Opening the black box of bird-window collisions: passive video recordings in a residential backyard

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Abstract

Collisions with windows on buildings are a major source of bird mortality. The current understanding of daytime collisions is limited by a lack of empirical data on how collisions occur in the real world because most data are collected by recording evidence of mortality rather than pre-collision behaviour. We deployed a home security camera system to passively record interactions between common North American bird species and residential windows in a backyard setting over spring, summer and fall seasons over two years. We captured events including collisions and near-misses in which birds approached the glass but avoided impact. Only two of the collisions resulted in immediate fatality, while most birds flew away immediately following impact. Birds approached the glass at variable flight speeds and from a wide range of angles, suggesting that the dynamic appearance of reflections on glass at different times of day may play a causal role in collision risk. Birds that approached the window at higher velocity were more likely to be immediately killed or stunned. We discuss the implications of characterizing pre-collision behaviour for designing effective collision prevention methods.

Introduction

Collisions with plate glass on buildings, transportation shelters, noise barriers and fences are a major source of bird mortality, killing hundreds of millions of birds each year in North America and resulting in uncounted mortality worldwide (Loss et al., 2014). Most bird-window collisions in North America occur at residential and low-rise buildings, the most numerous types of structure (Machtans et al., 2013; Loss et al., 2014). Developing strategies for managing the risk of bird-window collisions is an emerging priority for bird conservation management. There is mounting public and academic interest in methods for treating plate glass windows with materials that can alert birds to the presence of an obstacle to their passage so that they may avoid flying into it (Klem, 2021). However, there are few empirical data to show how birds behave in the moments leading up to a collision or how successful avoidance occurs. Characterizing pre-collision behaviour could have implications for designing collision prevention technology, because the effectiveness of deterrents will depend on birds' abilities to detect an obstacle.

Much of our knowledge about bird-window collisions has been inferred by studying bird mortality using an observational, "after-the-fact" approach. Numerous field studies have involved monitoring or surveying buildings and documenting bird carcasses and injured birds at buildings, including combinations of residential homes, institutional, and mid-rise and high-rise buildings. Monitoring studies produce empirical data that can inform conservation management in several respects. Collision monitoring provides data on the specific species that suffer collisions in a given study area (e.g., Sabo et al., 2017) and can help to identify locations of specific windows that are prone to collisions. Then, window retrofits can be justified using evidence and targeted around high-risk windows to maximize efficiency. Monitoring studies have helped to characterize the spatial, temporal, and structural factors associated with elevated collision risk for particular regions, buildings, or even specific façades. These studies have also revealed differences in collision risk across bird species. For instance, Nichols et al. (2018) analyzed multiple citizen science datasets of collision monitoring to model collision susceptibility of different groups of birds, classifying some as "supercollider" and others as "superavoiders". They found that nocturnal migrants were more susceptible to collisions than diurnal migrants, and that collision susceptibility for most species was strongly predicted by local abundance. Their top model suggested a connection between collision susceptibility and taxonomy, with genus and species categories predicting collision susceptibility in around 20% of the species represented in their dataset.Riding et al. (2020) studied façades at 16 mid-rise buildings and identified façade-level features that were associated with elevated collision risk, including proportional glass coverage, façade length and façade height, and the overall shape of the façade. Relatively fewer studies have used building surveys to document collision mortality at residential homes, perhaps because residential buildings are subject to privacy considerations (e.g., Klem et al., 1990). In recent years, citizen/community science tools are increasingly used to collect data from observations of bird-window collisions at residential homes reported by the public (e.g., Bayne et al., 2013; Kummer et al., 2016; FLAP Canada, 2021).

Observational building surveys provide strong naturalistic validity by documenting collisions as they occur in the real world but they reveal little about how collision events actually happen. For instance, if a bird is found dead below a window, nothing about the bird's condition can indicate the speed or angle at which it impacted the glass, nor can it describe what the bird was doing before it hit the window, nor the circumstances in which it failed to detect the obstacle. We also cannot generalize from the number of carcasses observed to the number of actual collisions that occurred. It is reasonable to assume that some collisions do not immediately kill or even ground the bird and would therefore not leave behind evidence to suggest that a collision occurred. No research published to date has presented the relative lethality of window collisions. Thus, we do not know the proportion of birds that strike windows which are ultimately not detected by standardized building survey protocols. Studies have examined differences among glass types and window markings in terms of effectiveness for preventing bird-window collisions by erecting panes of glass at a field site and counting the number of bird carcasses left by collisions (e.g., Klem and Saenger, 2013). However, like building surveys, these studies have not captured information about pre-collision behaviour or relative mortality.

To gain insight into how bird-window collisions occur at real buildings, we used passive video monitoring to record bird behaviour at windows. Because the behaviour of wild birds and the timing of potential collisions are unpredictable, observing collisions by passive video recording system requires a mechanism for detecting the onset of target events and filtering out noise (e.g., motion or audio detection). We used a commercial home security system in a residential backyard setting to passively record interactions between birds and window glass over two years. We analyzed footage to examine birds' behaviour in the moments leading up to potential collisions as well as outcomes of collision events.

Our analysis aimed to test the prediction[illegible]lision risk and the risk of being killed or incapacitated (i.e., stunned or injured) by a collision with a window, is related to the bird's flight velocity and angle of approach to the window. We predicted that higher flight speed, and angles of approach approximately perpendicular to the window, are more likely to result in injurious or lethal collisions. We also considered time of the day as a potential confounding factor as it can change the reflection of ambient light on the window.

Materials & Methods

Study area

We filmed in the backyard of a residential property in London, Ontario, Canada from May to October in 2019 and in 2020. The property is located immediately adjacent to a mature eastern deciduous forest nested within a suburban neighbourhood. The abundance of resident and migratory bird species in the forest and study site is presumed to be relatively high compared to the surrounding area. The property owners maintain a variety of bird feeders and bathing stations in the backyard that were included in the setup for the present study. We are aware that at a spatial level, we only gathered information from a single location, so our results and conclusions cannot be generalized to all window collisions contexts. However, we focused this study on the role of variables related to the behaviour of the animals (velocity, angle of approach, etc.) that are not well-understood. Therefore, we consider that our study can provide some novel insights for future testing despite the limited spatial representation.

The configuration of the backyard study area is shown in Figure 1. The backyard contained several bird feeders that were maintained with a combination of seed mixes by the homeowner throughout the study period. For the first year of monitoring, feeders were placed at two positions. In the second year, a third feeder was added by the homeowner positioned closer to one of the windows. The backyard also contained two bird baths as well as a large patio table with an umbrella and chairs. The position of the house relative to the mature trees on the property meant that the south-facing windows under study were shaded through most of the day and exposed to direct sunlight only in early morning (approximately 7:00-10:00 am) and late afternoon (approximately 4:00 – 5:00 pm).

Camera system

We installed four Arlo Pro 2 wireless home security cameras in the study area (VMS4430P, Netgear). The cameras recorded in 1080p resolution at 24 frames per second. Fluctuations in wireless signal strength occasionally reduced the resolution to 720p. We positioned three of the cameras along the back wall of the house immediately adjacent to three sets of large glass sliding doors (Figure 1). We used brackets to mount these cameras to the wall approximately 2 m above ground level to maximize the likelihood of the cameras capturing birds approaching the glass within the frame, given that the field of view for each lens could not capture the entirety of the nearest window. We positioned a fourth camera on a tripod near the bird feeders to provide a view of the entire backyard space. Thus, the configuration of the four cameras with overlapping fields of view allowed for most events to be captured from multiple angles.

The home security camera system provided several advantages over traditional camera traps that were useful for passive monitoring of birds interacting with windows. The cameras can be triggered synchronously to record video of a fixed duration using a combination of infrared motion detection (e.g., a bird passing in front of the lens) as well as audio (i.e., a spike in amplitude associated with the thud of a bird striking the glass). The sensitivity of each type of trigger was adjusted within each camera to optimize the signal to noise ratio and reduce the frequency of recordings being triggered by unrelated environmental events such as falling leaves, background noise or sudden changes in ambient light. In our configuration, the cameras were programmed to record synchronously for 10 seconds following a trigger, as well as 3 seconds before the trigger. The three cameras that were closest to the windows were set to medium audio sensitivity based on calibration by bouncing a bird-sized ball against the glass. The fourth camera positioned nearest to the bird feeders had audio triggers disabled to prevent that camera being triggered continuously by bird vocalizations.

