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COLLISIONS BETWEEN BIRDS AND WINDOWS: MORTALITY AND PREVENTION

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Abstract.—Bird strikes were recorded at the windows of commercial and private buildings to study the effects of collision mortality on birds, and several experiments were conducted to evaluate methods of preventing collisions between birds and glass panes. Two single houses that were systematically monitored annually killed 33 and 26 birds, respectively. Collisions at one house in the same 4-mo period (September- December) in consecutive years resulted in 26 and 15 fatalities, respectively. At least one out of every two birds were killed striking the windows of these single dwellings. The records from these homes also revealed that window strikes are equally lethal for small and large species. The annual mortality resulting from window collisions in the United States is estimated at 97.6-975.6 million birds. Experimental evidence indicates that complete or partial covering of windows will eliminate bird strikes. If parts of the window are altered, objects or patterns placed on or near the window must be no more than 5-10 cm apart and uniformly cover the entire glass surface. Eliminating bird attractants from the vicinity of windows will reduce or prevent strikes by reducing the number of birds near the glass hazard. If removal of attractants is unacceptable, place them within 0.3 m of the glass surface; birds are drawn to the attractant on arrival and are not able to build up enough momentum to sustain serious injury if they hit upon departure. My experimental results further reveal that the common practice of placing single objects such as falcon silhouettes or owl decoys on or near windows does not significantly reduce bird strikes. Window casualties represent a potentially valuable, but largely neglected source of data capable of contributing information on species geographic distributions, migration patterns, and various other studies requiring specimens.

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Too often the destructive influence of human activities on bird populations is recognized only after substantial damage has been done (Soule 1986). Plate glass is a non-selective lethal hazard for free-flying birds (Townsend 1931, Banks 1976, Weir 1976, Avery et al. 1980), and human lifestyles can hide the importance of this mortality factor for select species and birds in general (Klem 1979). Modest attention and meager quantitative evidence is available to evaluate the exact or potential impact of this human-caused mortality on avian populations (Banks 1979). From analyses of bird strike accounts, a survey of window-killed specimens, and a series of experiments, I found collisions to occur wherever birds and windows coexist (Klem 1979; Klem, in press). Here I (1) present results suggesting that glass is or could become a significant mortality factor for some birds, and (2) evaluate various techniques to prevent birds from striking windows.

METHODS

From 1974 to 1986 1 collected data on birds that were injured or killed at commercial and private buildings primarily in southern Illinois but also throughout the United States and Canada. To assess avian mortality at specific structures containing windows of different sizes and shapes, planned observations were obtained from individually monitored single homes in Carbondale, Jackson Co., Illinois (37'41'25"N, 89'15'50"W) and Purchase, Westchester Co., New York (41'02'22"N, 73'42'04"W). The Carbondale house was the principal study site and is located in a rural setting surrounded by mixed trees, shrubs, field and lawn. The Purchase house is located in a suburban setting surrounded by trees, shrubs, and lawn.

Two experimental designs were used in southern Illinois. The data collected were frequency counts of bird strikes at windows. A strike was registered when a specimen was found beneath a window or a specimen remnant in the form of a feather, body smudge, or blood smear was found on the glass. These data are likely to be incomplete but a conservative measure of glass as a mortality factor; collisions may have occurred without leaving evidence, and predators and scavengers are known to collect victims from the vicinity of windows (Klem 1981). The first design consisted of a single experiment. Five identical wooden-framed picture windows were placed immediately adjacent to each other along the edge of a mixed deciduous forest and corn field. The study site was a small farm near Cobden, Union Co., Illinois (37'33'05"N, 89'15'38"W). Each window was 1.4 m wide, 1.2 m high, and mounted 1.2 m above ground. Wire mesh trays were placed under each window to catch casualties and were checked daily at dusk.

Four of the 5 windows were altered by placing objects on or around the glass; the unaltered window served as a control. On one window, a diving falcon silhouette, 23.6 cm in length and with 45.4 cm wing spread was attached in the upper left corner as you face the window and angled downward such that it appeared to be stooping toward prey; it is an exact replica of a commercially available silhouette sold to prevent bird strikes. A Great Horned Owl *(Bubo virginianus)* replica, used to frighten birds at food processing plants, was placed such that it appeared perched in front of and at the bottom center of another window. Wind chimes constructed with 5 hollow metal cylinders that dangle on monofilament line from a star-shaped metal cap (length 35 cm, width 7.8 cm at the top) were hung in front of the top center of the window, and when activated by wind, the chimes combine sound and motion to frighten birds from windows. A light set of 7-watt clear bulbs placed 30.5 cm apart was placed around an entire window, and set to blink 32 times per minute. They were visible from both sides of the glass. An automatic timer turned the lights on and off at first and last light, respectively. The experiment was conducted over 52 days during which the preventative methods and control were randomly assigned on a daily basis.

