Citizens Committee to Complete the Refuge

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Sent via electronic mail only
Mr. Art Interiano
Deputy Community Development Director September 18, 2023
City of Newark
37101 Newark Blvd.
Newark, CA 94560

Re: Comments on the Draft Environmental Impact Report (DEIR) for the Mowry Village Project

Dear Mr. Interiano,

These comments are submitted on behalf of the Citizens Committee to Complete the Refuge (CCCR), together with counsel for CCCR, Aqua Terra Aeris Law Group (ATA). Thank you for the opportunity to provide scoping comments regarding the proposed Mowry Village housing development project. Also incorporated by reference are the comments submitted by Richard Grassetti on behalf of CCCR, also submitted on behalf of CCCR.

The project encompasses 35.3 acres which include the 29-acre housing site and 6.3 acres of other lands to support the extension of utilities and improvements to Mowry Avenue. The 29-acre site lies southwest of the intersection of Mowry Avenue and the Union Pacific Railroad (UPRR) tracks. It is bounded by Mowry Avenue and Alameda County Flood Control and Water Conservation District (ACFC&WCD) Line B to the west, the UPRR tracks to the north, ACFC&WCD Line D and city park and open lands to the east and Mowry Slough to the south. The proposed project is to construct 203 housing units and associated infrastructure on the existing 19-acre Pick-n-Pull Auto Dismantler site and an adjoining 10-acre undeveloped parcel.

The Citizens Committee to Complete the Refuge (CCCR), with a membership of 1,800, has an ongoing history of interest in wetlands protection, wetlands restoration and wetlands acquisition. Our senior members were part of a group of citizens who became alarmed at the degradation of the Bay and its wetlands. We joined together, and with the support of Congressman Don Edwards, requested that Congress establish the Nation's first national wildlife refuge in an urban setting. The process took seven long years and in 1972 legislation was passed to form the San Francisco Bay National Wildlife Refuge (Refuge). We turned to Mr. Edwards again, and in 1988 (the first year he submitted it), his legislation to double the size of the Refuge was signed into law. The Refuge now bears his name in honor of his efforts.

We have taken an active interest in Clean Water Act (CWA), California Environmental Quality Act (CEQA), Porter-Cologne Water Quality Act and Endangered Species Act (ESA) and California

Endangered Species Act (CESA) regulations, policies, implementation, and enforcement. We have established a record of providing information regarding possible CWA and ESA violations to the Corps, EPA, and FWS. We regularly respond to Corps public notices, and inform the public of important local CWA and ESA issues. We review and comment on CEQA documents. We also respond to ESA comment periods including five-year reviews, proposed listings, and recovery plans. All of these actions demonstrate our ongoing commitment to wetland and plant and wildlife issues, and towards protecting the public interest in wetlands, in Section 404 and 401 of the CWA, CEQA, the ESA and the CESA.

Based upon our review of the information contained in the Mowry Village Draft Environmental Impact Report (DEIR), prepared by Stantec Consulting Services, Inc. dated August 2, 2023, the DEIR has numerous flaws that must be rectified. We have identified the following issues with DEIR for this project.

Internal Inconsistencies Between Sections of the DEIR

The numerous internal inconsistencies between the chapters in the Mowry Village DEIR make it difficult to determine whether the analyses and mitigation measures are sufficient. These inconsistencies hinder the ability of the public and the decision makers to determine whether all the environmental impacts have been identified, analyzed and mitigated. A sample of the inconsistencies are noted below.

- Emergency Response or Evacuation Plan (HAZ-6) Page 3-161 and Emergency Access (TRANS-4) Page 3-272 – Baseline conditions are only partially described in Emergency Access (TRANS-4) and not described at all in Emergency Response or Evacuation Plan (HAZ-6).
- Water Supply (UTIL-3) - Mowry Village DEIR states "the development of the proposed project's 203 residential units would not be within the Specific Plan allocated residential units of 1,260 units and would be above the allowed number of units for the Specific Plan area (page 2-7)." This statement is in direct conflict to the statement that "because the Areas 3 and 4 Specific Plan's demands are already factored into the UWMP, the development of these 203 homes would not result in increased shortages, during normal and dry years, beyond those which are already factored into ACWD's planning under current and foreseeable conditions (City of Newark 2014) (page 3-282)."
- Project Inundation (HYD – 4) – The project import fill to elevate the building pads for the homes to an average pad elevation of 14.2 feet NGVD placing the development out of the current 100-year floodplain. There is no proposal to raise the elevation of the only roadway serving the development. Mowry Avenue is to remain at the existing elevation ranging from approximately 8 to 11 feet. Raising building pads but leaving the road below the current 100-year floodplain is inconsistent with the goals of the project.

