T3-2022-16220
Cottrell CPO
cottrellcpo@gmail.com
9/5/23

Response to I.74 - Filtration Facility Operations Supplemental Information

1. Hazardous Chemicals Usage and Storage are not Consistent with Character of the Area

Page 1: "All treatment chemicals currently used by the Water Bureau, and those proposed for future use at the filtration facility, are commonly and safely used at drinking water treatment facilities nationwide."

Page 3: "The treatment chemicals planned for use at the facility are summarized in the Hazardous Materials Management Plan."

Page 3 "*Chemical Storage"* section details how chemicals at the facility will be stored safely.

Response:

While the chemicals proposed for the filtration facility are used at drinking water treatment facilities nationwide, most are not commonly seen in this rural area, and never at the scale proposed.

Large quantities of chemicals that require special storage solutions to keep them safe are unseen in this area. No nursery or other area business has chemical storage facilities similar to what is proposed. Furthermore, if area nurseries or other agricultural businesses needed such chemicals with accompanying storage facilities, it would be consistent within the conditional use criteria. The conditional use criteria ensures agricultural protections since farming is one of the primary values in the area the county is required to protect.

The proposed facility is in a Rural Reserve, the "West of Sandy River Rural Planning Area". It is specifically set aside for agriculture and the protection of surrounding natural resources. It is not an industrial area. Similarly sized facilities nationwide are located in

industrially zoned areas or in areas not impacting established rural-residential communities (see our *rebuttal submitted 9/6/23 to I.79 Comparable Facilities*).

Introduction of large amounts of hazardous chemicals, however common to filtration plants and however safely stored, in an area that is zoned to protect natural resources and forest and farm uses, is out of the Character of the Area, and cannot be mitigated. MCC 39.7515(A) is not met.

2. Chemical deliveries, Inclement Weather create Hazardous Conditions

Page 1: "Operations History" "*The Water Bureau has been operating the Lusted Hill Treatment Facility in the Rural Fire Protection District 10 boundaries since 1992 and, according to Water Bureau records, has not required an emergency response from a fire department as a result of facility operations during that time."*

Page 2: "Treatment Deliveries" *"the filtration facility will see a maximum of 16 chemical delivery trucks entering and exiting the site during a 5-day work week"*

Page 2: "Treatment Deliveries" *"Some of the materials planned for use at the filtration facility have a hazardous materials classification for transport purposes"*

Page 3: "Inclement Weather" *"Facility operators monitor weather forecasts and may schedule a top off delivery of a particular chemical prior to or following a winter storm to avoid deliveries in inclement weather."*

Response:

In response to the "Inclement Weather" statement, there is a very recent contradiction of the stated practice of scheduling deliveries around weather at the already existing Lusted Hill facility.

The following incident is reported from Natalie Voruz, the community member living at the affected property:

On December 22, 2022 an ice storm moved into Portland and the Pacific Northwest region. It was the coldest day in years, coupled with icy precipitation and peak wind gust of over 46 mph in Portland. Wind gusts were well over 100 MPH at the Vista House steps, and the temperature was 15 degrees. Forecasters were predicting up to a 1" ice

storm in East Portland east of I-205. The National Weather Service issued a Winter Weather Advisory for the Portland-Vancouver metro area and lower Columbia Valley.

The Portland area was hit hard by sleet and freezing rain, setting up icy conditions throughout the region. Traffic was snarled and thousands were without power as accumulated ice brought down tree limbs and power lines. It should be noted that Dodge Park Blvd is heavily treed in many spots, with a canopy of trees hanging over the roadway.

On December 23, a Friday, roads were tricky, leaving many impassable. Another round of freezing rain began to arrive Friday evening with temperatures in the mid 20's.

The conditions on Dodge Park Blvd on the morning of December 24, 2022 were extremely hazardous. The road was covered with a thick coating of ice and tree limbs littered the street. Anyone who could help it was not driving.

Anyone except a fuel delivery tanker truck headed to the Portland Water Bureau's Lusted Hill facility. The truck lost control and slid across Dodge Park Blvd into the landscaping in front of the residence at 37185 SE Dodge Park Blvd. The truck's further descent into the residence was only stopped by large landscape boulders.

Afterwards, the truck was blocking the westbound lane facing the wrong direction. The driver unsuccessfully attempted to move the truck multiple times. The truck was blocking one lane of traffic for over five hours.

During this time, local residents were forced to use one lane of travel, creating additional risk in icy and hazardous conditions. This is also an area of curvy roadway with limited visibility. Cars were forced to abruptly come to a stop on the icy road and travel in the wrong direction, hoping no oncoming traffic was doing the same.

It took a large tow truck with traction devices over an hour to pull this truck out of the ditch.

It should be noted that at no time did anyone from the Portland Water Bureau come to assist. Ordering/accepting a fuel delivery in treacherous weather put our community at an unacceptable grave risk.

Natalie Voruz
37185 SE Dodge Park Blvd
dogzlyf@msn.com, (503) 502-2281

December 24, 2022, Fuel Tanker headed to deliver at Lusted Hill PWB Facility in icy conditions

The following reaction from Portland Water Bureau to this incident is detailed in the record for this case: *Exhibit E.9 Charles Ciecko Testimony rec 6.28.23.* Parts of it bear repeating here as it contradicts some of the statements in I.74.

In response to a question from Natalie about this incident, Michelle Check (PWB, Engineering Supervisor) stated: *"That's, uh, obviously a very unfortunate event that, um, did happen. And, um, it sounds like nobody was hurt and there wasn't any fuel spilled which was, um, good, but obviously we can't control the weather and, um, you know, have to just trust that truck drivers are doing there best to drive safely to deliver fuel to our site"*

The very low level of responsibility the Portland Water Bureau takes for their current deliveries is apparent here. They put the community at risk by ordering a fuel delivery during an ice storm. No one from PWB came to check on the situation or assist in any way.

It is true what Michelle Cheek said that it was good that no one was hurt this time; PWB was lucky with this incident. However, the facility proposed to be built will be much larger, and will require more deliveries, coordination with contractors, assertiveness, care for the community, and potential impacts to natural resources. As stated in I.74, chemical deliveries will increase to 16 per week, many hazardous. It seems **unlikely** that inclement weather will be avoided for these 16 deliveries, especially given that PWB does not seem to be able to avoid accepting deliveries in inclement weather at the current much lower delivery level. And thus a future incident where someone does get hurt is likely.

There are NO enforcement plans or consequences written into any of the 1000's of pages of documents submitted by PWB. Given the complete lack of PWB response to this incident it is very hard to "trust" as Ms. Cheek asks this community to do, that PWB will be working hard to keep the hazardous chemical delivery system safe, or to stick to their inclement weather protocols.

MCC 39.7515 (F) will not create hazardous conditions is not met and is not able to be mitigated.

3. Inherent danger of Water Facility Treatment plants

Page 3, "Operations and Maintenance" *"Along with engineered safety features, the filtration facility will be staffed with trained and certified operators to make sure the systems are managed in a manner that fully protects public health and the environment."* This section provides more details of plant safety procedures.

Page 4, "Training and Emergency Response". "*Water Bureau operators are trained to use safety procedures, engineering controls, and personal protective measures to minimize risk of any incident requiring emergency response."* This section provides more details about staff safety trainings.

Response:

The facility will be introducing hazardous conditions into this area that were not there before. For example, the sheer volume of chemicals, quick time frame for construction, and quantity of vehicles during and following construction will occur at a scale that is incomparable to existing conditions. Therefore, hazardous conditions will greatly increase compared to predevelopment conditions.

The amount of safety trainings, procedures, and certifications detailed in these sections is indicative of the level of danger that filtration plants impose on workers and the surrounding areas.

Exhibit A.4, 1.A Filtration Facility Conditional Use Application Narrative, Section A.O.1. states the facility is comparable in impact to the larger nurseries in the area, which are the only other institutions of size in this rural area. There are no nurseries or other facilities in this rural, agricultural, and forested area that necessitate this complex level of preparedness. MCC 39.7515(A) is consistent with Character of the Area is not met.

In addition, no matter what level of preparedness is mandated for workers, accidents may still occur.

A quote from Occupational Health & Safety sums it up: *"Water treatment plants may be touted as facilities that purify and treat water to make it safe for human consumption, but let's face it; they are also breeding grounds for accidents and injuries that could fatally injure workers." (*Appendix A)

In 2019, over 50 people were transported to hospitals in Birmingham, Alabama, after a chemical spill occurred at a water treatment plant. Attached are additional documented chemical accidents at Minnesota, Maryland, Illinois, and Massachusetts water treatment plants. (Appendix B)

Accidents can't always be avoided, no matter how certified someone is or how many safety procedures are followed. Testimony from FD 10 and others has noted that emergency responses to the water facility treatment plant will take away emergency resources for the community.

No matter the level of mitigation, the large size of the plant (The largest in Oregon - see *Exhibit H.40 Rural Filtration Plants Comparison Data from CCPO*) and the corresponding large amount of chemicals that are being utilized, will be introducing a large amount of hazardous conditions that were not present in this rural area before. MCC 39.7515 (F) will not create hazardous conditions is not met and is not able to be mitigated.

4. Facility Security not Consistent with Character of the Area

Page 4, “Facility Security”. “*The Water Bureau's operation of current and future facilities prioritizes safety and security of critical infrastructure...The facility will have 24/7 onsite operations staffing, security fencing, 24/7 offsite security personnel, remote monitoring, infrared cameras, and patrols.”*

Response:

Exhibit A.4, 1.A Filtration Facility Conditional Use Application Narrative, Section A.O.1. states the facility is comparable in impact to the larger nurseries in the area, which are the only other institutions of size in this rural area. However, no nursery requires 24/7 onsite operations staffing, security fencing, infrared cameras, and patrols. The nurseries in this area do not even keep their valuable trees fenced.

MCC 39.7515(A) is consistent with Character of the Area is not met and is not able to be mitigated because a large facility of this nature should have all of these security systems. It just doesn’t belong in a Rural Reserve among agricultural operations with minimal security systems and fencing.

5. Malevolent Acts

Page 4, “Facility Security”. *“Like other community water systems serving more than 3,300 persons, the Water Bureau complies with EPA America's Water Infrastructure Act requirements related to conducting risk and resilience assessments and developing emergency response plans that incorporate findings of that assessment. This process considers both potential malevolent acts and natural hazards as well as means to improve resilience of the system through physical and cybersecurity measures and monitoring practices.”*

Response:

While the risk could be considered low for a newly designed plant, it is worth noting that there have been incidents of attempted hacks into water treatment systems. See attachments for examples from Florida, Kansas, and California (Appendix C).

This added level of danger to a safe community is not consistent with the Character of the Area - MCC 39.7515(A) - and will create Hazardous Conditions - MCC 39.7515 (F).

6. Lighting is not Consistent with Character of the Area

Page 5, “Lighting and Sound”. This section details all the light mitigation strategies for the facility.

“The facility is designed to be as unobtrusive as possible. This includes clustering the facility campus toward the center of the approximately 95-acre site to help screen views of the facility and provide a buffer from adjacent neighbors. The exterior facility lighting is designed with fixtures that meet Multnomah County's Dark Sky standards (MCC 39.6850), have no uplight component, create no light spill beyond the property line, and use warm light sources to minimize nighttime lighting impact on people and animals. Beyond meeting code requirements, the lighting controls are also set to be dimmed to the minimum needed for security and safety under normal conditions and only increased to full output when needed using motion sensors or manual switches.”

Response:

596 facility lights can be counted in *Exhibit A.47, E.2 Land Use Permitting Lighting Report, Attachment A: Luminaire Schedule.*

Exhibit A.4 1.A Filtration Facility Conditional Use Application Narrative, Section A.O.1. states the facility is comparable in impact to the larger nurseries in the area, which are the only other institutions of size in this rural area. Scenic Fruit, one of the two largest facilities listed, has at maximum 30 lights illuminated at night, per a recent visual count by a resident. In other words, the water filtration plant would contain **20 times** the amount of exterior lights as one of the two next largest facilities in the area.

Nurseries do not need much lighting at night as they only operate during the day. All the lighting mitigation strategies detailed in I.74 are not needed in our area’s biggest employers because they simply do not need to turn many lights on at night and have far fewer of them to begin with. A large facility with a large number of lights that need to be turned on at night is not consistent with the Character of the Area.

In addition, despite lighting mitigation strategies, this facility is not consistent with the Character of the Area of Carpenter Lane. Please see the following exhibits already submitted to the record for video and photo evidence of current absolute black out

conditions at the proposed facility site and surrounding Carpenter Lane road:

- *Exhibit E.38.a COTA Evening Walk Carpenter Lane Video*
- *Exhibit E.38.d Night Sky RH Nursery Video*
- *Exhibit E.38.e Carpenter Lane Night Sky Video*
- *Exhibit E.38.f Refuting PWB Night Sky Report Video*
- *Exhibit I.22.a Night Sky May 23 Pleasant Home Water Towers 1 Video*
- *Exhibit I.22.b Night Sky Carpenter Lane Site Looking North Video*
- *Exhibit I.22.c Night Sky Photos*
- *Exhibit I.22.d Video Captions to the Record rec 8.6.23*
- *Exhibit I.22.e Night Sky East C-Lane Video*
- *Exhibit I.22.f Photos Carpenter Ln - Detour and Night Sky*

The caption to the E.38.e video states *“It's SO DARK out here on Carpenter Lane our flashlights barely light up the scene. Now imagine a 95-acre facility with interior and perimeter lighting that operates 24 hours a day, with employees changing shifts in the middle of the night. In no way does that scenario even remotely fit with the character of this area, even within a 2-mile radius.”*

MCC 39.7515(A) is consistent with Character of the Area is not met and is not able to be mitigated because a facility of this nature should include security and safety lighting. It just doesn’t belong in a Rural Reserve with very little nighttime lighting.

In addition, facility plans call for an entry sign to the site, lit with floodlights: *“Plant entry sign floodlights. Provide and install on 8 feet round pole elevated on a 1.5' planting bed.”* (*Exhibit A.212 A.1a Site Plans*, page 29). To continue with the comparison, most nurseries in the area do not even light up their entry signs at night, much less with floodlights. A floodlit entry sign is another example of how the lighting mitigation strategies do nothing to blend this proposed facility in with the Character of the Area and call into question the statement in I.74 that the lights are the *“minimum needed for security and safety”.*

Finally, I.74 reiterates that facility lighting will comply with Multnomah County's Dark Sky standards (MCC 39.6850). However, County dark sky standards are in place to ensure minimal effects, they do not mean there is no effect on wildlife. MCC 39.7515 (B) is very explicit that there should be *no* adverse effects to natural resources.

A journal article in Environmental Evidence states, *“Artificial light can also change birds’ perceptions of habitat quality, resulting in selection or avoidance of illuminated areas.”* (Appendix D)

Darksky.org explains light pollution in this way: *"Scientific evidence suggests that artificial light at night has negative and deadly effects on many creatures, including amphibians, birds, mammals, insects, and plants…Migratory birds depend on cues from properly timed seasonal schedules. Artificial lights can cause them to migrate too early or too late and miss ideal climate conditions for nesting, foraging, and other behaviors."* (Appendix E)

The pains that the PWB is taking to minimize light pollution from the 596 lights it has prescribed for its industrial facility that it wants to place in a rural reserve, 1239 feet from the Sandy Wild and Scenic River protected area (*see Exhibit I.21 L. Belson Testimony rec 8.5.23* page 4 for a visual) admits that there will be some effects. MCC 39.7515 (B) will not adversely affect natural resources is not met.

7. Sound Impacts are not Consistent with the Character of the Area

Page 5, "Lighting and Sound". This section details all the sound mitigation strategies for the facility.

"Although filtration facilities operate 24/7, typical activities vary throughout the course of the day. For example, routine maintenance and deliveries are generally scheduled during the day shift, while the night shift will have fewer staff onsite. In addition, the filtration facility is designed to move water by gravity rather than by using pumped systems which tend to be the most noticeable noise sources at water treatment facilities. The facility also has sound attenuation for mechanical equipment so those sounds stay within allowable code limits at all times. Other operational noises, like water moving through basins when the backwash filters run, will be intermittent."

Response:

Although the above statement appears to suggest that sounds will be intermittent, many will not be. *Exhibit A.49, E.3 Bull Run Filtration Facility Exterior Noise Analysis* states, *"Since the mechanical equipment is scheduled to operate continuously, compliance to the nighttime code, 50 dBA, is the design goal."*

Parts of the Results and Conclusion sections of *Exhibit H.31 Current Sound Measurements on Proposed Filtration Site dated 6-25-2023* bear repeating here.

Community members used sound measuring equipment to measure current sound levels at the proposed site. *"Measurements ranged from 30 to 55dB, with the highest observation detected at CPO Site 1 (Figure 2) at approximately 55 dB. The sound detected during the highest observation was primarily attributed to irrigation operations (water pumping and spraying) on Surface Nursery property directly to the south of the two Pleasant Home water towers. Irrigation was completed before 19:00 that day." (Results, Page 1)*

The report goes on to conclude: *"Sound mitigation options are proposed by PWB to comply with Multnomah and Clackamas County code compliance of staying below 60 dBA in a day and 50 dBA at night. However, both of these sound thresholds are not consistent with the existing conditions of the property, surrounding properties, and the community. Current conditions fall well below these thresholds, and noises approaching those thresholds are only episodic in nature.*

The operational noises will significantly exceed current ambient noise levels, which is primarily natural sounds with the occasional episodic agricultural and road sounds. Facility operations will be continuous throughout the day and night, all year long, in perpetuity. Facility operations will not be comprised of natural sounds. Sounds generated from facility operations will drown out many of the naturally occurring sound from the wind, birds, trees, etc. (Conclusion, Page 3)"

In other words, despite all the sound mitigation strategies proposed by PWB in their application and referred to in I.74, the baseline continuous noise level will be much higher, the sounds will be unnatural, and they will be 24 hours in nature. The current Character of the Area is a low dBA level of natural sounds (within the 30's decibel range) with intermittent farm or vehicle noise throughout daylight hours, with almost 0 non-natural sounds at night. MCC 39.7515(A) is consistent with Character of the Area is not met.

We will also refer you to *Exhibit I.39 Cottrell CPO Sound Impacts Testimony rec 8.7.23.* This testimony explains the exponential nature of dBA measurements. An increase from 41 decibels to 50 decibels is actually 794% louder. 60 decibels is 8000% louder than 41 decibels. An increase of 795 - 8000% in sound levels is not consistent with the Character of the Area.

One final note of testimony from community member Andrea Culver who lives at 35534 SE Bluff Rd, a full half mile from the Pleasant Home Water towers on the proposed site. When workers are working at the towers, Andrea is able to hear them talking, radios playing, etc. all the way from the site to her home. The strategies listed in I.74 do not

address the geological nature of the landscape and its ability to carry sound. Unnatural noise added into this sensitive landscape will cause a change in the Character of the Area.

Response to I.75 - Construction Supplemental Information

1. The Length of the Construction Period Combined with the Large Amount of Planned Construction Traffic Will Change the Character of the Area.

Page 1. “Noise Management” This section details the noise mitigation strategies the contractors plan to use during construction.

Page 1. “Dust Management”. This section details dust control plans for construction of the filtration facility.

Page 2. “Clean Air Construction Diesel Emission Requirements” details plans to reduce diesel emissions.

Response:

The Noise Management, Dust Management, and Diesel Emission limiting plans could possibly be suitable for a regular sized construction project and would mitigate the effects on an area. However, the proposed project will so intensely utilize road capacity for so many years, that these plans cannot mitigate the fact that the construction will change the Character of the Area.

A. The length of the construction period

In *Exhibit H.3 Pre-Hearing Statement by the Applicant*, Attachment 4 details estimated construction times. There are many construction activities detailed on this chart. Some highlights: “Shaft and Tunnel” will take 36 months, “Finish & Raw Water Pipeline Connections” will take 7 months, “Raw Water Pipeline” will take 26 months. These 3 items alone total over 5 years of work, and there are many more items listed.

The length of the construction period has been difficult to pin down for this complex project. 5 years has been stated, up to as many as 7. If we select 5 years, and do some math, we come up with:

Construction is at minimum 8 hours per day x 5 days per week x 52 weeks x 5 years = 74,000 hours.

74,000 hours of construction in such a small geographic area is an intense amount of construction. The lengthy construction period is in direct conflict with the quiet nature that is a defining element of this rural community's "character of the area". As can be seen by many of the community members' testimonies on record, many living in this area have selected it for its quiet peaceful nature. For a large period of their life, someone living in this area enduring 74,000 hours of construction would feel a disruption to this defining characteristic, no matter how many noise, dust, and diesel emissions mitigation strategies are put into place.

Applicant has failed to meet its burden. MCC 39.7515(A) is consistent with Character of the Area is not met and is not able to be mitigated as a plant of this size and character necessitates a long construction period.

B. The "maxing out" of collector roads for construction traffic.

Exhibit I.84 Response to Select Testimony from Dana Beckwith, Global Transportation Engineering on Transportation Impacts rec 8.7.23 states, *"Collectors within the project area are typically currently operating under a 1,500 vehicle ADT except for Bluff Road with a 2,700 ADT and Hosner Road with a 2,100 ADT. The addition of construction traffic will not cause these roads to exceed 4,000 ADT. Therefore, the collector roadways to be used by the project are designed and constructed to handle sufficient capacity for the project and for project construction."*

PWB's construction plans suggest that the roads surrounding the project site will be taken to their maximum allowed levels, adding as many as 2500 ADTs per day. Again, if this construction project were of a shorter length, it would be a slight annoyance to the area's residents. However, adding this many vehicles for 74,000 hours (5 years) to the area's roads significantly changes the Character of the Area for a good portion of our community members' lives.

