The Wilson Journal
of Ornithology

PREVENTING BIRD–WINDOW COLLISIONS

DANIEL KLEM JR[1]

Published by the
Wilson Ornithological Society

The Wilson Journal of Ornithology 121(2):314–321, 2009

PREVENTING BIRD–WINDOW COLLISIONS

DANIEL KLEM JR[1]

ABSTRACT.—Birds behave as if clear and reflective glass and plastic windows are invisible, and annual avian mortality from collisions is estimated in the billions worldwide. Outdoor flight cage and field experiments were used to evaluate different methods to prevent collisions between birds and windows. Stripe and grid patterns of clear UV-reflecting and UV-absorbing window coverings presented an effective warning that birds avoid while offering little or no obstructed view for humans. Birds used UV-reflected signals to avoid space occupied by clear and reflective sheet glass and plastic. Window coverings with effective UV-reflecting and UV-absorbing patterns as warning signals can prevent unintentional killing of birds from collisions with windows. One-way films that made the outer surface of windows opaque or translucent were successful in deterring bird strikes. Ceramic frit glass consisting of a visual pattern of densely spaced 0.32-cm diameter dots, 0.32 cm apart was an effective collision deterrent. Uniformly covering windows with decals or other objects that are separated by 5 to 10 cm was completely or near-completely effective in preventing strikes. Twice the number of window strikes occurred at non-reflective sheet glass compared to conventional clear panes. Continuous monitoring of windows revealed one in four bird strikes left no evidence of a collision after 24 hrs and, without continuous monitoring, 25% of bird strikes were undetected. *Received 11 September 2008. Accepted 19 January 2009.*

Avian mortality resulting from collisions with clear and reflective sheet glass and plastic is estimated to be in the billions worldwide (Klem 1990, 2006). Collisions are predicted and expected wherever birds and windows coexist (Klem 1989, 1990, 2006). Birds behave as if windows are invisible, and it is important to prevent this unintended killing, estimated to represent the largest human-associated source of avian mortality except habitat destruction (Klem 2006, 2009a, b). The diversity of species and the invisible threat suggest that birds in general are vulnerable to windows, but documented casualties of species of special concern indicates that avian mortality from window collisions is contributing to population declines of specific species and birds in general (Klem 2009a, b).

I evaluated several methods to prevent bird strikes at windows using previously effective outdoor flight cage and field experiments (Klem 1989, 1990). Most preventive treatments examined the use of ultraviolet (UV) signals to alert birds to windows, and the availability of materials affected the composition of what was tested in each experiment. The ability of birds to avoid clear plastic and the ability of one-way films, fritted glass, and feathers to prevent collisions were also evaluated. Specifically, I tested: (1) clear plastic with a UV-absorbing component, (2) single and uniform covering of multiple UV-reflecting maple leaves, (3) a string of colored contour feathers, (4) a one-way external film having an unobstructed view from inside and an obstructed view of dot pattern from outside, (5) a ceramic frit glass with a uniform covering of translucent dots, (6) a variety of UV-absorbing stripe patterns created by plastic strips, and different UV-absorbing and UV-reflecting complete covering, striped, and grid patterns created by external films.

METHODS

Flight cage and field experiments were conducted on a 0.2-ha open mowed grass suburban backyard surrounded and isolated from neighbors by mature shrubs and evergreens in Upper Macungie Township, Lehigh County, Pennsylvania (40° 34′ 35″ N, 75° 34′ 57″ W). Four field experiments were conducted on a 2-ha open rural area of mowed pasture bordered by second growth deciduous forest and shrubs in Henningsville, Berks County, Pennsylvania (40° 27′ 53″ N, 75° 40′ 07″ W).

Flight Cage Experiments.—These tests were conducted from 13 March to 30 April 2004. The basic design was reported previously by Klem (1990) and consisted of a trapezoidal flight cage 1.2 m high, 3.6 m in length, and 0.3 m wide at the narrow end and 2.6 m wide at the broad end. Five Dark-eyed Juncos (*Junco hyemalis*), one White-throated Sparrow (*Zonotrichia albicollis*), and one House

[1] Acopian Center for Ornithology, Department of Biology, Muhlenberg College, Allentown, PA 18104, USA; e-mail: klem@muhlenberg.edu

Sparrow (*Passer domesticus*) were captured in March for use as subjects, housed in small cages, and tested from mid-March and throughout April. Except for the House Sparrow which was an adult female, age and gender of all other subjects were unknown; previous studies of collision casualties document equal vulnerability for all age and gender classes (Klem 1989).

