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Ultraviolet film reduces bird–glass collision risk

Ewa Zyśk-Gorczyńska* & Michał Żmihorski

*E. Zyśk-Gorczyńska, Glass Traps Foundation, Murarska 25/27/6, 54–135 Wrocław, Poland * Corresponding author's e-mail: ewa.zysk@interia.pl*
M. Żmihorski, Mammal Research Institute, Polish Academy of Sciences, ul. Stoczek 1, 17–230 Białowieża, Poland

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It is estimated that millions of birds globally die due to collisions with glass surfaces. In order to reduce this mortality, it is essential to provide an objective assessment of the effectiveness of bird-friendly preventive methods. Several types of opaque films and stickers are available nowadays and can be highly effective in protecting birds from fatal collisions. However, by being visible to the human eye, they can affect the users' quality of view from within protected spaces. Products that take advantage of the birds' ability to see ultraviolet light seem to offset these impediments. This study determines if UV-reflective BirdShades film prevents birds from collisions with glass in natural environmental conditions. We monitored eight glass bus stops, where we had previously recorded high numbers of birds collisions. On four of them, we applied UV film, and the other four bus stops were used as control. A generalized additive mixed model showed a significant interaction between time (before vs. after) and film UV treatment (control vs. treated). Before the treatment, the number of collisions tended to be higher at treated bus shelters than control. However, this significantly changed after the treatment, suggesting that UV film reduces bird glass collision rate over 5-fold. Our study is the first worldwide that tested UV film on glass shelters and supports a conclusion that the UV film efficiently reduces the risk of bird collision.

1. Introduction

With millions of birds killed each year by collisions with glass, the issue is considered a major cause of bird mortality worldwide (Machtans & Thogmartin 2014, Loss *et al.* 2014). Birds often strike transparent panes while attempting to reach the habitat seen on the other side of the glass (Klem 2009). Collisions also occur when birds mistakenly fly towards reflected images, a common condition with some glass types and lighting conditions. Birds die flying into windows of different shapes and sizes, throughout the day and seasons of the year and during all-weather circumstances. Thus, the fatal strikes may occur wherever birds and glass coexist (Klem 2009, Klem 2014, Żmihorski *et al.* 2021).

Recently, more attention is being paid to finding and using methods that effectively prevent birds from deadly strikes (Klem 2009, Klem & Saenger 2013, Sheppard 2019, Ribeiro & Piratelli 2020). Numerous tests of the surface treatments indicate that opaque vertical stripes of particular widths and separations, as well as some arrangements of opaque dots and other shapes and patterns that do not leave too much open space on the windows (matching "the hand rule"), are effective in reducing bird collisions (Klem 2009, Klem & Saenger 2013, Rössler *et al.* 2015, Ribeiro & Piratelli 2020). However, various types of opaque patterns on glass can be problematic due to the purpose of the building, the architectural vision of the designer, and the preferences of the building users. Therefore, there is a challenge to create designs for glass that will be as unobtrusive to human vision as possible, while effectively preventing birds from fatal collisions.

Products taking birds' ultraviolet (UV) vision into account certainly meet such expectations (Aidala *et al.* 2012, Swaddle *et al.* 2020). The spectrum of birds' vision extends into the ultraviolet, thus UV markings that reflect differentially in the UV are visible to birds but mostly invisible for humans (Hart 2001, Lind *et al.* 2013). Spectral sensitivity of birds extends into the UV portion of the spectrum 300–400 nm. However, this sensitivity is not typical in all bird species. Instead, it is a property for passerines, parrots, gulls and terns, and ostriches (Hart 2001). The species commonly reported to collide with glass are for example White-throated Sparrow (*Zonotrichia albicollis*), Dark-eyed Junco (*Junco hyemalis*), American Robin (*Turdus migratorius*) and Swainson's Thrush (*Catharus ustulatus*) (Basilio *et al.* 2020). Some bird species (notably raptors) have intraocular filters that prevent UV light from forming the retinal image. UV may form part of the image in other non-passerines species, but it is not detected by the photoreceptors (Ödeen *et al.* 2011). Moreover, UV reflective markings on glass surfaces are only visible to birds if there is sufficient UV light falling on the glass (for example during daylight when UV light is the strongest) and the markings have high reflectivity in the UV (Ödeen *et al.* 2011, Håstad & Ödeen 2014). BirdShades (BirdShades Innovations GmbH, Erzherzog-Johann Straße 9, Austria, www.birdshades.com) has produced a window film reflective in the ultraviolet wavelength spectrum of light which has a striping pattern faintly visible to humans. The effectiveness of the reflective UV film by BirdShades was investigated by Swaddle *et al.* (2020) who showed in tunnel tests that it reduced the likelihood of collisions of two passerine species (zebra finch, *Taeniopygia guttata* and brown-headed cowbird, *Molothrus ater*) with windows during daylight by 75–90%. Also, they showed that both species slow their flight by approximately 25% when approaching windows treated with the BirdShades film, thereby reducing the force of collisions if they were to happen.

