Mayor's Alliance for NYC's Animals®

Steve Gruber, Director of Communications

Mayor’s Alliance for NYC’s Animals

Hearing before the New York City Council’s Committee on Environmental Protection in consideration of three bills designed to limit light pollution in New York City:

Int. 0265-2018*: A Local Law to amend the administrative code of the city of New York, in relation to limiting nighttime illumination for certain buildings*

Int. 0271-2018*: A Local Law to amend the administrative code of the city of New York, in relation to reducing unnecessary illumination in city-owned and city-controlled spaces*

Int. 0274-2018*: A Local Law to amend the administrative code of the city of New York, in relation to nighttime illumination during peak avian migration periods*

Wednesday, December 1, 2021

Good morning. My name is Steve Gruber and I am Director of Communications for the Mayor's Alliance for NYC's Animals. I'd like to thank the Chair and the Members of the Committee on Environmental Protection for the opportunity to speak today on Int. No. 265, 271 and 274 – three bills designed to limit light pollution in New York City.

Since our inception in 2003, the Mayor's Alliance for NYC's Animals has worked toward improving the lives of animals in New York City. While our primary mission has centered on improving the welfare of owned and homeless pets in New York City, our concerns have always extended to the welfare of all animals, including wildlife, with which we share our community.

As a member of the Lights Out Coalition, the Mayor's Alliance joins our colleagues in support of these three important bills. While we understand that light pollution creates a wide range of negative consequences, our focus is on its effect on wildlife, particularly migratory birds. We know that they are drawn to light. We know that on evenings during migration season, birds will alter their paths to approach areas with increased light pollution. We know that this will cause them to lose their way, and lure them toward tall, glass buildings. And we know the devastating results for our winged friends whose lifeless bodies litter our streets after colliding with buildings.

Our friends at the Wild Bird Fund and other bird rescuers and rehabbers do a heroic job working to save and rehabilitate the birds that survive. But hundreds of these precious birds don't survive. And that's a tragedy we can prevent.

Int. 274, 265, and 271 can reduce light pollution in New York City without disrupting our quality of life. By implementing these new measures, we can actually improve the quality of life for New Yorkers by ensuring that nonessential, decorative lighting does not disrupt their sleep schedules. By doing so, we can save the lives of countless birds, save the City money, and reduce our carbon footprint. These proposals are a win for everyone, human and non-human alike.

New York City has acted before to reduce harm to our winged friends who pass through our city. We turned off the twin beams of light in tribute to 9/11 victims during peak migratory times. And in 2019, the New York City Council passed Int. 1482 that requires bird-safe glass in new construction. But unfortunately, that bill does not impose requirements on existing buildings.

We need to do more if we are to further reduce injury and death to the migratory birds that travel New York City's airways. We, therefore, support the passage of Int. 274, 265, and 271, and make New York City a safer, gentler pass-through for our migratory bird visitors.

Thank you.

CITY COUNCIL COMMITTEE ON ENVIRONMENTAL PROTECTION

December 1, 2021 Hearing

Proposed Int. 2460

Good morning, members of the Committee. My name is Mark McIntyre, and I am the Director and General Counsel of the Mayor's Office of Environmental Remediation.

OER was established in 2009, and its statutory authority is set forth in § 15(e) and § 57-1404 of the City Charter, as well as Chapter 9 of Title 24 of the Administrative Code. We operate the City's land cleanup program that promotes cleanup and redevelopment of vacant and contaminated land in New York City. My office has promulgated extensive rules about the City Voluntary Cleanup Program, the Clean Soil Bank and other OER programs.

Under OER oversight, landowners and developers implement remedial actions that clean up land prior to the construction of new buildings. Our land cleanup program generally works very well and over the past decade has been responsible for overseeing the cleaning up of more than 400 acres of New York City property.

In operating our program, however, we have identified two areas where owners and developers sometimes violate program requirements. This bill would address both of them by establishing clear enforcement mechanisms that we can pursue.

First is with respect to the OER "Site Management Plan". This is the document that sets forth a property owner's obligation to maintain engineering and legal controls that limit exposure to residual contamination at a remediated site. Enforcement action is needed where owners violate a Site Management Plan by failing to submit reports certifying that long-term site controls continue to function as intended.

Approximately 200 sites that have completed our program are required to inspect the long-term engineering controls at their sites every year and certify their performance to OER. Owners of some of these sites fail to do so, and thus OER has no assurance that these site controls—ones that protect building occupants from residual contamination -- are functioning as intended. Failure to comply with a Site Management Plan could undermine a remedy and present a risk to public health and the environment. Thus we need the remedy of bringing an enforcement action to bring these buildings into compliance.

Second, enforcement is needed where developers-- participating in the City's land cleanup program --ignore requirements and remediate sites without OER oversight. Excluding OER from overseeing a site cleanup casts doubt on the completeness of the remedy and violates the central premise of a government land cleanup program.

The proposed amendments would authorize OER to issue civil penalties against parties that violate Site Management Plans or other OER program requirements to bring these properties into compliance and would ensure continued protection of public health and the environment.

I am happy to take questions from the Committee.

Hearing on Intros 265, 271, and 274

Committee on Environmental Protection

Testimony by Anthony J. Fiore

Deputy Commissioner, Department of Citywide Administrative Services

December 1, 2021

In Relation to Reducing Unnecessary Illumination from City-Owned and City-Controlled Spaces and Reducing Unnecessary Nighttime Illumination during Peak Avian Migration Periods

Good morning Chair Gennaro, and members of the Committee on Environmental Protection. I am Anthony Fiore, Chief Energy Management Officer for the City and Deputy Commissioner for Energy Management at the Department of Citywide Administrative Services ("DCAS"). Thank you for the opportunity to provide written testimony today on behalf of the Administration regarding these three introductions that seek to reduce unnecessary illumination from City-Owned and City-Controlled Spaces and to reduce unnecessary nighttime illumination citywide.

Background

As part of the *One City: Built to Last* climate action plan, this Administration set forth an ambitious vision for reducing Citywide greenhouse gas ("GHG") emissions 80 percent by 2050 over a 2005 baseline known as "80 x 50", also codified in Local Law 66 of 2014. In addition, the most recent OneNYC update, OneNYC 2050 extended this goal by committing to net-zero GHG emissions Citywide by 2050. This will require 100% clean energy and offsetting sources of irreducible emissions. Recognizing its own impact on GHG emissions, this Administration is leading by example, and with the passage of the Climate Mobilization Act, will reduce emissions from City government operations 40 percent by 2025 and 50 percent by 2030 from a 2006 baseline. I would also like to acknowledge the tremendous partnership between the Administration and this Committee. We have done a lot of great work together over the years which I'm sure will continue. .

DCAS' Division of Energy Management plays a critical role in supporting our agency partners' progress towards the City's major emissions reduction and energy mandates and commitments. We concentrate our efforts in six areas: The City's energy supply, clean energy generation, demand response and load management, energy-efficient operations and maintenance, energy efficiency retrofit projects, and energy training and innovation. DCAS oversees a $3 billion 10-year capital plan to invest in energy efficiency and clean energy projects at city-owned buildings and city-controlled spaces.

Over the past decade, DCAS has invested over $200 million to complete lighting retrofits in nearly 1,000 City buildings, which are estimated to reduce 178 million kilowatt hours ("kWh") of electricity on an annual basis—the equivalent amount of electricity consumed by over 40,000 homes in New York City—and save over $30 million per year in energy costs. These projects are also estimated to reduce over 67,000 metric tons of carbon dioxide equivalent ("MT CO2e") on an annual basis, which is the equivalent to removing

13,500 vehicles from the road. In addition, the City has committed to make a significant investment to purchase enough renewable energy to meet 100 percent of its electrical consumption. The City's participation in the State Clean Energy Standard Tier 4 solicitation has catalyzed the selection of two large-scale renewable energy projects that will bring more than 2500 megawatts of clean energy directly into New York City over new transmission infrastructure. This carbon-free energy will benefit all City residents by not only reducing GHG emissions but also by helping to reduce the amount of energy generated by inefficient in-city generation, improve air quality and attendant public health outcomes, and bolster the reliability and resiliency of the electrical grid in the city.

Today's Introductions 265, 271, and 274 align with the Administration's and Council's desire to create a more sustainable New York through seeking to improve the energy efficiency of buildings. Reducing excessive lighting from buildings during the daytime and at night is an objective that not only helps us reach our GHG emission reduction goals but also improves quality of life for New Yorkers and protects wildlife, particularly migrating avian populations. We do have some concerns about the bills as currently written and would like to offer some initial suggestions that would help to make these proposals more workable and effective.

Introduction 265

This bill seeks to prohibit nighttime illumination of the exterior and interior of certain types of buildings year-round. This bill would further the goal of improving quality of life while reducing energy use and GHG emissions, and as such the Administration is supportive of the objectives of this bill. As noted, we highlight specific concerns about the bill as currently drafted, and share the following ideas about ways to help improve the bill:

- **Appropriateness of Civil Penalties:** The bill as introduced would authorize civil penalties against building owners and operators for violations of wasteful lighting in unoccupied spaces. In many instances in these buildings, commercial tenants control their own lighting. As a result, the legislation may place an inappropriate and unfair burden upon building owners and operators who may not have direct control over their tenants' activities.

- **Scope of Covered Buildings:** The use of Building Code occupancy classifications to define which buildings are subject to the law might be overly limiting. The occupancy groups identified in the proposal are limited to buildings that are classified as B, Business, and M, Mercantile. We believe other occupancies should also be included, such as Assembly, which includes theaters and large restaurants. We should also examine whether the requirements should apply to office or retail spaces that are within buildings of another classification, such as Residential.

- **Enforcement:** We are concerned that enforcement of this bill would be challenging and costly. Whichever agency is made responsible for enforcing this bill would have to hire a dedicated team of inspectors to work overnight shifts for this purpose. Since building qualifications are determined based on factors from several agencies, an interagency building database would have to be designed and built to keep track of buildings that are subject to the light requirements. Moreover, once a building is determined to be subject to the requirements, it would not be possible for an inspector to determine with certainty that the building is unoccupied at any given time. Any violation issued by the enforcing agency could be easily vacated if a building owner claimed someone was inside when the notice of violation was issued. Finally, the bill as currently drafted does not define what amount of “illumination” is prohibited, which is a significant factor in understanding the scope and applicability of the proposal.

- **Waiver for Landmarked Buildings:** The bill as currently drafted permits the owner of a landmarked building twenty or more stories in height to apply to the Landmarks Preservation Commission for a waiver from the prohibition on nighttime illumination. Since all landmarks have been found to be important to the history of the city, state or nation the waiver should apply to all landmarks over 20 stories that also meet the occupancy classification criteria, and this waiver should apply to exterior lighting of facades, not internal lighting. As with other provisions, the bill could also require that such exterior lighting be turned off after a certain time.

Introduction 271

This bill would require the City to implement certain lighting efficiency measures in city-owned and city-controlled spaces. As I mentioned previously, the City has already made tremendous investments to reduce energy consumption and GHG emissions from lighting. We are therefore supportive of the apparent goal of this legislation. We do however have several concerns with the current draft of the bill that would need to be addressed to ensure its feasibility. At the threshold, we believe that the scope of the bill, as currently drafted, would be far more manageable if the bill were to apply to City-controlled buildings.

- **Implementation schedule:** We would like to work with the Council to refine the implementation targets and timelines specified in the bill to ensure that they reflect the current state of the City's building portfolio and to ensure that they are both ambitious and achievable.

- **Applicable measures:** We would like to work with the Council to better understand the requirement for certain lighting upgrades in existing spaces. Specifically, the sections of the NYC Energy Code that are cited in the bill were significantly revised in the recently adopted 2020 code. It would be helpful to better understand the Council's thinking on the specific nature of the required upgrades so that we can more accurately assess both feasibility and cost impacts. We would also like understand how these requirements would relate to the requirements established by Local Law 88 of 2009, as amended by Local Law 134 of 2016 (relating to upgrading of lighting systems and installation of sub-meters), as well as Local Laws 31 and 32 of 2016 (relating to low energy intensity building requirements and green building standards). We need to be concerned about and mitigate the potential for unintended consequences for the City's operations and fiscal management.

- **Consideration of recently completed projects:** As noted above, the recently adopted 2020 Energy Code requires even more stringent standards than were in place under the 2014 Energy Code, which was the prevailing standard for the majority of DCAS' recently completed lighting retrofit projects. We believe that it is critical to continue utilizing the City's limited capital budget to invest in the buildings and spaces that have the greatest need and highest potential impact. We therefore suggest that the bill exclude spaces that have recently undergone lighting upgrades and where incremental improvements would be minimal.

- **Consideration of operational factors:** The buildings and spaces operated by the City of New York provide life saving and sustaining services to all New Yorkers. While the 2020 Energy Code includes specialized provisions for lighting systems in certain high occupancy and critical facilities, we believe that it would be prudent to further specify how such spaces in the City portfolio would be treated under the bill.

- **Reporting:** The Administration is committed to public transparency and understands the purpose of the reporting provisions of Intro 271. We would like to work with the Council to ensure that these provisions are appropriately calibrated so as to avoid unwarranted complexity and an administrative burden that would detract from the overall objectives of the legislation.

Introduction 274

This bill aims to reduce unnecessary exterior nighttime illumination during peak avian migration periods, The Administration is supportive of protecting wildlife while at the same time saving energy usage from lighting. Not only does light pollution affect the quality of life for New Yorkers and disrupt the migratory patterns of birds, unnecessary illumination from empty offices and other buildings wastes electricity and contributes to GHG emissions. For this reason, the Administration is supportive of the general intent to reduce unnecessary nighttime illumination. We would like to work with the Council to craft clearer definitions of the concepts that are referenced in the current bill draft.

Finally, there are many operational complexities associated with implementing legislation such as those discussed herein, and we have several technical questions about each of the above bills. We look forward to working with the Council to ensure consideration of critical implementation concerns in order to most effectively achieve the intent of these bills.

Thank you again for the opportunity to provide written testimony today and the opportunity to partner in advancing the City's climate change mitigation efforts.

AMERICAN BIRD CONSERVANCY

Bringing back the birds

December 31, 2021

Testimony to the NYC Councils Committee on the Environment
In support of 265, 271 and 274

I'm Dr. Christine Sheppard, Director of American Bird Conservancy's Glass Collisions Program. I've been working on problems caused by excess artificial lighting at night and its negative impacts on both birds and people, for about 20 years. One important thing I've learned is that this is a complex problem we can't fix one building at a time! It is not just lights from tall buildings in cities that attract birds and impact people – even ground level lighting of roads and parking lots can have a negative effect. In addition to luring birds into danger, and causing depression and other effect in people, unnecessary lights at night also waste energy, create greenhouse gases and make it impossible to see the stars. NY City has recognized the importance of birds to sustainability and their approach with this legislation is an excellent one that can make a huge difference, both locally and by inspiring other jurisdictions to follow suit. –
American Bird Conservancy strongly supports this suite of legislation! Thank you for allowing me to testify.

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

Christine Sheppard, Ph.D.
American Bird Conservancy

Executive Summary

Artificial lighting at night (ALAN) increases the rate of bird mortality from collisions with glass. 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. We do know that birds probably 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 disrupts orientation mechanisms evolved to work with dimmer, natural nocturnal light sources and can cause birds to deviate from their flight paths. The magnitude of this deviation is variable in degree and could be species specific. There is good evidence that urban night lighting attracts birds. As night flying migrants approach light sources, they may become disoriented, and/or attracted towards light sources and eventually land in the built environment, where they are at risk from glass. However, we still have little information about how close or how bright a light must be to have an effect on bird behavior.

It is generally, but incorrectly believed that tall buildings cause the most collisions. 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. It was observed decades ago at the Washington Monument, Empire State Building and Statue of Liberty, among others. However, while still observed at rural cell towers, 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.

However, the amount of light emitted by a building is a stronger predictor of the number of collisions it will cause than is building height, even though the majority of collisions with buildings actually take place by day. As birds seek food to fuel their next migratory flight, they face a maze of structures. Many, unable to distinguish between habitat and reflections, or to perceive transparent barriers, hit glass. Presumably, collisions during the early morning are most likely to occur on the structures near where birds landed, while later, birds will have dispersed. Possibly, patterns of light intensity across a nocturnal landscape may influence the pattern of birds landing in that landscape at the end of migration stages, producing the correlation between light levels

and collisions frequency. Some birds might also move towards bright light sources during the stopover period.

Reducing emitted light from a few individual buildings may lower collision rates on those structures, while not reducing overall mortality for an area. Thus, reducing light trespass and site lighting from a few tall buildings, as is typical for Lights Out programs, is insufficient to have a real impact on collisions overall. Reducing light emission throughout the built environment must be part of any strategy to reduce collisions with glass. In addition, at least one study has documented behavioral changes in birds exposed only to ground level lighting. To have a significant impact may require regional level policy solutions aimed at general lighting schemes. There is some recent evidence that electromagnetic radiation outside the visible spectrum may also disorient birds and this may complicate the problem as we learn more about it.

Introduction

Birds evolved complex complementary systems for orientation and vision long before humans developed artificial light (Land and Nilsson, 2010). We still have much more to learn, but recent science has begun to clarify how artificial light poses a threat to birds, especially nocturnal migrants. Although most glass collisions take place during daylight hours, artificial lighting at night attracts birds and plays a role in the number and the distribution of collisions across the built environment. Unfortunately, the details of how birds respond to night lighting are different and less well understood than has been commonly believed.

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. While they migrate at night, these birds have poor night vision – but the majority of their night activity is aloft, with little to see. Instead, they use magnetic senses that allow them to navigate using the Earth's magnetic field (Wiltschko and Wiltscho, 2009, Deutschlander et al., 2012). One of these is located in the retina and requires dim blue natural light to function. 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. If a songbird flies into a home, darkening the room and opening a bright window is the best way to release it. Birds are attracted to artificial light at night as well (La Sorte, et al., 2017; McLaren et al., 2018), but we don't know what light level at what vertical/horizontal distance is sufficient to cause attraction or when attraction takes place in the temporal sequence of migratory flight. However, Watson et al. (2016) report… and Engels et al., (2016)electromagnetic … outside visible spectrum ….

Circling behavior at bright light sources in dark areas – communication towers, oceanic drilling rigs – is well documented and this type of behavior was reported from tall structures, like monuments and skyscrapers, when these were novel and not surrounded by lighted areas. We don't know whether a particular level of intensity contrast is necessary for circling behavior – nor at what combination of intensity and distance from light the behavior is elicited and this may differ among species. In the one available report, Marquenie and Van de Laar (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. It would be useful to know whether those authors found attraction, as well.

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 (again, it is not known whether this is species related). Thus, areas with significant light pollution may be completely disorienting to birds without causing circling. In the same studies, small 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 well play a part. Nobody has speculated how this might apply to birds flying across a lighted landscape, rather than simply through a beam.

The science is inconclusive: Lights may only 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, the electromagnetic radiation actively interferes with their magnetic orientation mechanism, 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

Because of the complexity of reducing bird collisions with glass, it is tempting to see turning lights off as a simple way to decrease mortality. 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. The programs themselves are diverse. 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. Many jurisdictions have NGO-led monitoring components. Monitoring programs could provide important information in addition to quantifying collision levels and documenting solutions but most are not designed to produce these answers.

Reducing exterior building and site lighting is believed to have been proven effective at reducing mortality of night migrants at individual, usually tall, buildings: this is the basis for Lights Out programs. However, only data from a single building, McCormick Place in Chicago, is cited as the basis for this belief. An analysis of collisions data, commissioned by FLAP on data from Toronto, the city with probably the most effective Lights Out program, was unable to demonstrate a reduction in total collisions in the city.

It would be advisable to determine whether or not the Lights Out approach will reduce collisions overall, as opposed to simply influencing patterns of collisions. It would be extremely valuable to determine the range at which light impacts migrants.

If modifying lighting can work, achieving overall reduction in collisions will require applying principles on a wide scale, not building by building. (Would it be possible to use lighting to attract birds to safe landing sites?) However, these measures also reduce building energy costs and decrease air and light pollution, increasingly desirable 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. 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.

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.

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 emphasis on tall structures by Lights Out programs ignores 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. (Hager, 2014; Kahle *et al.*, 2015; 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.

It is often said that birds are attracted to lights at night (Gauthreaux and Belser, 2006; Poot *et al*. 2008). However, we do not have direct evidence that birds are, in fact, attracted to lights; they may simply *respond* to lights they encounter incidentally. Gauthreaux and Belser quote Verheijen as suggesting that "capture" might be a better word for birds' response to night lighting. 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, "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

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 kills. Filtering out long (red) wavelengths and using the blue/ green range greatly reduced mortality, although we don't know whether the intensities of these two colors of lights were equal. Later, replacement of fixed-beam ceilometers with rotating beams essentially eliminated the impact on migrating birds (Laskey, 1960).

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 (Rappli *et al.,* 2000; Wiltschko *et al.,*1993, 2003, 2007). 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.

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 disoriention. Birds were not attracted to infrared light. 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).

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 effected up to five kilometers away.

Replacing about half the lights with new bulbs emitting 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 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 available for drilling platforms, but such lighting has been installed onshore, by Shell at some of its operations in Europe, and also by municipalities and other industries in the Netherlands. 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. (It is very possible that Powdermill would be a great place to do this type of work).

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Testimony to
New York City Council Committee on Environmental Protection
Regarding
Lights Out Legislation, INTs 265, 271, 274
December 1, 2021

Thank you for the opportunity to share this testimony. My name is Kaitlyn Parkins, Associate Director of Conservation and Science at New York City Audubon, which is a member of the Light out Coalition. NYC Audubon is a science-based conservation organization representing 10,000 Audubon members across New York City and thousands more who support our mission to protect 350-plus bird species—almost a third of all the species in North America—that live in or pass through New York City each year. Protecting these birds and their habitats also improves the quality of life for all New Yorkers.

As the lead bird conservation organization in NYC, we are all too aware of the threats that birds face throughout the city. We have been studying the negative effects of climate change, habitat loss, and human disturbance on birds in New York City for forty years. We know that in the five boroughs, the deadliest obstacles migratory birds encounter are the dual threat of light and glass, which, in the US alone, cause up to a billion birds to die in window collisions each year.

In 2019 the New York City Council passed Local Law 15, the Bird-Friendly Materials Law, to reduce bird-window collisions in NYC. By addressing the issue of glass architecture so boldly, the City of New York established itself as a global leader in bird conservation. Now, we must take the second step in addressing this dual threat—reducing nighttime light pollution.

70% of North American bird species are migratory: every year, in the spring and fall, they fly thousands of miles between their breeding and wintering grounds. Of these, 80% migrate at night. Radar data from our colleagues at the Cornell Lab of Ornithology shows that millions of birds fly over New York City every year during migration.

Artificial light at night attracts and disorients birds. The bright lights of the City skyline disrupts birds' migration and attracts them off their route from up to 3 miles away. Unable to continue their passage, they land in unsafe places, vulnerable on our sidewalks to predators and traffic, unable to find nutritious food, with a maze of built infrastructure to navigate. But many don't even make it that far, instead crashing into lit windows, their thousand-mile journeys ending abruptly in deadly collisions with glass.

We saw first hand the brutal effect of light on birds on September 14th this year, when more than 200 dead songbirds were recorded at just four buildings in Lower Manhattan— all fatalities from collisions with windows after being disoriented by the bright lights. And while this single mass mortality event drew the attention of numerous media outlets across the nation the compounded daily toll of these deaths is enormous.

Our collision monitoring volunteers collected 1,196 birds from just twenty buildings this fall. 1,500 more were reported to our online "dBird" collision reporting database between September and November. Nearly 100 different species are represented among the victims. And these are just the birds people find and report— the overwhelming majority go undocumented. Through our ongoing research on this issue since the 1990's we estimate that up to 230,000 birds die in collisions with buildings each year in New York City.

Turning lights off saves birds in two ways: it stops nocturnal collisions with lit windows and it reduces the number of birds attracted to areas where they are at risk of collisions during the day.

Research also shows that birds are affected by more than just individual lit buildings. The collective light pollution of many buildings— the urban glow— attracts birds at a broad scale. If an individual building reduces its lighting, birds may just collide with adjacent buildings. So while we applaud individual buildings taking voluntary action, we must remember that in NYC we have over a million buildings; legislative action requiring a reduction in light pollution is imperative to have meaningful impact.

Because both interior and exterior lighting contribute to light pollution that negatively affects birds, **we recommend that Introduction 274 be amended to include interior lighting** in addition to exterior lighting, **and to include city-leased buildings** as well as city owned buildings.

Turning off lights at night will allow most migratory birds to safely pass New York City, or land in our green spaces, out of harm's way. Local Law 15 is leading to a safer city for birds in the future. Legislation to reduce nighttime lighting can reduce bird deaths now. Therefore, we urge the passing of INTS 265, 271, and 274 (with recommendations stated above).

Thank you for your time and for hearing our requests and concerns on behalf of the birds that call New York City home.

Kaitlyn Parkins
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REBNY Testimony | December 1, 2021

The Real Estate Board of New York to

The Committee on Environmental Protection of the New York City Council Regarding Intro. No. 265, Intro. No. 271, Intro. No. 274, and Intro. No. 2460

The Real Estate Board of New York (REBNY) is the City's leading real estate trade association representing commercial, residential, and institutional property owners, builders, managers, investors, brokers, salespeople, and other organizations and individuals active in New York City real estate. REBNY thanks the New York City Council Committee on Environmental Protection for the opportunity to provide testimony on Intros 265, 271, 274, and 2460.

Confronting climate change requires collective effort from both the public and private sectors to deal with the crisis at hand. REBNY supports City and State emissions reductions goals, and we are proud to represent members who are innovating in the fields of building construction and technology to reduce carbon footprints, increase energy efficiencies, and take concrete steps to strengthen climate resilience.

We would encourage the City Council to work with the industry to find practical, data driven solutions to inform their approach to these problems. Below please find bill specific comments for consideration.

BILL: Intro 265

SUBJECT: A Local Law to amend the administrative code of the city of New York, in relation to limiting nighttime illumination for certain buildings, by request of the Queens Borough President

SPONSORS: Council Members Brannan, Rosenthal, Kallos, Reynoso, and Dromm

This proposed bill would prohibit nighttime illumination of the exterior or interior of any building whose main use or dominant occupancy is classified in group B or M pursuant to the New York City building code. The bill includes several exemptions and allows for waivers in certain instances, including for certain landmarked building. Where a building owner has made a showing of special circumstances indicating a need for night security lighting, the Department of Buildings (DOB) may vary or waive the requirements of this section. Buildings may remain illuminated where individuals remain inside and where nighttime illumination is required by law, rule, or zoning resolution. Seasonal displays may be illuminated until midnight and storefront displays are permitted limited illumination until midnight.

REBNY and its members share the goals of reducing our carbon footprint. However, for several operational reasons, Intro 265 is unlikely to reduce carbon emissions and instead poses substantial

problems for the city that never sleeps. Indeed, realizing the goals of this law would dramatically disrupt the operations of commercial buildings where significant activity occurs at night. As proposed, it will increase City the staff time needed to sort through the various permutations of the exemption language and heighten the need for a compliance regime with the necessary oversight to monitor illumination levels within every stairwell. For instance, the current legislation includes exemptions for buildings where there is a staff presence at night. Typically, however, tenant leases include the provision of building services after hours. Practically, this means that services such as cleaning, and garbage removal routinely occur during overnight shifts. Additionally, because leases include 24-hour access for tenants, buildings often maintain at minimum a security presence as well as the presence of a Fire Safety Director, who is required by the city when the building has an occupancy of 100 persons above and below grade or 500 persons in the entire building.

Furthermore, commercial buildings, by code, are required to have a certain amount of lighting at all times. This includes all stairwells, in elevators and elevator lobbies, major paths of egress, and common areas to aid in safe circulation through building spaces.

Architectural lighting has proved to be a valuable asset to key buildings, including many recognizable cultural icons and designated landmarks across our city such as the Empire State Building, and the Chrysler Building. Manhattan is home to hundreds of thousands of landmarked properties that will require an additional level of coordination between DOB and the Landmarks Preservation Commission. Additionally, the bill is silent to newer structures with marquee exterior lighting such as the World Trade Center and One Vanderbilt – both of which were subject to significant design review – and how they would be treated under the statute.

Finally, lighting at night also plays an important role in increasing public safety by increasing visibility on streets that can help deter crime.

REBNY is opposed to this legislation absent significant modifications to address the many operational concerns raised by this bill.

BILL: Int 271

SUBJECT: This bill would amend the administrative code of the city of New York, in relation to reducing unnecessary illumination in city-owned and city-controlled spaces, by request of the Queens Borough President

SPONSORS: Council Members Brannan, Rivera, Rosenthal, Reynoso, Dromm and the Public Advocate

The bill would require occupancy sensors be installed in City-owned and controlled spaces to reduce electricity usage over time. The effective dates for existing buildings are phased in over time, with newly constructed buildings required to be compliant immediately. The legislation also requires robust reporting by the Department of Citywide Administrative Services (DCAS) to the Mayor and the Speaker on key performance efforts on an annual basis, and every three years on the amount of energy saved.

While the intent of this bill is laudable, we would welcome the opportunity to further discuss the measure with the Council to discuss technical issues with the proposal.

BILL: Int 274

SUBJECT: **This bill would amend the administrative code of the city of New York, in relation to nighttime illumination during peak avian migration periods, by request of the Queens Borough President.**

SPONSORS: Council Members Rosenthal, Rivera, Reynoso, Brannan, Dromm and the Public Advocate

This bill would for city-owned buildings, non-essential outdoor lighting, shall be turned off between the hours of 11:00 p.m. and 6:00 a.m. during peak avian migratory periods to reduce or eliminate avian mortality during such periods.

REBNY supports reasonable efforts to protect the city's avian population and is proud to partner with the New York Audubon Society's *Lights Out Initiative.* Each year, REBNY encourages its members to participate in this initiative and to turn out lights in their buildings during migration season from midnight to dawn. Promotion of this initiative continues on an annual basis, and we welcome the Council and the City's collaboration in this matter.

While well intentioned, Intro 274 leaves key terms undefined and subject to rulemaking by DCAS, when the Department of Buildings may be a better arbiter given code and zoning considerations already highlighted in the companion bill Intro 265. Wholesale "lights out" mandates may have unintended consequences, and it is not clear from the data presented that every building poses the same risk. REBNY would encourage the sponsors to consider further study on the topic before committing significant City resources.

BILL: Int 2460

SUBJECT: **The bill would amend the administrative code of the city of New York, in relation to enforcement of environmental remediation plans and rules of the office of environmental remediation.**

SPONSORS: Council Member Gennaro

This bill would grant the City the authority to classify violations of any provisions of the site management plan for a local brownfield remediation site as a civil penalty of up 25,000 dollars. The bill would grant access to a yet to be determined City agency or staff to enter private property to inspect the terms of a site management plan.

The New York State Brownfield Cleanup Program is targeted towards remediating and repurposing contaminated and blighted areas known as brownfield sites. Over the years, the Cleanup Program has proved critical in our efforts to correct environmental injustices, combat neighborhood blight, and provide thousands of homes citywide for New Yorkers who need it the most. Since 2015, the program has supported 20,000 homes in New York City, of which 6,400 are considered income restricted[1], with more homes anticipated in the coming years.

A robust enforcement mechanism is vital to maintaining the integrity of the program. However, the bill language appears overly broad and could ultimately unintentionally penalize well-intentioned actors or

[1] *New York State Brownfield Cleanup Program and Tax Credits: Analysis of a Three Generation Program*, NYU Schack Institute of Real Estate, October, 2021

entities. The bill is inconsistent with existing OER programs and should be refined to target the problem of a select subset of second party non-compliance. This should include any such person, its transferee, successors, or assigns rather than referring to an entity. The bill also lacks a recourse mechanism to ensure participants have due process and are not unfairly penalized by anything that is found or determined in these "site visits." REBNY and its members would be happy to work with the Council and the City to craft legislation that meets the goals of better compliance with the Brownfield Clean Up Program while adequately balancing private property rights.

Thank you as always for your consideration on these points.

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TESTIMONY of LISA KOLE

for the WILD BIRD FUND, INC.

at the

Meeting of the New York City Council Committee on Environmental Protection

in support of

Int. 0265-2018; 0271-2018; 0274-2018; and 2460-2021

December 1, 2021

* * * * * *

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I. TESTIMONY

A. Oral Testimony

I am a member of the Board, and Board Secretary, of Wild Bird Fund, Inc.. I am a retired intellectual property attorney, and also hold scientific degrees: an M.D. from Cornell University Medical College and a Ph.D. in Molecular Cell Biology from The Rockefeller University.

I made the following statement at the virtual Meeting of the New York City Council Committee on Environmental Protection held December 1, 2021:

"Avian migration is a massive nocturnal event. 12 million birds were detected flying over Cape Cod on a single autumn night. We don't know much about how they navigate, but scientists tell us they are drawn to light.

I'm Lisa Kole from the Wild Bird Fund, New York City's only wildlife rehabilitation hospital. Thank you for hearing our testimony today supporting the proposals to reduce light pollution and help birds.

During migration seasons, we admit hundreds of birds injured by collisions with buildings. It isn't a steady flow. Some days, just a few birds are brought in, but sometimes, by 10 AM dozens of new collision patients wait for care. A recent study from Cornell by Van Doren and colleagues – including Dr. Farnsworth, who testifies today - may tell us why this happens.

The scientists studied 20 years of bird collision data from Chicago's McCormick Place, a conference center on the shores of Lake Michigan notorious for bird strikes. They found collision risk linked to three factors – number of birds migrating, wind, and light. Exterior lighting was important – since Chicago began its Lights Out policy, collisions at McCormick decreased by 80%. But interior lighting was very important too: decreasing the area of lit windows by half reduced collisions 6 or 11-fold.

Wild Bird Fund experience is consistent with their results. Days of largest patient intakes often follow nights of heavy migration when weather is poor and disproportionately more patients come from the commercial –brighter lit – parts of town.

Imagine being on a plane landing in New York on a stormy night – that moment when the aircraft breaks through the clouds and you see the bright lights of the city – the towers of Wall Street, the blaze of Times Square. That's what birds see, too – except to get through the storm, there's no plane to guide them, and their innate navigation system is confused by light. They arrive to find an obstacle course of tall buildings, and,the next day, a maze of mirrors. Please help these wild visitors avoid getting waylaid or worse in our city by passing the legislation before you."

B. Written Testimony

1. Urban Factors That Increase Risk Of Migratory Bird Collisions

Researchers reviewed two decades of bird collision data (11,567 fatal collisions) at McCormick place, a convention center near Chicago, located on the shores of Lake Michigan and historically a hotspot for bird collisions (40,000 dead birds have been recovered from the site since 1978). As reported in Van Doren, B., Willard, D., Hennen, M., Horton, K., Stuber, E., Sheldon, D., Sivakumar, A., Wang, J., Farnsworth, A., and Winger, B., (2021), "Drivers of fatal bird collisions in an urban center," Proc. Natl. Acad. Sci. U.S.A. 118(24):e2101666118 ("Van Doren (2021)"), the scientists found that the best predictors of collisions were magnitude of nocturnal migration, wind conditions, and building light output. The numbers of birds migrating through the area were determined by radar (for more details, see the BirdCast website, https://birdcast.info/). The authors state "[M]igration and lighted window area were consistently the strongest predictors of fatal collisions" (p.2) and "there is evidence that dense cloud and low visibility may increase collision counts, *especially in the presence of light pollution*" (p.3; *emphasis added*). In the section of the article captioned, "Darkening Individual Windows Reduces Mortality", they report:

> "In spring and fall, whether an individual window bay emitted light was the most important variable in predicting fatal bird collisions at that bay. Colliding birds appear to be attracted to specific light sources and are not simply disoriented by overall city or sky glow." (p.5)

They conclude:

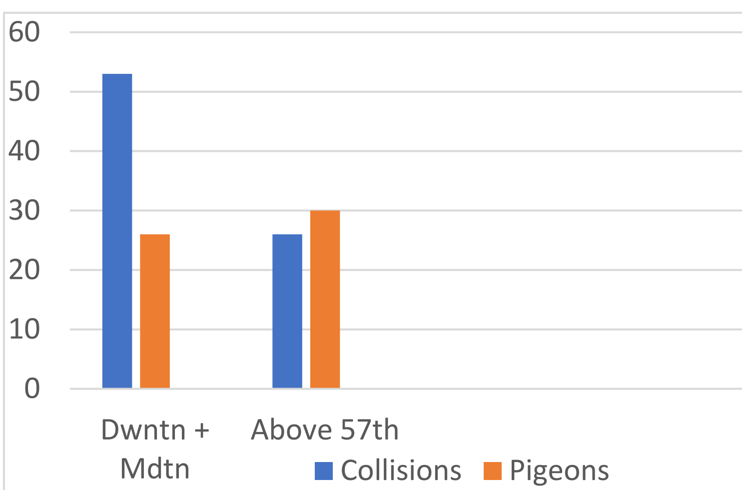
> "Where possible, permanent lighting adjustments, such as downshielding lighting, changing lighting color [reference], and automating the usage of window blinds between certain hours, will reduce the load on individual actors and decrease the risks posed to nocturnally migrating birds by light pollution." (p.6)

2. More Collision Patients Come from Brighter Parts of Town

The following data is described more fully in the Testimony of Ritamary A. McMahon, a portion of which is reproduced here.

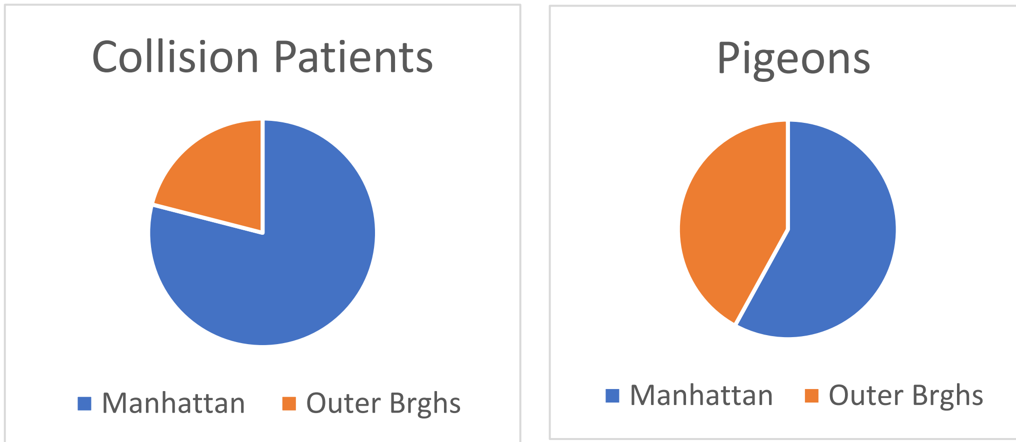
Considering the nighttime New York City skyline, it seems apparent that the area south of 57th Street in Manhattan is more commercial and brightly lit. While we at Wild Bird Fund have had the impression that many migrant collisions originate there, we performed a preliminary analysis of information collected in our patient database, using pigeons admitted within the same time period as controls. Pigeons are non-migratory and our most frequent patient. Although pigeons occasionally collide with buildings, none of those included as controls in this study were assigned a collision "distress code". It was observed that proportionally many more migratory collision victims, relative to pigeons, were found downtown, and, conversely, a greater proportion of pigeons were brought in from the outer boroughs. The total percentage of collision patients from downtown (below 20th Street) and midtown (between 21st and 57th Streets), fifty-four percent (54%) was much greater than the percentage of pigeons coming from both areas, twenty-eight percent (28%) (Figure 1, below). And, seventy-nine percent (79%) of collision patients were found in Manhattan, versus fifty-eight percent (58%) of pigeons (Figure 2, below). It appears that there were relatively more migratory collision patients coming from the brighter parts of town.

Figure 1



More collision patients come from downtown + midtown than from above 57th street (percentages)

Figure 2

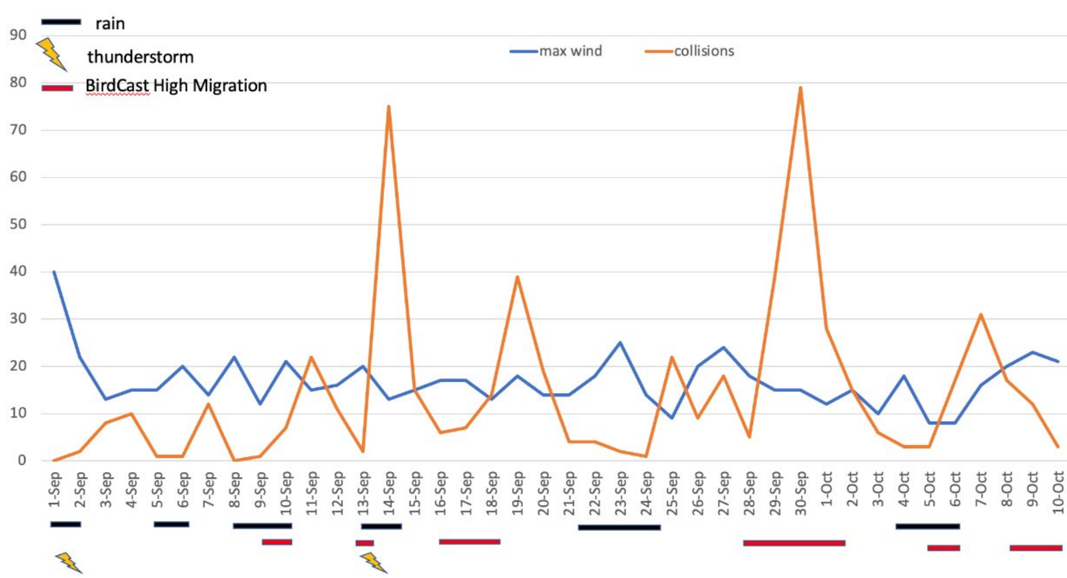


A lower percentage of migratory bird collision patients come from the outer boroughs, relative to pigeons.

3. <u>Patient Intakes Influenced by Birds Aloft and Weather</u>

In view of Van Doren (2021), Wild Bird Fund was curious to see, in a preliminary analysis, whether there was an association between its migratory collision intakes and weather (our anecdotal experience pairs increased intakes with storms). The results, drawn from our patient database and weather records, for the period September 1, 2021 through October 10, 2021, are shown in Figure 3, below.

Figure 3



There are two major peaks in Figure 3, at dates September 13-14 and September 28-October 1.

The peak at September 13-14 reflects the mass bird mortality event widely reported in the news when hundreds of migrating birds were found dead at the base of Wall Street Buildings (O'Neill, N., (September 15, 2021), "At least 291 migratory birds dead after smacking into WTC towers," *New York Post,* https://nypost.com/2021/09/15/at-least-291-birds-dead-after-smacking-into-wtc-towers/ . In his response to this catastrophe on the BirdCast website, Dr. Andrew Farnsworth (who also testified at the December 1 Committee Meeting) stated "Intense urban light pollution (and an abundance of tall buildings) together with poor flying conditions (this map shows the frontal boundary associated with the strong storms and poor visibility conditions) on a night of intense and low altitude migration contributed to these events." (https://birdcast.info/news/mass-mortality-events-in-manhattan-on-13-14-september-2021/). The night of September 13 was predicted, by radar, to be one of heavy migration with as many as 279 million birds in flight across the United States and heavy migration over New York City (BirdCast, Live Bird Migration Maps, 9/13/2021, https://birdcast.info/migration-tools/live-migration-maps/). Between 8 and 10 o'clock, there was light rain and thunder in the New York Area, and winds gusting to 22 mph (Weather Underground data for Manhattan, https://www.wunderground.com/history/daily/KLGA/date/2021-9-13). As shown in Figure 3, 75 of the surviving collision victims were brought to the Wild Bird Fund the following day.

The peak at September 28-October 1 corresponds to a period predicted to have heavy migration, but the weather was unremarkable. However, the magnitude of migration predicted over those nights was much greater than for September 13-14. Radar detected 371 million, 439 million, and 438 million birds traveling over the United States on the nights of September 28, 29, and 30 respectively, with heavy migration over the New York City area. Perhaps this deluge of migrants, together with light pollution, were sufficient basis for the surge in patients – Wild Bird Fund received 146 collision patients during the next three days.

Overall, we believe that these preliminary findings are consistent with the conclusions of Van Doren (2021), as well as our own prior experience, that heavy migration combined with urban lighting and/or poor weather spells trouble for migrating birds.

Of note, the data discussed in this testimony was manually tabulated, and would need to be analyzed by more rigorous methods before drawing any firm conclusions. In addition, it is possible that because a substantial number of collision patients were brought to Wild Bird Fund by Project Safe Flight volunteers, who are assigned to patrol collision hotspots, there may be a sampling imbalance. The Wild Bird Fund is in the process of seeking a collaboration with researchers to achieve a more formal review of its data.

4. Urban "Lights Out" Programs Can Save Birds

Van Doren (2021), cited above, stated that "over 40,000 dead birds have been recovered from McCormick Place alone since 1978", but their study, which began in 2000, studied only 11,567 fatal collisions. This would mean that in the 22 year period prior to 2000, there were 28,433 collisions, almost 2.5 times as many. What could explain this difference? Chicago began its "Lights Out" Program in 1995. According to Chicago's Field Museum Senior Conservation Ecologist Douglas Stotz, the benefit was even greater – he maintains that since Lights Out started, fatal collisions at McCormick have decreased by 80 percent (Sean Keenehan, "Building a Bird-Safe Chicago", Urban Nature, WTTW (Chicago PBS), https://interactive.wttw.com/urbannature/building-bird-safe-city#!/)

Today, the City of Chicago proudly reports:

> "Since 1995, Chicago's tall buildings in the Loop have served as an example to the nation as they save 10,000 birds' lives annually by participating in the Lights Out program. In addition to saving migratory birds, building owners have realized direct benefits, including decreased energy and maintenance costs."

(https://www.chicago.gov/city/en/progs/env/lights_out_chicago.html)

II. Conclusion

Scientists tell us that migrating birds are drawn to light and that reducing artificial light at night should reduce collision mortality. Wild Bird Fund's own, "on the ground" experience, in addition to witnessing the legions of mortally wounded migrant birds brought to our door, stands with the scientists. So do the reports from Chicago, which tell us that their Lights Out program has saved tens of thousands of birds. Wild Bird Fund believes that the proposed legislation, Intros. Nos. 0265-2018; 0271-2018; 0274-2018; and 2460-202 (the last regarding enforceability) should be passed into law in order to reduce the number of migrating birds entering our area and consequently decrease mortality stemming from bird/building collisions.

We would respectfully suggest that the scope of the legislation be expanded to, first, expressly include restrictions on interior lighting. To reprise, Van Doren (2021) found that halving the area of (interior) lit windows reduced collisions by 6 - or 11-fold depending on the season. Any concerns about safety, scope or accommodation of night-time workers could be addressed, for example, by limiting scope to apply to unnecessary lighting, interior lighting which radiates outside the building, interior lighting adjacent to an unshaded window, or similar formulations, or by requiring the use, for example, of lights activated by motion detectors, or, as suggested by Van Doren (2021), automated window blinds which close during periods of increased collision risk. Second, we would respectfully suggest that the scope be amended to include not only buildings owned by the City, but also buildings which are leased by the City. Finally, we would suggest that the legislation be extended to impose the same requirements as a condition for receiving a grant from the City above a set threshold amount.