Individuals were released from a holding box at the narrow end and forced to discriminate between left and right flight paths as they attempted to escape to wooded evergreen habitat visible outside the broad end of the cage. One half of the cage at the broad end was left unobstructed in all experiments. The other half was obstructed by clear plastic or objects tested to prevent bird strikes. During testing of a subject, the obstructed and unobstructed sides were changed for half the trials to ensure no bias flight path preference for one side or the other. Actual clear plastic was tested with two Dark-eyed Junco subjects to learn if they were capable of discriminating between clear plastic and unobstructed airspace. Previous studies revealed that Dark-eyed Junco subjects were not capable of discriminating between clear glass and unobstructed airspace (Klem 1990). Objects tested were hung on the obstructed side with clear monofilament line to appear as if taped, stuck, or applied as a coating to clear glass or plastic to prevent accidental collision injuries to subjects in subsequent experiments. No Institutional Animal Care and Use Committee existed during this study, but guidelines for the care of wild birds in research were followed (Gaunt and Oring 1999). All subjects were released unharmed at the end of the experimental period.

Eight flight cage experiments were conducted. Each experiment tested one to five subjects, and each subject flew a minimum of 10 trials per experiment with additional trials (up to 24) to clarify results (Table 1). A trial consisted of recording a subject passing through the unobstructed side of the cage or the side containing the object tested. If the subject chose the obstructed side it was scored as a window strike; if the subject flew through the unobstructed side it was scored as avoidance. Two to three objects were evaluated on any test day. Individuals were tested with a single object on any one test day, and subjects tested with more than one object were tested on different days. The objects tested were: (1) clear plastic with a UV-absorbing component, (2) single translucent UV-reflecting maple leaf (WindowAlert Decal) measuring 10 × 10 cm; (3) uniform covering of 12 UV-reflecting maple leaves as in #2, placed 10 cm apart in vertical columns and 5 cm apart in horizontal rows; (4) a single clear monofilament line attached to the quill of four colored (from top: red, blue, yellow, and green) contour feathers (FeatherGuard™) measuring 14.4–19.6 cm long and separated by 33 cm; (5) 0.32-cm thick vertically oriented 2.5-cm wide UV-absorbing plastic strips forming stripes separated by 10 cm; (6) vertically oriented 2.5-cm wide UV-absorbing strips forming stripes as in #5 but separated by 5 cm, (7) 2.5-cm wide UV-absorbing plastic strips forming stripes as in #5 but horizontally oriented and separated by 5 cm; and (8) ceramic frit glass uniformly covered with a pattern of translucent-appearing dots 0.32-cm in diameter separated by 0.32 cm. Binomial tests were used to examine the significance of each experiment (Siegel 1956).

Field Experiments.—The basic design of all field experiments was reported previously (Klem 1989, 1990) and consisted of wood-framed picture windows, accurately simulating those in houses; all were placed in the same habitat oriented in the same direction 1 m from a tree-shrub edge facing an open field (Klem 1989: figure 1). Each window measured 1.2 m wide × 0.9 m high and was mounted 1.2 m above ground. Plastic mesh trays were placed under each window to catch casualties. Three window units were used in the first and second experiments, and were separated by 4.2, 3.8, and 4.1 m. Three and seven window units were used in the third to sixth experiments separated by 7.8, 7.4, 7.9, 9.0, 7.4, and 8.3 m. A single platform feeder measuring 30.5 cm on a side and 1.2 m above ground mounted on crossed wooden-legs was centered and placed 10 m in front of each window to simulate a feeding station at a rural residential home. Feed consisted of a 1:1 mixture of black-oil sunflower seeds and white proso millet. All feeders were kept full throughout each experiment. No object was permitted at the same window on consecutive days for all experiments, and each object test-

TABLE 1. Preventive methods used in outdoor flight cage experiments to examine avoidance of bird–window collisions.