A UV film that reflects shorter wavelengths of light (spectrum 300–400 nm) should be visible to many birds, both passerines and non-passerines (Goldsmith & Butler 2005, Aidala *et al.* 2012, Lind *et al.* 2013). To the human eye, the BirdShades film appears highly translucent and the ultraviolet stripes are visible only in certain lighting conditions (when looking right at the glass surface then the stripes are invisible, but with a lot of sunlight and looking at different angles, a slight pattern of stripes is visible). However, additional research is still needed (*e.g.*, under various conditions, with different methods) to test the effectiveness of such products in preventing bird collisions.

This study aimed to determine if ultraviolet film efficiently prevents birds from collisions with glass in natural environmental conditions (at different times of day, birds might perceive the glass surface differently and that can affect the risk of collisions). Therefore, this study goes further than Swaddle *et al.* (2020) by testing the product's effectiveness in a real-world setting with free-living birds and random mix of species. Here, we used our former bird–glass collision data from glass bus shelters (Zyśk-Gorczyńska *et al.* 2020, 2021a) located in Poland, and experimentally placed the UV film on some of them. This allowed us to separate random temporal variation in collision risk from the treatment effect in before-after control-impact study design.

2. Material and methods

In 2017 and 2018, we monitored 85 glass bus shelters in the Lower Silesia Province (in South-West Poland) as a part of a larger study focused on bird–glass collisions (Zyśk-Gorczyńska *et al.* 2020, 2021a, b). Among these 85 locations, we selected eight glass bus shelters for which we found a particularly high number of bird collisions in 2017 and 2018. We divided the eight shelters into treatment and control groups (four shelter per group; Fig. 1). We assigned them according to the collision number. In general, the treatment group was composed of shelters with the highest number of bird collisions. On the bus shelters in the treatment group we applied BirdShades UV film. The entire exterior surface of the back glass panels was covered by the film expanded from a roll (30 cm wide) in May 2021 (Fig. 2). BirdShades film is reflective in the near UVA range between 300 and 400 nm, which means it is visible to passerines birds species and is mostly transparent to the human eye. The film was received from the company, which allowed us to perform an experimental evaluation of its effectiveness and publish results. The lateral panels were left uncovered as we aimed to see if collisions would occur on bus shelters if only the back panels were covered with the film (*i.e.*, one-sided UV film). Moreover, part of the reason we did not cover the lateral panels was the expense of the treatment film. The four remaining shelters were not protected from bird collisions and served as control group. The surroundings of the two groups were similar. They were located in a similarly urbanized area with similar bird communities. Moreover, our previous study at these shelters indicated that bird abundances recorded were poor predictors of bird–glass collisions. Similarly, habitat composition near bus shelters hardly predicted variation in bird–glass collision risk (see Zyśk-Gorczyńska *et al.* 2021a).

We monitored all eight shelters in 2017 and 2018 (130 visits in total; Zyśk-Gorczyńska *et al.* 2020) and again in 2021. We only included monitoring in the spring-summer season (May to August) for analyses as during these months in 2017 and 2018 we found the highest number of collisions (see Zyśk-Gorczyńska *et al.* 2020). During this period in each year, each bus shelter was visited every *ca.* 1–2 weeks (173 visits in total). The total number of visits and the time of visits were the same for all of the bus shelters. During each visit, all glass surfaces of each bus shelter were carefully checked for traces of bird–glass collisions, *i.e.*, feathers or bird contours, which were then removed after each visit to prevent examining them again during subsequent visits. All traces that could not be unequivocally

