Glass and Bird Kills: An Overview and Suggested Planning and Design Methods of Preventing a Fatal Hazard

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INTRODUCTION

Small sheets of glass existed as window panes as long ago as 290 A.D. (Phillips 1941:8). Glass permits a view from protected enclosures, admitting light and warmth into human dwellings. In the Middle Ages, tinted and clear panes were lavishly incorporated into cathedrals of Europe and then into the domestic homes of the rich, especially Tudor England (Anonymous 1967). Large sheets of glass were first produced about 1903 and are commonplace today in structures throughout much of the modern world. Many modern buildings are surfaced entirely with glass, and often human dwellings contain large picture windows. Thus, it appears that window glass has enriched man's aesthetic, cultural, physiological, and psychological well-being for at least 16 centuries.

Glass panes, as a source of avian mortality, probably are as ancient and progressive as their use, but confirmations of bird fatalities do not appear in the literature until well after 1800 with the development of modern ornithology in Europe and North America (Nuttall 1832:88, Baird et al. 1874:417, Townsend 1931). The literature now contains accounts of window-kills from most of the world's continents (Weir 1976, Klem 1979, Avery et al. 1980, Klem 1989).

Available evidence suggests that all free flying birds are potentially vulnerable to glass (Klem 1979, 1989,1990a). My extensive observational data and experiments indicate that, with the possible exception of hunting mortality, glass kills more birds than any other man-caused avian mortality factor, including the higher image catastrophes resulting from oil spills, pesticide poisoning, and collisions with vehicles, tall towers, and buildings (Table 1). With few exceptions, a willingness to modify or incorporate alterations to building and landscape designs can save millions of birds. Protecting our birds promotes sound environmental practices by conserving a group of animals that are used regularly to monitor the overall health of the environment, and provides an immeasurable source of human enjoyment through a variety of recreational activities (Temple and Wiens 1989). Although I have reported on this subject elsewhere in the scientific literature (Klem 1989; 1990a,b), my objectives in this paper are to: (1) briefly review existing knowledge, (2) further emphasize the magnitude, significance, and human perception of the problem, and (3) formally present site-specific alternative solutions to architectural and landscape professionals and their allies.

Table 1. Estimates of annual man-caused avian mortality in the United States.[a]

Mortality factor	Number of individuals killed	Percentage of total kill
Hunting	120,539,500	41.53
Depredation control	2,000,000	0.69
Scientific research and propagation	894,010	0.31
Other direct sources[b]	3,500,000	1.21
Pollution and poisoning[c]	3,815,000	1.31
Vehicle collisions	57,179,300	19.70
Tall structure collisions (towers, stacks, buildings)	1,250,000	0.43
Plate glass collisions[d]	97,563,626	33.61
Other indirect sources[e]	3,510,000	1.21
Total	290,251,436	100.00

[a]Modified from Banks (1979) and Klem (1990a).
[b]Includes casualties related to falconry and attempts to raise young wild birds, illegal shooting, and vandalism.
[c]Includes deaths related to the upper estimate (300,000) of one annual oil spill having the same effect as the 1989 Exxon Valdez spill in Alaska (Piatt et al. 1990).
[d]Lower estimate of 97,563,626 to 975,636,260 range (Klem 1990a). If the upper estimate of the range is used, glass would dominate all other man-caused mortality factors by representing 84% of the 1,168,324,070 total kill.
[e]Includes deaths due to bird banding, electrocution by power lines and fences, fish net and line entanglement, birds trapped in buildings, domestic pets such as cats, mammal traps, and other factors described by Lincoln (1931).

THE PROBLEM

Backyard birds, such as the American robin (*Turdus migratorius*) and northern cardinal (*Cardinalis cardinalis*), that repeatedly bang into and flutter against windows in the spring and summer are little harmed by such activity. These occurrences are often of concern to humans (and an annoyance to some), but, except for an occasional bloodied face, they are harmless to birds. Strikes of this type result from

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male birds defending their territories against their reflected image.

By contrast, birds are frequently killed when they strike windows as if unaware of the presence of these structures. These collisions can be a problem for birds and humans. As the human population and the dwellings in which we live and work increase, windows may contribute to significant declines of select species and the persistent and increasing losses may affect bird populations in general. Window-kills are a serious problem to a growing number of people who experience remorse, guilt, and anxiety when they discover, or are made aware, that the glass in their homes, work places, and the commercial buildings they frequent are unintentionally killing the birds they enjoy or appreciate as part of their environment.