TESTIMONY of RITAMARY A. McMAHON

for the WILD BIRD FUND, INC.

at the

Meeting of the New York City Council Committee on Environmental Protection

in support of

Int. 0265-2018; 0271-2018; 0274-2018; and 2460-2021

December 1, 2021

* * * * * *

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I. TESTIMONY

A. Summary

Each year, during the spring and, especially, the fall migration seasons, the Wild Bird Fund receives hundreds of avian patients that have collided with buildings. These are birds who have struck walls or windows in flight and then fallen, to lie on the cold ground or pavement until they were fortunate enough to be rescued by caring New Yorkers. These bird's injuries are often grievous and mortality is high. The mission of our organization is to help these injured birds and also to educate the public toward protecting and conserving wildlife.

Based on the scientific evidence, birds are attracted to light. It is believed that nocturnally migrating birds are drawn into brightly lit cities, where, trapped in a complex and unfamiliar landscape, they are injured or killed as they enter or try to leave. Indeed, looking at the locations where our collision patients are found, a disproportionate number come from the brighter lit, commercial areas of New York.

Other cities, by implementing "Lights Out" policies, have decreased bird/building collisions. We are presenting this testimony in the hopes that the City Council will be moved to pass legislation that reduces night time illumination, especially in commercial areas and during migration season, and specifically, Int. 0265-2018; 0271-2018; 0274-2018; and 2460-2021. We believe that decreasing the amount of light emanating from New York City at night will reduce the number of birds entering our area and consequently reduce the mortality stemming from bird/building collisions.

B. Oral Testimony

The following statement was made at the Meeting of the New York City Council Committee on Environmental Protection on December 1, 2021:

I am Rita McMahon, testifying today as Co-founder and Director of the Wild Bird Fund, New York City's only wildlife rehabilitation center.

Every spring and fall, compassionate New Yorkers bring us migrating birds that have collided with a building or window. These birds suffer from double concussions. First they strike the building, then they fall to the pavement below.

This spring we admitted 232 window-strike patients, and so far this fall, 900 – more than 1000 patients. Our thousand-plus birds are only a tiny fraction of the actual number of window-strike casualties in New York City each year. And our patients are the lucky ones who did not die immediately upon impact, but many of them are gravely injured and only about half will be released to continue their journeys.

Most birds migrate at night. Millions of birds pass through the skies above us each spring and autumn. Three to six million fly over New York City. Scientists tell us they are attracted to light and thus birds are drawn into the canyons of New York City at night by its bright lights. They come here to rest and feed. Some strike buildings on the way in, some on the way out.

We keep records of where each of our patients is found. I would like to share some of our preliminary observations with the Council. For all of New York City, three-quarters of bird strikes occur in Manhattan, the most brightly lit borough. About twice as many of our Manhattan patients this year were found in downtown and midtown, the parts of town more brightly lit at night, as compared to above 57th street.

Finally, a disproportionate number of our collision patients are juvenile birds. These are first-time migrators who need to look for cues – like light – to guide them on their way.

Birds have migrated down the Eastern seaboard for centuries – today's collision victims are the consequence of the city we humans have built. We should do what we can to reduce their danger. Wild Bird Fund urges the City Council to approve Introduced Bills 265, 271,274, and 2460 because, by decreasing nighttime illumination, these bills should reduce the number of migratory bird casualties.

C. Written Testimony

1. Birds Are Attracted To Light

To study the effect of artificial light at night on migrating birds, scientists observed birds in the vicinity of the powerful beams of New York City's annual "Tribute in Light" over a 7-year period. The Tribute provided the opportunity to test whether birds behaved differently over intervals when the beams were switched on or off. The results are published in Van Doren, B., Horton, K., Dokter, A., Klinck, H., Elbin, S., and Farnsworth, A., (2017), "High-intensity urban light installation dramatically alters nocturnal bird migration," *Proc. Natl. Acad. Sci. U.S.A.* 114(42):11175-11180. The researchers estimate that their study involved about 1.1 million migrating birds over the 7-year period.

They found that when the beams were illuminated, birds flying through the area slowed their speed and tended to fly in circles around the beams, resulting in crowding of birds around the Tribute. The birds appeared disoriented. When the beams were turned off, this aberrant behavior disappeared almost immediately and the birds dispersed and presumably went along their way. The effect of the beams on bird behavior occurred under different visibility conditions and appeared to reach altitudes up to 4 km. The authors state that these observations "corroborate previous findings that birds shift direction and fly more slowly and erratically in the presence of [artificial light at night]", citing nine other journal articles. They suggest that "selective removal of light during nights with substantial bird migration is a viable strategy for minimizing potentially fatal interactions among [artificial light at night], structures, and birds."

2. Bird/Building Collisions Are A Serious Problem in New York City

According to New York City Audubon research, between 90,000 and 230,000 migrating birds are killed each year by building collisions. At Wild Bird Fund, we see only a small portion of these victims, but collision patients represent a large percentage of our annual avian patients; about 15 percent of all birds, about 20 percent of all injured adult birds. Last year, 1186 of 7464 birds admitted to Wild Bird Fund were collision patients (16%) and this year, of our 8650 avian patients to date, 1188 were victims of collisions (14%). We do our best to help them recover – administer anti-inflammatory medications, splint broken bones. Some are gravely impacted with serious brain injuries, damaged eyes, wings that will never fly again, and there is little we can do.

To date, only 448 of the 1188 collision victims have been released back into the wild. The best way to lessen the death toll is to avoid collisions happening in the first place.

3. Decreasing Night -Time Illumination Can Reduce Collisions

Researchers reviewed two decades of bird collision data at McCormick place, a convention center near Chicago, located on the shores of Lake Michigan and historically a hotspot for bird collisions. As reported in Van Doren, B., Willard, D., Hennen, M., Horton, K., Stuber, E., Sheldon, D., Sivakumar, A., Wang, J., Farnsworth, A., and Winger, B., (2021), "Drivers of fatal bird collisions in an urban center," Proc. Natl. Acad. Sci. U.S.A. 118(24):e2101666118 ("Van Doren 2021"), the scientists found that the best predictors of collisions were magnitude of nocturnal migration, wind conditions, and building light output. They monitored the collisions at individual window bays, and found that there were about 4 times more collisions at lit windows. They estimated that if the total area of windows lit at night were halved, collisions would decrease by 11-fold in the spring and 6-fold in the autumn. The authors state "[a]lthough our research focuses on a single site, our findings have global implications for reducing or eliminating a critically important cause of bird mortality."

4. More Collision Patients Come from Brighter Parts of Town

After witnessing many migration seasons, we at Wild Bird Fund had a sense that we knew where the collision hotspots in Manhattan were – midtown, around brightly lit Times Square, the World Trade Center complex (79 out of 899 collision patients this autumn, 9 percent), or what might be the NYC version of McCormick Place, Brookfield Place (92 out of 899 patients, 10 percent). However, we were interested to see whether there was a more general pattern for collisions. Using a database of our patient records which includes where each patient was found, we tabulated the number of Fall 2021 collision patients found downtown (at or below 20th Street), midtown (between 21st and 57th Streets), uptown (above 57th Street), or outside Manhattan. We looked at 891 consecutive records from of the fall migration, August 15, 2021 through November 25, 2021, where 839 contained the relevant information.

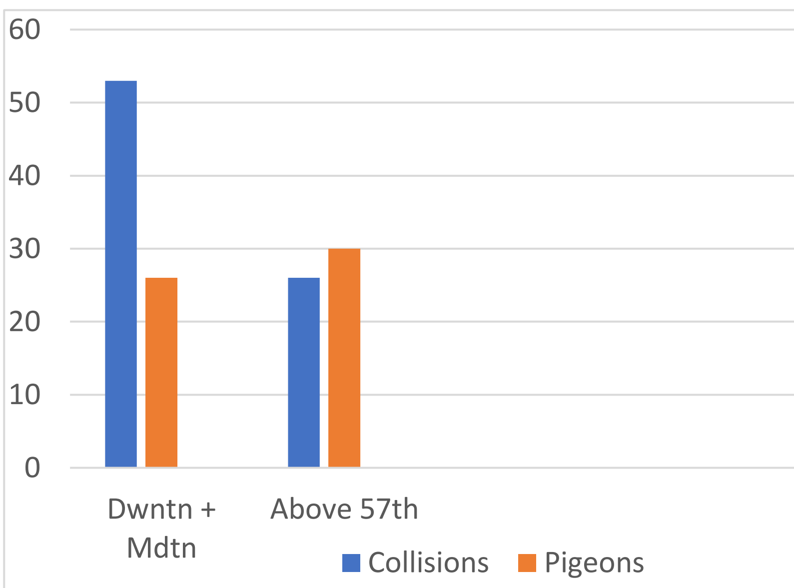
For comparison of location incidence, we needed a ubiquitous species of bird in great enough numbers that is found everywhere our collision patients come from. Pigeons comprise about half of our patient load and are brought to us in a steady stream all year round from every borough. Thus we had non-migratory birds who paralleled collision patients by locale. Because weather could impact whether people brought patients in from other parts of town (bad weather could deter people from travelling far), data over the same time period (September 15 to October 15, the midst of fall migration) was used. We looked at records for 400 consecutive pigeon admissions of which 360 contained the relevant location information. Table 1 below shows the raw data results.

Table 1

Patient	Downtown	Midtown	Uptown	Not Manhattan	Total
Collisions	274 (33%)	174 (21%)	217 (26%)	174 (21%)	839
Pigeons	41 (11%)	61 (17%)	107 (30%)	151 (42%)	360

This data shows that proportionally many more collision victims, relative to pigeons, are found downtown, and many more pigeons are brought in from the outer boroughs. Considering the night skyline of Manhattan, it is apparent that the area south of 57th Street is the more commercial and more brightly lit area. The total proportion of collision patients from downtown and midtown (54%) is much greater than the proportion of pigeons coming from both areas (28%) (Figure 1, below).

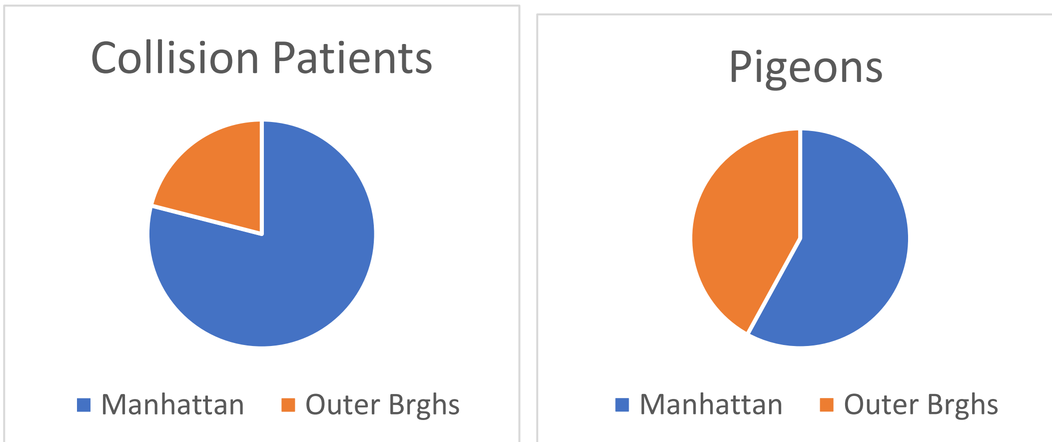
Figure 1



More collision patients come from downtown + midtown than from above 57th street – percentages.

There are more collision patients coming from the brighter parts of town – as is also reflected by the proportions of collision patients and pigeons originating in brighter Manhattan (Figure 2, below).

Figure 2



Fewer collision patients come from the outer boroughs

We also wanted to see where one particular migrant, the American Woodcock, a frequent collision patient, was found. To date this year, we have received 129 woodcock patients, about 10% of all collision patients. These shy birds, which look like a cross between a partridge and a sandpiper, do not fare well. The initial collision and fall most often damages their protuberant eyes, their long beak is often bloodied or broken, and they sometimes damage themselves further out of fear while being brought to us. Once safely at Wild Bird Fund, they are reluctant to eat, and, to keep them from banging their heads against a ceiling and encourage feeding, we keep them in small nylon tents with dirt and earthworms on the bottom. Table 2, which is based on data for autumn 2021, shows that this difficult patient – for whom survival rates are relatively low (only 28 out of 120 birds last year), has a tendency to fly into midtown. This is roughly consistent with last autumn's tally, where 64% of the woodcock patients were found in midtown.

Table 2

	Downtown	Midtown	Uptown	Total
American Woodcock	13 (19%)	54 (77%)	3 (4%)	70

The data discussed above was manually tabulated, and so needs to be analyzed by more rigorous methods. In addition, it is possible that because a substantial number of collision patients were brought to Wild Bird Fund by Project Safe Flight volunteers, who are assigned to patrol collision hotspots, there may be a sampling irregularity. The Wild Bird Fund is in the process of seeking a collaboration with researchers to achieve a more formal review of its data.

Notwithstanding these issues, however, we believe that the magnitude of differences between collision versus non-collision patients suggests that the collision patients were drawn to brighter areas of New York City, which would be consistent with scientific reports that migrating birds are drawn to light.

5. More Collision Patients Are Juveniles

Finally, we would note that a disproportionate number of our collision patients are juvenile birds, approximately one third, whereas the proportion of juvenile birds among all patients is otherwise closer to one fifth. The proportion of juveniles varies from species to species. One striking example is the Yellow-Bellied Sapsucker, a pretty member of the woodpecker family who migrates through New York City beginning in mid-September. First the adults come through. This autumn, we received five (5) consecutive adult Yellow-Bellied Sapsuckers before September 20th. After that, with one (1) exception, the next forty-eight (48) Yellow-Bellied Sapsucker collision patients were all juveniles. The juveniles have a high mortality rate, and only thirteen (13) of those forty-eight birds survived to be released. While we cannot know for certain, it seems plausible that this predominance of juveniles reflects inexperienced birds losing their way, perhaps being misdirected into the city. While there were slightly more birds found below 57th Street than above, the numbers are much lower than those used in the general analysis above and more data should be assembled before attempting analysis.

6. "Lights Out" Initiative is Important to Wild Bird Fund

Each year, the Wild Bird Fund witnesses the tragedy of migrating birds stopped dead by New York City buildings. Although we have encouraged "lights out" informally for a long time, this year we decided to step up our efforts. With enthusiastic approval from our Board, we joined a coalition led by Village Independent Democrats and signed a joint letter to the City

Council urging support for Intros. 265, 271 and 274. With cooperation from New York City Audubon, we initiated our own “Bird-Saver” campaign with much social media fanfare, provided links to helpful steps citizens can take to reduce bird collisions, turning off unnecessary lights chief among them, and provided posters and flyers to the public with slogans “Birds on the Way Tonight! Lights Off, Shades Down”, “Migration Alert - Lights Off or its Curtains for Birds” and “Every Window Makes a Difference.” People posted these in building lobbies, in internet forums, even at farmers markets. We provided postcards for people to reach out to their City Council representatives encouraging them to support Intros. 265, 271 and 274 and other bird-friendly legislation. We highlighted Bird-Savers at our “Flock to the Block” reception this fall. All this activity underlines the importance Wild Bird attaches to reducing artificial light pollution, and also demonstrates that New Yorkers want our City to be more bird-friendly and safe.

II. Conclusion

In view of scientific evidence that migrating birds are drawn to light and that reducing artificial light at night is a recommended step toward reducing collision mortality, together with Wild Bird Fund’s own observations that more collision patients tend to come from brighter, more commercial, parts of town or are juveniles susceptible to misdirection, we believe that the proposed legislation, Int. Nos. 0265-2018; 0271-2018; 0274-2018; and 2460-2021, should be passed into law to reduce the number of migrating birds entering our area and consequently avoid mortality stemming from bird/building collisions. We would respectfully suggest that the scope of the legislation be expanded to (1) expressly include restrictions on indoor light (Van Doren 2021 found that halving the area of (interior) lit windows on their study building reduced collisions by 6 - or 11-fold depending on the season); and (2) extend the reach of city-controlled buildings to include buildings leased by the city. As to the former and concerns about safety, scope or accommodation of night-time workers, the legislation could, for example, refer to interior-lit windows where the glazing is not bird-safe, unnecessary interior lighting, interior lighting which radiates outside the building, or a similar formulation. Further, the legislation could contemplate control of interior lighting by motion-activated sensors so that light is generated, and directed, as needed.

RE: **Support for Intros 274,271, 265**

FROM **Denise Kelly, NYC Resident, "Lights Out" Coalition Member, President, Avian Welfare Coalition**

I am a New York City resident, Member of the ***"Lights Out" Coalition***, and President of the Avian Welfare Coalition (AWC), http://www.avianwelfare.org an alliance dedicated to the protection and welfare of captive birds.

I write as a concerned bird advocate and on behalf of the Avian Welfare Coalition **to urge that you pass Intros 274,271,265, 3 bills which combined will help to protect Migratory Birds from flying into buildings and prevent bird fatalities by reducing excessive nighttime lighting.**

AWC fully supports any measure that will reduce the number of birds colliding with illuminated structures during bird migrations and provide more safety for migratory birds and resident birds of NYC.

Having witnessed hundreds of bird fatalities as a result of strikes with glass, particularly during bird migrations, I can attest to the severity of the problem. I've encountered numerous situations where bloodied, injured birds lying on city streets that were in need of immediate medical care as a result of colliding with reflective glass structures, and I've personally taken birds to rehabilitation centers for treatment.

These instances are very disturbing, and they also pose a threat to the survival of many bird species that are already experiencing significant population declines.

Most frustrating, however, is knowing that these unnecessary bird injuries and fatalities could be mitigated if only the right preventive measures were in place to safeguard birds on their passage over our skies.

With increasing heights of new building construction in New York City, it is more necessary than ever to implement measures that will help alleviate the number of avian injuries and deaths by restricting excessive lighting at night during peak migration seasons. Not only will these measures help birds, they will also lesson the negative impacts of light pollution on our environment.

Many cities, including San Francisco, Detroit, Minneapolis/St. Paul, Portland, and Boston, have already adopted progressive ***"Lights Out"*** Initiatives. Additionally, legislation to address this problem is pending in several states and at the federal level.

Lastly, birds serve a vitally important role to maintaining healthy thriving ecosystems worldwide, which benefits all living beings.

For these reasons and more, **I urge you to vote in support of all three Intros - 274,271, and 265 -** so that New York City can be among the leaders in adopting ***"Lights Out"*** standards that will reduce excessive lighting to reduce bird strikes and make our city 's skies safer for birds. Thank you.

HEARING TESTIMONY FROM
THE BUILDING OWNERS AND MANAGERS ASSOCIATION OF GREATER NEW YORK ON INT. NO. 265, A LOCAL LAW TO AMEND THE ADMINISTRATIVE CODE OF NEW YORK, IN RELATION TO LIMITING NIGHTTIME ILLUMINATION IN CERTAIN BUILDINGS

The Building Owners and Manager of Greater New York (BOMA New York) represents more than 750 owners, property managers, and building professionals who either own or manage 400 million square feet of commercial space. We are responsible for the safety of over 3 million tenants, generate more than $1.5 billion in tax revenue, and oversee annual budgets of more than $4 billion. BOMA New York is the largest Association in the BOMA International Federation, the world's largest trade organization.

BOMA New York finds that that this legislation is unnecessary, fails to take into consideration how buildings operate, and would be impossible to enforce in its current form. Therefore, for the following reasons, we oppose Int. No. 265.

First, using unnecessary electricity carries a cost, and building managers at BOMA New York's buildings are mindful of costs and operate buildings efficiently. In addition, Local Law 97 mandates will increase the costs of using excess electricity, in the form of fines, if buildings cannot cut their emissions.Therefore it is not accurate to say that unnecessary illumination is a significant problem in our buildings.

Second, controls such as motion sensors are required by code for lights in renovated spaces, and much commercial office space has steady turnover and so will quickly add these technologies. Others use these devices regardless of requirements in order to save money and conserve electricity. Sensors are a very effective way to turn off non-emergency lights in unoccupied parts of buildings. In addition, highly efficient lights, required and/or in widespread use, reduce the impact of nighttime lighting. This can include the use of LED lights for exterior lighting, which use very little electricity.

Third, certain lights, especially along paths of egress, which can include significant parts of commercial real estate, must be left on at all time for safety reasons. The bill exempts lights that must otherwise be legally left on, but these conflicting requirements could complicate building operations and would certainly make enforcement even more difficult.

Fourth, many buildings in New York City are used at night, and even when they are not, they are open to use by tenants and must be operated accordingly. When one BOMA New York member, Boston Properties, surveyed their buildings in an effort to investigate the possibility of reducing nighttime illumination to save money and energy, they found extensive use of their buildings throughout the night. These buildings also have security, cleaning crews, and often other staff throughout the night.

Even buildings that do not have significant usage at night still must be prepared to service tenants, as most, if not all, commercial office space is available 24/7 for tenants to access. It is simply impossible to know which areas of the building are occupied during any given time of night. Tennant use, as well as nighttime use by building staff and service providers, also requires the illumination of common areas such as lobbys.

Fifth, this bill would be impossible to enforce. There would be no easy way for whichever agency is given responsibility to enforce the bill to know if anyone is in a building, and searching a building is not only impracticable and time-consuming, it raises other thorny access issues.

Last, outside lighting is widely held to contribute to public safety and to help prevent illegal activities on the streets and sidewalks of the City. Therefore it is beneficial to the city as well as to the buildings themselves.

For these and other reasons, we believe this bill would not achieve significant energy savings and would create difficulties for building managers and enforcement agencies. Therefore, we oppose Int. No. 265.

TheCornellLab of Ornithology

3 December 2021

To Chairman Gennaro, Councilwoman Rosenthal, and all Council and committee members,
In addition to testimony I provided during the 11am NYC City Council Meeting of the Committee for Environmental Protection on 1 December 2021 by Zoom in full support of Intros 265, 271, and 274 to eliminate light pollution from buildings in New York City to protect migrating birds, I offer this written testimony to support, to clarify, and to document why such efforts will be invaluable, effective, and essential for making New York a better, greener, and bird friendlier city. Thank you for the opportunity to testify and to provide you my expert opinion based on published scientific research I have led or on which I have collaborated. With documentation in such literature, you can be assured that your passage of these bills would be support by data and the best scientific approaches available to provide information for decision making and support.

Artificial light at night is a novel stimulus in the evolutionary history of nocturnal animals. Light pollution significantly alters these organisms' behaviors, from migration to foraging to vocal communication. Nocturnally migrating birds are particularly susceptible to artificial light because of adaptations and requirements for navigating and orienting in darkness, relying on cues for navigation and orientation that artificial light at night can impair. Billions of nocturnally migrating birds move increasingly through heavily photopolluted skies. Such impairments include attraction and disorientation, with consequences including predation, detour and delay in migration timing and location, and at worst, death.

To outline this story for the purposes of this testimony, here are a collection of points and some respective, supporting, peer-reviewed citations and their abstracts.

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1. Bird populations in the US and Canada have declined precipitously in the last 50 years, with staggering losses estimated to be 3 billion birds, approximately 29% of the 1970 abundance. Greater than 80% of the losses represent migratory birds.
   - Rosenberg, K.V., Dokter, A.M., Blancher, P.J., Sauer, J.R., Smith, A.C., Smith, P.A., Stanton, J.C., Panjabi, A., Helft, L., Parr, M. and Marra, P.P., 2019. Decline of the North American avifauna. *Science*, *366*(6461), pp.120-124.

"Species extinctions have defined the global biodiversity crisis, but extinction begins with loss in abundance of individuals that can result in compositional and functional changes of ecosystems. Using multiple and independent monitoring networks, we report population losses across much of the North American avifauna over 48 years, including once-common species and from most biomes. Integration of range-wide population trajectories and size estimates indicates a net loss approaching 3 billion birds, or 29% of 1970 abundance. A continent-wide weather radar network also reveals a similarly steep decline in biomass passage of migrating birds over a recent 10-year period. This loss of bird abundance signals an urgent need to address threats to avert future avifaunal collapse and associated loss of ecosystem integrity, function, and services."

"Today, monitoring data suggest that avian declines will likely continue without targeted conservation action, triggering additional endangered species listings at tremendous financial and social cost. Moreover, because birds provide numerous benefits to ecosystems (e.g., seed dispersal, pollination, pest control) and economies [47 million people spend U.S.$9.3 billion per year through bird-related activities in the United States, their population reductions and possible extinctions will have severe direct and indirect consequences."

2. An important source of these losses is collisions with structures, represent up to a billion birds annually, many of which are migratory species and many of which occur during migration. Note, also, related to the discussion of potential New York City local laws is that cats outdoors is the greatest cause of bird mortality, highlighting the importance in the future of keeping cats indoors.

- Loss, S.R., Will, T. and Marra, P.P., 2015. Direct mortality of birds from anthropogenic causes. *Annual Review of Ecology, Evolution, and Systematics*, *46*, pp.99-120.

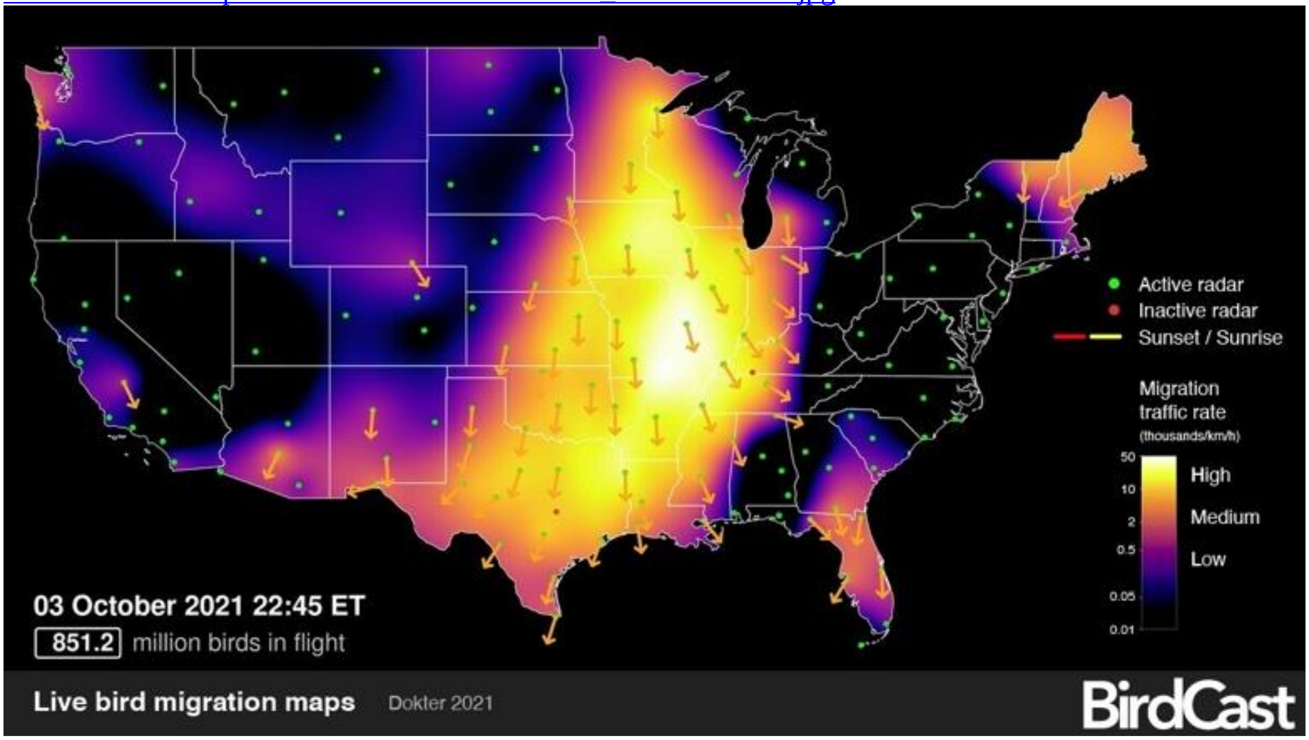
"Understanding and reversing the widespread population declines of birds re- quire estimating the magnitude of all mortality sources. Numerous anthropogenic mortality sources directly kill birds. Cause-specific annual mortality in the United States varies from billions (cat predation) to hundreds of millions (building and automobile collisions), tens of millions (power line collisions), millions (power line electrocutions, communication tower collisions), and hundreds of thousands (wind turbine collisions). However, great uncertainty exists about the independent and cumulative impacts of this mortality on avian populations. To facilitate this understanding, additional research is needed to estimate mortality for individual bird species and affected populations, to sample mortality throughout the annual cycle to inform full life-cycle population models, and to develop models that clarify the degree to which multiple mortality sources are additive or compensatory. We review sources of direct anthropogenic mortality in relation to the fundamental ecological objective of disentangling how mortality sources affect animal populations."

These losses from collisions in New York City are estimated to be nearly ¼ million birds annually, an estimate that is likely conservative and underrepresenting the true cost in avian life.

- Parkins, K.L., Elbin, S.B. and Barnes, E., 2015. Light, glass, and bird—building collisions in an urban park. *Northeastern Naturalist*, *22*(1), pp.84-94.

"NYC Audubon has extrapolated PSF data collected from 1997 through 2009 to estimate the average annual mortality in New York City from collisions is approximately 90,000 birds. Using our determined mean carcass persistence rate, we calculated a multiplier of 2.70 to adjust collision estimates. Using this multiplier, the estimated number of collisions in NYC could be as high as 243,000 birds per year."

3. Enormous numbers of birds migrate at night. In the continental US during peak migration periods, these numbers may reach more than **850 million birds on a single night**, as evidenced by mosaic imagery below from the BirdCast project depicting bird migration from weather surveillance radar data on the night of 3 October 2021, 1045pm ET, https://birdcast.info/migration-tools/live-migration-maps/; https://s3.amazonaws.com/is-birdcast-observed-prod/mosaic/2021/10/04/mosaic_202110040245.jpg



- Dokter, A.M., Farnsworth, A., Fink, D., Ruiz-Gutierrez, V., Hochachka, W.M., La Sorte, F.A., Robinson, O.J., Rosenberg, K.V. and Kelling, S., 2018. Seasonal abundance and survival of North America's migratory avifauna determined by weather radar. Nature ecology & evolution, 2(10), pp.1603-1609.
- https://birdcast.info/news/research-seasonal-abundance-and-survival-of-north-americas-migratory-avifauna-determined-by-weather-radar/

"Avian migration is one of Earth's largest processes of biomass transport, involving billions of birds. We estimated continental biomass flows of nocturnal avian migrants across the contiguous United States using a network of 143 weather radars. We show that, relative to biomass leaving in autumn, proportionally more biomass returned in spring across the southern United States than across the northern United States. Neotropical migrants apparently achieved higher survival during the combined migration and non-breeding period, despite an average three- to fourfold longer migration distance, compared with a more northern assemblage of mostly temperate-wintering migrants. Additional mortality expected with longer migration distances was probably offset by high survival in the (sub)tropics. Nearctic–Neotropical migrants relying on a 'higher survivorship' life-history strategy may be particularly sensitive to variations in survival on the overwintering grounds, highlighting the need to identify and conserve important non-breeding habitats."

4. Exposure to light is significant for migrating birds, globally, and across the United States.

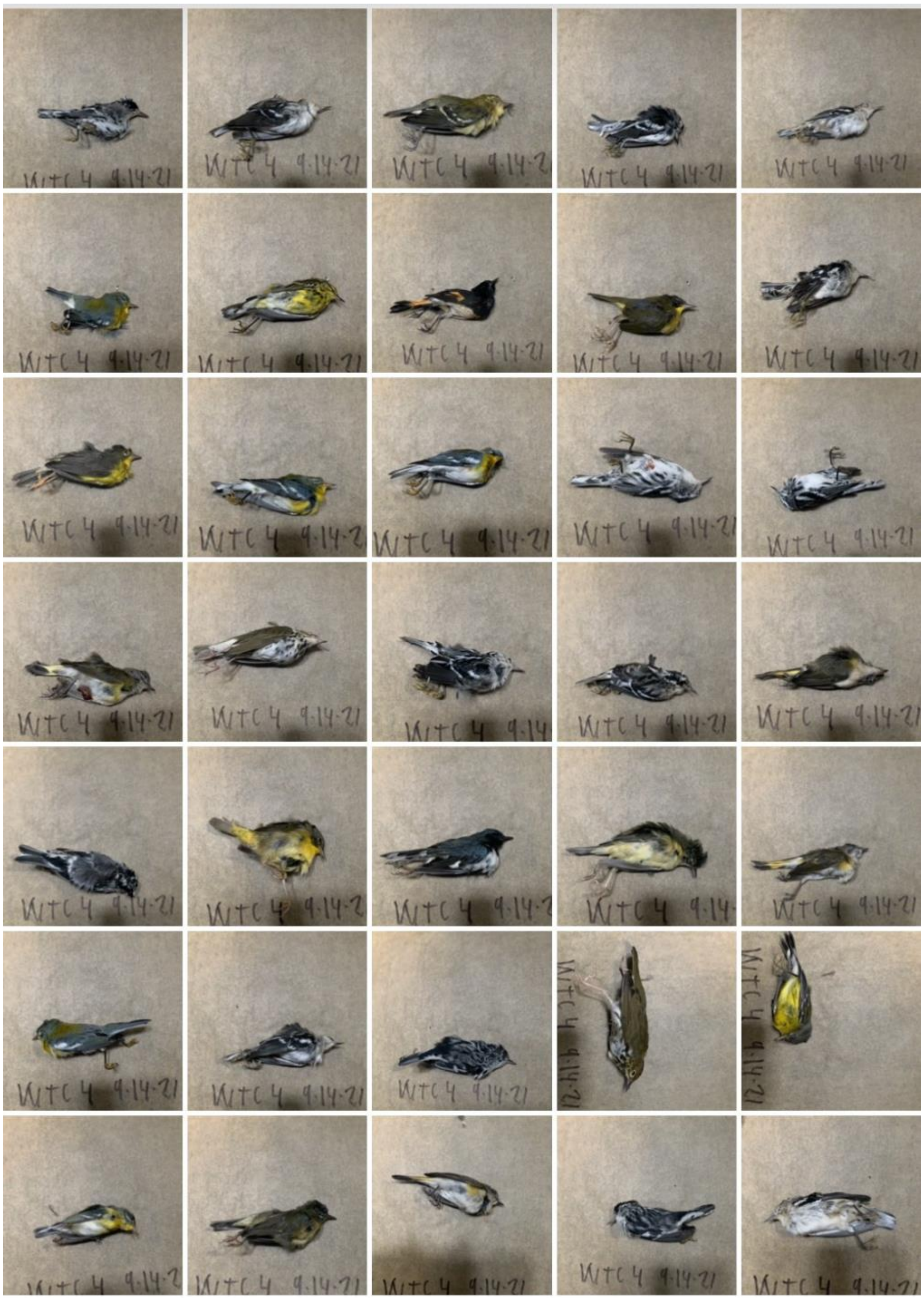
- Cabrera-Cruz, S.A., Smolinsky, J.A. and Buler, J.J., 2018. Light pollution is greatest within migration passage areas for nocturnally-migrating birds around the world. *Scientific reports*, *8*(1), pp.1-8.
- Horton, K.G., Nilsson, C., Van Doren, B.M., La Sorte, F.A., Dokter, A.M. and Farnsworth, A., 2019. Bright lights in the big cities: migratory birds' exposure to artificial light. Frontiers in Ecology and the Environment, 17(4), pp.209-214.

New York City consistently ranks in the top 10 of the 125 most populous US cities for risk in spring and fall of exposing birds to light pollution.

5. Light attracts and disorients nocturnally migrating birds. Numerous studies highlight these behavioral responses, including attraction and disorientation (e.g., aggregation, circling) and disproportionate occurrence of birds in urban areas because of these behaviors, as well as enormous numbers of dead birds (see photograph below from Melissa Breyer, taken on morning of 14 September 2021 after heavy casualties at the World Trade Center building complex):

- Allen, J.A., 1880. Destruction of birds by light-houses. Bulletin of the Nuttall Ornithological Club, 5(3), pp.131-138.
- Gastman, E.A., 1886. Birds killed by electric light towers at Decatur, Ill. *American Naturalist*, *20*(11), p.981.
- Cochran, W.W. and Graber, R.R., 1958. Attraction of nocturnal migrants by lights on a television tower. *The Wilson Bulletin*, *70*(4), pp.378-380.
- Evans Ogden, L.J., 1996. Collision course: the hazards of lighted structures and windows to migrating birds. *Fatal Light Awareness Program (FLAP)*, p.3.
- Longcore, T. and Rich, C., 2004. Ecological light pollution. *Frontiers in Ecology and the Environment*, *2*(4), pp.191-198.
- Gauthreaux Jr, S.A., Belser, C.G., Rich, C. and Longcore, T., 2006. Effects of artificial night lighting on migrating birds. *Ecological consequences of artificial night lighting*, pp.67-93.
- Spoelstra, K. and Visser, M.E., 2013. The impact of artificial light on avian ecology. *Avian Urban Ecol*, *4*, pp.21-28.
- La Sorte, F.A., Fink, D., Buler, J.J., Farnsworth, A. and Cabrera-Cruz, S.A., 2017. Seasonal associations with urban light pollution for nocturnally migrating bird populations. *Global Change Biology*, *23*(11), pp.4609-4619.
- McLaren, J.D., Buler, J.J., Schreckengost, T., Smolinsky, J.A., Boone, M., Emiel van Loon, E., Dawson, D.K. and Walters, E.L., 2018. Artificial light at night confounds broad-scale habitat use by migrating birds. *Ecology Letters*, *21*(3), pp.356-364.

- Winger, B.M., Weeks, B.C., Farnsworth, A., Jones, A.W., Hennen, M. and Willard, D.E., 2019. Nocturnal flight-calling behaviour predicts vulnerability to artificial light in migratory birds. *Proceedings of the Royal Society B*, *286*(1900), p.20190364.
- La Sorte, F.A. and Horton, K.G., 2021. Seasonal variation in the effects of artificial light at night on the occurrence of nocturnally migrating birds in urban areas. *Environmental Pollution*, *270*, p.116085.

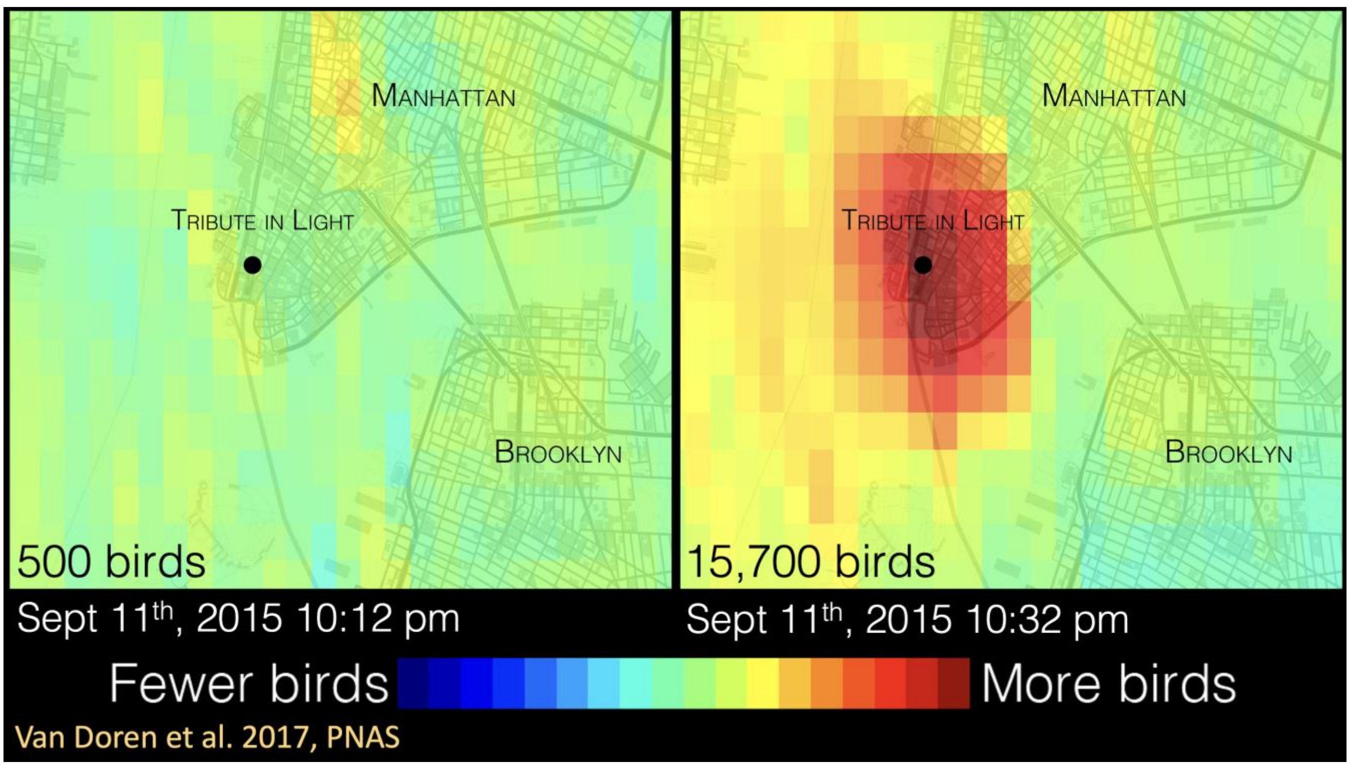


6. In New York City, specifically, turning off exterior lights has dramatic and immediate positive effects in reducing behavioral responses of birds to light and allowing birds to resume typical migratory behaviors.

- Van Doren, B.M., Horton, K.G., Dokter, A.M., Klinck, H., Elbin, S.B. and Farnsworth, A., 2017. High-intensity urban light installation dramatically alters nocturnal bird migration. Proceedings of the National Academy of Sciences, 114(42), pp.11175-11180.

"We have quantified impacts, in New York City specifically, of bright lights on nocturnally migrating birds by monitoring the beams of the National September 11 Memorial & Museum's "Tribute in Light" in New York, quantifying behavioral responses with radar and acoustic sensors and modeling disorientation and attraction with simulations. This single light source induced significant behavioral alterations in birds, even in good visibility (i.e., clear skies without cloud cover) conditions, in the city's heavily photopolluted environment, and to altitudes up to 4 km. We estimate that the installation influenced ≈1.1 million birds during our study period of 7 d over 7 y. When the installation was illuminated, birds aggregated in high densities, decreased flight speeds, followed circular flight paths, and vocalized frequently."

"Bird densities near the Tribute in Light installation exceeded magnitudes 20-100 times greater than surrounding baseline densities during each year's observations (e.g., figure below). However, behavioral disruptions disappeared when lights were extinguished, highlighting removal of light during nights with substantial bird migration is a viable strategy for minimizing potentially fatal interactions among ALAN, structures, and birds. "



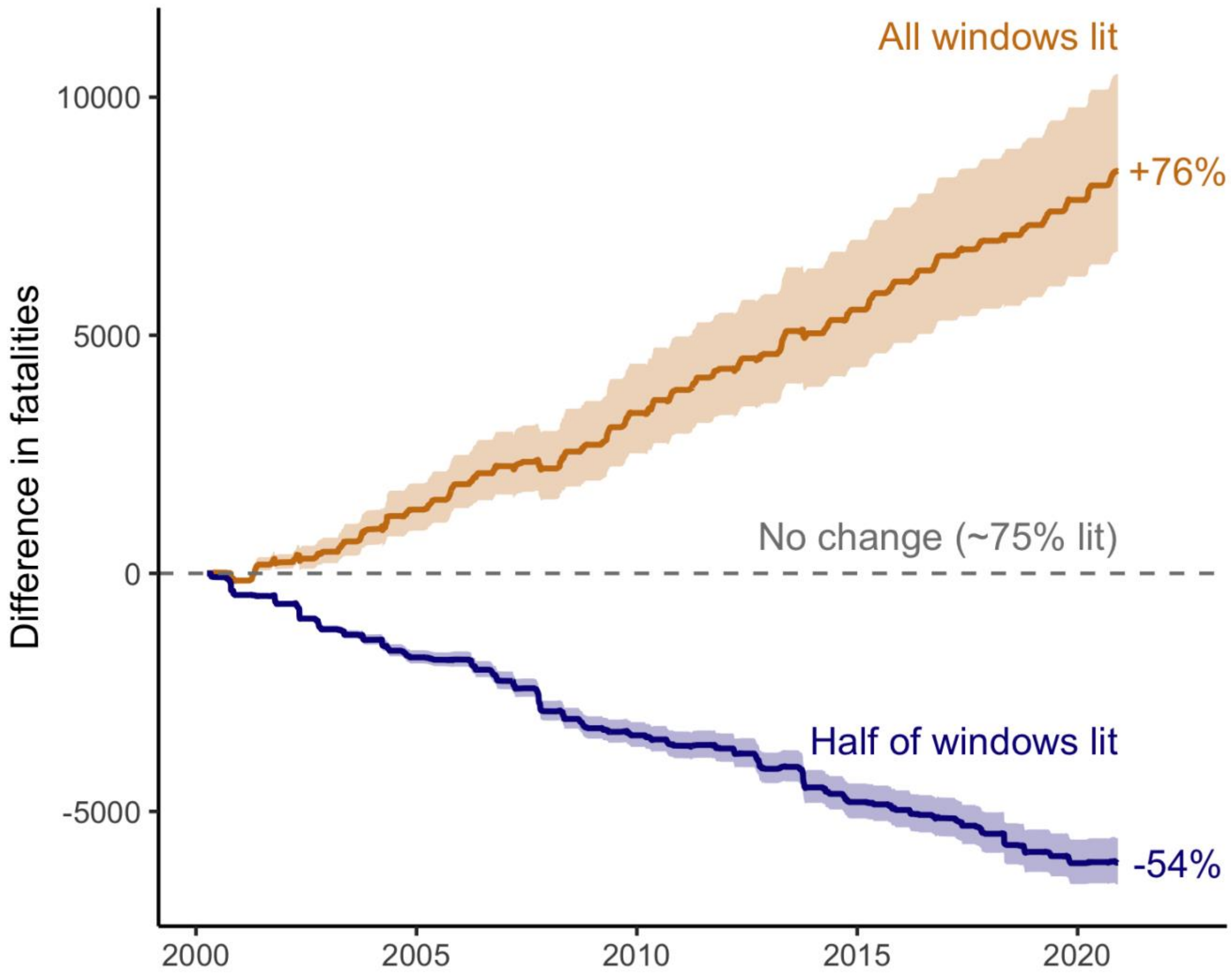
Among other media coverage of this research, the New York Times featured this story on 10 September 2018, "The Deadly Lure of Light."

7. In addition to positive impacts of turning off exterior lights, turning off interior lights has dramatic positive effects.

- Van Doren, B. M., D. E. Willard, M. Hennen, K. G. Horton, E. F. Stuber, D. Sheldon, A. H. Sivakumar, J. Wang, A. Farnsworth, and B. M. Winger (2021). Drivers of fatal bird collisions in an urban center. Proceedings of the National Academy of Sciences 118: e2101666118.

"Collisions with built structures are an important source of bird mortality, killing hundreds of millions of birds annually in North America alone. Nocturnally migrating birds are attracted to and disoriented by artificial lighting, making light pollution an important factor in collision mortality, and there is growing interest in mitigating the impacts of light to protect migrating birds. We use two decades of data to show that migration magnitude, light output, and wind conditions are important predictors of collisions at a large building in Chicago and that decreasing lighted window area could reduce bird mortality by ~60% (see figure below)."