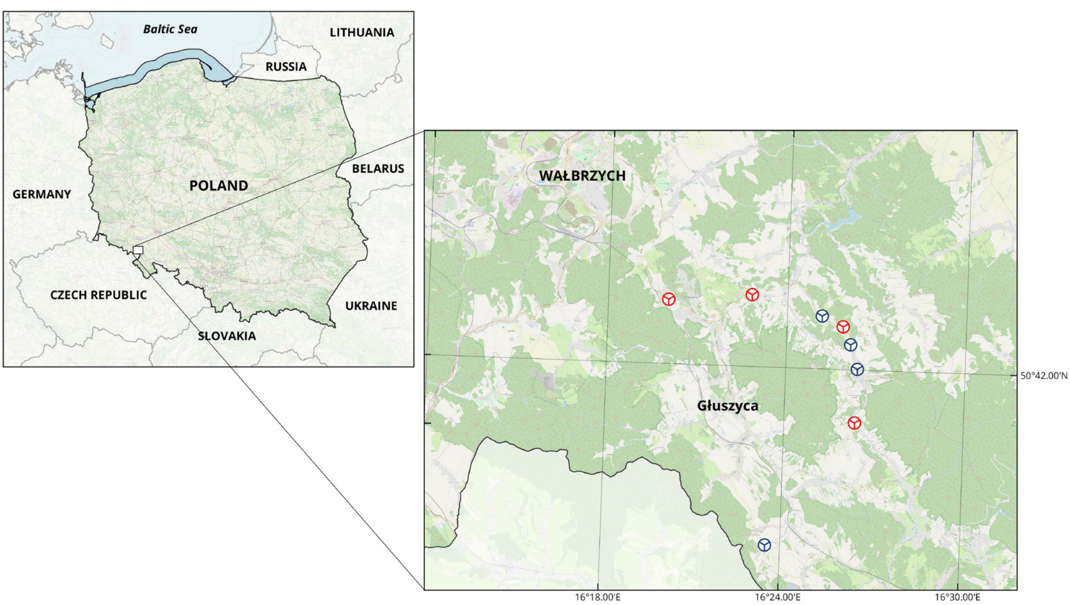

Fig.1. Study area with monitored bus shelter locations (red markers indicate bus shelters treated with UV reflective film and blue markers indicate control bus shelters). Source: Open Street Map.

Fig. 2. (A) The UV film was applied on the outer side of the bus stop glass panels. (B) An exemplary bus stop covered with BirdShades UV film (it is mostly invisible for human eyes).

classified as results of bird collisions (*e.g.*, smudges), were ignored. Moreover, we searched for bird carcasses within 3-meter radius from the bus shelter during each visit. As an effect, we obtained the number of collisions separately for each bus shelter and visits for the periods before and after treatment.

2.1. Statistical analysis

We analyzed bird–glass collision data with a generalized additive mixed model (GAMM) with the logarithmic link and Poisson error distribution implemented in the "mgcv" package (Wood 2017) in R (R Core Team 2021). In the GAMM, we included each visit at each bus shelter as a single data record (n=173) and the number of collisions as a response variable. We applied a before-after-control-impact (BACI) design by considering the interaction of the two explanatory variables: time (before vs after applying UV film, *i.e.*, 2017 and 2018 vs. 2021) and treatment (UV film applied vs. no UV film applied, the latter used as a control). We assumed that a significant interaction term in the GAMM indicates the effect of the UV film on bird–glass collision risk (Chavelier *et al.* 2019). Moreover, in the model, we included month as a categorical factor (May–August) as well as random bus shelter ID and year ID effects, to account for possible temporal and spatial data dependency. Random effects were fitted with the help of ridge penalty splines (Wood 2017). Additionally, we compared number of collisions inside vs. outside of bus shelters with the help of Chi-square test.