Corrections

Pages ES-14, 3-5, 3-81 - The Don Edwards National Wildlife Refuge should be referred to as the Don Edwards San Francisco Bay National Wildlife Refuge.

3.4 Biological Resources – Failure to Analyze and Mitigate the Impacts of Nighttime Lighting on Wildlife

The DEIR fails to identify, analyze and mitigate the impact of this nighttime lighting on wildlife, particularly the shorebirds and waterfowl migrating to the area that includes the project site and the adjacent area.

The DEIR notes that "The proposed project would provide exterior lighting throughout the site to illuminate the main entrances of the single-family homes, private streets, sidewalks, common space areas, and driveways for security and safety purposes. Additional lighting would be installed along the project frontage on Mowry Avenue (page 2-25)." The DEIR also notes "There is currently no street lighting located along the portion of Mowry Avenue in front of the project site and vehicle headlight glare is limited in the area, as this section of Mowry Avenue does not have a lot of vehicle traffic (page 3-5)." The area west of the UPRR tracks is dark at night and supports hundreds of resident birds and thousands of migratory shorebirds and waterfowl in the winter. The housing development will include street lighting within the development and along Mowry Avenue. The EIR acknowledges that the project will introduce more lighting to the area but fails to analyze the potential significant and adverse impacts to wildlife at all. Instead, the DEIR merely states the proposed lighting will be "designed in accordance with lighting and regulations and standards outlined under Newark Municipal Code Section 17.17.060 Lighting and Illumination." There is no assessment of whether following the code section will adequately mitigate the adverse impacts of night light pollution. The Newark Municipal Code Section states:

> "17.17.060 - Lighting and Illumination.
> A. Applicability. The standards of this section apply to all new development and to exterior alterations and additions that involve replacement light fixtures or systems, except as provided below:
>
> 1. Exemptions. The following lighting is exempt from the provisions of this section.
>   - a. Public and private street lighting.
>   - b. Athletic Field Lights. Athletic field lights used within a school campus or public or private park.
>   - c. Safety and Security Lighting. Safety and security lighting for public facilities.
>   - d. Construction and Emergency Lighting. All construction or emergency lighting fixtures, provided they are temporary and are discontinued immediately upon completion of the construction work or abatement of the emergency.
>   - e. Seasonal Lighting. Seasonal lighting displays related to cultural or religious celebrations.
>
> B. Prohibitions. The following types of exterior lighting are prohibited.
>   1. Searchlights. The operation of searchlights for advertising purposes.
>   2. Mercury Vapor. Mercury vapor lights.
>   3. Other Light Types. Laser lights or any other lighting that flashes, blinks, alternates, or moves.
>
> C. General Requirements. Outdoor lighting shall be designed to be an integral part of the built environment, reflecting a balance for the lighting needs with the contextual ambient light level and surrounding nighttime characteristics of the community.

Lighting for commercial installations adjacent to or near residential uses shall be compatible with and not directly illuminate nearby residential uses.

1. Maximum Height.
    a. Within one hundred feet of a residential district: sixteen feet.
    b. Other locations: twenty-five feet.
    c. Exceptions: The planning commission may allow additional height for activities, uses, or development with unique lighting needs; accentuating historic architectural features of a building; accentuating signage and/or landscape features; or for security purposes.