The cameras uploaded video directly to a cloud server that could be accessed remotely through a web browser. In addition to the motion and audio-triggered clips organized in a digital library by timestamps, we programmed two of the cameras (1 and 4) to record on a rolling basis (using the Continuous Video Recording function) to provide a failsafe in case events failed to trigger the cameras.

Video analysis

All of the video clips that were captured using audio or motion triggers were stored on the cloud server for a period of 7 days. The continuous recorded footage recorded by two of the cameras was stored for 14 days. Footage was inspected independently throughout the study period by the first author and an assistant. We only downloaded for permanent storage footage of birds approaching or interacting with the windows were downloaded for permanent storage and included in the analyses.

We analyzed the footage visually by a single rater using a standardized protocol in VLC Media Player (VideoLan, 2006) and Microsoft Excel (Microsoft Corporation, 2021). All of footage obtained throughout the study period was processed together in one batch. We included video frames in the flight analyses that began either when the bird first entered the frame from off-camera and passed a reference point within the measurements of the backyard, or from the last spot where the bird took off from perching within the backyard (i.e., the “starting” position). The frames included in the analyses ended either when the bird impacted a window or at the frame when the bird was closest to the window. We estimated the duration of each flight by multiplying the total number of video frames included in the analysis by 0.042 sec (the duration between frames at the 24 fps recording setting used by the cameras). We estimated the distance covered by the flight was estimated by marking the change in the position of the bird across consecutive video frames and comparing the difference relative to known dimensions of the backyard. We then calculated average velocity within each recording as the total distance covered in flight divided by the total flight duration. We used a similar analysis comparing changes in the position of the bird between frames with dimensions of the backyard was used to produce an overhead map showing the approximate flight paths followed by birds as they approached the windows. We estimated the horizontal angle of approach (i.e., the azimuth) for each flight path relative to the normal angle from the window (e.g., a head-on approach at exactly 90˚ from the window would be represented as 0˚). For including horizontal angle of approach in our statistical analyses, we took the absolute value of the estimated angle and thus controlled for the direction (i.e., using values that ignore whether the bird approached from the left or right side of the window).

Statistical analyses

We presented descriptive results with means and SDs. We ran generalized linear mixed models with the afex R package (Singmann et al. 2022) with two dependent variables (probability of collision, probability of visible injury) with the same independent factors: velocity, horizontal angle of approach, and time of the day. Because we had more than one collision event per species and we did not have individuals tagged, we decided to include species as a random factor to reduce the negative statistical implications of the same individual bird approaching the feeder over the duration of the study. The probability of collision when birds were on a collision approach included two values: 0, no collision (near miss), and 1, collision. The probability of visible injury considered only birds that collided with the window, including two values: 0, animals flew away immediately, and 1, animals were stunned (i.e., landed on the ground below the window for at least 5 seconds or past the end of the video recording) or died right after the collision. Angle of approach was considered relative to the perpendicular, so we used absolute values. Time of the day was transformed into decimals. None of our independent continuous factors showed any significant correlation between them (Pearson product moment correlation $r < 0.15$, $P > 0.40$). Statistical analyses were conducted using R 4.2.0 (R Core Team 2022). The data and code for the statistical analyses and their figures are presented in Appendix A.

Ethics statement

This study adhered to the guidelines of the University of Western Ontario and the Canadian Council on Animal Care (CCAC) and all animal handling procedures were approved by the institution's Animal Care Committee (protocol 2019-118).

Results

In total, we recorded 37 events comprising 29 collisions, in which a bird contacted the glass, and 9 near-miss events, in which birds approached the glass but appeared to change flight trajectory to avoid it. We excluded 2 recorded collisions (11, 28 in figures) from the flight velocity analysis because it seemed likely that the birds were attacking their reflection on the glass and not attempting to fly through; one additional recording (19) was excluded because it did not capture enough footage before impact to be useful for measuring changes in the position of the bird. Several other recorded events in which a bird flew close to the window and either did not contact the glass nor appeared to be on a collision course were excluded from the analyses. The flight paths taken by each bird are shown for collisions and near-miss events in Figures 2 and 3 respectively. Within collision events, four birds impacted screens covering a glass door (all flew away immediately), 13 birds collided with a glass door, and 12 birds collided with the upper transom windows above the glass doors. Interactions between birds of the same or different species prior to a collision or near-miss event were observed 13 times. Where footage allowed a clear view of the position of the bird's head in the moments leading up to impact, all video clips showed birds flying with their beak pointed forward towards the glass. We did not find evidence of birds turning their head during approach for near-miss or collision events. We provide a list of bird species that appeared in the recordings in Table 1.

Of the recorded collision events, 2 collisions resulted in an immediate fatality (one a Northern Cardinal, the other a Downy Woodpecker) as captured by the cameras and confirmed by the building occupants. Three birds were stunned and grounded upon impact but flew away within a few minutes, according to the homeowner. The other 24 collision events resulted in birds immediately flying out of the frame; the outcome for those birds could not be determined. For analyzed collision events (n=26), mean flight velocity leading up to impact was 7.71 m/s, SD = 2.53 m/s; mean angle of approach was ±20 degrees from perpendicular to the window; SD = 20.15; and mean time of the day was 12 hrs and 50 minutes, SD = 4 hrs and 31 minutes. Overall, we found high variability in these three parameters.

We first assessed the probability of collision with a window when birds were on a collision course. We found that the probability of collision was significantly affected by velocity ($\chi^2_1 = 4.67$, P = 0.031) and angle of approach ($\chi^2_1 = 4.08$, P = 0.043) but not by time of the day ($\chi^2_1 = 1.37$, P = 0.242). The probability of collision increased with the velocity of the approach to the point that birds that flew at > 7.5 m/s had > 75% chances of colliding with the window (Fig. 4a). Similarly, the probability of collision increased with angles greater than the perpendicular, but the effects were not as pronounced (Fig. 4b).

After birds collided with a window, we assessed the probability of collision of a visible injury (i.e., bird being stunned for a few moments before resuming flight or dying). We found that the probability of a collision leading to a visible injury was significantly affected by velocity ($\chi^2_1 = 8.78$, P = 0.003) and angle of approach ($\chi^2_1 = 8.70$, P = 0.003) but not by time of the day ($\chi^2_1 = 2.32$, P = 0.128). The probability of visible injury increased with the velocity of the approach, particularly above 7.5 m/s (Fig. 5a). The probability of visible injury tended to actually decrease with angles greater than the perpendicular, but this trend showed a high degree of variation in terms of confidence bands (Fig. 5b).

Discussion

We documented 29 collisions and 9 near-misses. Our data reveal previously undocumented variation in birds' pre-collision behaviour. We predicted that birds flying at higher speed and approaching the windows at approximately perpendicular angles would be more likely to suffer a visible injury or be killed immediately by the impact. We found support for this prediction, as flight velocity and angle of approach were both related to the outcomes following collisions. The horizontal angle of approach to the window varied widely across individual birds. This variability may be explained by several factors. The appearance of reflections of the backyard on the glass varied throughout day and may be related to the intensity and angle of ambient sunlight. The spatial arrangement of the backyard, including the position of feeders and trees, likely contributed to the angles at which birds approached the glass. All five of the collisions that resulted in birds being stunned or immediately killed involved angles of approach that were approximately perpendicular to the glass, while collisions that resulted in birds immediately flying away included more variable angles of approach. For our analyses that included horizontal angle of approach, we took the absolute value of angles relative to the perpendicular to the glass, and thus quantified angles of approach from the left or right side of the perpendicular as equivalent. One potential source of bias for our study is that the study area contained asymmetries which could have influenced birds' behaviour depending on the direction of their approach to the window. For instance, the amount of unobstructed space in front of the windows where birds could fly and gain velocity varied depending on positions of objects in the backyard, such as the bird feeders and perching surfaces.