"The greatest mortality occurred when the building was brightly lit during large nocturnal migration events and when winds concentrated birds along the Chicago lakeshore. We estimate that halving lighted window area decreases collision counts by 11x in spring and 6x in fall."



I am pleased to offer this documentation, on which I am pleased to expand if required and also on which I am pleased to offer my support for further interpretation and explanation, and so, too, to act as a resource for the committee and the council should you require scientific expertise regarding bird migration, light pollution, urban aeroecology, and the intersection of these topics in New York City specifically in regard to Intros 264, 271, and 274.

I would also like to highlight that, as part of my testimony during the committee meeting, I went on record as supporting that Intro 274 specifically be modified to include exterior and interior lighting for reduction in New York City buildings. Furthermore, I supported the expansion of terms beyond New York City owned buildings to include New York City leased buildings.

I would also like to add some additional discussion for future reference regarding additional testimony from 1 December 2021 highlighting the importance of dimming, altering color (wavelength, temperature), and shielding in addition to directly extinguishing and removing light. I highlight, specifically, that there are potential compromises that could mitigate adverse impacts to migrating birds from **essential** lighting that might not be covered by the proposed legislation. Such a suite of approaches may prove effective in addressing concerns beyond the scope of Intros 265, 271, and 274 made by the Real Estate Board of New York, which Councilwoman Rosenthal clearly addressed in her responses seeking to clarify that discussions regarding her and her colleague Councilman Brannan's bills receive only discussion relevant to their content.
Regarding this topic, I offer into the written record that approaches to selective removal of essential lighting during periods of peak migration are aspects of operations that we can define with data. For example, the following literature provides a strong, scientifically peer-reviewed background and body of knowledge on which to base such decisions:

- Van Doren, B.M. and Horton, K.G., 2018. A continental system for forecasting bird migration. Science, 361(6407), pp.1115-1118.
- Elmore, J. A., C. S. Riding, K. G. Horton, T. J. O'Connell, A. Farnsworth, and S. R. Loss (2021). Predicting bird-window collisions with weather radar. Journal of Applied Ecology 58:1593–1601.
- Horton, K. G., B. M. Van Doren, H. J. Albers, A. Farnsworth, and D. Sheldon (2021). Near-term ecological forecasting for dynamic aeroconservation of migratory birds. Conservation Biology. https://doi.org/https://doi.org/10.1111/cobi.13740

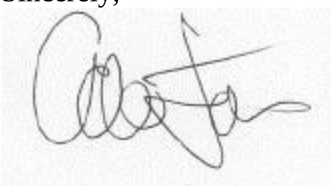
And finally, I offer that the relative ease of reducing light pollution is a simple, positive action that people can and do support. As director of the BirdCast project, I offer into the record the experiences and media coverage of the Lights Out Texas efforts, in which we use these scientific approaches to highlight when and where to extinguish lights at night in Dallas, Houston, and other major metropolitan areas of Texas, and with support of government and public figures (please visit this site, Lights Out Texas and see commentary and support from former First Lady Laura Bush and Texan by Nature).

New York has already begun to make serious strides in reducing bird collisions by adopting bird friendly building designs and taking the next step to reduce operational lighting at night will further help curb collision while acting to save energy and associated costs and minimize light and additional significant pollution. Lighting reductions are an operational decision, and they afford the opportunity for building design and operation in tandem that is energy-conscious and bird-conscientious. Eliminating light pollution is a win for birds, for all other nocturnally active animals, for energy efficiency, for human health, and for experiencing the wonder of the night sky. New York City has a unique opportunity to lead the charge into the 21st century as a forward thinking, bird friendly city that will be a model of global importance for how to enact smart legislation. As a representative for the Cornell Lab of Ornithology, and the director of the BirdCast project, as a long-time birder, and as a New Yorker, I support and urge you to pass Int 0265-2018, "A Local Law to amend the administrative code of the city of New York, in relation to limiting nighttime illumination for certain buildings," Int 0271-2018, "A Local Law to amend the administrative code of the city of New York, in relation to reducing unnecessary illumination in city-owned and city-controlled spaces," and Int 0274-2018, "A Local Law to amend the administrative code of the city of New York, in relation to nighttime illumination during peak avian migration periods."

Please feel free to contact me at af27@cornell.edu or (914) 672-5971 for any clarifications, needs, or expert opinion.

I thank you, all, for your Herculean efforts to move this legislation to its current position!

Sincerely,



Andrew Farnsworth, Ph.D.
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159 Sapsucker Woods Rd., Ithaca, NY 14850 (lab)
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Appendix

The following pages contain the primary, peer-reviewed publications that support and source much of the data I referenced in this written testimony. I can provide further resources including additional published research if needed.

High-intensity urban light installation dramatically alters nocturnal bird migration

Benjamin M. Van Doren[a,b,1], Kyle G. Horton[a,c,d,1], Adriaan M. Dokter[a], Holger Klinck[e], Susan B. Elbin[f], and Andrew Farnsworth[a,2]

[a]Information Science Program, Cornell Lab of Ornithology, Ithaca, NY 14850; [b]Edward Grey Institute, Department of Zoology, University of Oxford, Oxford, OX1 3PS, United Kingdom; [c]Department of Biology, University of Oklahoma, Norman, OK 73019; [d]Oklahoma Biological Survey, University of Oklahoma, Norman, OK 73019; [e]Bioacoustics Research Program, Cornell Lab of Ornithology, Ithaca, NY 14850; and [f]New York City Audubon, New York, NY 10010

Edited by James A. Estes, University of California, Santa Cruz, CA, and approved August 31, 2017 (received for review May 29, 2017)

Billions of nocturnally migrating birds move through increasingly photopolluted skies, relying on cues for navigation and orientation that artificial light at night (ALAN) can impair. However, no studies have quantified avian responses to powerful ground-based light sources in urban areas. We studied effects of ALAN on migrating birds by monitoring the beams of the National September 11 Memorial & Museum's "Tribute in Light" in New York, quantifying behavioral responses with radar and acoustic sensors and modeling disorientation and attraction with simulations. This single light source induced significant behavioral alterations in birds, even in good visibility conditions, in this heavily photopolluted environment, and to altitudes up to 4 km. We estimate that the installation influenced ≈1.1 million birds during our study period of 7 d over 7 y. When the installation was illuminated, birds aggregated in high densities, decreased flight speeds, followed circular flight paths, and vocalized frequently. Simulations revealed a high probability of disorientation and subsequent attraction for nearby birds, and bird densities near the installation exceeded magnitudes 20 times greater than surrounding baseline densities during each year's observations. However, behavioral disruptions disappeared when lights were extinguished, suggesting that selective removal of light during nights with substantial bird migration is a viable strategy for minimizing potentially fatal interactions among ALAN, structures, and birds. Our results also highlight the value of additional studies describing behavioral patterns of nocturnally migrating birds in powerful lights in urban areas as well as conservation implications for such lighting installations.

artificial light | nocturnal migration | remote sensing | radar ornithology | flight calls

The extent of artificial light at night (ALAN) at regional and global scales has increased 5–10% annually in portions of North America and Europe and exponentially in some other regions (1), resulting in sky glow that is often significantly brighter than luminance of the natural sky. ALAN may affect a diverse array of nocturnally active animals, and recent studies have highlighted the need for primary research into these potential impacts (2, 3). The biological effects of anthropogenic light pollution may be especially significant for nocturnally migrating birds (2–6).

Birds engage in seasonal migrations that are often global in distribution and span a broad range of spatial and temporal scales (7, 8). Avian migratory movements are often thought of as feats of endurance; some species undertake days-long, nonstop, transhemispheric flights, while others embark on complex, months-long journeys (9). Failed migration may have detrimental effects at individual and population scales (10, 11). Despite birds' primarily diurnal activity for the majority of the annual cycle, most migratory movements are nocturnal (7, 8), and the numbers of birds that migrate at night are enormous (12, 13). Numerous studies have offered perspectives on factors that govern nocturnal movements (14–18) and insights into adaptations necessary to orient and navigate at night (19, 20).

Visual cues are essential for navigation during migration (21), and ALAN may alter birds' abilities to orient and navigate (22, 23). The avian geomagnetic sense, which provides songbirds with a compass to inform their spatial maps (19, 20, 24), may function with a dependency on frequencies of light, and ALAN may interfere with this dependency (25–28). Impediments to orientation and navigation senses may prove costly for avian migrants, creating new hazards during an already challenging and dynamic period of the annual cycle (29). Additionally, ALAN can alter the ways birds communicate (30) and avoid predation (31).

Accounts of birds' responses to light are numerous in literary and historical anecdotes, peer-reviewed journal articles, and popular media. Mortality at lighted structures has been documented across a wide geographic area and a broad range of species (4, 6, 32–44). It is likely that hundreds of millions of birds die annually from nocturnal collisions with buildings (29), representing a diverse array of migrant species (32, 33). Understanding the causes of these events is paramount; proposed explanations include that birds exhibit phototaxis and experience light-induced disorientation.

Generally, negative impacts of ALAN for birds in flight have been associated with conditions that are already poor for navigation and orientation, such as low cloud ceiling, fog, and stalled or weak frontal boundaries between air masses (34–39, 43, 45–48). Experimental field studies are generally rare (22, 26, 49–51) and offer limited evidence of the extent and intensity of ALAN's effects on nocturnally migrating birds, particularly with respect to

Significance

Artificial light at night is a novel stimulus in the evolutionary history of nocturnal animals. Light pollution can significantly alter these organisms' behaviors, from migration to foraging to vocal communication. Nocturnally migrating birds are particularly susceptible to artificial light because of adaptations and requirements for navigating and orienting in darkness. However, light's effects on in-flight behaviors have not been well quantified, especially in urbanized environments. Here we report that an iconic urban light installation dramatically altered multiple behaviors of nocturnally migrating birds—but these effects disappeared when lights were extinguished. We recommend selective removal of light pollution during nights with substantial bird migration to mitigate negative effects on birds, in particular collisions with lighted structures.

Author contributions: A.F. developed the study, collected visual observations and weather data, and wrote the paper; B.M.V.D. shaped the study, performed statistical analyses, and contributed to writing the paper; K.G.H. analyzed radar data and contributed to writing the paper; B.M.V.D. and K.G.H. generated figures and animations; A.M.D. developed simulations and produced associated figures and text; H.K. performed acoustic energy analysis; H.K. and A.F. analyzed acoustic data; S.B.E. provided bird mortality data, provided coordination, support, and access to the study site.

The authors declare no conflict of interest.

This article is a PNAS Direct Submission.

Data deposition: All visual counts made at Tribute in Light are archived in the eBird database at ebird.org/ebird/hotspot/L1744278.

[1]B.M.V.D. and K.G.H. contributed equally to this work.

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behaviors in clear sky conditions (but see ref. 48) and urbanized (e.g., heavily photopolluted) environments. Understanding the disruptive effects of short-term ALAN (e.g., lighting installations, sporting events) on nocturnal bird migration in urbanized and photopolluted areas and identifying the extents of these effects in clear sky conditions are important conservation priorities.

We took advantage of a unique opportunity to quantify birds' responses to ALAN by monitoring numbers, flight patterns, and vocalizations of birds aloft during alternating periods of illumination and darkness in the powerful light beams of the National September 11 Memorial & Museum's (NSMM's) "Tribute in Light" (TiL) in New York, NY (Fig. 1*A*). First, we quantified densities and flight speeds of aerial migrants near the light installation using data from the KOKX Brookhaven, NY WSR-88D radar station, revealing how numbers of birds and their rates of passage changed in the presence or absence of illumination. Second, we measured birds' vocal activity by recording their in-flight vocalizations, or flight calls, from the base of the installation. Increased flight calling activity in nocturnally migrating birds may indicate disorienting or confusing conditions (30, 52). If nocturnally migrating birds were attracted to and disoriented by the lights, we expected to observe higher densities of birds flying at slower flight speeds and vocalizing more frequently during periods of illumination. Finally, we used a flow model to simulate bird behaviors in ALAN conditions for comparison with observed radar data. These spatiotemporal distribution simulations investigated three important behavioral parameters to explain bird concentrations at the installation: the probability that the lights affected nearby birds, the distance over which the lights affected birds, and whether disoriented birds showed preferred flight directions toward the display. Together, these parameters determined how long birds remained in the illuminated area.

Results

We detected large aggregations of circling birds above the installation under clear sky conditions during periods of illumination (Figs. 1 *B* and *C* and 2*A*, Movies S1–S3, and *SI Appendix*, Fig. S1). By summing the differences between bird numbers within 5 km of the installation and the number expected in that area given baseline densities, we estimate that ≈1.1 million birds (95% CI: 0.6–1.6 million) were affected by this single light source during our study period of seven nights over 7 y (*SI Appendix*, Fig. S2). The numbers of birds affected varied by year, in part due to variation in the magnitude of migratory passage through the surrounding area on the study night (*SI Appendix*, Fig. S3), but all years showed strong increases in bird density with decreasing distance to the light source (Fig. 3 and *SI Appendix*, Fig. S4*A*). Under illumination, peak bird densities near the installation reached magnitudes 20 times greater than the surrounding baseline during all 7 y (*SI Appendix*, Fig. S5*A*), where we defined baseline as the mean density in the area 2–20 km from the site. Peak bird densities exceeded 60 times baseline in 5 of the 7 y and 150 times baseline in 3 y (2008, 2012, and 2013), but peak densities never exceeded 13 times baseline in the absence of illumination (*SI Appendix*, Fig. S5*A*). Vocal activity beneath the lights was intense during periods of aggregation (Fig. 2*C* and *SI Appendix*, Fig. S6). Bird densities, flight speeds, and vocal activities all varied closely with illumination (Fig. 2). Removal of illumination resulted in rapid changes in nocturnal migration behaviors, with birds dispersing, increasing flight speeds, decreasing calling activity, and moving away from the site in a matter of minutes (Fig. 3 *C* and *D*).

We found a strong effect of illumination on the maximum standardized peak bird density and the maximum number of birds detected within 500 m of the installation during each period of darkness and adjacent periods of illumination. Considering the 0.5° radar elevation angle, maximum standardized bird densities were 14 times greater when the light display was illuminated ($t = 5.70$, $P < 0.0001$). Maximum bird numbers averaged 3.4 times greater during lit periods ($t = 3.89$, $P = 0.0003$). Remarkably, these effects were also present at high altitudes (1.5° radar elevation angle, sampling altitudes of 2.4–4.1 km): maximum standardized densities increased on average by 3.9 times ($t = 3.25$, $P = 0.002$) and maximum bird numbers by 3.3 times ($t = 2.34$, $P = 0.023$) during lit periods at high altitudes. We note that we did not detect many birds congregating in the beams during 2014; this year was not included in the above analyses because the lights were not shut down. We observed a strong effect of light on bird behavior during all other years (*SI Appendix*, Fig. S7).

Considering all radar observations, total numbers of birds within 500 m of the installation averaged 3.4 times higher during illuminated periods ($t = 9.34$, $P < 0.0001$). Standardized peak densities showed a similar pattern (factor = 6.4 times, $t = 3.72$, $P = 0.0003$), with the effect strengthened to 46 times higher during illuminated periods in 2015 ($t = 2.91$, $P = 0.004$). Again,

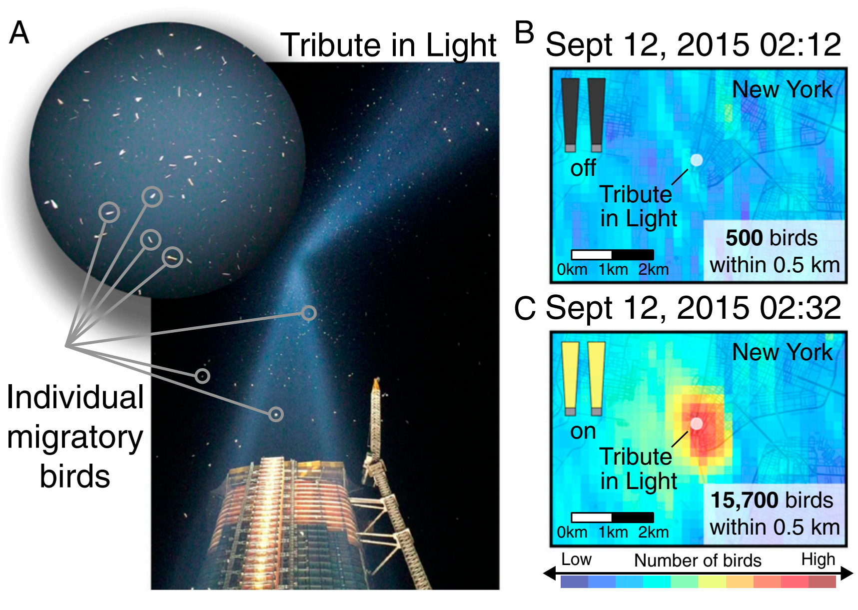

Fig. 1. Tribute in Light site. Observations (in Coordinated Universal Time) from the September 11–12 2015 Tribute in Light depicting altered behaviors of nocturnally migrating birds. (*A*) Direct visual observation. (*B*) Radar observation without TiL illumination and (*C*) with TiL illumination.

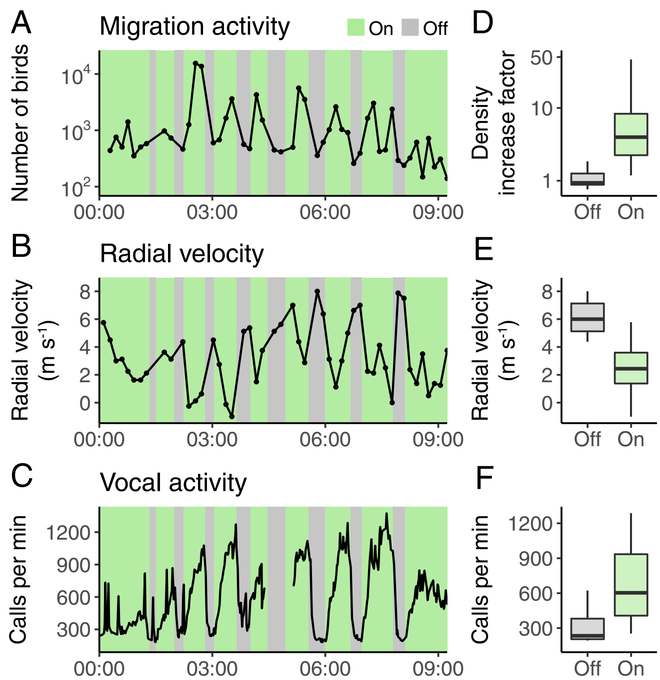

Fig. 2. Time series of radar and acoustic measures of Tribute in Light impact on migratory birds. Observations (in Coordinated Universal Time) from September 11–12, 2015 of (*A*) migration activity within 500 m of the installation, (*B*) radial velocity within 500 m of the installation, and (*C*) vocal activity during periods of TiL illumination. *D–F* show corresponding data with and without illumination. Density increase factor (*D*) is defined as the peak bird density near the installation divided by the mean density 2–20 km away.

these effects were also significant in the high altitude 1.5° radar data (total numbers: factor = 1.9 times, t = 3.49, P = 0.0006; standardized peak density: factor = 4 times, t = 4.00, P < 0.0001). Radial velocities were significantly lower during illuminated periods (main effect = −1.7 ms^{-1}, t = −2.10, P = 0.037), especially during 2012 (effect with interaction = −5.4 m/s, t = −2.38, P = 0.02) and 2015 (effect with interaction = −4.3 m/s, t = −2.52, P = 0.01). Flight call rates recorded beneath the installation were significantly higher during illuminated periods (main effect = 1.4 times, t = 4.53, P < 0.0001), especially in 2015 (factor with interaction = 2.9 times, t = 6.88, P < 0.0001); the effect was reduced in 2013 (factor with interaction = 1.1 times, t = −2.30, P = 0.02). Because our model of vocal activity included bird density as a predictor to account for variation in calling explained by the sheer quantity of birds, the significant increases in calling with illumination can be attributed primarily to behavioral differences.

Simulation results showed that birds were highly likely to become disoriented as they approached the installation (*SI Appendix*, Fig. S8). The model matching radar observations most closely (model 1; Fig. 4 and *SI Appendix*, Tables S1 and S2) had disorientation probability a = 0.95, indicating a very high likelihood of disorientation near ALAN, and the characteristic disorientation distance (σ) was 1,500 m. The concentrations of birds observed at the installation could only be explained by including directed flight toward ALAN for disoriented birds (concentration parameter $\kappa > 0$; best model $\kappa = 0.1$). In contrast, simulated birds diffused easily away from ALAN when assuming a nondirectional random walk ($\kappa = 0$; model 3 in *SI Appendix*, Table S1). These results support our visual observations of birds circling around the installation and are indicative of light attraction.

The stabilization time to a steady-state increased with disorientation probability (a) and flight directionality toward ALAN (κ) (Fig. 4, Movies S4–S8, and *SI Appendix*, Table S1). The stabilization time provides information on the residence time of birds in the beam, as a steady state is only reached over time periods longer than the average residence time. Our model 1, which is conservative in this regard, predicts a stabilization time of 34 min. We note that this is the result of average behavior for all birds contributing to the density pattern, and individual residence times may be considerably longer or shorter. Our simulation provides a theoretical framework for explaining our visual and remotely sensed observations, underscoring that the light installation attracted and entrained passage migrants.

Finally, direct visual observations showed that birds frequently circled the installation during periods of illumination and decreased speed on approach to the installation (*SI Appendix*). Such observations also highlighted a particular hazard that nocturnally migrating birds face in urbanized areas with ALAN: collisions with structures. Observers noted in 2015 and 2016 that many birds collided with the glass windows of a building under construction just north of the lights (50 West Street; Fig. 1*A*). The full extent of mortality was not clear, primarily because of challenges surveying nearby sites, scaffolding preventing birds from falling to ground level, and removal of carcasses by scavengers and building staff. We therefore do not have sufficient data to analyze mortality with respect to illumination and migration intensity. However, existing data are archived in the New York City Audubon D-Bird database (https://d-bird.org/).

Discussion

This study quantifies ALAN-induced changes in multiple behaviors of nocturnally migrating birds. Our data show that the light installation strongly concentrates and disorients migrants flying over a heavily urbanized area, influencing ≈1.1 million birds during seven nights over 7 y.

Existing published accounts report attraction to lights almost exclusively under poor-visibility conditions (45, 53), but our results show alterations to migrants' behaviors in clear and mostly clear

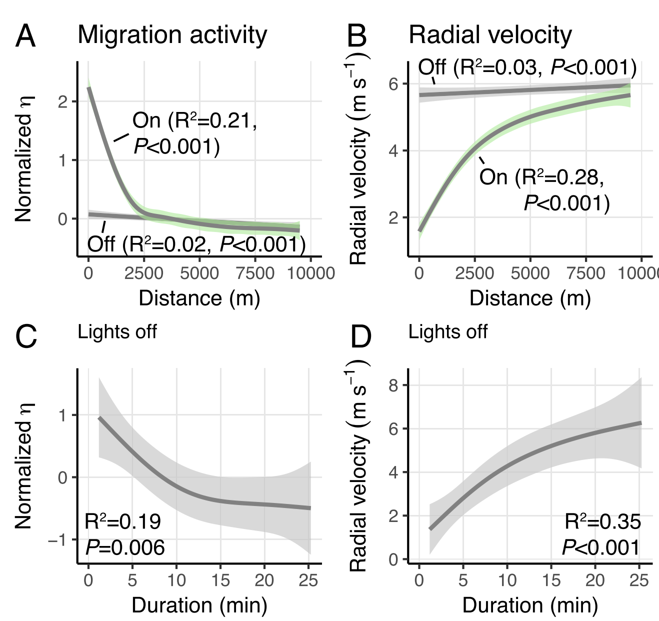

Fig. 3. Spatial and temporal influence of Tribute in Light on migratory birds. Migration activity (*Left* column) and radial velocity (*Right* column) at the installation pooled across years by distance from the study site (*A* and *B*) and activity as a function of time since TiL shutdown (*C* and *D*). To account for year-to-year variation, migration activity was normalized across years using a z-score standardization (values minus the nightly mean, divided by the nightly SD). Illumination represented by green and periods without illumination by gray. *C* and *D* include only measures ≤500 m from the installation. Data fit with generalized additive models (*A* and *B*: bs = "cs," m = 2, k = 10; *C* and *D*: bs = "ds," m = 2, k = 5) and weighted by migration activity for radial velocity models. Shading represents 95% confidence intervals.

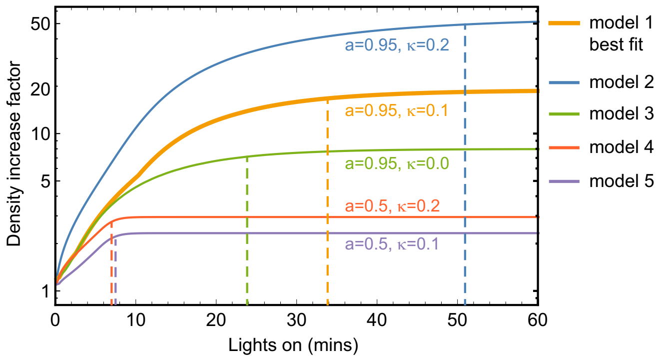

Fig. 4. Simulated bird concentrations over time at an ALAN source (solid lines). Vertical dashed lines indicate time to steady-state stabilization. Model parameters a and κ are described in *SI Appendix*, Eqs. **S1** and **S2**, with parameter σ fixed at 1,500 m (*SI Appendix*, Table S1). Model 1 represents the best fit to the observed patterns at the installation, but this model is still conservative in that higher-than-predicted concentrations of birds occurred in certain periods. In general, bird concentrations at the installation could only be explained by including directed flight toward ALAN for disoriented birds ($\kappa > 0$). These results support our observations that birds were disoriented by and attracted to the installation.

sky conditions (e.g., after ref. 48). Furthermore, to the best of our knowledge, no previous studies have reported attractive effects of ground-based lights to extend far above the ground, although nocturnally migrating birds will attempt to escape from direct illumination by a searchlight (54). In our study, we found behavioral responses to the installation up to ≈4 km above the ground. The vertical orientation of the light beams may be partly responsible for their high-altitude effects, as illuminated atmospheric moisture, dust, insects, or potentially other birds may attract migrants. We also demonstrated that short-term removal of ALAN eliminated its disruptive effects almost instantaneously. Our ground-truthed, direct visual observations of decreases in flight speed and increases in circling behaviors corroborate previous findings that birds shift direction and fly more slowly and erratically in the presence of ALAN (22, 23, 32, 33, 39, 44, 48, 49, 55). Furthermore, the increase in vocal activity that we describe agrees with other studies' findings, highlighting disorientation due to artificial lighting (23, 30). Finally, although each year exhibited a unique array of atmospheric conditions, we documented a strong concentrating effect of light in all but one of the 7 study years (*SI Appendix*, Fig. S7). We conclude that high intensity lights have the ability to greatly impact avian migratory behavior under a wide range of conditions. The fact that we did not document a strong effect during 1 y (2014) highlights a need for further research on how differing ambient conditions influence birds' attraction to light sources at night.

Light-induced alterations to nocturnal migration behaviors may represent significant energetic expenditures for migrating birds, but the effects of such alterations have not been quantified (56). Our visual observations indicate that bright lights alone can induce unnecessary ascent and descent, long periods of circling, and other types of complex and irregular maneuvering in birds close to the ground (22); these flight patterns are undoubtedly more energetically expensive than typical straight-path migratory flights. Specific hazards resulting from altered flight behavior may include susceptibility to predation (31), collisions with man-made structures (29), and changes to stopover ecology (57). Importantly, birds entrained for hours (39, 41, 42, 55, 58) by artificial lighting expend energy to remain airborne but do not make forward progress. Those that do not die from complications of exhaustion (59) may be delayed for days, as it takes time for lean migrants to regain fat stores during migratory stopover (60). Although our best model's stabilization time of 34 min suggests that most birds do not remain at the installation for hours, this model could not explain the largest concentrations we observed; other methods will be necessary to better understand variation in individual birds' behavior over time in the lights.

Further controlled experiments in field and laboratory settings would help determine the causes of attraction and disorientation at local and landscape scales. Studies that varied light intensity locally found that birds respond more strongly with more intense light (61–63). Sampling bird migration at and near light installations of varying intensities may provide additional opportunities to study attraction and disorientation. There are few vertically pointing light installations of comparable intensity in the United States (e.g., Luxor, Las Vegas, NV), but many structures use similarly powerful horizontal lights (e.g., sports stadia, construction sites, offshore oil rigs). Studies at such locations have not used multimodal remote sensing to quantify disruptions but have noted behavioral changes similar to those that we observed (e.g., aggregation, circling, and increased vocal activity) (57, 64).

Studies of ALAN are revealing large-scale effects on bird behavior that range from flight alterations to changes in stopover habitat use. There is mounting evidence that migratory bird populations are more likely to occur in urban areas during migration, especially in the autumn (65). Light pollution may explain this relationship, as recent research suggests that birds associate with higher levels of ALAN during migration (66). Given alarming declines in migratory bird populations (67, 68), these studies highlight a need to understand ALAN's implications for migratory bird populations.

Finally, our study highlights a model relationship for collaboration among diverse stakeholders. A hallmark of this project was frequent and public cooperation among the NSMM, the Municipal Arts Society, New York City Audubon, the Cornell Lab of Ornithology, and stakeholders with direct interest and responsibility for this event, all of whom acknowledged its potential to negatively impact birds. All parties agreed to keep the display illuminated unless potentially hazardous conditions for birds necessitated a short-term shutdown of the lights. Whereas discontinuing the display would be best for nocturnally migrating birds, such a scenario may not be possible at this time. TiL is arguably one of the world's most iconic and emotional displays of light. The fact that the event's organizers and participants were willing to periodically shut down the lights for the benefit of migratory birds is an encouraging acknowledgment of the importance of bird conservation. Moreover, despite occasional confusion and frustration among the tribute's viewers, media coverage often highlighted a unified message from stakeholders about balancing potential hazards to migrating birds with the intent and spirit of the display.

Methods

During our 7-y study period, the tribute lights were shut down a total of 22 times, for ≈20 min each. This allowed us to directly contrast birds' behaviors during adjacent dark and illuminated periods. We note that this study was opportunistic and not a controlled experiment. Furthermore, we note that such an opportunistic approach results in some inevitable challenges in interpretation, for example because we were unable to control for additional factors that could influence the degree to which birds congregate at light sources. Such factors likely include wind speed, wind direction, temperature, cloud cover, and ground-based sources of light and sound. However, because ambient conditions were generally similar within each night, we can still readily measure the additive effect of illumination on bird behavior, given each year's suite of conditions.

Study Site and Scope. TiL is an event held annually since 2002 on September 11th to memorialize lives lost during the terrorist attacks of September 11th, 2001 (www.911memorial.org/tribute-light). NSMM currently operates the light installation atop a parking garage near the site of the former World Trade Center in New York City (NYC), NY at the southern end of Manhattan Island (40.707°, −74.015°).

Massive nocturnal migratory movements of birds regularly occur over our study area during mid-September (12, 13, 69, 70). However, since the timing of these movements depends on local and regional weather and wind conditions (71–74), the magnitude of migratory passage on the single night of September 11th varies greatly among years. An agreement between New

York City Audubon (NYCA) and NSMM governs when to initiate the shutdown procedures: when numbers of birds circling in the beams exceed 1,000 individuals, based on visual observations, NYCA requests that lights be extinguished for ≈20 min. These requests originate from observers on site that are directly monitoring birds and their behaviors in the beams.

We examined September 11th nights from 2008 to 2016. High-resolution radar imagery did not exist before 2008, which limited our temporal scope. We excluded 2009 and 2011 because of the presence of precipitation, which interferes with analysis of radar data containing bird migration information. Of the remaining 7 y, migration conditions varied from marginal to favorable, assessed based on prevailing atmospheric conditions. Of these 7 y, the lights were shut down at least once during 5 of them; as a result, many of our analyses are restricted to these 5 y (2010, 2012, 2013, 2015, and 2016). Of the remaining 2 y, the first (2008) occurred before stakeholders could reach a consensus on a protocol for shutting down the light installation when birds were present and in danger. Organizers did not shut down the installation in 2014 because few birds were present in the lights.

Local Weather Conditions. We downloaded hourly local climatic data (LCD) for September 11 and 12, 2008–2016 (excluding 2009 and 2011 as described above) from the closest official National Weather Service station to the installation between evening and morning civil twilight (sun angle 6° below the horizon): WBAN 94728, Central Park, New York, NY at 40.789°, −73.967°; and meteorological terminal aviation routine weather reports (METARs) from Newark Liberty International Airport, the closest such station at 40.690°, −74.174°. Based on a review and summary of these data, we classified all nights during our study as clear (*SI Appendix*, Tables S3 and S4).

Weather Surveillance Radar Data. We gathered radar data from the Brookhaven, NY WSR-88D radar (KOKX; 40.866°, −72.864°) to quantify migrants' flight behaviors and extracted georeferenced measures of reflectivity (η; $cm^2\ km^{-3}$) and radial velocity (ms^{-1}) from the ≈0.5° and ≈1.5° elevation scales (12, 13, 70, 75, 76). We measured between civil twilight periods within a 20-km radius surrounding the installation (98.5 km from the radar, azimuth 260°) and consolidated analyses into 500-m height annuli bins. We dealiased velocities when necessary following refs. 76 and 77. We restricted our analyses to data points within 90 min of a shutdown period except when described.

We studied the effect of light stimuli on migratory birds using several metrics. First, we used the radar sweep with the lowest elevation angle (≈0.5°) to estimate the number of birds present in a cylinder centered on the installation with a radius along the ground of 500 m and a height of 1.7 km, the approximate width of the radar beam above the site (78). We calculated total effective scattering area per unit volume ($cm^2\ km^{-3}$) of birds in this cylinder using bird density measures from the 0–500-m bin. Then, we converted to numbers of birds using an estimated value of one bird = 8.1 cm^2, which is the measured cross-sectional area on S-band radar of a small passerine songbird (common chiffchaff, *Phylloscopus collybita*) (79). We chose a relatively small cross-section value because visual observations indicated that birds in the lights were predominantly small songbirds. The radar beam set to the 0.5° elevation angle passes above the installation at an altitude of ≈1.5 km (50% power range, 0.7–2.4 km), which is higher than the altitudes at which the greatest migratory activity during this season in this region generally occurs (80). Therefore, we used an analysis of the entire radar scan to estimate the proportion of migration occurring beneath (or above) the radar beam at the installation, out of sight of the radar. We then adjusted our estimates to account for these undetected birds by multiplying by the necessary correction factor (*SI Appendix*, Fig. S10). This approach assumes that the light beams did not greatly alter the altitudinal distribution of birds near the installation. The validity of this assumption is supported by direct visual observations at the site, where observers noted descent only by the lowest-flying individuals, which would not be detected by radar. Furthermore, any unaccounted-for descent at higher altitudes would render our estimates conservative, because a greater proportion of birds flying below the radar beam than expected would yield a lower estimate of total bird numbers.

To complement estimates of the total number of birds in proximity to the installation, we also calculated the extent to which birds were concentrated at high densities in the airspace near the installation, relative to the baseline value in the surrounding airspace. To produce this baseline, we calculated the mean and SD of density values between 2 and 20 km from the installation. We then found the peak bird density value within 500 m of the installation, and we subtracted the baseline mean density from this peak density and divided the difference by the baseline SD (again, 2–20 km from the installation). The resulting value, referred to as "standardized peak density," represents the number of SDs the peak density falls above the baseline density.

Acoustic Data. We collected continuous acoustic data at 32-kHz sampling rates and 16-bit sample sizes during each year's event with a pressure zone microphone (Old Bird 21c; Old Bird, Inc.) specifically designed for monitoring avian flight calls, connected to (*i*) a Nagra ARES-BB+ (2010 and 2013) or (*ii*) a custom-built passive acoustic recording system (2015 and 2016), comprising a Raspberry Pi 2 Model B (Raspberry Pi Foundation) with a Cirrus Logic Raspberry Pi audio card (Cirrus Logic). We focused analysis on the 6- to 9-kHz frequency band to minimize interference from anthropogenic, geophonic, and nonavian biophonic noise and because many of the migrating birds in the New York City area emit flight calls in this frequency band (81). The microphone sensitivity in the relevant frequency band for this study (6–9 kHz) was −33 dB re 1 V Pa^{-1} (±2 dB).

Visual Observations. We complemented remote sensing data that characterized behaviors of nocturnally migrating birds above the installation with visual observations. Numerous observers, including one of us (A.F.) and volunteers from NYCA and the local birdwatching community, made visual counts of nocturnally migrating birds at the installation during the period between civil twilight dusk and dawn. All visual counts are archived in the eBird reference database (ref. 82; ebird.org/ebird/hotspot/L1744278).

Statistics. We used generalized additive models (R package mgcv) (83) to quantify the effects of TiL illumination on birds' behaviors (*SI Appendix*). We tested the categorical factors of light (on/off) and year on four metrics: standardized peak density, the total number of birds present within 500 m of the installation, the radial velocities of birds above the installation, and the number of flight calls recorded beneath the site. For models of time series, we also included smooth terms that accounted for overall variation in densities and behavior through the night. We confirmed that there was negligible temporal autocorrelation of residuals using the acf function in R for all analyses involving time series (*SI Appendix*). We log-transformed response variables when necessary to reduce residual skewness; for models with log-transformed response variables, we express effect size as a multiplicative factor, found by exponentiating the coefficient. Finally, to determine whether the light effects we present in the study are representative of those observed across years, we compared standardized peak densities across the lighted periods of all 7 y, including the 2 during which no light shutdowns occurred.

Simulations. To understand the dynamic patterns of bird density at the installation, we formulated a spatiotemporal flow model to simulate behavioral changes resulting from exposure to light. In our simulation, birds could transition between two behavioral states: an undisturbed migratory state and a disoriented state induced by ALAN. Detailed methodology of our simulations is in *SI Appendix*.

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MIGRATION

A continental system for forecasting bird migration

Benjamin M. Van Doren[1]* and Kyle G. Horton[2]

Billions of animals cross the globe each year during seasonal migrations, but efforts to monitor them are hampered by the unpredictability of their movements. We developed a bird migration forecast system at a continental scale by leveraging 23 years of spring observations to identify associations between atmospheric conditions and bird migration intensity. Our models explained up to 81% of variation in migration intensity across the United States at altitudes of 0 to 3000 meters, and performance remained high in forecasting events 1 to 7 days in advance (62 to 76% of variation was explained). Avian migratory movements across the United States likely exceed 500 million individuals per night during peak passage. Bird migration forecasts will reduce collisions with buildings, airplanes, and wind turbines; inform a variety of monitoring efforts; and engage the public.

Billions of birds migrate between distant breeding and wintering sites each year, through landscapes and airspaces increasingly transformed by humans. Hundreds of millions die annually from collisions with buildings, automobiles, and energy installations (*1*), and light pollution exacerbates these effects (*2*). Pulses of intense migration interspersed with periods of low activity characterize birds' movements aloft (*3*, *4*), and efforts to reduce negative effects on migrants (e.g., turning off lights and wind turbines at strategic times) (*5*) would be most effective if they targeted the few nights with intense migratory pulses. However, bird movements are challenging to predict days or even hours in advance.

For decades, scientists have studied the drivers of avian migration. Winds, temperature, barometric pressure, and precipitation play key roles (*6*–*8*). However, such general relationships have not produced migration forecasts accurate at both broad continental extents and fine spatial and temporal resolutions (*9*, *10*). Local topography, regional geography, and time of season modify relationships between conditions and migration intensity, and hundreds of species with diverse behaviors frequently pass over a single location during migration. The complex interactions between environmental conditions and animal behavior make predicting bird migration at the assemblage level a challenge.

One major difficulty has been amassing behavioral data that appropriately characterize bird migration at a continental scale. Radar, used globally as a tool to study animal migration (*3*, *11*–*14*), offers a realistic solution to monitor hundreds of species (*15*). In the continental United States, the Next Generation Weather Radar (NEXRAD) network comprises 143 weather surveillance radars (*16*) and an archive with more than two decades of data. Although designed for meteorological applications, these radars measure energy reflected by a diversity of aerial targets, including birds. Only recently have advances in computational methods [e.g., (*17*)] facilitated the use of the entire radar archive for longitudinal studies of bird migration at continental scales.

Using the NEXRAD archive, we quantified 23 years (1995 to 2017) of spring nocturnal bird migration across the United States (Fig. 1). We developed a classifier to eliminate radar scans contaminated with precipitation. We then trained gradient-boosted trees (*18*) to predict bird migration intensity from atmospheric conditions reported by the North American Regional Reanalysis (*19*). Our model used 12 predictors, including winds, air temperature, barometric pressure, and relative humidity (fig. S1), which we used to predict a cube-root-transformed index of migration intensity (expressed in square centimeters per cubic kilometer). The cube-root transform reduces skewness but is less extreme than a log transformation, which would have given considerable weight to biologically unimportant differences between small values. We measured migration intensity in 100-m altitude bins up to 3 km to model the three-dimensional distribution of migrating birds over the continent. To express migration intensities in numbers of birds, we assumed a radar cross section per bird of 11 cm^2. The radar cross section is a measure of reflected energy; this value is typical of medium-sized songbirds and representative of migratory species (*12*).

Our migration forecast model explained 78.9% of variation in migration intensity over the United States (Figs. 2 and 3A). Performance was consistent across years (mean yearly coefficient of determination $R^2 = 0.781 \pm 0.010$ SD). We quantified the importance of each predictor by calculating gain, a measure of how much predictions improve by adding a given variable. Air temperature was most important, with an average gain more than three times that of the second-ranked predictor, date (fig. S2). High temperatures coincided with large migration pulses (Fig. 4 and figs. S3 and S4). As a predictor of bird migration, temperature likely plays a dual role as an index of spring phenology and a short-term signal for movement, as favorable

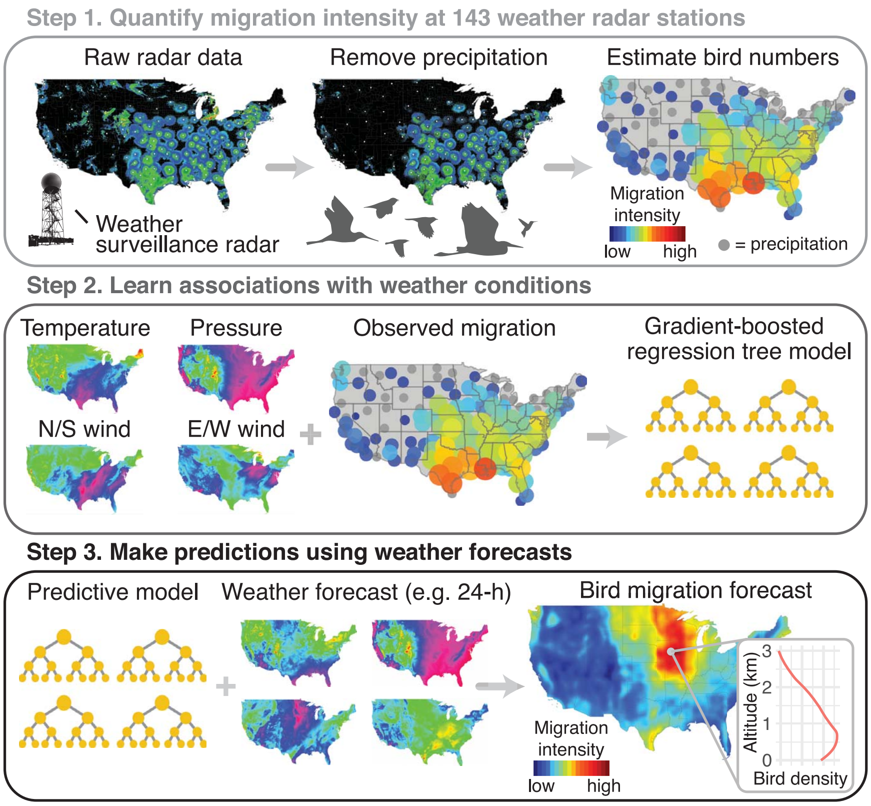

Fig. 1. Methodology for generating migration forecasts. We used weather surveillance radars to quantify 23 years of spring bird migration, modeled migration intensity as a function of observed atmospheric conditions, and used this model to forecast future migration events under predicted weather conditions.

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southerly winds usually accompany warmer air masses. Other important predictors included altitude, longitude, surface pressure, latitude, and wind (fig. S2).

The model provides informative predictions several days in advance. We evaluated its utility as a true forecast system with archived weather forecasts from the North American Mesoscale Forecast System (NAM) and Global Forecast System (GFS). NAM has higher spatial resolution but is a shorter-range forecast (12-km grid, 3-day range) than GFS (0.5° grid, >7-day range). We made predictions up to 3 days in advance with NAM and up to 7 days in advance with GFS, expecting performance to degrade with time because of the decreasing accuracy of longer-range weather forecasts. Predictions on the basis of 24-hour NAM forecasts explained 75% of variation in migration intensity, 3-day NAM forecasts explained 71%, and 7-day GFS forecasts explained 62% (fig. S5).

The model captures patterns of bird migration across the United States with high spatial accuracy, particularly in the central and eastern regions (fig. S6). We evaluated spatial accuracy over areas without radar coverage by iteratively removing the data from each radar station, retraining the model on the remaining data, and testing performance on the withheld station. Median R^2 for withheld stations was 0.72, and R^2 was 0.60 or higher for 75% of stations (fig. S7). Spatial variation in performance likely stems from local influences on migratory behavior (e.g., topography), which our model did not explicitly incorporate.

Previous research suggests that migration behavior and weather conditions in the days immediately preceding a migration event can predict its intensity [e.g., (*10*)]. We found that including atmospheric data from the preceding night and 24-hour changes in conditions did improve performance, but not markedly. A model that included atmospheric conditions 24 hours before an event explained 80.1% of variation in migration intensity, and further including observed migration intensity from the previous night increased R^2 to 81.3%.

Finally, we used model predictions to estimate the total number of birds actively migrating each night across the United States. Summing predictions countrywide, we infer that nightly movements frequently exceed 200 million birds (Fig. 3B). Peak passage occurred in the first half of May, when the median predicted movement size was 422 million birds per night. Although our model tended to underpredict the largest observed movements (Fig. 3A), a conservative forecast system

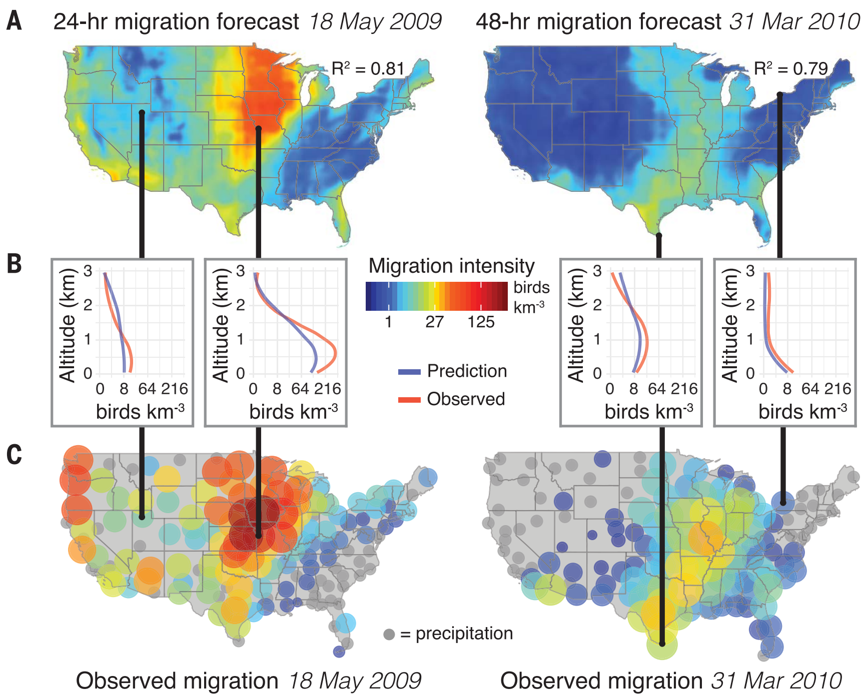

Fig. 2. Migration forecasts and corresponding observed migration. (**A**) Countrywide migration forecast surfaces showing predicted mean migration intensity across altitudes. (**B**) Altitudinal profiles at four stations, showing predicted and observed intensity values. (**C**) Mean migration intensity observed at all radar stations. Gray circles indicate stations where migration intensity could not be measured because of precipitation.