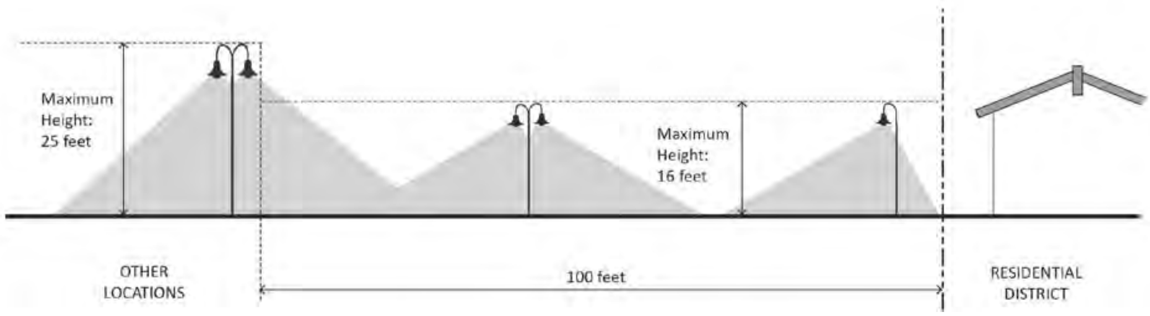

FIGURE 17.17.060.C.1: MAXIMUM HEIGHT, OUTDOOR LIGHTING

2. Design of Fixtures. Fixtures shall be appropriate to the style and scale of the architecture. Fixtures on buildings shall be attached only to walls or eaves, and the top of the fixture shall not exceed the height of the parapet or roof or eave of roof.
3. Timing Controls. All outdoor lighting in non-residential development shall be on a time clock or photo-sensor system and turned off during daylight hours and during hours when the building or, in the case of shopping centers, all buildings, are not in use and the lighting is not required for security.
4. Trespass. All lights shall be directed, oriented, and shielded to prevent light trespass or glare onto adjacent properties. The light level at property lines shall not exceed 0.3 foot-candles.

D. Supplemental Requirements.

1. Multi-Unit Residential Buildings.
    a. Lighting in parking areas, garage areas, and carport areas shall be maintained with a minimum of one foot-candle of illumination at the ground level during the hours of darkness.
    b. Aisles, passageways, and recesses related to and within the building complex shall be illuminated with an intensity of at least 0.25 foot-candles at the ground level during the hours of darkness.
2. Non-residential Buildings. All exterior doors, during the hours of darkness, shall be illuminated with a minimum of 0.5 foot-candle of light."

Mitigation measures may be incorporated into project plans, policies, or designs—but they nevertheless remain mitigation measures. CEQA Guidelines, § 15126.4(a)(2). CEQA Guidelines state:

> The discussion of mitigation measures shall distinguish between the measures which are proposed by project proponents to be included in the project and other measures proposed by the lead, responsible or trustee agency or other person which are not

included but the lead agency determines could reasonably be expected to reduce adverse impacts if required as conditions of approving the project.

CEQA Guidelines, § 15126.4(a)(1)(A). Moreover, CEQA requires that mitigation measures are likely to be effective, but the provisions of the Newark Municipal Code do not adequately consider, nor mitigate the negative biological impacts of Artificial Light At Night (ALAN) that will be introduced next to natural habitat as a consequence of the proposed project. *See*, *Sierra Club v. Cty. of San Diego,* 231 Cal.App.4th 1152*,* 1169 (2014)

The biological impacts of ALAN on the natural environment are pervasive, proven, and unregulated by the city or state law. ALAN is emerging as a significant disruptor to ecosystems because it impairs biological function in individuals, disrupts daily and seasonal ecological function and decouples critical interactions within and among species[1]. Attraction to light by insects is a driver of the insect "apocalypse"[2], has been shown to disrupt pollination even during the day. Disappearing insect populations are depleting food sources for fish and birds and unraveling our global food webs. Attraction to light is also affecting migration behavior in birds.[3] Increasing scientific evidence also shows links between ALAN (indoor and outdoor) and many common human diseases as well as impacts to mental health.[4] The blue light component of the spectrum emitted by LED fixtures has been shown to be especially harmful to all living organisms and to ecosystems.

Indeed, ALAN is documented to have serious adverse impacts for a wide range of wildlife ranging from invertebrates to mammals.[5] [Special Issue Light Pollution attachment 1] Longcore and Rich reported that light pollution disrupts migratory patterns, foraging capabilities, predation, nesting, breeding, etc.[6] Longcore and Rich also report the findings of Buchanan[7] in which three different species of amphibians forage at different illumination intensities. As an example, the squirrel treefrog (*Hyla squirrela*) forages only between 10^{-5} lux and 10^{-3} lux under natural conditions, while the western toad (*Bufo boreas*) only forages at illuminations between 10^{-1} and 10^{-5} lux. [The 0.3 footcandles cited in the Newark Municipal Code is equivalent to 3.23 lux.]

Evidence suggests light pollution affects the choice of nesting sites in the black-tailed godwit, with choice locations being the farther away from roadway lighting (De Molenaar et al 2000)[8]. Buchanan found frogs he was studying stopped their mating calls when the lights of a nearby stadium were turned on.