We also found variation in birds' flight velocity leading up to an impact with a window. Birds that were stunned or immediately killed by colliding with a window were flying significantly faster upon approach than were birds that collided with the window but flew away immediately. The distribution of flight velocities revealed that birds flying faster than 7.5 m/s faced a higher probability of suffering a collision, while birds flying slower were more likely to avoid making impact and be classified as a near miss. However, our study involved a small sample size, especially for video recordings of birds that were stunned or killed by a collision and for birds that nearly avoided making impact, so the importance of the observed difference in flight velocity should be interpreted with caution.

Although our sample size is small, our results support the idea that the angle at which a bird makes impact with a window may influence the outcome following the collision, in terms of whether the bird sustains injury, is killed immediately or flies away. Studies of birds admitted to rehabilitation centres following a collision with a window have documented patterns of soft tissue injury sustained by the head and body as force is absorbed upon impact (e.g., Hudecki & Finegan, 2018). Yet, there has been no research to date aimed at characterizing the mechanics of collisions and understanding how these injuries occur.

It seems likely that the severity of injury is related to the amount of force that the bird absorbs when it collides. Modelling collision dynamics in three-dimensional space requires more precise measurements than we were able to obtain with our video cameras through passive observational study. However, we can conceptualize how energy is distributed when birds impact a window under different configurations. For instance, consider a bird-window collision to be an elastic collision scenario in which kinetic energy is conserved, and assume that the velocity of the window remains relatively constant upon impact and that energy lost to vibrating the glass or generating sound is negligible. A bird flying forward generates momentum, defined as the product of its body mass and initial velocity. As the bird contacts the window, its momentum leading up to impact must be conserved. Some of the kinetic energy generated by the impact will be absorbed by the window, while the rest is directed outward at the bird. Generally, when a soft object (e.g., a bird) strikes a harder object (e.g., a window), most of the energy available for producing post-collision (final) velocity is stored in the soft object. Part of the energy pushes the bird outward from the window (i.e., normal force), generating its final velocity, while the rest of the force is absorbed by the bird's body, compressing its tissues, and potentially causing injuries such as ruptures of blood vessels and broken bones. In theory, the ratio between these two components of force acting on the bird post-collision may vary with the duration of the impact resulting from the extent that the bird's body compresses. More energy absorption by the bird's body may result in lower final velocity and displacement, but this could produce more damage to the bird's tissues. Future work using cameras with higher framerate and resolution could be used to observe differences in the durations of birds impacting the windows.

The angle at which the bird approaches the window may also affect the amount and direction of force its body experiences upon impact. For instance, a collision at a perpendicular angle to the window (i.e., a head-on collision) will result in momentum being conserved along only one axis. In other words, the momentum of the bird as it flies forward into the window will be transferred and redirected outward at the bird. However, a collision at an oblique angle, either in the horizontal or vertical plane, would result in components of momentum being conserved along multiple axes independently (Figure 6). A bird that collides at a glancing angle would experience less force, perhaps reducing the likelihood of it sustaining injury. In the real world, collisions occurring in three-dimensional space may be complicated by other factors, such as the bird's behaviour and wind acting on the bird, that cannot be accounted for in a simplistic model like we have examined here. One way that transfer of energy during bird-window collisions could be studied further is by simulating crash tests using objects with similar physical and mechanical properties to the body of a bird. The objects could be launched into windows under controlled circumstances that would allow for more precise measurements of initial and final velocities, angle of approach, and force absorbed upon impact. Collisions are rarely perfectly elastic, as some kinetic energy is lost upon impact to sound, vibration, etc. which could also be measured. The transfer of energy between the bird and the window during collisions may be described using the Coefficient of Restitution by comparing the relative final and initial velocities, split into components as required.

Previous studies of collision mortality at buildings have found evidence of a relationship between the risk of bird-window collisions and the surface area of the windows, with larger window surface area generally posing a higher risk of collisions (e.g., Hager et al., 2013; Elmore et al., 2020). However, in our study of collisions in a residential backyard, we found that nearly half of the collisions we observed involved birds impacting the smaller transom windows above larger glass doors. This suggests that small windows can also pose a significant risk of bird-window collisions. It seems likely that other contextual factors may be important for explaining birds' behaviour in this setting. For instance, one possible explanation for collisions with the smaller transom windows is that when birds take off from the feeders or surrounding trees, they aim their flight towards safe cover (i.e., protection from predators), and the appearance of a small opening (in the reflection on the transom window) is perceived as providing more coverage than the larger sliding door windows below. This effect may also be explained by the relative height of the transom windows above the doors; birds may simply prefer to fly higher and are therefore more likely to hit upper windows.

The perceptual mechanisms involved in successful detection and avoidance of windows by birds in flight have not been defined. Characterizing perceptual processes that birds use to avoid collisions could have implications for designing effective window collision prevention methods. These processes may interact with various factors, such as a bird interacting with a predator, or the rate of visual information being influenced by flight speed. For instance, the orientation of a bird's head in flight as it approaches a window influences how objects in front of the bird will project onto its visual field, which could affect the amount of visual information that the brain receives from the retina to inform rapid changes in behaviour (i.e., swerve and avoid). Our camera system did not provide the quality of footage necessary for analyzing birds' head orientation upon approaching the glass in detail, but in all of the clips where head orientation was evident, we found no signs of birds turning their head upon approach.

Recording bird-window interactions passively in the field allows for behavioural observations that might otherwise require prohibitive invasive methodology with captive animals. In the present study, we captured 9 near-miss events in which birds approached but did not collide with the windows. The total number of near-miss events was probably higher, but some events did not trigger video recording because the camera lenses and sensors were not oriented to observe birds several feet away from the glass where detection first occurs. Future studies aiming to record near-misses more effectively may wish to deploy more cameras oriented outwards from beside the windows.

Environmental stimuli appeared to play a role a subset of collision events. In one event, a male Northern Cardinal was chased into the glass by a second male. In another event, a Downy Woodpecker was chased into the glass by a raptor. In a third event, a tree branch fell from above the backyard and caused a flock of startled grackles to scatter from the feeders as one bird collided with a window. It is possible that additional collision events were influenced by contextual elements that were not captured by the cameras. Together, these observations suggest that some bird-window collisions may involve birds that are distracted by environmental factors, such as intraspecific or predator interactions, that could impact their visual or navigational capabilities while in flight. Distractions may be more common around bird feeders where individuals compete for access to resources and predators may learn there is an abundance of available prey. In comparison with experimental simulations of window collisions using captive birds, collision events that occur while a bird is fleeing from a predator more closely resemble the conditions of testing methods using flight tunnels, as birds fly forward to escape handling by a human experimenter (e.g., Sheppard, 2019; Rössler, 2015).

The risk of bird-window collisions is elevated in environments with bird attractants such as feeders, bathing stations and native plants (Klem et al. 2004, Bayne et al. 2012, Kummer and Bayne 2015, Kummer et al. 2016). Most bird-window collisions that we recorded using cameras at a residence with bird attractants left behind no trace and were not detected by the building occupants who were present for most of the study period. This provides support for the notion that bird-window collisions could be far more common in residential settings than is realized by homeowners. If a large proportion of collision events are not observed, this could have implications for the reliability of datasets built using collision-reporting community science tools (e.g., Kummer et al., 2016). In our study, two birds suffered collisions that resulted in an immediate fatality in which the bird died on camera within a few seconds after impact. However, of the other collisions that resulted in birds being temporarily stunned or flying away, it is unclear how many of those individuals suffered injuries or subsequent mortality. It may be the case that because bird feeders were positioned within a few meters of the home, most birds in the backyard were unable to gain enough flight speed to kill or injure themselves. The relative lethality of bird-window collisions is an important topic for future research that could help produce more accurate estimates of cumulative population-level impacts.