Again, no matter how many noise, dust, and diesel emissions mitigation strategies are put into place, the effects of this amount of increased traffic for such a prolonged period of time cannot be mitigated.

Applicant has failed to meet its burden. MCC 39.7515(A) is consistent with Character of the Area is not met and is not able to be mitigated as a plant of this size and character necessitates a large amount of vehicle trips.

C. Effects on Carpenter Lane

East Carpenter Lane is a dead-end street with only 8 residences, which generate hardly any traffic. Community members generally observe **few, often zero cars** using this part of Carpenter Lane during typical peak commuting hours**.**

Operations

If the facility is built at the proposed location it will completely change the character of this quiet, rural neighborhood. There will be 3 shift changes a day at the plant, meaning 10 workers will be driving in and out 3 times per day. In addition, PWB expects up to 30 visitors a day, including vendors, deliveries, and visitors (see *T3-2022-16220 Staff Report* page 9). In terms of big trucks on this end of Carpenter, R&H Nursery only utilizes about 20 semi-trucks per YEAR. Once the plant is operational, there will be 25 semi-trucks driving in and out of the site per WEEK (see *Exhibit A.227 Bull Run Filtration Construction Traffic Impact Analysis* page 11).

The effect for residents of Carpenter Lane will be: No more quiet, safe rural road to walk, jog, ride bikes, or horses. Not safe for kids to wait at the corner or in front of their houses for the school bus (there are no sidewalks). As can be seen by the testimony by Carpenter Lane residents on the record (see list below*), this is not the type of area that anyone that moved to this road chose. Residents of Carpenter Lane, like other rural roads in this area, moved here specifically for the character of the area as it is now and as it has always been.

Construction

Widening Carpenter Lane to accommodate the traffic needs of the applicant's proposed filtration plant means forever changing the character of this unique, rural, quiet street / neighborhood and putting it out of character with most of the roads in the area. Long time residents report that Carpenter Lane has only ever been chip sealed, never truly re-paved. Creating a two-lane road with a curb (*See Exhibit A.212 A.1a Site Plans,*

pages 11 and 19) is different than **all other** roads in the area, and will be different than the through portion of Carpenter Lane.

In other words, creating a road wide and “improved” enough to handle all construction and operations traffic is ruining the character of the neighborhood just to accommodate the plant.

Due to the land use decision in Clackamas County, Bluff Road will now not be used for construction. As a result, ALL construction-related traffic will use East Carpenter Lane. Besides creating a complete change of character for that end of the street, a lot of traffic will shift onto the West end of Carpenter Lane.

Residents have reported that if there are delays at the intersection of Dodge & Cottrell, GPS devices **will** send drivers down Carpenter between Altman and Cottrell. This rerouting is inevitable with the amount of traffic that will be backing up from the Cottrell/Carpenter and Cottrell/Dodge intersections, even when Dodge Park isn't under construction. When PWB begins building pipelines along Dodge on both East and West of Cottrell, causing months-long delays, detours and single-lane closures, GPS will once again route drivers down the length of Carpenter as a workaround.

PWB is planning no improvements to West Carpenter Lane, saying that they will not use it for any posted detours or planned traffic. With the expected hundreds of vehicles per day coming to and from the main construction site, a noticeable amount of those cars and perhaps even construction vehicles will indeed end up using West Carpenter Lane.

For reference, PWB has said they'll reduce hourly traffic during peak hours to just 387 vehicle trips per hour. (*H.3 Prehearing Statement by Applicant, see page 60*) Where is all this traffic going to go? And where is it coming from? PWB has not disclosed this. There is no effective and logical Traffic Control Plan that will ensure West Carpenter Lane is not used by outsider traffic.

Even with signs stating 'Local Residential traffic only' there will be drivers who see it as an alternative route on their GPS, or even PWB employees who consider themselves local traffic and don't want to wait for the flagger on Dodge.

The massive scale and scope of the construction of this project does not fit with the character of the area (MCC 39.7515 A). During construction, with the massive amount of traffic going in and out for 5-7 years, residents will not feel safe running, biking, letting their kids walk to their friends' house, riding their horses. 5-7 years to endure this type of disruption is a sizable chunk of someone's life - it is NOT temporary.

Again, no matter how many noise, dust, and diesel emissions mitigation strategies are put into place, the effects of this amount of increased traffic for such a prolonged period of time cannot be mitigated for the residents of Carpenter Lane.

Applicant has failed to meet its burden. MCC 39.7515(A) states the proposed project must be consistent with Character of the Area. This project is not consistent with the character of the area, and in fact permanently changes the character of the area to accommodate the project. The failure to meet this criteria cannot be mitigated, as a plant of this magnitude and the massive construction required to build it will permanently change the character of Carpenter Lane forever.

*Testimony to quiet rural nature of Carpenter Lane by its residents in the Multnomah County record:

- *Exhibit H.25.f Written Testimony from Mike & Carol Kost rec 6.30.23*
- *Exhibit I.27 Tanner & Macy Davis Written Testimony rec 8.6.23*
- *Exhibit H.26.b Written Testimony from Doug and Pat Meyer rec 6.30.23*
- *Exhibit I.32 Ron Roberts Written Testimony rec 8.6.23*
- *Exhibit H.29 Written Testimony from Kristy McKenzie rec 6.30.23*
- *Exhibit H.9 Memorandum to the Hearings Officer from Brent Leathers*
- *Exhibit I.7.a Additional Testimony in Opposition from Brent Leathers rec 7.27.23*

2. Lack of enforcement plans or consequences written into PWB plans

Page 1. "Noise Management" This section details the noise mitigation strategies the contractors plan to use during construction.

Page 1. "Dust Management". This section details dust control plans for construction of the filtration facility.

Page 2. “Clean Air Construction Diesel Emission Requirements” details plans to reduce diesel emissions.

Response:

There are NO enforcement plans or consequences written into any of the 1000’s of pages of documents submitted by PWB.

Contractors may promise to put up sound barriers, sweep roads to limit dust, and limit diesel idling to 5 minutes, and any number of noise, dust, and diesel emission mitigation strategies. However, the lack of any third party auditing will most likely allow strategies to go under utilized, forgotten, or deliberately ignored for a project of this size and complexity. The amount of resulting noise, dust, and diesel emissions generated will not be consistent with the character of the area, so the criteria MCC 39.7515(A) will not be met.

3. The high amount of Project Security measures during construction will not be consistent with the Character of the Area

Page 3, “Project Security”. “*Contractors will establish site access requirements and install physical controls such as perimeter barriers or fencing and adequate lighting to secure the work site from unauthorized entry, theft, vandalism, or other security related events.”*

Response:

As noted above, there is an intense and lengthy amount of construction planned for such a small, heavily rural area. Community members will be seriously impacted by at least 74,000 hours, or 5 years, of construction-related security barriers, fencing, and lighting - a significant portion of their lives. This lengthy visual disruption to the pastoral area residents are used to is inconsistent with the Character of the Area. Criteria MCC 39.7515(A) is not met and cannot be mitigated as a project of this size necessitates a lengthy construction period.

Response to Exhibit I.82 Attachment 27: Video of Truck driving on Existing Farm Road on Portland Water Bureau Property on Carpenter Lane

We assume this video is attempting to show that the existing traffic on the proposed site already generates dust.

Response:

The proposed facility is in a Rural Reserve, the “West of Sandy River Rural Planning Area”. It is specifically set aside for agriculture and the protection of surrounding natural resources. The current dust generated on this property is associated with agricultural practices, a primary approved land use.

It is true that any vehicle will generate dust on a dirt road. However, as we have said above, if this project is approved there will be a lot more vehicles over 5 years, generating lots more dust than already is being generated.

In addition, many of these vehicles will be large, such as dump trucks. These vehicles will generate more dust than smaller vehicles such as the pickup truck depicted in this vehicle.

As stated above, for a large period of their life, someone living in this area enduring 74,000 hours of large construction vehicles moving dirt and other materials on and off the site would feel an increase in the level of dust no matter how many dust management strategies were employed. This will change the Character of the Area. Criteria MCC 39.7515(A) is not met.

APPENDIXES

A

- https://ohsonline.com/articles/2023/04/13/10-safety-tips-for-workers.aspx

B

- https://www.wateronline.com/doc/chlorine-gas-leak-sends-water-treatment-workers-to-hospital-0001

- https://abcnews.go.com/US/50-hospitals-accidental-chemical-spill-birmingham-water-treatment/story?id=61361949
- https://www.mprnews.org/story/2012/02/14/water-plant-chemical-accident
- https://www.delmarvanow.com/story/news/local/maryland/2020/09/25/operator-discovers-hazardous-chemical-leak-salisbury-water-plant/3528678001/

- https://fluoridealert.org/news/hazmat-crews-respond-to-chemical-spill-at-rock-island-water-treatment-plant/
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Appendix A

10 Safety Tips for Workers in Water Treatment Plants

What steps can people who work in this environment take to protect themselves and their employees?

BY REKHA PHILIP APR 13, 2023

Water treatment plants may be touted as facilities that purify and treat water to make it safe for human consumption, but let's face it; they are also breeding grounds for accidents and injuries that could fatally injure workers.

A **water treatment company** relies on a range of equipment, chemicals and procedures that pose serious risks to workers. If you're one of those workers, it's important to equip yourself with the necessary skills and

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important to equip yourself with the necessary skills and knowledge to prevent accidents.

1. Wear appropriate PPE. To avoid being the next victim of a workplace tragedy, make sure to wear appropriate PPE at all times. You don't want to end up being exposed to harmful chemicals, biological agents or physical hazards just because you skimped on safety gear. Gloves, goggles, respirators and other PPE should be your best friends, as they will be one of your defenses against these dangers.

2. Follow all safety procedures and guidelines. But safety gear alone won't cut it. You also need to follow all safety procedures and guidelines put in place by your water treatment plant. Yes, those boring protocols that no one wants to read or follow. They are there for a reason, and that reason is to keep you alive and well. So, read them, understand them and follow them like your life depends on it because it does.

3. Avoid wearing loose clothing or jewelry that could get caught in machinery. Sure, you may think that a necklace or bracelet makes you look cool, but it won't look so cool when it's caught in a piece of machinery, leading to serious injuries. Save the fashion statements for another time and wear proper clothing without any accessories.

4. Be aware of potential hazards, such as chemicals or machinery. Take appropriate precautions to prevent

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4 Why OSH Professionals Should Embrace Sustainability

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accidents. Don't take anything for granted, and don’t assume that everything is safe. Water treatment plants use a wide range of chemicals and machinery, which can be dangerous if not handled correctly. So, be alert and aware of your surroundings at all times.

5. Properly label and store all chemicals. Properly label and store all chemicals to avoid accidental exposure. Don't let carelessness be the cause of your demise. Take the time to ensure that all chemicals are labeled correctly and stored in designated areas. Follow the manufacturer's instructions regarding the storage and handling of chemicals. You don't want to mix chemicals and cause an explosion that could lead to catastrophic consequences.

1 2 NEXT »

Appendix B

WATER ONLINE

News Feature | March 4, 2019

Chlorine Mishap Sends 50 Water Treatment Workers To Hospital

By Peter Chawaga

A rare incident at an Alabama drinking water treatment plant had scary results for workers last week.

The combination of treatment chemicals at the plant led to a dangerous release, sending 50 people to the hospital.

“An accidental mix of sodium hypochlorite (which is essentially bleach) and ferric sulfate caused a chlorine off gas at our Shades Mountain Filter Plant,” the Birmingham Water Works wrote on Twitter, per ABC 7. “We use these components to treat water as our normal practice, however they are not meant to be mixed together.”

Initially, only 14 contractors and one Water Works employee were taken to the hospital, but then 40 more people who had been close to the gas were sent as well.

“Authorities say exposure to the chemicals can cause respiratory problems, nausea and headaches,” according to *Insurance Journal*. “The water system says none of the injuries [were] believed to be life-threatening.”

While the immediate health concerns revolved around those working in the plant, a gas release like this could have had an impact on the surrounding community as well.

“The chemicals gave off gas as well as a strong odor at the plant,” ABC 7 reported. “Residents were asked to shelter in place for an hour as Highway 280 near the plant was closed.”

However, it appeared that the incident posed no threat to the drinking water supply and, ultimately, consumers were safe.

“The water supply has not been contaminated,” Birmingham Water Works said, per ABC 7. “The chemicals have been contained to the building at the facility where the accident occurred.”

More details about how the treatment chemicals became mixed were gathered by WBRC FOX6 News:

“‘What happened was they were delivered to the wrong site,’ said Rick Jackson, spokesperson for the Birmingham Water Works Board.

“The mix-up led to the combining of two chemicals, which in turn caused a chlorine gas to be released,” the station reported.

Luckily, it appears that despite their exposure, the plant’s workers will be fine and that the local water supply was protected.

To read about preparing for similar incidents at treatment plants, visit Water Online’s Resiliency Solutions Center.

More than 50 taken to hospitals after 'accidental' chemical spill at Birmingham water treatment plant

No one suffered life-threatening injuries, Birmingham Water Works said.

By Enjoli Francis and Rachel Katz
February 27, 2019, 1:46 PM

News headlines today: Feb. 27, 2019
Catch up on the developing stories making headlines today.

Over 50 people were transported to hospitals in Birmingham, Alabama, after a chemical spill occurred at a water treatment plant, fire officials said.

The incident occurred Wednesday at the Birmingham Water Works' Shades Mountain Filter Plant.

"An accidental mix of sodium hypochlorite (which is essentially bleach) and ferric sulfate caused a chlorine off gas at our Shades Mountain Filter Plant. We use these components to treat water as our normal practice, however they are not meant to be mixed together," Birmingham Water Works said in a statement on Twitter.

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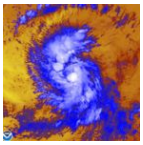

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> **BirminghamWaterWorks** · Feb 27, 2019
> @BhamWaterWorks · **Follow**
> An accidental mix of sodium hypochlorite (which is essentially bleach) and ferric sulfate caused a chlorine off gas at our Shades Mountain Filter Plant. We use these components to treat water as our normal practice, however they are not meant to be mixed together.
>
> **BirminghamWaterWorks**
> @BhamWaterWorks · **Follow**
>
> Initially 15 people were transported to local hospitals (1 BWWB employee) and another nearly 40 who were in close contact of the chemical reaction were also transported. There is no threat to the water supply and no immediate cause for evacuation.
>
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The company said that initially 14 contractors and one Water Works employee had been taken to the hospital immediately after the spill but that the number had grown by an additional 40 "who were in close contact" with the chemical reaction.

"None have sustained any life-threatening injuries," Birmingham Water Works said in a news release.

Birmingham Fire and Rescue said the 40 people had been taken to the hospital strictly as a precaution.

Emergency personnel gather near Birmingham Water Works where a chemical spill sent more

than 50 people to the hospital. Feb. 27. 2019.
Anna Beam/The Birmingham News/AP

The chemicals gave off gas as well as a strong odor at the plant, Birmingham Water Works spokesman Rick Jackson said during a news conference.

(MORE: Toxic chemical spill closes Atlanta freeway)→

"Some of the effects people can experience from being exposed to chlorine gas are sneezing, nose irritation, burning sensation and throat irritation, nausea, vomiting or a headache. People may also experience skin irritation or chemical burns and eye irritation," the Mountain Brook Police Department said in a statement.

“It’s almost like putting your nose to bleach and sniffing,” Jackson said.

Jackson said that there had been no threat to the water itself and that residents could continue drinking and using the water.

"The water supply has not been contaminated. The chemicals have been contained to the building at the facility where the accident occurred," the company said.

(MORE: 40 children taken to hospitals after chemical leak at YMCA pool) →

Residents were asked to shelter in place for an hour as Highway 280 near the plant was closed. The highway was later reopened.

“As part of its emergency response plan, the Birmingham Water Works is working in conjunction with fire and police departments in Birmingham, Homewood, and Mountain Brook as well as area

hospitals, to ensure the safety of employees and residents in the vicinity of the plant. The BWW will conduct a full investigation to determine why the accident occurred, but it has not been determined why the chemicals were mixed at this time," Birmingham Water Works said in its release.

Chemical accident shuts down water treatment plant

Matt Sepic St. Paul, Minn. February 14, 2012 7:48 PM

A chemical accident Tuesday afternoon has shut down one of the two water treatment plants that serve Minneapolis.

A worker at the Columbia Heights water treatment plant accidentally combined hydrochloric acid with caustic soda. The chemicals are used to clean the water filters.

Anyone who's poured vinegar on baking soda knows the results of mixing an acid and a base. That's what happened at the treatment plant — but on a larger scale.

The mess was contained and nobody was hurt, Minneapolis Water Treatment Director Bernie Bullert said, but the reaction set off fire sprinklers. Bullert said the plant will be out of service for a few days while staff investigate how the chemicals got mixed.

"We're going to have to investigate exactly what procedures broke down," he said. "They got together and they shouldn't have been."

The water is safe in Minneapolis and the suburbs the plant serves. The main treatment plant in Fridley is operating, so customers should see no change in service.

"We've got to make sure our equipment is all fine and check our procedures with what went on," Bullert said. "Hopefully it won't be very long. But in the next few days we'll be going in a little deeper to check out what happened."

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MARYLAND

Operator discovers hazardous chemical leak at Salisbury water plant

Kelly Powers
Salisbury Daily Times

Published 9:12 a.m. ET Sept. 25, 2020

SALISBURY, Md.— A Salisbury water operator came across a hazardous chemical leak as he carried out his typical shift Thursday, according to a recent press release from the city.

At Salisbury's Paleo Water Treatment Plant, the operator discovered a gaseous chlorine leak after entering the chlorine cylinder room to swap out an empty.

He immediately notified his superintendent, according to the city, who contacted Salisbury Fire Department. The exposed employee was then sent to TidalHealth Peninsula Regional for evaluation.

He received oxygen and has already been released in stable condition, according to the release.

NG-14 is here: How you can watch NASA Wallops' next rocket launch

H2Oi is back this week: Here's what you need to know from Ocean City officials

Salisbury and Delmar Fire Departments responded to contain the chlorine leak. Two members of the hazmat response team capped off the 150-pound cylinder of gaseous chlorine with a leak containment kit, according to the release. The cylinder, now safely secured, will be transported back to its distributor.

The city says the plant has been cleared to return to normal operations.

“I am so proud of the Water Works team for quickly acting when they realized there was a chlorine leak at our Water Plant. All protocols were followed and no one was hurt,” said

Acting Mayor Julia Glanz in a statement. “Additionally we couldn’t have returned to normal operations without the support of our Salisbury Fire Department Hazmat Team. Thank you SFD and Delmar Fire Department for making sure this leak was contained and no one was injured."

Salisbury's Department of Water Works uses gaseous chlorine to disinfect the water as part of the treatment process in "controlled and diluted amounts."

Gaseous chlorine is poisonous and classified as a pulmonary irritant, according to the release.

It has intermediate water solubility with the capability of causing acute damage to the upper and lower respiratory tract — giving it potential to be very hazardous.

The Paleo Water Treatment Plant is equipped with a large chlorine scrubber that automatically detects and neutralizes chlorine gas in the air as soon as it is leaked, like what occurred an incident such as this, accord to the city.

The chlorine scrubber functioned properly in this case — scrubbing the entire chlorine room of the gas as it continued to leak from the cylinder. But, because the leak was so slow, the decision was made "out of an abundance of caution" to remove the cylinder altogether.

HAZMAT CREWS RESPOND TO CHEMICAL SPILL AT ROCK ISLAND WATER TREATMENT PLANT

Source: WQAD TV | Reporter

Posted on March 24th, 2011

Location: United States (https://fluoridealert.org/news/?country=united-states), Illinois (https://fluoridealert.org/news/?country=united-states&sub=illinois)

ROCK ISLAND— It was just before one o'clock Thursday afternoon when hazmat crews were called to the Rock Island water treatment plant for a chemical spill coming from a tanker truck.

"It's a corrosive agent that the water treatment plant uses, overflow caused spillage out of the building onto driveway behind me" said Rock Island assistant fire chief Jeff Yerkey.

As plant employees evactuated, crews began suiting up, working quickly to stop the leak that had begun eating through concrete.

"They stopped the leak using some earthen berms, dirt, sand and commercial boom equipment. We had it pretty much contained to this facility within a short amount of time" said Yerkey.

The chemical, Hydrofluorosilicic acid is used to add fluoride (http://www.fluoridealert.org) to the plants water. Although it poses a burn risk to skin, those living nearby were in no immediate danger.

"There's no inhalation hazard at all so no need for us to evacuate the residences."

After several hours crews were able to clean up the leak, allowing operations to return to normal.

"Had to close off area but as far as treatment of water and amount being used by the public, no effect on it at all" said Yerkey.

No word on how much of the chemical actually spilled.

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SEE TV REPORT (HTTP://WWW.WQAD.COM/NEWS/ROCK-ISLAND-HAZMAT-WATER-TREATMENT-PLANT-03242011,0,4540527.STORY)

Tags: flouridation (https://fluoridealert.org/tag/flouridation/), flouride (https://fluoridealert.org/tag/flouride/), Fluoridation (https://fluoridealert.org/tag/fluoridation/), fluoride (https://fluoridealert.org/tag/fluoride/)

https://www.thesunchronicle.com/news/local_news/two-wrentham-water-treatment-plant-workers-injured-during-chemical-leak/article_5136aeda-8724-555f-b057-6b6f47b5b6d8.html

Two Wrentham water treatment plant workers injured during chemical leak

By David Linton dlinton@thesunchronicle.com
Jul 21, 2020

WRENTHAM — Fire officials are investigating the cause of a chemical accident at the town water treatment plant on Franklin Street Tuesday morning that sent two workers to the hospital.