Preventive method Species tested	Number tested	Number significantly avoiding method[a]	Number test trials	Avoidance	Non-avoidance	*P*
Clear sheet plastic						
Dark-eyed Junco	2	0	14	8	6	0.395
			10	6	4	0.377
Single UV-reflecting maple leaf in center of pane						
Dark-eyed Junco	5	1	16	15	1	<0.001
			17	7	10	0.834
			10	2	8	0.989
			15	7	8	0.696
			10	5	5	0.623
Uniform covering of 12 UV-reflecting maple leaves, 10 cm separating 2 vertical columns, 5 cm separating 6 horizontal rows						
Dark-eyed Junco	4	2	24	18	6	0.011
			10	4	6	0.828
			10	2	8	0.989
			12	10	2	0.019
Feathers on monofilament line						
Dark-eyed Junco	1	0	18	11	7	0.240
White-throated Sparrow	1	0	10	4	6	0.828
UV-absorbing 2.5 cm wide stripes forming vertical columns 10 cm apart						
Dark-eyed Junco	5	1	10	6	4	0.377
			10	10	0	<0.001
			10	8	2	0.055
			10	6	4	0.377
			10	7	3	0.172
UV-absorbing 2.5 cm wide stripes forming vertical columns 2.5 cm apart						
Dark-eyed Junco	5	3	10	10	0	<0.001
			10	8	2	0.055
			10	10	0	<0.001
			10	8	2	0.055
			10	9	1	0.011
UV-absorbing 2.5 cm wide stripes forming horizontal rows 5.0 cm apart						
Dark-eyed Junco	5	5	10	10	0	<0.001
			10	10	0	<0.001
			16	13	3	0.011
			15	12	3	0.018
			10	10	0	<0.001
Ceramic frit pane with translucent dot pattern, 0.32 cm diameter dots separated by 0.32 cm spaces						
Dark-eyed Junco	5	5	10	10	0	<0.001
			12	10	2	0.019
			18	13	5	0.048
			10	10	0	<0.001
			10	10	0	<0.001
House Sparrow	1	1	10	9	1	0.011

[a] Binomial tests were used to examine if results of 10 to 24 trials per subject differed ($P < 0.05$) from the expected equal distribution.

ed in each experiment was randomly assigned and moved to a new window unit daily. Windows were checked each day 30 min after first light and checked and changed daily 30 min before last light for all experiments. Windows were covered with opaque tarps and not monitored during inclement weather such as high winds, rain, or snow.

The parameter measured in all experiments was the number of detectable bird strikes. A strike was recorded when either dead or injured birds were found beneath a window, or when fluid or a blood smear, feather, or body smudge was found on the glass. The data are likely incomplete and conservative because some strikes may not have left evidence of a collision (Klem 1989, 1990, Klem et al. 2004). Predators and scavengers also are known to remove some injured or dead birds (Klem 1981, Klem et al. 2004). The length of each experiment was ascertained by the number of recorded strikes required to statistically evaluate the differences between treatments. The experiments for some species occurred during non-breeding and migratory periods, but previous studies indicate no seasonal difference in the ability of birds to avoid windows (Klem 1989).

The first experiment was conducted over 20 days from 5 to 27 December 2005 and tested the clear glass control, non-reflective clear glass pane exhibiting no glare when viewed from any angle, and the same plastic strips and spacing used in flight cage experiment #6; the 0.32-cm thick edges of the plastic strips were visible as translucent lines except when viewed from directly in front of the window.

The second experiment was conducted over 50 days from 1 February to 29 March 2006 and tested the clear glass control, complete covering of a commercially available clear UV-absorbing film supplied by CPFilms Inc. (Martinsville, VA, USA), and the same clear UV-absorbing film cut and applied as 2.5 cm wide UV-absorbing strips forming stripes separated by 5 cm of clear glass; no edgings of the strips were visible from any angle of view.

The third experiment was conducted over 90 days from 22 November 2006 to 23 February 2007 and tested five commercially available exterior window films by CPFilms Inc. UV measurements for wavelengths between 300 and 380 nm were recorded with a Cary 5000 Spectrophotometer. The clear glass control transmitted 74.6% UV while each of the films absorbed most UV, allowing UV transmittance of 0.13% or less. Each film type reflected 8.8% UV or less. The experimental windows were: (1) clear glass control; (2) complete covering of clear UV-absorbing film applied to exterior glass surface (UVC-O), (3) same as #2 but applied to interior glass surface (UVC-I); (4) complete covering of UV-absorbing REX20 film transmitting 20% and reflecting 65% visible light, having a high reflective quality; (5) complete covering of UV-absorbing REX35 film transmitting 35% and reflecting 55% visible light, having a high reflective quality; (6) complete covering of UV-absorbing NEX1020 film containing a metallic layer with a moderate reflective quality, and (7) complete covering of UV-absorbing RK20 Rynar film with a low reflective quality.