Multiple types of motion detection technology may be useful for recording collision events under different scenarios. The present study used home security cameras with built-in motion detection using front-facing infrared sensors. We previously piloted our study at a different location by recording video of windows on a high-rise building from cameras located inside a room behind the glass. We found that the motion detection function in our cameras, which uses infrared, was not sensitive to birds approaching on the opposite side of a multi-pane window. In this scenario, the amplitude of sound produced by collisions on the relatively thick window glass was likely insufficient to trigger audio recording. We therefore switched to recording at a residential setting with cameras positioned outside in order to not be impeded by glass placed between the lenses and the trigger events. However, even with the cameras positioned outside and with audio and motion detection sensitivity adjusted to capture events and filter out background noise, it is likely that some instances of birds interacting with the windows escaped detection. Given that most of the collision and near-miss events that produced triggers and were successfully recorded involved larger birds, it is possible that events involving smaller birds may be less likely to be picked up by the cameras.

Future monitoring studies using video recording cameras at mid and high-rise buildings could yield new information about dynamics of bird-window collisions under different scenarios. It seems plausible that pre-collision behaviour in migratory birds that fly near tall buildings differs from birds' behaviour surrounding bird feeders near the ground at a residence. To capture footage of birds' behaviour in flight near tall buildings, cameras with pixel-based object motion detection may be more effective than infrared motion detection if placed inside the glass (e.g., Sundaresan, 2020). Infrared motion detection may still be useful if additional cameras can be mounted on the exterior of the structure and cameras can be triggered synchronously. In selecting cameras that will remained armed or in recording mode continuously over a prolonged study period, it is important to balance image quality and frame rate with practical considerations such as available storage and network bandwidth for uploads. It may also be beneficial to include redundant monitoring of the study area by a human observer in case of camera trigger failure.

Our successful deployment of a basic home security video recording system to record bird-window interactions demonstrates the feasibility of scaling up collision monitoring efforts using camera technology. Many buildings have similar equipment installed for home security that may be repurposed for monitoring windows for bird collisions while risk is elevated such as during migration periods or as birds visit nearby attractants. Crowd-sourcing footage of bird-window interactions may provide a new community-science tool for improving understanding of how collisions occur in the real world. Large-scale systematic monitoring of real-world locations using video recording equipment may benefit from automated approaches to coding and analysing contents of footage, such as using motion tracking or pose estimation software. Video processing effort can be greatly reduced by selecting sites that minimize the extent of noise and risk of false-positive triggers (e.g., areas with low pedestrian traffic, falling leaves).

Our study provides confirmatory empirical evidence that bird-window collisions occur frequently at residences with untreated glass windows near bird attractants. The risk of bird-window collisions at existing and new structures can be reduced through the application of “bird-friendly” materials such as fritted glass, window film or appropriately spaced visual markers. In summer of 2021 the homeowner retrofitted the windows in the study area using Feather

Friendly® commercial film. In the time since the retrofit, the homeowner has not observed any further bird collisions with the treated windows.

Conclusions

In this study, we provide empirical data obtained from passive video recordings of bird-window collisions in a residential setting, and share novel observations of birds' pre-collision behaviour. We hypothesized that the risk of a bird colliding with a window and being killed or incapacitated (i.e., stunned or injured) by the impact is related to the bird's flight velocity and angle of approach to the window. We found a positive relationship between pre-collision flight velocity and the probability of birds being killed by the impact or suffering a visible injury. We also found birds that approached from horizontal angles close to perpendicular to the window were more likely to be injured or killed by the collision. The vast majority of collisions were not observed by the building occupants and birds flew away leaving no trace. At least some of these birds may suffer morbidity or mortality far from the window site. We conclude that building surveys and other monitoring methods vastly underestimate the number of window collisions by birds. Additional studies that can better characterize how flight characteristics affect the force experienced by a bird during a collision will provide better estimates of the negative effects on birds that are able to fly away following collision.

Acknowledgements

This study adhered to the guidelines of the University of Western Ontario and the Canadian Council on Animal Care (CCAC) and all animal handling procedures were approved by the institution's Animal Care Committee (protocol 2019-118). The authors thank Sherri Fenton for her support with carrying out the research.

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Figure 1

Overhead view of the backyard study area.

Drawing is not perfectly to scale. Measurements between points of reference are shown in centimetres. The dimensions of sets of transom windows and sliding doors are shown on the right; the middle and top sets were identical, while the lowest set were of a different size. 1-2 represent locations of bird feeders stocked with bird seed; 3 represents a hummingbird feeder; 4-5 represent bird baths; 6 represents an additional feeder added by the homeowner in 2020. Locations of four cameras are indicated by black hexagons with arrows depicting the orientation of the lens.

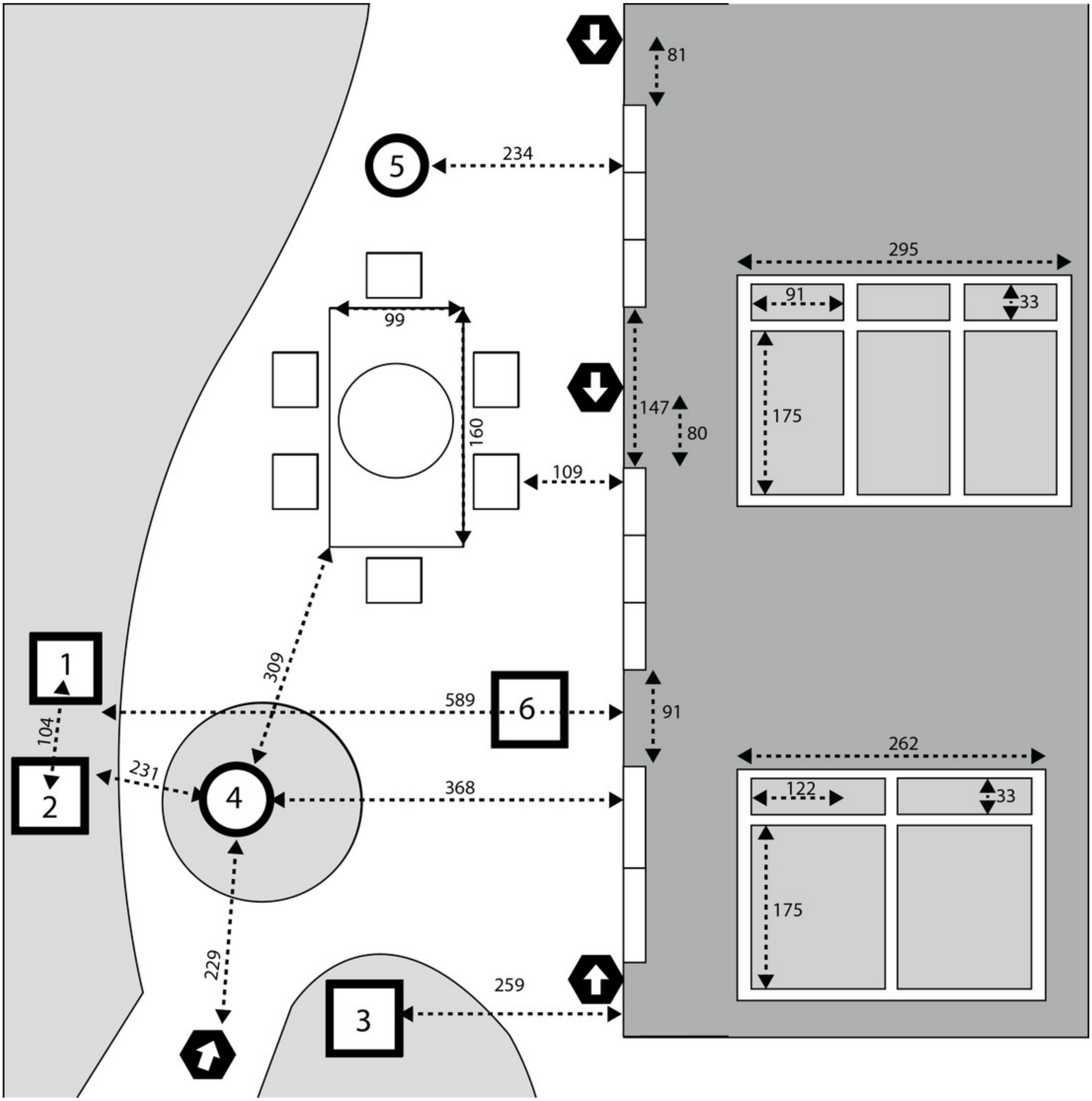

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Figure 2

Flight paths taken by birds in collision events.