The second design consisted of several experiments in which six Dark-eyed Juncos *(Junco hyemalls)* were tested in an outdoor flight cage. Juncos were captured in April and early May, housed in small flight cages, and tested throughout May. The flight cage was trapezoidal and 1.2 m high, 3.6 m in length, 0.3 m wide at the narrow end and 2.6 m wide at the broad end. Individuals were released from a holding box at the narrow end and forced to discriminate between left or right flight paths as they attempted to escape to wooded habitat visible outside the broad end of the cage. At the broad end, one half of the cage was left unobstructed in all experiments. The other half was obstructed by clear glass or various objects expected to prevent bird strikes. Actual glass was used only in experiments that tested techniques similar to those in the field experiment. To prevent accidental collision injuries to subjects in subsequent experiments, objects were hung on the obstructed side with clear monofilament line in order to appear as if taped to glass.

Twenty-seven experiments were conducted. Each tested one subject and consisted of 10 to 30 trials in which I recorded whether a Junco passed through the unobstructed side of the cage or the side with a preventative object. If the subject chose the obstructed side it was scored as a window strike. On any test day, a group of five or fewer preventative methods was evaluated. Subjects were tested with a single preventative method on any one test-day, and each subject was tested with each of the methods in a group on consecutive test-days. The objects tested were: (1) clear glass; (2) small diving falcon silhouette in upper left corner of pane (18.8 cm in length, 35.6 cm wing-spread); (3) the same small diving falcon silhouette in center of window; (4) large diving falcon silhouette (same as field experiment); (5) Barred Owl *(Strix varia)* silhouette (39.6 cm in length, 17.1 cm in width at breast); (6) mounted Barred Owl specimen at bottom center of pane (same dimensions as Barred Owl silhouette),(7) circle silhouette in center of pane (17.8 cm in diameter); (8) two vertebrate eyes in center of pane (each eye 10.2 cm in diameter, separated by 1.3 cm, and patterned after lepidopteran eyespots found by Blest (1957) to be most effective in frightening birds); (9) wind chimes (same as field experiments but without motion and sound); (10) the same wind chimes with motion and sound; (11) blinking lights (same as field experiment); (12) hanging ivy plant in planter at top-center of pane (35.6 cm in length, 12.7 cm pot diameter); (13) blinking lights around the same hanging ivy plant in planter at top-center of pane; (14) white cloth drapes covering entire pane,- 2.5 cm white cloth strips placed horizontally and vertically, and uniformly covering pane with mesh openings (width by height): (15) 43 x 58 cm, (16) 30 x 38 cm, (17) 20 x 30 cm, (18) 13 x 18 cm, (19) 10 X 13 cm, and (20) 8 x 10 cm; (21) single vertical 2.5 cm white cloth strip in center of pane; (22) single horizontal white cloth strip in center of pane; vertical 2.5 cm white cloth strips uniformly covering pane and separated by: (23) 18 cm, (24) 10 cm and (25) 5 cm; horizontal 2.5 cm white cloth strips uniformly covering pane and separated by: (26) 10 cm and (27) 5 cm. Binomial tests were used to determine the significance of each experiment (Siegel 1956).

RESULTS

Annual fatalities resulting from window collisions were 33 (54.1%) of 61 strikes at the Carbondale house and 26 (55.3%) of 47 strikes at the Purchase house. Collisions at the Purchase house in the same 4-mo period (September to December) in consecutive years resulted in 26 (76.5%) fatalities from 34 strikes the first year, and 15 (51.7%) fatalities from 29 strikes the next. These data indicate that mortality rates may vary as much as 24.2% from one year to another at one locality, and at least at these houses, one out of every two birds is killed striking windows.

These same data were used to determine the vulnerability of different size birds. No significant differences in mortality rates were found for two arbitrary weight classes (0-39 g, hummingbirds-sparrows and >39 g, cardinals-bobwhite) at either the Carbondale ($P > 0.5$, $\chi^2 = 0.18$) or Purchase ($P > 0.5$, $\chi^2 = 0.94$) houses.

Thirty-three collisions were registered in the field experiment, and of these 18 (54.5%) were fatal. The distribution of strikes among the control and altered windows was not significantly different from a uniform distribution ($P > 0.05$, $\chi^2 = 8.7$). These results indicate that the diving falcon silhouette, owl decoy, wind chimes, and blinking lights do not significantly reduce strike rates.

