0.00	0
Common Grackle (*Quiscalus quiscula*)	1	0.11	1	0.16	0	0.00	0
Corvus sp.	1	0.11	1	0.16	0	0.00	0
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
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
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
Least Flycatcher (*Empidonax minimus*)	1	0.11	1	0.16	0	0.00	0

APPENDIX TABLE 4. Continued.

Species	*n*	Percentage of total reported collisions	Survived (*n*)	Survived (percentage of total)	Died (*n*)	Died (percentage of total)	Survival unknown (*n*)
Lincoln's Sparrow (*Melospiza lincolnii*)	1	0.11	1	0.16	0	0.00	0
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 Saw-whet Owl (*Aegolius acadicus*)	1	0.11	1	0.16	0	0.00	0
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
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
Ruby-crowned Kinglet (*Regulus calendula*)	1	0.11	0	0.00	1	0.97	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
Swallow sp.	1	0.11	0	0.00	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
Warbling Vireo (*Vireo gilvus*)	1	0.11	1	0.16	0	0.00	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

APPENDIX TABLE 5. Models and coefficients for the best-fitting neighborhood, yard, and house models and the best-fitting overall model for all birds that collided with windows. Data were collected from citizen scientists across Alberta, Canada, who surveyed their houses daily. Parameters are defined in the text. Summary includes the standard error (SE) for each coefficient, the *P* value to illustrate the significance of each term, and either the incident rate ratio (for each term of the neighborhood, yard, house, and overall models) or the odds ratio (for each term of the window model).

Level	Model	Coefficient	SE	$P > z$	Ratio
Neighborhood	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 story	0.595	0.831	0.474	1.813
	2–3 stories	1.450	0.822	0.078	4.264
	>3 stories	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
	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	–	–

APPENDIX TABLE 5. Continued.

Level	Model	Coefficient	SE	$P > z$	Ratio
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	3,117.948	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	2,555.38	0.994	1.91E08
	West	0.0912	0.342	0.789	1.096
	GLASSTYPE				
	Low-E	0.525	0.713	0.461	1.690
	Other	−0.060	0.821	0.942	0.942
	SunStop/UV	0.431	0.931	0.643	1.538
	Unknown	16.617	1,163.948	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 story	0.329	0.823	0.689	1.389
	2–3 stories	1.281	0.811	0.114	3.599
	>3 stories	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	–	–

APPENDIX TABLE 6. Akaike's Information Criterion (AIC) scores comparing the neighborhood and yard models for factors affecting bird–window collisions at residential houses. Data were collected from citizen scientists across Alberta, Canada, who surveyed their houses daily. Parameters are defined in the text. All models were run (1) with collisions by birds that visit feeders and (2) with collisions by birds that do not visit feeders. Summary includes the relative difference between models and the best model (ΔAIC) and Akaike weights (w_i). Some models for nonfeeder birds at the yard level could not achieve model convergence and have not been included. Only models with $w_i > 0.05$ for each group of birds have been included for each level.

	Feeder birds			Nonfeeder birds		
Model	AIC	ΔAIC	w_i	AIC	ΔAIC	w_i
Neighborhood						
URBANRURAL*SEASON	2,825.65	0.00	0.87	2,007.14	2.22	0.21
URBANRURAL*SEASON + DISTNAT	2,829.57	3.92	0.12	2,010.25	5.33	0.04
URBANRURAL	2,837.9	12.25	0.00	2,004.92	0.00	0.63
URBANRURAL + DISTNAT	2,841.75	16.1	0.00	2,008.24	3.32	0.12
Yard						
LEVELDEVEL + FEEDYESNO*SEASON + VEGHEIGHT	2,790.73	0.00	0.90	–	–	–
LEVELDEVEL + FEEDYESNO*SEASON	2,796.01	5.28	0.06	–	–	–
LEVELDEVEL + VEGHEIGHT	2,830.40	39.67	0.00	2,006.66	1.10	0.31
LEVELDEVEL	2,835.57	44.84	0.00	2,009.06	3.50	0.09
FEEDYESNO	2,828.41	37.68	0.00	2,005.56	0.00	0.54