Colours are used to distinguish individual birds. Coloured boxes containing numbers in the figure indicate the starting position of the bird. Events in the legend are ordered chronologically by date. In the legend, (U) = bird collided with the upper transom windows above the door, (GD) = bird collided with the glass door, (S) = bird collided with the screen over a glass door.

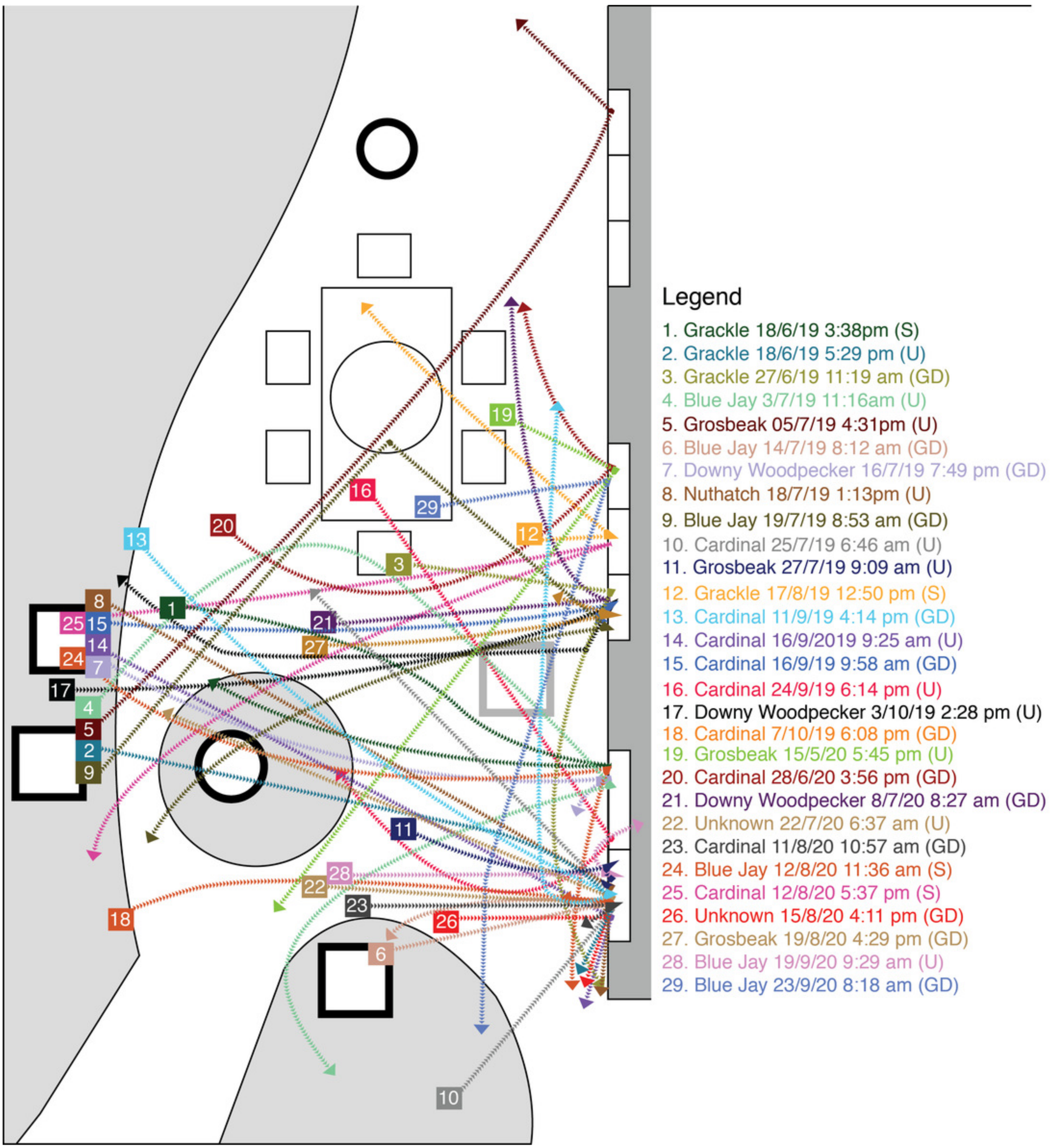
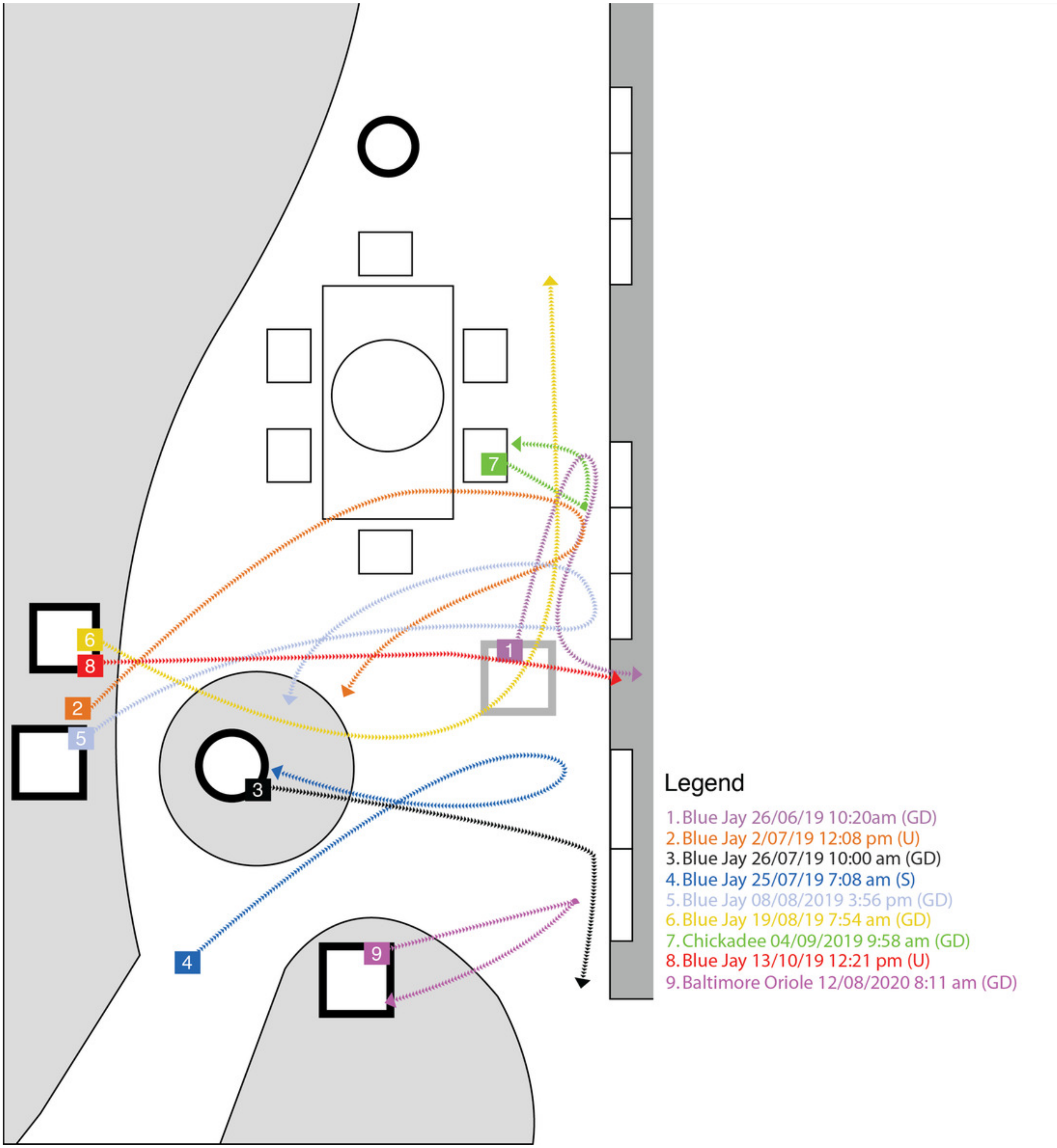