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[1] Effects of anthropogenic light on species and ecosystems. Annika K. Jägerbrand and Kamiel Spoelstra. 2023. Science 380(6650) DOI:10.1126/science.adg3173

[2] https://www.smithsonianmag.com/smart-news/light-pollution-contributes-insect-apocalypse-180973642

[3] High-intensity urban light installation dramatically alters nocturnal bird migration https://www.pnas.org/content/early/2017/09/26/1708574114

[4] https://time.com/5033099/light-pollution-health/ and
Reducing nighttime light exposure in the urban environment to benefit human health and society
K. M. Zielinska-Dabkowska, E. S. Schernhammer, J. P. Hanifin, G. C. Brainard. 2023. Science 380(6650) DOI:10.1126/science.adg3173

[5] Artificial Light at Night: State of the Science 2023. DarkSky International DOI: 10.5281/zenodo.8071915. https://zenodo.org/record/8071915

[6] Longcore, T. and Rich, C. "Ecological Light Pollution" Front Ecol Environ. 2004. 2(4): 191-198

[7] Buchanan, B.W. "Low-illumination prey detection by squirrel treefrogs" 1998. J Herpetology 32: 270-74

[8] De Molenaar, JG, DA Jonkers, and ME Sanders . 2000. Road illumination and nature. III. Local influence of road lights on a black-tailed godwit (Limosa l. limosa) population. Wageningen, The Netherlands: Alterra.

The Newark Municipal Code exempts street lighting and athletic field lights, and these lights can "vacuum" insects and disorient migratory birds. The code also exempts all construction lighting, which is of great concern because the project will take years to build, and the lighting (even if it moves from one building site to another within the development footprint) will likely impact generations of insects, amphibians, birds and other animals.

The Newark Municipal Code prohibits the use of searchlights, mercury vapor lights, and "laser lights or any other lighting that flashes, blinks, alternates, or moves," though it is unclear whether the reference to laser lights and the lighting that follow, are or are not exempt if they are "seasonal lighting." The Newark Municipal Code is completely silent regarding the use of LED lighting. Kerbiriou et al[9], concluded:

> "Our re-analysis clearly indicates that the switches in spectrum and in intensity with replacement of LPS [low pressure sodium] lamps with LEDs [light emitting diodes] have significant additive and interactive effects, on bat activity. We also show that bat activity and buzz ratio decrease with increasing LED intensity while an opposite effect is observed with LPS lamps.
> …Our results stress the need to consider simultaneously the effects of changes in the different lights characteristics when street lighting changes."

The Newark Municipal Code does not adequately address potentially significant and adverse impacts of Artificial Light at Night (ALAN). The DarkSky website[10] quotes research scientist Christopher Kyba, regarding the impacts of ALAN on nocturnal animals:

> "…the introduction of artificial light probably represents the most drastic change human beings have made to their environment.
> …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."

The website also includes a quote from Chad Moore, who co-founded the U.S. National Park Service Night Skies Program, "**When we add light to the environment, that has the potential to disrupt habitat, just like running a bulldozer over the landscape can**."[emphasis added]
Sufficient evidence exists that demonstrates artificial lights have adverse impacts on wildlife. The project as proposed would locate night lighting adjacent to wetlands utilized by amphibians and resident and migratory birds. The adjacent wetlands are of ecological significance as they lie within historic Baylands, were recommended for restoration by The Baylands and Climate Change: What We Can Do. Baylands Ecosystem Habitat Goals Science Update 2015[11] and by the Recovery Plan for the Tidal Marsh Ecosystems of Northern and Central California[12].

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[9] Kerbiriou, Christian, Barré, Kévin, Mariton, Léa, Pauwels, Julie, Zissis, Georges, Robert, Alexandre, Le Viol, Isabelle. 2020/04/24. "Switching LPS to LED Streetlight May Dramatically Reduce Activity and Foraging of Bats" Diversity 2020, Vol 12, 165
[10] DarkSky. Resources Page. https://darksky.org/resources/what-is-light-pollution/effects/wildlife-ecosystems/ accessed 9-14-23.
[11] California State Coastal Conservancy. 2015. The Baylands and Climate Change: What We Can Do. Baylands Ecosystem Habitat Goals Science Update 2015. Oakland, CA.
[12] U.S. Fish and Wildlife Service. 2013. Recovery Plan for the Tidal Marsh Ecosystems of Northern and Central California.