The flight cage experiments support the field results and reveal that Dark-eyed Juncos could not discriminate between clear glass and unobstructed airspace, or most of the preventative methods evaluated. Fifteen of the preventative methods produced statistically significant results with one or more subjects (Table 1). Only four preventative methods resulted in statistically significant avoidance for all subjects. All Juncos avoided windows that were completely covered and rendered translucent by a white cloth drape, and three patterns consisting of 2.5 cm wide white cloth strips that uniformly covered the entire window. The effective patterns were: (1) a rectangular mesh forming 8 cm wide by 10 cm high openings, (2) vertical strips separated by 10 cm, and (3) horizontal strips separated by 5 cm (Table 1).

TABLE 1. Results of laboratory experiments in which Dark-eyed Juncos (*Junco hyemalis*) significantly[a] avoided preventative method.

Preventative method	Number tested	Number significantly avoiding method[a]
Large diving falcon silhouette	5	1
Barred Owl silhouette	5	1
Blinking lights around window frame	3	1
Blinking lights around hanging plant.	5	2
White cloth drape covering entire window	5	5
White cloth strips, 2.5 cm wide forming mesh sizes (cm):		
44 x 58	5	1
29 x 38	5	1
21 x 28	5	2
14 x 18	1	2
10 x 13	4	3
8 X 10	5	5
White cloth strips, 2.5 cm wide placed vertically and separated by (cm):		
10	4	4
5	4	3
White cloth strips, 2.5 cm wide placed horizontally and separated by (cm):		
10	5	3
5	4	4

[a]Binomial tests were used to determine if the results of 10 to 30 trials per subject differed significantly ($P < 0.05$) from the expected equal distribution.

DISCUSSION

Window casualties have the potential and already may be a significant mortality factor for some species of birds. My findings, reported here and elsewhere, clearly indicate that birds do not recognize glass as a barrier (Klem 1979, Klem, in press). Potential victims are the fit and unfit of abundant as well as rare, threatened, and endangered species. At the windows of one building in Europe, 54 birds were killed over a 2 mo period (Morzer Bruijns and Stwerka 1961). My records document at least 33 deaths/yr resulting from window strikes at a single dwelling, and 1 out of 2 strikes resulted in a fatality. These same data reveal that window strikes are equally lethal for small and large species. Documenting the effects on local populations, Löhrl (1962) described the regular attrition of Swallows *(Hirundo rustica)* killed hitting a clear glass corridor until their nearby colony was abandoned. Windows increase the threat to endangered populations; Walkinshaw (1976) reported a window-killed Kirtland's Warbler *(Dendroica kirtlandii),* and Burns (pers. comm.) related another account of Kirtland's Warbler hitting and surviving a window strike. L. Kiff (pers. comm.) cited the persistent losses of Peregrine Falcons *(Falco peregrinus)* from collisions with reflective windows as a serious threat to the successful reintroduction of this species in urban environments. My survey of museum curators and individuals throughout the United States and Canada suggest greater vulnerability for those species whose activities occur on or near the ground, such as several species of thrushes, wood warblers, and finches (Klem 1979; Klem, in press).

The window hazard is likely to increase for resident and migrant birds as more and more undisturbed habitat is modified by human development and the construction of new buildings containing large expanses of glass. In addition to commercial growth stimulated by economic interests, human population trends in the U.S. show a return to rural areas (Long and DeAre 1982) resulting in increased land development and an increased threat for birds.

One annual estimate of avian mortality resulting from strikes is 3.5 million for the United States alone (Banks 1979). This figure is based on the assumption that 1 bird is killed per square mile of land per year. My findings of multiple windowkills at several man-made structures of various types in urban, suburban, and rural settings, throughout every season, and under almost every weather condition suggest this is an extremely low figure. Admittedly no less speculative, I offer an alternative based on the criteria that 1 to 10 birds are killed per building per year in the U.S. Attempting to be conservative, I used U.S. Bureau of Census (1986) data and estimated the number of U.S. buildings by assuming each housing unit (93,519,000), commercial building (3,948,000), and school (96,626) equated to 1 building each; this yields an annual windowkill toll of 97.6 to 975.6 million birds. The estimate is fundamentally speculative because it assumes U.S. buildings that kill no birds are compensated for by those that kill many. Direct evidence supporting this assumption is not available, but given known collision fatalities at single buildings, I submit that my suggestion is reasonable if not overly conservative. Moreover, compensating for man-made structures that kill no birds are buildings known to kill many but were not included in my estimate. They are corporations and businesses that have more than I structure such as those in multistory and multibuilding shopping mall complexes, schools such as colleges and universities consisting of more than 1 building, and all types of local, state, and federal government buildings.