Legend
1. Grackle 18/6/19 3:38pm (S)
2. Grackle 18/6/19 5:29 pm (U)
3. Grackle 27/6/19 11:19 am (GD)
4. Blue Jay 3/7/19 11:16am (U)
5. Grosbeak 05/7/19 4:31pm (U)
6. Blue Jay 14/7/19 8:12 am (GD)
7. Downy Woodpecker 16/7/19 7:49 pm (GD)
8. Nuthatch 18/7/19 1:13pm (U)
9. Blue Jay 19/7/19 8:53 am (GD)
10. Cardinal 25/7/19 6:46 am (U)
11. Grosbeak 27/7/19 9:09 am (U)
12. Grackle 17/8/19 12:50 pm (S)
13. Cardinal 11/9/19 4:14 pm (GD)
14. Cardinal 16/9/2019 9:25 am (U)
15. Cardinal 16/9/19 9:58 am (GD)
16. Cardinal 24/9/19 6:14 pm (U)
17. Downy Woodpecker 3/10/19 2:28 pm (U)
18. Cardinal 7/10/19 6:08 pm (GD)
19. Grosbeak 15/5/20 5:45 pm (U)
20. Cardinal 28/6/20 3:56 pm (GD)
21. Downy Woodpecker 8/7/20 8:27 am (GD)
22. Unknown 22/7/20 6:37 am (U)
23. Cardinal 11/8/20 10:57 am (GD)
24. Blue Jay 12/8/20 11:36 am (S)
25. Cardinal 12/8/20 5:37 pm (S)
26. Unknown 15/8/20 4:11 pm (GD)
27. Grosbeak 19/8/20 4:29 pm (GD)
28. Blue Jay 19/9/20 9:29 am (U)
29. Blue Jay 23/9/20 8:18 am (GD)

Figure 3

Flight paths taken by birds in near-miss events.

Colours are used to distinguish individual birds. Events are ordered chronologically by date. In the legend, (U) = bird approached the upper transom windows above the door, (GD) = bird approached the glass door, (S) = bird approached the screen over glass door.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Legend
1. Blue Jay 26/06/19 10:20am (GD)
2. Blue Jay 2/07/19 12:08 pm (U)
3. Blue Jay 26/07/19 10:00 am (GD)
4. Blue Jay 25/07/19 7:08 am (S)
5. Blue Jay 08/08/2019 3:56 pm (GD)
6. Blue Jay 19/08/19 7:54 am (GD)
7. Chickadee 04/09/2019 9:58 am (GD)
8. Blue Jay 13/10/19 12:21 pm (U)
9. Baltimore Oriole 12/08/2020 8:11 am (GD)

Figure 4

Probability of bird colliding with a window relative to velocity of approach.

Probability of collision is indicated on the vertical axis as 0 (near miss) or 1 (impact occurred). Flight velocity upon approach is indicated on the horizontal axis in meters per second. Line depicts the mean. Shaded area indicates standard deviation (SD). Points represent approaches by individual birds.

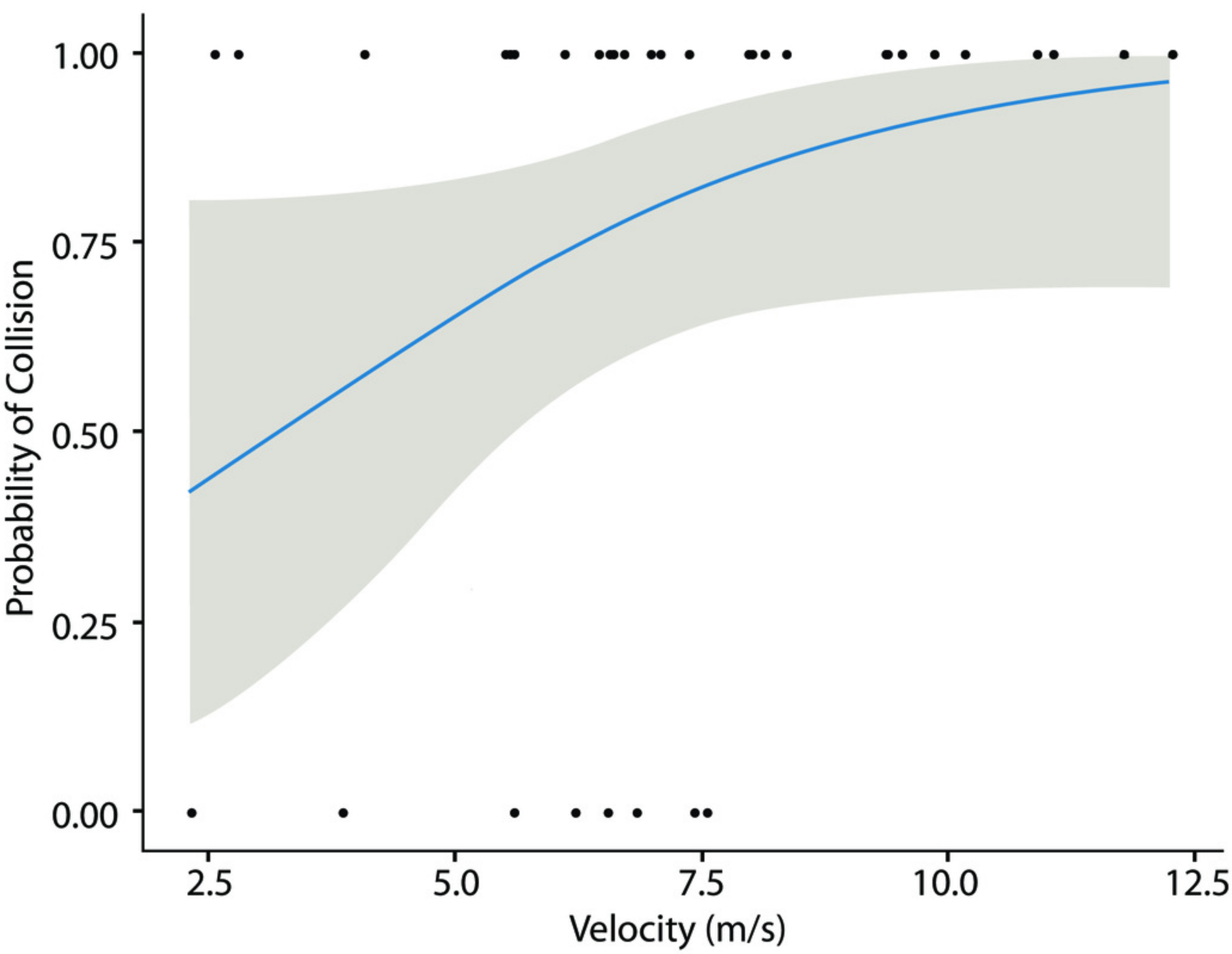

Figure 5

Probability of bird colliding with a window relative to the absolute horizontal angle of approach

Probability of collision is indicated on the vertical axis as 0 (near miss) or 1 (impact occurred). Horizontal angle of approach is indicated on the horizontal axis in absolute value relative to perpendicular to the window. Line depicts the mean. Shaded area indicates standard deviation (SD). Points represent approaches by individual birds.