Evidence from documented collisions and controlled experiments clearly indicates that birds are not able to recognize glass as a potentially lethal obstacle. Glass is simply invisible to birds. Other animals such as insects, fish, and mammals like dogs, deer, and humans strike stationary windows, but the momentum at which they impact usually does not cause serious injury. Alternatively, even the smallest flying birds can reach speeds that result in fatal collisions.

No birds appear to be immune to the hazard. Approximately 25% (225/917) of all avian species in the United States and Canada have been documented striking windows. The species not recorded as window-kills are those that usually do not occur near human dwellings, such as most waterbirds, soaring hawks, and terrestrial species occupying unpopulated or sparsely populated desert, grassland, and forest. Sex, age, and resident status have little influence on vulnerability to collisions. There is no season or time of day, and almost no weather conditions during which birds elude glass. Transparent or reflective windows of various colors are equally lethal to birds. Strikes occur at windows of various size, height, and orientation in urban, suburban, and rural environments, but birds are more vulnerable to large ($>2m^2$ panes near ground level and at heights above 3 m in suburban and rural areas.

Strike rates at specific sites are unique and require attention to a combination of contributing factors. Overall, the magnitude of the kill at any one site is directly related to avian, dwelling, or environmental features that increase the density of birds near windows. From extensive analyses of bird strike accounts, a survey of window-killed specimens, and a series of experiments, I found that collisions and their resultant fatalities are possible wherever birds and windows coexist (Klem 1989).

The significance of this type of man-caused mortality is unknown, but I suggest that enough evidence exists to indicate it may be substantial for some species and for birds in general (Table 1). The widespread, persistent, and increasing loss due to windows contrasts sharply with the relatively meager losses from higher image catastrophes resulting from oil spills, pesticide poisoning, and collisions with vehicles, tall towers, and buildings. If my 100 million toll is accepted as a relative order of magnitude (Table 1), an equal number of victims would require approximately 333 Exxon Valdez oil spills. The Exxon Valdez released 260,000 barrels of crude oil into Alaska's Prince William Sound on 24 March 1989, and the spill was estimated to have killed from 100,000 to 300,000 marine birds (Piatt et al. 1990). Of course, to keep the disaster in perspective, the Valdez oil spill harmed numerous species other than birds and also affected the fishing-based economy and general ecology of the region.

These seemingly dramatic figures only have biological relevance if windows affect the survival of birds as a whole or local breeding populations that contribute uniquely to the genetic diversity of a species. If relevant, the problem demands serious attention by all professionals acting in an environmentally responsible manner and dedicated or sympathetic to conservation, management, and the preservation of biodiversity. In my view, enough evidence already exists to suggest that unless preventive measures are enacted, glass will become an ever increasing threat to select species and birds in general. There appears to be no avian trait that has evolved to permit individuals to recognize and avoid man-made sheet glass. Potential victims are the fit and unfit of abundant as well as rare, threatened, and endangered species. My estimates of 98 to 976 million annual window-kills represent 0.5 to 5.0% of the estimated continental U.S. bird population after the breeding season (Klem 1990a); 10 billion are estimated at the start of the breeding season (American Ornithologists' Union 1975). These seemingly low percentage rates mask the impact on select species, and potential increasing tolls on all birds, as more construction places more windows in avian breeding and non-breeding habitats and across their migratory routes.

Specific cases support a serious cause for concern. At one European building, 54 birds were killed in a 2-month period (Morzer Bruijns and Stwerka 1961). Another European site was abandoned by a local breeding colony of swallows (*Hirundo rustica*) after the population suffered critical declines due to window-kills at a nearby glass corridor (Lohrl 1962). Through continuous and systematic monitoring of two single houses in the United States, I found annual kills of 33 and 26 birds, respectively (Klem 1990a). Collisions at one of these houses in the same 4-month period (September to December) resulted in 26 (1975) and 15 (1976) fatalities. For both homes, one out of every two strikes was lethal, and small (hummingbird to sparrow) and large (cardinal to bobwhite) species were equally vulnerable.

Specific accounts also document window deaths for endangered or other species of special concern. A Kirtland's warbler (*Dendroica kirtlandii*) was killed on migration (Walkinshaw 1976), and peregrine falcons (*Falco peregrinus*) have died crashing into the windows of buildings near their urban reintroduction sites. A survey of North American window-kills suggested a 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,

1990a). These same data revealed that most neotropical migrants—North American species that travel to Central or South America during non-breeding periods—are known to be killed at windows. Windows will continue to exact a non-selective toll on these particular migrants, already suspected of population declines due to tropical forest destruction and temperate forest fragmentation (Robbins et al. 1989a). One neotropical migrant, the ovenbird *(Seiurus aurocapillus)*, was a bird reported most often as a window-kill in my survey and a species under intense study due to suspected population declines resulting from habitat fragmentation.