The 98 to 976 million death toll is offered as a general order of magnitude, but still represents only 0.5 to 5.0% of the 20 billion birds estimated to compose the continental U.S. bird population after the breeding season each year (A.O.U. 1975). Banks' (1979) estimate of yearly window-kills represents 2.0% of the approximately 197 million annual bird deaths he attributes to all human activity. Other comparative yearly estimates for other human-related avian mortality range from approximately 3.5 million (2.0%) fatalities due to pollution and poisoning to 57 million (29.2%) resulting from road collisions and 120.5 million (61.5%) from hunting. My lowest estimate of annual window-kills for the U.S. exceeds all but the mortality figures for hunting, and I suspect that additional study will reveal glass panes to exact the highest toll of any human-related avian mortality.

A uniquely human concern is the guilt and anxiety felt by a growing number of the general public who discover that the windows of their houses and work place are killing birds. This concern will likely have an increasing impact on the glass industry, architectural designs, landscape planners, and the conservation community as more publicity and studies reveal the details of this mortality factor for wild bird populations. Ironically, many aesthetic buildings housing local, state, and federal park visitor centers are literally covered with glass, and these buildings regularly kill some of the birds that the public comes to see.

Any factor that increases the density of birds near windows is known to increase strike rate (Klem, in press). Consequently, the human propensity for placing bird attractants such as feeders, watering areas, and nutritious and aesthetic vegetation in front of windows increases the hazard. Interestingly, collisions and most evidence of their occurrence are often masked by the presence of foundation plantings and the actions of scavengers, predators, and building personnel that regularly patrol and collect the unsightly dead and dying.

Elimination of bird attractants near windows will reduce or completely prevent strikes by reducing bird densities near the glass hazard. Alternatively, place attractants such as feeders within 0.3 m of the glass surface. Birds are drawn to the attractant upon arrival, and due to the close proximity of the attractant to the window, they are not able to build up enough momentum to sustain serious injury if they hit the glass upon departure.

My experimental results have revealed varied and effective methods of preventing bird strikes. Other than removing windows from man-made structures, an action taken in some instances but obviously unacceptable under most circumstances, glass panes must be completely covered if collisions are to be eliminated. Covering windows with netting is most effective when cost and aesthetic appearance are acceptable. Alternatively, glass panes must be transformed into obstacles that birds can recognize and avoid. Spiders seem to have solved similar problems using stabilimenta to make their orb webs more visible to flying birds (Eisner and Nowicki 1983). In a like manner, to successfully protect hummingbirds and the smallest passerines, windows must be uniformly covered with objects on or near the glass surface and separated by 5 to 10 cm. I found 2.5 cm cloth strips oriented vertically and separated by 10 cm must be separated by 5 cm to be as effective when oriented horizontally. The difference in the effectiveness for these two orientations may be associated with a bird's adaptive response to the placement of vertical tree trunks separated by greater distances than horizontal tree branches. These results indicate that birds in flight are more apt to give vertical objects wider clearance than horizontal ones.

For new or remodeled buildings, architects and designers are encouraged to install windows at an angle such that the pane reflects the ground instead of the surrounding habitat and sky. Preliminary observations indicate that at a single building with windows angled in at their base, birds avoid flying into an illusion of the ground, but are easily deceived by and strike reflected images of habitat and sky on windows installed in the conventional vertical position.

Single objects such as falcon silhouettes or owl decals, large eye patterns, various other pattern designs, and decoys did not reduce strike rates to a statistically significant level in my field or flight cage experiments. Many such objects are commercially available, but they fail to prevent most strikes because they cover only part of the glass and are not applied in sufficient numbers to alert the birds to the glass barrier. Glass surfaces must be uniformly covered with objects or patterns, separated by 5 to 10 cm, to effectively prevent bird strikes at windows.

My survey of museums revealed that window-kills are a valuable but largely neglected ornithological resource. Of obvious value is the availability of specimens for anatomical and plumage studies. Knowledge of geographic distribution and migration routes can be enhanced through careful documentation of window casualties (Johnson and Hudson 1976). Nisbet (1970) provided an excellent example of how similar data from television and radio tower-kills were used to study migration patterns. Man-made structures with windows are distributed worldwide in contrast to the relatively restricted geographic distribution of towers. Moreover, where towers typically collect nocturnal migrants under adverse weather, windows kill birds in the day and night, throughout the year, and under most weather conditions. An Indigo Bunting *(Passerina cyanea)* that was banded after surviving a window collision in Canada killed itself striking the same window a year later; this account provides direct evidence of individual migrants reusing the same migratory routes from one year to the next (M. T. Butler, pers. comm.). Studies designed to band a select number of window strike survivors should be considered to further address survival rates and other migration-related questions. In general, studies of bird strikes at windows are encouraged to better understand the toll that this source of man-caused avian mortality exacts on specific species, and as an additional source of museum specimens.

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