The Role of Light in Bird Mortality from Collisions with Glass: we need a policy solution

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Executive Summary

Artificial lighting at night (ALAN) increases the magnitude of bird mortality from collisions with glass by attracting birds to the built environment. Most birds, with obvious exceptions, are active by day, with eyes best adapted for daylight sight. However, many bird species migrate by night, allowing them to use daylight hours for feeding and taking advantage of less turbid air, cooler temperatures and lack of predators. We still don't know everything about how night-flying birds navigate but many bird species have two special senses that allow them to determine location and direction using the Earth's magnetic field. One of these, located in the eye, may allow birds to "see" magnetic lines in the presence of dim blue light. Star maps, landmarks, and other mechanisms are also involved and use may differ by species. Artificial night lighting overwhelms orientation mechanisms evolved to work with dimmer, natural, nocturnal light sources and causes birds to deviate from their flight paths.

A common internet meme suggests that birds are attracted by lighting to tall structures where they circle until they 'drop from exhaustion'. Circling is a real behavior, associated with strong contrast between a bright light source and dark background but while circling may deplete birds' energy stores, (Bruinzeel et al., 2009; Bruinzeel et al., 2010) most mortality is caused by collisions. The circling phenomenon was observed decades ago at the Washington Monument, Empire State Building and Statue of Liberty, among others, and as far back as the 1880s, when lighthouses were first electrified and did not have rotating beams. However, while still observed at rural cell towers, isolated oceanic drilling rigs and, most notably, the 9/11 Memorial in Lights in NYC, the behavior is now much rarer in cities, because the enormous expansion of light pollution has reduced the incidence of bright light sources surrounded by relative darkness.

In 1997, the Fatal Light Attraction Program (FLAP) in Toronto began a 'Lights Out' program, negotiating with individual buildings to turn some of their lights out during spring and fall migration. A report from FLAP in 2002 was unable to confirm an overall reduction in collision numbers but did show that the amount of light emitted by a building is a stronger predictor of the number of collisions the building will cause than is building height. Even ground level lights have been shown to cause changes in bird behavior. While some collisions have been reported on lighted windows, the majority of collisions with glass actually take place by day. As birds seek food to fuel their next migratory stage, they face a maze of structures and glass, resulting in collisions. Presumably, collisions during the very early morning are most likely to occur on the structures nearest where birds landed, with more birds attracted by the brightest buildings, while later, birds will have dispersed. Differential attraction by patterns of light intensity across a nocturnal landscape may influence the pattern of birds landing in that landscape, producing the correlation between light levels and collisions frequency.

Reducing emitted light from individual buildings can dramatically lower collision rates on those structures but may not reduce overall mortality for an area. Thus, reducing light trespass and site lighting from a few tall buildings is insufficient to have a real impact on collisions overall. Lighting of parking lots, highways and other non-structures must be considered. Reducing light emission throughout the built environment must be part of any strategy to reduce collisions with glass but to have a significant impact will require regional or national level policy solutions aimed broadly at multiple types of lighting.

The Problem

Birds evolved complex, complementary systems for orientation and vision long before humans developed artificial light (Land and Nilsson, 2010) or used firelight as a hunting tool at night (Gauththreaux and Belser, (2006). We still have much more to learn, but recent science has begun to clarify how artificial light poses threats to birds, especially nocturnal migrants (Horton et al., 2019; La Sorte et al, 2017; McLaren et al., 2018). Although most bird-glass collisions take place during daylight hours (Riding et al., 2021; Hager and Craig, 2014; Kahle et al., 2016; Klem, 1989; Nichols et al., 2018; Parkins et al., 2015; Powers et al, 2021; Switala-Elmhurst and Grady, 2017), artificial lighting at night draws birds into the built environment and likely plays a role in the number and the distribution of collisions.

Many collision victims, especially songbirds, are ordinarily active by day and have eyes specialized for color vision and bright light, with cone cell dense retinas. Although they migrate at night, these birds have poor night vision – but the majority of their night activity is aloft, where black and white vision, sensitive to dim light of stars, may be key. Birds also use magnetic senses that allow them to navigate using the Earth's magnetic field (Wiltschko and Wiltscho, 2009, Deutschlander et al., 1999). One of these is located in the retina and requires dim blue light; red/yellow wavelengths found in most artificial light have been shown to disrupt that magnetic sense at very low levels (Wiltschko and Wiltschko, 2001, 2002, 2009, 2013; Wiltschko et al., 1993, 2003, 2004 a, 2004b, 2007, 2010, 2013). It is also possible that the brightness of night lighting simply overwhelms the visual system.