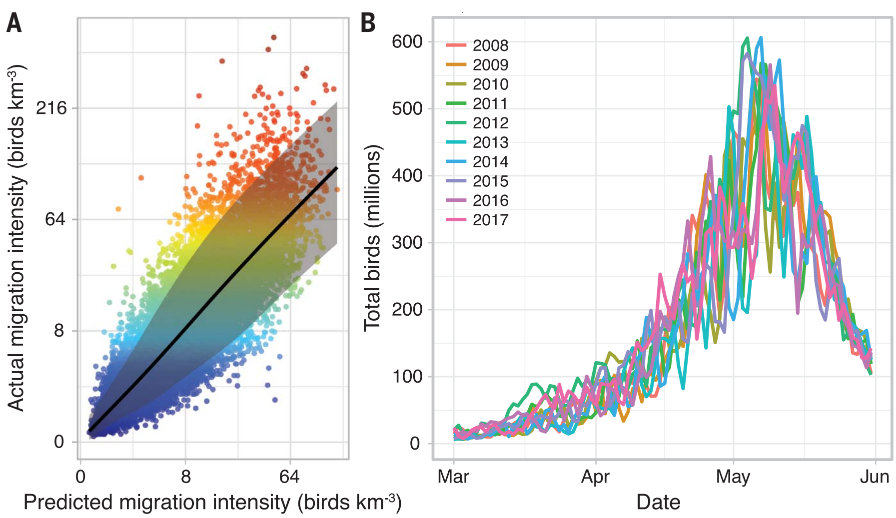

Fig. 3. Accuracy of forecasts and nightly continental predictions. (**A**) Mean predicted and observed migration intensities for test data, with points colored by observed migration intensity (*y* axis). The scatterplot shows values after averaging across altitudes. Shading shows empirical 90% prediction intervals, which covered 90.5% of observed values. (**B**) Nightly peak migration magnitude estimated across the continental United States for 2008 to 2017. The size of migratory movements varied markedly from night to night during the peak of the migration season.

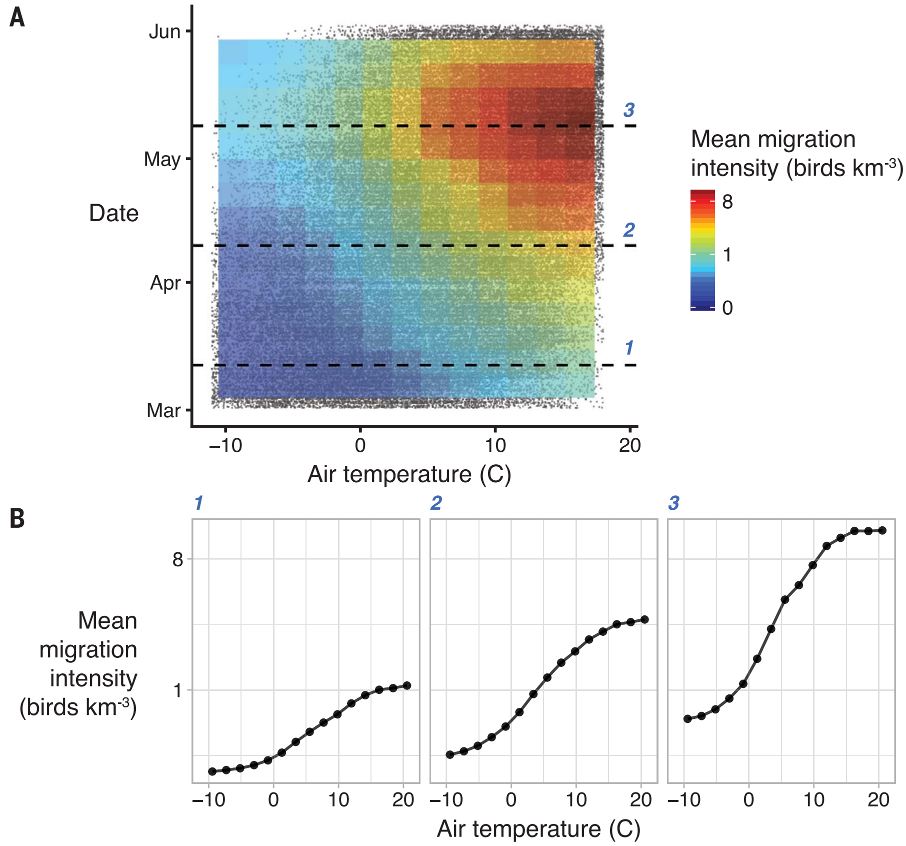

Fig. 4. Migration intensity predictions by air temperature and date. (**A**) Heat map colors show migration intensity predictions for dates and air temperature values. Each data point on the scatterplot behind the heat map represents data for one night from one radar. Only well-supported predictions and corresponding data points are shown (the outer 10% of temperature and date values are excluded). Temperature values correspond to air temperatures at altitudes up to 3000 m. (**B**) Cross sections of model predictions for three spring dates. For a given date, the model predicts migration intensity to vary closely with temperature. Fewer observations correspond to cold temperatures later in the season.

decreases the risk of taking unneeded mitigation action. More accurately predicting the largest migration events may require explicit modeling of migrant flow across the continent, including responses to topographical features (*20*).

Migration forecasts will further ecological research while aiding monitoring and mortality mitigation efforts. Accurate predictions can inform decisions to temporarily shut down lights and wind turbines, halt gas flares, choose airplane flight paths, and take other actions to prevent human and avian mortality (*10*, *21*). Global health workers monitoring avian-borne diseases can use migration forecasts to anticipate bird movements. Further integration of large citizen science datasets with radar observations will provide the means to study species-specific patterns of behavior at a large scale (*22*), and studying local variation in migratory behavior will lead to more accurate models of atmospheric bird distributions (*23*). Migration forecast systems have great potential to aid environmental monitoring and conservation efforts; fully realizing this potential will require the cooperation not just of scientists but also of governments and agencies that produce and disseminate radar products (*21*).

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SUPPLEMENTARY MATERIALS

www.sciencemag.org/content/361/6407/1115/suppl/DC1
Materials and Methods
Figs. S1 to S10
References (*25–37*)

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Science

A continental system for forecasting bird migration

Benjamin M. Van Doren and Kyle G. Horton

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Bird forecast

Billions of birds migrate across the globe each year, and, in our modern environment, many collide with human-made structures and vehicles. The ability to predict peak timing and locations of migratory events could greatly improve our ability to reduce such collisions. Van Doren and Horton used radar and atmospheric-condition data to predict the peaks and flows of migrating birds across North America. Their models predicted, with high accuracy, patterns of bird migration at altitudes between 0 and 3000 meters and as far as 7 days in advance, a time span that will allow for planning and preparation around these important events.

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ARTICLES
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Seasonal abundance and survival of North America's migratory avifauna determined by weather radar

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Avian migration is one of Earth's largest processes of biomass transport, involving billions of birds. We estimated continental biomass flows of nocturnal avian migrants across the contiguous United States using a network of 143 weather radars. We show that, relative to biomass leaving in autumn, proportionally more biomass returned in spring across the southern United States than across the northern United States. Neotropical migrants apparently achieved higher survival during the combined migration and non-breeding period, despite an average three- to fourfold longer migration distance, compared with a more northern assemblage of mostly temperate-wintering migrants. Additional mortality expected with longer migration distances was probably offset by high survival in the (sub)tropics. Nearctic–Neotropical migrants relying on a 'higher survivorship' life-history strategy may be particularly sensitive to variations in survival on the overwintering grounds, highlighting the need to identify and conserve important non-breeding habitats.

Seasonal animal migrations are events of extraordinary spatial and numerical scale[1,2]. Each year, billions of individuals travel the Earth to reach more suitable areas in which to live and reproduce, often covering astounding distances[1,3,4]. These mass movements constitute biomass exchanges across continents that may profoundly influence multiple facets of ecosystem function, through migrants' roles as competitors, predators and prey, and in transporting nutrients, propagules and pathogens[2]. Migratory behaviour has evolved to exploit seasonal variation in resources and environmental conditions, such that long-distance migrants may benefit from high reproductive output on their resource-rich temperate breeding grounds and from high survival on their tropical overwintering grounds. However, spatiotemporal patterns in mortality and recruitment within migratory bird communities remain poorly understood[5]. In particular, the relative importance of recruitment and overwintering survival in offsetting the costs of presumed higher mortality during the migration journey[6–9] is still unclear. Understanding vital rates across the annual cycle is critical for designing conservation strategies to reverse the steep population declines observed in many migratory bird populations[8,10].

Distributions of migratory bird species are often broad and shift seasonally[11], exposing populations to a complex array of threats and selective pressures[12]. To understand their combined effect on population sizes, we need comprehensive information on demographic rates (for example, mortality and recruitment)[10,13]; however, this information is challenging to obtain at relevant spatial and temporal scales. Population monitoring programmes[7,14] and tracking studies on larger-bodied birds[6] have provided estimates of baseline vital rates for a few bird species at various points in their annual cycles. Yet, these studies are highly local, labour intensive, and yield widely varying estimates of survival and reproductive rates within and across species and sites[15]. Therefore, generalization of current results to broader geographic areas and larger species assemblages can be problematic[10,13]. Recruitment data are equally challenging to collect, especially recruitment into the migratory population after birds have dispersed out of researchers' breeding-ground study areas. Nevertheless, consensus is emerging that mortality rates during migration are higher than in any other period of the annual cycle[7–9], with the most direct evidence from larger-bodied species[6,16] and larger uncertainty remaining for small songbirds[9,17]. Because longer-distance migrants presumably have greater exposure to risks and challenges of migration, we expect a lower proportion of their population to return from their overwintering grounds than shorter-distance migrants, unless high survival rates at their distant overwintering grounds offset mortality during migration.

We tested these expectations regarding seasonal changes in biomass for migratory birds in North America using an existing network of weather surveillance radars[18] distributed across the contiguous United States. Data from this radar network provide a unique and unprecedented opportunity for quantifying continent-wide patterns of animal movements and abundances[19]. Because radar networks operate continuously, have continental-scale coverage, and provide velocity and biomass density measurements in a highly standardized manner, they can provide quantitative large-scale estimates of biomass transport in the atmosphere (see Methods). However, until recently, obtaining and analysing radar data has been prohibitively time consuming[19], precluding continent-wide analyses.

Recently, the National Oceanic and Atmospheric Administration and Amazon Web Services (AWS) Cloud made available one of the largest datasets describing animal movement ever compiled[20]: the Next Generation Weather Radar (NEXRAD) archive. The NEXRAD network contains 143 WSR-88D weather radars in the contiguous United States (Figs. 1 and 2)[18], which since 2013 have collected dual-polarization data. Here, we used established methods to extract vertical profiles[21] of the density, speed and direction (Supplementary Fig. 1) of nocturnally migrating birds from 2013–2017 for all 143 radars in the network. By combining data across all radars, we provide estimates of total migratory biomass transport across the

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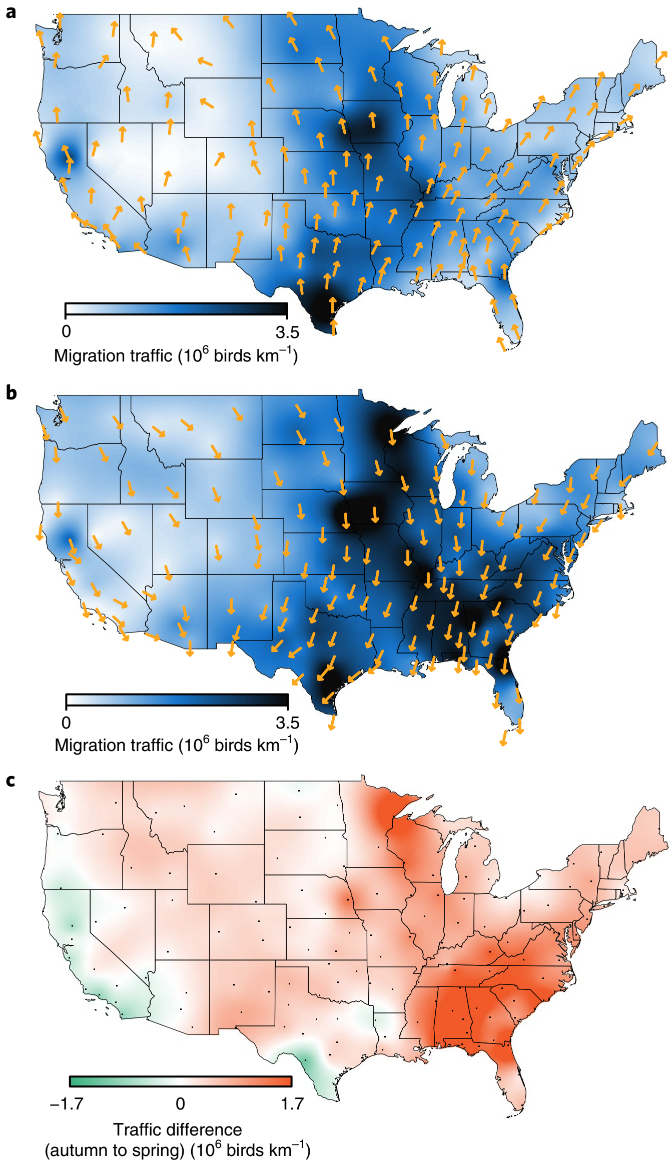

Fig. 1 | Cumulative nocturnal migration traffic in spring and autumn. **a**,**b**, Migration traffic (logarithmic colour scale) in spring (1 March to 1 July; **a**) and autumn (1 August to 1 December; **b**) averaged over five years (2013–2017). Orange arrows indicate the seasonally averaged directions of migration. **c**, Difference in migration traffic between spring and autumn. Orange and green colours indicate higher autumn and spring biomass passage, respectively. Migration passage was higher in autumn in most areas due to the new cohort of juveniles after reproduction. In spring, biomass passage peaked in the central United States, while in autumn migration was more easterly, with high traffic above the Appalachian Mountains and eastern Gulf of Mexico. Higher spring passages in California and Texas indicate looped migratory pathways that are more westerly in spring. See Supplementary Videos 1–4 for animated versions.

continental United States, and by comparing total biomass flows during spring and august migrations, we gain insights into assembly-wide demographic processes affecting the entire North American migratory avifauna.

Results

We found considerable spatial and seasonal variation in migration pathways across the contiguous United States (Fig. 1), reflecting both shifts in migration routes and demographic changes in total bird biomass detected across radar stations. In spring (1 March to 30 June), migration was concentrated throughout the central United States (Fig. 1a and Supplementary Videos 1 and 3). In autumn (1 August to 30 November), the average migration pathway shifted eastward (Fig. 1b,c and Supplementary Videos 2 and 4) and divided at the Gulf Coast, with an eastern pathway crossing the Gulf of Mexico and a western pathway circumventing the Gulf through Mexico (Fig. 1b). The eastward shift in migratory passage from spring to autumn is consistent with looped migrations[11,22] driven by seasonal patterns in wind and food availability.

To measure the total migratory passage into and out of the contiguous United States while controlling for the effect of seasonally shifting pathways, we delineated two coast-to-coast transects across the northern and southern United States borders (Figs. 2–4). These transects acted as continent-wide gateways for quantifying migratory passage (biomass abundances and timing) that, owing to the cross-continental extent, are insensitive to seasonal variation in the longitudinal location of migration pathways.

Our quantification of migration passages reveals a continental exchange of several billion birds across the two transects (Fig. 2 and Supplementary Table 1). Across the northern transect, the biomass equivalent of 3.97 ± 0.17 billion (mean ± s.d. over years) passerine-sized birds migrated southward in autumn and an equivalent of 2.56 ± 0.11 billion birds returned northward in spring. Across the southern transect, 4.72 ± 0.19 billion passerine-sized birds migrated southward in autumn and 3.55 ± 0.07 billion birds returned northward in spring. Our radar-based estimates are of the same order of magnitude as several indirect estimates for continental-scale exchanges based on estimated population sizes of breeding birds. Using Partners in Flight (PIF) population size estimates, and breeding and overwintering ranges of migratory landbirds[23,24], we estimate that 2.5 billion (south transect) to 2.7 billion (north transect) landbirds migrate into and out of the contiguous United States in spring (see Methods). On the same order of magnitude, in the Palaearctic–African migration system, 2.1 billion landbirds were estimated to migrate from Europe into Africa in autumn[1].

We calculated return ratios of spring to autumn passage, $\phi_{s/a}$, across each transect—proportions that indicate the net loss of biomass due to mortality in the non-breeding period, lasting from the autumn transect passage to the subsequent spring passage. Across the northern transect, the return proportion was $\phi_{s/a} = 0.64 \pm 0.06$ (mean ± s.d. over 5 years; Fig. 2b and Supplementary Table 2). Across the southern transect, the return proportion was $\phi_{s/a} = 0.76 \pm 0.03$, which is significantly higher than that for the northern transect (Wald $\chi^2(1) = 16.4$, $n = 4$, d.f. = 1, two-tailed $P < 0.001$). This difference in return proportions (that is, between $\phi_{s/a}$ and $\phi_{a/s}$) remained significant after converting to temporal rates (that is $\tilde{\varphi}_{s/a}$ and $\tilde{\varphi}_{a/s}$; see Methods; $\chi^2(1) = 9.2$, $n = 4$, d.f. = 1, $P = 0.002$) to account for differences in the time birds spent south of each transect (228 ± 2 days in the northern transect and 207 ± 2 days in the southern transect; Fig. 3, Supplementary Fig. 2 and Supplementary Tables 1 and 2).

In a similar manner, we calculated the ratio of autumn biomass passage to the previous spring passage as an index of recruitment into the migratory population, accounting for both reproductive output and subsequent mortality during the post-breeding and early august migration periods. For the southern transect, this estimate ($\phi_{a/s} = 1.36 \pm 0.04$) shows that for each northward migrating adult only an additional 0.36 recruits are added to the southward migrating population. A larger (Wald $\chi^2 = 46.0$, $n = 4$, d.f. = 1, two-tailed $P < 0.001$) additional biomass returned across the northern transect ($\phi_{a/s} = 1.60 \pm 0.09$), representing an additional 0.60 recruits added to the southward migrating population for every adult bird heading north the previous spring.

To account for birds that might bypass the southern transect in autumn due to a more easterly transatlantic migration route, we also quantified the passage of birds that may be departing off

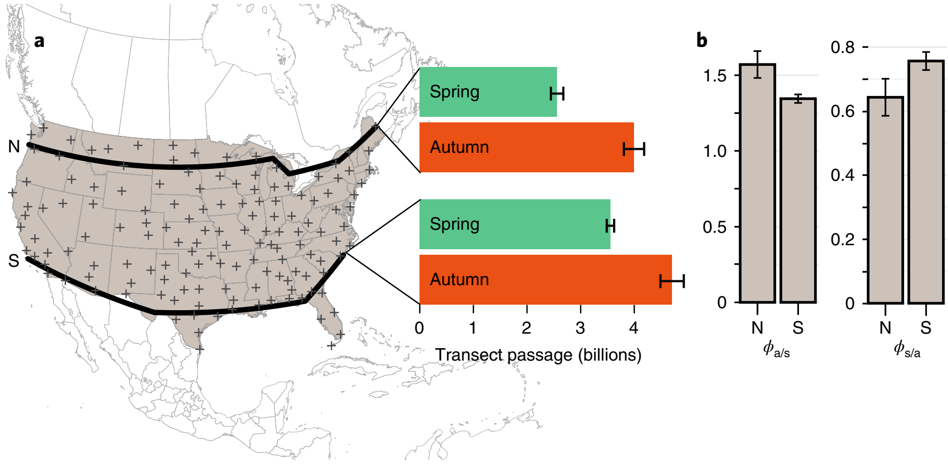

Fig. 2 | Southern and northern transects for quantifying seasonal biomass passage, migration traffic across these transects, and associated demographic indices. a, Seasonal cumulative migration traffic across the transects in spring (green bars) and autumn (red bars). Thick black lines indicate the southern and northern transect for quantifying seasonal biomass passage. Plus signs indicate the location of radar stations. **b**, $\phi_{a/s}$ is the ratio of autumn transect passage over the preceding spring passage, representing a demographic index of recruitment into the migratory period. $\phi_{s/a}$ is the return of spring passage over the preceding autumn passage, an index of mortality occurring south of the transect. Error bars indicate the interannual variation across the study years expressed as s.d.

the Atlantic coast, using an additional transect running from the easternmost tip of the northern transect to the easternmost tip of the southern transect (Maine to North Carolina). We found that, in autumn, a biomass equivalent of 219 ± 63 million birds crossed this coastal transect towards the southeast. In spring, the net passage across this coastal transect was also eastward, equalling 63 ± 12 million birds. In the unlikely scenario that all birds crossing this coastal transect bypass the southern transect only in autumn but not in spring (in a looped migration), this would lead to an overestimation of the southern transect return rate $\phi_{a/s}$ by 4%. Accounting for this potential bias did not change the significance of the difference in return rate between the northern and southern transect. However, we note that even though looped migration is common in eastern North America, most birds that migrate in a looped trajectory do not perform transatlantic migration in autumn[11], and the number of species—especially passerine species—bypassing the southern transect in autumn is probably very small[25].

Birds crossing the northern and southern transects differ in species composition and the total distance required to complete their migration journey (see Fig. 3), which we estimated using independent distribution maps and breeding population estimates (see Methods and Supplementary Information). Passage across the northern transect was dominated by shorter-distance migrants with an assembly-averaged overwintering area located around 400 km south of the transect (still well within the contiguous United States). In contrast, the assemblage crossing the southern transect was dominated by longer-distance migrants whose overwintering area was located around 1,400 km south of the transect, on average. Body size distributions of landbird species passing the transects were similar for the two assemblages (17 ± 13 g for the north transect and 17 ± 14 g for the south transect; weighted t-test by species population size: $t = 0.288$, d.f. = 311, $P = 0.8$; see Supplementary Information). Based on the same distribution maps and breeding population size data, we estimate that at least 19%, and at most 40%, of all migrants crossed both transects. The assemblages represented at the two transects are thus partly overlapping.

Discussion

Our finding that the return rate of biomass from autumn to spring was higher across the southern transect than at the northern transect has a surprising implication: cumulative mortality experienced during migration and the overwintering periods was significantly lower for birds migrating towards the Neotropics than for birds overwintering in the temperate United States, despite a greater average migration distance remaining for birds crossing the southern transect. Therefore, longer migration distances did not result in higher relative biomass loss and lower spring return rates, suggesting that high overwintering survival in the tropics might be compensating for the increased mortality presumably associated with longer migration. Alternatively, a higher return rate across the southern transect could result from latitudinal variation in migration mortality if mortality during migration at (sub)tropical latitudes is substantially lower than at temperate latitudes. Although mortality has not been quantified at different points in the migration route, the 'latitudinal variation in migration mortality' explanation seems unlikely as southern latitudes include major ecological barriers to migration; for example, Mexican arid zones and the Gulf of Mexico, which are thought to be dangerous to cross[26]; however, note the specific challenges in highly industrialized landscapes described below.

In stable populations, opposite patterns of recruitment would be necessary to compensate for differences in mortality rates of temperate- and southern-wintering birds. We found that at the northern transect the number of recruits added to the migratory population was significantly higher (0.60) than at the southern transect (0.36). This contrast between northern and southern transects is consistent with latitudinal increases in clutch size[27] and a higher fecundity of shorter-distance migrants compared with long-distance migrants[28,29]. Because average migration distance (and associated mortality during migration) north of the two transects was similar (1,396 versus 1,510 km), our return rates probably indicate that latitudinal increases in clutch size and fecundity resulted in higher numbers of fledglings produced, thus increasing recruitment into the migratory population at more northern latitudes.

Our radar-derived demographic indices are inherently seasonal, spanning clearly defined portions of the annual cycle. Very few studies have so far quantified seasonal demographic rates away from breeding grounds[8], and estimates are available for only a handful of migratory species[7,9]. Published estimates come from long-term studies of simultaneously monitored populations on breeding and wintering areas for highly site-faithful species[7–9], as well as satellite tracking studies on larger-bodied birds[6]. The latest full annual cycle population models for small passerines suggest very high adult

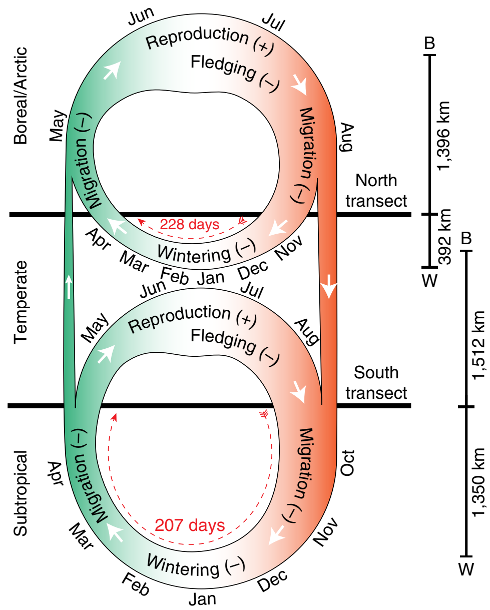

Fig. 3 | Annual cycle of avian biomass flow across the north and south transect. Segment widths represents the amounts of biomass of the avian assemblages associated with the two transects. Distance markers on the right indicate the average distance from the breeding (B) and wintering (W) area for the assemblage of birds crossing each transect, respectively. Monthly labels indicate the progression of time (time is not proportional to the length of the segments). (+), (−) indicate biomass growth, loss, respectively.

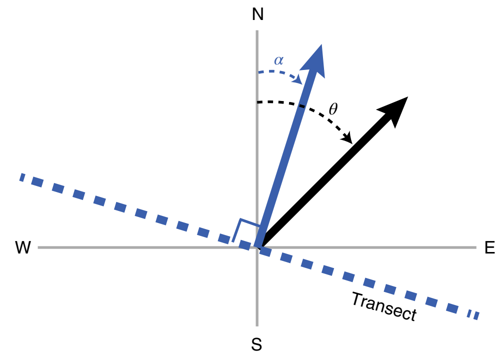

Fig. 4 | Angular definitions of transect direction and bird ground speed direction. The transect is displayed as a dashed line. The direction of the transect is given by the angle α defined relative to the blue arrow perpendicular to the transect, whose value is limited to the −90° to +90° range. The black arrow gives the ground speed vector of migration, with the direction θ.

survival during stationary periods on the wintering grounds in the Neotropics[7–9]. Our observation of a relatively high spring return $\phi_{s/a}$ at the southern transect provides continent-wide evidence of higher survival among the full assemblage of Neotropical migratory birds south of the United States, which potentially offsets higher expected mortality rates during migration[6,7,9,16] compared with the combined non-breeding and migration survival of shorter-distance temperate-wintering migrants.

Relative to the number of fledglings produced by most migratory landbirds (around 1–2 per capita[1,28,29]), our recruitment indices indicate that per northward migrating adult in spring, relatively few recruits are added to the migratory population in autumn (0.36 at the southern transect and 0.6 at the northern transect). These numbers suggest a major loss of biomass through mortality even before the transects are reached, which is also consistent with high mortality rates during the immediate post-fledging period, as observed in numerous species-specific studies[15,30–32] and during migration.

We suggest that differences in mortality and recruitment rates observed between the two transects are primarily related to general differences in life-history strategies among their associated species assemblages, including a broad range of adaptations to climate, vegetation types and food resources that vary according to the latitude of breeding and non-breeding distributions. From a life-history perspective, our results suggest that, on average, birds overwintering south of the United States showed a 'higher survivorship' strategy, while migrants overwintering in the temperate zone tended towards a 'higher recruitment' strategy. Life-history strategies relying on high survivorship are more sensitive to perturbations in adult survival rates in non-breeding areas[33]. Thus, even though birds overwintering south of the United States had an overall higher return rate than temperate-wintering birds, their populations may be more sensitive to perturbations in adult non-breeding survival, emphasizing the need to monitor survival rates of birds outside the breeding areas, especially within the Neotropics.

As unprecedented anthropogenic changes in land use and climate strongly impact ecosystems and organisms worldwide[34], migratory birds in particular are suffering widespread population declines[10,13]. Large-scale demographic patterns in mortality and recruitment may no longer reflect environmental conditions under which life-history strategies of migrants evolved. In highly industrialized countries such as the United States, migrants face new sources of direct mortality from anthropogenic causes; for example, collisions with structures (sometimes mediated by the effects of artificial light[35,36]) or predation by cats[37], potentially decreasing survival in temperate (more urbanized) latitudes. Indirect effects of climate change and human-induced habitat degradation affect migrants throughout the annual cycle, with habitat loss accelerating especially at tropical latitudes[38]. Understanding and mitigating the effects of global change and human activity on demographic rates will be crucial for conservation. Our study illustrates how meteorological radar infrastructure can provide a baseline of seasonal abundances and return rates for the entire migratory bird assemblage of North America, which can be monitored for years and decades to come as conditions along flyways continue to change.

In summary, by taking advantage of an existing meteorological radar infrastructure, our study provides baseline information on seasonal passages of bird biomass across the contiguous United States. We used these data to calculate continental-scale demographic indices that indicate average differences in mortality and recruitment rates between assemblages of migratory birds overwintering predominantly within the United States and birds spending the non-breeding season predominantly in the Neotropics. These indices offer a benchmark for putting species-specific studies into a more general context, and an unprecedented opportunity to track and assess shared drivers of population change for billions of migratory birds simultaneously. Our findings indicate a 'higher survivorship' strategy used by longer-distance migrants spending the northern winter south of the United States, with an emphasis on high adult survival within Neotropical non-breeding grounds. For birds that rely on high survival to offset the risks of long-distance migration, even small reductions in habitat quality can potentially drive population declines, as observed in many Neotropical migratory species. Understanding how global change is likely to affect non-breeding habitats, where these migrants spend the majority of the annual cycle[38], will be critical for preserving this hemispheric migration system.

Methods

Extraction of vertical profiles of birds. We extracted vertical profiles of bird speeds, directions and densities (see Supplementary Fig. 1a) using the algorithm vol2bird (version 0.3.15)[21], which is available on GitHub (https://github.com/adokter/vol2bird). We briefly describe the main processing steps and study-specific settings.

Vertical altitude bins were defined relative to sea level in 200 m height intervals up to 4 km altitude. We removed meteorological signals based on high correlation coefficient values (>0.95) provided in the dual-polarization radar data (which indicate the temporal autocorrelation of the vertically and horizontally polarized components of the detected signal by the radar)—a highly reliable polarimetric indicator of precipitation[39,40]. Polarimetric data are only available since 2013 upgrades to US radars, which is why we restricted our analyses of NEXRAD S-band data to the 4.5 years of available dual-polarization data.

A cell-searching algorithm detected contiguous cells of high correlation coefficients, defining cells as groupings of sample volumes within an elevation scan for which each sample volume has a correlation coefficient greater than 0.95, and at least 5 directly neighbouring sample volumes (in a Moore neighborhood sense) that also meet this requirement. We removed only data from contiguous precipitation cells of 0.5 km^2 or larger, to retain the occasional speckle of high correlation coefficient sample volumes found in bird migration areas. We added an additional buffer of 5 km width around the selected precipitation cells to effectively remove the borders of precipitation areas, which tend to have less well-defined correlation coefficient values, thus limiting the risk of precipitation contaminations[21].

We produced static beam blockage maps for all weather radar sites following Krajewski et al.[41]. We excluded all sectors from the analysis for areas with (partial) beam blockage based on surrounding topography, as obtained from a 100-m-resolution topographical map provided by the US Geological Survey[42], and assuming a 1° beam width. We assumed a standard refraction of the beam towards the Earth's surface by using an effective Earth's radius of 4/3 × (true radius)[43]. From this topographical map, we also extracted the minimum, mean and maximum ground level within a 25 km radius of each radar (Supplementary Table 5). For radars with a minimum ground level below the antenna height, we extrapolated migration estimates for the lowest bin (at antenna level) down to 400 m below the antenna level. At even lower altitudes, the radar was considered blind, which mainly applied to some radars in the central Rocky Mountains, away from the transects used for counting bird passages (see Supplementary Table 5).

An additional dynamic clutter map was used to exclude sample volumes with a Doppler velocity in the interval of −1 to 1 m s^{-1}, to filter out ground echoes associated with anomalous beam propagation[43] and other clutter from other remaining static ground targets. We used sample volumes in the 5–35 km range only, which excludes the closest sample volumes with a high probability of ground clutter contamination and maintains a narrow beam width that can resolve the altitudinal distribution of birds. The processing steps described below were conducted only on the sample volumes that remained after exclusion of precipitation and ground clutter.

We de-aliased radial velocities using a torus mapping method[44], which is also used in the product generation framework of the European Operational Programme for the Exchange of Weather Radar Information (OPERA) network, as well by meteorologists in the Baltrad weather radar network for the Baltic sea region[45]. This method de-aliases velocities using a fit to a linear velocity model that is wrapped at the Nyquist velocity of each scan, very similar to a de-aliasing technique[46] applied earlier in bird migration studies using North American NEXRAD radars. We applied separate de-aliasing of each altitude layer of interest, which may contain sample volumes of different elevation scans. In the de-aliasing fit, we took into account each of the (potentially different) Nyquist velocities of the elevation scans.

We extracted speed and direction estimates from the de-aliased velocity fields using the volume velocity profiling (VVP) technique[21,47,48]. Weather radar reflectivity factor values (dBZ) were converted to reflectivity ($cm^2\,km^{-3}$), and for each altitude layer the geometric mean reflectivity η over all sample volumes in the altitude layer was calculated. Reflectivity can be expressed as bird numbers using an estimate of the average radar cross-section (RCS) of an individual migrating bird. Here, we used a yearly mean RCS of 11 cm^2 for an individual bird, determined in a calibration experiment spanning a full spring and autumn migration season[21]. This value corresponds to passerine-sized birds (10–100 g range)[49], which represents the highest-abundance species group dominating our radar signals (Supplementary Fig. 5; Supplementary Table 3 and Methods).

The vol2bird algorithm finally removes altitude layers with radial velocity standard deviations $\sigma_{VVP} < 2\,m\,s^{-1}$, with σ_{VVP} a measure of radial velocity texture, defined as the root of sum of the residual squared errors between the radial velocity data and the VVP velocity model. This radial velocity texture represents an additional filter for cases of precipitation, and wind-drifting insects that cause smooth velocity fields that represent the wind. Birds, however, have active and highly variable self-speeds[21], causing high spatial variability in radial velocities.

We accessed NEXRAD weather radar data from the public 'noaa-nexrad-level2' Amazon S3 bucket[20]. We containerized a pipeline for downloading and processing these data using Docker[50], and deployed this in the AWS Cloud using the AWS Batch service (https://aws.amazon.com/documentation/batch/). Cloud computing reduced this computation task of 14,000 central processing unit (CPU) hours to less than a day.

Migration traffic from vertical profile time series. The vertical profiles of single radars make up time series, which we used to calculate the cumulative seasonal passage of migratory birds for each individual radar. Our analysis focuses on nocturnal migration, which is by far the most common migratory strategy because it is highly time and energy efficient[51]. We first calculated the migration traffic rate (MTR) for each nocturnal profile in the time series (see Supplementary Fig. 1b), which is a flux measure defined as the number of targets crossing a 1 km transect per hour (in individuals $km^{-1}\,h^{-1}$; see Fig. 4 for definitions of the angles in relation to ground speed and transect direction). For a transect always kept perpendicular (⊥) to the migratory ground speed direction, MTR is always a positive quantity, defined as:

$MTR_{\perp,t} = \sum_i \rho_{i,t}\; v_{i,t} \Delta h$, where t is an index of time, $\rho_{i,t}$ is the bird density at altitude layer i (in km^{-3}), $v_{i,t}$ is the bird ground speed at altitude layer i (in $km\,h^{-1}$) and Δh is the width of the altitude layers (0.2 km). MTRs can also be calculated for transects with a fixed direction, α (see Fig. 4), in which case the number of crossing targets per hour per km of transect is calculated as:

$MTR_{\alpha,t} = \sum_i \rho_{i,t} v_{i,t} \cos[\vartheta_{i,t} - \alpha] \Delta h$, where $\vartheta_{i,t}$ is the migratory direction at altitude bin i and time index t. Note that this equation evaluates to the previous equation when $\alpha = \vartheta_{i,t}$, as required. In this definition, MTR_α defines the flux of birds in a direction of interest. Targets moving northward over the transect contribute positively to MTR_α, while targets moving in southward directions contribute negatively to MTR_α. Therefore, MTR_α can be either positive or negative, depending on the direction of migration θ. As an additional quality control, we only included $\rho_{i,t}$ when θ was in the southward semicircle surrounding a radar station in autumn and when θ was in the northward semicircle in spring. As we define directional angles clockwise from north, MTRs in spring were positive and MTRs in autumn were negative.

The MTR values of individual profiles were further aggregated into values of cumulative night-time migration traffic (in individuals km^{-1}):

$$MT_\perp(T_{start}, T_{end}) = \sum_{t=T_{start}}^{T_{end}} MTR_{\perp,t} \Delta t$$

$MT_\alpha(T_{start}, T_{end}) = \sum_{t=T_{start}}^{T_{end}} MTR_{\alpha,t} \Delta t$, where Δt is the time difference between consecutive profiles in hours. Profiles were calculated at half-hour intervals for each radar during night time only, selecting the profiles closest to 0 and 30 min for each hour. A 30 min time interval was found to be optimal for balancing computational efficiency and accuracy of the results. A test run on a subset of 18 radars for 3 years at the full available temporal resolution (around 5–10 min) showed that down-sampling to 30 min produced estimates of migratory passage migration traffic that were within 1% of the original.

In calculations of seasonal migration traffic, the spring season was taken to be from 1 March to 31 June; that is, T_{start} equalled the index of the first profile of March and T_{end} the index of the last profile in June. The autumn season was taken to be 1 August to 31 November; that is, T_{start} equalled the index of the first profile of August and T_{end} the index of the last profile in November. Figure 1 shows plots of the spatial interpolation of $MT_\perp$ calculated for the autumn and spring seasons (see next paragraph for interpolation methods).

Seasonal transect passage. We chose the northern and southern transects to minimize orographic obstructions. A few radars in the central Rocky Mountains are located on higher mountains, which makes these areas less suitable for coast-to-coast transects, as some migrations may pass below the field of view of the radar. We selected the radar stations to use for the northern and southern transects because their radars were relatively free from such topographic effects (see Supplementary Table 5), and their transect segments were chosen to roughly follow the northern and southern border of the United States. Each transect consists of multiple line segments, each with a line segment direction α_j of constant course. The north transect largely follows 46° N latitude, defined by straight line segments in Mercator projection between locations 46° N/124° W, 46° N/85° W, 44° N/83° W, 44° N/75° W and 46° N/67.78° W. The south transect largely follows 30° N latitude through locations 34° N/120° W, 30° N/103° W, 30° N/84° W and 34° N/78° W. An additional coastal transect was defined from the easternmost tip of the northern transect to the easternmost tip of the southern transect; that is, from 46° N/67.78° W to 34° N/78° W. To calculate migratory passage over a line segment, we first calculated seasonal migration traffic MT_{α_j} for all radars. Spatial interpolations of seasonal migration traffic were generated using ordinary kriging in the R package gstat[52]. We clipped water areas after interpolating, leaving land areas of the contiguous United States. A small section of the transect in the north-east runs over Canadian territory and the Great Lakes, and we extended interpolations of migratory movements into this area when calculating transect passages. Finally, we integrated the migration traffic values (in individuals km^{-1}) over the length of the line segment, giving the total migratory passage of individuals for that line segment. These calculations were repeated for all line segments of a transect, and the total transect passage was calculated as the sum of the migratory passage over all segments.

For each radar, we calculated the mean passage date of birds into the direction α as:

$$t_\alpha(T_{start}, T_{end}) = \frac{\sum_{t=T_{start}}^{T_{end}} t\, MTR_{\alpha,t} \Delta t}{\sum_{t=T_{start}}^{T_{end}} MTR_{\alpha,t} \Delta t}$$

Supplementary Fig. 2 shows the spatial variation in mean transect passage date in spring and autumn $t_{\perp}$ (keeping α parallel to the migratory direction θ as in $MT_{\perp}$). Values of t_{α} were spatially integrated and summed over the line segments of transects as for MT_{α} into seasonal mean transect passage dates t_{pass}, and summarized in Supplementary Table 1.

We calculated the transect parameter $\phi_{s/a}$ as the spring passage over the preceding autumn passage, and $\phi_{a/s}$ as the autumn passage over the preceding spring passage. These ratios do not depend on the assumed RCS factor converting reflectivity to bird numbers, as they are a biomass ratio for which RCS cancels in division. The parameters $\tilde{\varphi}_{s/a}$ and $\tilde{\varphi}_{a/s}$ are the same ratios expressed as return rates per month, which take into account the average time passed between the autumn and spring passages, as in:

$$\tilde{\varphi}_{s/a} = \phi_{s/a}^{\frac{1}{(t_{pass,s}-t_{pass,a})}\frac{365}{12}}$$

$\tilde{\varphi}_{a/s} = \phi_{a/s}^{\frac{1}{(t_{pass,a}-t_{pass,s})}\frac{365}{12}}$, with the mean spring and autumn transect passage dates ($t_{pass,s}$ and $t_{pass,a}$) expressed in days since 1 January of the respective season (Supplementary Table 2).

The Supplementary Information discusses in detail the potential effects on return rates introduced by seasonal differences in flight altitude and insect migration in the nocturnal boundary layer[3,53,54]. We find that each effect minimally changes the estimated seasonal biomass passages, biasing the return rates downward, at most by 4%.

Species composition. To assess which species groups predominantly contribute to our radar signals, we obtained breeding bird population estimates for the United States and Canada from the PIF Population Estimates Database for landbirds[24], supplemented with population size estimates for waterbirds and waders from the PIF Conservation Assessment Database[23] (with recent updates to population sizes provided by K.V.R.). We assessed for each species whether it was likely to migrate at night in the United States, following the migration status provided by PIF where available and complemented by an assessment by the authors (A.F. and K.V.R.) (see Supplementary Table 3). We gathered the average body mass per species from ref. [55] and took mass raised to the power (2/3) as a proportional measure of RCS. We estimated that 78% of the cross-sectional area of all nocturnally migrating birds in the United States combined are songbirds, and 22% are waterbirds and shorebirds. Supplementary Fig. 5 shows the cumulative distribution function of the cross-section values based on the PIF population estimates. It shows that 80% of the cross-sectional area is represented by birds with a body mass of less than 125 g, and 90% by birds smaller than 1 kg. These figures support our interpretation that the majority of the radar signals are caused by small songbirds, which is why our discussion of mortality and survival indices focuses on the songbird literature.

It is likely that the proportion of songbirds in our radar signals will be larger than the above estimates, because many waterbirds have (partly) overseas routes, and because these species also migrate during the day (especially geese and ducks), with radar signals from daylight hours not considered in our analyses. Very little migration was detected from November onwards (see Supplementary Video 2), which is when considerable waterfowl migration is expected, suggesting that waterfowl contributed relatively weakly to our estimates of migration passage.

To determine species composition of the assembly crossing each transect, and to compare our radar estimates of biomass passage with independent population estimates of migrating landbirds, we used information in the PIF Population Estimates Database[24] to determine landbird species (from Supplementary Table 3) with part or all of their populations migrating out of the contiguous United States in spring or autumn (that is, crossing the northern or southern transect, respectively). Because the PIF population estimates are for breeding adults only, our comparison is focused on spring migration passage, when the number of migrating individuals will be closest to the breeding population size. We used the percentage of the population that breeds in Canada and Alaska, or for short-distance migrants the percentage of the population wintering in the contiguous United States. To estimate the number of birds returning across the southern transect in spring, we used the percentage of the breeding population that winters on the Florida Peninsula or south of the United States in Latin America or the Caribbean.

We found that the total estimated spring passage of landbirds using this method (Supplementary Table 4) was similar to the biomass equivalent of passerine-sized birds estimated from the weather radar (2.68 versus 2.56 billion at the northern transect, and 2.46 versus 3.55 billion at the southern transect), suggesting that our quantification is biologically meaningful.

Migration distance. To estimate geographic characteristics of North American migratory bird distributions within the Western Hemisphere, we used range maps of species' breeding and winter distributions from NatureServe[56]. Following La Sorte[57], we converted range-map polygons to collections of equal-area hexagons of a global icosahedron[58] having a cell size of 12,452 km^2. We estimated the total migration distance between each species' breeding and winter ranges using the great circle (orthodromic) distance between the geographic centroids of the breeding and winter ranges, which were estimated by averaging the geographic locations of the hexagon cell-centres occurring within each species' breeding and winter ranges. We calculated the intersection of the great circle between breeding and wintering centroids with the transect and took the resulting segments as the distances travelled north (d_{north}) and south (d_{south}) of the transect. If breeding and non-breeding centroids were both positioned south of the transect, we took the distance travelled north of the transect to be zero, and the distance travelled south of the transect to be the full distance between the centroids. To determine assembly-averaged migration distances north and south of each transect (see Fig. 3), we calculated averages of species-specific line segment distances, weighed by the earlier-determined species population size crossing each transect, and by the average species mass[55] raised to the power (2/3) to account for RCS effects, resulting in $d_{north} = 1,396$ km and $d_{south} = 392$ for the north transect and $d_{north} = 1,512$ km and $d_{south} = 1,350$ km for the south transect. The result of a much longer d_{south} for the south transect is highly robust and remains when weighing only by population size (north transect: $d_{north} = 2,436$, $d_{south} = 539$; south transect: $d_{north} = 1,639$, $d_{south} = 1,726$), or when simply averaging over species without weighing (north transect: $d_{north} = 2,552$, $d_{south} = 368$; south transect: $d_{north} = 1,365$, $d_{south} = 1,370$). Furthermore, any small waterbird contribution to the biomass signal will reinforce the pattern further, as the majority of waterfowl winter at temperate latitudes within the United States, and most shorebirds crossing the southern transect tend to winter quite far south at tropical latitudes. We therefore expect the distances to be fairly robust against uncertainties in species composition, population size estimates and RCSs.

Statistics. Differences in seasonal transect passages were tested with linear mixed models using the R package lme4[59], with transect (north and south) as a fixed effect and year as a random effect. Two-sided P values for the fixed effect were calculated with a Wald chi-squared test, using the Anova function from the R package car[60]. Throughout the paper, values are reported as means ± s.d. over years.