The fourth experiment was conducted over 50 days from 10 March to 3 May 2007 and retested the clear glass control, UVC-O film applied as 2.5 cm wide vertically oriented strips forming stripes separated by 2.5 cm clear glass, and commercially available CollidEscape film supplied by Large Format Digital Inc. (Edgerton, WI, USA) applied to the exterior glass surface, permitting a relatively unobstructed view looking at the inside surface of a covered pane and a completely obstructed view looking at the outside surface. Windows covered in CollidEscape appear uniformly white.

The fifth experiment was conducted over 90 days from 29 October 2007 to 9 February 2008 and tested a new clear UV-reflecting film, alone and in combination with existing exterior clear UV-absorbing film from CPFilms Inc. The new clear film reflected 80% UV. The experimental windows were: (1) clear glass control; (2) complete covering of clear UV-reflecting film applied to exterior surface (CUV-O); (3) same as #2 but applied to interior glass surface (CUV-I); (4) 2.5-cm wide UV-reflecting film strips forming stripes oriented vertically and separated by 5 cm UV-absorbing film strips forming stripes oriented vertically and applied to the outside glass surface (S-1R); (5) 5-cm wide UV-reflecting film strips forming stripes oriented vertically and separated by 2.5 cm UV-absorbing film strips forming stripes oriented vertically and applied to the outside glass surface (S-2R-O); (6) same as #5 but applied to the interior glass surface (S-2R-I); and (7) a grid pattern 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 applied to the outside glass surface (GRID).

The sixth experiment was conducted over 50 days from 29 February to 25 April 2008 and retested the clear glass control and clear UV-reflecting and UV-absorbing films CUV-O, S-1R, and S-2R-O.

All windows were continuously monitored for 17 hrs over 4 days (6, 12, 24, and 30 Jan 2007) during the fourth experiment to learn if strikes occurred without leaving any visible evidence. Additionally, 60 hrs of continuous observation were conducted over 14 days (11, 13, 14, 17, 18, 21, 25, and 28 Mar and 3, 7, 8, 10, 14, and 15 Apr 2008) during the sixth experiment to observe active avoidance or failure to avoid the experimental windows. The flight path of individual birds moving from a platform feeder toward a window was recorded and assessed as active avoidance if the bird changed direction immediately in front and passed around or over a window.

I used SPSS (SPSS Inc. 2006) for all statistical analyses of the field experiments. Chi-square goodness-of-fit was used to evaluate experimental results: number of strikes per treatment compared to a uniform distribution of strikes across all treatments per experiment. Test results were considered statistically significant when $P < 0.05$.

RESULTS

Flight Cage Experiments.—Dark-eyed Juncos did not discriminate between clear plastic and unobstructed airspace. There was mixed discrimination among Dark-eyed Juncos and individual White-throated and House sparrows compared with other preventive methods evaluated (Table 1). Only the UV-absorbing 2.5-cm wide horizontally oriented plastic strips forming stripes separated by 5 cm and the ceramic frit dots uniformly covering the entire window resulted in statistically significant avoidance for all subjects. The UV-reflecting maple leaves were more effective in alerting birds to a barrier when applied in enough numbers to be separated by 10 cm in vertical columns and 5 cm in horizontal rows; a single UV-reflecting maple leaf in the center of a window was ineffective in alerting four of five subjects to the presence of a clear window barrier.

Field Experiments.—Forty-two strikes were recorded in the first experiment; 17 (41%) were fatal. The number of strikes differed significantly across all treatments with 14 (33%) at the clear glass control, 28 (67%) at the non-reflective glass, and none at the vertically oriented 2.5-cm UV-absorbing plastic strips forming stripes separated by 5 cm ($\chi^2 = 28.0$, df = 2, $P = 0.001$). Species numbers and window at which fatalities occurred were: two White-throated Sparrows and three House Sparrows at the clear glass control; and four Northern Cardinals (*Cardinalis cardinalis*), two House Finches (*Carpodacus mexicanus*), four White-throated Sparrows, and two Dark-eyed Juncos at the non-reflecting glass.