Representing an ever increasing threat to birds are human population trends that show a return to rural areas in the United States (Long and DeAre 1982), and worldwide development of farmland, forest fragments, and previously undisturbed large tracts of habitat (Robbins et al. 1989a, Robbins et al. 1989b).

The actual cause of death resulting from window strikes is almost always described by the uninformed as a "broken neck." This explanation is wrong in every known case. Detailed internal and external examinations and x-rays of over 500 victims revealed that birds died from head injuries (Klem 1990b, Veltri and Klem, in prep.). The sustained injuries are similar to those occurring in fatal human accidents involving head collisions. Additionally, documented accounts record birds succumbing to injuries after leaving the collision site and seemingly recovering completely (Klem 1990b). Initially recovered individuals are generally debilitated for varying periods, or they dramatically exhibit increasing paralysis over time (Klem 1990b). In either case, while attempting to recuperate, they are in a weakened condition to face the pressures of a demanding climate, predators, scavangers, and other environmental forces.

Humans are affected most often by the realization that windows have fatal consequences for birds, and to a lesser extent by the damage that some birds pose to windows. Although accounts of window breakage by large birds are documented (Blain 1948, Giller 1960, Dawson and Dalby 1973), it is a rare event; most windows are unaffected by bird strikes.

To my knowledge, the earliest attempt to inform architects of the problem of window-killed birds was made by Lohrl (1962). He justified a plea to eliminate transparent glass in new buildings, especially in schools where students regularly found victims beneath glass panes, by stating that such action would set an example for our children by protecting birds and demonstrating a respect for nature.

Ironically, many 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. Even more ironically, many conservationists and conservation groups who directly or indirectly criticize the collecting of specimens for scientific study own homes or buildings that regularly kill birds. In two instances, complaints from employees that the windows of their work places in New York and Maryland were killing birds prompted corporate architects to seek advice to address the concerns. As more attention is given to the extent of mortality and debilitating injury resulting from window strikes, similar concerns for the safety of birds, especially at higher image structures, may be expressed by all conservation-minded individuals and groups.

Developers, architects, landscape planners, or other associated professionals may become involved in litigation as attention and concern for this man-caused lethal hazard for birds increases. In the past 5 years, advice was sought for two possible court cases in Connecticut and California. The Connecticut case dealt with the construction of a large glass-covered building adjacent to a wildlife refuge. The California case dealt with a series of glass-covered buildings proposed for construction on a university campus. Overall, I believe the concern about window-kills and their significance to birds and humans will pose demands and expectations for responsible action from the glass industry and associated professionals as well as the conservation community in general. To date, the sheet glass industry and its commercial allies appear to be unaware of, or have chosen to ignore, the problem. Almost equal ignorance and concern have been expressed by individuals and groups whose interests focus on birds. Most textbooks and encyclopedia treatments of ornithology, as well as articles addressing man-caused avian mortality in professional and popular periodicals, present little, if any, description of the fatal hazards that windows pose to birds. Exceptions include two current textbooks that introduce the problem to students of ornithology (Gill 1990) and wildlife management (Robinson and Bolen 1989).

One might very well ask: Why has this subject not received more attention? Some concerned individuals often have the impression that window-kills are rare or the consequence of some abnormal trait or disease. I suspect that most people are simply unaware of the regularity and extent of the kill. Although window bumps occur while occupants are home, these sounds are often forgotten or dismissed as having an unknown origin. Because of practices of placing foundation plantings beneath and around windows, after a collision, bird victims are often hidden when they fall into adjacent vegetation, and the injured or weak seek out nearby concealed perches. Also, predators and scavengers learn that the dead and dying are readily available prey beneath or in the vicinity of windows (Klem 1981). Even seemingly unlikely scavengers, such as the eastern gray squirrel *(Sciurus carolinensis)*, take advantage of available victims. One squirrel on the Muhlenberg College campus collected a window-killed adult male rose-breasted grosbeak *(Pheucticus ludovicianus)*, opened its skull, and was observed feeding on the brain. To remove the offending or unsightly dead and dying birds from some commercial sites, such as the large plate glass windows of motels and hotels along the gulf coast of Texas, owners hire personnel to make early morning

collections of window-kills that lie beneath their picture windows.