We propose the following mitigations to reduce the impacts of ALAN on the environment:

a. The EIR should include as mitigations all the best practices that the International Dark-sky Association includes in its Board Policy on the Application of the Lighting Principles document[13] (June 24, 2021). This policy provides guidance for implementing the Five Principles for Responsible Outdoor Lighting[14] that are offered by the International Dark Sky Association as mitigation for the significant impacts of ALAN on the environment. Thus, policy and additional work suggest the following outdoor lighting guidelines for private, public, residential, and non-residential lighting.

- Street lights should be reduced to 40% capacity during "quiet" hours (i.e. 10:00pm-5:00am).
- Residential and non-residential lighting should turn off or dim at least 50% during "quiet" hours.
- Follow the IDA model lighting ordinance use of five lighting zones to systematically regulate appropriate lighting levels for different areas. These zones range from LZ0 (pristine natural environments and limited outdoor lighting) to LZ4 (limited application in areas of extensive development in the largest cities)[15].
- Private and public lighting should complement each other to prevent over lighting spaces.
- All outdoor lighting fixtures will be capable of accepting 7-pin controls that can enable use of dimmers, timers, motion sensors, and networking.

b. Lighting should not shine onto open space / riparian corridors / habitat. Light trespass should be limited to 0.1 foot-candle, which is less than the Newark Municipal code maximum of 0.3 foot-candle. For comparison, a night with a full moon has 0.01 foot-candle and an overcast night has only 0.00001 foot-candle. 0.03 foot-candles is brighter than the moon, and the impacts of this level of light trespass to animals that are attracted to light, or use moonlight for navigation and seasonal rhythm internal clocks are harmful and unmitigable.
c. To the largest extent possible, avoid lighting within 300 feet of wetlands and natural areas.
d. Lighting near sensitive habitats (300-ft from water features, open space, parks…) should have a wavelength of no more than 520NM, or no more than 2400 Kelvin. All outdoor lighting that is visible from open space, including parking areas, should have Correlated Color Temperature of no more than 2700 Kelvin. All other outdoor lighting fixtures should have CCT of no more than 300 Kelvin.
e. Should be limited to CCT of 2700 Kelvin or less.
f. Require and implement Lights-out programs during bird migration seasons.

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[13] https://www.darksky.org/wp-content/uploads/bsk-pdf-manager/2021/08/BOARD-policy-application-of-light-FINAL-June-24-2021.docx.pdf
[14] https://www.darksky.org/our-work/lighting/lighting-principles/

[15] https://www.darksky.org/wp-content/uploads/bsk-pdf-manager/16_MLO_FINAL_JUNE2011.PDF

The Newark Municipal Code states that the maximum height for outdoor exterior lighting fixtures for residential districts of 16 feet, but fails to place adequate limitations on the extent of lateral spread or the Correlated Color Temperature (CCT) of lighting, which is a measure of how much harmful blue light is present in the spectrum.

The DEIR fails to adequately address the issue of lateral spread (light trespass) into undeveloped areas adjacent to the project site, as stated above in recommended mitigation "b" above, light trespass should be limited to 0.1 foot-candles, but the Newark Municipal Code allows a maximum of 0.3 foot-candles. What mitigation measures will be implemented to reduce lateral spreading of light to surrounding habitat areas? How will this mitigation measure be enforced in the long-term once the development is occupied? Will the exterior lighting fixtures prevent lateral spreading regardless of the type of bulb used? How will residents of the proposed development be prevented from changing the light fixtures? These issues cannot be deferred until after the DEIR is circulated, or after the project is approved. *Cf., Sacramento Old City Ass'n. v. City Council*, 229 Cal.App.3d 1011 (1991); CEQA Guidelines, § 15126.4(a)(1); *Clover Valley Foundation v. City of Rocklin*, 197 Cal.App.4th 200, 236 (2011); *Cmtys. for a Better Env't v. City of Richmond,* 184 Cal.App.4th 70, 92 (2010).

As we stated earlier, the DEIR is flawed as the potentially significant and adverse impact to biological resources, of adding ALAN to an area that is described as currently not having any street lighting.