The workers, ages 23 and 40, were taken by medical helicopter to Massachusetts General Hospital with injuries described as not life-threatening, Fire Chief Antonio Marino said in a press release.

An initial investigation indicates that the two employees were conducting routine maintenance when a pressurized hose began to leak and sprayed potassium hydroxide on them, Marino said.

The 40-year-old employee was sprayed in the face and eyes with the chemical and seriously injured. Both were wearing protective eye equipment at the time, according to the fire chief.

The chemical is used to adjust the pH level of the water, according to Michael Lavin, the public works director.

The accident, categorized as a Tier 1 hazardous material incident, occurred about 9:20 a.m. at the plant at 655 Franklin St. (Route 140).

A Tier 1 incident is one with the lowest risk to the environment and public health with containment and cleanup. The highest level is a Tier 5.

Following protocol for incidents involving chemical exposure, fire officials called the state hazardous materials response team to the scene. The state Department of Environmental Protection was also notified.

The hazmat crew assisted in cleaning up the small amount of liquid that spilled and ensured that all was safe at the scene, which was cleared at approximately 11:20 a.m., Marino said.

Lavin said normal operations at the plant resumed after the incident.

Local police and the Norfolk and Foxboro fire departments responded to the scene to assist.

David Linton may be reached at 508-236-0338.

DAVE LINTON

TECH / SECURITY / US & WORLD

Hackers tampered with a water treatment facility in Florida by changing chemical levels

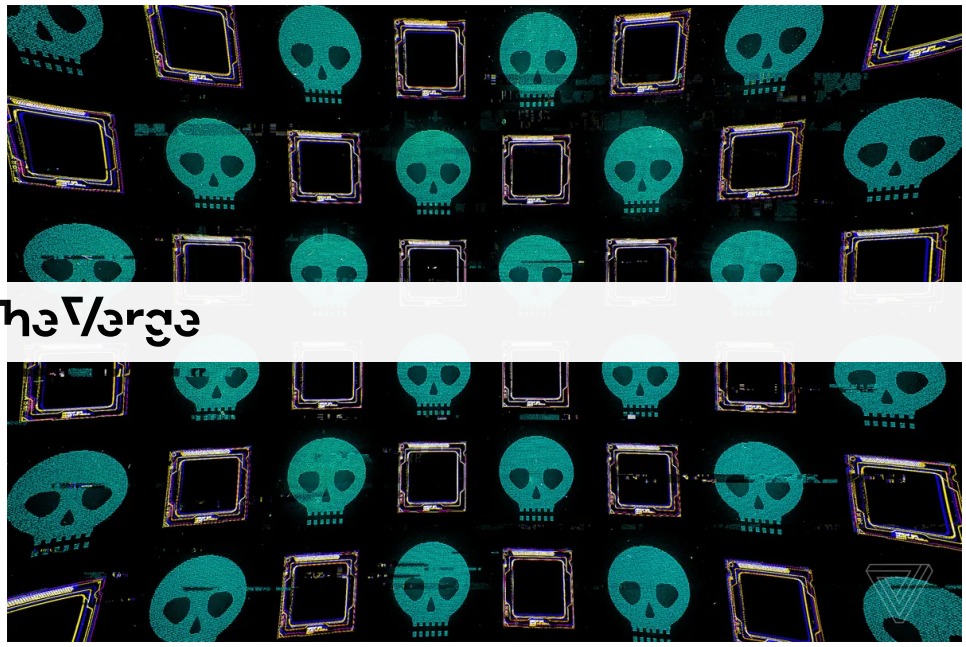

Illustration by Alex Castro / The Verge

/ No residents were harmed

By Nick Statt
Feb 8, 2021 at 2:01 PM PST |
0 Comments / 0 New

Hackers successfully infiltrated the computer system controlling a water treatment facility in the city of Oldsmar, Florida, according to a report from the *Tampa Bay Times*. In doing so, the hackers were able to remotely control a computer to change the chemical levels of the water supply, increasing the amount of sodium hydroxide before a supervisor was able to catch the act in real time and revert the changes.

“At no time was there a significant adverse effect on the water being treated,” Pinellas County Sheriff Bob Gualtieri said during a press conference on Monday, which was later posted to YouTube. “Importantly, the public was never in

danger." Sodium hydroxide, commonly known as lye, is used in water to regulate acidity levels, the *Tampa Bay Times* reports, but in excess it can be dangerous to human beings because it's the same inorganic compound used in corrosive household cleaners like Drano.

Hackers tried to increase the amount of lye in the water supply

Although no one was injured, the incident is a disturbing example of hackers taking aim at public infrastructure with unclear intentions. Pinellas County is currently investigating the hack alongside the FBI and the Secret Service. Other nearby cities and towns have also been alerted to the potential threat.

It is not the first incident of water supplies being targeted — a water utility in Illinois was targeted by suspected Russian hackers in November of last year, while an attempted cyberattack on Israel last year that intelligence officials have linked to Iran involved attempts to manipulate the water supply, *The Washington Post* reported.

The *Tampa Bay Times* has a rather chilling anecdote in its report detailing the moment the remote plant operator noticed something was terribly wrong, when his mouse started moving on-screen without him touching it:

> A plant operator was monitoring the system at about 8 a.m. Friday and noticed that someone briefly accessed it. He didn't find this unusual, Gualtieri said, because his supervisor remotely accessed the system regularly.
>
> But at about 1:30 p.m. the same day, Gualtieri said, someone accessed the system again. This time, he said, the operator watched as someone took control of the mouse, directed it to the software that controls water treatment, worked inside it for three to five minutes and increased

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> the amount of sodium hydroxide from 100 parts per million to 11,100 parts per million.
>
> The attacker left the system, Gualtieri said, and the operator immediately changed the concentration back to 100 parts per million.

The county says there are other safeguards in place that would have prevented direct harm to the 15,000 or so residents that rely on the Oldsmar plant for drinking water. For one, the water would have taken more than a day to enter the water supply, the sheriff says, meaning ample public warnings could have been issued in that time. There are also “redundancies in the system” that would have caught changes to the acidity of the water supply, the sheriff says.

NEWS

Hackers Tried to Poison California Water Supply in Major Cyber Attack

BY **JAMES CRUMP** ON 6/18/21 AT 4:12 AM EDT

NEWS HACK SAN FRANCISCO WATER CYBERCRIME

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00:00 03:32

A hacker accessed the system of a California water treatment plant in January and deleted several programs used to treat drinking water.

NBC News reported on Thursday that an unidentified hacker carried out the attack on

an unspecified water treatment plant on January 15 in the San Francisco Bay Area by using the username and password of a former employee at the facility.

The hacker managed to access the former staff member's TeamViewer account, which allows employees to remotely use their computers, according to a report compiled by the Northern California Regional Intelligence Center in February that was obtained by NBC.

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The report claimed that after the hacker logged in to the plant's system, they deleted several programs that the facility uses to treat the drinking water in the area.

The hack was unnoticed until the next day, but when it was discovered the plant reinstalled all the deleted programs and reset the passwords for its employees.

"No failures were reported as a result of this incident, and no individuals in the city reported illness from water-related failures," the report from the unidentified facility said about the hack.

NBC reported that the hacker "tried to poison" the area's water, but Michael Sena, the executive director of the Northern California Regional Intelligence Center, denied that claim while speaking to *The San Francisco Chronicle*.

"No one tried to poison any of our water. That is not accurate," he said, as Sena explained that tampering with the computer programs would be unlikely to result in any serious widespread poisoning.

"It takes a lot to influence a water supply chain," he said. "For a large impact, there has to be a large change in the chemicals in the system. The amount of chemicals it would

take to cause harm to people...the numbers are astronomical."

A few weeks after the incident in San Francisco, a hacker infiltrated the system of the water treatment plant in Oldsmar, Florida, and attempted to add a "dangerous" level of chemicals to the facility's water.

Speaking during a press conference on February 8, Pinellas County Sheriff Bob Gualtieri said that the hack occurred on February 5 at the Oldsmar Water Treatment Facility when someone accessed a TeamViewer account.

READ MORE

Ransomware Hacker Skills Now As Good or Better Than Countries, Expert Says

Gualtieri said that in the morning a plant employee "noticed that someone remotely accessed the computer system that he was monitoring," which controls the chemicals at the plant, but didn't think much of it as colleagues regularly use the system from home.

At around 1:30 p.m. local time, the employee once again noticed that his computer was being accessed remotely.

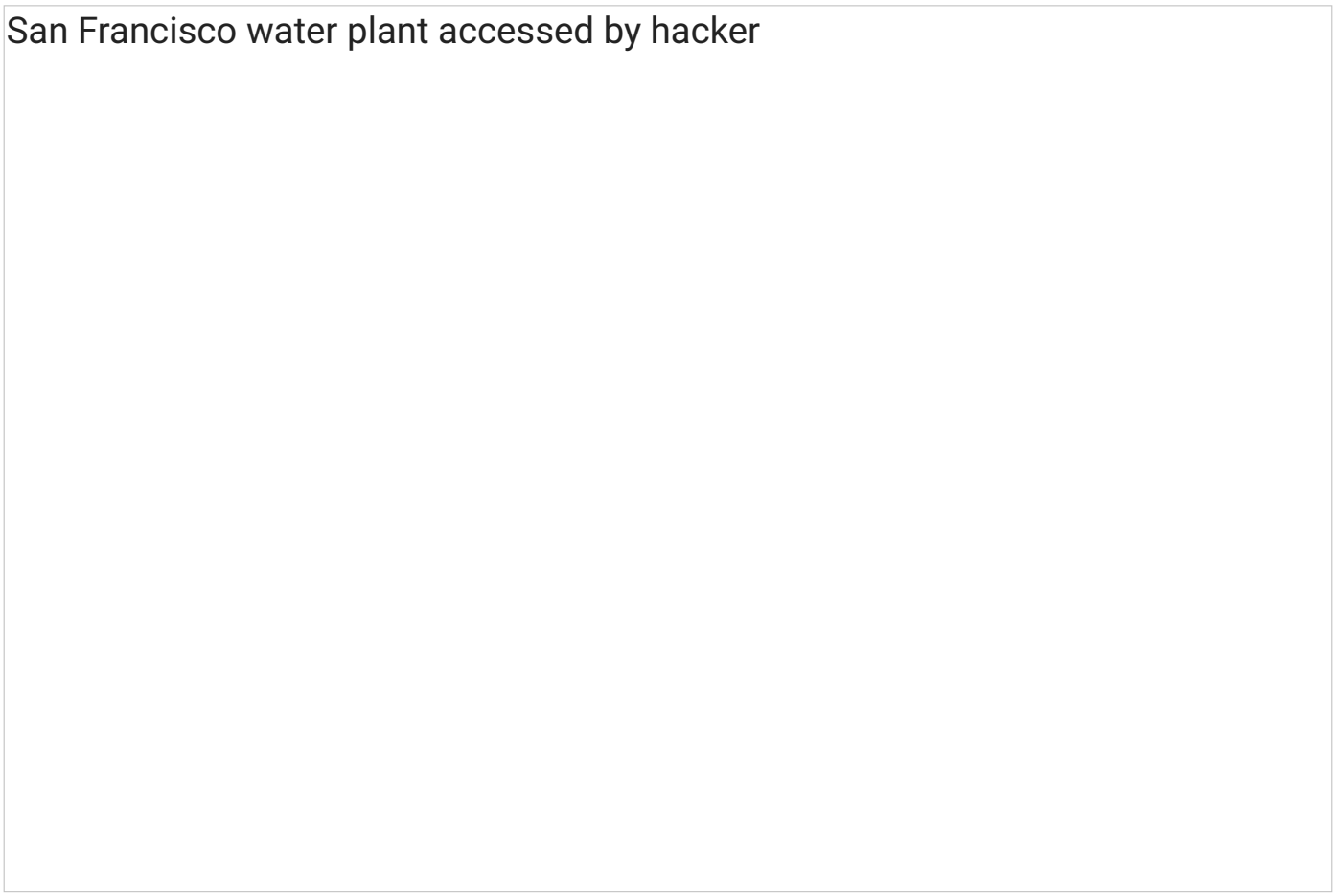
"The person remotely accessed the system for about three to five minutes, opening various functions on the screen," Gualtieri said. "One of the functions opened by the person hacking into the system was one that controls the amount of sodium hydroxide in the water.

"The hacker changed the sodium hydroxide from about 100 parts per million to 11,100 parts per million. This is obviously a significant and potentially dangerous increase."

The employee at the plant noticed that the hacker had made changes and was able to lower the level of the chemical. Gualtieri confirmed that "at no time was there a significant adverse effect on the water being treated."

Newsweek has contacted the Northern California Regional Intelligence Center for comment on the hack.

San Francisco water plant accessed by hacker



OAKLAND, CALIFORNIA - APRIL 29: An aerial view of the East Bay Municipal Utility District Wastewater Treatment Plant on April 29, 2020, in Oakland, California. A hacker accessed the system of a California water treatment plant on January 15 and deleted several programs used to treat the drinking water.

JUSTIN SULLIVAN/GETTY IMAGES

lica

Technology

America's Drinking Water Is Surprisingly Easy to Poison

Despite a decade of warnings, thousands of water systems around the country are still at risk.

by Peter Elkind and Jack Gillum

March 17, 2021, 5 a.m. EDT

ProPublica is a nonprofit newsroom that investigates abuses of power. Sign up to receive our biggest stories as soon as they're published.

On Feb. 16, less than two weeks after a mysterious attacker made headlines around the world by hacking a water treatment plant in Oldsmar, Florida, and nearly generating a mass poisoning, the city's mayor declared victory.

“This is a success story,” Mayor Eric Seidel told the City Council in Oldsmar, a Tampa suburb of 15,000, after acknowledging “some deficiencies.” As he put it, “our protocols, monitoring protocols, worked. Our staff executed them to perfection. And as the city manager said, there were other backups. … We were breached, there’s no question. And we’ll make sure that doesn’t happen again. But it’s a success story.” Two council members congratulated the mayor, noting his turn at the press conference where the hack was disclosed. “Even on TV, you were fantastic,” said one.

“Success” is not the word that cybersecurity experts use to describe the Oldsmar episode. They view the breach as a case study in digital ineptitude, a frightening near-miss and an example of how the managers of water systems continue to downplay or ignore years of increasingly dire warnings.

The experts say the sorts of rudimentary vulnerabilities revealed in the breach — including the lack of an internet firewall and the use of shared passwords and outdated software — are common among America’s 151,000 public water systems.

“Frankly, they got very lucky,” said retired Adm. Mark Montgomery, executive director of the federal Cyberspace Solarium Commission, which Congress established in 2018 to upgrade the nation’s defenses against major cyberattacks. Montgomery likened the Oldsmar outcome to a pilot landing a plane after an engine caught fire during a flight. “They shouldn’t celebrate like Tom Brady winning the Super Bowl,” he said. “They didn’t win a game. They averted a disaster through a lot of good fortune.”

The motive and identity of the hackers, foreign or domestic, remain unknown. But Montgomery and other experts say a more sophisticated hacker than the one in Oldsmar, who attempted to boost the quantity of lye in the drinking water to dangerous levels, could have wreaked havoc. They’re skeptical of the city’s assurances that “redundant” electronic monitors at the plant protected citizens from any possible harm. “If the attackers could break into the lye controls,” Montgomery said, “don’t you think they could break into the alarm system and alter the checkpoints? It’s a mistake to think a hacker could not introduce contaminated water into our water systems.” Oldsmar officials, citing the ongoing investigation, declined ProPublica’s requests for an interview or to address emailed questions about the city’s cybersecurity practices.

The consequences of a major water system breach could be calamitous: thousands sickened from poisoned drinking water; panic over interrupted supplies; widespread flooding; burst pipes and streams of overflowing sewage. (This is not merely theoretical. In 2000, a former municipal wastewater contractor in Australia, rejected for a city job, remotely manipulated computer control systems to release 264,000 gallons of raw sewage, which poured into public parks, turned creek water black, spilled onto the grounds of a Hyatt Regency Hotel and generated a stench that investigators called “unbearable.” The man was sentenced to two years in prison.)

In congressional testimony on March 10, Eric Goldstein, cybersecurity chief for the federal Cybersecurity and Infrastructure Security Agency, described the Oldsmar incident as illustrating “the gravest risk that CISA sees from a national standpoint.” He said it should be “a clarion call for this country for the risk that we face from cyberintrusions into these critical systems.”

Grave warnings have sounded for years. As far back as 2011, a Department of Homeland Security alert advised that hackers could gain access to American water systems using “readily available and generally free” internet search tools. Such admonitions have abounded in recent years. Booz Allen Hamilton’s 2019 “Cyber Threat Outlook” called America’s water utilities “a perfect target” for cyberattacks; a 2020 Journal of Environmental Engineering review found “an increase in the frequency, diversity, and complexity of cyberthreats to the water sector”; and the Cyberspace Solarium Commission’s March 2020 report warned that America’s water systems “remain largely ill-prepared to defend their networks from cyber-enabled disruption.”

Despite the warnings, and some high-profile breaches dating back a decade, the federal government has largely left cyberdefense to the water utilities. For years, it relied on voluntary industry measures, dismissing any need for new regulation. Then, in 2018, Congress included a provision

addressing cybersecurity in a 129-page water bill that covered everything from river levee repairs to grants for school water fountains.

The requirements were less than demanding. Every U.S. water system serving more than 3,300 customers was obliged to conduct a self-assessment of the risks and resilience of its physical and electronic systems and prepare an emergency-response plan. Different-sized utilities got different deadlines; for the smallest covered by the law, such as Oldsmar, the self-assessment must be done by June 30, 2021, more than two and a half years after the law was signed. (Oldsmar had completed its cybersecurity review by early November but hadn't yet incorporated its recommendations in the city's emergency response plan before the February hack, according to a statement provided by the city manager.) Tens of thousands of U.S. water systems with fewer than 3,300 customers were exempted entirely from the law's requirements.

Those utilities required to perform a self-assessment were not obliged to submit a report to any government agencies. The utilities merely had to attest to the Environmental Protection Agency that they had conducted the assessment. The 2018 legislation also provided $30 million for grants to help water districts deal with "risk and resilience" problems, including cyberattacks. But Congress never appropriated that money.

The water provisions fall far short of federal requirements (including penalties for violating those rules) and funding aimed at protecting electricity infrastructure, according to Montgomery. "An assessment's a good thing," he said. "But this is well short of what we require from energy companies. We have developed a tool for self-identification of problems. But if you're really bad at cybersecurity, I'm not sure your self-identification is going to solve the problem."

He also pointed to low staffing at the EPA's Water Security Division. "The water security office is a handful of people, probably three," Montgomery said. "It historically has not done much, if any, cybersecurity work. This is the product of 20 years of low prioritization." The agency's most recent report to Congress on "Drinking Water Infrastructure Needs," submitted in 2018, identified $472.6 billion in long-term priorities, but it didn't mention the word "cybersecurity" once in its 75 pages.

An EPA official, speaking on the condition of anonymity, agreed that the agency had only "a small team" devoted to water cybersecurity but said Oldsmar "and other recent incidents have highlighted the importance of the priority and the investments we need to make."

The origins of the problem are clear. The vast majority of the nation's water systems are small and publicly owned, with limited resources and aging infrastructure. As they turned to digital systems and monitors to boost efficiency while saving money and staff, they failed to install the safeguards and carry out employee training needed to secure the resulting vulnerabilities. "Every one of them had one guiding principle over the last 50 years: increased automation to lower the size of the workforce to keep costs down," Montgomery said. "Along with that, there should have been an investment in the cybersecurity of the infrastructure. But that did not happen."

Traditionally focused on physical risks, such as natural hazards, burst pipes and on-site intruders, most water systems also have little or no in-house IT staff. The pandemic, which encouraged remote management, has only made the problem worse. In testimony last month to the House Homeland Security Committee, former CISA Director Chris Krebs called Oldsmar's vulnerability "probably the rule rather than the exception. … These are municipal facilities that do not have sufficient resources to have robust security programs. That's just the way it goes."

The industrial control systems that water districts use to manage valves, pipes and other infrastructure are notoriously open to attack. A 2018 study by IBM and a private security company found 17 major vulnerabilities in equipment widely deployed in "smart cities," a term that refers to municipalities that manage a wide array of their systems — anything from water treatment plants to parking meters and street lamps — via the Internet. Among the security problems: Every product the group examined was still using the default passwords (such as "admin") they came with in the box, allowing "even the most novice hacker to easily gain access to these devices." A 2018 study by the firm Positive Technologies reported that it was able to penetrate nearly three-fourths of industrial

organizations it investigated, revealing gaps offering hackers “plenty of opportunity to access critical equipment.” The most common vulnerabilities: remote-access networks, obvious passwords and software so old that the manufacturer had stopped making fixes to protect against intruders. The report found that vulnerabilities known for years often “remain untouched, because organizations are afraid to make any changes that might cause downtime.”

These industrial control systems are considered such obvious targets that hacking contests use them as quarry. At the DEFCON computer security conference, an “ICS Village” let curious programmers try to break into devices set up inside a Las Vegas hotel room — demos not connected to real-life systems — in an effort to expose weaknesses. At the event in 2018, one water pipe control system, likely used for a commercial building, had its computer screen defaced with graffiti-type messages.