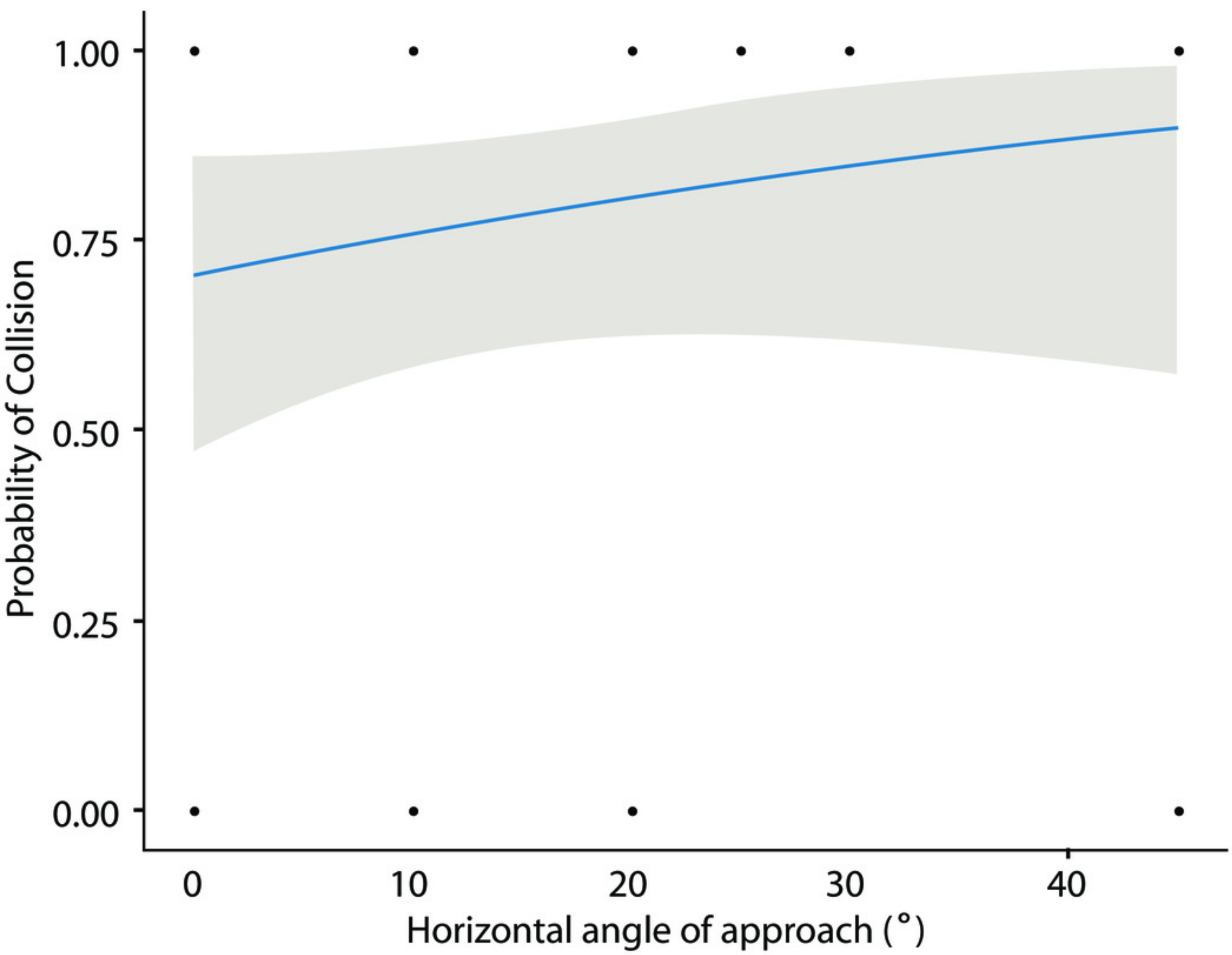

Figure 6

Probability of bird showing visible injury following a collision relative to velocity of approach.

Probability of a visible injury (stunned, killed) is indicated on the vertical axis as 0 (bird flew away immediately) or 1 (injury observed). Velocity of approach is indicated on the horizontal axis in meters per second. Line depicts the mean. Shaded area indicates standard deviation (SD). Points represent approaches by individual birds.

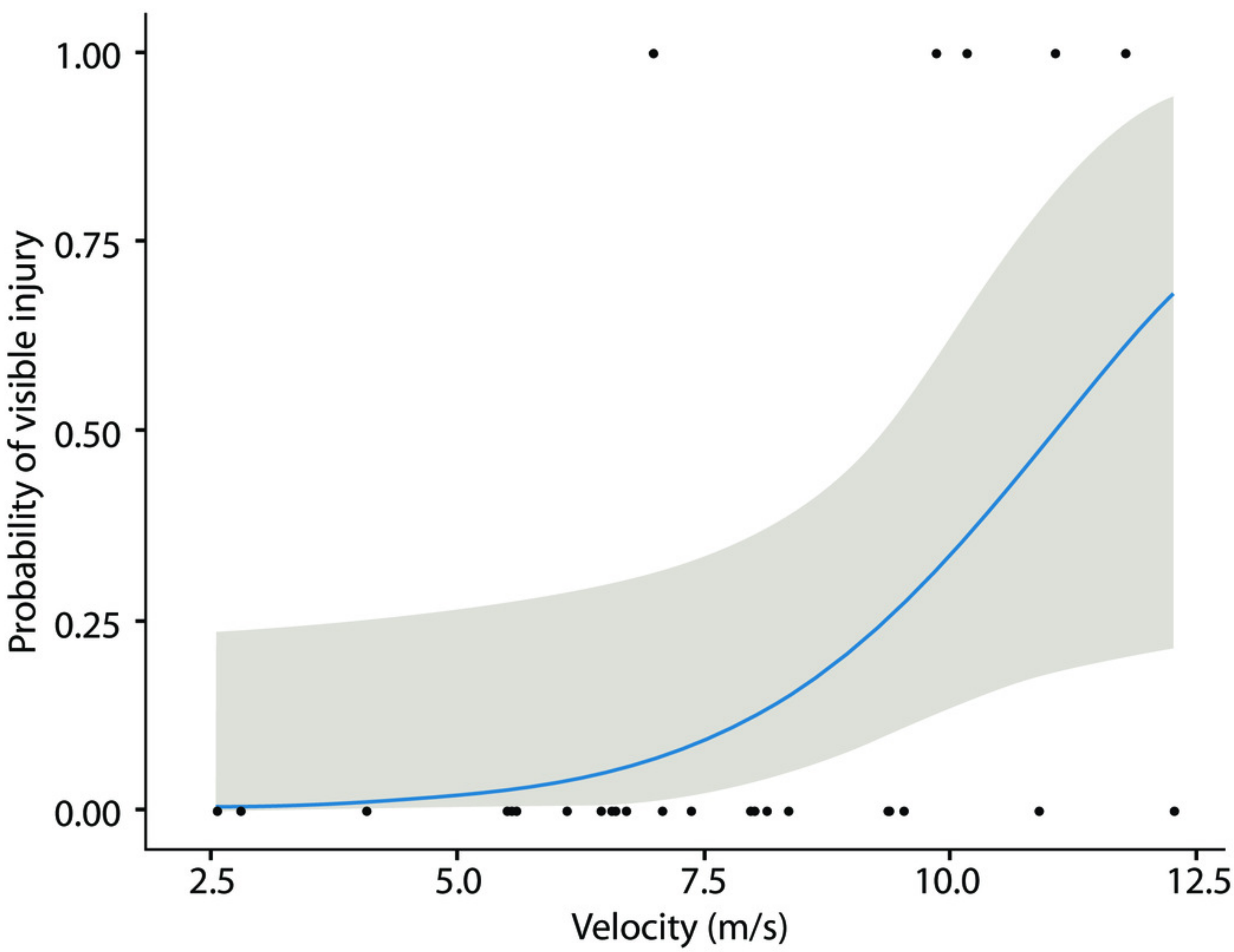

Figure 7

Probability of bird showing visible injury following a collision relative to horizontal angle of approach.

Probability of a visible injury (stunned, killed) is indicated on the vertical axis as 0 (bird flew away immediately) or 1 (injury observed). Horizontal angle of approach is indicated on the horizontal axis in absolute value relative to perpendicular to the window. Line depicts the mean. Shaded area indicates standard deviation (SD). Points represent approaches by individual birds.

