

AVIAN MORTALITY AT WINDOWS: THE SECOND LARGEST HUMAN SOURCE OF BIRD MORTALITY ON EARTH

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Abstract. A vast and growing amount of evidence supports the interpretation that, except for habitat destruction, collisions with clear and reflective sheet glass and plastic cause the deaths of more birds than any other human-related avian mortality factor. From published estimates, an upper level of 1 billion annual kills in the U.S. alone is likely conservative; the worldwide toll is expected to be billions. Birds in general act as if sheet glass and plastic in the form of windows and noise barriers are invisible to them. Casualties die from head trauma after leaving a perch from as little as one meter away in an attempt to reach habitat seen through, or reflected in, clear and tinted panes. There is no window size, building structure, time of day, season of year, or weather conditions during which birds elude the lethal hazards of glass in urban, suburban, or rural environments.

The best predictor of strike rate is the density of birds in the vicinity of glass, and vegetation, water, and feeders best explain increased density and mortality at a specific site. Glass is an indiscriminate killer, taking the fittest individuals of species of special concern as well as the common and abundant. Preventive techniques range from physical barriers, adhesive films and decals to novel sheet glass and plastic, but no universally acceptable solution is currently available for varying human structures and landscape settings.

Key Words: architecture, avian mortality, birds, glass, landscape, window-kill, windows.

LA MORTALIDAD AVIAR POR CAUSA DE VENTANAS: LA SEGUNDA MAYOR FUENTE HUMANA DE MORTALIDAD DE AVES EN EL PLANETA

Resumen. Una enorme y creciente suma de evidencias respalda la interpretación de que, con excepción de la destrucción del hábitat, las colisiones con láminas de vidrio y plástico claro y reflectante, causan la muerte de más aves que cualquier otro factor humano de mortalidad aviar. De los estimados publicados, el nivel superior al de un billón de muertes anuales solo en Estados Unidos, es probablemente conservador; el número de muertes a nivel mundial se juzga en miles de millones. Las aves en general actúan como si los vidrios y plásticos en las ventanas o en barreras de sonido les fueran invisibles. Las víctimas mueren a causa de traumas en la cabeza, tras volar apenas un metro de distancia desde una rama en un intento por alcanzar un hábitat visto, bien a través de, o reflejado en, cristales claros y tintados. No existe tamaño de ventana, estructura edificada, hora del día, estación del año o condición climática, en que las aves consigan eludir los letales peligros del vidrio, tanto en contextos urbanos, suburbanos o rurales.

El mejor pronóstico de la tasa de choques, se deriva de la densidad de aves en proximidad al vidrio, mientras que la vegetación, el agua y los comederos de aves, explican el porqué de una mayor densidad y mortalidad en un sitio específico. El cristal es un asesino indiscriminado, que arranca la vida tanto a los individuos más adecuados en especies de especial inquietud, como a aquellos más comunes y cuantiosos. Las técnicas de prevención abarcan desde barreras físicas, películas adhesivas y calcomanías, hasta novedosos vidrios y plásticos, pero ninguna solución universalmente aceptable está actualmente disponible para su aplicación en diversas estructuras humanas y escenarios del paisaje.

INTRODUCTION

Arguably habitat destruction ranks number one among the human-associated threats to wild birds. Destroy or alter the habitat in some essential way and you destroy the fundamental resources upon which any free living bird depends for survival.

Here I provide a summary of what I claim is the second greatest threat to wild birds: clear and reflective panes made of glass or plastic, and used as windows in human dwellings and other buildings, and as noise barriers along roadways.

The fundamental problem for avian conservationists is that birds behave as if clear and

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reflective panes are invisible to them, and they kill or injure themselves attempting to reach habitat or the illusion of habitat seen through or reflected in windows. The resulting unintended mortality is so devastating because all free flying species the world over are potentially vulnerable, the common as well as the rare, threatened and endangered. The nature of the hazard suggests that the fittest individuals of a species population are just as likely to become a collision victim as those that are least fit.

More specifically, this paper is an overview of what I claim is an extremely important conservation issue for birds and people. The content has been presented elsewhere (Klem 1991, 2006, 2007, in press), but in slightly greater detail. My justification for providing a summary on this topic here is that the organizers of the 4th International Partners in Flight Conference invited this paper in hopes of reaching a different and more influential audience who in turn may be convinced to help educate and further study the important growing threat that this human-associated source of mortality poses for birds.

Here I draw on historic (Baird et al. 1874a, 1874b, Townsend 1931) and modern studies conducted over the past 34 years that include descriptive and experimental investigations (Banks 1976, Dunn 1993, Ogden 1996, Graham 1997, O'Connell 2001, Gelb and Delacretaz 2006, Hager et al. 2008, Klem in press).