Reporting Summary. Further information on research design is available in the Nature Research Reporting Summary linked to this article.

Data availability

NEXRAD weather radar data were accessed from the public 'noaanexrad-level2' Amazon S3 bucket[20] (https://aws.amazon.com/public-datasets/nexrad/).

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Author contributions

A.M.D., A.F. and S.K. conceived the study. A.M.D. performed the research and analysed the data. F.A.L.S. calculated species breeding and wintering distribution centroids. K.V.R. compiled transect species compositions from PIF population estimates. A.M.D. wrote the paper with input from all authors.

Competing interests

The authors declare no competing interests.

Additional information

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Bright lights in the big cities: migratory birds' exposure to artificial light

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Many species of migratory birds have evolved the ability to migrate at night, and the recent and rapid expansion of artificial light at night has markedly altered the nighttime sky through which they travel. Migrating birds regularly pass through heavily illuminated landscapes, and bright lights affect avian orientation. But risks to migrating birds from artificial light are not spatially or temporally uniform, representing a challenge for mitigating potential hazards and developing action plans to catalog risks at continental scales. We leveraged over two decades of remote-sensing data collected by weather surveillance radar and satellite-based sensors to identify locations and times of year when the highest numbers of migrating birds are exposed to light pollution in the contiguous US. Our continental-scale quantification of light exposure provides a novel opportunity for dynamic and targeted conservation strategies to address the hazards posed by light pollution to nocturnally migrating birds.

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Trillions of flying organisms (eg birds, bats, insects) occupy the airspace within the troposphere during different periods of their annual cycles (Diehl 2013). The recent recognition of airspace as vital habitat – one that is subject to increasing modification by humans – highlights the fundamental need to understand how organisms cope with such alterations (Lambertucci *et al.* 2015), which pose numerous challenges to airborne organisms during periods of transit, including nocturnally migrating birds. Of the nearly 630 terrestrial species of birds regularly occurring in North America, approximately 70% are considered migratory, and of these more than 80% migrate at night (WebTable 1). Yet most studies of associated risks have focused on terrestrial habitats, underscoring a fundamental knowledge gap that can be addressed with recent technological (including computational) advances.

Light pollution of the airspace is a relatively recent but growing threat to nocturnally migrating birds (Longcore and Rich 2004; Van Doren *et al.* 2017; Cabrera-Cruz *et al.* 2018). Increasing urbanization has greatly amplified the amount of artificial light at night (ALAN; Kyba *et al.* 2017), with almost one-half of the contiguous US experiencing substantially photo-polluted nights (Falchi *et al.* 2016). Light sources – including streetlights, safety lights, and extensively lit buildings – can disturb wildlife in a multitude of ways (Gauthreux and Belser 2005; Hölker *et al.* 2010; Rodríguez *et al.* 2017). High-power light installations like lighthouses and communication towers are known to attract nocturnal migrants and are responsible for substantial mortality (Gauthreux and Belser 2005; Longcore *et al.* 2012). The numbers of birds attracted to or trapped by illumination depend on light wavelength (Poot *et al.* 2008) as well as weather factors such as fog and precipitation (Gauthreux and Belser 2005). High-power light installations can even attract migrants in already heavily photo-polluted areas and in skies with clear weather conditions (Van Doren *et al.* 2017).

An increasing number of artificial structures are now present in the lowest reaches of the troposphere (Davy *et al.* 2017), and their continued expansion poses an ever-increasing threat to wildlife. In the contiguous US, annual fatal bird collisions with buildings, communication towers, power lines, and wind turbines cumulatively number in the hundreds of millions (Loss *et al.* 2015). For nocturnally migrating birds, direct mortality as a result of collisions due to attraction to light (Gauthreux and Belser 2005) is the most obvious and direct effect of ALAN, but there are also more subtle effects, such as disrupted orientation (Poot *et al.* 2008) and changes in habitat selection (McLaren *et al.* 2018). There is also growing evidence that light pollution alters behavior at regional scales, with migrants occupying urban centers at higher-than-expected rates as a function of urban illumination (La Sorte *et al.* 2017). While ALAN acts as an attractant at both large (La Sorte *et al.* 2017) and local (Van Doren *et al.* 2017) scales, there is also evidence of migrating birds avoiding strongly lit areas when selecting critical resting sites needed to rebuild energy stores (McLaren *et al.* 2018).

Challenges to conservation and mitigation

To date, mitigating actions to reduce impacts of ALAN have involved directed and specific efforts, including reductions in excess lighting, the periodic switching off of high-intensity lights (Van Doren *et al.* 2017), and adjusting wavelengths in situations where lights cannot be shut down (Poot *et al.* 2008; Longcore *et al.* 2018). These actions are

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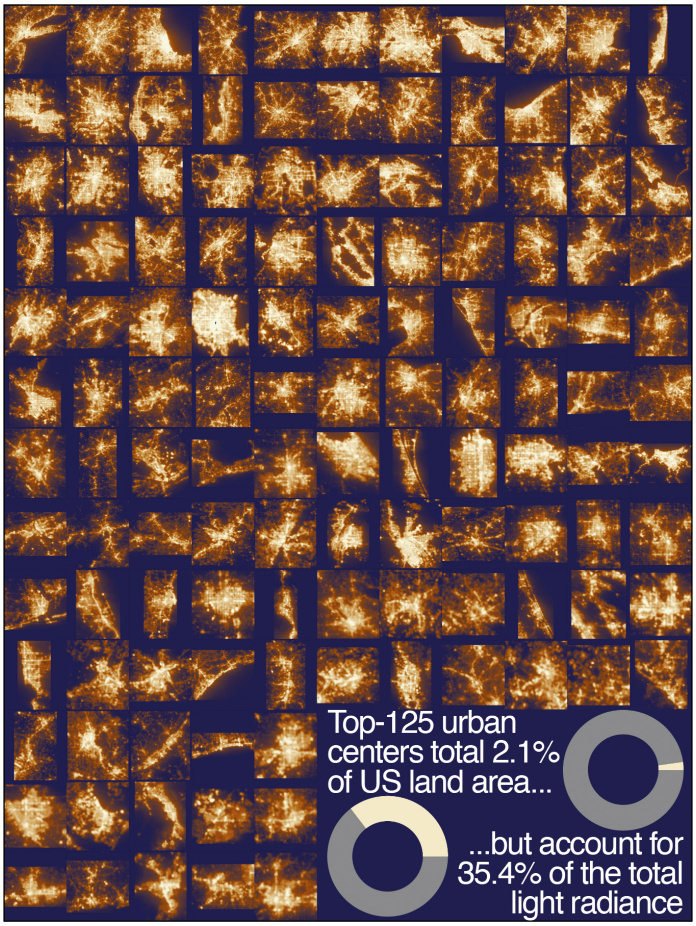

Figure 1. Log_{10}-scaled radiance of artificial light at night (ALAN) measured by the Visible Infrared Imaging Radiometer Suite (VIIRS) on the Suomi-NPP satellite of the 125 largest urban centers (by area) in the continental US. The largest urban center area is depicted in the top-left corner; the second largest area appears to its immediate right, and so forth, across the top-most row. In each successive row, urban center areas continue to decrease in size from left to right.

typically carried out at the scale of individual buildings but occasionally at much larger scales (eg Lights Out Toronto). However, as the intensity and extent of bird migrations vary considerably in space and over time (Van Doren and Horton 2018), so too may exposure risks, requiring detailed and site- and time-specific considerations when implementing mitigation actions and developing conservation plans. To this end, we used radar to quantify the passage of nocturnally migrating birds across the contiguous US, identified the areas where the greatest number of migrants are exposed to light pollution, and mapped this exposure across the US, focusing specifically on the 125 largest urban centers.

Methods

Weather surveillance radar

We used weather surveillance radar (WSR) data from 143 stations from spring (1 March to 31 May) and fall (15 August to 15 November) between spring 1995 and spring 2017 to characterize cumulative migration activity across the contiguous US. We acquired radar data through the Amazon Web Service portal, extracting data from a 30-minute window centered on 3 hours after local sunset. This time period was chosen because it represents the average peak in nocturnal migratory activity (eg Farnsworth *et al.* 2015; Horton *et al.* 2015; see Horton *et al.* [2018] and Van Doren and Horton [2018] for additional details regarding radar processing).

With respect to creating profiles of migration activity, we calculated altitude, speed, and direction using the lowest elevation scans (0.5–4.5°) at distances of 5 km to 37.5 km from the radar station (Farnsworth *et al.* 2015). We determined migration activity from reflectivity (η, $cm^2\ km^{-3}$) and flight direction and groundspeed from radial velocity between 100 m and 3000 m above ground level, at 100-m altitudinal bins using the WSRLIB package (Sheldon 2015). We excluded altitudinal bins with velocity azimuth displays with root mean squared error (RMSE) $<1\ m\ s^{-1}$ to limit contamination of radar readings by insects and removed samples with RMSE $>5\ m\ s^{-1}$ to limit poor fits. In addition, we removed slow-flying objects (airspeed $<5\ m\ s^{-1}$), which are representative of insects (Larkin 1991). To calculate airspeeds, we paired all radar measures of groundspeed and flight direction with wind measures using the North American Regional Reanalysis (NARR). Following these filtering procedures, we integrated reflectivity ($cm^2\ km^{-3}$) across the column of airspace sampled (100–3000 m) into vertically integrated reflectivity (VIR, $cm^2\ km^{-2}$), which represented our measure of migration activity.

To discriminate contaminated scans (ie with precipitation) from precipitation-free scans (ie clear or biologically dominated), we designed a random forest classifier (Horton *et al.* 2019) using the R package "randomForest" (Liaw and Wiener 2002). We trained the classifier on 318,047 (spring: 157,279; fall: 160,768) manually classified nocturnal scans, selected from a 2.5-hour period centered on 3 hours after local sunset on 15 March, 15 April, 15 May, 1 September, 1 October, and 1 November. Scans for each radar and for each year were represented in the training set. We extracted derived predictor variables from profiles of reflectivity, groundspeed, and summaries of the number of volumes above 35 decibels of reflectivity (dBZ) (a value typical of precipitation). We populated 1000 trees and restricted node size to 50 scans. The algorithm classified a total of 2,176,126 scans (spring: 979,326; fall: 1,196,800) with 5.6% classification error during the spring and 4.5% during the fall, as determined using the manually classified scans. As an additional step to reduce the inclusion of samples classified as clear but containing weather, we used only scans with a confidence of being precipitation-free of 75% or higher (rather than a majority rule; ie >50%).

To extrapolate migration activity to areas not sampled by the radars, we relied on a generalized additive model using the R package "mgcv" (Wood 2011; R Core Team 2017). We first calculated the average migration activity for each ordinal day across all years and then summed each night through the season to estimate the cumulative migration activity for each radar station. We fit radar station latitude, longitude, and the interaction of latitude and longitude with smoothing splines to predict the cumulative seasonal activity across the contiguous US.

Artificial light at night

We used the monthly Day/Night Band (DNB) product from the Visible Infrared Imaging Radiometer Suite (VIIRS) onboard the joint National Oceanic and Atmospheric Administration (NOAA)/National Aeronautics and Space Administration Suomi-NPP satellite to quantify the magnitude of ALAN radiance (Earth Observation Group, NOAA National Geophysical Data Center; https://bit.ly/2nCjqvz). Monthly composites of radiance (nanoWatts per square centimeter per steradian; nW cm^{-2} sr^{-1}) are projected at 15 arc-second geographic resolution and are filtered to exclude data from stray light, lightning, lunar illumination, and cloud cover. However, because these data are not filtered for auroras and fires, we averaged across 3 months (October–December) over 6 years (2012–2017) to dampen the influence of episodic lighting events; these months were chosen because they fall outside the primary storm season in North America, which would obscure radiance measures. As an added step to ensure data quality, we excluded any pixel with fewer than 5 use-days prior to averaging monthly composites. Finally, we removed pixels with radiance values greater than 900 nW cm^{-2} sr^{-1} to remove wildfires and other ephemeral high-intensity lighting events (Kyba *et al.* 2017).

Exposure index calculation

To quantify migrant exposure to ALAN, we summarized exposure at two levels: (1) across the contiguous US and (2) in the top 125 largest urban centers by area (Figure 1). We used the 2017 US Census database to define the boundaries of these urban centers and used the primary city name in our presentation of urban area (eg Dallas–Fort Worth–Arlington, Texas, is presented as "Dallas"). Across the contiguous US, we calculated exposure as the product of *cumulative migration activity* × *radiance*, whereas over urban areas we calculated exposure as the product of *cumulative migration activity* × *summed radiance of the entire urban area*. To differentiate seasonal differences irrespective of increases in bird populations, we standardized cumulative migratory activity to range between 0 and 1, and standardized activity relative to the highest value across the contiguous US. Exposure difference was calculated as the product of log_{10}-scaled VIIRS radiance (standardized 0 to 1) and seasonal differences in migratory activity.

Results

Migration activity

Migration activity in spring was greatest in the central US (Figure 2a) and generally more widespread and more easterly in distribution in the fall (Figure 2b). In the western US, we observed greater migratory activity in the spring than in the fall. Furthermore, we observed a 63% increase in cumulative migratory activity from spring to fall. Examining the annual nightly pulses of migratory movements at each radar station, we observed that half of the cumulative migratory activity passed each station in 6.2 ± 2.5 (mean ± standard deviation [SD]) nights in spring and 7.1 ± 2.6 nights in fall.

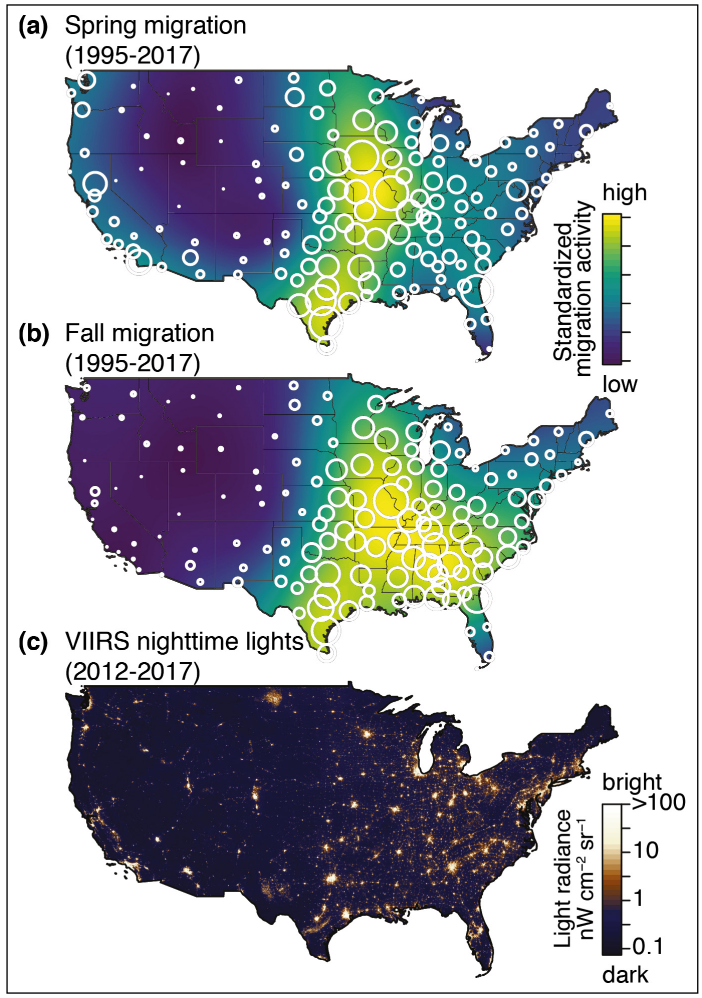

Figure 2. Average cumulative distribution of migrant birds during (a) spring and (b) fall migrations from 1995 to 2017 measured by weather surveillance radar (WSR). Circles indicate WSR station locations and are scaled to cumulative migration activity. The magnitudes of spring and fall cumulative movements are standardized to the same range. (c) Log_{10}-scaled mean radiance of ALAN measured by the VIIRS on the Suomi-NPP satellite.

Light pollution

The general pattern of nightly radiance showed greater average radiance in the eastern half of the US, with a few notable exceptions from urban areas in the Pacific states, Desert Southwest, and a few Rocky Mountain cities (Figure 2c). As expected, the strongest radiance values were observed

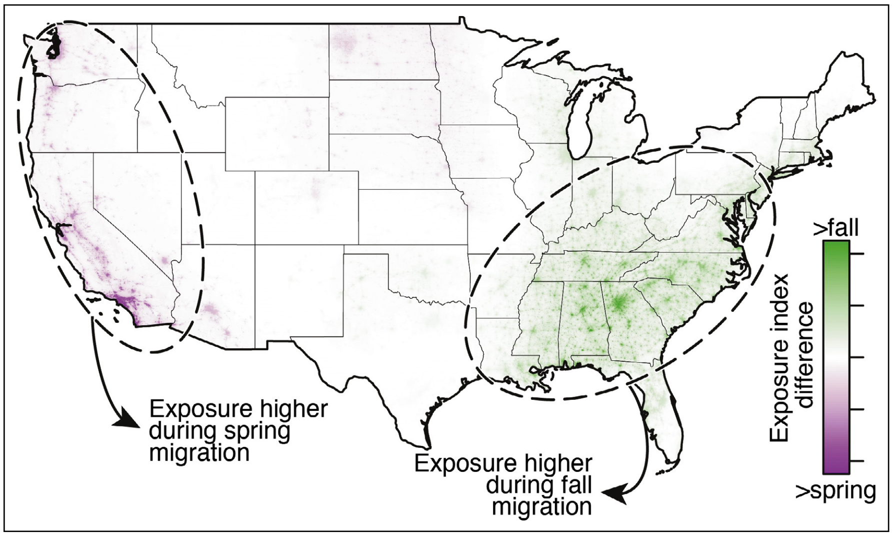

Figure 3. Seasonal differences in exposure to ALAN. The magnitude of spring and fall cumulative movements were standardized to the same range (0 to 1) to highlight seasonal differences in migratory routes. Exposure difference was calculated as the product of $\log_{10}$-scaled VIIRS radiance (standardized 0 to 1) and seasonal differences in migratory activity.

in urban areas. Across the US, 69.5% of the summed linear light radiance came from just 5% of the land area. The top 125 largest urban areas accounted for only 2.1% of total land area and 35.4% of total summed linear radiance.

Continental exposure risk

Increased migratory activity during fall was observed in almost all areas, resulting in 53.8% higher total of exposure in the fall. After standardizing for differences in overall migration activity between seasons, we determined that there was still a 13.1% higher sum of exposure in the fall, when migrants moved through more photo-polluted airspaces in the eastern half of the US (Figure 3). Departures from this trend were evident in the western half of the country, where spring movements along the Pacific coast led to higher spring exposure (Figure 3).

Urban exposure risk over the 125 largest US cites

Mean avian light exposure in cities was 24 times as high as the countrywide average. Larger cities tended toward greater exposure risk (linear regression, spring: $F_{1,123} = 135.8$, $P < 0.001$, $R^2 = 0.52$; fall: $F_{1,123} = 203.1$, $P < 0.001$, $R^2 = 0.62$), but there were notable exceptions, such as Boston (4th in size but 36th and 24th in exposure in spring and fall) and Des Moines (99th in size but 28th and 36th in exposure in spring and fall) (WebTable 2). Regardless of season, the highest levels of exposure to anthropogenic light at night were observed in Chicago, Houston, and Dallas, in descending order (Figure 4; see WebTable 2 for a complete list). These three cities showed exposure magnitudes that were 19 (spring) to 21 (fall) times as high as the median exposure of the remaining 122 cities (Figure 4a). In total, 45 and 74 urban areas exhibited higher spring exposure rankings and higher fall exposure rankings, respectively. Six areas, including Chicago, Houston, and Dallas, showed no change in ranking (Figure 4b). Of the 125 largest US cities, the top 10 greatest changes in seasonal rankings occurred in western states (eg Riverside, San Diego, San Jose; Figure 4b). Of the top 10 risks for exposure, the majority occurred in the central US: seven in spring and six in fall.

Discussion

We conducted a quantitative assessment of continent-scale exposure of actively migrating birds to nighttime light pollution. The findings leverage recent advances in data access and machine learning to capture new and rich details in characterizing bird movements aloft in relation to radiance from human population centers. With considerations for urban areas and the numbers of migrants flying above them, we can now provide the data necessary to guide conservation actions to identify locations where ALAN-reducing programs may be most effective.

Shifted seasonal distributions

Greater abundance of migrants in fall increases the number of birds at risk to ALAN, which was apparent in the general increase in exposure indices from spring to fall. However, shifts in migratory routes between spring and fall migration also affect the numbers of birds exposed to higher light levels (Figure 2). More easterly fall routes, often described as looped migration (La Sorte *et al.* 2014), take birds over more heavily photo-polluted areas than do spring routes, leading to even higher numbers of birds – and many young birds – exposed to ALAN in fall. At most sites, exposure indices are therefore higher during fall than in spring, indicating that any mitigation efforts (eg lights-out campaigns) would have a larger effect during the fall, especially with juveniles as they undertake their first migratory journey. However, while the risk of mortality for juveniles is likely to increase in the fall, any effects of ALAN on migrants in the spring will directly affect breeding activities. Birds moving along westerly routes during spring migration are the exception to this general pattern, likely related to their use of more westerly, low-elevation routes during spring as compared to fall (La Sorte *et al.* 2014). For example, the patterns in Los Angeles and other cities in California are the opposite of most East Coast cities, with higher exposure during spring migration (Figures 3 and 4).

Uneven temporal distributions

Migration periods may span more than 6 months in total, with hundreds of millions of individual migrants aloft on a

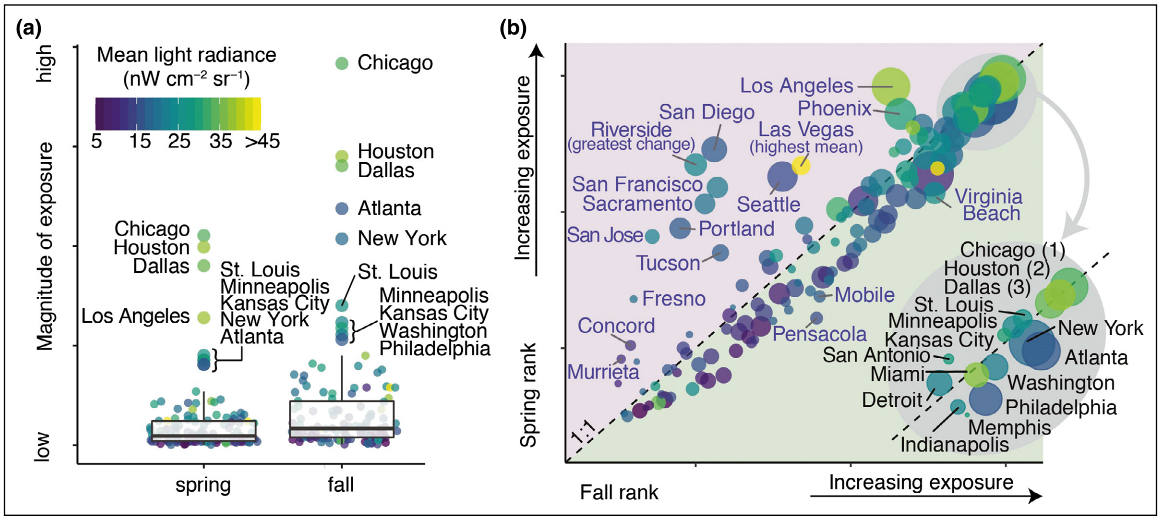

Figure 4. Seasonal (a) magnitude and (b) relative rankings of the 125 largest urban areas in the continental US. Point color shaded by the mean light radiance and sizes (in [b]) are scaled by the square root of urban area. (a) Only urban areas outside the 25th and 75th quartiles are labeled and (b) areas with a change in seasonal rank of ≥20 positions are labeled and identified in blue. Inset in (b) depicts the top 15 (spring or fall) rankings; note that Los Angeles and Phoenix show both ranking changes ≥20 and are ranked in the top 15, and therefore are not included in the inset. Urban areas in the purple shading (above the 1:1 dashed line) had higher spring exposure rankings, whereas those in the green shading (below the 1:1 dashed line) had higher fall exposure rankings.

given night; however, their passage occurs in sporadic waves, with a large majority of birds passing individual sites during just a few peak nights. We observed that half of the total number of migrants for each season passed each radar site in just 6.7 ± 2.6 (mean ± SD) nights, a notable finding when paired with the recent capacity to confidently forecast (12–72 hours in advance) these episodic events (Van Doren and Horton 2018). This advance has the potential to offer a detailed and tailored guide for mitigation actions to substantially lower the numbers of birds exposed to risks of ALAN while simultaneously minimizing adverse effects to stakeholders, including municipalities and industry. In addition, birds disproportionately use modified habitats (eg urban areas) during fall migration (Zuckerberg *et al.* 2016), and because migrants are more numerous and less experienced in fall, an emphasis on fall mitigation efforts is especially important.

Conclusions

ALAN continues to increase in many areas globally (Kyba *et al.* 2017), presenting an ever-growing ecological threat to all nocturnally active animals (Longcore and Rich 2004; Guetté *et al.* 2018), particularly migrating birds. Concerted conservation efforts at local (eg Van Doren *et al*. 2017) and continental scales are necessary to reduce exposure of migrants to light pollution. The disproportionate relationship between the land area occupied by cities and the amount of ALAN emitted leaves little doubt where conservation action is most needed: urban centers. Such efforts require balance with the needs of stakeholders. ALAN ranges from bright sources to dim stray light, and it remains an open question how conservation action should be prioritized over these widely differing sources. In addition, the extent to which species – or even populations – differentially respond to ALAN remains unclear, but could have important conservation implications. Furthermore, different datasets are available (eg a world atlas of artificial night sky brightness; Falchi *et al.* 2016), which may provide valuable information for characterizing ALAN's disruptions to aerial organismal biology (eg horizon glow versus upward radiance). Although we did not directly compare different sources of ALAN information with respect to exposure risks, we believe that such comparisons will be fundamentally important.

Reducing nighttime lights for the benefit of migrants and other wildlife represents yet another instance of anthropogenic and environmental trade-offs, in this case among avian safety, human safety, energy expenditure, and societal and psychological expectations. It is therefore important that conservation efforts and future research are directed to the times and places where they will have the largest impact. An important step in this direction is identifying where the highest numbers of birds are exposed to the highest amounts of ALAN. Here we have shown where the greatest threats exist, and how these threats vary seasonally. The combination of large amounts of nocturnal illumination and their location in the most trafficked airspace across the US elevate metropolitan Chicago, Houston, and Dallas to the top of the exposure risk ranking. While all urban areas should take care to minimize ALAN, our analysis indicates that actions taken in these particular cities would benefit the largest numbers of birds. Through our analysis, we have identified risk; however, directly linking risk with adverse effects on bird populations is a challenge, and future research is needed to fully understand the impacts of ALAN on migratory species.

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Supporting Information

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TITLE

Predicting bird-window collisions with weather radar

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ABSTRACT

1. Up to one billion birds die annually in the U.S. from window collisions; most of these casualties represent migratory native species. Because this major mortality source likely contributes to the decline of the North American avifauna, mitigation tools are needed that accurately predict real-time collision risk, allowing hazards to be minimized before fatalities occur.
2. We assessed the potential use of weather surveillance radar, an emerging tool increasingly used to study and to predict bird migration, as an early warning system to reduce numbers of bird-window collisions.
3. Based on bird-window collision monitoring in Oklahoma, USA, we show that radar-derived migration variables are associated with nightly numbers of collisions. Across the entire night, numbers of collisions increased with higher migration traffic rate (i.e., numbers of birds crossing a fixed line perpendicular to migration direction), and migration variables for specific periods within the night were also related to nightly collisions.
4. *Synthesis and applications:* Our study suggests that radar can be an invaluable tool to predict bird-window collisions and help refine mitigation efforts that reduce collisions such as reducing nighttime lighting emitted from and near buildings.

KEYWORDS

Avian migration, anthropogenic threats, building collisions, WSR-88D, NEXRAD, urbanization, wildlife mortality

1. **INTRODUCTION**

Human structures and activities are increasingly encroaching into the aerosphere, the aerial habitat used by volant animals (Lambertucci et al. 2015). Collisions with human-built structures (e.g., buildings, communication towers, energy infrastructure) are primary hazards, causing up to 1.5 billion avian fatalities annually in the United States (Loss et al. 2015). Collisions with buildings, especially their windows, cause up to 1 billion of these annual fatalities and primarily affect migratory native bird species during migration periods (Loss et al. 2014, Elmore et al. 2020a). Nocturnally migrating birds comprise the majority of these casualties and are the most frequent collision victims at buildings and many other structures (e.g., communication towers), partly due to attraction and disorientation caused by artificial light at night (ALAN) emanating from and near buildings (Lao et al. 2020, Winger et al. 2019). Collisions may occur when birds are ascending to or descending from migration cruising altitudes during time periods near dusk or dawn, respectively, or at any time of night when birds fly at lower altitudes, including due to changing and inclement weather conditions (Newton 2007; Lao 2019).

Mitigation to reduce bird collisions (e.g., reducing ALAN), including the hundreds of millions of window collisions, would be improved if collision risk could be related to numbers of migratory birds aloft. Confirming this relationship would provide a mechanism to use migration forecasts as a proxy for collision risk. Nocturnally migrating birds are extremely difficult to monitor because direct visual observation of birds flying under cover of darkness and at high speed and altitude is often impossible. Acoustic monitoring can help identify species composition of migratory birds aloft but is severely constrained by species' behavior and factors influencing detection (e.g. distance, signal-to-noise ratio) (Farnsworth 2005, Sanders and Mennill 2014). Weather surveillance radar (WSR) is a proven tool for monitoring nocturnally migrating birds and other organisms in the aerosphere (Dokter et al. 2018b, Horton et al. 2016). Recent studies have used radar to examine how abiotic variables (e.g., wind, barometric pressure, precipitation) influence flying animals (e.g., flight timing, speed, orientation, direction, and altitude) (Dokter et al. 2013). Radar-derived estimates of variables like migration traffic rate (MTR, the number of birds crossing a fixed imaginary line perpendicular to migratory direction), migration speed (distance covered over time at ground-level), and migration altitude (average altitude above ground), have shed unprecedented light on bird migration and could be valuable for predicting collisions with manmade structures (Shamoun-Baranes et al. 2016).

Recent technological advances using radar—including machine learning approaches that enhance the ability to discern biological signatures from precipitation (Lin et al. 2019) and continent-scale prediction of bird migration (Van Doren and Horton 2018)—suggest the possibility of characterizing broad-scale relationships between collisions and radar-derived estimates of aerial migration activity. However, only small-scale applications of mobile, low-powered, marine surveillance radar units (Gauthreaux and Besler 2003) have been investigated. The larger, higher-powered WSR-88D (NEXRAD) network, which includes 143 units across the continental U.S., has been employed for near real-time, broad-scale monitoring and forecasting of bird migration (Horton et al. 2016, Van Doren and Horton 2018), and could allow broad-scale prediction of bird-structure collisions.

To test the use of NEXRAD to predict bird collisions more broadly, we conducted bird-window collision monitoring in Stillwater, Oklahoma, USA, and related nightly numbers of collision fatalities to radar-derived measures of nocturnal bird migration. Specifically, we considered radar-derived bird migration traffic rate, speed, and altitude averaged across entire nights preceding collision surveys. We also considered these variables measured for particular periods of the night to evaluate risk in association with important migration events (i.e. ascent to and descent from migration cruising altitude at dusk and dawn, respectively) and with weather conditions and changes during different times of night.

2. MATERIALS AND METHODS

2.1 Collision data

We conducted collision monitoring in Stillwater, Oklahoma, USA, a small urban area with only three buildings taller than five floors. Stillwater covers an area of approximately 76.51 km^2, had an estimated human population of 50,299 in 2019 (United States Census Bureau 2019), and is located in the cross-timbers ecoregion (a transitional zone where eastern deciduous forests interlace with grasslands of the Great Plains). The amount and brightness of ALAN in Stillwater is substantially less than in larger cities, including nearby large cities ≥65 km away (maximum level of approximate total brightness in Stillwater: 1.96-3.74 millicandelas [mcd]/m^2, compared to Tulsa and Oklahoma City, Oklahoma: 3.74-7.30 mcd/m^2, and Dallas, Texas: >7.30 mcd/m^2) (Falchi et al. 2016; see also analysis of ALAN variation among U.S. cities in Horton et al. 2019).

Study design and collision surveys are fully described in Riding et al. (2020). Early morning surveys were conducted at 17 buildings during spring migration (April-May) 2015-2017 and fall migration (September-October) 2015-2016. Although most buildings were surveyed 6 days/week, we occasionally missed surveys at one or a few buildings, and only one building was surveyed on Sundays. As described below, these differences in survey effort and schedule were accounted for in the carcass removal estimates and statistical analyses. Monitored buildings were selected based on size and amount of surrounding vegetation; selected buildings were less than 27 m tall and included individual residential houses, commercial and university office buildings, and an athletics arena. Authors, technicians, and citizen scientists conducted surveys, which began between 0700-0900 CST. Surveyors walked around each building (alternating directions on successive days) searching for bird carcasses within two meters of the exterior base of buildings and documenting species or descriptions of all carcasses/remains (Figure 1). When we discovered a carcass, we took photographs, documented location and descriptive information, and collected remains in sealable plastic bags. We summed total fatal collisions across all buildings for each day, only including birds that were likely migrants. We designated migratory status (resident, migrant, or unknown, with only migrants included in analyses) for individual birds based on date of collision occurrence, bird age (e.g., hatch year birds unlikely to be migrants in late spring or early summer), seasonal occurrence data from eBird (Sullivan et al. 2009), and species-specific arrival, migration, and departure dates for our study area (Oklahoma Bird Records Committee 2014). We also used information from experimental carcass removal and surveyor detection trials, conducted at the same buildings and time, to generate adjusted nightly estimates of migratory bird collisions that account for carcass removal by humans and animals and imperfect detection by surveyors (Riding & Loss 2018). As part of these adjusted estimates, among-building differences in inter-survey time intervals were accounted for because removal estimates require building-specific schedules of collision surveys.

2.2 Radar-derived migration data

We collected radar data from level-II NEXRAD archived on the Amazon Web Services cloud (Amazon Web Services, Ansari et al. 2017), which scans the airspace every 5-10 minutes, collecting data in each 250 m-radius horizontal distance band centered on the radar. The radar also collects elevation-specific information within each distance band, allowing characterization of the distribution of birds' flight altitudes. Because our study area was >85 km from all NEXRAD installations, estimates of migration variables were averaged among three Oklahoma radar sites (KTLX in Oklahoma City, KVNX in Jet, KINX in Inola) (Figure 2). We averaged measures across all scans for the entire night preceding each collision survey (civil dusk to civil dawn, i.e., inclusive of times when the sun is $\geq 6^0$ below horizon, with times shifting seasonally), and for four time periods within the night associated with different migration events (e.g., ascension to and descent from migration cruising altitude at dusk and dawn), intensities of bird migration, and effects of weather on collisions (Lao 2019). These periods included: (1) civil dusk until one hour later, (2) one hour after civil dusk until the nightly midpoint between civil dusk and dawn, (3) the nightly midpoint until one hour before civil dawn, and (4) one hour preceding civil dawn.

We used the bioRad package (Dokter et al. 2018a) in R version 3.5.3 (R Core Team 2019) to extract bird migration variables for each scan 5-25 km from each radar. We used recommended settings of algorithm parameters in the 'calculate_vp' function to filter out precipitation (correlation coefficient threshold set to 0.95) and insects (standard deviation of volume velocity profiling technique threshold set to one m/s; radar cross-section of individuals=11 cm^2; Dokter et al. 2018a). We calculated three specific radar-derived migration variables (with each averaged across all horizontal bands and altitudes for each radar, then averaged across radars): migration traffic rate (MTR), speed, and altitude. We define MTR as number of birds hr^{-1} within the elevation layer of interest crossing a one km line perpendicular to migratory direction. The unit for MTR was birds km hr^{-1} calculated as: MTR=bird density (birds km^{-3}) x bird speed (km hr^{-1}) for each layer (altitude in km above ground level). We define speed as distance covered over time at ground level (groundspeed) and altitude as average distance above ground level at each radar location (since altitude above sea level varies among radar locations).

2.3 Statistical Analyses

Because adjusted nightly estimates of collision fatalities (replicate=night) were continuous, not integers, we used the cplm package in R (Zhang 2013) to implement generalized linear models with a tweedie compound poison-gamma error distribution, a distribution type that handles continuous, zero-inflated data without modeling zero and non-zero values separately. We also accounted for variation in survey effort among buildings by including an offset in all models for the daily number of buildings surveyed. Predictor variables considered included MTR, speed, and altitude. For highly correlated predictors ($|r| \geq 0.7$), we used variable importance rankings from the party package (Strobl et al. 2008) and retained variables ranked highest for analysis. Highly correlated variables were never included in the same model.

For analyses with migration variables averaged across the entire night (three analyses, one each for spring and fall and one for both seasons combined), no predictors were highly correlated, thus we considered 14 candidate models. These included: a null model, 7 models capturing all possible combinations of predictor variables but with no interactions, 3 models capturing all possible single, two-way interactions (here and below, interactions included both linear and interaction effects, e.g., MTR*altitude tested both independent and interactive effects of MTR and altitude), and 3 models capturing all combinations of one two-way interaction with one additional two-way interaction (e.g., MTR*altitude+MTR*speed). For analyses with migration variables calculated for separate periods of night (again, including a spring analysis, fall analysis, and combined-season analysis), we considered 55 candidate models. These included: a null model, 4 models with only MTR from each time period, 18 models capturing all possible single, two-way interactions between MTR from each time period and each other radar-derived predictor variable from each time period, and 32 models capturing all combinations of one two-way interaction with one additional two-way interaction including MTR from each time period (MTR was evaluated in this way because this factor was determined to be extremely important in variable importance rankings, but was often highly correlated across different times periods within a night).

For each analysis, we used Akaike's information criterion (AIC) in the bbmle package (Bolker 2017) to rank models and considered models competitive when ΔAIC=0-2 and at least two less than the null model, after elimination of uninformative parameters (Arnold 2010). Variables in supported models were considered meaningfully associated with collisions when 85% confidence intervals (CIs) of coefficient estimates did not overlap zero; use of 85% CIs (instead of 95% CIs) to evaluate variable importance aligns with the AIC model selection framework by avoiding disregard of variables supported by lower AIC values (Arnold 2010). When there were multiple competitive models, we used model averaging in the MuMIn package (Barton 2018) to recalculate beta coefficients and CIs.

3. RESULTS

We conducted 3857 collision surveys over 301 total days (a survey entailed one building being surveyed once) and documented 304 total bird collision fatalities. Of these, 227 fatalities (representing 54 species) were considered migrating individuals and thus included in analyses, including species that only occur as passage migrants in our study area (e.g,. Swainson's Thrush [*Catharus ustulatus*], Nashville Warbler [*Leiothlypis ruficapilla*], Mourning Warbler [*Geothlypis philadelphia*]) and individuals of summer resident species (e.g., Ruby-throated Hummingbird [*Archilochus colubris*], Painted Bunting [*Passerina ciris*], Grasshopper Sparrow [*Ammodramus savannarum*]) or winter resident species (e.g., Cedar Waxwing [*Bombycilla cedrorum*], Lincoln's Sparrow [*Melospiza lincolnii*], Orange-crowned Warbler [*Vermivora celata*]) that we found during species-specific migration periods (Elmore et al. 2020b). Our total adjusted fatality estimate across all buildings, considering only migrant individuals and accounting for carcass removal and detection, was 270 birds. At least one collision occurred on 127 nights, and the greatest nightly collision count was seven birds.

For the spring analysis with radar-derived migration variables averaged throughout the night (n=179 nights), the top model included a MTR*altitude interaction and independent effects of MTR and altitude (Supplementary material). However, MTR was the only variable with a meaningful effect (i.e., with the 85% CI of its coefficient estimate not overlapping zero) (Figure 1). For the fall whole-night analysis (n=122 nights), six top models were averaged and included MTR*altitude and MTR*speed interactions, as well as independent effects of MTR, speed, and altitude (Supplementary material); however, 85% CIs of coefficient estimates overlapped zero for all of these variables (Table 1). When pooling spring and fall (n=301 nights), the top model included MTR*altitude and MTR*speed interactions, as well as independent effects of MTR, altitude, and speed (Supplementary material). However, only MTR had a meaningful effect based on 85% Cis (Figure 1). These results collectively suggest that sample size may have limited the apparent importance of MTR for the fall season analysis, and that this factor may be important regardless of season. The positive coefficient for this factor indicates that the number of collision fatalities increases with increasing MTR.

For the spring analysis with migration variables calculated for different periods of night, the top model included three variables with 85% CIs not overlapping zero: the independent effect of MTR at civil dawn; the interaction between MTR at civil dusk and MTR at civil dawn; and the interaction between MTR at civil dusk and speed at civil dawn (Table 2 and Supplementary material). The first term indicates increasing collision fatalities with higher MTR at civil dawn. The two interactions indicate that fatalities increase with higher MTR at dusk, especially when MTR is also high at civil dawn, or when migration speed is low at dawn. For the fall analysis for different periods of night, the top model included only one variable with its 85% CI not overlapping zero: speed at civil dusk (Table 2 and Supplementary material). The negative coefficient for this variable indicates collision fatalities increase with decreasing speed at civil dusk. For the analysis with data for both seasons pooled together, and with migration variables calculated for different periods of night, only one model was strongly supported, and MTR during the first half of night was the only variable with its 85% CI not overlapping zero (Table 2 and Supplementary material). The positive coefficient for this variable indicates that collision fatalities increase with increasing MTR in the first half of night.

4. DISCUSSION

The ability to predict bird-window collisions would greatly benefit efforts to mitigate this substantial threat to birds, and thus contribute to halting and reversing widespread declines of avian populations (Rosenberg et al. 2019). We demonstrate that radar-derived migration variables were associated with nightly numbers of bird-window collisions in Stillwater, Oklahoma, USA. Although further research in multiple study areas is needed to confirm the broad-scale predictive capability of the NEXRAD network across the United States, our findings show that radar has strong potential to help refine management approaches that reduce bird collisions with buildings, and perhaps other human-built structures.

For spring and pooled spring-fall analyses of radar-derived variables averaged throughout the night, nightly collisions were positively associated with MTR. Thus, our study confirms that higher numbers of birds passing over areas with many human-built structures in the airspace and/or light pollution associated with buildings and cities (Horton et al. 2019) can lead to increased bird-window collision fatalities. An interaction between MTR and flight altitude was also included in top models for all analyses with radar variables averaged throughout the night. Although coefficients for this interaction suggest that the increase in collisions with increasing MTR is especially pronounced when flight altitude averages lower, CIs of coefficients overlapped zero, complicating interpretation of this effect. Other studies have speculated that when large numbers of birds migrate at low altitudes, collisions with human-built structures (e.g., wind turbines) likely increase (Drewitt and Langston 2006, Furness et al. 2013). These studies have focused primarily on risk prediction, and no research has directly validated the predicted relationship between flight altitude and collisions. Bird migration altitudes vary with time of year, time of day/night, and multiple interacting weather conditions, including presence of low cloud ceilings, headwinds, and precipitation (Bruderer et al. 2018, Dokter et al. 2013, Lao 2019). Further, ALAN "sky glow" is exacerbated by low clouds and precipitation (Kyba et al. 2015). Studies have linked building collisions with both ALAN (Winger et al. 2019 Lao et al. 2020) and the above types of inclement weather (Loss et al. 2020), suggesting that low average flight altitude, as driven by factors like weather and lighting, may also increase collisions.

Analyses with radar variables measured for separate periods of night provide further insight into how radar could be used to predict collisions and how mitigation could potentially be targeted toward particular time periods and/or weather conditions. Spring collisions increased with high MTR at dawn, and with high MTR at dusk especially when MTR was also high at dawn or flight speed was also low at dawn. Fall collisions increased with low flight speed at dusk, and for the pooled spring-fall analysis, collisions increased with high MTR in the first half of night. In spring, high MTR at dawn, especially when combined with high MTR at dusk of the previous evening, could indicate favorable conditions (e.g., tailwinds) throughout the night causing high-volume migration, including from exodus near dusk until set-down at or after dawn. Such favorable migration conditions throughout the night could increase collisions near dusk and dawn as large numbers of low-flying individuals ascend or descend, respectively, or they could cause collisions to be increased throughout the night due to a relatively large number of birds migrating in the airspace all night long. The increase in spring collisions with reduced migration speed at dawn, and the similar effect of reduced speed at dusk in fall, could reflect unfavorable weather conditions (e.g., headwinds) causing birds to descend in an exhausted state near dawn or to struggle to depart during migration exodus in the evening, both of which could increase collision vulnerability. For the pooled spring-fall analysis, the higher number of collisions with high MTR in the first half of night may occur for similar reasons as for the effect of MTR at dusk in spring; specifically, favorable conditions early may cause a high number of birds to depart, possibly increasing collisions during ascension to cruising altitude.

Although the above results strongly suggest the utility of radar for predicting bird collisions, increased predictive understanding of collisions requires studies that merge radar and meteorological data to assess how birds alter migration in response to the interaction between weather and lighting at different times of night. Our study was in a small urban area with few tall buildings (i.e., no skyscrapers and few buildings taller than 5 floors), and compared to larger metropolitan areas, the amount and brightness of ALAN is substantially less. We expect patterns exhibited by our results to be even more pronounced in areas with numerous tall structures and a greater amount or brightness of ALAN because large amounts of bright lighting projected into the aerosphere greatly alter MTR, flight altitude, and speed, attracting migrants (Horton et al. 2019, Van Doren et al. 2017) and elevating numbers of collisions (Lao et al. 2020, Winger et al. 2019). Further, even though our study was >85 km from the three radar installations, radar-derived variables measured within 5-25 km of our study area were still associated with collisions. This suggests that using distant radars is still a valid approach to predict collisions; predictive ability may be further increased for cities with closer radar sites.

Although we focused our analysis on migrating individuals, most of which were species that are known nocturnal migrants (e.g., thrushes, warblers, sparrows) and a few diurnal migrants (e.g., hummingbirds), some collisions may have occurred during daylight hours on the day preceding our early morning surveys. We would not expect these collisions to be associated with radar-derived variables calculated for the night after they occurred. Nonetheless, a companion study conducted at a subset of the same buildings found that the majority of bird collisions occurred during the night, as evidenced by far more collision casualties being found on early morning surveys than midday and evening surveys (Riding 2019; see also Loss et al. 2019). Despite most collisions occurring at night, further research is needed to clarify the exact time of night when most collisions occur. This information would clarify if variables measured for particular times of night are related to collisions due to collisions occurring at those same times of night or due to indirect relationships with collisions occurring at other times of night.

5. CONCLUSION

Bird-window collisions are an increasing threat to migratory birds due to urban expansion, infrastructure growth, and increasing ALAN (Cabrera-Cruz et al. 2018, Horton et al. 2019, Kyba et al. 2016, Seto et al. 2012). We show that collisions are associated with radar-derived measurements of migration, including migration traffic rate and speed. In addition to high MTR being associated with more collision fatalities based on nightly measurements of this migration variable, MTR and migration speed at particular times of night also influenced nightly collisions, suggesting that these measurements can help refine collision predictions.