3. Results

We recorded 91 bird–glass collisions on the eight bus shelters during the three-year study, ranging from 0 to 6 per bus shelter and visit. In 2017 and 2018 (*i.e.*, before treatment), we recorded 58 collisions, including 15 in control bus shelters and 43 in treatment bus shelters. In 2021 (*i.e.*, after treatment), we found 33 evidences of bird collisions (feathers, bird contours, or carcasses), 24 collisions in control bus shelters, and 9 collisions in treatment bus shelters (covered with UV film). Before the treatment (*i.e.*, in 2017 and 2018) number of collisions tended to be marginally higher at treated (covered UV film afterward) bus shelters as compared to control bus shelters ($p=0.113$), but this changed after the treatment: in 2021 the number of collisions was lower ($p=0.050$) at treated bus shelters as compared to control bus shelters (Fig. 3, Supplementary Table S1) and interaction between time and treatment was significant ($p<0.001$). The effect

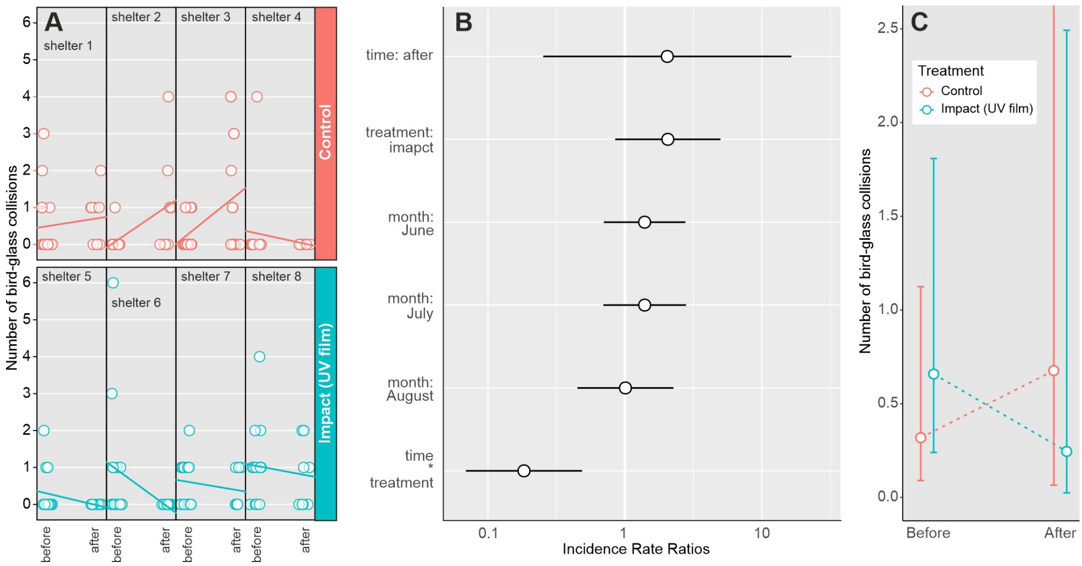

Fig. 3. (A) Raw observations together with regression lines of bird–glass collisions before and after treatment (with point jittering to reduce overplotting) at controlled and treated bus shelters, (B) parameter estimates of GAMM model analyzing bird–glass collisions in relation to time and treatments, and (C) number of bird–glass collisions (accompanied by 95% confidence intervals) predicted by the GAMM for glass bus shelters with different treatments, before and after applying UV film on the glass. At shelters covered with UV film, the number of collisions dropped by *ca.* 5-times compared to control shelters. See Supplementary materials for full parameter estimates of the GAMM.

size of interaction was estimated at 0.175 (95% CI: 0.066–0.463), indicating that the predicted number of collisions after UV film was applied was reduced in treatment group of shelters 5.71-times (95% CI: 2.15–15.13) as compared to control shelters. No significant effect of month was confirmed.

Among 91 recorded collisions, 46 were recorded at the outer while 45 at the inner side of the glass bus shelters. The proportion of the number of collisions between outer and inner sides did not differ from 1:1 (Chi-square test, p=0.071 for "before" period, and p=0.103 for "after" period) at control bus shelters. For impact bus shelters the share of collisions at inner and outer sides was similar for "before" period (p=0.170) but significantly differed from1:1 for "after" period (p=0.020) in which only one collision was recorded at outer (*i.e.*, UV film-covered) side, while six were recorded at inner, non-covered side and two of the collisions occurred on the lateral panels which were also not protected with UV film (Fig. 4).