PROBLEM: IN GENERAL BIRDS BEHAVE AS IF CLEAR AND REFLECTIVE PANES ARE INVISIBLE TO THEM

GENERAL DESCRIPTION

Extensive and detailed observations and several validating controlled experiments reveal that birds in general do not see clear or reflective glass or plastic panes as barriers to be avoided (Klem 1979, 1981, 1989, 1990b, 2009, Klem et al. 2004, Ogden 1996, O'Connell 2001, Hager et al. 2008). An individual can be killed outright after leaving a perch and striking a window from as little as just over a meter away (Klem et al. 2004). Collision victims succumb from head trauma—brain swelling, intracranial pressure, cranial herniation, and breaking of the blood-brain barrier—and not from the often assumed “broken neck” (Klem 1990a, Veltri and Klem 2005).

Continuous monitoring at two single-family homes for 1.5 years revealed that one out of every two strikes resulted in a fatality (Klem 1990a). Except in urban areas during migratory periods when glass casualties are conspicuous on sidewalks in front of large plate glass windows, dead, dying, or injured birds are most

often hidden from view in vegetation around human structures. Experimental results indicate that many, perhaps most, collision casualties are quickly taken by predators and scavengers (Klem 1990b, Klem et al. 2004).

Given the invisible nature of the hazard, fatal collisions are predicted to occur whenever birds and glass coexist. Collision casualties have been documented worldwide at panes of all sizes in single and multilevel residential and commercial buildings (Klem 1979, 1989, Klem et al. 2009). A bird's sex, age, or resident status has little to no influence on its vulnerability to windows. There is no season, time of day, and almost no weather conditions during which birds have not been recorded striking windows.

Window-kills also have been documented at clear and reflective tinted panes of various colors. Strikes occur in urban, suburban, and rural settings at panes of various sizes, heights, and orientation, but birds are more vulnerable to large (> 2 m²) windows near ground level and at heights of 3 m in suburban and rural areas.

Continuous monitoring at single homes in northern latitudes reveal strikes to be more frequent during the non-breeding seasons when birds are attracted to feeders in larger numbers than at any other time of the year (Klem 1989). Bird strikes at commercial buildings in Illinois were recorded more often during migratory periods than during the summer or winter (Hager et al. 2008). Media coverage of collision casualties also is typically restricted to migratory periods when the dead and dying are most conspicuous in cities where reporters often live and write about these tragedies after being alerted to their presence by residents.

The physical properties of clear and reflective panes and the limitations of the vertebrate eye suggest all vertebrate organisms are vulnerable to being deceived by sheet glass and plastic in the form of doors, walls, and windows. Although a human casualty can sustain a nasty bruise or cut from a collision, birds flying at even relatively low speeds are able to strike with enough momentum to be killed outright. Given that windows are invisible to birds, the best predictor of the number of casualties at any one location is the density of birds in the immediate vicinity of a window. Bird density near windows in differing settings can be best explained by artificial and natural foods, watering areas, vegetation, weather conditions that affect visibility, and overall landscape features that influence flight paths (Klem 1989, 1990b, Klem et al. 2004, Klem et al. 2009, Gelb and Delacretaz 2006, Hager et al. 2008)—the more birds in the immediate vicinity of windows, the more bird strikes, and the more fatalities.

CASUALTIES AND EXTENT OF MORTALITY

Surveys of staff at North American museums and select individuals from 1975-76 revealed 225 (25%) of the 917 species occurring in the continental U.S. and Canada are window casualties (Klem 1979, 1989, American Ornithologists' Union 1983). Since then 39 additional species have increased the total to 264 (28%) of the 947 species currently listed for North America north of Mexico (American Birding Association 2007).

Additional global surveys and publications of glass casualties currently report 798 species or about 8% of the approximately 10,000 bird species the world over. Collision victims are diverse, but those not typically recorded are major groups such as tubenoses, waterfowl, waders and shorebirds, several gulls, terns and auks, almost all soaring raptors, and many terrestrial species of galliforms, columbiforms, and passeriforms that occur in desert, grassland, and forested habitats with little or no glass-containing human structures.