Our study highlights the importance of using radar data to inform mitigation such as lighting reduction policies and guidelines (e.g., Audubon's "Lights Out" program, BirdCast "Lights Out Alerts", and other specific migration alerts; e.g., https://aeroecolab.com/uslights), which may decrease avian attraction, increase flight altitude, and reduce collisions for migratory birds. Implementation of such mitigation efforts may be particularly important on nights when bird migration is forecasted or observed to be intense with high migration traffic rate throughout the night. Our results also suggest that such mitigation measures could be refined using radar variables measured for particular periods of the night. For example, while general ALAN reduction alerts could always be issued when MTR is high throughout the night, alerts with enhanced wording or urgency could be issued when migration speed is also predicted or observed to be low at dusk or dawn, including in association with changing or inclement weather conditions, like storm fronts, that reduce migration speed. Moreover, if such conditions at particular times of night directly lead to collisions at those same times of night (as opposed to being indirectly related to collisions at other times of night), then targeting ALAN reduction toward certain times could be an effective approach to reduce collisions that may have broader appeal than turning lights off for the entire night.

Our results indicate the potential for near-real time, continent-scale prediction of bird collisions based on modification of algorithms used in existing bird migration forecasts such as

BirdCast (Van Doren and Horton, 2018). Although further studies should be conducted across multiple sites at broader spatial scales, radar has potential to predict bird collisions at a wide variety of human-made structures, and thus contribute to reducing human-caused mortality that affects North American bird populations.

AUTHORS' CONTRIBUTIONS

JAE Conceptualization, Methodology, Formal analysis, Investigation, Writing- original draft, review, & editing, Visualization. **CSR** Methodology, Investigation, Resources, Data Curation, Writing- review & editing. **KGH:** Conceptualization**,** Methodology, Writing- review & editing. **TJO:** Methodology, Investigation, Resources, Data Curation, Writing- review & editing. **AF:** Conceptualization**,** Methodology, Writing- review & editing. **SRL:** Conceptualization, Methodology, Resources, Writing- review & editing, Supervision, Funding acquisition. **All Authors**: gave final approval for publication.

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SUPPLEMENTARY MATERIAL

Candidate models and AIC rankings are available as tables in the supplementary material.

DATA AVAILABILITY STATEMENT

All radar data used in this analysis is open access and archived on the Amazon Web Services cloud (Amazon Web Services, NEXRAD on AWS). The full dataset of bird collisions is available via the Dryad Digital Repository https://doi.org/10.5061/dryad.b2rbnzsd2 (Elmore et al. 2020b).

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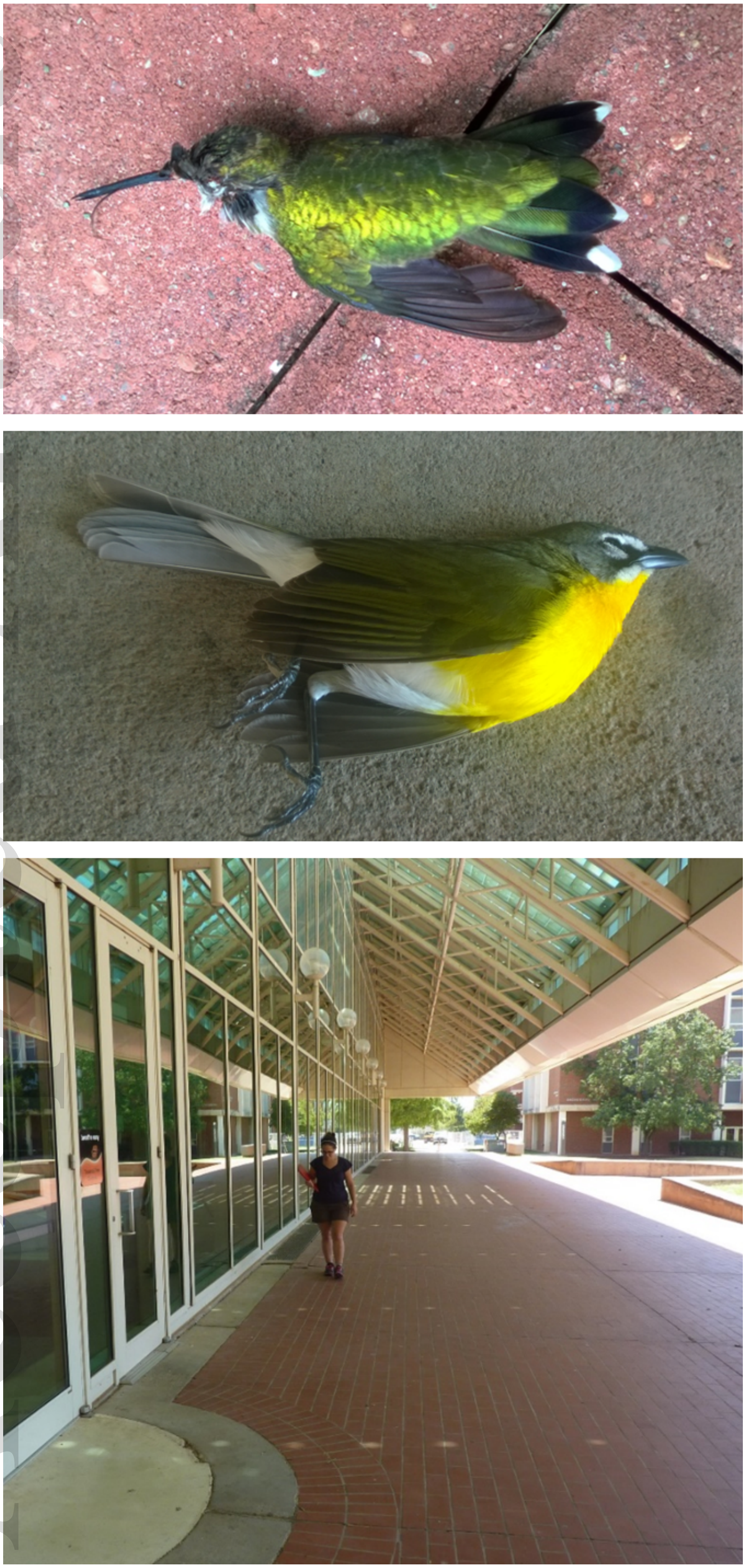

Figure 1. Collisions with building windows annually cause up to 1 billion bird fatalities in the United States. This (a) Ruby-throated Hummingbird (*Archilochus colubris*) and (b) Yellow-breasted Chat (*Icteria virens*) were both collision casualties found at our study site in Stillwater, Oklahoma, USA where we conducted (c) near-daily surveys of building perimeters to document bird collisions during migration periods.

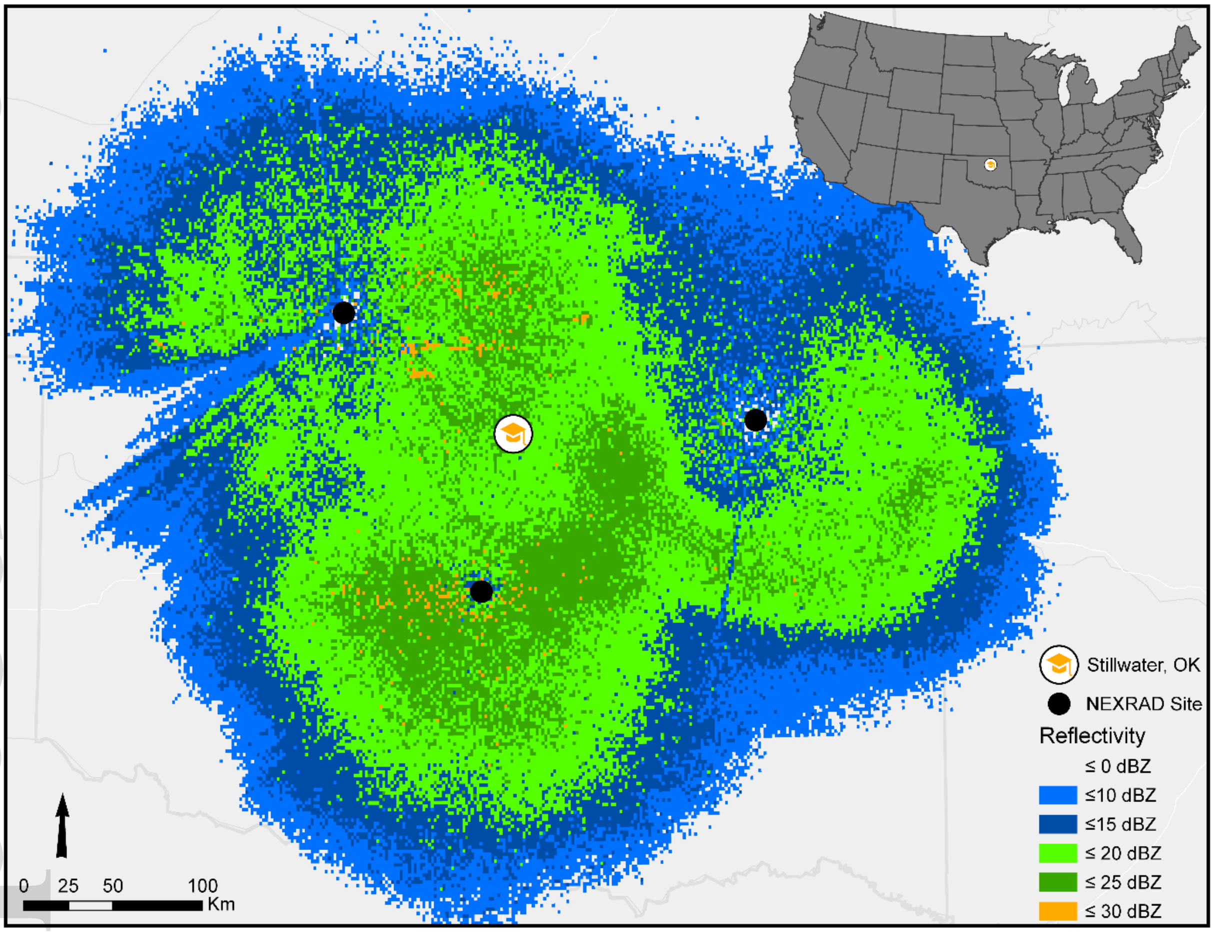

Figure 2. Map of Stillwater, Oklahoma, USA, with three surrounding NEXRAD sites used for data analysis (color overlay represents radar-derived reflectivity; estimated numbers of birds aloft increases with increasing reflectivity). Because NEXRAD sites were >85 km from Stillwater, data were averaged across these three radars (although image shows reflectivity beyond 25 km from each radar, we only used data 5-25 km from each radar to generate migration variables; see text for details).

Table 1. Top model beta coefficients and 85% confidence intervals for models averaged across the entire night (see WebTable 1 for full model rankings). * designates interaction term.

Spring model predictors	Beta coefficient	7.5%	92.5%
MTR	3.757^{-4}	1.152^{-4}	7.886^{-4}
Altitude	-2.459^{-4}	-2.046^{-3}	1.554^{-3}
MTR* altitude	-4.280^{-7}	-9.456^{-7}	8.970^{-8}
Fall model predictors	**Beta coefficient**	**7.5%**	**92.5%**
MTR	2.320^{-4}	-5.456^{-5}	5.186^{-4}
Altitude	-8.106^{-4}	-3.523^{-3}	1.901^{-3}
Speed	-1.849^{-1}	-4.991^{-1}	1.293^{-1}
MTR* altitude	-4.222^{-7}	-1.117^{-6}	2.721^{-7}
Speed*altitude	4.905^{-4}	-2.253^{-4}	1.206^{-3}
MTR*speed	-1.353^{-5}	-3.233^{-5}	5.275^{-6}
Combined season model predictors	**Beta coefficient**	**7.5%**	**92.5%**
MTR	4.613^{-4}	2.054^{-4}	7.171^{-4}
Altitude	-5.041^{-4}	-2.044^{-3}	1.036^{-3}
Speed	4.784^{-2}	-9.014^{-3}	1.047^{-1}
MTR* altitude	-3.235^{-7}	-7.237^{-7}	7.680^{-8}
MTR*speed	-1.110^{-5}	-2.341^{-5}	1.213^{-6}

Table 2. Top model beta coefficients and 85% confidence intervals for models averaged during four different time periods throughout the night (see WebTable 2 for full model rankings). * designates interaction term.

Spring model predictors	Beta coefficient	7.5%	92.5%
Civil dusk MTR	-1.059^{-4}	-4.570^{-4}	2.452^{-4}
Civil dawn MTR	5.257^{-4}	2.960^{-4}	7.554^{-4}
Civil dawn speed	-4.139^{-2}	-1.225^{-1}	3.972^{-2}
Civil dusk MTR* civil dawn speed	3.149^{-7}	4.757^{-6}	5.823^{-5}
Civil dusk MTR* civil dawn MTR	-1.115^{-7}	-1.743^{-7}	-4.878^{-8}

Fall model predictors	Beta coefficient	7.5%	92.5%
First half MTR	-1.719^{-4}	-5.214^{-4}	1.775^{-4}
Civil dusk speed	-2.874^{-1}	-5.094^{-1}	-6.550^{-2}
Civil dawn speed	1.948^{-1}	-1.102^{-2}	4.006^{-1}
Civil dusk speed* first half MTR	3.166^{-5}	-5.645^{-7}	6.389^{-5}
Civil dawn speed* first half MTR	3.744^{-6}	-1.978^{-5}	2.727^{-5}

Combined season model predictors	Beta coefficient	7.5%	92.5%
First half MTR	1.671^{-5}	3.096^{-5}	3.033^{-4}
Civil dusk speed	-2.899^{-2}	-1.057^{-1}	4.771^{-2}
Civil dawn speed	7.029^{-2}	-1.092^{-2}	1.515^{-1}
Civil dusk speed* first half MTR	-8.004^{-6}	-1.967^{-5}	3.663^{-6}
Civil dawn speed* first half MTR	3.527^{-6}	-5.116^{-6}	1.217^{-5}

Near-term ecological forecasting for dynamic aeroconservation of migratory birds

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Article impact statement: Ecological forecasting can efficiently alert conservation activities to mitigate aerial hazards for in-flight migratory birds.

Abstract: Near-term ecological forecasting has potential to mitigate the negative impacts of human modifications on wildlife by directing efficient dynamic conservation action through relevant and timely predictions. We use the North American avian migration system to highlight ecological forecasting applications for aeroconservation. We use millions of observations from 143 weather surveillance radars to construct and evaluate a migration forecasting system for nocturnal bird migration over the contiguous United States. We identified the number of nights of mitigation action required to reduce risk to 50% of avian migrants passing a given area in spring and autumn based on dynamic forecasts of migration activity. We also investigated an alternative approach, employing a fixed conservation strategy using time windows that historically capture 50% of migratory passage. In practice, during both spring and autumn, dynamic forecasts required fewer action nights compared to fixed window selection at all locations (spring: mean of 7.3 more alert days; fall: mean of 12.8 more alert days). This pattern resulted in part from the pulsed nature of bird migration captured in the radar data, where the majority (53.4%) of birds move on 10% of a migration season's nights. Our results highlight the benefits of near-term ecological forecasting and the potential advantages of dynamic mitigation strategies over static ones, especially in the face of increasing risks to migrating birds from light pollution, wind energy, and collisions with structures.

Introduction:

Knowing when to direct action to protect species and habitats is essential for successful conservation efforts (Wilson et al. 2005; Knight et al. 2010), and there are many examples of such campaigns (Luther et al. 2016; Liberati et al. 2019; Wilson et al. 2019; Burgess et al. 2019; Watts et al. 2020). Safeguarding highly dynamic ecological processes, such as movement and migration, poses a greater challenge (Reynolds et al. 2017). However, the spatial process of migration also creates an opportunity to reduce the amount of time during which conservation measures are necessary at any particular location. Ecological forecasting of animal movements at relevant spatial and temporal scales may provide a pathway toward real-time conservation (Dietze et al. 2018; Van Doren & Horton 2018). Days, hours, or even minutes can make the difference between successful intervention and missed opportunity when considering highly vagile species. Timely, forecasted conservation actions relevant to migrating species may include the temporary removal of terrestrial or aquatic barriers (e.g., fences, dams), aerial obstacles (e.g., wind turbines, aircraft), or point-source pollutants (e.g., light pollution, chemical pollution) (Marschall et al. 2011; Naidoo et al. 2012; Van Doren et al. 2017).

Amidst a large diversity of migratory taxa, bird movements embody these conservation challenges, both in space and time, with movements spanning weeks to months across hundreds to thousands of kilometers through diverse ecosystems (Thorup et al. 2020; Bauer et al. 2020). While a large percentage of migratory birds' annual cycles may be based in terrestrial or aquatic systems, twice annually, billions of birds fill the lower atmosphere en route to wintering or breeding grounds (Dokter et al. 2018). Spring and autumn migratory seasons often encompass multiple months, but movements are not uniformly distributed in space or time (Horton et al. 2020). During any year in a given location, the majority of migrants will pass overhead within a period of days or weeks (Horton et al. 2020), but the specific nights of the highest migration vary across locations and years. Understanding, quantifying, and predicting this variation is essential in directing conservation action.

Migratory birds increasingly encounter aerial threats from human development (Davy et al. 2017), some of which can be mitigated by specific conservation actions. These threats are diverse in size, shape, and their impact on migratory birds. Some of these threats induce mortality directly, for instance collisions with buildings (Loss et al. 2014a), wind turbines (Loss et al. 2013), or communication towers (Gehring et al. 2009; Loss et al. 2014b). Other threats are more diffuse in their impact. For example, light pollution may direct migrants to inhospitable urban spaces (Zuckerberg et al. 2016; La Sorte et al. 2017; Van Doren et al. 2017; Lao et al. 2020), putting those individuals at risk through diminished energy reserves, phenological delays, and susceptibility to predation or injury — each factor potentially resulting in difficult-to-measure fitness consequences. Mitigation is possible for some types of these threats, thereby enhancing safe passage of migrating birds. For example, on nights of high migratory activity, lights can be dimmed or turned off on man-made structures, or activities changed (e.g., stopping wind turbines). Predicting the specific nights on which birds will migrate has tremendous value for safeguarding aerial passage.

A significant hurdle to implementing dynamic conservation approaches is the availability of timely alerts for when action is necessary. Remote sensing tools (e.g., radar, acoustics, infrared imaging) can measure real-time nightly movements of avian migrants (Horton et al. 2015), providing invaluable information to employ toward conservation. But even such instantaneous measures are too late to prevent collisions. One approach to address this challenge is to leverage historical measures to identify the seasonal windows during which the majority of migration tends to occur (e.g., a time period that captures 50% of activity) and direct conservation action during those fixed time windows; however, migration is highly dynamic, and the timing of migratory movements is strongly influenced by shifting atmospheric conditions (Åkesson & Hedenström 2000; Liechti 2006; Shamoun-Baranes et al. 2010). For this reason, migration shows night-to-night periodicity (Åkesson & Hedenström 2000; Deppe et al. 2015). A fixed window approach would, therefore, be apt to capture nights of both high and low migratory activity, that may lead to costly effort that has limited impact and the potential to miss important events occurring outside the fixed window. Ecological forecasts offer an alternative approach for facilitating short-term conservation actions (Clark et al. 2001; Luo et al. 2011). Forecasts, by nature, are temporally and spatially dynamic, offering lead-time for the deployment of conservation action. Van Doren and Horton (2018) built a forecasting system for predicting bird migration using radar and atmospheric conditions, however this study did not examine how to operationalize forecasts to direct conservation efforts. Analytically, this dynamic selection approach presents a modeling challenge, as large movements comprise a small fraction of the duration of a migratory season (Horton et al. 2019a). While error is an inherent property of any ecological forecast, a sufficiently accurate forecast may still capture more activity across fewer nights than a historically defined window.

To address the need for conservation solutions to mitigate hazards for nocturnally migrating birds, we examine the behavior of the dynamic and fixed approaches. We quantify the utility of a near-term forecasting system for aeroconservation (i.e., conservation of aerial habitats) using a data-intensive approach via radar remote sensing. We frame our analysis in the following context: *if* we could take actions that were 100% effective in protecting birds, on *how many nights* would we need to take action to protect 50% of all migratory birds passing through a given location? In the specific case of light pollution, there is evidence that immediate mitigation action can be effective (Van Doren et al. 2017). We address this question with both a fixed window approach using historical data and a dynamic conservation setting using near-term forecasts across the continental United States.

Methods:

(a) Weather surveillance radar data

We quantified nocturnal migration from 143 weather surveillance radar (WSR) stations across the contiguous United States from 1995 to 2018. We characterized the spring migratory period from March 1st to June 10th and autumn from August 1st to November 10th, with each season spanning a maximum of 102 nights. To capture the complete passage of migrants, radar samples were processed from sunset to sunrise at 30-minute intervals. Level-II NEXRAD data were downloaded from the Amazon Web Services (AWS) archive (https://s3.amazonaws.com/noaa-nexrad-level2/index.html) and processed using the WSRLIB package (Sheldon 2015). We identified signatures consistent with precipitation using MISTNET (Lin et al. 2019) and removed these from reflectivity factor (migration intensity) and radial velocity (migration speed and direction) measures. While some migration may persist through periods of light precipitation, the intersection of precipitation and migratory movements tend to be mutually exclusive, with precipitation, especially heavy precipitation, halting the movement of migrants (Richardson 1978, 1990). For both reflectivity factor and radial velocity, profiles of activity were constructed from the lowest five radar scans (0.5 to 4.5°) at 100 m vertical intervals between 0 and 3 km above ground level (Buler & Diehl 2009). We extracted data from a 5-37.5 km radius surrounding the radar. We converted reflectivity factor to reflectivity following Chilson et al. (2012), yielding units of $cm^2 km^{-3}$, also termed η. We derived migrant ground speed ($km\ h^{-1}$) and direction (°) from velocity azimuth displays (VADs) following Browning & Wexler (1968) and when necessary radial velocity was de-aliased following Sheldon et al. (2013). In total, just over 13 million radar scans were processed from 2,115 spring nights and 2,152 autumn nights.

(b) Migration forecast

We used the previously described profiles of activity to train seasonal bird migration forecast models. Our goal was to generate separate spring and autumn forecast models to predict migration traffic rate at 30-minute intervals, the same frequency as the radar measurements. To implement this, we used the product of radar reflectivity factor and groundspeed ($cm^2 km^{-2} hr^{-1}$) with a cube root transformation as the model's response variable. We used a gradient boosted regression tree framework (Chen & Guestrin 2016) to capture the complex spatio-temporal interactions of migratory movements as described by Van Doren & Horton (2018). We constructed models using the XGBoost package (Chen et al. 2017) in the R environment with thirteen predictors: three spatial predictors of latitude (°), longitude (°), height above ground level (m); two temporal predictors of ordinal date and hour after sunset; and eight atmospheric predictors of meridional wind ($m\ s^{-1}$), zonal wind ($m\ s^{-1}$), air temperature (°C), surface pressure (Pa), relative humidity (%), total cloud cover (%), visibility (m), and mean sea level pressure (Pa). Atmospheric predictors were extracted from the North American Regional Reanalysis (NARR) dataset (Mesinger et al. 2006) and linked with radar measures to align spatially (latitude, longitude, and height above ground level) and temporally (date and hour). NARR measures possess a spatial resolution of 32-km, 25 hPa vertical resolution, and 3-hour temporal resolution. For variables with multiple pressure levels, we used data up to the 300 mb level. We averaged weather data within 37.5 km of each radar. We determined height above ground level by subtracting surface geopotential height from the geopotential height of each pressure level, and we linearly interpolated data at 100-m increments from 0-3000 m. Temporally, we matched radar and weather data by using the weather observation closest in time to each radar observation. We trained seasonal models using the following parameters: *max_depth* = 12, *eta* = 0.01, *gamma* = 1, *colsample_bytree* = 1, *min_child_weight* = 5, and *subsample* = 0.7. *max_depth* is the maximum depth of regression trees, *eta* the step size shrinkage used in updates to prevent overfitting and to make the boosting process more conservative (0.01 is a fine scale update), *colsample_bytree* is set for subsampling of columns (no subsampling applied with a value of 1), *min_child_weight* corresponds to the minimum number of instances needed in each node, and *subsample* refers to the proportion of data XGBoost randomly samples from the training data prior to growing trees (Chen et al. 2017). These parameters were selected to maximize variance explained from a tuning training set which accounted for 10% of our total radar data set (see Van Doren and Horton 2018 for additional details).

To determine the seasonal utility of predictions produced by forecast models, models were iteratively trained with one year held out. For each resultant model, we made predictions of migration traffic on the held-out year using covariates from the Global Forecast System (GFS), (https://www.ncdc.noaa.gov/data-access/model-data/model-datasets/global-forcast-system-gfs). We used GFS data for this exercise, rather than NARR, because GFS data offer true meteorological forecasts, and represent the data source that would be used to generate real-time bird migration forecasts. We made 30-minute predictions of migratory activity across nine years (spring 2010 to spring 2018), with predictions aligned spatially (latitude, longitude, and height above ground level) and temporally (ordinal date, time after sunset) with radar measures derived from NEXRAD (see Methods section a). GFS predictions have a 0.5° spatial resolution and 3-hour temporal resolution that extends 384 hours (16 days) into the future. GFS predictions are updated four times daily (00, 06, 12, 18 UTC), however we only use the 0 UTC forecast that preceded the onset of nightly migration. We constrained our analyses to these nine years as a point of utility as the download of GFS data are cumbersome and require many terabytes of storage; GFS data are archived to 2004.

(c) Summing nightly migration activity

For our analyses, we used migration night as our sampling unit, and for this reason we integrated our 30-minute migration activity samples from sunset to sunrise following (Horton et al. 2020). In brief, we accounted for the flow of migrants over the sampling area (i.e., WSR-station) by multiplying cm^2km^{-3} (η) by the measured groundspeed (km h^{-1}) and integrating through the night to account for the nightly passage using linear interpolation for area under the curve, resulting in $cm^2km^{-2}night^{-1}$. We multiplied by the altitudinal resolution (0.1 km) of each profile height bin, resulting in $cm^2km^{-1}night^{-1}$. We used a radar cross-section of 11cm^2, which represents an average sized migratory species (Dokter et al. 2018; Horton et al. 2019b), to yield a nightly WSR-station traffic rate of birds km^{-1}. We applied this procedure to measured and forecasted values and used these units to summarize total passage. Because some stations had missing data in the radar archive, only annual radar-season combinations with at least 100 nights were used in our analyses. During spring, this resulted in the removal of 389 radar-year replicates (of 1,119) and 467 radar-year replicates (of 1,260) during the autumn.

(d) Quantifying migration alerts in practice

We evaluated two approaches for directing aeroconservation action: 1) dynamic selection and 2) fixed window selection. To compare these approaches, we used as a reference the number of nights needed to capture 50% of migratory activity. Under the dynamic selection scenario, we identified the minimum number of nights of conservation action (hereafter termed *action nights*) needed to capture 50% of seasonal activity. We applied dynamic selection in two ways: first, we identified nights based on the realized migration passage measured by the radars, as if we could predict the truth with complete accuracy (hereafter "*idealized dynamic* action nights"); and second, we identified nights using our migration forecast, which is imperfect (hereafter "*forecasted dynamic* action nights"). In practice, action nights are triggered by a threshold of activity, meaning nights below the threshold receive no action and those above receive action. Thresholds are expected to vary across our coverage area.

We computed the number of forecasted dynamic action nights to capture different quantiles of migration activity as follows. First, we predicted the migration intensity for each night in the held-out year, using a seasonal model trained on the remaining years. Then, for each quantile ranging from 0.05 to 0.95 by increments of 0.05, we searched for the smallest threshold of migration activity (*t)* such that the nights with predicted intensity greater than or equal to *t* captured at least the desired fraction of total seasonal migration. For example, we define the threshold at the 90th percentile of activity for a WSR-station and subsequently determine how many forecast nights per season are captured as action nights. For those nights labeled as action nights, we also determine the percent of activity (from known historical measures) captured in those events (e.g., the 90th percentile results in 10 action nights that capture 50% of activity). We searched for thresholds using predicted migration intensities rather than measured ones, because the forecast model has high correlation between predicted and actual migration intensities (see results section B for correlation metrics), but is not perfectly calibrated in terms of magnitude, so this procedure is useful to account for any differences (Van Doren & Horton 2018). We defined the threshold from forecast predictions from all years except the year of interest.

The fixed window selection approach identifies a minimum continuous window of time that historically captures 50% of migration activity. This approach does not rely on ecological forecasting and is seasonally fixed but spatially variable. To quantify the optimal seasonal window of time for each WSR-station, we iterated through window widths ranging from 1 to 100 nights and stepped through each combination of window width and start time (e.g., a window of 10 nights starting on April 15th). For each combination, we examined the percent of activity captured on an annual basis. We averaged the percent capture across all years and selected the optimal window that minimized duration but captured at least 50% of migratory activity. For determining the efficacy of this approach in practice, we held out the year of interest when determining the optimal window.

Results:

(a) Passage metrics from idealized dynamic and fixed window selection

Across 1,628 unique sampling nights (92,296 spring and 85,315 fall nightly samples), the majority of total migratory passage (54.3%) occurred on 10% of nights for each season (Figure 1). Under idealized dynamic selection (Figure 2A), 10.0 ± 2.9 nights (±SD) during the spring (Figure 3A) and 10.9 ± 3.8 nights (±SD) during autumn (Figure 3B) captured 50% of activity at each station. These nights occurred within a continuous span of 34.7 ± 9.8 nights (±SD) during spring and 48.4 ± 10.0 nights (±SD) during autumn. In both seasons, the majority of migration occurred on fewer nights further north (linear model showing effect of °latitude, spring, -0.27±0.07, $p<0.001$; autumn, -0.18±0.09, $p<0.001$) and further east (linear model showing effect of °longitude, spring, -0.05±0.03, $p=0.002$; autumn, -0.14±0.04, $p<0.001$).

Fixed windows that captured 50% of passage (Figure 2B) spanned 19.2 ± 3.9 nights (±SD) in spring (Figure 3C) and 26.5 ± 4.6 nights (±SD) in autumn (Figure 3D). Window width generally decreased further north (linear model, spring, -0.08±0.11, ±CI, $p=0.159$; autumn, -0.19±0.13, $p=0.005$) and further east (linear model, spring, -0.08±0.04, $p<0.001$; autumn, -

0.01±0.05, p=0.728); however, these linear spatial dependencies were weaker than the idealized dynamic selection trends and at times non-significant. The fixed window selection approach required significantly more time than idealized dynamic selection to capture 50% of activity (paired *t*-test, spring mean of differences 9.3 nights, t_{142}= - 36.5, p<0.001; autumn mean of differences 15.6 nights, t_{142}=-41.7, p<0.001). In both idealized dynamic and fixed window scenarios, spring periods were significantly shorter than autumn periods (paired *t*-test, mean dynamic seasonal difference 1.0 nights, t_{142}= -3.2, p=0.002; mean fixed-window seasonal difference 7.2 nights, t_{142}=-15.1, p<0.001).

(b) Forecasted passage metrics

On average, our forecast models using NARR reanalysis data explained 73.0 % (±0.008 SD) of the variance of the cube-root transformed migration intensity during spring and 69.8 % (±0.010 CI) during autumn. Using the Global Forecast System to predict migration traffic one day in advance, our spring model explained 70.4 % (±0.009 SD) of the variance and 68.8 % (±0.009 SD) of the variance in autumn.

Because migration forecasts are imperfect, more action nights were required to capture 50% of migration activity compared to an idealized scenario (above; Figure S1). During spring, 13.7 ± 3.5 (±SD) forecasted dynamic action nights were necessary and 15.9 ± 4.6 (±SD) during autumn. However, this was still far fewer than with fixed selection, which required 53% more action nights in the spring (mean of 7.3 more alert days, Figure 4A) and 81% more action nights in autumn (mean of 12.8 more alert days, Figure 4B). At all WSR-stations, forecasted dynamic selection resulted in fewer action nights needed to capture 50% of migratory passage as compared to fixed window selection (Figure 4).

Our analysis used a benchmark of capturing 50% of migratory activity. We also examine the continuous gradient of migratory activity and number of action nights across the idealized dynamic, forecasted dynamic, and fixed window selection approaches (Figure 5). Consistently across our sampling space, forecasted dynamic selection captured more activity with fewer action nights as compared to fixed window selection. Lastly, we generally saw that after capturing 75% of migratory activity, the percent gain for each additional action night began to taper off (Figure 5).

Discussion:

At present, conservation action often embodies a tension between society's desire to protect species and society's willingness to incur costs for that protection (Miller & Hobbs 2002; Singh et al. 2015). In the era of big data, when more tools and data are available than at any previous point in history to tackle complex ecological concerns (Luo et al. 2011), we can design strategies that provide conservation benefits for lower cost — here identifying fewer action days to reduce this tension. We show that near-term ecological forecasting can aid in realizing such a goal of dynamic and optimized action, in our case for aeroconservation, performing more efficiently than status-quo techniques and creating a path for dynamic, real-time conservation alerts that reduce society's costs of conservation. At all locations examined in this study, forecasting resulted in fewer action nights as compared to static fixed window approaches to capture comparable aerial passage and alert protective actions.

In our framework, we defined two important criteria: the number of action nights as a proxy for costs and our policy goal of capturing 50% of migration passage as a proxy for an important ecological benchmark. Our analysis finds a set of dates for a fixed time window and for forecasted dynamic mitigation approach(es) that can have the greatest impact per cost incurred. This approach does not capture all of the costs, including opportunity costs, of each action night and does not capture all of the benefits of migratory bird conservation; instead, this approach sets the ecological goal of 50% of migration captured and asks how to minimize the action nights (costs) to achieve that goal. This cost-effectiveness approach avoids the complications of determining the socially preferred level of conservation for economic efficiency that requires a full assessment of all market and non-market costs and benefits. Using action nights as a proxy for costs corresponds to the reserve site selection literature's use of the number of sites as a cost proxy and then minimizing the number of sites chosen for a reserve network that conserves a specific number of species. That process only matches the cost-minimizing reserve network to achieve a level of species conservation if all land units have the same cost (Ando et al. 1998; Polasky et al. 2008); it may be possible to find a set of sites that provides the target level of conserved species for lower cost than in the site-minimizing reserve. Here, if costs are heterogenous across nights, economic cost effectiveness shifts action nights toward less costly nights, which can mean more action nights but lower cost overall. One potential next step to improving the cost effectiveness of dynamic mitigation involves assessing the heterogeneity of action night costs to take advantage of opportunities to provide collision mitigation at a lower cost.

Incorporating other economic considerations could further increase conservation per dollar through appropriate use of near-term forecasting information. First, positive correlations between higher cost action nights and numbers of migrating birds makes conservation more expensive, while negative correlations create efficiency gain opportunities (Figge 2004; Koellner & Schmitz 2006; Moore et al. 2010; Schindler et al. 2010). For example, if high wind nights pose a high opportunity cost of energy generation by turning off wind turbines but high wind also prevents many birds from migrating, the daily heterogeneity in costs can be leveraged to achieve the mitigation goal at lower cost (Hayes et al. 2019). Second, cost effectiveness relies on the characteristics of the dynamic versus fixed window approaches' cost functions and the differences between these cost functions. Each approach's cost function likely contains a fixed cost (e.g., costs incurred to lay the groundwork to use action nights) and variable costs (e.g., costs incurred as a function of the number of action nights). Assessing the relative impact of the fixed and variable costs across the fixed window and dynamic action night choices could identify situations in which the dynamic action nights approach provides particularly large or small cost improvements over the fixed window approach. Similarly, both fixed window and forecasted dynamic conservation costs for avian conservation might include costs of the foregone energy generation of turning off wind turbines (Kennedy 2005; Cullen 2013), which interacts with energy source switching costs (Bird et al. 2016), or the costs of turning off lights in urban or energy development sites. Third, dynamic conservation may provide information that engages individuals in a positive way, which could create a social benefit that reduces the action night's social costs. Further economic efficiency analysis that addresses the specific costs of fixed window and dynamic conservation approaches, the heterogeneity of costs across space and time, and the engagement of potential participants could further improve the efficiency of conservation action decisions and provide the target level of conservation at a lower cost.

While our forecasting approach already shows improvements over static approaches, at least in terms of reducing the number of action nights, we predict that the efficiency and accuracy of this dynamic approach will continue to improve with each passing migration season through the addition of new training data, inclusion of commentary sensors, and advances in computational machinery. Methodologically, we believe our predictions will improve through additions of landscape variables (e.g., landcover, greenness), finer temporal updates (e.g., every three hours), broader spatial predictors of synoptic weather conditions, and the integration of within-season migration activity measurements. Furthermore, we expect the explicit integration of natural history data (e.g., species observations) will enhance taxonomic resolution, increase the specificity of conservation decision-making, and reveal potential biases of our approach, particularly in light of stratified timing of migrant passage either by species or higher taxonomic classification (Horton et al. 2019b). While our threshold of protecting 50% activity is a subjective choice, our approach is extensible to conservation or economic priorities that may dictate different levels of protection (see Supplementary material for data on 25% and 75% thresholds).

We recognize that spatial heterogeneity exists in the geographic distribution of action nights in spring and autumn. For example, California and the Desert Southwest required larger numbers of action nights for both idealized dynamic and fixed window selection relative to the rest of the U.S., reflecting more protracted migration passage through those regions (Figure 3). Additional anomalies during spring were evident in Texas and portions of the southeastern U.S. While forecasted dynamic selection yielded fewer action nights than fixed-window selection, deviations between forecasted and idealized dynamic selection were still high in some regions of the contiguous U.S. (Figure S1). It is likely that the complexities of topographic features, such as coastlines and terrain (e.g., Rocky Mountains), are not sufficiently captured by our model and highlight the challenge of forecasting movements in these regions. Additionally, differences between forecasted and idealized selection were higher during autumn as compared to spring. Variability of autumn movements may be larger due to age-specific departure and flight strategies (Mitchell et al. 2015) and elevated selection of weather events to promote southward flights (Horton et al. 2016), manifesting in large flights over a wider range of time (Figure 3). Capturing these spatial patterns is both important from a conservation standpoint and in the context of economic cost effectiveness, wherein action nights may have differing inherent value.

We have demonstrated that near-term ecological forecasting can address conservation challenges that evolve rapidly in space and time. Our approach uses volumes of data gathered to learn associations of avian migration and atmospheric conditions (Van Doren & Horton 2018). We believe these tools, both in forecasting and alerting, directly translate to areas with existing radar infrastructure and archives. These approaches may encompass whole continents, e.g., Europe, Asia, or Australia, but are applicable at smaller spatial scales, requiring only a small number of radar installations. Big data analytics have arrived, particularly in wildlife ecology through large data collection efforts founded on sensor networks (e.g., radar, community science). These applications reinforce the power of these growing repositories for building new and better performing forecasts. Ecological forecasting lends itself to many conservation challenges, ranging across a wide variety of taxa and scales. For instance, predicting the emergence of ephemeral insects blooms (Stepanian et al. 2020), nesting returns of sea turtles (Van Houtan & Halley 2011), or movements of terrestrial migrants through fragmented and shifting landscapes (Fischer & Lindenmayer 2007; Lendrum et al. 2013; Geremia et al. 2020). Each of these examples are integrally linked with shifting climate, seasonal weather, and landscape and oceanic variability, requiring models that adapt to current conditions. Rethinking conservation goals in this dynamic framework opens new opportunities in the face of the growing intersection between humans and wildlife.

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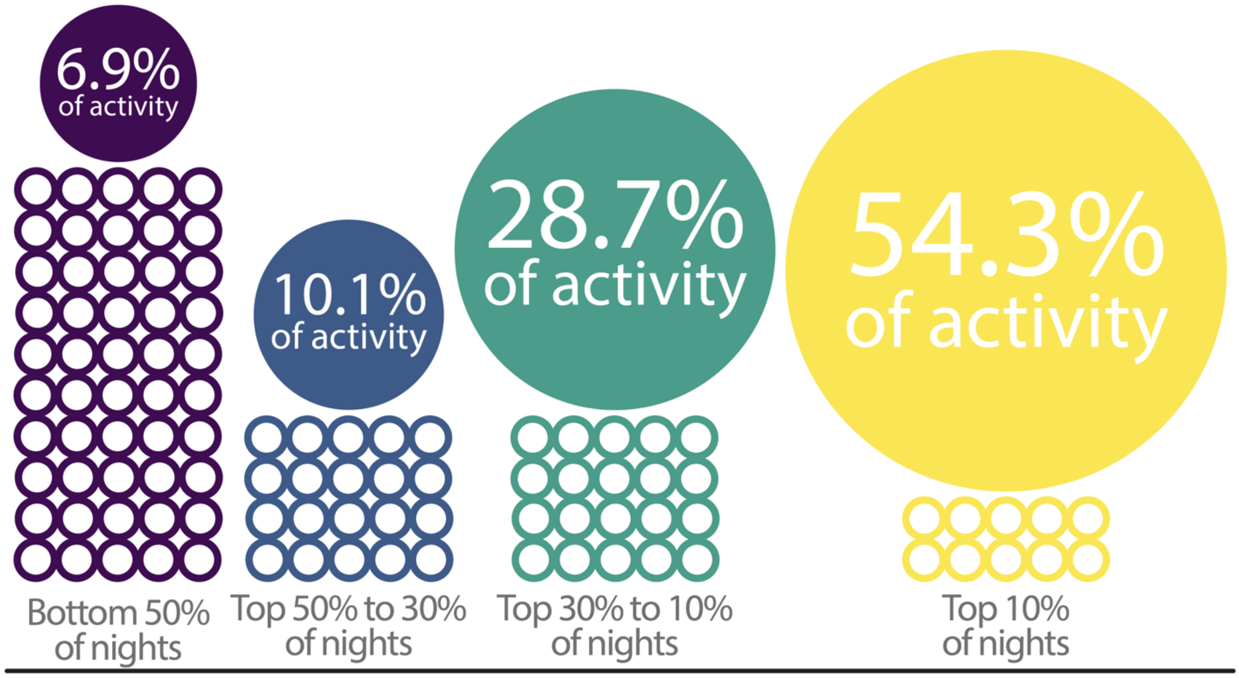

Figure 1: Mean percent of migration activity captured across four percentile categories: bottom 50% of nights (purple), top 50% to 30% of nights (blue), top 30% to 10% of nights (green), and top 10% of nights (yellow). Small, hollow circles denote number of nights per season in each category. Large, solid activity circles are scaled by summed percent of activity in each category and are the average of spring and autumn seasons across all WSR-stations.

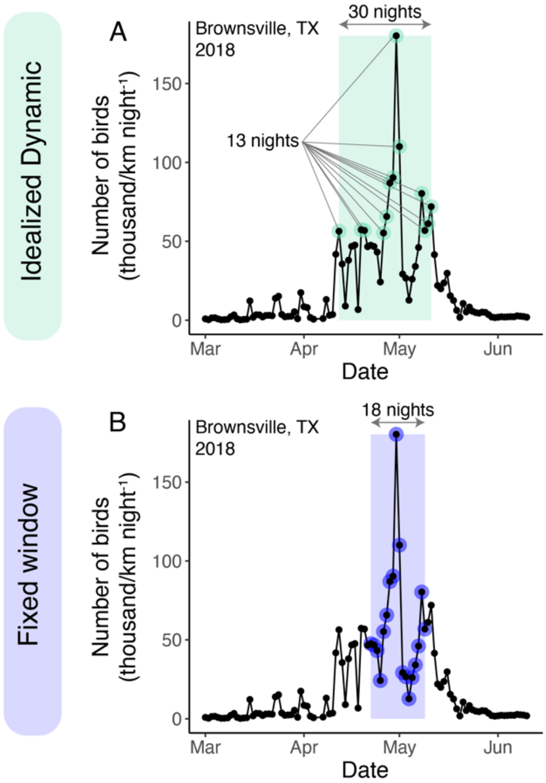

Figure 2: (A) Idealized dynamic and (B) fixed window selection scenarios for Brownsville, Texas during spring 2018. Idealized dynamic selection (A) shows 13 nights that tally 50.5 % of total passage across a window of 30 nights. Fixed window selection (B) shows a historically defined window of peak activity and for 2018, this window captures 52.1% of activity.

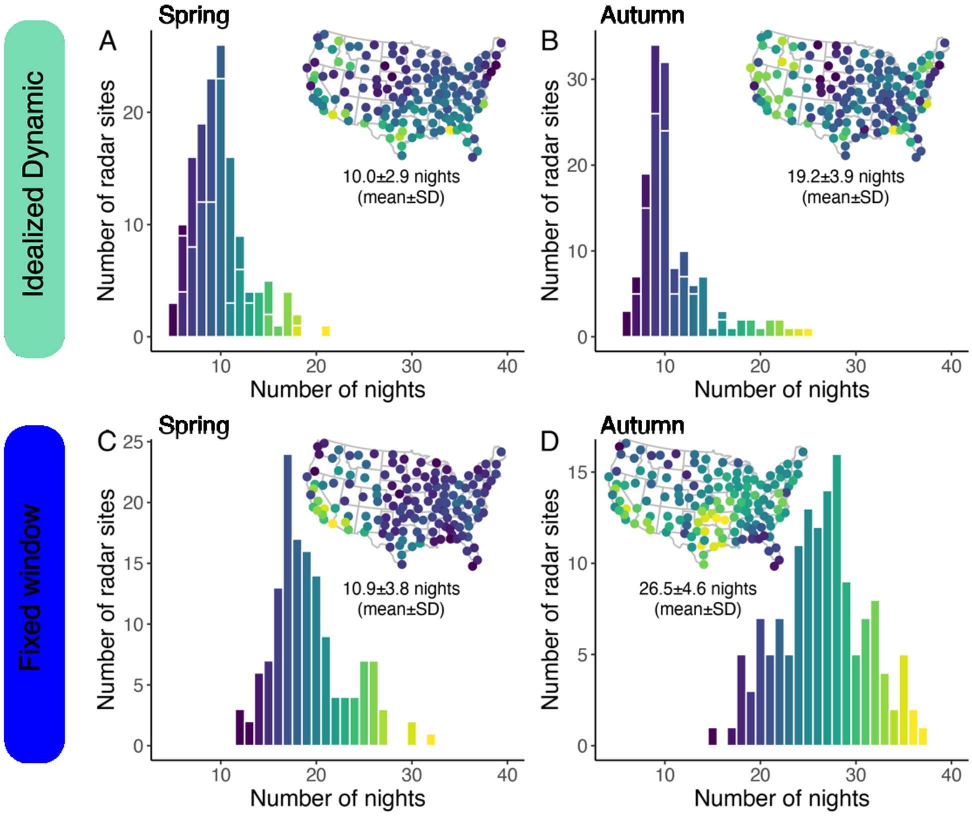

Figure 3: (A) Spring and (B) autumn mean number of nights required to dynamically capture 50% of activity in an idealized setting. Spring (C) and autumn (D) mean fixed window width that historically captures 50% of activity. Note, color scales of A-D vary.