The exact number of attacks on water utilities remains unknown. Many go undetected or unreported, and no federal law requires disclosure, even to regulators or law enforcement. Michael Arceneaux, managing director of the Water Information Sharing and Analysis Center, an industry group promoting cybersecurity, said water systems often refuse to reveal breaches, even to his group, out of fear that they will somehow reveal their vulnerabilities to other hackers. “It’s not something members wanted potentially floating around in some database.”

The episodes that have been made public reveal a growing array of threats, from random vandalism and disgruntled employees to identity theft and ransomware.

In Oldsmar, for example, the FBI and the Pinellas County Sheriff’s Office, which are jointly investigating, have already revealed multiple lapses. The attack took place at the city’s water treatment plant, which purifies groundwater for drinking using filters and chemicals, including small amounts of sodium hydroxide. Commonly known as lye, it is used to reduce the water’s acidity. (In considerably stronger concentrations, sodium hydroxide is also a chief ingredient in drain cleaner.)

The hack began around 8 a.m. on Feb. 5, when a plant operator noticed someone had remotely accessed the computer system that monitors and controls the chemical levels added to the water. The hackers entered through a remote access software program called TeamViewer. The city had actually replaced TeamViewer six months earlier, but it never disconnected the program, according to county Sheriff Bob Gualtieri. Logging into the system remotely was a breeze: The water plant’s computers all used a single shared password, required no two-factor verification and had no firewall in place protecting the controls from the internet, according to FBI findings described in a Massachusetts state advisory. A final vulnerability: All the computers were still running on Windows 7, a decade-old, discontinued operating system; Microsoft had stopped issuing regular software updates to plug its security vulnerabilities in January 2020.

After noticing the hacker’s morning log-in, Gualtieri later said at the press conference, the plant operator “didn’t think much of it” and didn’t contact anyone since other city employees routinely accessed the system remotely. (It’s not clear why the attacker’s use of the replaced TeamViewer software didn’t immediately raise concern.)

The hacker reappeared about 1:30 p.m., this time visibly taking over the computer, mousing around for three to five minutes and opening the plant’s control system software. After ratcheting up the water’s sodium hydroxide level from 100 parts per million to 1,100 parts per million, the intruder departed.

After watching all this, the Oldsmar plant operator quickly lowered the sodium hydroxide level and called his boss. The city contacted the county sheriff’s office nearly three hours later, at 4:17 p.m., according to an incident report on the event.

Oldsmar officials maintained that the public was never in danger. They noted that it would have taken at least 24 hours for poisoned water to start flowing out of kitchen taps, and that even if the onsite operator hadn’t intervened, the plant had backup systems monitoring the water’s chemical balance that would have sounded alarms long before then.

A small number of other incidents present the nightmarish “what-if”

scenarios that scare experts, particularly from so-called state actors. Both Russia and Iran have been implicated in such accounts, according to government reports and legal actions. One such episode occurred in 2013, when a state-backed hacker sitting at his keyboard in Iran breached the computer controls at the Bowman Dam in suburban Rye, New York, with a presumed plan to open the sluice gates. The gates happened to have been manually disconnected at the time for maintenance, and the dam was actually just a narrow, 20-foot-high structure holding back a babbling brook. Federal intelligence officials speculated that the Iranians had actually intended to seize controls at the massive Arthur R. Bowman Dam in Oregon, where similar actions would have flooded thousands of homes. A federal indictment later charged that the Bowman Dam hacker worked for Iran's Revolutionary Guard and was part of a seven-man team that successfully breached America's biggest banks, paralyzing their computer servers and blocking customers from accessing their accounts online. The hacker remains at large, and on the FBI's "most wanted" list. In 2019, Revolutionary Guard hackers struck again, deploying malware to launch an ultimately unsuccessful attack on a municipal water system in Israel.

In recent years, three U.S. states — New York, New Jersey and Connecticut — decided to go beyond the federal rules and adopted tougher cybersecurity measures for the water utilities within their borders. After passing new legislation, New Jersey required all public water systems with internet-connected controls to develop a cybersecurity risk-mitigation plan within 120 days, submit it to the state, create a process for reporting all cyberattacks and join a special state-government clearinghouse promoting strong cybersecurity practices. Connecticut launched a "Cybersecurity Action Plan" and began holding private annual meetings with each of the state's largest water (and other) utilities to scrutinize the adequacy of their cyberdefenses.

For its part, New York amended its public health law to require water systems to conduct assessments of their susceptibility to cyberattacks and submit them to the state within a year. A team at the state comptroller's office has also conducted seven cybersecurity audits of municipal water systems, in each case posting the audit publicly while reserving some findings for confidential briefings to avoid offering hackers a road map of vulnerabilities. Its audit of the city of Syracuse's water system, for example, found shared user passwords and accounts that hadn't been disabled long after employees left the city. The Binghamton audit discovered a video on the water department's own webpage showcasing the treatment plant's controls.

"There's a tremendous amount of work that needs to be done to shore up the systems," said assistant New York state comptroller Randy Partridge, who oversees the water system audits. Since January 2019, he said, his auditors have issued 239 findings at various municipal facilities (including water systems) regarding weak password security alone. "It's a health and safety risk for any resident that lives in our local government. No community can really survive for any length of time without access to potable water."

Arthur House, who served as Connecticut's chief cybersecurity risk officer, said: "I hope it doesn't take the poisoning of a lot of people or a catastrophic shutdown for people to say, 'Omigosh, this is serious.' The federal government has to have a role on this. You cannot leave something that would cripple us as a country solely in the hands of 50 different states."

Doris Burke contributed reporting.

Do you have access to information about infrastructure security that should be public? Email peter.elkind@propublica.org or jack.gillum@propublica.org. Here's how to send tips and documents to ProPublica securely.

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Technology

Peter Elkind
Peter Elkind is a reporter covering government and business.

peter.elkind@propublica.org

Jack Gillum
Jack Gillum was a reporter at ProPublica based in Washington, D.C., covering technology and privacy.

jack.gillum@propublica.org @jackgillum 202-886-9504 Signal: 202-854-9062

CYBERSECURITY

Kansas Remote Tampering Case Raises Water Treatment Concerns

A former employee of the Post Rock Rural Water District is accused of tampering with water treatment systems after leaving the job two months earlier. The incident, and others like it, raise serious cybersecurity concerns.

April 13, 2021 • Jonathan Shorman and Steve Vockrodt, The Kansas City Star

Shutterstock

(TNS) — Wyatt Travnichek was just entering his 20s, but he had a vital job.

After residents across eight central Kansas counties headed home for the night, Travnichek would keep watch — virtually — over the utility that supplied them with clean drinking water. As a worker at the Post Rock Rural Water District, headquartered in Ellsworth, he was periodically responsible for monitoring the plant after hours by remotely logging into its computer system. His duties lasted until he resigned in January 2019, the circumstances of which are unclear.

Two months later, an unauthorized person gained remote access to the Post Rock system and shut down the facility's cleaning and disinfecting procedures. Earlier this month, federal prosecutors unveiled a grand jury indictment accusing Travnichek, now 22, of tampering with the Post Rock system. The indictment alleges he logged in remotely with the intent of harming the water district.

"By illegally tampering with a public drinking water system, the defendant threatened the safety and health of an entire community," said Lance Ehrig, special agent in charge of the Environmental Protection Agency's criminal investigation division in Kansas. But the Post Rock case isn't a bizarre fluke.

In February, the Florida city of Oldsmar, population 15,000, reported a hacker attempted to poison its water supply by remotely accessing its system and changing chemical levels. An employee was able to quickly reverse the hacker's actions, but the incident triggered a new wave of national concern over water security. A growing number of high-profile electronic break-ins and attempted hacks of water systems around the country are exposing the vulnerabilities of one of our most basic services — clean water. As water and other critical infrastructure become more plugged into the Internet, their security shortcomings are drawing more attention from those who fear hackers and others will seize opportunities to wreak havoc.

The Board of Public Utilities, a city-owned electric and water utility serving most of Wyandotte County, frequently faces attempted hacks from outside, often coming from Asian countries, said spokesman David Melhaff. "That's kind of widely known among electric utilities," he said.

No centralized database of attacks exists, but the Department of Homeland Security responded to 25 water cybersecurity incidents in 2015, according to a 2016 report prepared for the Department of Energy. The true number of attacks is almost certainly higher and growing.

Yet even as the cyber threat looms, small water systems like Post Rock face daunting challenges in securing their computers, The Star found. These small utilities often don't have the resources to hire dedicated information technology staff. Employees juggle multiple roles, with cybersecurity just one in a long list of items to check on. And any significant financial investment — including for cybersecurity — may raise the prospect of higher rates.

"As far as cities having an IT person, I just don't know of any our size," said Bill Shroyer,

assistant city administrator in Sabetha, in northern Kansas, and president of the Kansas Rural Water Association. "And if we did have an IT person, they better know how to repair pot holes, fix water leaks, pick up snow and everything else that we do."

A SAMSUNG PHONE

Kansas is home to nearly 1,000 water systems, ranging from tiny multi-family setups to sprawling metropolitan utilities. Post Rock, created in 1979 by a group of farmers, has grown into one of the largest rural water districts in the state by geographic size. The district serves more than 1,500 customers and can deliver 1.1 million gallons of water a day — all of it drawn from Kanopolis Lake, an artificial lake spread across more than five square miles in Ellsworth County, just west of Salina.

The district was one of only four systems in the state with chlorine dioxide and chlorite monitoring breaches in 2019, according to the latest annual report from the Kansas Department of Health and Environment. Chlorine dioxide is used to disinfect water, and chlorite is a byproduct of that process.

Travnichek worked for Post Rock for a year — from January 2018 until January 2019. His tampering allegedly took place in March 2019. Travnichek's attorney, a federal public defender, didn't respond to a request for comment.

"There's a lot of turnover in the people who are operating these systems," said Elmer Ronnebaum, general manager of the Kansas Rural Water Association. On March 27, 2019, Travnichek remotely logged into Post Rock's computer system and "performed activities that shut down processes at the facility which affect the facility's cleaning and disinfecting procedures," according to the indictment.

The indictment indicates Travnichek used a Samsung phone "to commit or to facilitate the commission" of the offense. If convicted, he must turn over the phone.

While the incident took place more than two years ago, it's become public at a time of heightened anxiety over water security. But almost no details have emerged beyond the indictment, leaving unanswered questions about how, exactly, an ex-employee was able to shut down cleaning and disinfecting at Post Rock's plant. Kayla Errebo, chair of Post Rock's board, declined to comment. None of the board's seven other members responded to requests for comment.

Supervisors at the utility also didn't respond to requests for comment. According to the district's website, Post Rock is currently searching for a general manager. Security experts indicated the explanation could be as simple as Post Rock not revoking Travnichek's electronic access after he quit, but the indictment doesn't say.

"If this is indeed a case with an insider, of course an insider could possess the methods to use that remote access if you don't have good policies," said Marty Edwards, an expert on critical infrastructure at the cybersecurity firm Tenable. "When the individual is terminated, for example, from a job, you want to make sure you remove their credentialed access from these systems."

Remote access can be a powerful tool for utility operators, allowing employees to keep an eye on systems as they go about other tasks. For departments stretched thin, the ability to check key data from a phone or laptop can prove invaluable to productivity.

"Of course, these days with COVID, the ability to work remotely ... is very important. You can't always send personnel to the facility," Edwards said. But remote access is also among the top five security gaps identified in water systems, according to the 2016 report for the Department of Energy. The report, produced by government officials and security consultants, also listed documented procedures and trained staff as shortfalls.

HELP FOR SMALLER UTILITIES

The vast number of water systems and their range in size have resulted in a hodgepodge of rules and policies on cybersecurity across the industry. The largest operators may have sophisticated approaches. Melhaff said employees of the Wyandotte County BPU face restrictions for the Internet sites and utility facilities they can access.

"It's very limited and controlled where people badge in and out," he said. Regulators may struggle to get cybersecurity on the radar of some smaller utilities, however. A 2018 water cybersecurity briefing document from the EPA spells out the challenge, noting that many water utilities, especially small systems, lack the resources for IT and security specialists to help them start a cybersecurity program.

"Utility personnel may believe that cyber attacks do not present a risk to their systems or feel that they lack the technical capability to improve their cybersecurity," the document says. Mike Keegan, a regulatory analyst at the National Rural Water Association, said the federal government needs to measure what water systems are doing to secure themselves. The government doesn't have a true assessment of what steps utilities are taking, he said.

Some of that is already happening. A 2018 federal law requires water systems that serve more than 3,300 people to complete a risk assessment and develop an emergency response plan. The plan must include strategies to improve cybersecurity. Keegan called the assessment a "good exercise" because it gives systems leeway to use their own standards and encourages community involvement in cybersecurity. He warned against a flat federal standard on cybersecurity, saying there are thousands of regulations covering drinking water utilities, and more are coming out all the time.

"So to think you can just publish a Federal Register regulation and it can be metabolized at the local level is just missing what's happening," Keegan said. "People are busy and they need to know exactly what they need to do in their community." Katie Miller, director of technical services at Kansas Municipal Utilities, a statewide association of city-owned utilities, said there's varying degrees of interest and understanding on cybersecurity issues among utilities. While smaller utilities don't typically have dedicated security staff, the association can walk them through how to get in touch with experts who can help, she said.

Her group is also providing cybersecurity curriculum to its members and has held a couple training workshops with plans to hold more. "They've focused on ... like 'What is cybersecurity? What do data breaches look like?'" Miller said. The training, geared toward smaller utilities, focuses on cybersecurity basics, she said and includes a self-assessment component.

"Once they have that framework," Miller said, "then it allows them to start to potentially prioritize, "OK, what is something manageable we can work toward in strengthening our cybersecurity?"

Public Sector Cybersecurity Summits in 2023

- Florida September 14
- Kansas September 20
- Oregon September 27
- California October 12
- New York November 1
- Indiana December 5

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Appendix D

Environmental Evidence

SYSTEMATIC MAP

Open Access

Effects of artificial light on bird movement and distribution: a systematic map

Carrie Ann Adams[1*], Esteban Fernández-Juricic[2], Erin Michael Bayne[1] and Colleen Cassady St. Clair[1]

Abstract

Background: Artificial light is ubiquitous in the built environment with many known or suspected impacts on birds. Birds flying at night are known to aggregate around artificial light and collide with illuminated objects, which may result from attraction and/or disorientation. In other contexts, birds are repelled by light-based deterrents, including lasers and spotlights. Artificial light can also change birds' perceptions of habitat quality, resulting in selection or avoidance of illuminated areas. Studies documenting aggregation, deterrence, and habitat selection are typically considered separate literature bodies, but they actually study a common set of populations, interventions/exposures, and responses. Our systematic map provides a comprehensive, searchable database of evidence of the effects of artificial light on bird movement and distribution, increasing both the quantity and diversity of studies that are accessible for further comparison and synthesis. We identify and describe the evidence available for four secondary questions relevant to conservation or management: aggregation/mortality at structures with artificial lights, evidence that light attracts and/or disorients birds, light-based deterrent efficacy, and the influence of continuous illumination on habitat selection.

Methods: Using the principles of systematic reviews and methods published in an earlier protocol, we conducted an extensive and interdisciplinary literature search. We searched multidisciplinary citation indices as well as databases and websites specific to conservation, pest management, transportation, and energy. In our map, we included all studies reporting eligible populations (birds), interventions/exposures (artificial light), and outcomes (movement through space, behaviour preceding movement, or distribution). We evaluated the quantity of available evidence based on meta-data fields related to study context, population traits, light source characteristics, and outcome variables. We used these meta-data to identify relevant evidence for each secondary question and describe aspects of our secondary questions that may support reviews (evidence clusters) and others that require more research (knowledge gaps).

Review findings: We manually screened 26,208 articles and coded meta-data for 490 eligible studies in a searchable database, organizing the literature to facilitate future reviews and evidence-based management. Much of the evidence was concentrated in particular locations (Northern hemisphere), taxonomic orders (*Passeriformes, Charadriiformes*, and others), and light wavelengths (red and white). We identified 56 distinct response variables and organized them into 3 categories (behaviour, distribution, and avian community), showing the diversity in bird responses to light.

Conclusions: Our database can be used to answer the secondary questions we identified and other questions about the effects of artificial light on bird movement and resulting changes to distribution. There may be sufficient evidence

*Correspondence: caadams1@ualberta.ca
[1] Department of Biological Science, University of Alberta, CW 405, Biological Sciences Building, Edmonton, AB T6G 2E9, Canada
Full list of author information is available at the end of the article

for a review of the weather and lunar conditions associated with collisions, which could help identify nights when reduction of artificial light is most important. Further experiments should investigate whether specific types of light can reduce collisions by increasing the detectability of structures with artificial lights. The efficacy of lasers as deterrents could be evaluated through systematic review, though more studies are needed for UV/violet lasers. To reduce the impacts of outdoor lighting on birds, research should investigate how spectral composition of white light influences bird attraction, orientation, and habitat selection.

Introduction

Background and objectives

Artificial light is growing worldwide [1], with diverse biological and ecological impacts [2]. Electric light sources have different spectral properties and higher intensities than celestial light, and both electric lighting and anthropogenic flames change the daily, monthly, and annual light cycles under which most organisms evolved [3]. Artificial light at night (ALAN) can alter daily activity patterns and affect organismal physiology, particularly hormone levels and stress responses [2]. In some species, ALAN elicits positive phototaxis [4, 5] or interferes with orientation and navigation [6, 7], limiting dispersal [8] and changing broad scale distributions [9]. Phototaxis can lead directly to mortality in sea turtles [10], insects [5], and fledgling seabirds [11], and may have sublethal impacts that are more difficult to quantify [9]. ALAN can also affect habitat selection [6, 12, 13] and population metrics including abundance [14–16] and reproduction [5], potentially affecting population trajectories [17–19]. The strength and direction of the effects of ALAN varies widely among species, creating imbalances that disrupt trophic relationships and pollination networks [20–24]. Most research has focused on artificial light at night, but daytime artificial lighting can also have ecological impacts and management applications if it: (a) illuminates places that are otherwise dark [25]; (b) uses wavelengths that are lethal or harmful to particular species [26]; or (c) creates a novel stimuli that may act as an attractant or activate an organisms' anti-predator response (e.g. light-based deterrents) [27].

For birds, most well-known effects of artificial light occur during nocturnal migration, when birds are frequently observed aggregating around or colliding with structures with artificial light, such as communication towers and their associated guy wires [28, 29]. Birds aggregate around beams of light projected into the sky, as seen at ceilometers and at the September 11th memorial, diverting, delaying, and sometimes grounding them during migration (e.g. [30, 31]). Groundings have been documented extensively for fledgling seabirds at coastal light sources [11]. These aggregations present a conservation concern because artificial light has been associated with all major sources of collision mortality: buildings and windows, transmission lines, roads, and communication towers [32].

The proximate and ultimate causes of these aggregations remain unclear. Many authors attribute these aggregations to birds preferentially flying towards light sources, which would suggest attraction to them [31, 33]. Even if they do not preferentially fly towards light sources, birds may be unwilling to leave an illuminated area once they encounter it in their flight path, a phenomenon called capture [28, 34, 35]. Attraction could be caused by an overstimulation of the visual system [36]. Artificial light becomes polarized when reflected off of asphalt surfaces, which may attract waterbirds who mistake the asphalt for water and become injured or stranded [37]. This interpretation assumes that birds see polarized light, which is controversial [38]. Additionally, birds may fly towards light sources to increase visibility during flight or enhance the chances of detecting predators.

Most authors agree that birds aggregating around light sources are disoriented; they have lost the ability to select and maintain a certain direction [39]. Artificial light has the potential to disrupt each of the three primary mechanisms of compass orientation in migratory birds: solar, stellar, and magnetic. Birds use the position of the sun to orient during the day and at dusk, taking the time-of-day and day-of-year into account [39, 40]. Clock-shift experiments have shown that some birds orient in the wrong direction when exposed to daylight periods shifted by several hours, even when daylength matches the local photoperiod (e.g. [40–42]). It is unknown whether outdoor lighting causes birds in the wild to perceive clock-shifts of sufficient magnitude to disorient them. Artificial light may also interfere with the stellar compass, which forms when young birds identify the center of celestial rotation during their first spring and learn to use constellations to orient north and south [39, 43, 44]. There is individual variation in which and how many stars they require to orient [45]. The night sky birds encounter during migration could be very different than the stellar patterns they learned if skyglow levels change or increasing numbers of satellites move across the night sky, as is expected within the next decade [46–48]. During magnetic compass orientation, a radical-pair process

in the retina allows birds to detect the inclination of the earth's magnetic field and specific types of artificial light interfere with this ability [49]. If artificial light bleaches the rhodopsin in their retina, birds could lose their ability to see relatively dim light coming from the stars and the reflection of dim celestial light off of landmarks [50]. Disorientation can explain the loss of a linear flight path, though it is unclear why disoriented birds remain near the artificial light sources.