4. Discussion

We showed that the use of UV BirdShades film can prove effective to reduce bird collisions with glass. We found a significant decrease in the number of collisions after UV film application (reduced in the treatment group of shelters 5.71-times as compared to control shelters) which generally confirms former findings concerning the effectiveness of the BirdShades UV film in preventing collisions in flight tunnel tests (Swaddle *et al.* 2020). Several studies showed that some birds species perceive UV wavelengths from approximately 300–400 nm (Bennett & Cuthill 1994, Hunt *et al.* 1998, Klem 2009, Swaddle *et al.* 2020). Klem (2009) described a solution that uses ultraviolet (UV) signals in the form of adjacent and contrasting UV-reflecting and UV-absorbing elements, while Klem & Saenger (2013) found external films with UV-reflecting components of 20–40% over 300–400 nm to effectively prevent bird-window collisions. Importantly and unlike some experimental studies performed in a flight tunnel, we confirmed the effectiveness of the UV

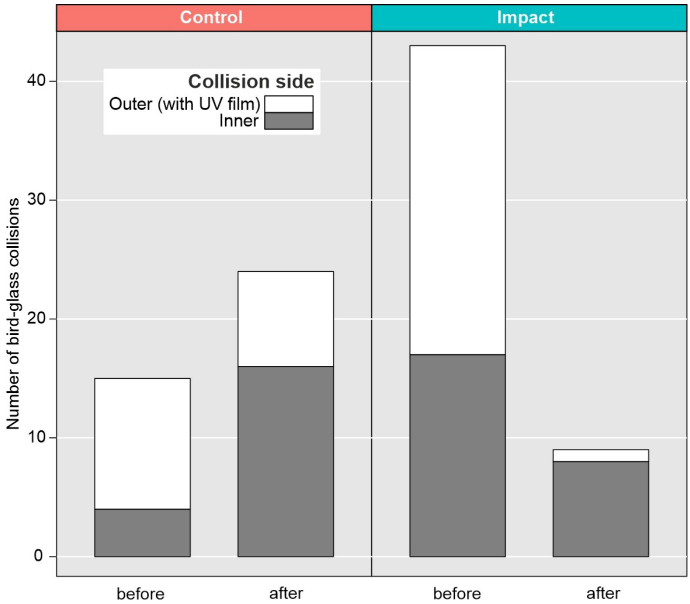

Fig. 4. Location of 91 bird–glass collisions (outer vs. inner side of a bus-shelter) recorded at four control and four impact bus-shelters before (2017 and 2018) and after (2021) treatment. After applying UV film at the outer side of four shelters, only one collision was recorded at outer side (*i.e.*, UV film-covered).

film in natural light conditions and on the actual objects located in the landscape: highly reflective glass panels of bus shelters formerly reported as an important source of bird–glass mortality (Zyśk-Gorczyńska *et al.* 2020).

Typically of field studies, we were not able to fully control conditions and there may have been more bird strikes on the glass panels of both control and film-covered shelters than recorded by us. First, many dirt smudges were hard to clearly classify as traces of bird collisions (Zyśk-Gorczyńska *et al.* 2020, 2021a) and all these non-obvious traces were ignored. Thus, some of the indirect evidence of bird collisions may have been ignored. Second, some bird strikes on windows may not leave any traces of collisions (such as feathers, smudges, bird counters). Importantly, in our opinion, the presence of the UV film did not affect the detection of collision evidence. Smudges, dirt, and dust appeared on the glass panels as a result of the typical use of the bus stops by passengers. Therefore, we assume that if there was evidence of collision, *i.e.* feathers or bird contours, they would be visible on the glass during controls. Interestingly, the number of detected bird collisions at not treated shelters increased in 2021 compared to 2017 and 2018. Several reasons can be mentioned to explain this trend. The number of bird collisions might depend on various factors, including the time of day, the land cover, or the presence of places attractive to birds for feeding, nesting, or shelters (Klem 2009). In the case of bus shelters, these factors may have changed over several months. Additionally, the degree of dirt on the glass panels/ the degree of glass visibility for birds, acts of vandalism (graffiti) and even human presence at a bus stop (and its surroundings, *e.g.*, sidewalk, bike routes) could have been additional variables affecting the number of bird collisions (Zyśk-Gorczyńska *et al.* 2020). Furthermore, the increase in the number of collisions at non-treated bus shelters in 2021 balances the potential error resulting from the non-random selection of shelters for the study (we assigned the bus shelters with the most collisions to the "treatment" and those with less collisions to the "control"). It appeared that the number of collisions recorded at shelters in control group increased in 2021, and, therefore, the division between control group and the treatment group (the stops with the highest number of bird strikes) might not have been that obvious anymore. Various factors may affect variation in number of bird collisions that can change also seasonally.