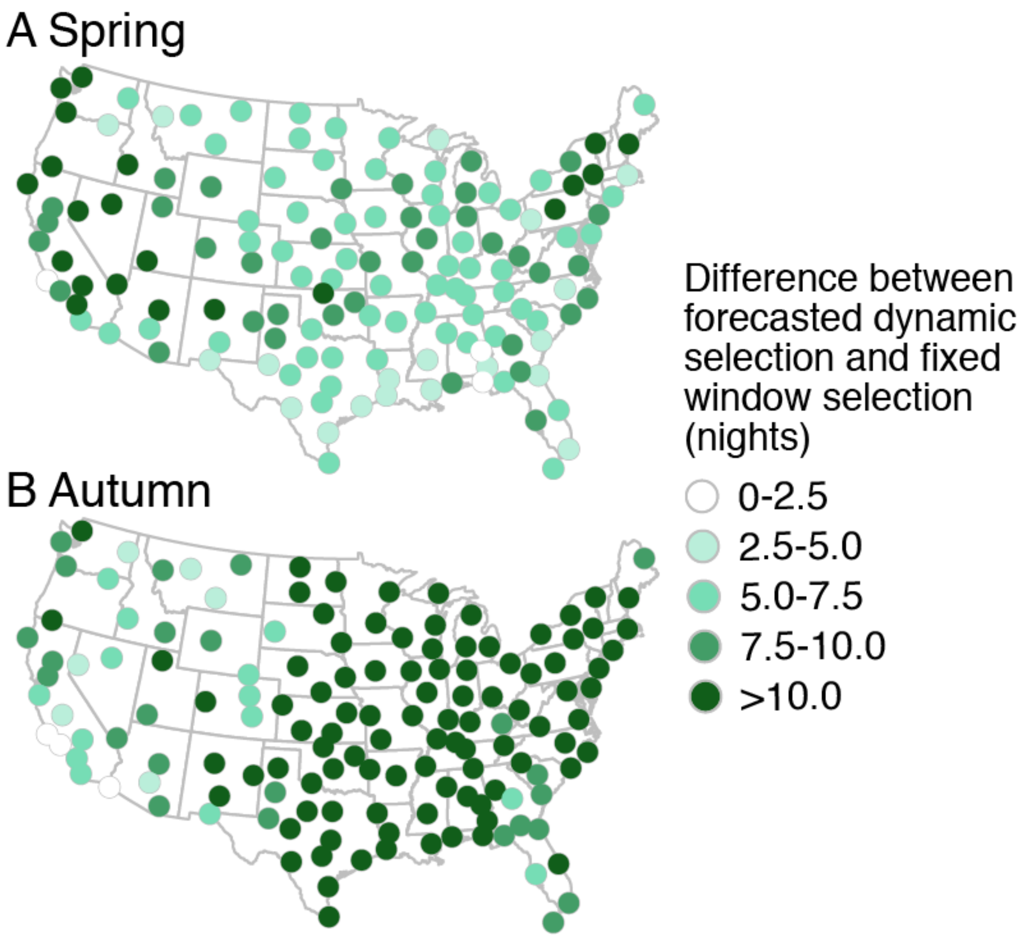

Figure 4: (A) Spring and (B) autumn differences between number of action nights between forecasted dynamic selection and fixed window selection. The number of action nights for both methods is that needed to capture 50% of activity. Note, in all cases, fixed window required *more* nights than forecasted dynamic.

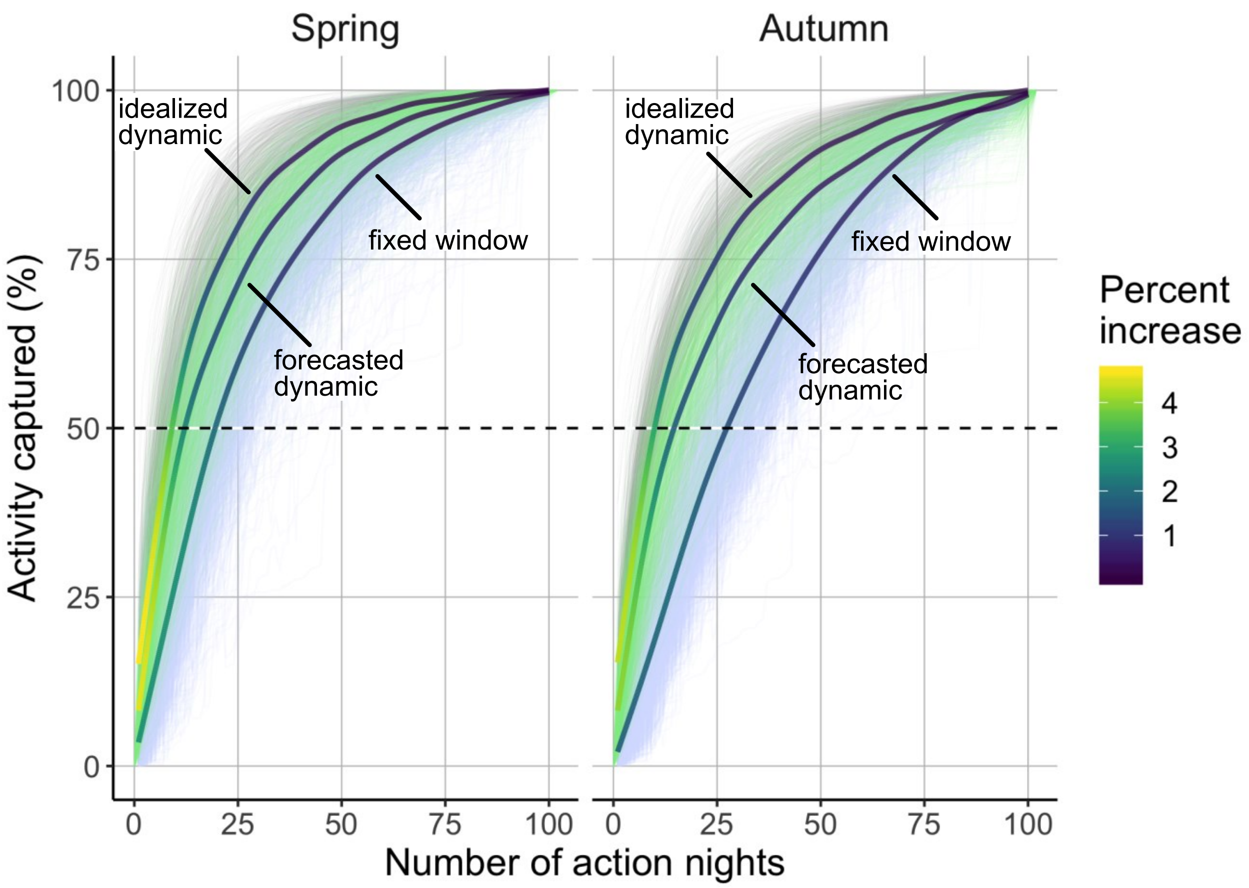

Figure 5: Spring (left) and autumn (right) relationship between number of action nights and activity captured for idealized dynamic, forecasted dynamic, and fixed window selection. Gray, green, and blue lines show the annual cumulative migration traffic rates for individual WSR-stations from spring of 2010 to spring of 2018. Each method has been fit with a generalized additive model and the line shading signifies the rate of increase in percent activity captured.

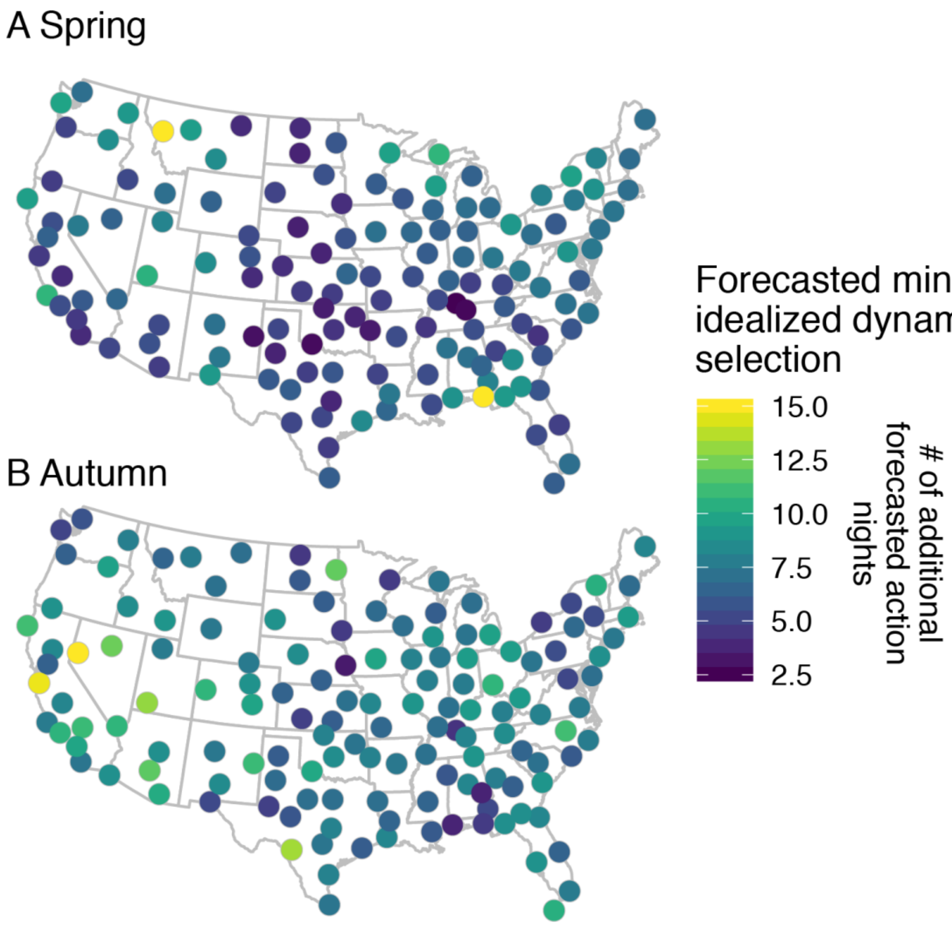

Figure S1: (A) Spring and (B) autumn differences between number of action nights between forecasted and idealized dynamic selection. The number of action nights for both methods is that needed to capture 50% of activity.

Drivers of fatal bird collisions in an urban center

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Millions of nocturnally migrating birds die each year from collisions with built structures, especially brightly illuminated buildings and communication towers. Reducing this source of mortality requires knowledge of important behavioral, meteorological, and anthropogenic factors, yet we lack an understanding of the interacting roles of migration, artificial lighting, and weather conditions in causing fatal bird collisions. Using two decades of collision surveys and concurrent weather and migration measures, we model numbers of collisions occurring at a large urban building in Chicago. We find that the magnitude of nocturnal bird migration, building light output, and wind conditions are the most important predictors of fatal collisions. The greatest mortality occurred when the building was brightly lit during large nocturnal migration events and when winds concentrated birds along the Chicago lakeshore. We estimate that halving lighted window area decreases collision counts by 11× in spring and 6× in fall. Bird mortality could be reduced by ∼60% at this site by decreasing lighted window area to minimum levels historically recorded. Our study provides strong support for a relationship between nocturnal migration magnitude and urban bird mortality, mediated by light pollution and local atmospheric conditions. Although our research focuses on a single site, our findings have global implications for reducing or eliminating a critically important cause of bird mortality.

light pollution | conservation | bird migration | urban planning | mortality

North America has lost nearly one-third of its birdlife in the last half-century, with migratory species experiencing particularly acute declines (1). Fatal collisions with built structures represent a major source of direct, human-caused bird mortality across North America, second only to predation by domestic cats (2). Estimates indicate that between 365 million and 988 million birds die annually in collisions with buildings in the United States, with another 16 million to 42 million annual deaths in Canada (2, 3). Birds may collide with glass windows because they reflect the surrounding environment or allow birds to perceive a seemingly open pathway to the interior of the building (4). For the billions of birds that migrate at night, outdoor lighting (e.g., streetlights and floodlights) and interior lighting from buildings may be disorienting and draw birds into built-up areas, at high risk to collide with infrastructure (5–8). Light pollution not only alters nocturnal migratory behavior on a large scale (5, 7), but is also an acute conservation concern. Nocturnal collisions with well-lit communication towers alone are estimated to kill appreciable percentages of the populations of sensitive species (9).

Avian collisions with lighted structures have been documented in the scientific literature as early as the 19th century (10–12). In recent decades, this link between collisions and light pollution has been the subject of detailed investigation (8, 13–16). Observers of bird–building collisions and tower kills have long remarked on the apparent influence of meteorological factors such as cloud ceiling, fog, frontal passage, and abrupt changes in conditions, all of which have been associated with large mortality events (10, 13, 17–24). Steady-burning lights may be particularly hazardous (25). Due to high building density and intensity of artificial lighting, cities are of particular concern. Reports of mass collisions at lighted buildings in urban areas are frequent in both the popular and scientific press (13, 19–21, 26).

Understanding, predicting, and preventing collision mortality are areas of active scientific inquiry and priorities for policymakers (1, 13). Collisions occur more frequently during migration seasons and impact numerous species of migratory birds (29), and recent work suggests that nocturnal migratory movements can be useful for predicting bird–window collisions (30). Lights-out programs, which encourage the public to extinguish outdoor lighting to protect migratory birds, are receiving increasing attention (13). The act of extinguishing lighting allows birds to immediately return to normal, safe behavior (7) and reduces mortality at lighted buildings (13). Presently, advisories are generally issued for a given time period (e.g., peak migration periods) or on specific nights when weather conditions are favorable for large migratory movements [e.g., using migration forecasting, (31, 32)].

Here, we integrate meteorological, migration-intensity, and window-radiance data to understand how these factors interact to cause bird collisions. We use a 21-y dataset of fatal collisions recorded at a single large building (McCormick Place Lakeside Center) in Chicago, IL (Fig. 1), to understand the behavioral, environmental, and anthropogenic drivers of these mortality events. Chicago poses the greatest potential risk from light pollution to migrating birds of all cities in the United States

ECOLOGY

SUSTAINABILITY SCIENCE

Significance

Collisions with built structures are an important source of bird mortality, killing hundreds of millions of birds annually in North America alone. Nocturnally migrating birds are attracted to and disoriented by artificial lighting, making light pollution an important factor in collision mortality, and there is growing interest in mitigating the impacts of light to protect migrating birds. We use two decades of data to show that migration magnitude, light output, and wind conditions are important predictors of collisions at a large building in Chicago and that decreasing lighted window area could reduce bird mortality by ∼60%. Our finding that extinguishing lights can reduce bird death has global implications for conservation action campaigns aimed at eliminating an important cause of bird mortality.

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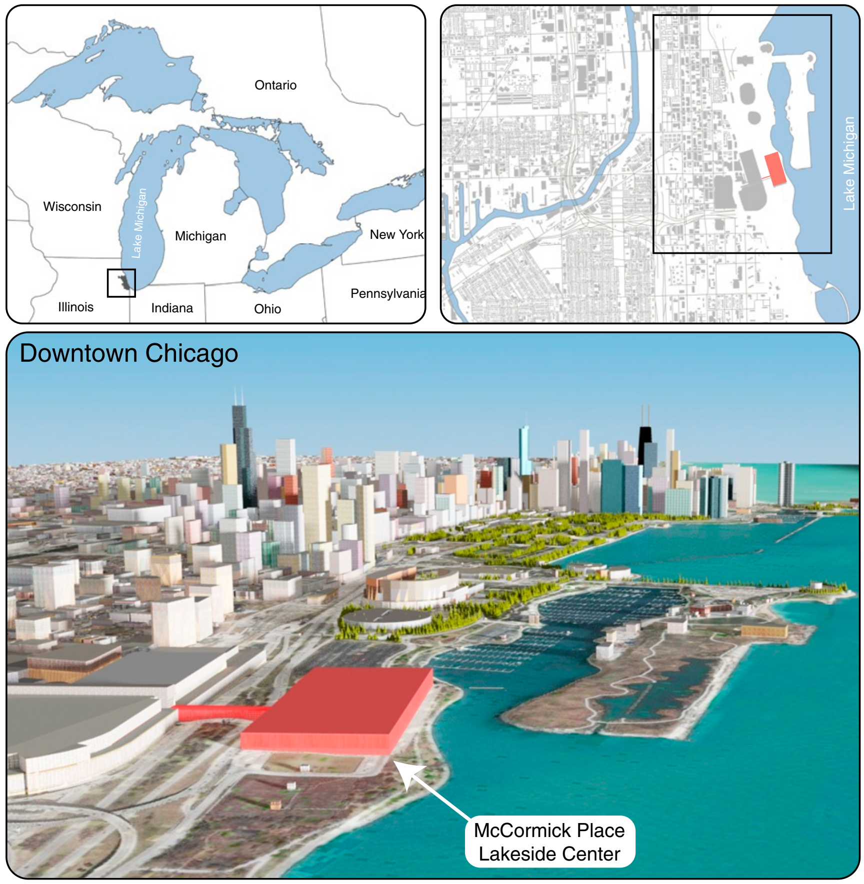

Fig. 1. Location of McCormick Place along the Chicago lakefront. The Lakeside Center building monitored in this study is highlighted in red in a three-dimensional rendering.

(33), and over 40,000 dead birds have been recovered from McCormick Place alone since 1978 (Figs. 2 and 3). Since 2000, we have recorded the number of birds and the lighting status of each window bay during dawn collision monitoring. Nocturnal lighting at McCormick Place correlates positively with bird collisions in many songbird species (34), but this association has not been quantified in the context of other important factors, including migration intensity and weather conditions. We estimate the effect of window lighting on collision counts and assess how the intensity of nocturnal bird migration mediates this relationship. We also test whether wind and weather conditions may magnify these associations. Finally, we investigate the spatiotemporal scales at which weather and migration data best explain collision mortality, identifying the times of night and areas of airspace associated with these events.

Results

Of 11,567 fatal collisions recorded between 2000 and 2020, 64.8% occurred in fall. In both spring and fall, nearly half of all documented collisions occurred on 25% percent of nights with the largest migration events (fall: 49.6%; spring: 49.4%).

Spatiotemporal Scales of Collision Predictors. We monitored nocturnal bird migration and atmospheric conditions using Doppler weather radar (WSR-88D) and weather observations from nearby Chicago Midway Airport, and we used Bayesian latent indicator scale selection (BLISS) (36) to choose the spatial and temporal scales of these predictors that best explained bird collisions. From radar data, we derived a regional measure of nocturnal bird migration, as well as localized measures from the immediate Chicago airspace. Birds migrating over the Great Lakes are known to reorient toward the coastline at dawn (37–39), but the extent to which collisions at McCormick Place may represent individuals over water attempting to reach land is unknown. We found that radar returns from the airspace over Lake Michigan explained collisions better than returns from over land (*SI Appendix*, Fig. S1); in spring, overwater airspace across a 4-km radius received the most support, whereas a 32-km scale was favored in fall. The analysis selected the middle third of the night, when birds are in active migration, over the beginning or end of the night as the period that best explained collision counts (*SI Appendix*, Fig. S1).

Drivers of Daily Fatal Collisions. Migration and lighted window area were consistently the strongest predictors of fatal collisions (Figs. 3 and 4; *SI Appendix*, Figs. S2, S3, and S4 and Tables S1 and S2). We defined lighted window area as the proportion of total window-bay area emitting light from within the building. The estimated exponentiated effect of lighted window area on collisions was a 1.95× (95% CI [1.77, 2.15]) increase in spring and a 1.52× (95% CI [1.42, 1.63]) increase in fall for a one-SD increase in lighted window area. These estimated effects correspond to a predicted 10.7-fold increase in collision counts between 50% and 100% lighted window area in spring and a corresponding 6.3-fold increase in fall. These predictions are estimated at the average values of all other predictors and high-visibility conditions. Two lines of evidence support a causal interpretation of this effect: First, these estimates were virtually identical in models that excluded the local migration predictor (spring: 1.95× vs. 1.94×; fall:

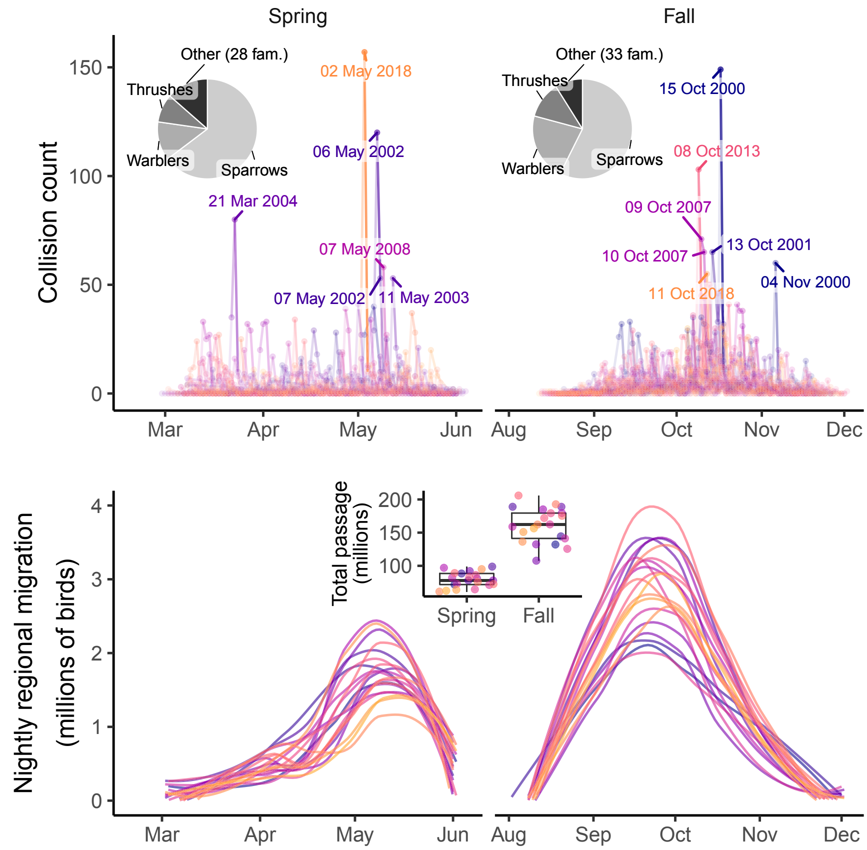

Fig. 2. Summary of collisions recorded at McCormick Place and regional bird migration between 2000 and 2020. (*Upper*) Individual years are drawn in different colors. Dates are given for mortality events totaling more than 50 birds. Pie charts show the family (fam.) composition of collected birds, with families representing less than 5% of total collisions merged into a single "other" category. (*Lower*) Summed annual migration passage at the KLOT radar in estimated number of individual birds (years colored). (*Lower*, *Inset*) Summed seasonal passage totals in estimated number of birds crossing a 75-km transect, with each point representing a year. Estimates are based on methods from ref. 35.

1.52× vs. 1.52×), the only variable we identified as a possible confounding factor (*SI Appendix*, Fig. S5), and, second, a strong causal effect of window lighting was supported by multivariate matching analysis (*SI Appendix*, Fig. S6 and Table S3).

Local weather phenomena may be important in creating conditions conducive to fatal bird collisions (10, 18–20). This may be especially evident in the context of local topography in the Chicago region, where migrating birds frequently concentrate along the shore of Lake Michigan (24, 37–39). Furthermore, there is evidence that dense cloud and low visibility may increase collision counts, especially in the presence of light pollution (10, 18–20). Regional migration intensity and westerly winds showed strong positive associations with collision counts (Fig. 4). In spring, southerly winds, lower visibilities, less moon illumination, and higher local migration intensities were also associated with increases in fatalities (*SI Appendix*, Fig. S3 and Table S1). Cloud ceiling interacted with lighted window area: When fewer window bays were lighted, cloud ceiling was only weakly predictive of collisions; however, when many bays were lighted, lower cloud ceilings strongly increased collision counts. Fall demonstrated similar patterns to spring (*SI Appendix*, Fig. S4 and Table S2), but we detected no strong association with cloud ceiling, visibility, or moon illumination.

Our collision model successfully predicted observed data (*SI Appendix*, Fig. S7). Cross-validation revealed that most years showed consistently low prediction error calculated by using mean absolute error (MAE). Annual mean MAE was 2.66 ± 0.76 SD in spring and 2.98 ± 0.83 SD in fall, and models performed similarly well during years with below- and above-average lighting levels (*SI Appendix*, Fig. S8). Due to the COVID-19 pandemic, few entertainment or conference events occurred at McCormick Place in 2020, leading to low lighting during the entire year. Model performance for this atypical year was comparable to performance during other years, lending confidence that our model can accurately explain collision counts across a range of lighting conditions.

Drivers of Collisions at Individual Window Bays. Lighting of individual window bays was a key driver of mortality at those window bays. In spring, the predicted collision count at a window bay was 4.1× higher when that bay was illuminated at night. When taking individual window lighting into account, total lighted window area was less important (Fig. 5*A*; *SI Appendix*, Table S4). This pattern was similar in fall (Fig. 5*B*; *SI Appendix*, Table S5) and supported by multivariate matching analysis (*SI Appendix*, Fig. S6 and Table S3). Overall, these results suggest that fatal collisions are driven primarily by lighting at the level of the individual window bay, although surrounding lighting still elevates collision counts. The direction each window bay faced significantly influenced collision count (Fig. 5*C*). The sides of the building facing north and east showed the highest predicted collision count in both seasons, a pattern likely related to idiosyncratic features of our study site (*Discussion*). Wind direction influenced which sides of the building were most prone to collisions in different seasons (*SI Appendix*, Fig. S9).

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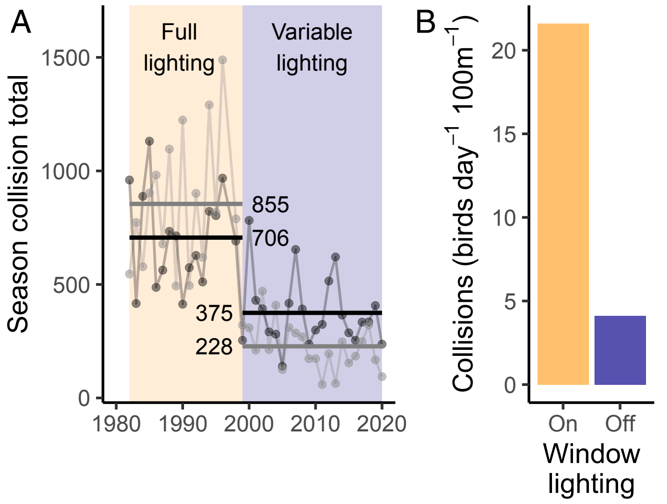

Fig. 3. Recorded collisions by year and window lighting. (*A*) Collisions recorded at McCormick Place between 1982 and 2020 for spring (light gray) and fall (dark gray) seasons. Horizontal lines with numeric labels show average seasonal collision totals before and after the window-lighting regime changed from fully lighted to partially lighted in 1999. The year 1997 is not shown because construction limited access to the site during that year. (*B*) Mean recorded daily collisions by window-lighting status from 2000 to 2020.

Predicted Efficacy of a Lights-Out Program. We predicted how collision counts might have differed under different lighting scenarios. In spring, we expect a 59% (95% CI [52, 65]) decrease in collisions if lighting had been reduced every night to the minimum levels historically recorded (∼50% lighted window area). In fall, the predicted decrease was 53% (95% CI [47, 59]). Likewise, if all building windows had been emitting light every night, we expect that total mortality would have been higher by 116% (95% CI [97, 136]) and 47% (95% CI [40, 54]) in spring and fall, respectively. It may not be feasible to extinguish lighting every single night, so we quantified the predicted decrease in mortality if lighted window area had been reduced only on the nights with the largest 25% of migration events. In this scenario, we expect a decrease of 32% (95% CI [26, 38]) in collisions in spring and 27% (95% CI [22, 31]) in fall.

Our model results illustrate that collision risk is dependent not only on migration intensity, but also atmospheric conditions, so we identified the 25% of nights with the highest predicted risk of collisions, taking into account both migration intensity and weather conditions (and assuming constant lighted window area). Then, we quantified the predicted decrease in mortality if lighting had been reduced on these high-risk nights. In this scenario, we expect that taking action on high-risk nights would have decreased total seasonal collisions by 44% (95% CI [38, 50]) in spring and 31% (95% CI [27, 36]) in fall.

These differing scenarios highlight that, although many nights with large migration events are high risk, other nights may also pose high collision risk due to weather conditions, despite lower migration intensities (*SI Appendix*, Fig. S10). In both spring and fall, only about half of high-risk nights were also nights in the top 25% of migration events (spring: 52%; fall: 60%).

Discussion

Bird mortality from collisions represents hundreds of millions of deaths annually in the United States alone (2). Attraction to artificial light at night contributes greatly to these collisions, and there is growing interest among community, municipal, and conservation stakeholders in mitigating the impacts of light on nocturnally migrating birds. Our data show that nightly bird mortality at an urban convention center is strongly related to migration traffic, lighted window area, and local weather conditions. Consistent with previous assessments (8, 16, 34, 40), the area of lighted windows in the building had a dramatic effect. After accounting for meteorological conditions and migration intensity, predicted collision counts were 11 and 6 times higher (in spring and fall, respectively) when all windows were lighted compared to when half were darkened. Collisions were most frequent when winds were from the west and south, concentrating birds along the Chicago lakefront.

Much attention in scientific and popular literature has focused on the contribution of high-rise buildings to avian mortality. This

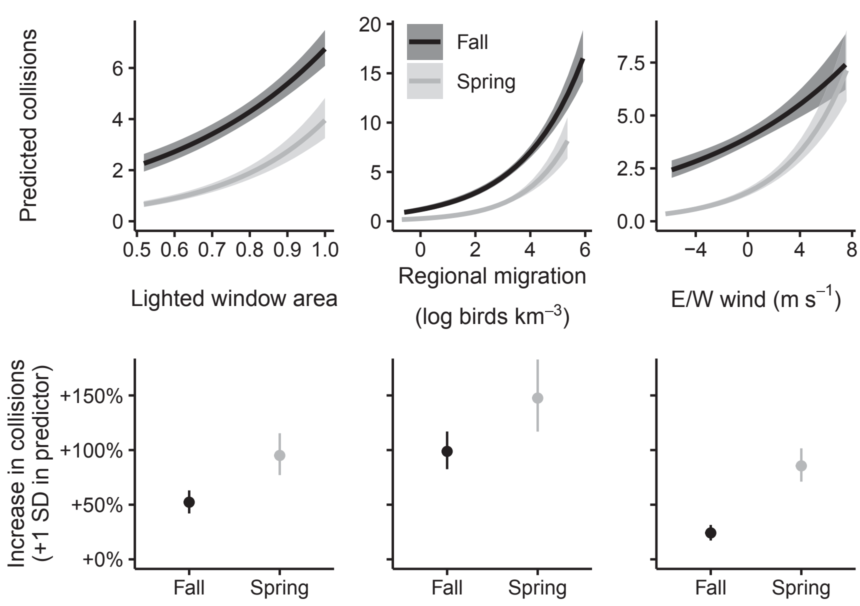

Fig. 4. Number of collisions by light, winds, and migration intensity. (*Upper*) Line plots show model predictions for three important variables. Positive values of the E/W wind component indicate winds blowing from west to east. For predictions, other predictors are held at their average value (continuous variables) or reference level (categorical variables). Continuous predictions are shown between the 0.01 and 0.99 quantiles of observed data. (*Lower*) Model-estimated coefficients by season with 95% CIs. See *SI Appendix*, Figs. S3 and S4 for plots of all predictors and *SI Appendix*, Tables S1 and S2 for all coefficient estimates.

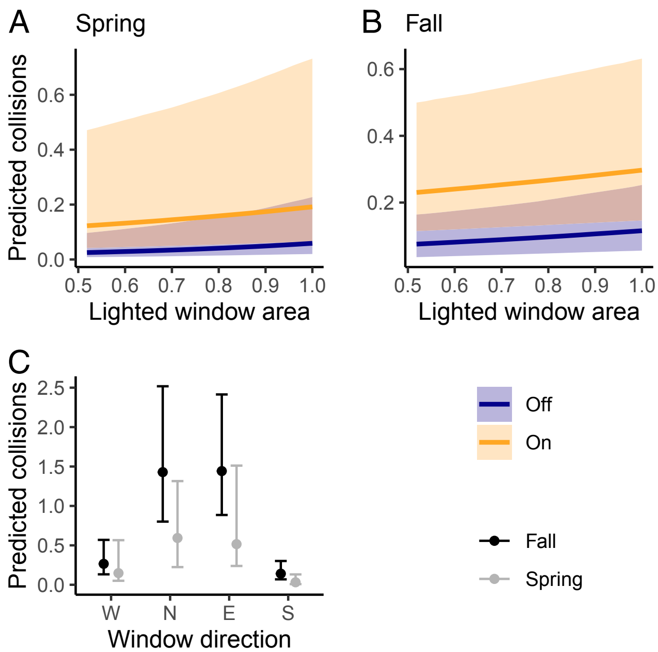

Fig. 5. Predicted number of collisions per window bay. The response variable was the number of collisions at a given window bay, accounting for its size. (*A* and *B*) Predicted collisions by total building lighted window area (*x* axis) and whether the focal window was emitting light (shading color). Continuous predictions are shown between the 0.01 and 0.99 quantiles of observed data. (*C*) Predicted collisions by window direction. See *SI Appendix*, Tables S4 and S5 for coefficient estimates.

study provides a key example of a low-rise building that poses substantial risk to migrating birds. In locations with high migration traffic, lighted window area may be a more important risk factor for collision than building height (13, 15, 26).

Darkening Individual Windows Reduces Mortality. In spring and fall, whether an individual window bay emitted light was the most important variable in predicting fatal bird collisions at that bay. Colliding birds appear to be attracted to specific light sources and are not simply disoriented by overall city or sky glow. This result strongly suggests that reducing the number of lighted windows, even in an otherwise brightly lit area, may make a difference in decreasing local bird mortality. This is consistent with research showing that birds immediately resume normal migratory behavior when bright lights are extinguished (7).

Our results are most applicable to structures with large areas of lighted windows, which raises an additional question: If individual windows are darkened, is this likely to decrease total mortality or simply cause birds to collide with other lighted windows? If the latter were true, we would expect that collisions at a given window bay would increase when surrounding lights are extinguished. However, we observed the opposite: After accounting for individual window-bay lighting, we see a positive, though subtle, relationship between total building lighted window area and predicted collision counts (Fig. 5). This suggests that each darkened window makes it less likely for birds to collide with nearby windows. Additional experiments focused on the effects of individual window lighting would be informative.

Efficacy of Turning Off Lights on High-Risk Nights. Our modeling results show that reducing internal lighting during the entire migration season would be an effective way to reduce collisions, resulting in an ~60% reduction in collision counts from observed totals. In the years before formal light monitoring began in 2000, McCormick Place was constantly fully lighted. The building began regularly turning off lights starting in 1999, and bird mortality abruptly decreased (Fig. 3*A*). Although we cannot rule out a contribution of long-term population declines to this decrease in collisions (1), the sharp change shown in Fig. 3*A* suggests that the change in lighting was an important factor in the subsequent decrease in collision counts.

Seasonal Variation. We observed seasonal differences in the strength of the associations between collision counts and weather, moon illumination, lighting, and migration; most relationships were stronger in spring than in fall (Fig. 4). Seasonal differences in flight altitudes might explain some of this variation. The average altitude of nocturnal migration was 23% (96 m) higher in fall compared to the spring of the same calendar year (*SI Appendix*, Fig. S11). Birds migrating at higher altitudes may be less likely to interact with illuminated structures on the ground, resulting in weaker observed associations in fall. The underlying cause of this seasonal difference in flight altitude is unclear, but it has been documented elsewhere in North America (41) and may relate to seasonal atmospheric dynamics or behaviors over open water.

Directional Associations. The north and east faces of the building had the greatest number of predicted collisions after accounting for lighting in both seasons. This may reflect topography, habitat, and building configuration. A natural area lies to the northeast and Lake Michigan to the east. Lighting fixtures and possibly bulbs differ between north and south faces, and trees grow adjacent to the north and east sides, while the south and west have less vegetation. Collisions with the eastern face were closely associated with westerly winds in both seasons, suggesting that colliding birds may be flying into headwinds when trying to reach land from open water. When encountering headwinds, birds are expected to fly at lower altitudes (42), increasing collision risk. This may also explain increased collisions on the northern face in fall under unfavorable southerly winds.

Spatiotemporal Scales. Current bird-migration analysis and forecasting tools (31) across North America make predictions using vertical reflectivity profiles constructed from data aggregated over a 37.5-km radius from each Next Generation Radar network (NEXRAD) Doppler radar station. We found that adding finer-resolution local migration data meaningfully improved collision models. Studies could incorporate local migration data from spatially explicit weather radar analyses, individual small radars, or automated acoustic monitoring (43). However, the relatively small estimated effect sizes of local metrics, compared to regional, indicates that regional data likely contain sufficient information for most modeling purposes.

The middle third of the night—generally the peak period of nightly bird migration—was the most relevant time for predicting collision counts from migration and weather. However, our analysis does not reveal exactly when collisions occurred, and behaviors such as dawn reorientation over open water (37–39) may still be a contributing factor. Indeed, the predictive importance of radar measures over Lake Michigan hints that migrants flying over water may show a particularly strong attractive response to coastal light pollution, possibly in combination with a general tendency to seek nearby land. These hypotheses should be further investigated.

Conservation Implications and Recommendations. This study can help inform conservation efforts to protect bird populations through reducing collisions. Current guidelines for collision reduction highlight the contribution of light pollution to mortality and the need to reduce unnecessary lighting (44–46). Our

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findings affirm these recommendations and provide information that can be incorporated into policy initiatives.

In our study, lighted window area strongly predicts fatal collisions, highlighting the need for lights-out initiatives to reduce nocturnal lighting. Given the difficulty of fully reducing nighttime lighting across urban centers, the efficacy of lights-out programs and other conservation efforts to mitigate collisions could be improved by targeting nights of increased collision risk for mitigation action. As we show, both migration intensity and weather conditions meaningfully influence collision risk, often at a local scale. Therefore, we propose incorporating both weather and migration forecasts (31, 32) into lights-out advisories. Associations with weather conditions may be idiosyncratic, varying by city, building, and even window orientation; thus, effective advisories for particularly problematic structures may require on-the-ground efforts to determine the optimal mitigation strategy.

Ultimately, although selective reduction of lighting can make a meaningful difference in reducing bird mortality and help to raise public awareness of the issue, permanent reductions in lighted window area are likely to have a greater positive impact on bird populations. Where possible, permanent lighting adjustments, such as downshielding lighting, changing lighting color (47), and automating the usage of window blinds between certain hours, will reduce the load on individual actors and decrease the risks posed to nocturnally migrating birds by light pollution.

Methods

Collision Monitoring. The McCormick Place Lakeside Center is a large building that is part of a larger convention center located on Chicago's lakefront (Fig. 1). The building contains three stories above ground with large window bays that are illuminated from within and recessed beneath a roof. Since 1978, from early March to June and from mid-August through November, personnel from the Field Museum have surveyed the building daily at dawn for birds that have collided with the windows (Fig. 2). The surveyed perimeter length of the building is 1.5 km, and search effort has been standardized throughout the survey. Birds are collected from a smooth, cement-like walking surface. As a result, detection probability is consistent and not influenced by seasonal vegetation.

Over this 43-y period, over 40,000 birds have been collected in this manner (48). Prior to 1999, interior lights were on nearly continually. Starting in 1999, lighting became more variable, depending on activity in the building. Since 2000, the number of birds and lighting status of each window bay have been recorded during dawn collision monitoring. In this period, Field Museum personnel have conducted combined light and bird monitoring for a median of 77 d (range: 25 to 87) each spring between 28 February and 4 June and 93 d (range: 71 to 109) each fall between 12 August and 2 December, resulting in a total of 3,463 d of monitoring over 21 y. Of these, we removed 9 d due to ambiguous light or collision records.

The majority of collisions at this building are songbirds (34, 48), but some nonpasserine species collide in appreciable numbers as well (e.g., American Woodcock and Yellow-Bellied Sapsucker).

Light Scoring. Winger et al. (34) defined light output at McCormick Place based on whether each of 17 window bays that form the exterior of the building's ground level were illuminated from within. As the windows are of unequal size, we refined this definition by dividing some large bays to consider a total of 21 individual window bays, with nightly lighting status and number of collisions recorded at each (*SI Appendix*, Fig. S12). Because multiple window bays look out from the same interior space, they often change lighting simultaneously. The architecture of the building contains clear separations, such that there was generally no ambiguity in assigning collisions to window bays. Where these separations are lacking, birds close to the border between two bays were assigned to the nearest bay. The data for bays 16 and 17 were not always collected separately, so we combined these two bays in our analysis.

We considered a window bay or bay division lighted if the interior lighting was on and visible from the exterior. Our building light score was the proportion of lighted window bays, accounting for the size of each bay. At least seven window bays were always lighted (bays 14 to 21), representing circa 50% of the surveyed area. Thus, our light index takes values from approximately 0.5 (half of building window area lighted) to 1 (all windows lighted).

Migration Intensity. To quantify nightly bird-migration activity, we used reflectivity measures from the National Oceanographic and Atmospheric Administration's NEXRAD radar network. Specifically, we used nocturnal radar scans from the nearest radar station (KLOT; 41.605°N, −88.045°W) from 2000 to 2020 to characterize spring (March to May) and fall (August to November) movements. We extracted biological measures at two scales: regional and local. For regional migration activity, we calculated profiles of reflectivity from 0 to 1,000 m above ground level at 100-m intervals using well-established methods (49, 50). We used MistNet (51) to remove precipitation and clutter from radar imagery and retained only biological targets. Any pixels classified as precipitation were coded as 0 birds per km^3 because few birds typically migrate in these conditions (52). Following standard practice, we constructed profiles from the lowest five elevation scans (0.5° to 4.5°) and aggregated measures from 5 to 37.5 km from the radar location. We used these vertical profiles of reflectivity from the KLOT radar as a measure of regional bird-migration activity, focusing on altitudes below 1,000 m to specifically quantify densities of birds migrating closer to the ground and, therefore, most likely to interact with terrestrial structures.

Second, we obtained local measures of migration intensity by extracting KLOT radar returns within a given radius of the McCormick Place study site from the lowest elevation scan (0.5°). We extracted mean bird densities for circles with radii 4, 8, 16, and 32 km from the study site to investigate the scale at which radar data best explain collisions, averaging over all biological returns (i.e., not precipitation or clutter) extracted by MistNet (51). We separately quantified migration densities in airspace over land and over Lake Michigan to investigate whether bird numbers over land or over water better explain collisions. Because local and regional migration measures were highly correlated, for modeling, we also constructed relative metrics describing whether local measures were higher or lower than the regional measure: We divided the local measure by the regional measure and log-transformed this ratio.

For local and regional migration metrics, we converted standard radar units of reflectivity factor (dBZ) to reflectivity (dBη) following: η[dB] = Z[dBZ] + β, where $\beta = 10 log_{10}(10^3 \pi^5 |K_m|^2/\lambda^4)$ (53). We then converted η to an estimate of the number of individual birds by dividing by 11 cm^2, a representative average radar cross-section per bird (54), yielding birds per km^3. Ground clutter can result in strong radar returns, particularly in urban environments, and we removed this potential contamination with a combination of static and dynamic clutter masks. For each season, we applied yearly static clutter masks by summing a minimum of 100 low-elevation scans (0.5°), starting on 1 January (16:00 Coordinated Universal Time [UTC] to 18:00 UTC) and continuing to 15 January. We classified any pixel above the 85th percentile of the summed reflectivity as clutter and masked it from our analyses. We removed dynamic clutter in two ways: We excluded any pixel with radial velocity between −1 and 1 ms^{-1} and those with reflectivity >35 dBZ (51). For local migration measures, we applied an additional mask as an extra precaution against clutter: We took the mean of all spring and fall measures and removed any pixels with an average value greater than 10 dBZ, reflecting consistently high reflectivity, as well as those in the upper 5% of remaining reflectivity values in each radar scan. Because we were focused on measuring nocturnal bird migration, we retained data only between local sunset and sunrise. Night lengths in our dataset ranged from 9 to 14.9 h. We split the night into thirds (early/middle/late) and averaged data across each third to investigate which period of the night best explained collision counts.

Local Weather and Moon Illumination. Like the radar data, we split the night into thirds (early/middle/late) and averaged data across each third. Migrating birds respond strongly to wind conditions (52, 55), so we obtained local hourly wind speed and direction, cloud ceiling height, and visibility data from the Integrated Surface Database (56). The closest weather station operating continually during our study period was located at Chicago Midway Airport (ID: 14819), 13.4 km from the study site. Nightly moon illumination (range from zero to one) was calculated by using the R package suncalc (57).

Statistical Analyses.

Drivers of daily collision counts.

Model structure. We modeled daily fatal collision counts derived from early morning surveys using conditions and behavior during the preceding night of migration. We standardized all continuous variables to have a mean of zero and a variance of one so that coefficient estimates could be directly compared across parameters with different units. We constructed separate models for spring and autumn, with the following main effects:

- Regional migration intensity, mean $<$ 1,000 m above ground (birds per km^3, log-transformed)
- Local migration intensity relative to regional (ratio of local:regional, log-transformed)
- Lighted window area, measured as a proportion of total window-bay area emitting light from within the building, ranging from $\sim$0.5 to 1 because at least 50% of bay area was always lighted
- Zonal (east/west) wind speed component ($m \cdot s^{-1}$; positive values indicate winds blowing from west to east)
- Meridional (north/south) wind speed component ($m \cdot s^{-1}$; positive values indicate winds blowing from south to north)
- Cloud ceiling height (m)
- Visibility (categorical: $>$15 km, 7.5 to 15 km, $<$7.5 km)
- Moon illumination fraction (daily measure ranging from zero to one)
- Day of year (ordinal, including quadratic term)
- Year (continuous)

In addition, we tested six pairwise interactions chosen a priori because of direct relevance to our hypotheses about bird behavior and how it may be modified by atmospheric conditions. Given historical and anecdotal evidence that large mortality events at lighted structures are often associated with cloud and fog (10, 18–20), we tested whether a low cloud ceiling or low-visibility conditions might amplify the association with light pollution or influence the relationship between migration intensity and collision counts. We also expected that lighted window area might affect the relationship between migration intensity and collisions; that cloud cover might affect the relationship between moon illumination and collisions (i.e., if the moon is hidden by clouds); and that moon illumination might impact the relationship between light pollution and collisions. Finally, we expected that wind conditions might affect the relationship between migration intensity and collisions—for example, if westerly winds cause migrants to concentrate along the Chicago lakefront. Thus, we added the following interactions:

- Cloud ceiling × lighted window area
- Visibility × lighted window area
- Cloud ceiling × regional migration intensity
- Visibility × regional migration intensity
- Lighted window area × regional migration intensity
- Cloud ceiling × moon illumination
- Lighted window area × moon illumination
- Zonal wind × regional migration intensity

Model fitting and spatiotemporal scale selection. We fit our collision model using a Bayesian framework, specifying the model with JAGS (Just Another Gibbs Sampler) implemented in the R package rjags (58). For all parameters, we specified Gaussian priors with a mean of 0 and SD of 100. We fitted our model structure as a generalized linear model with a negative binomial distribution, as opposed to a Poisson distribution, because the collision count data were substantially overdispersed. Negative binomial models estimate a parameter to account for overdispersion. We used BLISS (36) to choose the spatial and temporal scales of our predictors that best explained collision data. Using BLISS, we determined whether weather and migration data from early, middle, or late nocturnal periods best explained collision counts. We also compared several spatial scales for local migration data. Our intention here was to determine if local, spatially explicit migration information above Chicago was important in addition to regional migration measures and, if so, the optimal local area size. To this end, we compared local migration data from 4-, 8-, 16-, and 32-km circles centered on Chicago, further subdivided into airspace above land or above water (i.e., above Lake Michigan).