By day, birds are attracted to relative brightness, often orienting toward the sun. Birds are attracted to ALAN as well (La Sorte, et al., 2017; McLaren et al., 2018; Van Doren, et al., 2017), but we don't know what brightness at what range is sufficient to cause attraction or at what point attraction takes place in the temporal sequence of migratory flight (Bruderer et al., 1999). The fact that some birds successfully migrate through the well-lit gauntlet between Boston and Washington DC implies that some proximity is necessary. Possibly, some bird species become vulnerable to attraction during their descent but are unaffected at height.

Circling behavior at bright light sources in dark areas – communication towers (Gehring et al., 2009), oceanic drilling rigs (Russell, 2005; Marquenie and Van de Laar, 2013) is well documented. In one report, Marquenie et al. (2013), studying birds and lights on a drilling rig in the North Sea, estimated that when all the lights on the platform were lit, they impacted birds up to 3 to 5 kilometers away, causing many to circle the platform.

Van Doren et al., (2017), studying the National September 11 Memorial & Museum's Tribute in Lights, in New York City, noted that the powerful, vertically oriented light source impacted behavior of birds up to 4 kilometers above and this type of behavior was reported from tall structures, like monuments and skyscrapers, when these were novel and not surrounded by lighted areas. However, the dramatic increase in widespread light pollution makes this phenomenon rare in cities in the present day, and they are generally associated with weather events that cause birds to fly at lower altitudes.

Studies in Germany and Russia (Bolshakov *et al*., 2010; Bolshakov *et al*., 2013; Haupt and Schillemeit, 2011) have documented birds flying through beams of light and diverting from their course anywhere from a few degrees to a full circle. In Haupt and Schillemeit (2011) lighting was decorative ground level up-lights on trees. Thus, areas with significant light pollution may be completely disorienting to birds without causing circling. In the same studies, smaller songbirds were more likely to change track than thrushes, when they crossed a light beam. The proportion of birds that deviated from a straight path was smaller when the test was undertaken in a lighted area, so contrast may play a part here as well. No-one has speculated how this might apply to birds flying across a lighted landscape, rather than simply through a beam. However, Watson et al. (2017) and Clark (2007) report increased flight calls in migrants over lighted areas, compared to rural areas or dark urban areas.

Different combinations of mechanisms may produce the patterns of collisions that we see: Lights may primarily impact birds as they end a migratory stage and come down close to the built environment, or lights may divert birds that would ordinarily pass over. Bad weather can cause birds to fly lower, while also eliminating any visual cues and bringing them into range of lights. The interactions that produce correlations between building light emissions and collisions may take place only at relatively close range. Once birds come close enough to a light source, glare may blind them, possibly causing them to land. Some combination of attraction and disorientation may result in larger numbers of birds landing in the vicinity of brighter buildings and thus, by day, in more collisions. Interestingly, there seem to be no reports of lights attracting or disorienting migrants as they take off on a new migratory stage.

Solutions

Across the United States and Canada, "Lights Out" programs at municipal and state levels encourage select building owners and occupants to turn out lights visible from outside during spring and fall migration. The first of these, Lights Out Chicago, was started in 1995, followed by Toronto in 1997 and there are now about 50 programs in North America. The programs themselves are diverse but generally create partnerships with individual buildings, which pledge to turn some lights off during migratory periods. Some are directed by environmental groups, others by government departments, and still others by partnerships of organizations. Participation in most, such as Houston's, is voluntary. Minnesota mandates turning off lights in state-owned and leased buildings and the City of New York recently passed similar legislation. Many jurisdictions have NGO-led monitoring components. Monitoring programs can provide important information in addition to quantifying collision levels and documenting solutions but most are not designed to produce these answers. Reducing ALAN should be a simple and effective way to decrease mortality. However, this is greatly complicated by diverse human attitudes and competing policy issues. The most common reaction to a proposal to reduce ALAN is fear of increased crime and decreased safety. This concern has been studied and there is no evidence that reducing ALAN should cause concern. In some cases, less light actually increases safety (see [Lighting, Crime and Safety - International Dark-Sky Association (darksky.org)]() for a detailed treatment).