SOLUTIONS AND MANAGEMENT

Solutions at various problem sites will require varying financial investment and structural modifications that may influence the aesthetic appearance of houses, and commercial and other buildings. Some solutions at some sites will be cost prohibitive, and some designers will find any modification of their designs unacceptable. My hope is that such conditions or intolerant attitudes will be rare, and environmentally responsible solutions will be enacted at most, if not all, existing or potential collision sites.

At most sites, realistic solutions will have to maintain the functional and aesthetic qualities of glass. Successful solutions at any one site will require compromises that consider visual alterations and an acceptable level of bird protection.

To prevent collisions with existing windows, birds must recognize that the area glass covers is a space to be avoided. Collisions can be completely eliminated by covering windows with netting that prevents birds from ever reaching the unyielding surface. This solution is acceptable for small to medium-sized plate glass, but netting is cost prohibitive for large or continuous sheets forming glass walls.

Covering all or parts of the external glass surface with opaque or translucent curtains also can completely eliminate bird strikes. Proper external coverings disrupt the transparent or reflective image enough to direct flying birds away from the glass area. Partially covering the outside of windows is as effective as complete covering if individual elements of varying sizes and shapes uniformly cover the entire glass surface and are separated by 5 to 10 cm. Interestingly, if covering elements are individual strips as narrow as 2.5 cm and oriented either horizontally or vertically like venetian blinds, the strips must be separated by 5 cm horizontally but can be as much as 10 cm apart when placed vertically.

My test results of the effectiveness of partially covered windows in reducing bird kills suggest the potential for a new conservation product to prevent bird strikes at individual windows (Klem 1990a). I suggest the development and manufacture of an external roll up window covering that completely or partially covers the glass surface and consists of various creative designs. Coverings could be made with one of several different patterns, such as hawk silhouettes or pleasing geometric figures, or a combination of different patterns. Depending on technical production, requests for custom patterns also could be accommodated. If not in place at all times, coverings could be lowered when occupants were away from their windows such as at night, during the early morning hours when birds might be more active, or when away from their dwellings for extended periods.

Single objects such as falcon silhouettes or owl decals, large eye patterns, various other pattern designs, and decoys do not reduce strike rates to a statistically significant level (Klem 1990a). Many such items are commercially available, sold by conservation groups and garden clubs, or illustrated and described as solutions in landscaping publications (Henderson 1987). However, these objects fail to prevent most strikes because they cover only one part of the glass and are not applied in sufficient number to alert the birds to the glass barrier. These objects, like any others, must uniformly cover the glass surface and be separated by 5 to 10 cm to be effective.

New developments and resultant new products from the glass industry may eventually offer the best solutions for reducing bird kills at windows. Non-reflective tinted glass would uniformly transform windows into visible obstacles for birds. Alternatively, glass with non-reflective or interference zones containing patterns that uniformly alter the surface by the 5 to 10 cm criterion is expected to be as effective as analogous external coverings. However, to my knowledge, such products are not currently available, and they may be technically impossible to manufacture given the physical structure of glass.

For new or remodeled buildings, architects and allied professional designers are encouraged to install windows at an angle so that the pane reflects an image of uninviting ground instead of an illusion of safe passage through habitat or into the sky. The angle at which glass is offset from its conventional vertical position will vary depending on the position of the structure relative to the surrounding terrain. The effective angle will require knowledge of the point at which the pane reflects a complete image of the ground and knowledge of the stress applied to panes of varying size and thickness. My research group is currently collecting observational data and designing various experiments to further quantify the effectiveness of window angling.

Placement of bird attractants such as feeders, watering areas, and nutritious and aesthetic vegetation in front of windows increases the hazard of bird strikes. Eliminating bird attractants near conventional windows will reduce or completely prevent strikes by reducing the number of birds near the hazard. However, using preventive techniques such as netting or partial but uniform external coverings will permit the use of attractants and retain the enjoyment of viewing birds up close without the worry of exposing them to injury or luring them to their deaths. If attractants are used without preventive strike measures, attempt to place feeders or other resources within 0.3 m of the glass surface. Birds will be drawn to the attractant upon arrival, but due to the close proximity of the attractant to the window, they will not build up enough momentum to sustain serious injury if they hit the glass upon departure.