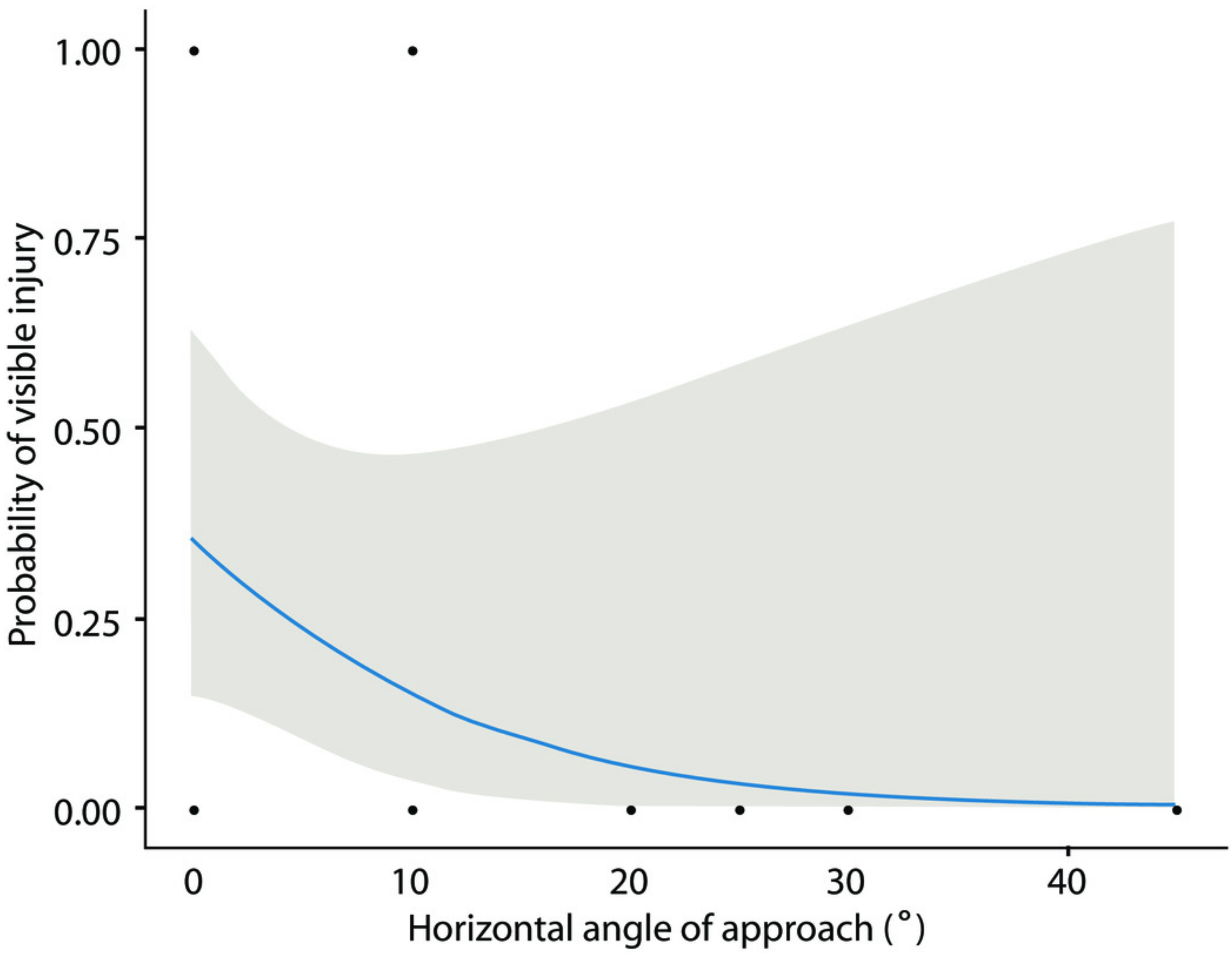

Figure 8

Probability of birds enduring a visible injury (stunned, death) after colliding with windows

Probability of birds enduring a visible injury relation to: (a) approach velocity, and (b) absolute angle relative to the perpendicular direction of approach.

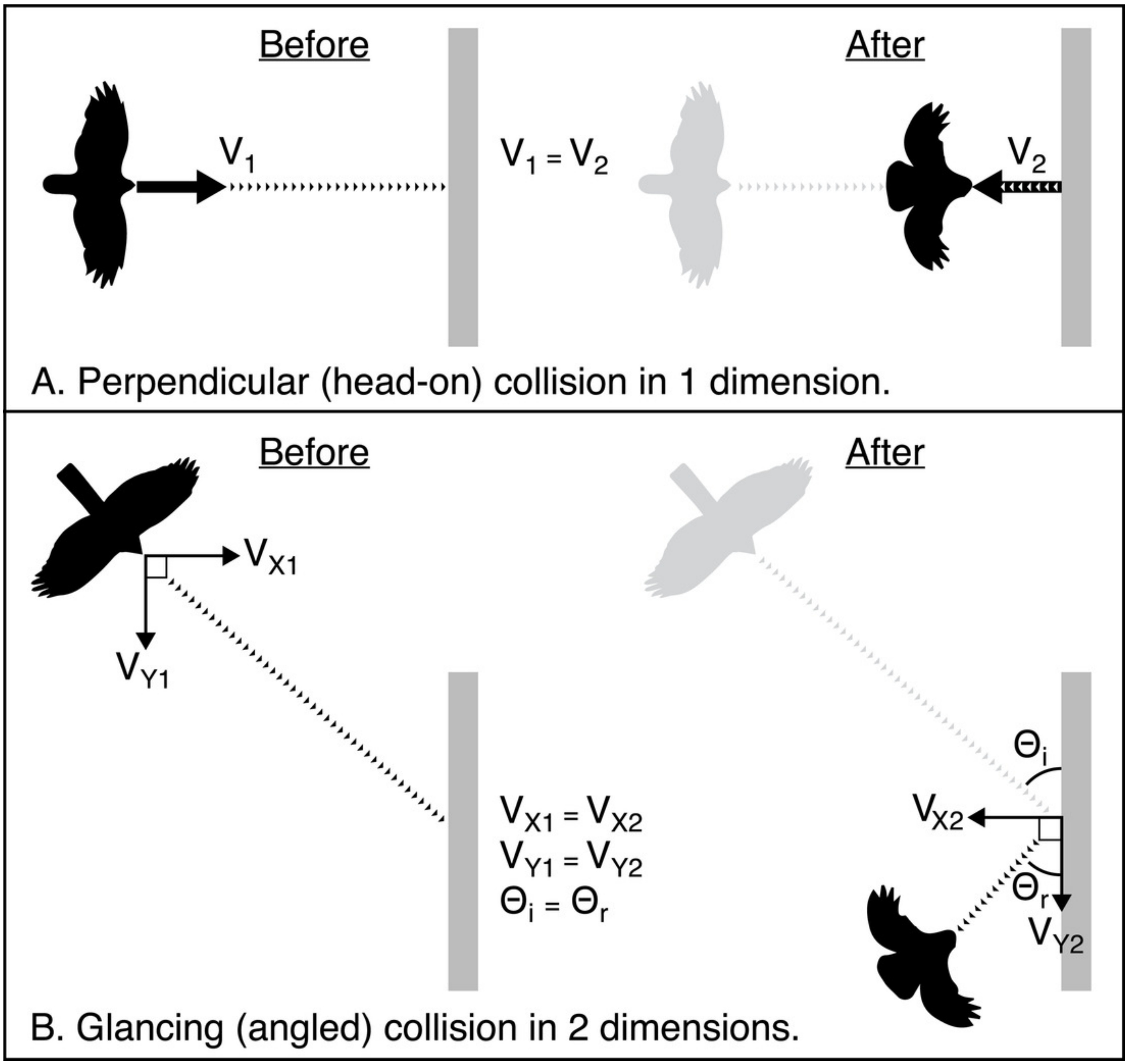

Table 1(on next page)

Bird species represented in the collision and near-miss events.

Species name		Event count
Blue Jay	*Cyanocitta cristata*	13
Northern Cardinal	*Cardinalis cardinalis*	8
Baltimore Oriole	*Icterus galbula*	1
Rose-Breasted Grosbeak	*Pheucticus ludovicianus*	4
Downy Woodpecker	*Dryobates pubescens*	3
White-Breasted Nuthatch	*Sitta carolinensis*	1
Common Grackle	*Quiscalus quiscula*	4
Black-capped Chickadee	*Poecile atricapillus*	1
Unknown	*Passeriformes sp.*	2
	Total	37

1