Brief periods of darkness can release birds that are circling and reduce calling rates. Notably, using strobe lighting on cell towers has been shown to reduce bird mortality substantially (Gehring et al., 2009). This tactic has been used at the 9/11 Memorial since its inception; monitors signal when an estimated 1000 birds are circling in the beams. Turning the lights out for five minutes seems to release those birds to leave the area (Van Doren et al., 2017).

If modifying lighting can work, achieving overall reduction in collisions will require applying principles on a wide scale, not building by building. However, these measures also reduce building energy costs and decrease air and light pollution, increasingly desired outcomes for modern cities and a potential area for partnerships. Ideally, lights-out programs would be in effect year-round and be applied generally, saving birds and energy costs and reducing emissions of greenhouse gases, as well as negative impacts on human health and wildlife. New lighting technologies, particularly LED lighting, are beginning to stimulate discussions about overall lighting strategies and birds should become part of those discussions. Policy based strategies are likely to have the greatest chance of broad application. However, even with highly effective, broad scale reduction of ALAN, collisions will continue to occur, because glass is so widespread, and birds range so widely across landscapes.

At the same time, new strategies should be explored. An increasing body of evidence shows that red light and white light (which contains red wavelengths) particularly confuse birds, while green and blue light may have far less impact. Strategies based on light color may become useful, but need to be field tested.

General Recommendations
Eliminate all unnecessary lighting
Downshield all external light sources
Use minimum light intensity for each task
Use motion sensors whenever possible
Avoid uplights and other vanity lights

REVIEW OF THE LITERATURE

Avian Orientation and the Earth's Magnetic Field

In the 1960s, it was discovered that migrating birds possess the ability to orient themselves using cues from the sun, polarized light, stars, the Earth's magnetic field, visual landmarks, and possibly even odors to find their way. Exactly how this works—and it likely varies among species—is still being investigated. (For a comprehensive review of the mechanisms involved in avian orientation, see Wiltschko and Wiltschko, 2009). The Earth's magnetic field can provide both directional and positional information. It appears that night-flying migrants, and perhaps all bird species, have magnetic field-detecting structures in the retina of the eye that depend on light for function and provide compass orientation. This magnetic sense is wavelength dependent.

Experiments have shown that birds' magnetic compass is disrupted by long wavelength light but requires low-intensity short wavelength light (Wiltschko *et al.* 2007). This research has taken place only in laboratories, and it is important to determine how it translates to the real world. In addition, anthropogenic electronic noise (radio waves), found throughout urban environments, has recently been shown to disrupt magnetic compass orientation in European Robins at very low intensities (Engels *et al.* 2014). This finding may have serious implications for strategies aimed at reducing collisions by reducing artificial night lighting alone and should be a priority for additional work. A second magnetic mechanism, providing birds with positional information, has been postulated, but its details have not been determined. (For a review of magnetoreception and its use in avian migration, see Mouritsen, 2015.)

Birds and Light Pollution

The earliest reports of mass avian mortality caused by lights were from lighthouses, but this source of mortality essentially disappeared when steady-burning lights were replaced by rotating beams (Jones and Francis, 2003). Flashing or interrupted beams apparently allowed birds to continue to navigate, which has also been found more recently at cell towers with strobe lighting (Gehring *et al.* 2009). The tendency to associate collisions, light and tall structures misses the fact that light from many sources, from urban sprawl to parking lots, can affect bird behavior and potentially strand birds in the built environment (Gauthreaux and Belser, 2006).

Evans-Ogden (2002) showed that light emission levels of 16 buildings, ranging in height from 8 to 72 floors and indexed by the number of lighted windows observed at night, correlated directly with bird mortality, and that the amount of light emitted by a structure was a better predictor of mortality level than building height, although height was a factor. Parkins *et al.* (2015) made similar findings. Evans-Ogden was unable to demonstrate a net reduction in collisions in Toronto after their lights out program was established.

Mass collision events of migrants associated with light and often with fog or storms have been frequently reported (Weir, 1976; Avery et al. 1977; Avery et al. 1978; Crawford, 1981a, 1981b; Gauthreaux and Belser, 2006; Newton, 2007). But these are no longer the predominant sources of mortality at buildings, possibly because the night landscape has changed radically since early reports of mass collision events at tall structures like the Washington Monument and Statue of Liberty. These and other structures were once beacons in areas of relative darkness, but are now surrounded by square miles of light pollution. While collisions at structures like cell towers continue to take place at night, the majority of collisions with buildings now take place during the day. (Riding et al., 2021; Hager and Craig, 2014; Kahle et al., 2016; Klem, 1989; Nichols et al., 2018;

Parkins et al., 2015; Powers et al, 2021; Switala-Elmhurst and Grady, 2017; Olson, pers. comm.) Changes in the relative incidence of mass collisions events may also relate to changes in the types of lighting used, from gas lamps, to arc-lighting, incandescent, fluorescent and LED bulbs, each with different ranges of intensity and wavelengths of light.