In contrast to the examples of apparent attraction, light has also been used to deter birds from zones of human-wildlife conflict. A better understanding of deterrent efficacy is necessary to prevent millions of dollars in damage to crops and aircraft [51, 52]. Birds are assumed to respond to approaching vehicles as they would to a predator [53], and artificial light is used to increase the detectability and perceived risk of the vehicle, increasing detection, alert and flight initiation distances [54, 55]. To elicit an avoidance response without an approaching object, light-based deterrents must create the illusion of risk that outweighs the benefits of using a resource (e.g. food). Deterring birds can be especially challenging when there is no immediate risk to the bird (e.g. roost trees in cities), the birds may not perceive the risk (e.g. toxic tailings ponds), or there are significant attractants (e.g. aquaculture ponds). If non-lethal deterrents fail, continued conflict may result in lethal management strategies. Ultimately, interventions to reduce bird attraction to artificial light or increase bird deterrence using light-based interventions have the same goal—to change bird movement and distribution.

Understanding how light changes bird distributions is important because it is often the goal of interventions using or reducing artificial light, but it is also sometimes the metric by which the ecological impacts of exposure to artificial light are measured. Bird distributions result from habitat selection, the process of choosing resources through a series of innate or learned behavioural decisions [56]. Studies of bird distributions, including population density or locations of individuals, are often used to infer habitat selection and identify important habitat components in conservation planning under the assumption that species have evolved to select higher quality habitat [57, 58]. Artificial light can influence habitat quality in diverse ways that include changes to diel activity patterns [59, 60], hormone production [61], cognitive function [62, 63], and nestling development [64–66]. Artificial light can also change the relative abundance of bird prey and predators [67–69], affecting the chances of survival and reproduction. Even when artificial light seems to increase bird abundance or use of illuminated areas, there may not be corresponding increases in reproductive success, particularly in human-modified landscapes [70]. Habitat selection may also be driven by innate attraction to or avoidance of light [71]. Birds may adequately perceive some impacts of artificial light on habitat quality (e.g. changes to prey abundance) and respond with selection decisions that improve fitness, while other impacts could be more difficult for both birds and human researchers to perceive (e.g. increased stress hormone levels in nestlings under artificial illumination [66]). Each of these elements of habitat selection—attraction, deterrence, and perception of habitat quality—involves a series of cognitive processes that cannot be directly observed as outcome variables but may be inferred based on changes to movement or distributions. Providing the evidence for these inferences drives the primary question in our systematic map: *How does artificial light affect bird movement and distribution?*

Large bodies of research address two aspects of how artificial light affects bird movement and distribution: collision mortality of nocturnal migrants (e.g. [31, 72, 73]) and bird deterrence from zones of human-wildlife conflict (e.g. [74–76]). More recent studies use bird distributions to estimate the ecological impacts of ALAN on birds (e.g. [77, 78]). These literature bodies are typically synthesized separately (e.g. [28, 79]), despite shared emphases on bird movement and distribution. Evidence from each body of research is directly relevant to the others. For example, light-based deterrents that reduce the number of birds in zones of human-wildlife conflict could also reduce collision mortality of nocturnal migrants. Through our extensive literature search, we found and included in our map additional bodies of research that studied bird movement and distribution in response to artificial light. We sought to combine all the available evidence from multiple literature bodies to increase both the quantity of evidence available to inform review or management decisions and the diversity of species and light characteristics for which evidence is available.

Stakeholder engagement

Informal conversations with stakeholders from industries, government agencies, and non-profit organizations confirmed that this topic is relevant in many fields. We developed a questionnaire for stakeholders to inform our search strategy, identify secondary questions of particular importance, support map interpretation, and guide subsequent systematic reviews and primary research (Additional file 1 in our protocol [80]). Ten stakeholders responded to our questionnaire, helping us to expand our literature search and identify secondary questions of particular importance. Stakeholders included two academic researchers, four researchers or managers at government organizations, two non-profit leaders, and two industry stakeholders. The diversity of stakeholders was

reflected in the broad range of topics identified as important, including the efficacy of deterrents, the contribution of ALAN to bird-building collisions, and the ecological impacts of artificial light in bird breeding and foraging habitat. All stakeholders were professional contacts of the authors, or were referred to us by other stakeholders who completed the survey, resulting in geographic bias, with nine of the ten stakeholders based in North America. We reached out to five additional stakeholders who did not respond. All stakeholders surveyed indicated that they were interested in how birds' behavioural responses to light are affected by light characteristics (e.g. wavelength, intensity, and direction). Future systematic reviews should engage in further stakeholder engagement to determine the level of interest in the evidence clusters we have identified.

Objectives of the review

Our primary question is:

How does artificial light affect bird movement and distribution?

We evaluated study relevance to our primary question according to the PI/ECO framework [81], characterizing the population, intervention or exposure, comparator (when available), and outcome for each study. We defined the PE/ICO elements as:

> **(P) Population:** All bird species
> **(E or I) Exposure or Intervention**: Anthropogenic light sources (including anthropogenic flames and electric light). We include both interventions (lights that are used to deliberately alter bird behaviour) and exposures (lights that are in place for a different reason).
> **(C) Comparator**: Similar habitats, laboratory environments, structures, or landscapes that are unlit or lit with different types of light; same study site before or after intervention/exposure. Studies without a comparator were included in the map and the lack of comparator was recorded during metadata coding.
> **(O) Outcome:** Bird movement through space, behaviours that precede movement through space (e.g. alert behaviour or orientation), or distributions (including presence/absence, use, abundance, or locations).

The first objective of our systematic map was to provide a database of evidence to answer questions about the effects of artificial light on bird movement and distributions. The results of the systematic map are contained in a database, which includes all eligible studies and metadata relating to the PE/ICO elements. The second objective was to provide an evidence base for four secondary questions that we identify below based on our expertise and consultation with stakeholders. Our third objective was to identify key evidence clusters (questions with sufficient evidence for review) and knowledge gaps (questions requiring more research) pertaining to each secondary question that are important from a conservation, management, or basic science perspective. Our secondary questions are:

1. What information is available documenting that birds in flight aggregate around and collide with artificial lights or structures with artificial lights?
2. What evidence exists on aggregation and mortality as a result of attraction and/or disorientation?
3. What information is available to describe the effect of light as a means of deterring or dispersing birds?
4. What evidence exists on continuous artificial illumination changing bird habitat selection for activities other than flight?

The primary question, the PE/ICO framework, and our secondary questions were published in our systematic map protocol [80]. We edited the language of our primary and secondary questions to reduce ambiguity and to allow us to identify relevant evidence based on population, exposures/interventions, comparators, and outcomes. We specified that our questions relating to aggregation/mortality and the causes of aggregation/mortality focused on birds in flight because this is the context in which birds aggregate around lights and collide with illuminated structures. We specified that our question related to habitat selection excluded birds in flight because they have not yet settled in a particular location. We also narrowed the focus of this secondary question to continuous illumination because we focused on ecologically relevant light pollution, and flashing lights and lasers are rare in urban and suburban landscapes, outside of bird deterrence efforts. We incorporated the final secondary question from our protocol into all of our secondary questions, describing the range of weather, light, and population characteristics for which evidence is available.

Methods

This systematic map follows CEE guidelines [81] and ROSES reporting standards [82] (Additional file 1 *ROSES form*).

Deviations from the protocol

We altered our secondary questions to identify relevant studies based on PE/ICO elements. In order to increase the number of unique search results in our Google

Scholar search, we used four search strings instead of the two written in our protocol. We used the program Publish or Perish [83] to save our Google Search results as .csv files. We changed our method for selecting reviews for bibliographic checking to identify reviews that focused on birds, artificial light, and one or more of our secondary questions. We added details to our eligibility criteria to promote transparency and consistency. We altered some of our metadata fields and codes to accommodate the diversity of studies included in the map. Records of these alterations and the final coding fields are listed in Additional file 11 (*Data coding fields)*. Volunteers assisted with data coding. We further explain these changes to our protocol in the relevant sections below.

Searching for articles

We did not apply any document type restrictions to our search. All searches were conducted in English in Google Chrome using incognito mode. Although we did not include language restrictions in the database searches, we included only articles written in English. As described in our protocol [80], we compiled a list of 78 articles representative of the diverse studies that were eligible for inclusion in our map ("benchmark articles") and created a search strategy that found all of these articles.

Database, citation indexing service, and website searches

We used a search string consisting of population and exposure/intervention components of the primary question to search databases and citation indexing services. In the Web of Science Core Collection and in the Web of Science Zoological Record, we used the search string (*TS = *Bird* OR Avian OR Ave$)* AND (*TS = Light* OR Laser* OR Strobe$ OR Streetlight* OR Headlight$ OR Spotlight* OR Lamp$ OR Beacon$ OR Beam$ OR Flash* OR Flare$ OR Flaring OR Reflector$ OR Ceilometer$)*. As outlined in our protocol [73], when searching for articles indexed without abstracts or keywords in the Web of Science Core Collection we expanded our population search string to include all English common family names (Additional file 2 *WOS search strategy*). We pre-screened the Web of Science search results to exclude articles that only used our exposure/intervention search terms in common irrelevant phrases (e.g. in light of, comes to light, or light-level geolocator), listed in Additional file 2. A complete explanation of this strategy and the macros used to implement it are provided in Additional files 2 and 3 (*WOS search strategy* and *WOS search records*). This strategy ensured that we found all benchmark articles indexed in Web of Science Core Collection or in Web of Science Zoological Record.

We also searched the following additional databases: Proquest Dissertations and Theses Global, Open Access Theses and Dissertations, Conservation Evidence, Crop Protection Compendium, Tethys Knowledge Base, Artificial Light at Night (ALAN) Research Literature Database, NWRC Staff Publications, and Internet Center for Wildlife Damage Management, and Environmental Studies Program Information System (Additional file 4 *Database search records*). We modified our search string to fit the format of each database (Additional file 4). Finally, we searched the 18 websites that we identified in our protocol, using a combination of hand searching and built-in search functions on the website (Additional file 12; *Supplementary tables and figures*, Table S1). We used Google to search within the websites that were too large to feasibly manually check every page (Additional file 5 *Website search records*). All website searches were conducted on August 21, 2019, and were not updated due to time constraints. All Web of Science and specialized database searches were conducted in February or August 2019 and updated in August 2020 (Additional file 4).

Web-based search engines

We searched Google Scholar using Publish or Perish 6 [83] with the following search strings:

1. All of the words: Avian; Any of the words: Light Spotlight Streetlight Headlight Lamp Beacon Beam Ceilometer
2. All of the words: Avian; Any of the words: Laser Strobe Flash Flare Flaring Reflector
3. All of the words: Bird; Any of the words: Light Spotlight Streetlight Headlight Lamp Beacon Beam Ceilometer.
4. All of the words: Bird; Any of the words: Laser Strobe Flash Flare Flaring Reflector

We saved the first 1000 results from each search to.csv files (Additional file 6 *Google Scholar search records*). We combined all search results into a single Microsoft Excel spreadsheet, removed duplicates, and uploaded all search results to Rayyan QCRI for further screening (Additional file 6) [84]. Rayyan QCRI is a free web and mobile app for screening abstracts and titles for systematic maps and reviews. Using the program Publish or Perish caused a deviation from our protocol, but allowed us to retain a record of the Google Scholar search results and import them into Rayyan QCRI for screening. Using the four search strings, instead of the two written in our protocol, increased the number of unique search results.

Assessing search comprehensiveness

We chose one review for each secondary question for bibliographic checking. To select these reviews, we downloaded a list of all articles we had identified as reviews

during screening in Rayyan QCRI and determined their relevance to each secondary question based on their titles. We then scored the articles based on the relevance and date of publication (details in Additional file 7 *Bibliographic checking*), giving higher priority to reviews that specifically focused on birds, artificial light, and one or more of our secondary questions. We randomly selected a review among the top scores for each secondary question and identified all eligible articles referenced in each review. When the first review of bird deterrence yielded only two relevant references, we randomly chose an additional review for this exercise. In total, we used five reviews to assess our search comprehensiveness, and we calculated the proportion of references for each review that were found with our systematic search.

Bibliographic checking confirmed that our search strategy found nearly all available evidence for most secondary questions. We found all four eligible references from the two reviews of deterrents [79, 85], all 17 eligible references from the orientation review [86], and eight out of 9 eligible references in the review relevant to habitat selection [87] (Additional file 7). Our search found 26 of the 44 eligible references in the review of aggregation/mortality [28].

Finding all articles that documented birds aggregating or colliding around any structure with artificial lights (buildings, windows, towers, oil platforms, etc.) would require substantial additional search effort. Two of the 18 missed articles were theses and were only indexed in Open Access Theses and Dissertations. They did not include the terms "bird," "avian," or "Aves" in their titles (Additional file 7). However, the studies in these theses were included in the map because our search found peer-reviewed articles reporting these studies. Eight of the 18 missed articles were not indexed in any of the databases we searched. Searching additional databases would not substantially improve the search comprehensiveness because none of these articles were indexed in Scopus and only one was indexed in JSTOR. The remaining eight articles were indexed in the Web of Science Zoological Record, but were not found because they did not include the term "light" or another exposure/intervention term in their topic fields. The shortest search string that could find all of these articles (*TS = (*bird* OR Avian OR Ave$) AND TS = (tower OR migration OR destruction)*) returned 52,459 results, far more than we could feasibly screen.

Article screening and study eligibility criteria

We used Rayyan QCRI to screen search records from Web of Science, Google Scholar, and Proquest Dissertations and Theses Global. We first screened articles at the title and (if available) abstract level. Any articles excluded at the full text level are listed in Additional file 9 (*Articles excluded at full text*) with exclusion reasons. The remaining specialised databases did not provide an export to csv function, so they were screened in Microsoft Word if the text could be easily copied. Otherwise, they were screened on the website with the search results pages saved as PDF files. We initially screened using the information available on the webpage, recorded any articles that were potentially relevant, then made full-text eligibility decisions and recorded reasons for excluding any article (Additional file 9). CAA and AB performed all screening, and neither screener authored any articles considered for inclusion/exclusion.

As we screened articles for study eligibility, we added details to the eligibility criteria published in the protocol to better define the scope of our map and promote consistency in the eligibility determinations (Table 1). We included further justifications for these eligibility criteria in Additional file 8 (*Explanations of eligibility criteria*). In accordance with our original criteria, we excluded specific exposures/interventions that did not involve an artificial light source, such as studies of reflected or filtered daylight. This necessarily excluded some studies of bird hazards (e.g. windows), deterrents (e.g. mylar, streamers, mirrors), and orientation (e.g. filters on natural daylight).

For interventions/exposures that are so broadly applied as to make mapping their use prohibitive, we required that they compared bird response under artificial light of different wavelengths or intensities. This criterion excluded laboratory studies using only broad-spectrum (i.e. white) light of a single intensity and a single photoperiod. We included laboratory studies that compared, within the same study, bird responses to light of varying intensities, different spectral compositions, or different photoperiods, providing that they also studied an eligible outcome.

In making eligibility decisions about outcomes, we included outcomes documenting movement through space or behaviours that directly precede movement (e.g. orientation or alert response). We excluded general locomotor activity (e.g. perch-hopping or overall activity levels). We excluded studies testing birds' ability to see specific wavelengths or using light as a visual cue to elicit a trained response. We excluded outcomes involving temporal changes in daily or annual movements (e.g. timing of entering/exiting nest boxes or migration), timing of daily activities (e.g. timing of feeding, sleeping, etc.), or circadian rhythms. We excluded studies of bird foraging behaviour that did not involve movement through space or changes to distribution (e.g. time spent foraging or changes to foraging strategies). We included incidental reports of nocturnal

Table 1 Eligibility Criteria used to screen articles for inclusion in the systematic map

	Eligibility criteria	Exclusion criteria
Population	Any bird species, including domesticated species	
Exposure/Intervention	Anthropogenic light sources, including, but not limited to, point sources of light, illuminated habitat, skyglow, and gas flares	Reflected daylight (e.g. mylar tape reflectors, windows) Filters on natural daylight
Comparator	Same site under different lighting conditions Nearby site at the same time of day with similar habitat type, anthropogenic activity, migration density (if applicable) and weather as the treatment site Documentation of aggregation, mass landing, mortality, foraging, or other relevant outcomes near artificial light sources without comparator were included in the map and coded as "No Control"	Laboratory experiments that use only one intensity or spectral composition of light within the "light" or "dark" portions of the light cycle Laboratory experiments that use an artificial photoperiod but do not vary the photoperiod
Outcome	Bird density or presence/absence, including (but not limited to) radar observations, visual counts and vocalization counts Bird mortality Resource consumption (such as crop damage or aquaculture predation) Behavioural outcomes directly involving movement through space, including (but not limited to) flight path, flight initiation, diving and flushing Behavioural response (flushing or immobilization) to spotlights used for capturing birds Behaviours known to precede movement: orientation, overt reaction distance, alert response (e.g. moving head laterally or vertical, crouching) Documentation of birds foraging under artificial lights Habitat use metrics at foraging sites such as feeders (e.g. arrival/departure times, feeder visit rates)	Responses that are not conventionally associated with movement (e.g. hormonal responses) Behavioural responses that do not include or directly precede movement through space (e.g. preening, dust-bathing, sleep behaviour, vocalizing) General locomotor activity (e.g. perch-hopping or time spent walking) Temporal changes in daily or annual activity rhythms (e.g. entering/leaving nest box, migration) Changes to timing of activities in laboratory experiments (e.g. feeding, drinking) Total feed consumption in laboratory experiments Trained responses (e.g. trained to perform a task when a light is on) Ability to see specific wavelengths (e.g. mate choice or ability to distinguish objects under varying light conditions) Changes to timing in chick provisioning in field studies

foraging under artificial lights surrounded by dark habitat, while recording the comparator as *None*.

Two members of the map team (CAA and AB) conducted consistency checking by screening the first 200 articles at the title/abstract level in Rayyan QCRI (Additional file 10 *Consistency check records*), resulting in a Kappa score of 0.71. We clarified the eligibility criteria and repeated the consistency checking on an additional 200 articles, achieving 100% agreement. CAA screened the remaining articles. In cases where study eligibility was unclear, CAA consulted with the mapping team and defined additional eligibility criteria. After CAA screened 7000 articles, AB and CAA repeated the consistency checking exercise. To correct for possible bias in the order in which the articles appeared on Rayyan, we screened a random selection of 200 articles from all Web of Science search results. We disagreed on the eligibility of only one article, resulting in a Kappa Score of 0.93. After further discussion, we included this article at the title/abstract stage, but ultimately excluded it at the full text level. In total, we conducted consistency checking on 400 (1.9%) out of 21,150 articles screened on Rayyan QCRI at the Title/Abstract level (including the updated search).

Two members of the map team (CAA and CCSC) conducted consistency checking on 20 randomly selected articles at the full text screening level (Additional file 10). After disagreeing on 7 articles, we discussed and refined the eligibility criteria until we agreed on all eligibility decisions. We employed an external screener, NL, who had not previously worked on the map to ensure our eligibility criteria were clear to a naive screener. After reading the eligibility criteria, NL made inclusion decisions for the 20 randomly selected articles. NL agreed with CAA and CCSC for 19 out of 20 articles, resulting in Kappa score of 0.77. After further discussion, NL agreed that the article in question should be excluded. In total, we performed consistency checking on 20/819 articles (2.4%) screened at the full text level. CAA screened the remainder of the articles.

Study validity assessment

We did not conduct a study validity assessment because the diversity of context, discipline, and study design included in the scope of the map did not support consistent criteria for evaluating studies. To facilitate future assessments of study validity, we described the control and coded the type of control design (e.g. none, before/

after, control/impact, gradient—spatial, gradient—temporal), the data collection method (systematic or opportunistic), whether the study was observational or experimental (Additional file 11 *Data coding fields*).

Data coding strategy

We found a greater quantity of articles than we expected when writing our protocol, so we altered our data coding strategy in order to complete the systematic map. We hired a research assistant (NL) and engaged 25 undergraduate student volunteers to code metadata, each contributing on average 60 h (over 1500 h total). Undergraduate students were trained by CAA and typically worked in pairs to read articles and extract metadata while CAA supervised on live video calls. CAA proofread all data coding performed by volunteers, reading the abstracts and methods sections of the articles and confirming that metadata were correct. In articles without methods sections (e.g. lighthouse reports), CAA skimmed the articles to find relevant metadata. Any data coding performed solely by CAA or NL were similarly proofread by a volunteer. Any potential mistakes found by the proofreader were discussed by both readers until an agreement was reached. The questions posed by volunteers during data coding were answered and recorded in the coding instructions (Additional file 11 *Data coding fields*), helping to clarify our coding methods. This spreadsheet also lists and justifies all modifications made to the data coding fields outlined in our protocol. We coded any missing data as unavailable (UA). The large number of studies and metadata fields precluded us from obtaining missing data from the authors.

We conducted two data coding consistency checking exercises. In October 2018, three members of the mapping team (AB, CAA, and SS) coded data from 10 articles selected randomly from all of the articles that were known to the authors at that time. Each article was coded by two readers. Minor inconsistencies that occurred in four of these articles were discussed and corrected. The only inconsistencies were between SS, the undergraduate volunteer, and one of the systematic map authors. In March 2020, CAA and NL performed an additional consistency checking exercise on 10 articles. Some inconsistencies occurred in the "Study Design" category, resulting in the addition of "Behavioural Assay—with control" and "Behavioural Assay—no control" to this field's codes. As part of training, volunteers demonstrated their skills by correctly coding data on two or three sample articles, but we did not complete a full consistency checking exercise with every volunteer. Instead, we used proofreading strategy described above.