Unfortunately, glass causes refraction of light rays, including ultraviolet, which can decrease the visibility of this marking from the side where the film was not applied. Our findings conclude that some collisions occurred at glasses covered with UV film, but almost exclusively from side without the film. We suggest that if the use of the film is to be limited to the windows of buildings, then the film may prove to be effective (when the film covers problem/external surfaces where bird collisions appear). In the case of remaining glass objects, however, UV film should be applied at both sides of the glass, but this still needs to be empirically verified. Also, BirdShades film is not one of the easiest to apply. Although the film is supplied in rolls, two people, preferably with experience in this type of work, are needed for the application. In addition, despite strenuous efforts, air bubbles between the surface of the glass and the film may appear. In our opinion, the problem may be in the film's location on large glass surfaces (probably for smaller glass panels, certainly smaller than bus shelters panels, it would be easier to apply). This feature of the film should be improved if possible.

5. Conclusion

To prevent bird-window collisions, windows must be altered to be easily detected and avoided by birds. Using UV signals that birds see and humans do not is an elegant and practical solution. Our study showed that the BirdShades UV film reduces the risk of bird collisions in a natural setting with free-living birds and we conclude that such products could be largely effective in mitigating and preventing window collisions. UV-based films are usually more expensive than traditional glass stickers or other glass marking techniques, so to reduce the costs, one may consider leaving the outer part of the glass without the UV filter, as birds rarely hit parts of the glass close to its edge (Zyśk-Gorczyńska *et al.* 2021b). External UV films can be used to retrofit existing windows to render them bird-safe, and the use of sheet glass with UV coating (glazing) patterns in new and remodeled construction may provide a long-term solution to protect birds from the harmful effects of window strikes worldwide.

Undoubtedly, it is vital to test the effectiveness of the BirdShades film on windows in buildings where the light levels are most often lower inside a room than outside and this creates a high reflection of the adjacent habitat and sky that misleads birds that attempt to reach it.

Ultraviolettikalvo lasipinnoilla vähentää lintujen törmäysriskiä

Lasipintoihin törmääminen aiheuttaa arviolta miljoonien lintujen kuoleman vuosittain. Kuolleisuuden vähentämiseksi tarvitaan tietoa siitä, kuinka hyvin erilaiset törmäyksiä estävät menetelmät toimivat. Läpinäkymättömiä kalvoja ja tarroja käytetään nykyään paljon ja niiden oletetaan suojelevan lintuja törmäämiseltä. Tällaiset kalvot voivat toisaalta olla haitallisia ihmisen näkökulmasta, koska ne heikentävät lasipintojen läpinäkyvyyttä. Tuotteet, jotka hyödyntävät lintujen UV-valonäköä, voivat siksi olla käyttäkelpoisempia. Tässä tutkimuksessa selvitimme, estävätkö UV-valoa heijastavat BirdShades-kalvot lintuja törmäämästä linja-autokatosten lasipintoihin. Seurasimme kahdeksaa linja-autokatosta, joissa olimme aikaisemmin havainneet runsaasti lintujen törmäyksiä. Asensimme UV-kalvot neljään katokseen, ja toiset neljä katosta toimivat kontrolliryhmänä. Analyysimme (GAMM) mukaan ajan (ennen vs. jälkeen asennuksen) ja UV-kalvon asentamisen (kontrolli vs. UV-kalvollinen) välillä oli merkittävä yhteys. Ennen UV-kalvon asentamista törmäysten määrä oli suurempi UV-kalvollisissa linja-autokatoksissa kuin kontrollikatsoksissa. Tämä kuitenkin muuttui merkittävästi UV-kalvon asentamisen jälkeen. Tulos viittaa siihen, että UV-kalvo vähentää lintujen törmäyksiä yli viisinkertaisesti. Tutkimuksemme oli ensimmäinen, joka testasi UV-kalvoa linja-autokatoksissa. Tulokset tukevat johtopäätöstä siitä, että UV-kalvon lisääminen lasipinnoille vähentää tehokkaasti lintujen törmäysriskiä.

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Online supplementary material

Supplementary material available in the online version includes Table S1, the summary of generalized additive mixed model (GAMM) analysing number of bird–glass collisions in relation to time and bus-stop characteristics.