A species with a documented significant decline due to collisions with windows is the globally threatened Swift Parrot (*Lathamus discolor*) of Australia -1.5% of the 1000 breeding pair population is annually documented as window-kills (BirdLife International 2000, Klem 2006, 2007). Other known window collision casualties that are also of global conservation concern are: 2 Critically Endangered, 2 Endangered, and 5 Vulnerable, among them the North American Cerulean Warbler (*Dendroica cerulea*); 17 Near Threatened, among them the Northern Bobwhite (*Colinus virginianus*), Black Rail (*Laterallus jamaicensis*), Plain Pigeon (*Patagioenas inornata*), Red-headed Woodpecker (*Melanerpes erythrocephalus*), Olive-sided Flycatcher (*Contopus cooperi*), Bell's Vireo (*Vireo bellii*), Golden-winged Warbler (*Vermivora chrysoptera*), Kirtland's Warbler (*D. kirtlandii*), Brewer's Sparrow (*Spizella breweri*), and Painted Bunting (*Passerina ciris*). The Plain Pigeon and Kirtland's Warbler are window-kills that also appear on the U.S. Endangered Species List. Glass casualties for the U.S. that appear on the National Audubon Society's 2007 WatchList are: 6 (9%) of the 67 species on their Red List, and 24 (26%) of the 94 species on their Yellow List (Butcher et al. 2007, National Audubon Society 2007, Klem in press).

With the exception of the Swift Parrot, the actual losses and survival effect associated with the mortality attributable to windows for all other species and bird populations in general is unknown and needs study. Nevertheless, the type of threat posed by sheet glass and plastic suggests this source of attrition is an additive,

not a compensatory mortality factor (Klem 1989, 2006, in press).

Published estimates of the annual toll exacted on birds in the U.S. alone range from 100 million to 1 billion based on the assumption that one bird is killed per building per year (Klem 1990b). Based on their studies in Illinois Hager et al (2008) offer that the annual mortality at commercial buildings may be five times higher than these figures. The kill attributable to strikes in urban areas during fall and spring migrations in North America north of Mexico is 34 million annual glass victims (Klem et al. 2009). Accepting the most conservative of these estimates, the lower limit of 100 million annual kills at glass for the entire U.S., we would need a comparable 333 Exxon Valdez oil spills each year to match the losses. This dramatic and highly publicized oil spill killed an estimated 100 000 to 300 000 marine birds in Alaska in 1989, and it continues to be often cited as a world-class environmental disaster. Yet the far greater lethal toll by sheet glass largely goes unnoticed, ignored, or is simply not understood by most professional and non-professional ornithologists and conservationists. Past and present encyclopedic works on birds either ignore (Terres 1980, Podulka et al. 2004) or barely mention (Gill 2007) bird kills at sheet glass. Some editors of ornithological and conservation journals consider the topic so unsuitable that they return manuscripts without peer-review.

Other annual sources of human-associated avian mortality are: 120 million from hunting, 60 million from vehicle road-kills, 10 000 to 40 000 from wind turbine strikes, and hundreds of millions by domestic cats (American Ornithologists' Union 1975, Banks 1979, Klem 1990b, Klem 1991, Erickson et al. 2001, Harden 2002). The kills at clear and reflective glass and plastic are surely in the billions worldwide. The conservation community simply must begin to address this enormous source of mortality in a much more active and effective way.

SOLUTIONS

The means to protect birds from windows include: (1) physical barriers that completely cover a pane, (2) patterns composed of elements that uniformly cover the surface and are visible when viewed from the outside, and (3) potentially uniform coverings made of ultraviolet (UV) reflecting and absorbing patterns that are visible to birds but invisible to the human eye. What can be considered short-term bird strike prevention consists of applying these varied techniques to existing clear and reflective conventional glass and plastic. The long-

term prevention is incorporating the visible and invisible patterns into manufactured panes for use in new construction.

SHORT-TERM SOLUTIONS

Covering windows with garden netting or conventional insect screening protect birds by keeping them from hitting the unyielding surface of sheet glass and plastic; a commercial screen is currently available for residential homes (see www.birdscreen.com). Moving bird feeders within 1 m of a window prevents injury and death because birds do not build up enough momentum to be harmed if they strike that window (Klem et al. 2004). Every effort should be made to move all feeding stations as close to the window surface as possible, wherever birds are fed: at homes, arboreta, and the visitor centers of private sanctuaries and those in local, state, and national parks where visitors enjoy viewing wild birds up close.

The use of single objects such as falcon silhouettes or UV-reflecting maple leaves placed on windows to prevent strikes are not significantly effective (Klem 1990b, 2009). The more decals applied to a window the more prevention. If you apply enough elements to the glass surface to uniformly cover the entire pane such that they are separated by 5 to 10 cm (2-4 in), you will prevent strikes completely. Fewer elements with greater distances between them result in less prevention.