Fifty-five strikes were recorded in the second experiment; 11 (20%) were fatal. The number of strikes differed significantly across all treatments with 35 (64%) at the clear glass control, 12 (22%) at the complete UV-absorbing film covering, and 8 (14%) at the vertically oriented 2.5-cm wide UV-absorbing film strips forming stripes separated by 5 cm ($\chi^2 = 23.2$, df = 2, $P = 0.001$). Species numbers and window at which fatalities occurred were: two Northern Cardinals and one Dark-eyed Junco at the clear glass control; two White-throated Sparrows, two Song Sparrows (*Melospiza melodia*), and one House Sparrow at the complete UV-absorbing film covering; and one White-throated Sparrow, one Song Sparrow, and one House Sparrow at the vertically oriented 2.5-cm wide UV-absorbing film strips forming stripes separated by 5 cm.

One-hundred and ninety-four strikes were recorded in the third experiment; 20 (10%) were fatal. The total number of strikes differed significantly across all treatments, with 51 (26%) at the clear glass control, 24 (12%) at UVC-O, 20 (10%) at UVC-I, 30 (15%) at REX20, 24 (12%) at REX35, 21 (11%) at NEX1020, and 24 (12%) at RK20 ($\chi^2 = 25.0$, df = 6, $P < 0.001$). Species killed and the windows at which fatalities occurred were: one White-throated Sparrow, one American Tree Sparrow (*Spizella arborea*), five Dark-eyed Juncos, and two House Finches at the clear glass control; one Black-capped Chickadee (*Poecile atricapillus*), one White-throated Sparrow, two House Finches, and one Northern Cardinal at UVC-O; one House Finch at UVC-I; two American Tree Sparrows at REX20; two Dark-eyed Juncos at REX35; and one Mourning Dove (*Zenaida macroura*) at RK20.

Seventy-seven strikes were recorded in the fourth experiment; two (3%) were fatal. The total number of strikes differed significantly across all treatments, with 49 (64%) at the clear glass control, 27 (35%) at the vertically oriented 2.5-cm wide UV-absorbing film strips forming stripes separated by 5 cm, and one (1%) at the CollidEscape covered window ($\chi^2 = 44.99$, df = 2, $P = 0.001$). Eight (30%) of the 27 strikes at the window with the UV-absorbing film stripes occurred over film, there were 14 (52%) strikes at clear glass between film, and five (18%) strikes included parts of both film and non-film areas; there was no significant difference between striped and no striped impact sites ($\chi^2 = 1.64$, df = 1, $P = 0.20$).

Eighty-six strikes were recorded in the fifth experiment; 13 (15%) were fatal. The total number of strikes differed significantly across all treatments with 60 (70%) at the clear glass control, eight (9%) at CUV-O, seven (8%) at CUV-I, two (2%) at S-1R, one (1%) at S-2R-O, four (5%) at S-2R-I, and four (5%) at the GRID ($\chi^2 = 219.23$, df = 6, $P < 0.001$). All 13 fatalities occurred at the clear glass control and were: one Black-capped Chickadee, one White-breasted Nuthatch (*Sitta carolinensis*), two House Finches, one American Goldfinch (*Carduelis tristis*), one American Tree Sparrow, and seven Dark-eyed Juncos.

Fifty-five strikes were recorded in a validating sixth experiment retesting selected treatments of experiment #5; 11 (20%) were fatal. The total number of strikes differed significantly across all treatments, with 38 (69%) at the clear glass control, 11 (20%) at CUV-O, three (5.5%) at S-1R, and three (5.5%) at S-2R-O ($\chi^2 = 60.13$, df = 3, $P = 0.001$). Species numbers and windows at which fatalities occurred were: one Black-capped Chickadee, two American Tree Sparrows, and five Dark-eyed Juncos at the clear glass control, and two American Tree Sparrows and one Dark-eyed Junco at CUV-O.

