# Misguiding Light:
# The Role Artificial Light Plays in Bird Mortality from Collisions with Glass

## *Why 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 such as owls and nightjars, 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 fewer 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 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 other sites, and as far back as the 1880s, when lighthouses were first electrified and before they had rotating beams. However, while still observed at rural cell towers, isolated oceanic drilling rigs, and, most notably, the National September 11 Memorial & Museum's Tribute in Lights in New York City, 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 (Weisshaupt et al., 2022).

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 correlations between light levels and collision frequency (Weisshaupt et al., 2022).

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

## 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 to navigate using 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, even at very low levels, have been shown to disrupt that magnetic sense (Wiltschko and Wiltschko, 2001, 2002, 2009, 2013; Wiltschko et al., 1993, 2003, 2004 a, 2004 b, 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 yet know which brightness at which range is sufficient to cause attraction, or at which point attraction takes place in the temporal sequence of migratory flight (Bruderer et al., 1999). There are birds that successfully migrate through the well-lit gauntlet between Boston and Washington, D.C., and this implies that some proximity is necessary for attraction to take place. Possibly, some bird species become vulnerable during their descent but are unaffected at height.

Circling behavior at bright light sources in dark areas — communications towers (Gehring et al., 2009), oceanic drilling rigs (Russell, 2005; Marquenie and Van de Laar, 2013) — is well documented. 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 (1.86 to 3.1 miles) 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 (2.49 miles) above. This type of behavior was also 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), ground level landscape lighting caused birds to deviate from their courses. Thus, areas with significant light pollution may be completely disorienting to birds without causing repeated circling. In the Bolshakov studies, when crossing a light beam, smaller songbirds were more likely to change track than were thrushes. 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 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 (Weisshaupt et al., 2022). 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 building owners and occupants to turn out lights visible from outside, as well as unnecessary exterior lighting, during spring and fall migration. The first of these, Lights Out Chicago, was started in 1995, followed by Toronto in 1997. There are now about 50 such programs in North America. The programs themselves are diverse but generally create partnerships with individual buildings, which pledge to turn some lights off during migration 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 they are not designed to produce answers to key questions raised about what exactly causes migratory birds' attraction to artificial light. 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 1,000 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. There are other benefits, as these measures also reduce building energy costs and decrease air and light pollution, increasingly desired outcomes for modern cities, and they provide promising opportunities for partnerships. Ideally, "lights out" programs would be in effect year-round and would be applied generally, saving birds and energy, while 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.

**General Recommendations:**

- Eliminate all unnecessary lighting
- Downshield all external light sources
- Focus light only where needed, especially near sensitive habitat
- Use minimum light intensity required for each task
- Light color: 2200K best, no more than 2700K
- Reduce light transmitted through windows by indoor lights
- Use motion sensors, automatic dimmers and timers whenever possible (so that lights are off whenever possible)
- Avoid uplights and other vanity lights
- Remember that even downshielded lighting can impact insect, bats and other wildlife

## REVIEW OF THE LITERATURE

### Avian Orientation and 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, 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.) 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 that provide compass orientation. This magnetic sense is wavelength dependent.

Experiments have shown that birds' magnetic compass is disrupted by long-wavelength light, but that it 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 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 eight 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 was 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 — often occurring during 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 collision events may also relate to changes in the types of lighting used, from gas lamps to arc-lighting, to incandescent, fluorescent, and LED bulbs — each with different ranges of intensity and wavelengths of light.

Patterns of light intensity, however, seem to play a role in the distribution of collisions in the built environment. 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. Although there have been some studies that use radar to map birds' movement through the built environment, they 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, rather 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 percent 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. Using this apparatus, researchers 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; and 3) wing-beat pattern and its variation depending on wind direction and velocity. 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). Their findings seem to support the idea that strong beacons in dark skies cause more disruption to migrating birds. Songbirds were distinguished as one of two groups, either small passerines or thrushes. The shape of flight tracks was compared for the two groups (small passerines and thrushes) under the two conditions (dark and light). 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 dark and light situations, small songbirds deviated more than did thrushes. The authors suggest that the light beam causes less contrast in the lit 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 which actions must be taken to reduce those effects, we need to know much more. For example, at which range (horizontal and vertical) and under which conditions do birds feel disruption from light, and at which intensities and wavelengths? How do these factors change their behavior? Does night lighting have any effect on birds departing at the beginning of migratory stages?

**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 (i.e. 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 (deliberate movement toward or away from light) 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 short intervals of darkness.

A complex series of laboratory studies in the 1990s demonstrated that birds required light in order to sense 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 a clear sky, which could mean that any useful effects of color occur when lights are very dim or when birds are far away. However, it should be noted that 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 disorientation. 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), studying migrating birds in China, reported strong phototactic responses with blue light and minimal for red. 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 on different sets of lights. 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 1,800 watts, and a few birds were seen. When the total was increased to 1,960 watts, by adding helicopter landing pad lights, numbers were still limited, but as light was brought to 2,440 watts, there was a clear increase. With all lights switched on (estimated 3,000 watts), large numbers of birds were seen. At this level of illumination, it was estimated that birds were affected up to 5 kilometers (3.1 miles) away.

Replacing about half of the lights with Clearsky bulbs (Philips), which emitted minimal red light, reduced circling behavior by about half. The authors speculate that completely re-lamping the platform would reduce bird aggregation by 90 percent, but that significant decreases could also be achieved by down-shielding lights. In general, special bird-friendly lighting has not been made 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.

Gehring et al. (2009) demonstrated that mortality at communications towers was greatly reduced if strobe lighting was used, as opposed to steady-burning white or, especially, red lights.

At the 9/11 memorial's 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 in some circumstances but, overall, eliminating unnecessary lights and downshielding the remainder are the best strategies for protecting birds, while providing cost-savings and other benefits to humans.

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migration nights with red light using double the quantity of light we used in our previous field work. Birds' rod cells (for night vision) are more sensitive to blue and green light than red light, so it makes sense on a visual basis that a red light source might need to be stronger to induce aggregation than blue or green. Many interesting questions still to be answered, and as Al noted, more research and confirmation of research is needed all around."

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