3.4 Biological Resources – Protected Wetlands (BIO-3)

As noted above, the DEIR acknowledges "Historically high groundwater at the project site has been reported at 5 feet bgs and based on the preliminary investigations and borings conducted at the project site, groundwater is estimated to be at a depth of 4 to 8.5 feet bgs (Berlogar, Stevens, and Associates 2019). Groundwater could be encountered during excavation activities and require dewatering (page 3 – 173)." As such the DEIR calls for "Mitigation Measure GEO-3 which requires the preparation and implementation of a dewatering plan in accordance with the waste discharge requirements of the RWQCB (page 3 – 173)." Dewatering activities could impact the wetlands immediately south and east of the site, and yet the DEIR has no analysis of the potential impacts to wetlands and provides no information as to whether any potential impacts would be mitigated through the RWQCB dewatering plan. Additionally, no information is provided in the DEIR on the anticipated duration of the dewatering process needed to support cleanup of groundwater contaminants and construction of the project. *Cf. Sacramento Old City Ass'n. v. City Council*, 229 Cal.App.3d 1011 (1991); CEQA Guidelines, § 15126.4(a)(1); *Clover Valley Foundation v. City of Rocklin*, 197 Cal.App.4th 200, 236 (2011); *Cmtys. for a Better Env't v. City of Richmond,* 184 Cal.App.4th 70, 92 (2010).

"In accordance with the Corrective Action Plan issued for the proposed project, the impacted groundwater would be exposed via remedial excavation and treated with the rapid chemical oxidizing agent PersolfOx as well as a time-released oxygen release compound (ORC) to treat residual levels of benzene, toluene, ethylbenzene, and xylenes (BTEX) after the excavation has been backfilled. ORC will be added to any remedial excavation that extends to groundwater elevation. Benzene in soil gas would be released during the remedial soil excavation process (page 2-34)." What impact could PersulfOx as well as a time-released oxygen release compound (ORC) have on the wetlands and wildlife surrounding the site? Have these chemicals been used in or near sensitive wetland habitats? What is the anticipated persistence and degradability of these chemicals? The DEIR fails to identify, analyze and mitigate the impact of these chemicals on the adjacent wetlands and wildlife using this habitat.

3.4 Biological Resources – Burrowing Owl Mitigation (BIO-1 and MM BIO-4 and MM BIO-5)

MM BIO-4 states, "If resident burrowing owl(s) are found in the proposed project site during pre-construction surveys and eviction is necessary to facilitate construction, Mitigation Measure BIO-6 shall be implemented." However, Bio-6 addresses impacts to bats species, not to burrowing owls. Please correct.

MM BIO-5 does not adequately address the potential indirect impacts of the proposed project on Burrowing Owl or the cumulative losses of local Burrowing Owl (BUOW) habitat.

The DEIR acknowledges that Burrowing Owls are "known to occur in the vicinity of the project site." The Biological Resources Technical Report for the Mowry Village Project, dated June 2022 states, "Burrowing owl has the potential to nest and forage within the Study Area."

MM BIO-5 states that "To reduce impacts of the project on the local (South Bay) burrowing owl population, habitat shall be preserved and managed for burrowing owls off-site if eviction of resident owls is required," and, "California burrowing owl mitigation guidelines recommend that 6.5 acres of foraging habitat be preserved and managed per occupied burrowing owl burrow (whether by a pair or singly) in mitigation sites." These obsolete guidelines have proven to be useless in protecting burrowing owl habitat in the south bay, and have actually led to the precarious situation of burrowing owls in the Bay Area. Mitigation for loss of burrowing owl habitat should be based upon the Santa Clara County Habitat Agency, which actually invests in sustaining the local population of burrowing owls.

We disagree with the DEIR statement, "Because the nearest burrowing owl mitigation banks are currently located outside of the South Bay, this mitigation may occur outside the region," since the Santa Clara Valley Habitat Agency provides the opportunity for local mitigation. How does the proposed mitigation measure reduce the impacts of the project on the local Burrowing Owl population if the mitigation may occur outside the region?

The DEIR appears to address this issue in part with the following statement:

> "Assuming burrowing owl habitat mitigation would occur off-site, <u>some on-site enhancements shall also be made to reduce impacts of the project on the local (South Bay) burrowing owl population</u>. <u>Such enhancements shall include the provision of two artificial burrow complexes on the sides of the adjacent levees</u> (if allowed by levee managers) and management of at least portions of levee side slopes around these burrow complexes to provide suitable conditions for burrowing owls and ground squirrels (e.g., periodic mowing to maintain short vegetation)."

The California Code of Regulations Title 14 §15126.4 (a)(2) require:

> "Mitigation measures must be fully enforceable through permit conditions, agreements, or other legally-binding instruments."