Patterns of light intensity seem to play a role in the distribution of collisions in the built environment, however. Birds may land in patterns dictated by the pattern of light intensity in an area, so the brightest buildings are the most likely to cause collisions early in the day. As birds move through the landscape seeking food, patterns related to distribution of vegetation appear. Studies using radar to map movement of birds through the built environment are starting to appear, but can be challenging to interpret. We may need information at the level of species and individuals to truly understand how light is impacting birds.

Gauthreaux and Belser (2006) quote Verheijen as suggesting that "capture" might be a better word for birds' response to night lighting than 'attraction'. While "capture" does seem appropriate to describe the phenomenon of birds circling drilling platforms, or in the lights of the 9/11 Memorial's Tribute in Light in Manhattan, recent work (La Sorte et al., 2017; McLaren et al., 2018; Van Doren et al. 2017) has made a persuasive case for birds being attracted by lights into the built environment.

"Disorientation" is a term that covers more of the spectrum of behaviors seen when birds interact with light at night. Gauthreaux and Belser (2006), reporting unpublished data, stated that "exposure to a light field causes alteration of a straight flight path (for example hovering, slowing down, shifting direction, or circling)," and this has been reported by other authors. Larkin and Frase (1988, in Gauthreaux and Belser, 2006) used portable tracking radar to record flight paths of birds near a broadcast tower in Michigan. Birds showed a range of response, from circling to arcs to linear flight. Haupt and Schillemeit (2011) described the paths of 213 birds flying through up-lighting from several different outdoor lighting schemes. Only 7.5% showed no change in behavior, while the remainder deviated from their courses by varying degrees, from minimal course deviation through circling. It is not known whether response differences are species related.

Bolshakov *et al.* (2010) developed the Optical-Electronic Device to study nocturnal migration behaviors seen with moon watching and watching birds cross ceilometer light beams. The device uses searchlights to illuminate birds from the ground, while a recording unit documents the birds' movements. They can study 1) ground- and airspeed; 2) compensation for wind drift on the basis of direct measurements of headings and track directions of individual birds; 3) wing-beat pattern and its variation depending on wind direction and velocity, using this apparatus. In some cases, species can be identified.

Bolshakov *et al.* (2013) examined the effects of wind conditions on numbers of birds aloft and flight trajectories of birds crossing the light beam from the apparatus. They determined that numbers of birds do differ with wind strength, but that birds may be attracted to or aggregate at the light beam under calm conditions. They also found that the light beam disturbs straight flight trajectories, especially in calm wind conditions. Regression models suggest that the probability of curved flight trajectories is greater for small birds, especially when there is little or no moon.

Bulyuk *et al.* (2014) used the same device to compare behaviors of night-migrating passerines in a dark area (at the Courish Spit of the Baltic Sea) with birds passing through an urban light environment (inside the city limits of St. Petersburg, Russia). Songbirds were distinguished as one of two groups, either small passerines or thrushes. The illuminated background caused a decrease in image quality. The shape of flight tracks was compared for the two groups under the two conditions. A larger proportion of small songbirds changed flight path while crossing the light in the dark condition (79% vs 56%) with a similar trend for thrushes (95% vs 80%). In both cases, small songbirds deviated more than thrushes. The authors suggest that the light beam causes less contrast in the urban environment, but also speculate that birds flying through a lighted environment may change their mode of vision to a diurnal one.

To understand exactly how light affects birds and what actions must be taken to reduce those effects, we need to know much more. For example, at what range (horizontal and vertical) and under what conditions do birds feel disruption from light, and of what intensity and wavelength composition? How do these factors change their behavior? Does night lighting have any effect on birds departing at the beginning of migratory stages? Do we ever actually see birds changing course to move toward a bright light source?