Mylar strips, feathers on monofilament line, strung beads or bamboo sections, and awnings are equally effective in preventing strikes if elements making up the pattern are applied to uniformly cover the glass surface. They should be spaced 10 cm (4 in) apart when oriented vertically, and 5 cm (2 in) apart when oriented horizontally. Whatever patterns are applied to a reflective pane, they must be visible when looking at the window from the outside. This typically means that the patterns are applied to the outside surface.

An additional caution for reflective panes is that it is important to know that perfectly clear windows can mirror the facing habitat and sky when no light is visible from the interior of a structure. Ceramic frit glass offering a dot pattern that is dense, translucent, and covering entire panes is an effective preventive glass product when the pattern is visible looking at the window from the outside (Klem 2009).

One-way window films that render a window opaque or translucent when viewed from the outside are also significantly effective strike prevention coverings (Klem 2009; see CollidEscape film at www.flap.org).

LONG-TERM SOLUTIONS

A promising and hopeful solution to bird collision prevention is the use of UV reflecting and absorbing elements creating a window covering pattern, using films to retrofit existing structures and as an integral part of manufactured glass for new construction.

Some studies suggest that birds may not be able to interpret UV signals as an alert to danger (Young et al. 2003). Several organisms, to include birds, perceive and use the lower wavelengths of UV, blue, and purple colors as attractants, such as in behaviors associated with sexual selection and finding foods (Burkhardt 1982, Bennett and Cuthill 1994, Vitala et al. 1995, Bennett et al. 1996, Hunt et al. 1998). The upper visual wavelengths such as yellows, oranges, and reds are most often used as an alert to danger (aposematic coloration). Notwithstanding these contrasting functions, it is reasonable to suspect and recently reported experimental results reveal that UV signals can also be used to warn birds of danger (Klem 2009). A German glass manufacturer currently claims to use UV to effectively prevent bird strikes (see ORNILUX glass at www.bird-sandbuildings.org).

Another promising means of preventing strikes by creating patterns visible to birds and humans is to use nanoparticle technology to create a type of one-way pane. Such a product would create patterns with elements visible when looking at the exterior surface of a window, but would not be visible to viewers looking from the inside. Such externally visible patterns could be created from interfering wavelengths similar to what occurs when viewing the gorget of a hummingbird or the head of a male Mallard (*Anas platyrhynchos*) from different angles.

Angling windows by 20 and 40 degrees from the vertical is thought to protect birds by reducing the force with which they hit clear and reflective surfaces (Klem et al. 2004).

HELP WANTED: CALLING ALL ORNITHOLOGIST, CONSERVATIONISTS, ANYONE INTERESTED IN SAVING BIRD LIVES

I have repeatedly asked my avian conservation colleagues if they know something I do not, and if not, why are they not alarmed and taking some action to protect birds from sheet glass and plastic. Here is a feature in the human built environment that by all estimates is an order of magnitude greater than any other human associated avian mortality factor. Moreover, it is a product that is dramatically increasing as more global human construction occurs on the breed-

ing and non-breeding grounds, and across the migratory routes of the birds of the world.

During the session entitled Anthropogenic Causes of Bird Mortality at the Partners in Flight McAllen Conference (14 February 2008), I marveled at the level of cooperation and effort devoted to addressing bird kills from communication towers, power lines, and wind turbines. Although not as committed an effort, fatalities due to domestic cats continue to receive marked attention from national conservation campaigns. The Discussion portion at the end of this session was dominated by issues stemming from these sources of avian fatalities. The huge impact that sheet glass and plastic pose for birds worldwide was meagerly addressed and, as such, seemingly not taken as seriously as any other human-associated mortality factor.

Just what explains this seeming lack of interest and attention? Are the published works on this topic suspect? Do conservationists not believe the numbers? Is it a simple lack of appreciation? Are they overwhelmed by the ubiquitous nature of glass and a perceived low likelihood that they can be effective in reducing this source of mortality?

The Migratory Bird Treaty Act (MBTA) of 1918 and the Endangered Species Act of 1973, as respectively amended, can be powerful tools to protect our native birdlife. And although the unintentional killing of a single individual wild bird is theoretical cause for legal action under these documents, it seems unreasonable to expect law enforcement to bring legal action against homeowners whose property is responsible for the deaths of several birds from collisions with their windows.

However, I forcefully argue that it is reasonable to expect law enforcement to monitor and address the unintentional killing at glass in structures at which hundreds die in a single day, in several well-known and documented sites in the U.S. and Canada. The annual kills at single residences and well-known commercial sites are substantial, foreseeable, and avoidable, and birds merit protection from sheet glass and plastic at these locations under the purview of the MBTA and ESA (Corcoran 1999).