The proposal to create artificial burrow complexes on the sides of adjacent levees is infeasible if the "adjacent levees" are associated with flood control channels. Flood control agencies would not permit actions that could threaten the stability of levees along flood control channels. Ceccato et al[16] state, "Earth dams and levees often offer an attractive habitat for burrowing animals such as porcupines, nutria, badgers, etc. However, their activity may damage the earth structure, potentially leading to catastrophic failures." And, "This study shows once again that the burrowing of animals in dams and levees can damage the earthen structures increasing the probability of failure."

The mitigation measure proposed to mitigate the loss of Burrowing Owl habitat fails to adequately mitigate the potentially significant and adverse impacts of the proposed project on the local Burrowing Owl population.

In addition, **MM BIO-8 Post-Construction Predator Management Plan and Program** fails to mitigate the potentially significant and adverse indirect impacts of the project on Burrowing Owls that may occur on lands adjacent to the proposed project site (see discussion below regarding inadequacy of **MM BIO-8**).

3.4 Biological Resources – Special Status Bat Species (BIO-1 and MM BIO-6)

If special status bat species are documented to be roosting on-site, the bat survey results should be reviewed by the California Department of Fish and Wildlife (CDFW) staff and any proposed mitigation reviewed and approved by CDFW staff as well, and not just the Community Development Director.

Any potential evictions of bats should be reviewed and approved by CDFW and not just a bat biologist.

MM BIO-6 mentions mitigation for impacts to a day roost, which provides that an "alternative bat roost structure shall be provided." Where would this structure be located? Somewhere within the vicinity of the lost roost or at a distant location? Who is responsible for the construction of the "alternative bat roost structure? If a day roost is located, then any plans for eviction or provision of an alternative structure, must be reviewed and approved by CDFW prior to the removal of the existing bat day roost.

3.4 Biological Resources – Reduce the Spread of Invasive Species (BIO-1 and MM BIO-7)

This mitigation measure targets reduction in the spread of invasive plant species during the construction phase of the project. The mitigation measure states "Areas identified to have weed infestations shall be treated prior to ground disturbance according to weed control methods detailed

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[16] Ceccato, F.; Malvestio, S.; Simonini, P. "Effect of Animal Burrows on the Vulnerability of Levees to Concentrated Erosion." Water 2022, 14, 2777. https://doi.org/10.3390/w14182777 . Accessed 9-14-23.

below…" but fails to provide a definition of "weed infestation" so it is not possible to determine if the mitigation measure is responsive to the described impact.

The mitigation measure states an Invasive Species Management Plan will be developed and implemented to "reduce the presence and spread of non-native, invasive plant species for the area to be developed." This management plan is required to be provided "prior to the issuance of any building or grading permits," which is well after the close of the DEIR comment period, thus circumventing the ability of the public and agencies to review and comment on the adequacy of the plan.

The mitigation measure also states:

> "Consultation with a City of Newark approved wildlife biologist or plant ecologist shall be required prior to weed control treatments in sensitive habitats with the intent of avoiding any adverse impacts to special-status species in the area."

This portion of the mitigation measure must be altered to require evaluation and approval of any weed control treatments in sensitive habitats that may support special-status species, by the USFWS and CDFW.

3.4 Biological Resources – Predator Management (BIO-1 and MM BIO-8)

As stated earlier in this comment letter, the California Code of Regulations Title 14 §15126.4 (a)(2) require:

> "Mitigation measures must be fully enforceable through permit conditions, agreements, or other legally-binding instruments."

The mitigation measures proposed to address potentially significant and adverse impacts of the project regarding the introduction of, increase in, subsidizing of non-native predators, as well as those proposed for the introduction of non-native invasive plant species, fail to meet this standard.

The DEIR is unresponsive to substantive concerns identified in our scoping comment letter. Specifically, we commented that:

- The DEIR should describe how the prohibition of feeding pets outdoors, to avoid attraction or subsidization of nuisance species, would be enforced and specifically which department within the City of Newark would be responsible for ensuring compliance with this mitigation measure.
- Similarly, we asked how the prohibition of off-leash dogs in offsite wetland areas and the prohibition against free-roaming cats would be enforced and specifically which department within the City of Newark would be responsible for ensuring compliance with this mitigation measure.
- The same concern identified above applies to the requirement that food waste be contained to avoid the attraction or subsidization of predators.

- The same concern applies to the "requirement" that plants contained on the California Exotic Plant Pest Council List of Invasive Plants being barred from use within landscaping of the development or use on private lots.