Throughout the systematic map process, we identified diverse outcomes (i.e. response variables) that described bird behaviour, distribution, or community, adding outcome codes as necessary during data coding (Additional file 11). As the number of outcomes grew, we categorized them into subcategories to aid our synthesis. The subcategories for distribution outcomes are straightforward (e.g., bird locations, bird counts, mortality), while the behaviour subcategories require more explanation. Any description of flight path (e.g. velocity, altitude, direction) was included in the subcategory titled *flight path characteristics*. In the subcategory titled *approach or flee response*, we included any outcomes showing bird movement towards or away from light when not in flight (e.g. on the ground or water). There are other logical subcategories for grouping the behaviour outcomes, and we invite users to find studies with outcomes relevant to their specific questions using the search form in our database.

Community outcomes were not originally included in our PE/ICO framework, but we added community as an outcome category because studies reporting community metrics are relevant to our primary question. They measure the distributions (e.g. presence/absence or relative abundance) of groups of birds (e.g. species or functional groups) and summarise these data using various indices (e.g. species richness or functional diversity). The way in which the distribution data were interpreted determined if the study outcome category was coded as Distribution, Community, or both. If the study reported the presence/absence or abundance of individual species, bird groups, or all birds as one group, we coded the outcome category as Distribution. If a study reported metrics that summarized the number or traits of species present, we coded the outcome category as Community. All but one study with a Community outcome also reported a Distribution outcome.

Data mapping methods

Our systematic map is a relational database in Microsoft Access (Additional file 13 *Adams et al. 2021 Systematic Map*) and in Microsoft Excel (Additional file 15: *Adams et al 2021 Systematic Map Excel*).The search function in the Access version allows the database to be filtered by any of the coded fields, returning a list of studies that meet the criteria chosen in the search form. In our Review Findings, we examine each metadata category (Context, Population,Exposure/Intervention, Comparator, and Outcome) and describe the quantity of evidence for particular populations, exposures/interventions, and outcomes. For each of our secondary questions, we identified the available evidence based on PE/ICO filters that are relevant to these questions, as we have framed them (Table 2). Users of the database may refine these criteria to meet

Table 2 Filters applied for each secondary question and quantity of evidence identified

	Aggregation/ mortality	Causes of aggregation		Deterrence	Habitat selection
		Orientation	Attraction		
Population Filters	Bird activity during intervention/exposure = *flying*		Bird activity during intervention/exposure = *flying*		Bird activity during intervention/exposure ≠ *flying*
Exposure/ Intervention Filters				Deterrent type = *Laser, Spotlight or Beam, Flashing light, UV or near-UV light, Line markers*, or *Pyrotechnic*	Continuous/Flashing = *Continuous* AND Deterrent Type ≠ *Laser*
Comparator Filters					Control design ≠ *No Control*
Outcome Filters	Outcome category = *Distribution* OR Outcome subcategory = *flight path characteristics*	Outcome subcategory = *Orientation behaviour*	Outcome subcategory = *preferences* OR Outcome = *Change in flight direction relative to a light source, Capture of birds in flight, Modeled flight behaviour based on observations of birds in flight, Distance of flight path from light source,* or *flight altitude*	Outcome category = *Distribution* OR Outcome subcategory = *Approach or Flee Response* or *Alert behaviour* OR Outcome = *Change in flight direction relative to a light source, Capture of birds in flight, Modeled flight behaviour based on observations of birds in flight, Distance of flight path from light source,* or *flight altitude*	Outcome subcategory = *Preferences, Bird counts, Bird Locations,* or *Presence of foraging birds*
Number of relevant studies	219	38	26	228	88

their specific management or synthesis objectives. In our Review Findings, we describe evidence clusters and knowledge gaps for each secondary question.

Relevant evidence for our first question (aggregation/mortality of flying birds) included studies that measure flight path characteristics, collision mortality, or the distribution of birds in flight. We filtered the database to include studies where the bird activity during intervention/exposure was coded as *flying* and the outcome measured was in the *distribution* category or in the *flight path characteristics* subcategory.

We also identified the potential evidence for two possible mechanisms of aggregation/mortality: attraction and disorientation. Evidence suggesting attraction included studies of flying birds that measured any of the following behaviour outcome subcategories: *change in flight direction relative to a light source, capture of birds in flight, modeled flight behaviour based on observations of birds in flight,* or *flight altitude.* We did not include outcomes related to bird distributions as evidence of attraction because a different relative abundance of birds in lit than unlit areas could be due to capture (failing to leave illuminated areas once they encounter them) rather than attraction (preferentially flying towards lights). Evidence suggesting disorientation included any study with outcomes in the subcategory of *orientation behaviour*.

To describe the evidence for our third secondary question, we identified the types of light used for the purpose of deterring birds. We included all studies using these types of light and reporting response variables that could demonstrate deterrence. We included studies of flying and non-flying birds because light is used to deter both flying birds (e.g. during aircraft flight) and non-flying birds (e.g. on airport runways and in agricultural fields). Any outcome in the category *distribution* could demonstrate deterrence if the light treatment reduces bird numbers or bird deaths. Behavioural outcomes in the subcategory *approach or flee response* or the subcategory *alert behaviour* could also demonstrate deterrence, as could any of the *flight path characteristics* outcomes that could suggest attraction (listed above).

Using our broad definition of habitat selection as a process rather than a specific study design, evidence relevant to our fourth secondary question includes several type outcomes documenting changes to bird presence, abundance, or other measures of distribution. The evidence

included, but was not limited to, studies modeling relative selection probability by comparing the light levels at used to available locations [88]. We included any studies that measured one of the following outcome subcategories: *preferences*, *bird counts*, *bird locations*, or *presence of foraging birds*. We required studies to include a control treatment, control period, or light gradient in order to demonstrate whether the measured outcome was different in lit than unlit times or places. We only included studies involving continuous illumination, excluding lasers and flashing lights because they are not common in the built environment and are typically evaluated in the context of our third secondary question (deterrents). We excluded studies that only observed birds in flight because flying birds have not settled in a particular location that would demonstrate habitat selection.

Review findings

Review descriptive statistics

Our systematic search used multiple steps (Fig. 1), ultimately resulting in the manual screening of 26,208 records to return 469 eligible articles (Table 3). The majority of articles (351) came from the comprehensive searches of Web of Science Core Collection and Web of Science Zoological Record (Table 3), for which we applied several pre-screening processes (Additional file 12 *Supplementary tables and figures*: Figure S1). Specialized databases provided 61 unique articles, with 23 found in the Artificial Light at Night (ALAN) Literature Database, 14 found in Open Access Theses and Dissertations, and 9 found in the Internet Center for Wildlife Damage Management. An additional 10 articles were found on websites and 19 were found incidentally (e.g. recommended by stakeholders or found when searching for the full text of a different article).

We found documentation of bird response to artificial light dating back to 1880 and the number of studies has increased markedly since 1990 (Fig. 2a). Most studies were conducted in the Northwestern quadrant of the globe (290), and many were also conducted in the Northeastern (129) and Southeastern quadrants (53) (Additional file 12: Table S2). We found only 18 studies from the Southwestern quadrant. There were 127 studies involving light that was only turned on at night, 33 during the day only, and 10 at sunset or dusk only (Additional file 12: Table S3). Many other studies applied the light treatment at multiple times of day or did not specify when the lights were turned on.

Our interdisciplinary search found studies from many economic sectors with diverse study purposes. The most common sectors were transportation (126 studies) and urban/suburban/rural developments (123) (Table 4). Few studies came from the mineral mining or waste management sectors, despite the need to reduce bird numbers at toxic tailings ponds and landfills [89, 90]. Many studies were conducted to document and/or reduce bird aggregations or mortality (169 studies), while deterring birds (88), monitoring or describing bird migration (35), and documenting birds foraging under artificial light (47) were also common study purposes (Table 5).

Additional information about the number of articles found during each stage of the Web of Sciences searches is provided in Additional file 12: Figure S1.

Mapping the quantity of evidence for the primary question

We fulfilled the first objective of our map by providing a database of all available evidence for our primary question regarding the effects of artificial light on bird movement and distribution. In this database (Additional files 13, 14, 15), we brought together literature from many research bodies that study relevant populations (birds), interventions/exposures (artificial light), and outcomes (movement and distribution). Others can easily search and filter this database with metadata related to PE/ICO elements to find evidence for specific management questions and future systematic reviews. The metadata and narrative descriptions provided for each study allow the user to quickly evaluate the relevance of each study to their question.

We provide three versions of the systematic map database. The Microsoft Access database (Additional file 13) can be opened and edited using Access, and the Microsoft Access ACCDE Database (Additional file 14) can be opened using the freely available program Microsoft Access Runtime [91]. Both versions of the database can be browsed using the VIEW form or searched using the SEARCH form, which produces a list of studies that meet metadata criteria specified by the user. We also provide a Microsoft Excel version of this database (Additional file 15), but we recommend using the Access version if possible to more easily search for studies and view the metadata fields.

Population

Broad reviews could target the most well-studied taxonomic orders. Of the 40 avian orders in IOC World Birds List [92], 26 were included in the map at least once (Table 6). *Passeriformes* (perching birds) was by far the best studied order, followed by *Charadriiformes* (shorebirds and relatives) and *Procellariiformes* (petrels, shearwaters, and albatrosses). Migrating birds were recorded in 188 studies, with an additional 29 studying fledgling seabirds migrating to sea and 22 studying a mix of migrating and non-migrating birds (Additional file 12: Table S4). Most studies (377/490) involved wild species

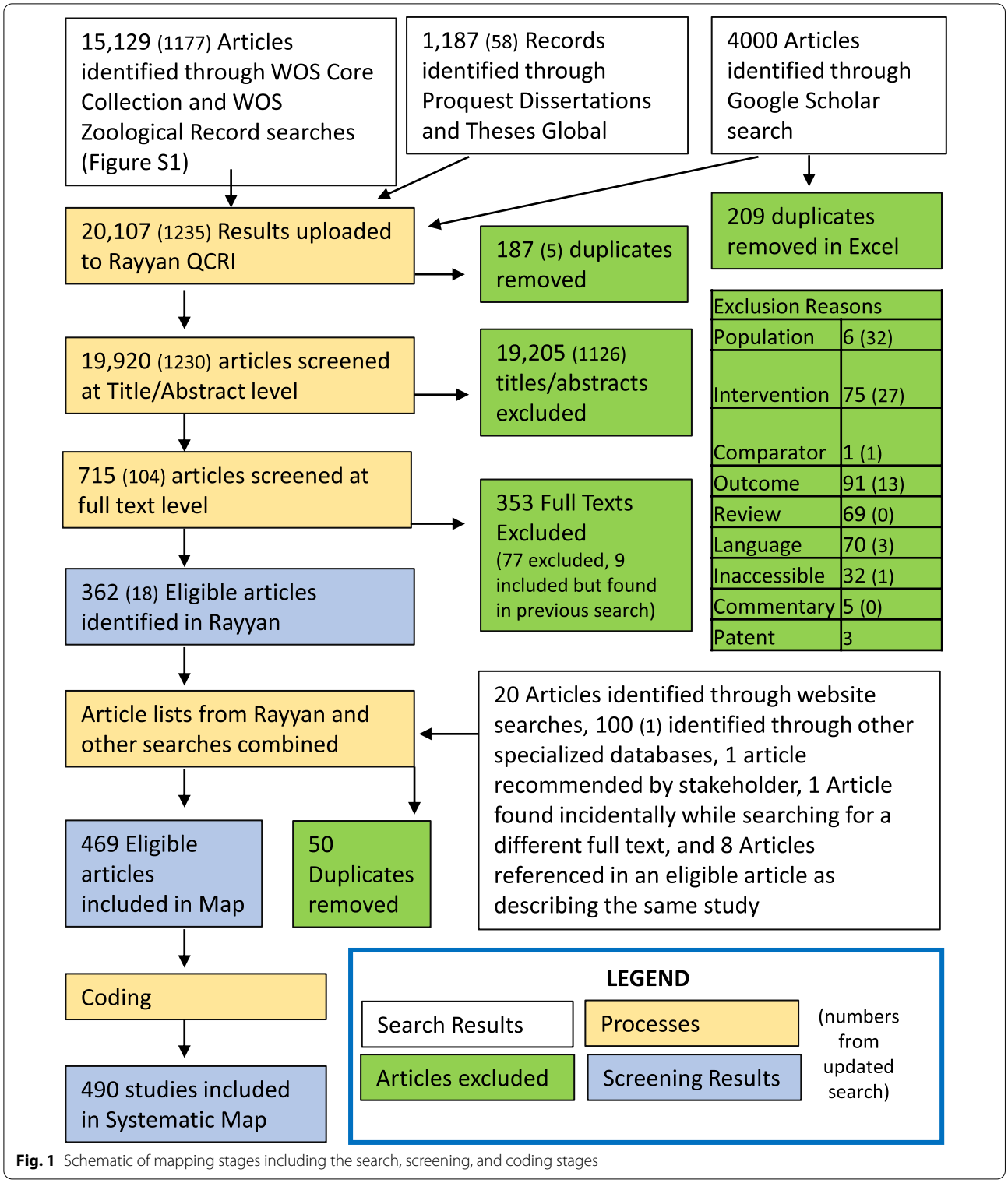

Fig. 1 Schematic of mapping stages including the search, screening, and coding stages

in the wild, while 81 studied wild species in captivity and 32 studied domesticated species (Additional file 12: Table S5).

Knowledge gaps may limit the application of these reviews for particular populations. Fourteen avian orders were never studied (Additional file 12: Table S6). Three of these orders are endemic to South America (e.g.

Table 3 Number of articles found in each search step

Source type	Captured articles	Eligible articles	Unique articles
Web of Science (Core Collection)	11,331 (1,028)*	136 (14)	136 (14)
Web of Science Zoological Record	6,353 (417)*†	205 (9)	199 (2)
Google Scholar	3,791*	22	19
Proquest Dissertations at Theses Global	1,187 (58)	8 (1)	8 (1)
Specialized Databases	4,734 (132)	100 (1)	60 (1)
Organizational Websites		17	10
Found Incidentally		19	19
	Total: 29,031†		Total: 469

* These represent the number of articles captured after pre-screening with Microsoft Excel Macros (Additional files 2 and 3) and removal of duplicates (Additional file 12: Figure S1)

† This is the number of articles captured from the Web of Science Zoological Record before removing articles also found in the Web of Science Core Collection (2555 such articles were removed in the original search, 149 in the updated search). After removing these duplicates, 26,208 articles were screened (21,342 in Rayyan, 4866 on websites or in downloaded documents).

Tinamiformes, Otidiformes, and *Musophagiformes*). More information on these orders may be available in Spanish or Portuguese, but our map only includes articles written in English. With only 18 studies conducted in the southwest quadrant of the globe (Additional file 12: Table S2), there is limited knowledge of how neotropical migrants respond to light during the non-breeding season, an important and understudied part of their life cycle [93] that can be key to increasing our understanding of bird collisions with buildings.

Exposure/intervention

There may be enough evidence to compare interventions/exposures that used well-studied wavelengths and flashing patterns and combinations of these two variables. The majority of studies (272/490) of continuous light were white or presumed white (described by study authors as white or presumed by the mapping team to be white based on context) (Fig. 3; Table 7). Continuous light was well-studied for other wavelengths visible to birds, including red (61), green (55), and blue (29). Only white and red were studied in more than 10 studies using flashing lights, while green, blue/green, and blue had 6, 6, and 8 studies, respectively. Rotating lights (a continuous light whose restricted visual angle rotates on a horizontal plane) were only included in 19 studies, but were likely also present in many of the 36 studies at lighthouses that were coded as UA (unavailable) because the text did not specify that the light rotated.

When identifying which light characteristics are important to study, it is important to consider the avian visual system. Orange, yellow, and UV or violet wavelengths were rarely studied (Table 7). UV and violet wavelengths are particularly important to consider for birds because some (but not all) bird species have a cone photoreceptor with peak sensitivity in the UV portion of the spectrum [86]. These wavelengths were only studied 13 times, and flashing UV or violet light was only studied three times. Different lamp types have distinct spectral compositions and flicker rates [94]. Birds have different spectral sensitivity and temporal visual resolution than humans [95, 96], so lamp types that all appear white to humans can appear distinct to birds [94, 95]. Only two studies using continuous light reported the flicker rate [97, 98]. Among the studies reporting lamp type, there were many using LED, Incandescent, Halogen, or Fluorescent bulbs for white lights (Table 8), providing an opportunity for review. A review comparing these lamp types could consider only white lights to avoid confounding lamp type with wavelength. Other lamp types that are commonly used for outdoor lighting were rarely recorded in our database, including Metal Halide, Mercury-Vapor, and Sodium Vapor [99], but were likely common in the 283 studies that did not report lamp type.

For wavelengths that were used in fewer than 5 studies (green/yellow, yellow/orange, and indigo), we recategorized them as the longer wavelength (yellow, orange, and blue) for this table and for all subsequent tables and figures. Wavelengths described by the article authors as turquoise were counted as blue/green.

Outcome

The fifty-five distinct outcome variables identified in our map demonstrate the diverse ways in which artificial light can change bird movement through space and distribution, with variety far beyond what we anticipated in our own systematic map protocol. We provide the first organized view of this literature, grouping outcomes into three categories (behaviour, distribution, and community) and eleven subcategories. This organization provides an easy way for map users to find evidence that documents particular outcomes or groups

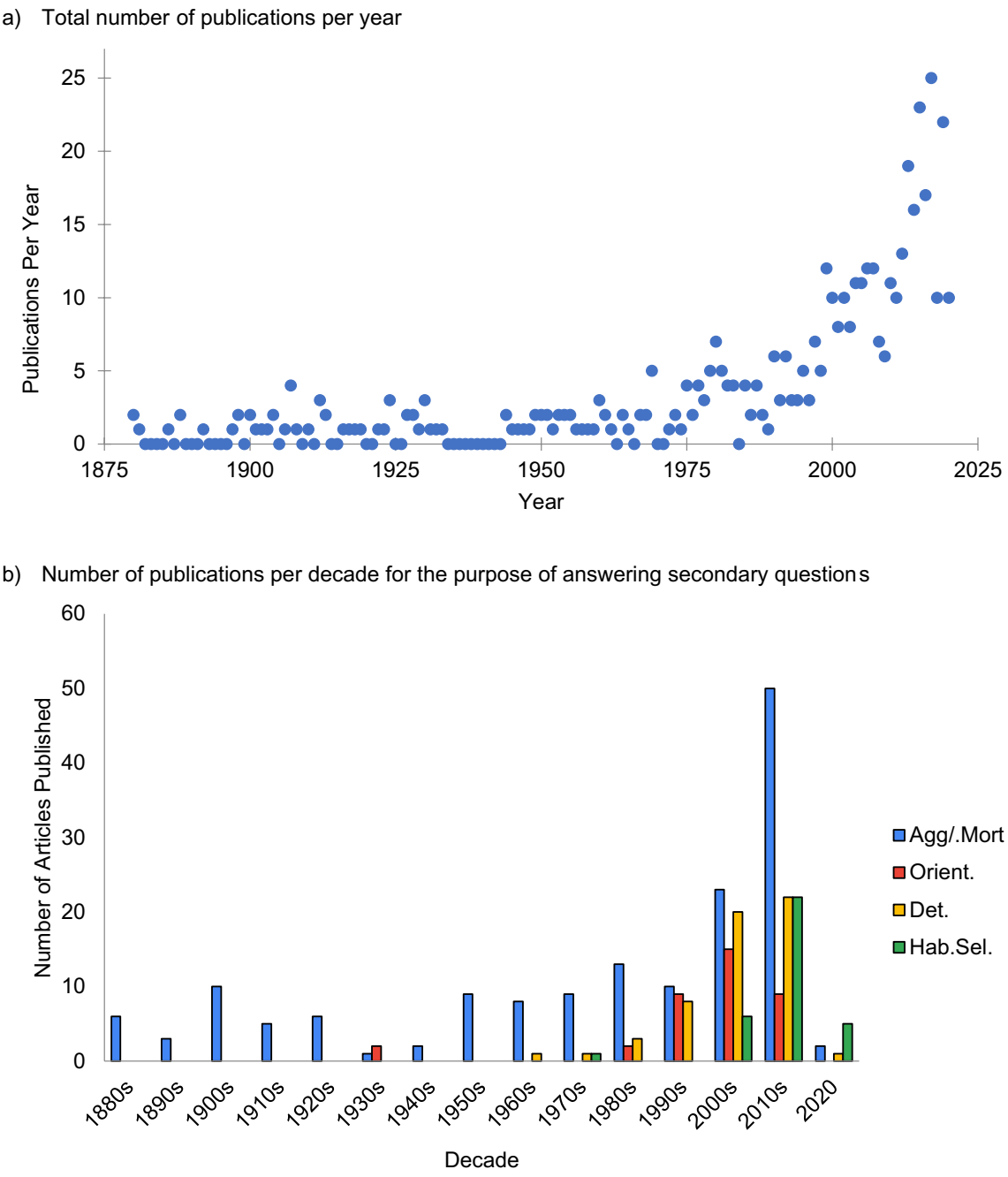

Fig. 2 Publication count over time

of outcomes. Within the behavioural outcome category, there were four subcategories showing distinct types of movement or behaviours preceding movement and each subcategory includes several outcome variables (Table 9). Outcomes related to behaviour or distribution were each recorded in well over 200 studies, while only five studies recorded the impact of artificial light on bird communities. In the behaviour category, flight path characteristics, approach or flee response, and orientation were well studied, while studies documenting alert behaviour were relatively rare. All subcategories in the distribution category contained at least 25 studies. While outcomes related to behaviour and distribution were well-studied, there is not enough evidence to

Table 4 The number of studies in each economic sector

Sector	Number of studies
Transportation	126
Urban/Suburban/Rural	123
Laboratory Behavioural Research	56
Wildlife Research	54
Food Production	52
Energy	47
Communication Towers	16
Recreation/Tourism	10
Human-wildlife Conflict—no sector specified	10
Natural Protected Area	8
Military	5
Zoos	4
Forestry	2
Port or Harbour	2
Waste Management	2
Mineral Mining	1

Table 5 The number of studies conducted for each study purpose

Purpose of study	Number of studies
Document and/or reduce bird aggregations or mortality	169
Deter birds	88
Document birds foraging under artificial light at night	47
Test ability to orient under artificial light conditions	40
Study effects of artificial light on bird distribution or habitat selection	40
Capture or count birds for wildlife research	38
Improve welfare or production of captive birds	36
Monitor or describe bird migration	35
Basic behavioural research	7
Study effects of artificial light on bird community	4
Document occurrence of a rare species	3
Study weight loss during nocturnal migration	2
Document unusual bird behaviours	2

inform conservation initiatives targeting avian community outcomes, such as species richness or functional diversity.