For both spring and fall, we ran the JAGS model for 110,000 iterations, including 10,000 burn-in iterations. For each multiscale covariate, we calculated the posterior probabilities of each spatial or temporal scale considered using indicator variables to represent the selection of a particular scale. We then retained the scale with the highest posterior probability. We used the subset of Markov chain Monte Carlo iterations with these selected scales for model inference.

Cross-validation of model performance. We assessed model performance across years (n = 21 folds) by retraining the model on data excluding those from a focal year and then testing performance on the withheld year. To assess performance, we calculated the MAE of predictions on the response (count) scale.

Drivers of Daily Mortality at Individual Window Bays. After selecting the best spatial and temporal scales for predictors and identifying drivers of collisions across the study site, we conducted an additional analysis in which the response variable was the daily collision count at individual window bays, as opposed to summed across the whole building. Our goals were twofold: 1) to understand how lighting of individual window bays interacts with building-wide lighted window area; and 2) to understand how weather conditions mediate the spatial pattern of collisions and the particular window bays that pose the greatest risk.

We fit this second model in the same Bayesian framework as above, with the following modifications: 1) We did not perform scale selection; instead, we used the scales selected by the daily mortality models in the previous step. 2) The response variable was the number of collisions recorded at the individual window-bay level on a given night. (3) We added an offset term for the length of each window bay (in meters of perimeter) to account for window bays of different sizes. Thus, our predictions can be interpreted as the number of expected collisions per 100 m. 4) We added a random intercept term of window-bay identity and a fixed effect of the direction the window faced (north/south/east/west). 5) We added a binary fixed effect describing lighting at the individual window bay (on/off), with off (no light) as the reference level. 6) We added an interaction between individual window-bay lighting and the proportion of lighted window area for the entire building. 7) We added two interactions between window-bay direction (north/south/east/west) and wind conditions (with zonal and meridional winds, respectively).

Causal Inference. Although we did not perform a formal causal analysis, we present two lines of evidence that our measured association between window-bay lighting and collision counts likely reflects a causal relationship. First, we constructed a directed acyclic graph with DAGitty (59) to determine whether any variables could potentially confound the estimated effect of lighting on collision counts (60) (*SI Appendix*, Fig. S5). Second, we performed multivariate matching with the R package Matching (61) to compare collision data for nights with and without window lighting that were otherwise highly similar in all other covariates (e.g., weather, migration intensity, date, etc.). This procedure created two matched groups of data that were as similar as possible, except for the light treatment, allowing us to infer a causal effect of this treatment (*SI Appendix*, Fig. S6).

Data Availability. All data and code used in this analysis are publicly accessible on Mendeley Data (http://dx.doi.org/10.17632/mjvt3yxdkv.1) (62).

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FBC

Feminist Bird Club
est. 2016

Comments to
NEW YORK CITY COUNCIL COMMITTEE ON ENVIRONMENTAL PROTECTION
Regarding
Introductions 265-2018, 271-2018 and 274-2018

Feminist Bird Club
December 3, 2021

Dear members of the Committee,

The Feminist Bird Club enthusiasticly supports passing Introduction 265, Introduction 271, and Introduction 274 in order to limit nocturnal lighting in New York City. We believe that these laws will help provide a more just and healthy city for humans and wildlife.

Our organization is an international non-profit dedicated to promoting inclusivity in birding and conservation while fundraising for and engaging in social justice issues. We have over a dozen chapters of compassionate birders throughout the United States, Canada, the Netherlands, and Ireland, but we started our original chapter here in NYC. Our founder was inspired by both the diversity of birds that can be seen in the city, as well as the New York birding and conservation community's failure to include underserved populations in the city. Since nocturnal lighting is a known hazard to both human health, disproportionately in disadvantaged comunities, and migratory bird species, we are especially passionate about promoting a solution to this deadly issue.

Nearly every New Yorker has experienced the negative effects of light pollution in the city, but often these impacts disproportionately affect disadvantaged communities. According to a study on light pollution by Nadybal et al published in 2020 looking at this issue through an environmental justice lens, they found that Black Americans, people of color and people with low-income are two times more likely to be exposed to excessive ambient light. These populations are already often forced to live in areas with high air pollution and within close proximity to toxic waste, compounding devastating health risks. Extended exposure to nocturnal light can cause sleep disorders directly linked to an

Feminist Bird Club
est. 2016

increased chance of developing anxiety, depression, diabetes, gastro-intesinal disorders, cardiac disease, and different types of cancers.

In addition to the negative health impacts that nocturnal lighting has on humans, it contributes to the death of 90,000-230,000 birds per year in NYC. The majority of birds in North America migrate at night, and large, bright cities like New York attract birds and lure them into areas with lots of buildings with reflective windows. Birds collide with reflective or transparent windows mostly in the early hours of the day after their long migration journeys. This can be very distressing for people who live in buildings with collisions, or those who find dead and injured birds on the sidewalk. Bird collisions are one of the biggest threats to bird populations in North America. Turning off the lights will allow more birds to pass safely through NYC, landing in less urban areas often with less risks of collision.

While we care greatly about birds and bird conservation, we believe that the most important function of laws will be that they improve the quality of life for New Yorkers. Low-income and minority neighborhoods have also been hit harder by Covid-19, leaving families devastated by death, and others disabled by long-covid and unable to work. Passing Introductions 265, 271, and 274 and shutting off the lights will bring immediate relief to those who need it most. It is an added bonus that our avian friends will benefit as well.

Molly Adams
Founder and Board Member, Feminist Bird Club

Comments to

NEW YORK CITY COUNCIL COMMITTEE ON ENVIRONMENTAL PROTECTION

Regarding

Introductions 265, 271 and 274

Feminist Bird Club

December 1, 2021

Thank you all for the opportunity to testify today! My name is Rachel Kimpton and I am representing the Feminist Bird Club. We enthusiastically support passing Introduction 265, 271, and 274 in order to limit nocturnal lighting in New York City. We believe that these laws will help provide a more just and healthy city for humans and wildlife.

The Feminist Bird Club is an international non-profit with a goal to promote inclusivity in birding and conservation while fundraising for and engaging in social justice issues. We have over a dozen chapters of compassionate birders throughout the United States, Canada and Europe, with affiliated groups in Central and South America, but we started our original chapter here in NYC. Since nocturnal lighting is a known hazard to both human health and migratory bird species, we are especially passionate about promoting a solution to this deadly issue.

Nearly every New Yorker has experienced the negative effects of light pollution in the city, but often these impacts disproportionately affect disadvantaged communities. According to a research paper on light pollution that looks at this issue through an environmental justice lens, Black Americans, people of color and people with low-income are two times more likely to be exposed to excessive ambient light. These populations are already often forced to live in areas with high air pollution and within close proximity to toxic waste, compounding devastating health risks. Extended exposure to nocturnal light can cause sleep disorders directly linked to an increased chance of developing anxiety, depression, diabetes, gastro-intesinal disorders, cardiac disease, and different types of cancers.

Low-income and minority neighborhoods have also been hit harder by Covid-19, leaving families devastated by death and others disabled by long-covid and unable to work. Passing Introductions 265, 271, and 274 and shutting off the lights will bring immediate relief to those who need it most. It is an added bonus that our avian friends will benefit as well.

FOOD INDUSTRY ALLIANCE OF NEW YORK STATE, INC.
130 Washington Avenue • Albany, NY 12210 • Tel (518) 434-1900 • Fax (518) 434-9962
Government Relations (518) 434-8144

Testimony by
the Food Industry Alliance of New York State, Inc.
in Opposition to Int. 265-2018

Thank you for the opportunity to testify regarding Int. 265-2018. My name is Jay Peltz and I am the General Counsel and Senior Vice President of Government Relations for the Food Industry Alliance of New York State (FIA). FIA is a nonprofit trade association that advocates on behalf of grocery, drug and convenience stores throughout the state. We represent a broad spectrum of NYC food retailers, from independent, neighborhood grocers to large chains, including many unionized stores. Our members account for a significant share of the city's grocery market and the stores they operate are valuable community assets, providing neighborhood residents with jobs and access to a wide assortment of fresh foods at affordable prices.

Background. Neighborhood grocers have never faced a more difficult regulatory and operating environment. The Climate Mobilization Act and the transition to a commercial waste zone system have created immense uncertainty and, according to our analysis, will significantly increase operating expenses. This will add to the enormous cost of doing business in the city, including high rents, expensive health insurance and the $15.00 minimum wage. The pandemic caused the city's grocers to incur millions of dollars of additional costs, including higher labor expenses due to bonus pay and increased overtime, purchasing and installing protective plexiglass and frequent deep cleaning of stores. Grocery stores operating in neighborhoods that lost population or that are dependent on office workers experienced significant sales declines. Neighborhood grocers are trying to manage these considerable challenges while losing market share to nontraditional retailers (that are largely nonunion operators) such as internet grocers and natural/organic food retailers. This context should be considered when proposing additional regulatory burdens.

In addition, food deserts and related high obesity rates are a long-standing problem in the city. According to the 2019 Food Metrics Report prepared by the Mayor's Office of Food Policy, 1.2 million residents were food insecure during 2017, before the problem was exacerbated by the pandemic. Moreover, due to the persistence of food deserts in the city, the Department of City Planning (DCP) is updating the FRESH program to incentivize the construction of new food stores and the improvement of existing locations. As part of the update, DCP is significantly increasing the number of "high need areas," so that 30 of the city's 59 community districts will have them. This makes it clear that many of the city's high need communities are still underserved. Accordingly, the Council should refrain from adopting legislation that may threaten the viability of neighborhood grocery stores.

The legislation. This bill generally prohibits the nighttime illumination of the exterior or interior of certain buildings, including buildings whose main use is classified in group M under the New York City building code. It is our understanding that supermarket, drug and convenience store uses fall within the group M classification.

The legislation allows lights to remain in use until the last person leaves the store. However, at that point, the exterior and interior of the building must go completely dark, unless an exception applies. This mandate can apply even though grocery stores, depending on the size, can have six or seven figures worth of inventory inside plus thousands of dollars in cash in safes and ATMs. This can make grocery stores as inviting a target as banks.

Without an express, categorical exception, store managers will often open and close in the dark. Sometimes, those managers will have to walk, in the dark, the entire length of a store to an electric panel in the back to turn the lights on or off. Similarly, when answering a burglar alarm, police officers would enter a completely dark store.

Darkened parking lots would become hazardous due to potholes, cement blocks, ice and other conditions that are manageable with light but dangerous in the dark. Darkened parking lots can also become hangouts. In addition, security would be weakened as security cameras would be useless in the dark and police officers would no longer "peek-in" to darkened stores at night.

The security exception in the legislation falls far short of providing our stores, and their workers, with the immediate, comprehensive security protection they need. Under the measure, for the security exception to apply, each building owner would have to separately apply for a waiver based on "special circumstances" indicating a need for night security lighting for that building. The first problem is that most of our members operate stores as tenants, not building owners, and tenants cannot force their landlords to seek a waiver. The second is that decisions will be made case-by case, which inevitably leads to inconsistent outcomes, with some buildings being allowed to leave their lights on to varying degrees, while others won't be permitted to leave their lights on at all. The third is that the city's grocers will have to wait for the Department of Environmental Protection to coordinate with two other agencies before promulgating rules defining "special circumstances" and other major aspects of the exception, then hope that the landlord requests a waiver, then wait for a decision. Finally, an exception, if granted, can only waive or vary the provisions of the mandate "…to the *minimum* extent necessary to accommodate such lighting… (emphasis added)." Minimizing the amount of lighting needed for security is counterintuitive; the amount of lighting needed to protect workers, customers and property should be *maximized*.

In addition, none of our member stores meet the definition of "small store," since each member store is part of a "chain of stores" or occupies at least 4,000 square feet of retail space, excluding storage space.

The security of the city's neighborhood grocery stores, and the people who work and shop there, should not be left to the ambiguities of the rulemaking process. Accordingly, we respectfully request that the bill be revised to exempt the city's grocery, drug and convenience stores as a class. The standard should be that lights can be left on to the extent necessary to maximize security.

For the foregoing reasons, FIA opposes adoption of this legislation and respectfully requests that the proposed local law be held in committee while we discuss the enumerated issues with the sponsor and committee staff.

Thank you for your time and attention to our concerns.

Respectfully submitted,

Food Industry Alliance of New York State, Inc.
Jay M. Peltz
General Counsel and Senior Vice President of Government Relations
Metro Office: 914-833-1002 | jay@fiany.com

December 1, 2021

From: Nicole Rivard <nrivard@friendsofanimals.org>
Sent: Wednesday, December 1, 2021 3:31 PM
To: Testimony
Subject: [EXTERNAL] Committee on Environmental Protection RE: SUPPORT Intro 274-2018, 265-2018, and 271-2018

~~EXPLOITERS~~
FRIENDS of ANIMALS

December 1, 2021

Committee on Environmental Protection
Submitted by Priscilla Feral, President/FoA
testimony@council.nyc.gov
RE: SUPPORT Intro 274-2018, 265-2018, and 271-2018

Dear members:
On behalf of the hundreds of Friends of Animals' members living in New York City, I am asking that you support three bills—Intro 274-2018, 265-2018, and 271-2018—which are designed to limit light pollution in NYC.

Friends of Animals joined the Lights Out Coalition because migratory birds have been flying unfriendly skies for far too long. It's time to protect them from bright lights, big cities.

According to a study released in 2019 by the Cornell Lab of Ornithology, the five most dangerous cities for birds during spring migration are: Chicago, Houston, Dallas, Los Angeles and St. Louis. During fall migration, they are Chicago, Houston, Dallas, Atlanta and New York. The study combines satellite data showing light pollution levels with weather radar measuring bird migration density.

The study's aim is to raise awareness that bird strikes are not isolated events; they are part of a global problem that everyone—from architects and city building managers to homeowners—is responsible for solving. The study highlights artificial light at night as a contributing factor. Songbirds, especially warblers, seem most susceptible to light pollution. Building glass is the other major threat to birds, as it can be so clear that birds don't see it, or it can reflect nearby trees, duping birds who then fly into it.

But the good news is, it's an environmental issue with relatively easy solutions compared to something like climate change, which can be so overwhelming that the public feels paralyzed instead of motivated to take corrective action.

As council members you can to make real on-the-ground change happen.

Artificial light pollution and building glass is responsible for the deaths of up to a billion birds every year in the United States. And New York City is at the center of the region with the worst light pollution in the country as well as in the midst of the Atlantic Flyway, one of the main routes of migratory birds traversing the U.S.

In New York City alone, avian collisions kill as many as 230,000 birds each year, according to NYC Audubon. It is so unnecessary that we endanger birds lives this way.

The harms of light pollution are widespread, but our focus is on its effect on wildlife, particularly migratory birds. New Yorkers have become accustomed to finding dead or seriously injured migratory birds at the base of taller buildings. Some, such as the Circa Central Park buildings on 110th street, are notorious for their death toll during migration season.

Migratory birds are drawn to light. On evenings during migration season, birds will alter their paths to approach areas with increased light pollution. Unfortunately, these areas will cause them to lose their way and are often the most dangerous for the birds, as they are replete with tall, glass buildings. The results are predictable.

Int. 274, 265, and 271 are targeted to reducing light pollution in New York City without disrupting quality of life. Instead, they would significantly improve the quality of life of New York residents by ensuring that inessential, decorative lighting does not disrupt their sleep schedules and circadian rhythms. It saves the lives of countless birds and other non-human New Yorkers, saves the city substantial money, and reduces our carbon footprint. The proposals are a win-win-win.

The New York City Council has taken strides in caring for New York's wildlife, treating our non-human neighbors with respect and dignity. The 2019 passage of Int. 1482, requiring bird-safe glass in new construction, was an important step toward improving our relationship to our environment. However, the bill does not impose requirements on existing buildings, even when they are changing their windows. As a result, these buildings continue to kill birds.

Lights Out efforts as well as glass remediation programs have had a positive impact in other places like Washington D.C. Volunteers began collaborating with the architect of the Thurgood Marshall Federal Judiciary Building in 2011. The building features a five-story glass atrium that showcases live, tall trees in the lobby. After many meetings with several people, the building's management agreed to turn off the atrium lights during spring and fall migration. As a result, there was a two-thirds reduction in bird-glass collisions.

Please support **Intro 274-2018, 265-2018, and 271-2018** so New York City could also be a role model for cities around the country.

Friends of Animals is an international animal protection organization founded in New York in 1957, advocates for the rights of animals, free-living and domestic around the world.

Nicole Rivard
Editor-in-Chief
Media/Government Relations

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Testimony in Favor of 274 from Robin Schwartz IDA Dark Sky Association Advocate
robin.schwartz@mountsaintvincent.edu

Dear City Council,

Please allow me to introduce myself, I'm Robin Schwartz, a constituent of your community and an Advocate for the International Dark Sky Association. I would like to talk with you about establishing Lights Out in New York City by passing 274. A Lights Out program will make our community more bird-friendly while also supporting our sustainability goals by reducing energy usage.

Because many birds migrate at night using natural light cues like the moon and stars, bright lights and sky glow can confuse them, causing some to collide with windows and walls while others circle in confusion until exhaustion overcomes them. From our best current scientific understanding, millions of birds die in the U.S. every year because of this. Fortunately, a simple thing like turning out lights can help birds navigate our environment and protect them from unnecessary harm. A landmark study conducted by the Field Museum in Chicago showed that by turning the lights off in one building, the number of birds killed there dropped by over 80 percent.

What can we do here? Participating in Lights Out is simple, building managers only need to:

- Turn off unnecessary lighting (especially near the tops of buildings)
- Put necessary lighting on timers or use motion sensors
- Make sure external lighting is down shielded
- Dim or extinguish lobby or atrium lighting

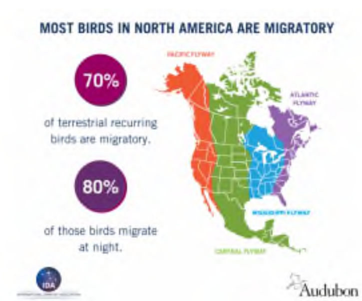
It is particularly important to take these measures between the hours of midnight and sunrise (when most night migrants are flying) and during spring and fall migration periods (April/May and September/October).

In addition to helping birds, these efforts have the additional benefits of reducing energy usage and saving money. Communities across the country from Atlanta to St. Paul to Portland, Oregon have seen the benefits and implemented Lights Out. Can I count on you to support and lead efforts to implement Lights Out here in our community?

Thank you so much for your time and consideration of this request. By making these simple changes in New York City, we truly can have a positive impact on the birds that share our community.

Sincerely,

Robin Schwartz
International Dark Sky Association NYC Advocate
Bronx NY



Int. No. 274: By Council Members Rosenthal, Rivera, Reynoso, Brannan, Dromm and the Public Advocate (Mr. Williams) (by request of the Queens Borough President)

Title: A Local Law to amend the administrative code of the city of New York, in relation to nighttime illumination during peak avian migration periods

NYC testimony December 1st 11 am
Re: Committee on Environmental Protection
Night Lighting
Int 0265-2018; Int 0271-2018; Int 0274-2018; Int 2460-2021.

To the Members of the Committee,

As the New York representative of the International Dark Sky Association, I am here in support of the measures to enact the sensible legislation to limit bird deaths from excessive and unnecessary night lighting.

Our organization helps educate municipalities and the public on the ways and means to reduce the impacts of light pollution, namely glare, unshielded, excessive, and unnecessary night lighting. We, along with our partners with the Illuminating Engineering Society, produced a set of 5 Principles for Responsible Outdoor lighting, which could be a guide to continuing your legislative efforts to protect our nighttime environment for all creatures, great and small.

These 5 Principles are based in common sense and professional guidelines:

1. All light should have a clear purpose: Before installing or replacing a fixture, determine if light is needed for safety. Consider how the use of the light will impact the area, including wildlife and the environment.
2. Light should be directed only to where needed. Use shielding and careful aiming to target the direction of the light beam so that it points downward and does not spill beyond where needed.
3. Light should be no brighter than necessary. Use the lowest light level required.
4. Light should be used only when it is useful. Use controls such as times or motion detectors to endure that light is available when it is needed, dimmed when possible, and turned off when not needed.

Use warmer color lights where possible. Limit the amount of shorter wave-length (blue-violet) light to the least amount, for example, use low "blue light" sources, rated at 2200 Kelvin which are better for night vision. Blue light waves are problematic for many reasons:

1. Night vision is impaired: the pupil contracts more in the presence of blue light.
2. Blue light contributes to macular degeneration
3. Circadian rhythms are disrupted, disturbing sleep and lowering melatonin production, a tumor suppressant.
4. With less blue, the light is warmer and more pleasant with less glare
5. And since blue light waves scatter more in the atmosphere, there is greater skyglow, obscuring the stars in the night sky.

The International Dark Sky Association supports the measures under consideration today.

Susan Harder
NY – IDA
www.darksky.org

November 30, 2021

Dear Chairman Gennaro,

Hoping this finds you well. We write to urge you to pass Int. 274-2018, 265-2018, and 271-2018, three bills designed to limit light pollution in New York City that we fully support and that will be heard in your Environmental Protection Committee tomorrow. Many of our Lights Out coalition members will be testifying in favor of them.

New York City is at the center of the region with the worst light pollution in the United States that spans from Washington, D.C. to Boston, and some of the worst light pollution in the world.

Light pollution alone is responsible for the deaths of between 300 million and 1 billion birds every year in the US – which exceeds the entire human population of the United States.[1] It also wastes $2.2 billion of electricity per year and produces about 31 billion pounds of carbon dioxide.[2] Lastly, it has a substantial impact on human health, leading to sleep disregulation that causes health issues from depression to certain forms of cancer,[3] the cost of which is difficult to estimate but easy to underestimate. Importantly, these impacts do not fall evenly across all demographics; the burden is felt disproportionately by poor people of color.

The harms of light pollution are widespread, but our focus is on its effect on wildlife, particularly migratory birds. New Yorkers have become accustomed to finding dead or seriously injured migratory birds at the feet of taller buildings. Some, such as the Circa Central Park buildings on 110th street, are notorious for their death toll during migration season.

Migratory birds are drawn to light. On evenings during migration season, birds will alter their paths to approach areas with increased light pollution. Unfortunately, these areas will cause them to lose their way[4] and are often the most dangerous for the birds, as they are replete with tall, glass buildings. The results are predictable and have increased in the past month.[5]

Int. 274, 265, and 271 are targeted to reducing light pollution in New York City without disrupting quality of life. Instead, they would significantly improve the quality of life of New York residents by ensuring that inessential, decorative lighting does not disrupt their sleep schedules and circadian

1https://academic.oup.com/condor/article/116/1/8/5153098

2https://futurism.com/the-energy-cost-of-light-pollution

3https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2627884

4https://www.nytimes.com/2021/07/29/science/animals-starlight-navigation-dacke.html

5https://www.huffpost.com/entry/birds-migrating-nyc-crash_n_614631a3e4b0e5dd4b27611f rhythms. It saves the lives of countless birds and other non-human New Yorkers, saves the City substantial money, and reduces our carbon footprint. The proposals are a win-win-win.

The New York City Council has taken great strides in caring for New York's wildlife, treating our non-human neighbors with respect and dignity. The 2019 passage of Int. 1482, requiring bird-safe glass in new construction, was an important step towards improving our relationship to our environment. However, the bill does not impose requirements on existing buildings, even when they are changing their windows. As a result, these buildings continue to kill birds. Therefore, we urge you to vote Yes to Intros 274, 265, and 271.

We will follow up with you shortly.

Thank you for your time.

Respectfully submitted,

Kathy Nizzari & Linda Jacobson, Co-chairs
Village Independent Democrats, Animal Welfare Committee

Kathryn Heintz, Executive Director
New York City Audubon Society

Rita McMahon, Co-founder and Director
Wild Bird Fund

Denise Kelly, President
Avian Welfare Coalition

Kiley Blackman, Founder
Animal Defenders of Westchester

Lorraine Platt, Co-founder
Conservative Animal Welfare Foundation

Gene Baur, President & Co-founder
Farm Sanctuary

Danika Oriol-Morway, Executive Director
FOUR PAWS USA

Nicole Rivard, Media & Government Relations
Friends of Animals

Jane Halevy Moreno, Founder
International Anti-Fur Coalition

Melissa Hoffman, Director
Jewish Initiative for Animals

Nina Jackel, Founder
Lady Freethinker

Sherry Reisch, Wildlife Policy Director
League of Humane Voters

Ken Chaya, President
Linnaean Society of New York

Jane Hoffman, President
Mayor's Alliance for NYC's Animals

Jill & Robert Lewis, Founders
Northeast Avian Rescue

Taffy Williams, President
NY4Whales

Taffy Williams, President
NY4Wildlife

Edita Birnkrant, Executive Director
NYCLASS

Ashley Byrne, Director of Outreach, Communications
PETA

Donny Moss, Director
Their Turn

Stewart Mitchell, Founder
V.O.I.C.E.4Change

NYC Council Environmental Protection Committee December 1, 2021 Hearing on Intros 274, 265, 271

Good morning Chairman Gennaro and members of the Environmental Protection Committee. Thank you for giving me the opportunity to speak about an issue that impacts the lives of millions of migratory birds each year and also impacts everyday New Yorkers and our sidewalks. My name is Kathy Nizzari and I am the co-chair of the Village Independent Democrats' {VID} Animal Welfare Committee and lead organizer of the Lights Out Coalition.

As we now turn the corner on fall, we also complete a violent cycle of completely unnecessary and preventable deaths of migratory birds who fly by New York City along the "Atlantic Flyway" on their way south. Each spring and fall, millions make this journey and over 200,000 of those birds die in our City from colliding with glass windows and disorienting artificial nighttime lights. That's only in New York. Up to a BILLION birds die from colliding with tall glass buildings across the country annually.

Intros 265, 271, and 274, collectively the "Lights Out Bills," are designed to limit light pollution in New York City. These bills not only reduce the death toll of migratory birds, but they also help conserve electricity and tackle light pollution. Intros 271 and 274 are focused on city-owned properties that are unlikely to be occupied at night. They create reasonable time limits on lighting, only apply during the migratory period and also give the City the tools it needs to comply with the limits by installing building occupancy sensors on city property. Intro 265 extends nighttime lighting restrictions to businesses, but only when it is safe to do so and exempts small businesses. We ask that these bills also include interior lighting as well as buildings leased by the City.

VID is part of one of the largest coalitions of animal protection organizations in New York that have joined together in support of the Lights Out Bills. You will hear from several of them here today and others via email. In addition, over 27,000 people from across the City have signed a petition in support of these bills. Supporters range from advocates, ordinary New Yorkers, to real estate developers and owners of some of the tallest skyscrapers in the City. We are all standing together to speak up because the hundreds of thousands of migratory birds who die unnecessarily each year do not have a voice. Dozens of cities across the country have enacted Lights Out and Suffolk County is enacting a "light pollution" amendment to their County Code to reduce skyglow. New York City must get on board. Therefore we thank Helen Rosenthal and Justin Brannan for sponsoring and urge you all to pass Intros 265, 271, and 274 to dramatically reduce the senseless death and injury to birds.

Thank you for your time.

Kathy Nizzari
917 609 2407
kathy.nizzari.nam@gmail.com

Kathy Nizzari & Linda Jacobson, Co-chairs
Village Independent Democrats, Animal Welfare Committee

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PETA

Catherine Skopic, Chair
Sierra Club NYC Chapter

Donny Moss, Director
Their Turn

Stewart Mitchell, Founder
V.O.I.C.E.4Change

December 1, 2021

Dear Council Members,

I have just finished viewing today's online testimonies regarding Intros 274, 265, and 271, and as President of The Linnaean Society of New York (the second oldest bird and nature organization in the United States, founded in 1878), as well as being a long-time NYC birder and urban naturalist, I would like to add the Society's support as well as my own to the passing of these three bills.

In addition, I would like to add my support for the additional language proposed by Council Member Rosenthal to expand the contract language to include "City Leased" buildings, as well as to include interior lighting as well as exterior building lighting to be affected by the legislation proposed by these bills.

Have you ever paused to pick up the small body of a migrant bird from a NYC sidewalk killed by a collision with a building or window? If not, I am surprised. Unfortunately, they can be found by the hundreds (perhaps even thousands) on our city streets on any given spring or fall morning when their Atlantic Flyway migration route takes them directly through New York City.

New York City sits at the center of the region with the worst light pollution in the United States that spans from Washington, D.C. to Boston, and some of the worst light pollution in the world.

As we heard from many who provided testimony today, light pollution alone is responsible for the deaths of between 300 million and 1 billion birds every year in the United States. It also wastes $2.2 billion of electricity per year and produces about 31 billion pounds of carbon dioxide. In addition, it has a substantial impact on human health, leading to sleep disorders that may cause health issues ranging from depression to certain forms of cancer, the cost of which is difficult to estimate but easy to underestimate. Importantly, these impacts do not fall evenly across all demographics; the burden is felt disproportionately by poor people of color.

The harms of light pollution are widespread, but its effect on wildlife, particularly migratory birds in NYC is devastating. New Yorkers have become accustomed to finding dead or seriously injured migratory birds at the feet of taller buildings during the annual spring and fall migration periods. Some, such as the Circa Central Park building on the northeast corner of West 110th street and Central Park West, are notorious for their death toll during migration season.

Migratory birds are drawn to light. On evenings during migration season, birds will alter their paths to approach areas with increased light pollution. Unfortunately, these areas—notably in midtown and lower Manhattan—are often the most dangerous for the birds, as they are tall, glass buildings that are surrounded by bright, night-time illumination. The results are predictably horrific, and CAN BE AVOIDED.

Int. 274, 265, and 271 are targeted to reducing light pollution in New York City without disrupting quality of life. Instead, they would significantly improve the quality of life of New York residents by ensuring that inessential, decorative lighting does not disrupt their sleep schedules and circadian rhythms. It saves the lives of countless birds and other non-human New Yorkers, saves the City substantial money, and reduces our carbon footprint. The proposals are a win-win-win.

The New York City Council has taken great strides in caring for New York's wildlife, treating our non-human neighbors with respect and dignity. The 2019 passage of Int. 1482, requiring bird-safe glass in new construction, was an important step towards improving our relationship to our environment. However, the bill does not impose requirements on existing buildings, even when they are changing their windows. As a result, these buildings continue to kill and maim thousands of birds. Therefore, I urge you to support Intros 274, 265, and 271.

We all know that NYC can still do better to become a more environmentally-friendly city. I urge you to act now to protect the birds that live and migrate through our city with Int. 274, 265, and 271.

Thank you kindly for your time and consideration.

Sincerely yours,

Ken Chaya
President
The Linnaean Society of New York
https://linnaeannewyork.org

NYCLASS
WE LOVE ANIMALS AND WE VOTE!

NYCLASS Memorandum of Support: Intros 265, 271, 274
December 1, 2021: Environmental Protection Hearing

New Yorkers for Clean, Livable, and Safe Streets (NYCLASS) strongly supports passage of Intros 265, 271, and 274, which would limit light pollution in New York City and would therefore prevent the needless deaths of hundreds of thousands of migrating birds who smash into buildings due to the artificial lights disorienting them. NYCLASS is a 501 (c)(4) non-profit organization founded in New York in 2008 with over 100,000 supporters that works to enact animal welfare legislation into law and elect pro-animal candidates to office through activism and political action.

New York City has some of the worst light pollution in the world, and this means quality of life and health issues for people, and it sadly also means mass deaths of birds. Light pollution is shown to be responsible for the deaths of between 300 million and 1 billion birds every year in the US - a staggering number. While it is difficult to have an exact number of birds killed yearly in NYC by artificial lighting, the number is estimated to be around 200,000.

NYCLASS has received many emails and phone calls from very upset NYC residents who have discovered dead or seriously injured migratory birds at the feet of taller buildings. Some buildings, such as the Circa Central Park building, have seen hundreds of bird deaths in just one day. Media widely covered this shocking incident. The Wild Bird Fund has been a valuable resource in helping rehabilitate and save the lives of some injured birds in these situations, but they only can do so much, and many birds are beyond help.

The problem is that migratory birds are drawn to light, and New York City happens to be on a major migratory bird path. This means that once it is dark, birds will alter their intended migratory flight path and mistakenly head towards areas with light pollution, where they then become lost and disoriented and then crash into the tall buildings.

Int. 274, 265, and 271 are targeted to reducing light pollution in New York City without disrupting quality of life. Instead, they would significantly improve the quality of life of New York residents by ensuring that inessential, decorative lighting does not disrupt their sleep schedules and circadian rhythms. It saves the lives of countless birds and other non-human New Yorkers, saves the City substantial money, and reduces our carbon footprint. We see these proposals as a win-win-win all around.

For Intro 274, we would like to suggest that this bill be amended to include interior lighting and buildings leased by the City, to make it even more impactful.

In closing, we urge the Environmental Protection Committee to pass bills 265, 271, and 274 out of the Committee and to pass the bills in a full floor vote and enact them into law before the end of the year.

NYC Council - Testimony for Hearing, Wed. 12/1/21, 11:00 AM, Committee on Environmental Protection, Intro, 265, 271, 274- 2018

Virtual, Testimony of Catherine Skopic

Thank you, Chair of the Committee on Environmental Protection, James Gennaro and council members, for this opportunity to address the issues of safety for peak avian migration periods of local Laws Intro, 265-2018, 271-2018 and 274- 2018.

Back in 2015 when C.M. Donovan. Richards was Chair of the Committee on Environmental Protection, he held a NYC Council hearing on the issue of night lights. I presented testimony on Limiting Nighttime Lighting, and was quoted in the New York Times Thursday, April 30, 2015, referring to the visual impact of New York City's nighttime skyline, "Many of us have felt a sense of pride in its beauty; however, now that we are in this climate crisis, we see these lights as something else. We see them as wasteful of energy."

Today, I testify that these lights from city-owned and city-controlled spaces during peak avian migration periods are #1, endangering one of our most delicate, sensitive, threatened, treasured species that know no boundaries or borders - that belong to all citizens, all countries and cities of the world - migratory birds, and #2 that in this time of accelerated climate crisis, excessive, unnecessary nighttime lighting is akin to lack of responsibility, bordering on sinfulness.

For those people working in these buildings during nighttime hours, we have lighting systems that automatically turn on and off when persons enter and leave a room. We have dim lights that illuminate EXIT signs and steps of stairways. There is no excuse NOT to dim building illumination, not only during peak avian migratory periods as these bills call for, but also, at ALL times of year, as our climate crisis calls for.

Thank you.

Respectfully and in PEACE,
Catherine Skopic
Chair, Sierra Club New York City Group

My name is Laura Leopardo and I am testifying on behalf of Voters For Animal Rights. I live in District 35 in Brooklyn. Thank you Chairman Gennaro for holding this important hearing. I'm here asking that you pass Intros 274, 265, and 271— the Light Pollution bills.

I'd like to start out by sharing how birds are important members of our ecosystem. They play a vital role in controlling insects and rodents, act as pollinators and provide seed dispersal, all which are tangible benefits to us. However, a recent study published by the journal titled, "Science," found that since the 1970's there has been a 29% loss in the total number of birds, about three billion in North America alone. With this great emptying of the skies, there are now three billion fewer beaks to snap up insects, and three billion fewer pairs of wings for moving nutrients, pollen and seeds through the world. In addition, according to The Audubon Society, two-thirds of our existing birds in North America are at risk of extinction due to climate change. That all spells A LOT of trouble for our important bird friends!

Now let's add on the additional facts of light pollution to the above equation. The New York City Audubon Society has also stated that somewhere between 90,000 and 230,000 birds die each year in New York City alone after colliding with glass buildings, with light pollution being a very significant factor in these collisions. New York City is a major flyway for migrating birds with millions of them passing through during the fall and spring. Birds migrate at night and are attracted to the artificial lights. The lights on tall buildings disorient them and confuse the navigation systems of the unlucky ones that have these buildings in their flight path. They circle the buildings repeatedly, frequently striking transparent or reflective windows or die of exhaustion. According to the U.S. Department of Agriculture this phenomenon has led to the death of an estimated 500 million to a billion birds annually in the United States through collisions with windows, walls, floodlights or the ground.

In addition to saving the lives of countless birds, these bills would, in turn, reduce energy consumption, and thus be a logical part of our city's sustainability strategy by reducing our carbon footprint. The proposals are a win-win-win.

I do thank the Council for recently passing the 2019 passage of Int. 1482, which requires bird-safe glass in new construction. This was an important step towards improving our relationship to our environment, but these additional bills will add an important much-needed safety measure. We are the guardians of the earth, and it is our job to make sure our birds remain a significant and important element of our ecosystem.

Thank you,

Laura Leopardo
Voters For Animal Rights
157 St. Marks Avenue
Brooklyn, NY 11238
lauraleopardo94@gmail.com
woof@vfar.org

From:
Sent: Wednesday, December 1, 2021 11:58 AM
To: NYC Council Hearings; Testimony
Subject: Fwd: [EXTERNAL] City Council Committee on Environmental Protection Hearing

Begin forwarded message:

From: Larry Schnapf <Larry@schnapflaw.com>
Date: December 1, 2021 at 11:50:26 AM EST

Subject: [EXTERNAL] City Council Committee on Environmental Protection Hearing

Hi Samara,

I'm not sure I will be able to attend the hearing so I wanted to provide the following comment to the proposed amendment to Article 24.

I understand that OER has been experiencing issues with property owners or operators not complying with the Site Management Plans so I agree that OER needs more robust enforcement authority. However, I think the proposed amendment is too broad in scope since it could be construed to include people or entities without the actual ability to implement the SMP. I suggest the Council look to OER's own regulations to help fashion a more targeted amendment.

§ 43-1408(g) (Transfer of a notice of completion) of the OER regulations provides that a Notice of Completion may be transferred to "successors and assigns". It goes on to say that "*Any party to whom a notice of completion is transferred shall be responsible for the operation and maintenance of any required engineering controls and compliance with all required institutional controls, in accordance with the approved site management plan and declaration of covenants and restrictions*."

Moreover, § 43-1407(l)(3) ("Institutional control/engineering control certification") provides that the responsibility for providing annual certifications under OER's regulations are the enrollee or owner of the site.

Accordingly, my proposed change would be as follows:

24–907 [Civil Penalties] Enforcement. (a) Any applicant, enrollee, or recipient of a certificate of completion who misrepresents any material fact related to the investigation, remediation or site management of a local brownfield site; or any such person, its transferee, successors or assigns ~~entity~~ that violates any provision of a site management plan for a local brownfield site; or any such person, its transferee, successors or assigns ~~or entity that~~ violates any provision of this chapter or the rules of the office of environmental remediation, shall be liable for a civil penalty of not more than twenty-five thousand dollars.

Larry

Lawrence Schnapf

Schna

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2016-17 Chair- NYSBA Environmental Law Section

AV Preeminent Rating from Martindale-Hubbell
Listed in 2010-20 New York Super Lawyers-Metro Edition
Listed in 2011-20 Super Lawyers-Business Edition
Listed in The International Who's Who of Environmental Lawyers 2008-20
Chambers USA Client Guide of America's Leading Lawyers for Business
Adjunct Professor of Law- New York Law School Center for Real Estate Studies

From: Larry Schnapf <Larry@schnapflaw.com>
Sent: Wednesday, December 1, 2021 1:02 PM
To: Testimony
Subject: [EXTERNAL] Testimony In support of Intro 2460 (12/1 City Council Committee on Environmental Protection Hearing)

I am testifying in support of Intro 2460 with some suggestions to improve the bill. I have been an environmental lawyer for over 35 years with an emphasis on brownfield development. I am also an adjunct professor at New York Law School where I teach Environmental Law and Policy, a course on Brownfields as well as Real Estate Transactions and Finance. I am also a board emeritus of the New York Brownfield Partnership and the Brownfield Coalition of the Northeast (BCONE) though my comments are in my personal capacity.

I understand that OER has been experiencing issues with property owners or operators not complying with the Site Management Plans so I agree that OER needs more robust enforcement authority. However, I think the proposed amendment is too broad in scope since it could be construed to include people or entities without the actual ability to implement the SMP. I suggest the Council look to OER's own regulations to help fashion a more targeted amendment.

For example, § 43-1408(g) (Transfer of a notice of completion) of the OER regulations provides that a Notice of Completion may be transferred to "successors and assigns". It goes on to say that "*Any party to whom a notice of completion is transferred shall be responsible for the operation and maintenance of any required engineering controls and compliance with all required institutional controls, in accordance with the approved site management plan and declaration of covenants and restrictions*."

Moreover, § 43-1407(l)(3) ("Institutional control/engineering control certification") provides that the responsibility for providing annual certifications under OER's regulations are the enrollee or owner of the site.

Accordingly, I proposed the following minor amendments to Intro 2460 (red language is new text):

24–907 [Civil Penalties] Enforcement. (a) Any applicant, enrollee, or recipient of a certificate of completion who misrepresents any material fact related to the investigation, remediation or site management of a local brownfield site; or any such person, its transferee, successors or assigns ~~entity~~ that violates any provision of a site management plan for a local brownfield site; or any such person, its transferee, successors or assigns ~~or entity that~~ violates any provision of this chapter or the rules of the office of environmental remediation, shall be liable for a civil penalty of not more than twenty-five thousand dollars.

Lawrence Schnapf

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Listed in The International Who's Who of Environmental Lawyers 2008-20
Chambers USA Client Guide of America's Leading Lawyers for Business
Adjunct Professor of Law- New York Law School Center for Real Estate Studies

From: MARGARET LEE <mlee282828@gmail.com>
Sent: Thursday, December 2, 2021 3:55 PM
To: Testimony
Subject: [EXTERNAL] Margaret Lee - Public Testimony to PASS intros 265, 271, and 274

NEW YORK CITY COUNCIL
Committee on Environmental Protection

Thank you for this opportunity to testify for birds!

My name is Margaret Lee. As a bird-lover and neighborhood bird caregiver from lower Manhattan District 1, I'm acutely aware of the many challenges and levels of suffering of NYC birds - those who live here as permanent residents and the thousands of migratory ones passing through to their seasonal destinations. I'm grateful to the Council - especially CM Helen Rosenthal and Justin Brannan - for this act of compassion toward migratory birds in proposing LIGHTS OUT NYC to reduce or prevent their needless and horrific deaths from nighttime illuminated windows. Please PASS intros 265, 271, and 274.

And, after doing so, please continue to put your thoughts into other ways NYC can be a more compassionate city to our wildlife inhabitants and seasonal visitors, perhaps inspiring other cities to follow our lead!

Such future Bills would include but not be limited to:

Education to encourage compassion for non-human animals.

Provision of fresh water in garden settings; fountains with running water; regular supply of seed, cracked corn. Even small areas can make a big difference for birds' survival.

Removal and banning of dreadful bird-deterrent spikes.

Specially planned bird-inspired areas conducive to rest and nourishment that would also enhance human appreciation of our feathered everyday neighbors, and our occasional visitors.

Banning of detergents so often used as sidewalk cleansers. It's horrible how we allow our precious birds to be poisoned by earth-destroying chemicals. Have we not learned anything since Rachel Carson's SILENT SPRING ???

The ultimate goal being a WILDLIFE-FRIENDLY NYC, CRUELTY-FREE NYC to inspire the entire world💜

Margaret Lee
NYC
Dec 1, 2021

I can remember in my childhood days walking outside in the spring and summer and hearing the chirping and songs of birds. If I was quick enough I would see a fleeting image of them as they bounced from tree to tree. Honestly, the sounds today are not the same. There are far fewer birds that I now hear. Sadly, more than 22 species were listed as extinct this year, several of them being birds. Birds who fly in New York are more likely to have collisions with buildings due to the lighting and the light pollution they create.

We must protect the biodiversity of our world. What would our world sound like without the beautiful songs of birds? Or walking in Central Park and finding no birds to view through our binoculars?

We are lucky enough to live on the eastern corridor, one of the biggest migration paths of birds. It is a joy to see all the different species of birds and if only for a moment view them with awe and wonderment.

It is incumbent on us to ensure they have safe travels. City lights confuse birds during their migration, and in general. They are often paralyzed, flying in circles, having lost their way. the light pollution is such a threat to birds as it causes the birds to collide into buildings. These collisions cause injuries and sometimes death. The lucky ones are rescued and rehabilitated and released. But not every bird is lucky. And those that do help these injured birds do so out of their own pockets, since NYC does not aid wildlife rehabilitators.

We must take action before it is too late and save the birds who either migrate through New York City or who make New York City their home.

Please co sponsor and pass the three bills to limit light pollution in NYC; Int. 274-2018, 265-2018 and 271-2018.

Sherry Reisch

THE LEAGUE OF HUMANE VOTERS® OF NEW YORK

POLITICAL ACTION FOR ANIMALS

"Updated testimony for Intros 274, 265 and 271, December 1, 2021 Environmental Protection Hearing".

Hello Chair Gennaro and NYC Council Committee members on Environmental Protection.
My name is Sherry Reisch with the League of Humane Voters® and we are part of the Lights Out NYC Coalition.

I can remember in my childhood days walking outside in the spring and summer and hearing the chirping and songs of birds. If I was quick enough I would see a fleeting image of them as they bounced from tree to tree. Honestly, the sounds today are not the same. There are far fewer birds that I now hear. Sadly, more than 22 species were listed as extinct this year, several of them being birds. Birds who fly in New York are more likely to have collisions with buildings due to the lighting and the light pollution they create.

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We must take action before it is too late and save the birds who either migrate through New York City or who make New York City their home.

Please co sponsor and pass the three bills to limit light pollution in NYC; Intro's. 274-2018, 265-2018 and 271-2018.

As per Helen Rosenthal's request we ask that bill Intro 274 include interior lighting and buildings leased by the City.

I want to personally thank Council Member Rosenthal for her important bill, as I am her constituent. I also recognize the miraculous work of the Wild Bird Fund.

The Mission of the League of Humane Voters® (LOHV) is to create, unite, and strengthen local political action committees, which work to enact animal-friendly legislation and elect candidates for public office who will use their votes and influence for animal protection.

From:	T Williams <tlwilliams4mail@gmail.com>
Sent:	Tuesday, November 30, 2021 6:52 PM
To:	Testimony
Subject:	[EXTERNAL] Re: LightsOut NYC, Bills 271, 274 and 265

We are NY4Wildlife, a non-profit part of the Lights Out Coalition. Our hundreds of members and supporters throughout the area are deeply concerned with the biannulal plight of migrating birds through the perilous landscapes of New York City. Thank you for allowing public input on this issue. As a federally and state-licensed wildlife rehabilitator, I have witnessed first-hand the tragedies that occur when various night-flying migrating species crash into lighted buildings. Most of the time the birds are injured beyond recovery, or simply die upon impact. While perhaps not a complete solution to the bird-building collision problem, we believe these 3 laws are a worthy initial effort to save the many species that pass through our area.

Given global warming's evident effect on migration time, we would prefer that Law 274 would require lights out from dusk until dawn and extend one month before and after peak migration periods. Climate change has skewed the birds' choice migration days making their perilous journey ever more unpredictable.
Law 271 will be extremely beneficial to the birds traveling at night, as will 265. These laws are not perfect but they will certainly help save many birds' lives. NY4Wildlife would like to officially request that these three laws be re-evaluated after 3 years to determine if they can be modified to further increase their capacity to stop bird-building collisions.
Thank you for these efforts, and you for hearing my testimony. Please send updates to us as they occur.

Taffy Williams, MS Comparative Biomedical Sciences, University of Georga (in progress)
President, NY4Whales