CONCLUSIONS

Windows are non-selective killers of birds, and this particular man-caused mortality factor may be contributing to population declines of select species and birds in general. Windows also are important and valuable components of

human dwellings, and a solution at any one problem site most likely will have to maintain the functional and aesthetic qualities of glass. Because transparent and reflective plate glass is invisible to birds, various current and potential future solutions require altering windows so that birds functionally recognize them as barriers. Problem sites generally are unique, and acceptable solutions will require creative planning and design for new or remodeled man-made structures. Whatever solution or management practice is enacted at a particular site, it is likely that humans will have to sacrifice some aesthetic appearance to their dwellings. The birds will have to sacrifice some lives.

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REFERENCES CITED

American Ornithologists' Union. 1975. Report of the ad hoc committee on scientific and educational use of wild birds. Auk 92(Suppl.):1A-27A.

Anonymous 1967. Mississippi handbook. Mimeographed, 54pp.

Avery, M. L., P. F. Springer, and N. S. Daily. 1980. Avian mortality at man-made structures: an annotated bibliography (Revised). U.S. Fish and Wildl. Serv., Washington, D.C. 152pp.

Baird, S. F., T. M. Brewer, and R. Ridgway. 1874. A history of North American birds: land birds. Volume I. Little, Brown and Co., Boston, Mass. 596pp.

Banks, R. C. 1979. Human related mortality of birds in the United States. Spec. Sci. Rep. 215, U.S. Fish and Wildl. Serv., Washington, D.C. 16pp.

Blain, A. W. 1948. On the accidental death of wild birds. Jack-Pine Warbler 26:59–60.

Dawson, G. A., and P. L. Dalby. 1973. A goshawk-thermopane encounter. Jack-Pine Warbler 51:128.

Gill, F. B. 1990. Ornithology. W. H. Freeman and Co., New York, N.Y. 606pp.

Giller, F. 1960. Eine moderne "Vogelfalle." Ornithologische Mitteilungen 12:152–153.

Henderson, C. L. 1987. Landscaping for wildlife. Dep. of Nat. Resour., St. Paul, Minn. 145pp.

Klem, D., Jr. 1979. Biology of collisions between birds and windows. Ph.D. Dissertation, Southern Illinois Univ., Carbondale. 256pp.

———. 1981. Avian predators hunting birds near windows. Proc. Pa. Acad. Sci. 55:90–92.

———. 1989. Bird-window collisions. Wilson Bull. 101:606-620.

———. 1990a. Collisions between birds and windows: mortality and prevention. J. Field Ornithol. 61:120–128.

———. 1990b. Bird injuries, cause of death, and recuperation from collisions with windows. J. Field Ornithol. 61:115–119.

Lincoln, F. C. 1931. Some causes of mortality among birds. Auk 48:538–546.

Lohrl, H. 1962. Vogelvernichtung durch moderne glaswande. Kosmos 5:191–194.

Long, L., and D. DeAre. 1982. Repopulating the countryside: a 1980 census trend. Science 217:1111–1116.

Morzer Bruijns, M. D., and L. J. Stwerka. 1961. Het doodvliegen-van vogels tegen ramen. De Levende Natuur 64:253–257.

Nuttall, T. 1832. A manual of the ornithology of the United States and of Canada. Volume I. Hilliard and Brown, Cambridge, Mass. 683pp.

Phillips, C. J. 1941. Glass: the miracle maker. Pitman Publ. Corp., New York, N.Y. 424pp.

Piatt, J. F., C. J. Lensink, W. Butler, M. Kendziorek, and D. R. Nysewander. 1990. Immediate impact of the 'Exxon Valdez' oil spill on marine birds. Auk 107:387–397.

Robbins, C. S., J. R. Sauer, R. S. Greenberg, and S. Droege. 1989a. Population declines in North American birds that migrate to the neotropics. Proc. Natl. Acad. Sci. 86:7658–7662.

———, D. K. Dawson, and B. A. Dowell. 1989b. Habitat area requirements of breeding forest birds of the Middle Atlantic States. Wildl. Monogr. No. 103. 34pp.

Robinson, W. L., and E. G. Bolen. 1989. Wildlife ecology and management, 2nd ed., Macmillan Publ. Co., New York, N.Y. 574pp.

Temple, S. A., and J. A. Wiens. 1989. Bird populations and environmental changes: can birds be bio-indicators? Am. Birds 43:260–270.

Townsend, C. W. 1931. Tragedies among Yellow-billed Cuckoos. Auk 48:602.

Walkinshaw, L. R. 1976. A Kirtland's warbler life history. Am. Birds 30:773.

Weir, R. D. 1976. Annotated bibliography of bird kills at man-made obstacles: a review of the state of art and solutions. Dep. Fish and Environ., Can. Wildl. Serv., Ottawa, Ont. 85pp.