Mapping the quantity of evidence relevant to each secondary question

Our second objective was to provide an evidence base for four secondary questions with conservation and management importance, identifying relevant evidence based on objective PE/ICO criteria rather than the authors' purpose for conducting the study (Table 2). Evidence for each question can be found using the *Secondary Questions* tab on the *SEARCH* form in our Access database (Additional files 13 and 14).

This interdisciplinary approach expanded the quantity and diversity of evidence for each question by including studies that were conducted for many different purposes. For example, evidence relevant to our secondary question about habitat selection came from 30 studies whose purpose was to improve welfare or production of captive birds and five studies conducted to deter birds (Additional file 12: Table S7). Evidence relevant to our secondary question about deterrence included 84 studies whose purpose was to document and/or reduce bird aggregations or mortality and 34 studies that captured or counted birds for wildlife research (Additional file 12: Table S7). By considering all studies with relevant populations, exposures/interventions, and outcomes—rather than only considering studies that describe bird responses as attraction, deterrence, or habitat selection—reviews can draw on a broader evidence base with a greater diversity of bird species and light characteristics.

All four of our secondary questions received considerable study constituting evidence clusters, but aggregation/mortality, deterrence, and habitat selection were studied more than disorientation and attraction (Table 2). Below, we describe the evidence clusters and knowledge gaps within each secondary questions and explain their importance from perspectives of conservation, management, or basic science.

What information is available documenting that birds in flight aggregate around and collide with artificial lights or structures with artificial lights?

Hundreds of papers documented bird aggregation or collision mortality in association with artificial light. There may be sufficient literature for a review to identify weather or lunar conditions or light characteristics that are associated with high probability or intensity of aggregation and mortality events, helping to target light reduction efforts on nights with those conditions. Such an analysis is likely possible because 75 studies made observations under multiple cloud cover/visibility conditions (Table 10) and 36 studies observed bird aggregation/mortality under multiple lunar phases (Table 11). The lunar phases in other studies could be calculated based on locations and dates. A more accurate representation of lunar illumination could include illuminated fraction and elevation, in addition to atmospheric conditions [100].

Table 6 Orders included in studies relevant to the primary question and each secondary question

Order	Description	Primary question	Aggregation/ mortality	Disorientation	Attraction	Deterrence	Habitat selection
Passeriformes	Perching birds	258	141	33	14	118	36
Charadriiformes	Shorebirds and relatives	87	50	0	6	56	9
Procellariiformes	Tube-nosed seabirds	63	54	0	3	22	6
Galliformes	Landfowl	44	7	2	0	18	22
Anseriformes	Waterfowl	43	14	0	3	37	4
Gruiformes	Diverse terrestrial and marshbirds, including rails, cranes, and others	27	18	0	1	21	0
Pelecaniformes	Ibis, herons, pelicans, and others	23	11	0	0	11	2
Columbiformes	Pigeons	18	6	3	0	6	3
Falconiformes	Falcons	16	7	0	1	5	3
Suliformes	Frigatebirds, cormorants, anhingas, and boobies	14	7	0	3	10	1
Caprimulgiformes	Nightjars	14	5	0	0	2	4
Accipitriformes	Raptors including new world vultures	14	7	0	3	6	3
Strigiformes	Owls	12	5	0	0	3	5
Podicipediformes	Grebes	9	6	0	0	6	0
Sphenisciformes	Penguins	8	1	0	0	2	7
Coraciiformes	Kingfishers and allies: rollers, todies, motmots, bee-eaters	6	3	0	0	1	1
Apodiformes	Owlet-nightjars, treeswifts, swifts, hummingbirds	5	0	0	0	0	1
Cuculiformes	Cuckoos	4	3	0	0	1	1
Gaviiformes	Loons	3	1	0	0	3	0
Ciconiiformes	Storks	3	1	0	1	1	0
Piciformes	Woodpeckers and allies	2	1	0	0	0	1
Apterygiformes	Kiwis	2	0	0	0	0	2
Pterocliformes	Sandgrouse	2	0	0	0	1	1
Psittaciformes	Parrots	2	0	0	0	0	2
Rheiformes	Rheas	1	0	0	0	1	0
Bucerotiformes	Hornbills, hoopoes, wood hoopoes	1	1	0	0	0	0

Order descriptions based on the IOC World Bird List [92]

A review of the evidence in this map could support or amend current recommendations for flashing instead of steady-burning lights (e.g. US Federal Aviation Administration [101] and Bureau of Ocean Energy Management [102]) and add details to these recommendations by determining how flashing rate influences bird response. International standards require that communications towers and other obstructions install combinations of red or white and flashing or continuous lights [103], and these towers are a significant source of mortality for birds [32]. Twenty-five studies included both red and white lights within the same study, and 25 included both continuous and flashing or rotating lights, providing an opportunity to compare the effects of these wavelengths or flashing patterns on bird aggregations and mortality when other conditions were held relatively constant.

There is insufficient evidence to compare the effects of different types of white light and few studies on wavelengths other than red. Most studies in this evidence base do not describe the spectral compositions of white light, and only 33 describe the type of light bulb used. In circumstances that require steady-burning white light (e.g. office towers, illuminated monuments, and airfield runway lighting), there may be an opportunity to change the spectral properties of white lights to reduce bird aggregation and mortality. Light of wavelengths other than red should also be studied because international standards require yellow and blue lights for mobile obstacles [103] and many other wavelengths are used for decorative lighting on bridges and buildings. In the evidence base for this secondary question, the green and blue each have only 7 studies each, while yellow and UV each have even fewer (Fig. 3).

There is also a knowledge gap concerning the relative danger of structures with flashing lights compared to unlit structures. Studies in the deterrent literature used

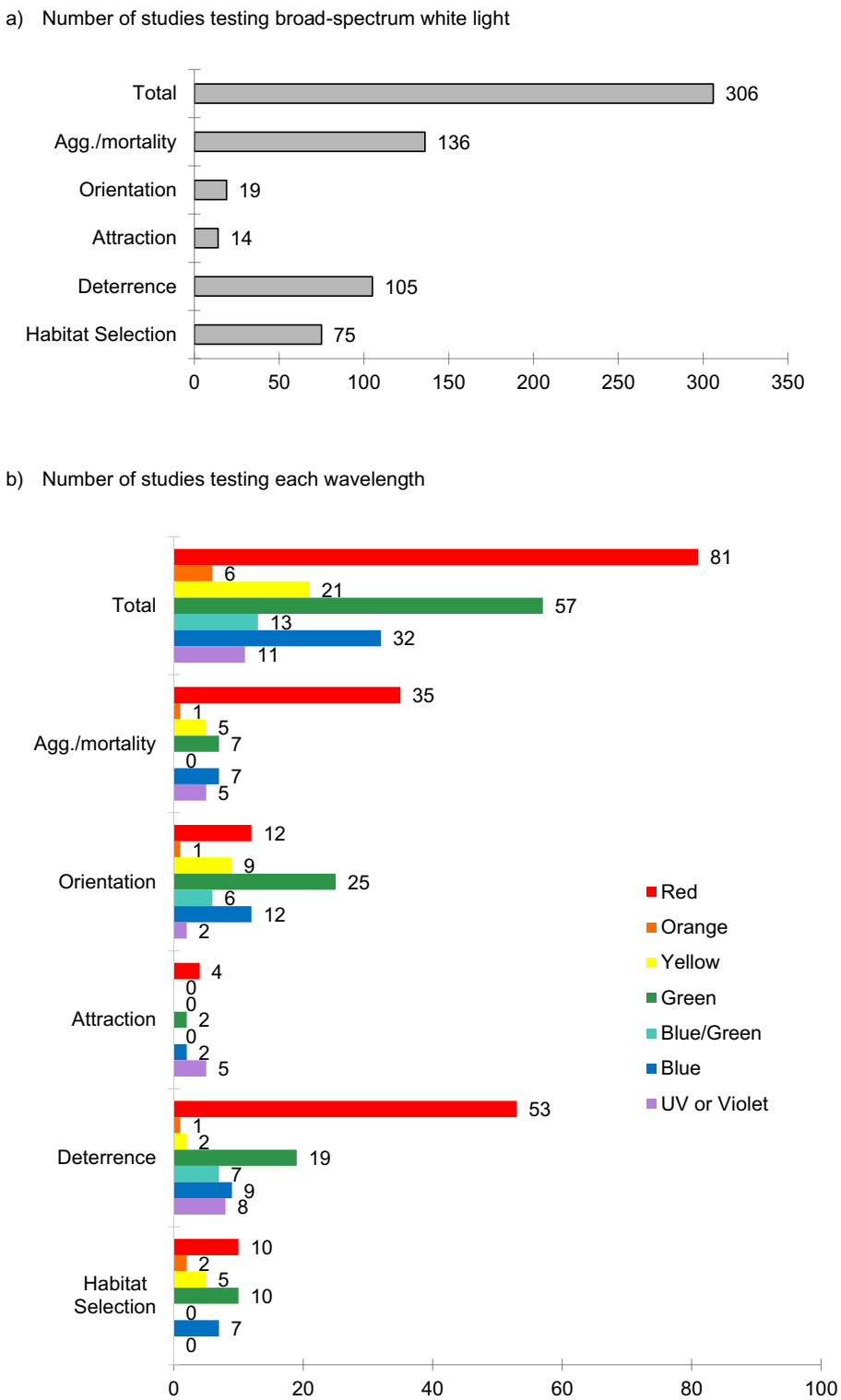

Fig. 3 Number of studies testing each wavelength of light in the evidence base and for each secondary question

Table 7 Heat map showing the number of studies including interventions/exposures with each light wavelength, flashing pattern, and combinations of wavelengths and flashing patterns

Wavelength	Total Number of Studies	Continuous	Flashing	Rotating	Simultaneous flashing and continuous lights	Unavailable
White or Presumed White	309	272	32	14	9	11
Infrared	1	1	0	0	0	0
Red	86	61	19	7	15	3
Orange	6	6	1	0	0	0
Yellow	22	20	2	0	0	0
Green	59	55	6	0	0	0
Blue/Green	13	13	6	0	0	0
Blue	33	29	8	0	0	1
UV or Violet	13	9	3	0	2	0
UV+	10	10	0	0	0	0
Flame	10	10	0	0	0	0
Unavailable	92	26	13	6	2	54
	TOTAL	*378*	*57*	*19*	*19*	*67*

Blue shading represents the number of studies with each wavelength, from 1(light blue) to 309 (dark blue). Yellow/red shading in columns three through seven represents the number of studies with each wavelength/flashing pattern combination, from 1 (pale yellow) to 61 (red). The *TOTAL* row shows the number of studies with each flashing pattern. The total is less than the sum of the columns because some studies included multiple wavelengths. UV + treatments added UV wavelengths to broad spectrum white light

Table 8 Number of studies including each lamp type

Lamp type	All	White or presumed white	Aggregation/ mortality	Causes of aggregation/mortality		Deterrence	Habitat selection
				Attraction	Orientation		
Unavailable	285	202	165	13	8	135	42
LED	72	38	16	6	28	20	18
Laser	45	0	0	0	0	45	1
Incandescent	37	35	8	1	7	11	16
Halogen	27	21	9	2	5	13	4
Fluorescent*	21	20	4	0	1	2	13
Flame	15	3	15	3	0	5	0
Sodium Vapor (Low or High Pressure)*	11	10	7	0	0	1	2
Mercury-Vapor*	9	6	6	0	0	5	0
Metal Halide*	8	8	6	0	0	1	1
Xenon	3	2	1	1	2	0	0
Electric Light (type UA)	3	2	3	0	0	2	0
Neon	1	1	0	0	1	0	0
Multi-metal Vapor	1	1	0	0	0	0	1
Magnesium	1	1	1	1	0	1	0

Table shows the number of studies testing each lamp type in the whole evidence base, for all studies testing white light (or light presumed by the mapping team to be white), and in the evidence base for each secondary question

*Dominant lighting types for older streetlights and other outdoor lighting [82]

flashing lights or UV lights to attempt to prevent collisions by increasing the bird's ability to detect an object in its path (e.g. [104]), but there have been no studies comparing collision rates at tall structures with unlit control structures. Most tall structures require aviation safety lights, but new technology may permit unlit structures by using radar detection to turn on obstruction lighting only when an aircraft approaches [105]. While structures

Table 9 Counts of Outcomes, Outcome subcategories, and Outcome Categories

Outcome category (count)	Outcome subcategory (count)	Outcome	Study count
Behaviour (229)	Alert behaviour (9)	Other alert response	6
		Overt reaction distance	2
		Alert reaction time	1
	Approach or flee response (67)	Flying	31
		Capture of birds on the ground or water	28
		Flush (unspecified)	23
		Immobilization	16
		Diving	12
		Running or walking	10
		Unspecified	8
		Distance moved	5
		Other flee response	3
		Swimming	3
		Head movement	2
	Flight path characteristics (123)	Circling, hovering, or other description of "attraction"	77
		Observations of bird collisions	50
		Altitude	19
		Direction	13
		Linear/non-linear flight path	12
		Velocity	7
		Change in flight direction relative to light source	5
		Capture of birds in flight	4
		Distance of flight path from light source	2
		Distance travelled	2
		Modeled flight behaviour based on observations of bird locations or distributions	2
		Other flight behaviour	2
	Orientation behaviour (40)	Ability to orient in migratory direction	32
		Ability to locate reward	3
		Other orientation behaviour	3
		Homing	2
Community (5)	Composition (3)	Abundance of species grouped by type	2
		Stability	1
	Diversity (5)	Species richness	5
		Beta diversity	1
		Evolutionary distinctiveness	1
		Functional diversity	1

Table 9 (continued)

Outcome category (count)	Outcome subcategory (count)	Outcome	Study count
Distribution (372)	Bird counts (140)	Abundance or density	101
		Presence/absence	40
	Bird locations (26)	Locations of individual birds	12
		Locations of nests	5
		Locations of roosts or groups of birds	3
		Light exposure of tracked individuals	3
		Mean or median light exposure of a species	2
		Proximity of dead or injured birds to artificial light sources	1
	Mortality (150)	Counts or presence of dead or injured birds	134
		Locations of dead or injured birds	10
		Absence of bird deaths or injuries	5
		Seabird bycatch	5
		Type of mortality observation UA	5
	Preferences (61)	Free choice (time spent in each lighting option)	46
		Discrete choice (instantaneous choice among lighting options)	15
	Presence of foraging birds (56)	Multiple individuals foraging under artificial lights	38
		One individual foraging under artificial lights	12
		Amount of food consumed	4
		Number of foraging events (individuals not distinguished)	3
		Arrival or departure time of foraging birds	2

Numbers in parentheses show the number of studies in each outcome category and outcome subcategory

without lighting may cause less attraction or disorientation, birds will not be alerted to the presence of dark structures in their flight path [106]. Before this new technology is adopted, it will be important to compare bird mortality at dark structures to structures with various types of lights, particularly flashing or UV lights that are sometimes used as deterrents.

Table 10 Cloud Cover/Visibility in studies relevant to aggregation/mortality

Cloud cover/visibility	Study count
Only clear days/nights	6
Only cloudy days/night	29
Varied—descriptive	31
Varied—events only	17
Varied—events only and descriptive	2
Varied—systematic	25
UA	107

Cloud Cover/Visibility was coded as *Varied—systematic* if it was recorded at regular intervals throughout the study period. It was coded as *Varied—events only* if it was only recorded during aggregation/mortality events and *Varied—descriptive* if authors described in general terms the conditions under which aggregation/mortality were most likely to occur

Table 11 Lunar phase in studies relevant to aggregation/mortality

Lunar phase	Study count
New	3
Full	0
In between	1
Varied—systematic	26
Varied—descriptive	7
Varied—events only	2
Varied—other	1
UA	176

Lunar phase was coded as *Varied—systematic* if it was recorded at regular intervals throughout the study period. It was coded as *Varied—events only* if it was only recorded during aggregation/mortality events and *Varied—descriptive* if authors described in general terms the conditions under which aggregation/mortality were most likely to occur

What evidence exists on aggregation and mortality as a result of attraction and/or disorientation?

While many authors assume that aggregations and mortality result from attraction, we only identified 26 studies with response variables that could suggest attraction (Table 2). By definition, these studies can also suggest deterrence if birds fly away from the light source. A review could describe whether birds show opposing responses depending on light characteristics (e.g. moving v. stationary, flashing v. continuous). Identifying where attraction occurs and the mechanism of attraction could help design lighting that is safer for birds. However, the relatively small number of relevant studies limits the potential for review, with only 14 studies including white light, 5 including UV/violet, and even fewer studies including red, green, or blue wavelengths (Fig. 3).

To conclusively demonstrate attraction to light, birds must be given a simultaneous choice between light treatments when all other conditions are identical (i.e., choice tests, [107]). Only one study used a controlled choice test on birds in flight [97] (Additional file 12: Table S8). Two studies modeled flight behaviour based on observations of bird locations or distributions [31, 33], but did not directly observe their flight paths. Twenty-three studies recorded a change in altitude, flight direction relative to a light source, or capture of birds in flight, but did not offer simultaneous choice. Further choice tests could determine the light characteristics and ambient conditions under which attraction is most likely to occur, with relevance for both reducing attraction and more effectively deterring birds.

Birds flying around lights (e.g. circling, fluttering, hovering) may be disoriented, but only one orientation mechanism has been extensively tested. Thirty studies tested bird magnetoreception (Additional file 12: Table S9), and a review concluded that birds cannot perform magnetoreception in the complete absence of short-wavelength light from UV to green (565 nm) [49]. Some conservation biologists have speculated that the long wavelengths in broad-spectrum (i.e. white) light disorient birds by interfering with magnetoreception [73], but a review of laboratory research concluded that birds orient appropriately under broad-spectrum light that contains these wavelengths [49]. It is unclear whether birds can perform magnetoreception under all types of white light because only incandescent, halogen or xenon white lamps were tested in the twelve magnetoreception studies using white light (Additional file 12: Table S10). These lamps have broad emissions spectra, while other lamp types (e.g. metal halide and some LEDs) have distinct spectral peaks [99]. These spectral peaks may interfere with magnetoreception, as is the case for monochromatic and bichromatic light [49, 108]. Two magnetoreception studies did not report the direction of the light, and the remaining 28 used overhead lights to illuminate Emlen funnels [109], mazes, or cages. These conditions differ from the built environment that birds experience on migration, where light intensity can vary across a bird's visual field (e.g. when flying in or above cities).

Loss of a single orientation mechanism may not disorient birds because the aviation orientation system includes redundancy [39]. Only eight studies tested how artificial light interferes with orientation mechanisms other than magnetoreception, including the disorienting effects of horizon glow (3), clock-shifts (3), and photoperiod changes (2) (Additional file 12: Table S9). None tested the impacts of skyglow or satellite clusters on the ability for birds to orient using their stellar compass. Together, conservation biologists and sensory ecologists should collaborate to design studies that fill these knowledge gaps and determine how the many types of artificial light common in the built environment interfere with some or all of birds' orientation mechanisms.

What information describes the effect of light as a means of deterring or dispersing birds?

Lasers formed the most promising evidence cluster for meta-analysis of studies specific to deterrent efficacy, while spotlights and flashing lights could be reviewed while including studies documenting bird aggregation, deterrence, and capture. A review might include red, green, and blue green lasers (studied 21, 10, and 7 times, respectively), while blue and violet were each studied only once (Additional file 12: Table S11). Forty of the 42 studies using lasers measured an approach or flee response, offering a common set of outcomes on which to base a meta-analysis. A meta-analysis of laser efficacy would be particularly useful because they are commonly sold as bird deterrents and were by far the most common type of light-based deterrent in our map (Table 12).

For flashing lights and spotlights, including evidence from studies with other purposes increased the size of the evidence base (Table 12). A review of bird response to flashing lights and spotlights would have applications for reducing aggregations, improving deterrents, and capturing wildlife. Spotlights were commonly documented in the aggregation/mortality literature, primarily at lighthouses, and in studies whose purpose was to capture birds for wildlife research (Table 12). When capturing birds, many authors recorded whether each species would typically flee or freeze in response to the spotlight. With the 21 taxonomic orders studied at least once in the spotlight studies, there may be an opportunity to investigate which species traits impact the efficacy of spotlights as deterrents or trapping tools. We did not record the characteristics of the spotlight used (e.g. light

intensity, beam angle, predictability of movement) in this map, but a review could compare these characteristics to identify important predictors of bird responses. Deterrent efficacy may depend on ambient light levels, which change over the course of the day [27]. The evidence base may support a review of this topic, with 23 studies that applied the intervention/exposure at multiple times of day, 18 studies conducted only during the day, and 72 studies conducted only at night (Additional file 12: Table S12).