Another related and prominent environmental cause within the conservation and building industry communities are the promotion and construction of so-called "green buildings." But no matter how many recyclable materials, energy conserving features, or erosion controls a building possesses, it should not be considered "green" if birds are dying by flying into its windows. Although attempts are ongoing, we need to more effectively encourage and convince The U.S. Green Building Council (USGBC) to

incorporate bird-safe glass and bird-safe architectural and landscape practices as a distinct evaluation point in the very next version of their building rating system called Leadership in Energy and Environmental Design (LEED). Building guidelines were recently prepared to inform architects and other building professionals about how to make human structures safe for birds (Brown and Caputo 2007, City of Toronto Green Development Standard 2007), and architectural and landscape risk factors associated with bird-glass collisions in urban environments were recently documented (Klem et al. 2009).

A dedicated educational effort and additional research is needed to inform and convince more of the avian conservation community, building industry professionals, and the general public that sheet glass and plastic has a devastating effect on bird populations. Notwithstanding the single current example described above, few if any other manufacturers will invest in producing bird-safe glass or plastic if they judge there is no market for such a product; effective education can create the needed market.

ACCIDENTAL VALUE

Our goal should be to eliminate all the unintended bird deaths resulting from window strikes, but given what we know about the complexities of the problem for birds and humans, collision victims will continue to occur with the continuing growth of buildings, and the differential ability to apply preventive methods throughout the planet. Consequently, a valuable source of data is available from window casualties given that every piece of sheet glass and plastic in any human structure the year round and the world over is a potential killing site, and as such, a source of museum specimens. Systematic searches of most human buildings will reveal collision specimens in rural, suburban, and urban areas. Practical uses of window casualties are: as a means of informing us about migratory movements and distribution, breeding and non-breeding ranges and their contractions and expansions, new occurrence records for geographic locations, and as subjects for whole or in part specimen related studies of species-specific form and function (Klem 1979, 1990b). A Kirtland's Warbler window-kill was documented along its migratory route between Michigan and the Bahamas (Walkinshaw 1976). Glass collision specimens were used to study the migration of several Australian birds (Talpin 1991). The first record of a White-bellied Emerald (*Amazilia candida*) for El Salvador was a window collision victim

in downtown San Salvador on 3 November 2004 (Jones 2005). Detailed gross anatomy and histology of the alimentary tract of House Sparrow (*Passer domesticus*) and American Robin (*Turdus migratorius*) were described from window-kills (Klem et al. 1982, 1983, 1984). Like the Field Museum in Chicago where annually about 1000 window-kills are added to their bird collection (Lowther 1995) and the University of Nebraska State Museum in Lincoln (Labeledz 1997), collected window-kills elsewhere should be properly documented and preserved in authorized collections if we are unwilling or unable to stop the killing at clear and reflective panes.

SUMMARY OF BIRD-WINDOW COLLISION PREVENTION

1. Cover windows with netting.
2. Move bird feeders, watering areas, perches, and other attractants to within 1 meter or less of the glass surface.
3. Place decals on or hang strings of objects in front of windows such that they uniformly cover the surface and are separated by 10 cm (4 in) or less in vertical columns or 5 cm (2 in) or less in horizontal rows.
4. Use one-way films that consist of patterns and color shades acceptable to homeowner and commercial building manager; these films provide a minimally obstructed view from inside while rendering a window opaque or translucent when viewed from the outside.
5. Reduce the proportion of glass to other building materials in new construction.
6. Use ceramic frit glass with 0.32-cm diameter translucent appearing dots separated 0.32 cm apart in new or remodeling existing structures.
7. When commercially available for use in new or remodeled buildings, use external film or glass coatings that create a pattern of: (a) 2.5-cm wide UV-reflecting stripes oriented vertically and separated by 5 cm UV-absorbing stripes oriented vertically, (b) 5-cm wide UV-reflecting stripes oriented vertically and separated by 2.5 cm UV-absorbing stripes oriented vertically, and (c) a grid consisting of 10-cm wide UV-reflecting vertical columns separated by 2.5 cm wide UV-absorbing vertical columns, and 8-cm wide UV-reflecting horizontal rows separated by 2.5 cm wide UV-absorbing horizontal rows.
8. Angle windows 20 to 40 degrees from vertical in new or remodeled construction.
9. When landscaping near windows, reduce bird attracting features such as watering areas, and ground cover, to include eliminating shrub and trees from areas in front of buildings.
10. For new and remodeled construction, include the use of bird-safe glass and bird-safe landscaping features as distinct evaluation points in the next version of The U.S. Green Building Council (USGBC) rating system entitled Leadership in Energy and Environmental Design (LEED).

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