Light Color and Avian Orientation

It has been proposed that light color could be a tool to reduce the impact of nocturnal light sources on birds (Poot, 2008). However, studies have produced conflicting results (Evans et al., 2007; Poot et al, 2008; Marquenie et al., 2013, 2014; Goller et al., 2018; Zhao et al., 2020). This may be because standardizing stimuli, (ie lights of different colors), is difficult (Johnsen, 2012; Longcore, 2022.), as each light color must be tuned to the sensitivity of the avian retina. There may also be issues if phototaxis and disorientation are confused (Zhao, 2020).

Starting in the 1940s, ceilometers—powerful beams of light used to measure the height of cloud cover—came into use and were associated with significant bird attraction and mortality (Laskey, 1960). Filtering out long (red) wavelengths and using only the blue/ green range greatly reduced mortality, although filtering the light presumably changed the intensity as well as the color of the signal. Later, replacement of fixed-beam ceilometers with rotating beams essentially eliminated the impact on migrating birds an early indication that birds can be released from light attraction by relatively sort intervals of darkness.

A complex series of laboratory studies in the 1990s demonstrated that birds required light in order to sense the Earth's magnetic field. Birds could orient correctly under monochromatic blue or green light, but longer wavelengths (yellow and red) caused disorientation (Wiltschko *et al.,*1993, 2003, 2007; Rappl *et al.,* 2000). Wiltschko et al. (2007) showed that above intensity thresholds that decrease from green to UV, birds showed disorientation. Disorientation occurs at light levels that are still relatively low, equivalent to less than half an hour before sunrise under clear sky, which could mean that any useful effects of color occur when lights are very dim or when birds are far away. However, in the laboratory, birds are much closer to light sources than they are while migrating.

Poot *et al.* (2008) demonstrated that migrating birds exposed to various colored lights in the field responded the same way as they do in the laboratory. Birds responded strongly to white and red lights and appeared disoriented by them, especially under overcast skies. Green light provoked less response and minimal disorientation; blue light attracted (or aggregated) few birds and did not produce visible disoriention. Birds were not attracted to infrared light. Again, it is not clear that color was the only variable.

Evans *et al.* (2007) also tested different light colors but did not see aggregation under red light. However, they subsequently determined that the intensity of red light used was less than for other wavelengths, and when they repeated the trial with higher intensity red, they did see aggregation (Evans, pers. comm. 2011). However, Zhao (2020) reported strong phototactic responses with blue light and minimal for red, for migrating birds in China. This study used 'monochromatic' red, blue and green 100 watt lights. These may not produce stimuli of identical magnitude, because of differential wavelength sensitivities of the avian retina.

Scientists working in the Gulf of Mexico (Russell, 2005), the North Atlantic (Wiese *et al.* 2001), and the North Sea (Poot *et al.* 2008) report that bright lights of oceanic drilling rigs induce circling behavior and mortality in birds at night. Working on a rig in the North Sea, Marquenie *et al.* (2013) were able to switch lights on and off, with an immediate reduction in circling birds when the lights were off. They also compared different levels of brightness, achieved by turning different sets of lights off. Limited amounts of light that were not directly visible (300 watts) had no effect. Adding lights on a crane, which faced out, brought the total to 1800 watts, and a few birds were seen. When the total was increased to 1960 watts, by adding helicopter landing pad lights, numbers were still limited but there was a clear increase as light was brought to 2,440 watts and with all lights switched on (estimated 3000 watts) large numbers of birds were seen. It was estimated that birds were affected up to five kilometers away.

Replacing about half the lights with Clearsky bulbs (Philips), which emitted minimal red light, reduced circling behavior by about 50%. The authors speculate that completely re-lamping the platform would reduce bird aggregation by 90% but that significant decreases could also be achieved by down-shielding lights. Unfortunately, a variety of factors inherent in the lighting industry has meant that special bird-friendly lighting is not commercially available. Turning lights off or manipulating lighting is thus the most likely approach to reducing circling events at platforms. However, the design of older platforms makes this impossible in some cases and some platforms are operated 24 hours a day.

Gehring *et al.* (2009) demonstrated that mortality at communication towers was greatly reduced if strobe lighting was used as opposed to steady-burning white, or especially red lights. At the 9/11 Memorial Tribute in Light in Manhattan, when birds aggregate and circle in the beams, monitors turn the lights out briefly, releasing the birds (Elbin, 2015, pers. comm.). Regular, short intervals of darkness, or replacement of steady-burning warning lights with intermittent lights, are excellent options for protecting birds, and manipulating light color also has promise, although additional field trials for colored lights are needed.

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