More research is needed on ultraviolet and violet light as a deterrent and the potential for light-based deterrents to reduce bird collisions or entanglement in wires and lines. UV or violet light was only tested in 8 studies in the deterrence evidence base (Fig. 3), and only once for lasers (Additional file 12: Table S11). Orange and yellow were included in fewer studies, UV/violet could be a particularly important knowledge gap because many bird species have a cone receptor with peak sensitivity in the UV or violet portions of the spectrum [96]. For example, a vision model indicated that light peaking in the UV/violet range (380–400 nm) would be most visible to Canada Geese (Branta canadensis), which are common targets of laser deterrent efforts, under a specific set of visual conditions (i.e., certain objects with specific types of illumination) [76]. In general, deterrent studies would benefit from more information about the spectral sensitivity of target species [53]. In addition to alerting birds to approaching vehicles or dispersing birds from zones of human-wildlife conflict, light-based deterrents were used in a few cases to increase awareness of stationary obstacles like power lines [104] and fishing lines [110–112]. More research is needed to determine what types of lights are effective for warning birds about obstructions without inducing bird aggregations [106, 113]. Like attraction, the strongest evidence for deterrence comes from controlled choice tests, but these were rare. Eighteen studies, coming from only seven unique articles, conducted choice tests using light sources typically used as deterrents (lasers, UV/violet lights, flashing lights, or spotlights) (Additional file 12: Table S13). Choice experiments could greatly improve our understanding of the potential for different types of light to attract or deter birds and how the effects depend on species, light characteristics, and context of the intervention/exposure.

What evidence exists on continuous artificial illumination changing bird habitat selection for activities other than flight?

A review of the 88 studies for this secondary question would include 20 different bird orders, providing an opportunity to examine how life history or physiological traits influence selection for or avoidance of artificially illuminated environments. Examples of traits that could influence whether a species prefers or avoids artificially illuminated habitat patches include eye morphology [114], nocturnality [2], and foraging strategy [13]. Much of the continuous illumination experienced by birds in the wild comes from outdoor lighting like streetlights and illuminated signs, which are rapidly converting from older technology to LED [1]. To study whether LEDs have different effects on habitat selection than other types of white light, a review could compare the results of studies using fluorescent, incandescent, and LED lights (each studied at least 13 times, Table 8). However, such a review may be limited because LEDs can have varying spectral properties and the spectral power distribution of any light is rarely described. A few studies tested blue, green, and red light, providing further opportunity to review how birds respond to different parts of the visual spectrum (Fig. 3). Because study design varied widely across the evidence base, a review of the impacts of artificial light on bird habitat selection must incorporate multiple study designs to include sufficient evidence for meaningful inference. Seven studies measured relative abundance, while 16 modeled probability of selection

Table 12 Number of studies documenting bird response to each deterrent type

Deterrent type	Number of studies using deterrent type to deter birds	Total number of studies documenting bird response to deterrent type
Laser	46	46
Flashing light	23	68
Spotlight	11	158
UV or near-UV light	7	9
Line markers	4	4
Pyrotechnic	1	1

The first column shows the number of studies using each deterrent type to intentionally deter birds. The second column shows the number of studies documenting bird responses to each deterrent type with outcomes that could demonstrate deterrence, regardless of the purpose for which the study was conducted

or occupancy (Additional file 12: Table S14). Nineteen studies used other types of control/impact, before/after, or gradient designs. The 43 preference tests could form an evidence cluster, but 20 of these tested domestic poultry species, which may have little application to wildlife [115]. While incorporating diverse study designs expands the evidence base, it may limit the comparison of results across studies.

For habitat selection, knowledge gaps remain for non-passerine species, many lamp types commonly used for outdoor lighting, and different spectral properties in LED lamps. Only *Passeriformes* (perching birds), *Galliformes* (landfowl), *Procellariiformes* (tube-nosed seabirds, including petrels, shearwaters, and albatrosses), and *Charadriiformes* (shorebirds and relatives) were studied more than five times, limiting the ability to predict how other taxonomic orders will respond to the global increase in ALAN (Table 6). As older street lamps are converted to LED, the choice to convert and the type of LED chosen will alter the night-time environment for decades to come, potentially changing both the sensory experience and prey availability for birds [14, 116–118], which may impact their habitat selection. LED lamps vary in their spectral properties and intensities even within comparable costs and energy efficiencies [116], so there may be opportunities to choose lights that are less likely to impact bird habitat selection while keeping costs low. We found that there is little evidence on the impacts of different types of white light on bird habitat selection, with very few studies using lamp types common for older streetlights and outdoor lighting (Table 8) and none reporting the spectral power distributions of white light.

Habitat selection is a particularly important domain for understanding the effects of artificial light on birds because it has widespread implications for both management and conservation. Changing or reducing artificial light can discourage birds from settling in areas where they pose a danger or nuisance to humans. For example, three studies in our map showed how artificial light levels can influence roost site selection for nuisance species in urban environments [119–121]. Another study changed the colour of runway lighting to reduce insect attraction, thereby reducing the number of birds on the runway [122]. From a conservation perspective, understanding the impacts of ALAN on habitat selection can help target light abatement efforts towards species that are most negatively impacted. As ALAN increases, species that avoid using illuminated areas will suffer reduced habitat availability regardless of whether habitat quality is affected. Species that select artificially illuminated habitat despite low reproductive success may face ecological traps and population declines [71]. The evidence in this map can identify loss in habitat availability and potential ecological traps, but does not include evidence of ALAN's effects on bird fitness other than collision mortality. Reviews or further research should also consider additional metrics (e.g. survival or reproduction rates) when evaluating the ecological impacts of artificial light on birds [57].

Mapping the quality of evidence

Further critical appraisal is necessary to determine the number of articles that could be included in systematic reviews. Requiring a comparator would disqualify approximately a third of the evidence in the map, and further critical appraisal may reduce the evidence base. To aid users in assessing how many studies are likely to pass critical appraisal and determining if there is sufficient evidence for a systematic review, we coded each study's control design in the database and wrote a description of the control treatment.

The majority of studies included a comparator, with light characteristics (e.g. presence/absence, intensity, wavelength, polarization, total illuminated area) varying across treatment periods or sites in 290 of 490 studies (Additional file 12: Table S15). The remaining 200 studies had no comparator but offer evidence of bird response to light if certain assumptions are accepted about bird behaviour or distribution in the absence of artificial light (Additional file 12: Table S15). For example, reports of birds aggregating around artificial light sources attribute the aggregations to the presence of light, assuming that aggregations did not occur in unilluminated areas. Fifty-one behavioural assays recorded bird behaviour only when the light treatment (e.g. lasers or spotlights) was applied, assuming that birds did not flee in the absence of a light treatment (Additional file 12: Table S16). Other studies did not include a control treatment for light, but included controls with respect to other variables and tested whether the effect of light on bird behaviour or distribution depends on other factors (e.g. recording the number of birds aggregating at the same light source under varying weather conditions [123]).

Limitations of systematic map

We strove to find all available evidence and our bibliographic checking confirmed successful realization of that goal for the contexts of bird disorientation, deterrence, and habitat selection. However, we missed about one third of articles that documented aggregation/mortality at illuminated structures. Finding all of the eligible articles indexed in the Web of Science Zoological Record that don't reference light in their topic fields would require screening more than 50,000 additional records, which would delay the publication of this map by many

months or years. Our systematic search found all references where light was emphasized by the authors as a main contributor to aggregation or mortality in their title, abstract, or keywords. Our search may be biased towards articles that investigated light or assumed light to be a factor contributing to aggregation or mortality, but not articles whose authors considered light irrelevant.

Our search may also have a geographic bias towards North America. We only included articles written in English, which may have contributed to the low number of studies found from South America. Most of our stakeholders were located in North America.

In our Review Findings, we discuss the limitations of the primary evidence base, which limits the potential for further synthesis or evidence-based management. For example, there were 14 bird orders that were never studied, and most studies using white light did not report lamp type or information on spectral composition. Over forty percent of studies in the systematic map lack a control, with this proportion rising to fifty percent in studies relevant to bird deterrence. Many studies reported changes to bird behaviour and distribution, but distribution data were rarely used to quantify species richness or other community outcomes (Table 9).

Where metadata were not possible to code quantitatively or categorically, we described them narratively, and further categorization or unit conversion will be required before conducting a quantitative review or meta-analysis. For example, we categorically coded whether cloud cover/visibility varied within a study, but we narratively reported the cloud cover/visibility values provided by each study's author. These values included proportion cloud cover, visibility distance, clear v. cloudy, and narrative descriptions of how bird behaviour was affected by weather conditions. Lack of detail on weather conditions in many studies limits the potential for reviewing how weather affects bird responses to light. Similarly, we reported light intensity in the units provided by the authors because the variety of units they used (e.g. lux, watts per meter squared, candlepower, candela, nanowatts per square centimetre steridian) are not easily converted to a common unit. The values we reported for light intensity included measurements of brightness, radiance, irradiance, and radiant flux. Further unit conversion and study eligibility screening will be required before comparing bird response across varying light intensities.

Finally, a year has passed between our updated systematic search of the literature and the completion of the map, during which more literature accumulated that we did not assess. The enormous time commitment required of systematic maps and reviews appears to impose a similar limitation on other authors. Creating this database was a substantial effort, involving over 900 hours of work by the authors and an additional 1,500 hours by volunteers. Updating the database would require significant time and funding.

Conclusion

Our systematic map provides a comprehensive database spanning many human applications of artificial light, countries, bird species, and types of light sources. As scientific research grows exponentially [124], the breadth and depth of human knowledge increases, but finding and comprehending all the available evidence on a broad topic becomes more difficult. The number of search results generated by our search string in the Web of Science Core Collection has nearly doubled over the past 10 years, from approximately 6,500 in 2011 to over 12,500 in 2021. Our inclusive search string and use of specialized databases and websites provided a much more comprehensive evidence base than could be gathered with a basic search of popular databases, such as Google Scholar and Web of Science. Even our own systematic search of these databases found only 75% of the articles that were ultimately included in this map (Table 3). Our systematic map provides an evidence base that can be searched based on dozens of metadata fields. We hope others will use our systematic map to find evidence relevant to biological and management questions and write reviews, make policy decisions, and target research towards under-studied topics.

Implications for syntheses to inform policy/management

Using our database, we identified several key evidence clusters with important conservation and management implications that could be prioritized for review. For aggregation and mortality, a subsequent review could study the effects of cloud cover/visibility and lunar phase on bird aggregation and mortality to predict when mortality events are likely and recommend that lights be turned off or dimmed at these times. Another review in this context could identify obstruction lighting characteristics (specifically contrasting red v. white light and flashing v. continuous light) that reduce bird mortality from collisions with tall structures while meeting international standards for aviation safety [88]. For deterrence, the efficacy of red and green lasers could be evaluated in a meta-analysis to provide guidelines for choosing among the most commonly sold lasers. For habitat selection, a review could determine if birds respond differently to white lights produced by halogen, fluorescent, and LED lamps with diverse spectral properties [99]. It may also be possible to review how life history or physiological traits,

such as foraging strategy or eye-size [13, 114], predict species responses to light (Additional file 16).

Implications for further laboratory or field research

We also identify knowledge gaps with conservation and management implications that require further laboratory or field research. Considering that light may cause birds to aggregate around structures with artificial lights [28], but can also increase birds' ability to detect and avoid obstacles [54], field studies should investigate whether turning off all light reduces bird mortality at communication towers and other obstructions. The safest lighting options might maximize detectability while minimizing attraction. Choice tests could determine which combinations of wavelengths and flashing rates attract or deter birds, informing efforts to deter birds from zones of human wildlife conflict and reduce collisions. Further research should test deterrents that use UV lights for those bird species that can see in the UV portion of the spectrum. Orientation research should test magnetoreception under artificial light conditions typically experienced by birds in the wild and determine whether artificial light interferes with other orientation mechanisms, especially the stellar compass. We also recommend comparing the effects of different lamp types on bird aggregation/mortality, habitat selection, and orientation. Testing varying spectral properties of LEDs is particularly important to inform lamp choice as older obstruction lighting and streetlamps are replaced [1].

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s13750-021-00246-8.

Additional file 1. ROSES form.pdf contains our ROSES form.

Additional file 2. WOS search strategy.doc is a detailed explanation of our Web of Science search and pre-screening strategies

Additional file 3. WOS Search Records.zip is a compressed folder containing the results of our Web of Science searches. WOS_CC_Long_String_Search_Results.xlsm is a record of our search in Web of Science Core Collection using the expanded population search string, before any macros were applied. WOS_CC_Short_Search_Results.xlsm is a record of our search in Web of Science Core Collection using the shorter population search string, before any macros were applied. Applying_No_A_or_K_Macro.xlsm contains the macros used to identify articles in our Web of Science Core Collection search results indexed without abstracts or keywords and add those search results to the search results that used the short search string, and shows the results of applying those macros. Applying_Replace_Terms_Macro_CC.xlsm contains the macros used to identify articles that only used an intervention/exposure search term in an irrelevant context and shows the results after removing those articles. WOS_CC_for_Rayyan .csv contains the results of the pre-screened Web of Science Core Collection search, formatted for upload to Rayyan QCRI. WOS_ZR_Search_Results.xlsm is a record of our search in Web of Science Zoological record, before any macros were applied. Applying_Replace_Terms_ZR.xlsm contains the macros used to identify articles that only used an intervention/exposure search term in an irrelevant context and shows the results after removing those articles. Applying_Remove_dups_ZRCC.xlsm contains the macros used to remove articles that were found in both the Core Collection and the Zoological Record from the Zoological Record search results. WOS_ZR_for_Rayyan.csv contains the results of the pre-screened Web of Science Zoological Record search, formatted for upload to Rayyan QCRI. Documents in the folder Web of Science Core Collection Updated Search and Web of Sciences Zoological Record Updated Search show the equivalent information for the updated searches. Documents in the folder Blank Macro Workbooks are blank macro-enabled workbooks that can be used to apply our macros to any Web of Science Core Collection or Zoological Record search results.

Additional file 4. Database_Search_Records.xls contains several sheets. The first sheet shows the database search records (date of search, screening platform, search string). The other sheets show the articles identified as potentially eligible at the title/abstract screening level, and reasons for exclusion if they were found ineligible at the full text level.A compressed file of PDFs and .doc files containing the raw search records is available upon request.

Additional file 5. Website_Search_Records.xls contains three sheets. The first sheet lists the website searched the search string used in Google or the URL of each page within the website that was searched. The second sheet lists the number of eligible articles found on each website. The third sheet lists the URLs of articles found eligible at the title/abstract level, the exclusion reasons for any articles excluded at the full text level, and the citations for any articles found eligible at the full text level.

Additional file 6. Google_Scholar_Search_Results.xls contains multiple sheets. The first sheet shows the combined results from the Google Scholar searches after removing duplicates and formatting them for upload to Rayyan QCRI. The other four sheets show the raw Google Scholar search results, before removal of duplicates.

Additional file 7. Bibliographic_Checking.xls has several sheets. On the READ ME sheet, we explained how we selected reviews for bibliographic checking and describes our scoring system. All_Reviews_From_Rayyan lists all articles found ineligible at the full text level because they were reviews. This sheet also contains the scores assigned to each review. Reviews_for_biblio_checking lists the reviews selected for bibliographic checking. The next 5 sheets list all of the relevant references found in each review and whether or not they were found by our search. The final sheet shows the reasons why some of the references in the review of aggregation/mortality were missed.

Additional file 8. Explanations of Eligibility Criteria.doc provides a detailed explanation or our eligibility criteria.

Additional file 9. Articles_Excluded_at_Full_Text.xls has three sheets. The first lists the articles screened on Rayyan QCRI excluded at the full text level, with reasons for exclusion. The second contains the list of articles screen on other platforms excluded at full text, with reasons for exclusion. The third shows a table of the number of studies excluded for each reason. The fourthlists all articles that were excluded from the map because we could not access their full texts.

Additional file 10. Consistency_Check_Records.xls is the results of the consistency checking exercises for screening at the title/abstract level and the full text level.

Additional file 11. Data_Coding_Fields.xls lists the metadata fields, the codes used in each field, and a description of how the field or codes changed from the protocol. It also lists instructions and notes given to coders. For fields requiring extensive instructions, we list the codes and their instructions on separate sheets.

Additional file 12. Supplementary tables and figures.docx contains all supplementary tables and figures.

Additional file 13. Adams_et_al_2021_Systematic_Map.accdb is the systematic map database for viewing and editing in Microsoft Access.

Additional file 14. Adams_et_al_2021_Systematic_Map_Runtime.accde is the systematic map database for viewing in Microsoft Access or in Microsoft Access Runtime, which can be downloaded for free at https://

support.microsoft.com/en-us/office/download-and-install-microsoft-365-access-runtime-185c5a32-8ba9-491e-ac76-91cbe3ea09c9. If opened in Microsoft Access, the user can edit the database and run queries, but not edits or queries will be saved.

Additional file 15. Adams_et_al_2021_Systematic_Map_Excel.xls contains a version of the systematic map in Microsoft Excel

Additional file 16. How_to_use_the_systematic_map_database.doc provides instructions on how to search for studies within the Microsoft Access and Microsoft Excel versions of the database.

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Authors' contributions
CAA, CCSC, EB, and EFJ collectively identified the topic for the systematic map and developed the protocol. CAA conducted the search and data coding processes, with assistance from a research assistant and volunteers (see acknowledgements). CAA and EB designed the relational database in Microsoft Access. CAA conducted the analyses and wrote the manuscript under the advice of CCSC, EB, and EFJ. All authors read and approved the final manuscript.

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Availability of data and materials
All data generated or analysed during this study are included in this published article and its additional files. Where available, article URLs are included in the Systematic Map database.

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
Not applicable.

Competing interests
The authors declare that we have no competing interests.

Author details
[1]Department of Biological Science, University of Alberta, CW 405, Biological Sciences Building, Edmonton, AB T6G 2E9, Canada. [2]Department of Biological Sciences, Purdue University, 915 W. State Street, West Lafayette, IN 47907, USA.

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Publisher's Note

Appendix E

Light pollution harms wildlife and ecosystems

For billions of years, all life has relied on Earth's predictable rhythm of day and night. It's encoded in the DNA of all plants and animals. Humans have radically disrupted this cycle by lighting up the night.

Plants and animals depend on Earth's daily cycle of light and dark to govern life-sustaining behaviors such as reproduction, nourishment, sleep, and protection from predators.

Scientific evidence suggests that artificial light at night has negative and deadly effects on many creatures, including amphibians, birds, mammals, insects, and plants.

Artificial lights disrupt the world's ecosystems

Nocturnal animals sleep during the day and are active at night. Light pollution radically alters their nighttime environment by turning night into day. According to research scientist Christopher Kyba, for nocturnal animals "the introduction of artificial light probably represents the most drastic change human beings have made to their environment."

“Predators use light to hunt, and prey species use darkness as cover,” Kyba explains. “Near cities, cloudy skies are now hundreds or even thousands of times brighter than they were 200 years ago. We are only beginning to learn what a drastic effect this has had on nocturnal ecology.”

Glare from artificial lights can also impact wetland habitats that are home to amphibians such as frogs and toads, whose nighttime croaking is part of the breeding ritual. Artificial lights disrupt this nocturnal activity, interfering with reproduction and reducing populations.

> “When we add light to the environment, that has the potential to

disrupt habitat, just like running a bulldozer over the landscape can."

– Chad Moore, formerly of the U.S. National Park Service

Artificial lights can lead baby sea turtles to their demise

Share

Resources

What is light pollution?

Effects of light pollution

A hatchling loggerhead sea turtle turns

inland following human-made lights instead of seaward toward safety. (Photo credit: Blair Witherington)

Sea turtles live in the ocean but hatch at night on the beach. Hatchlings find the sea by detecting the bright horizon over the ocean. Artificial lights draw them away from the ocean. In Florida alone, millions of hatchlings die this way every year.

Artificial lights have devastating effects on many bird species

Birds that migrate or hunt at night navigate by moonlight and starlight. Artificial light can cause them to wander off course and toward the dangerous nighttime landscapes of cities. Every year millions of birds die colliding with needlessly illuminated buildings and towers. Migratory birds depend on cues from properly timed seasonal schedules. Artificial lights can cause them to migrate too early or too late and miss ideal climate conditions for nesting, foraging, and other behaviors.

Ecosystems: Everything is connected

In addition to their ecological role, fireflies are a source of wonder and delight for children and adults.

Many insects are drawn to light, but artificial lights can create a fatal attraction. Declining insect populations negatively impact all species that rely on insects for food or pollination. Some predators exploit this attraction to their advantage, affecting food webs in unanticipated ways.

GET INVOLVED

Learn more about how light pollution

impacts wildlife and ecosystems

Explore the Artificial Light at Night (ALAN) Database to find the latest scientific literature on how light pollution affects wildlife. There is no login required. Research on specific topics can be found by entering a key word (such as *birds*, *turtles*, or *migration*) into the search window in the upper right. Search results will then appear in the main part of the window.

Visit the ALAN Database

GET INVOLVED

Protect the natural nighttime environment

Join DarkSky's global network of advocates working to protect the night from light pollution! The process is simple: Take the DarkSky 101 training and you will be invited to join DarkSky's global communication platform, get access to exclusive advocate resources, and be invited to join additional monthly advocate training on various aspects of light pollution and dark sky conservation.

Become an Advocate