Flight paths of 67 individual birds flying from the bird feeders toward the windows were recorded during 60 hrs of continuous observation over 14 days to examine the movements of individuals during the sixth experiment. Six (55%) of 11 individuals flying toward the clear glass control moved to avoid and five (45%) hit the window. Fourteen (93%) of 15 individuals flying toward CUV-O moved to avoid and one (7%) hit the window. All 24 individuals flying toward S-1R moved to avoid the window. Fifteen (88%) of 17 individuals flying toward S-2R-O moved to avoid and two (12%) hit the window. One strike in four left no evidence of a collision lasting 24 hrs based on 17 hrs of continuous observation.

DISCUSSION

The application of clear and reflective UV-absorbing films to the exterior of windows offered some protection from strikes by reducing the deceptive quality of reflections. The use of clear UV-absorbing external films to create stripe patterns had mixed results. The incremental use of 0.32-cm thick plastic strips used to form stripes and then external films in experiments were attempts to create UV signals to learn if test subjects and birds flying in the wild would behave as if they could see and avoid the treated panes. All attempts to create protective patterns visible to birds using a UV-absorbing plastic and film offered a weak UV-reflecting signal, no greater than 13% UV-reflectance. A new clear UV-reflecting exterior film that produced a UV-reflecting signal with 80% reflectance offered an improved opportunity to meaningfully test the utility of UV signals to deter bird–window collisions. The promise of UV signals serving to alert birds to danger was uncertain given that lower wavelengths of UV, blue, and purple colors are often associated with attraction behavior, sexual selection, and finding food (Burkhardt 1982, Bennett and Cuthill 1994, Vitala et al. 1995, Bennett et al. 1996, Hunt et al. 1998).

Color signals used by birds and other animals as warnings or an alert to danger (aposematic coloration) are most often in the upper visual wavelengths perceived as yellows, oranges, and reds. Supporting the questionable value of UV signals to deter window strikes were comparative records of strike rates at wind turbines painted with UV-reflecting and conventional non-UV-reflecting paints (Young et al. 2003). Notwithstanding the ability to attract, it is reasonable to suspect that UV signals could also be used to alert birds to the presence of clear and reflective sheet glass and plastic. Repeated validating field experiments supplemented by detailed recording of avoidance by individual birds revealed that a combination of UV-reflecting and UV-absorbing stripe and grid patterns were effective in preventing bird–window collisions. These results document that birds were able to recognize the window-covering UV stripes and grid pattern as barriers to avoid. Applications that combine alternating and contrasting UV-reflecting and UV-absorbing patterns to existing clear and reflective windows have promise of preventing bird strikes while offering little or no visual distraction for humans.

The results of both flight cage and field experiments provide additional confirmation that birds behave as if clear sheet glass and plastic in the form of windows are invisible, and that several methods are available to effectively prevent bird–window collisions. The clarity and lack of any visible cues best explains twice as many strikes at the non-reflective glass pane compared to a conventional clear window. These findings support the interpretation that decals or other objects such as feathers placed on or hung in front of a window are ineffective at preventing bird strikes when used alone. Increasing their numbers so they uniformly cover the window surface, and separating decals or strings of feathers and beads by 5 to 10 cm provides complete or near-complete avoidance.

One-way films that result in a complete opaque or translucent covering when viewed from outside, but only weakly diminish the view from inside, were expected and confirmed to be effective strike deterrents. The uniformly dense dot pattern created as ceramic frit was effective in alerting birds to the presence of a glass barrier. The presence of dotted ceramic frit glass in the science building at Swarthmore College in Swarthmore, Pennsylvania, USA since installation has experienced as few as two known collisions a year (E. C. Everbach, pers. comm.). This same dotted ceramic frit glass has experienced no known collisions at a corridor in the renovated science building on the campus of Muhlenberg College in Allentown, Pennsylvania, but a dozen collision fatalities have been documented at conventional clear glass panes elsewhere in this same building for 1 year since installation (DK, pers. obs.). The dot or other objects creating patterns of visual noise must be placed on the exterior surface of windows to be visible; exceptions are at see-through sites such as corridors and where glass walls meet at corners and where protective patterns will be visible when placed on interior surfaces.

These experiments further reveal that strike frequency at intensely monitored sites is likely to be incomplete and conservative because some impacts may not leave any evidence of a collision. Moreover, predators and scavengers may have removed some casualties that were not detected such as a Northern Shrike (*Lanius excubitor*) that was seen taking a window casualty during the final field experiment (Klem 1981, Klem et al. 2004).

Methods using UV signals to alert birds to window hazards should have special utility because they offer visual cues in wavelengths that birds are known to see but humans do not (Burkhardt 1982, Bennett and Cuthill 1994, Vitala et al. 1995, Bennett et al. 1996, Hunt et al. 1998). The promise of using UV signals to prevent collisions between birds and windows is especially relevant to architectural professionals for addressing and eliminating avian injury and mortality by retrofitting existing buildings and using new types of glass and plastic panes in new construction.

ACKNOWLEDGMENTS

I thank CPFilms Inc. and Anthony Port specifically for supplying films for experiments, and P. G. Saenger in the Acopian Center for Ornithology, Department of Biology, Muhlenberg College for assistance in collecting data and reviewing earlier drafts of this manuscript. I am also grateful to K. E. Blum and J. D. Goodrich for collecting the continuous monitoring data. I thank the Baird Ornithological Club, Lancaster County Bird Club, and especially the late Sarkis Acopian, CPFilms Inc., Detroit Audubon Society, and the Safari Club at the Philadelphia Zoo for encouragement and financial support of our ongoing studies on the bird–window issue at Muhlenberg College. I am especially thankful for the extensive and useful comments from an anonymous reviewer, and L. Evans Ogden and C. E. Braun which improved the manuscript.

LITERATURE CITED

BENNETT, A. T. D. AND I. C. CUTHILL. 1994. Ultraviolet vision in birds: what is its function? Vision Research 34:1471–1478.

BENNETT, A. T. D., I. C. CUTHILL, J. C. PARTRIDGE, AND E. J. MAIER. 1996. Ultraviolet vision and mate choice in Zebra Finches. Nature 380:433–435.

BURKHARDT, D. 1982. Birds, berries and UV. Naturwissenschaften 69:153–157.

GAUNT, A. S. AND L. W. ORING. 1999. Guidelines to the use of wild birds in research. Second Edition. Ornithological Council, Washington, D.C., USA. www.nmnh.si.edu/BIRDNET/guide.html (accessed February 2004).

HUNT, S., A. T. D. BENNETT, I. C. CUTHILL, AND R. GRIFFITH. 1998. Blue Tits are ultraviolet tits. Proceedings of Royal Society of London, Series B 265:451–455.

KLEM JR., D. 1981. Avian predators hunting birds near windows. Proceedings of the Pennsylvania Academy of Science 55:53–55.

KLEM JR., D. 1989. Bird-window collisions. Wilson Bulletin 101:606–620.

KLEM JR., D. 1990. Collisions between birds and windows: mortality and prevention. Journal of Field Ornithology 61:120–128.

KLEM JR., D. 2006. Glass: a deadly conservation issue for birds. Bird Observer 34:73–81.

KLEM JR., D. 2009a. Avian mortality at windows: the second largest human source of bird mortality on earth. Proceedings Fourth International Partners in Flight Conference 2008, McAllen, Texas, USA. USDA, Forest Service Technical Report: In press.

KLEM JR., D. 2009b. Sheet glass as a principal human-associated avian mortality factor. Chapter 2 *in* Avian ecology and conservation: a Pennsylvania focus with national implications (S. K. Majumdar, T. L. Master, M. Brittingham, R. M. Ross, R. Mulvihill, and J. Huffman, Editors). The Pennsylvania Academy of Science, Harrisburg, Pennsylvania, USA: In press.

KLEM JR., D., D. C. KECK, L. MARTY, A. J. MILLER BALL, E. E. NICIU, AND C. T. PLATT. 2004. Effects of window angling, feeder placement, and scavengers on avian mortality at plate glass. Wilson Bulletin 116:69–73.

SIEGEL, S. 1956. Nonparametric statistics for the behavioral sciences. McGraw-Hill, New York, USA.

SPSS. 2006. SPSS for Windows, Version 15.0. SPSS, Chicago, Illinois, USA.

VITALA, J., E. KORPIMAKI, P. PALOKANGAS, AND M. KOIVULA. 1995. Attraction of kestrels to vole scent marks in ultraviolet light. Nature 373:425–427.

YOUNG JR., D. P., W. P. ERICKSON, M. D. STRICKLAND, R. E. GOOD, AND K. J. SERNKA. 2003. Comparison of avian responses to UV-light-reflecting paint on wind turbines. National Renewable Energy Laboratory, Golden, Colorado, USA.