Without identification of a party responsible for monitoring (frequent, consistent monitoring) and enforcement, the mitigation measures identified amount to nothing more than lip service, for impacts that could result in significant adverse impacts to biological resources.

One of the proposed mitigation measures is "minimizing disturbance" by:

> "…educating the public about the importance of preserving the ecological integrity of the adjacent natural areas instructing recreational users to stay on the levee tops out of sensitive habitats and keep dogs on leashes."

Dogs negatively impact wildlife in three ways: (1) by causing direct mortality of wildlife through predatory action, (2) by disrupting normal behavior, which can affect population parameters (e.g., reproductive success), and (3) through disease transmission.[17] These impacts can be significant, especially to special-status species, which are generally more prone to population decline.[18]

The mitigation measure proposed would not eliminate the potentially significant impacts dogs would have on wildlife.

Several studies have shown low compliance with leash laws at parks.[19] Without an effective monitoring and enforcement program, it is highly likely that leash laws will not be observed. Pet owners frequently allow their dogs to run off-leash even where it is clearly signed that dogs are not permitted or are only permitted if on a leash.[20]

In addition, many wildlife species view dogs as a threat, even leashed dogs can have an adverse impact on wildlife.[21] Banks and Bryant (2007) showed that dog walking in woodland leads to a 35% reduction in bird diversity and a 41% reduction in abundance, both in areas where dog walking is common and where dogs are prohibited.[22] Based on their review of 133 publications, Weston et al. (2014) reported: "[s]tudies presenting results on how wildlife reacts to dogs report that flushing

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[17] Weston MA, JA Fitzsimons, G Wescott, KK Miller, KB Ekanayake, T Schneider. 2014. Bark in the park: A review of domestic dogs in parks. Environmental Management 54:373-382.
[18] *Ibid.*
[19] Weston MA, JA Fitzsimons, G Wescott, KK Miller, KB Ekanayake, T Schneider. 2014. Bark in the park: A review of domestic dogs in parks. Environmental Management 54:373-382. *See also* Jorgensen JG, MB Brown. 2017. Evaluating Persuasive Messages to Influence Dog Leash Law Compliance at a Public Area in the Great Plains. Great Plains Research 27:131-142. *See also* Jorgensen JG, M Bomberger Brown. 2014. Piping Plovers *Charadrius melodus* and dogs: compliance with and attitudes toward a leash law on public beaches at Lake McConaughy, Nebraska, USA. Wader Study Group Bulletin 121(2):7–12.
[20] United States Fish and Wildlife Service. 2007. Recovery Plan for the Pacific Coast Population of the Western Snowy Plover *(Charadrius alexandrinus nivosus).* Sacramento, California. xiv + 751. *See also* Jorgensen JG, M Bomberger Brown. 2014. Piping Plovers *Charadrius melodus* and dogs: compliance with and attitudes toward a leash law on public beaches at Lake McConaughy, Nebraska, USA. Wader Study Group Bulletin 121(2):7–12.
[21] Banks PB, JV Bryant. 2007. Four-legged friend or foe? Dog walking displaces native birds from natural areas. Biology Letters 3:611-613. *See also* Lord A, JR Waas, J Innes, MJ Whittingham. 2001. Biological Conservation 98:233-240.
[22] *Ibid.*

behavior of mammals and birds is usually greater when pedestrians are accompanied by a dog compared to pedestrians walking alone."[23]

Other issues - There is no mention of specific mitigation measures dealing with domestic cats, feral cats, gulls, corvids, Norway and roof rats, etc. that might be attracted to the development. How will these species be dealt with, and in particular, how will Norway and roof rats be controlled. These species are of particular concern as often, anti-coagulant poisons are used by homeowners to control these pest species, which could result in significant adverse impacts to special-status species such as the federally-listed salt marsh harvest mouse, Burrowing Owl, and other raptors.

MM BIO-8 also fails to adequately address potential indirect impacts to the federally-listed endangered salt marsh harvest mouse resulting from the proposed project. The DEIR states that suitable habitat does not exist within the project boundaries and that an exclusion fence has been installed to prevent adverse impacts during construction, and that "…the preparation and implementation of a post-construction predator management plan and program to educate the project residents regarding measures to minimize the potential for subsidizing predator species and to minimize the potential effects of pets on sensitive species." We have already commented regarding the ineffectiveness of the proposed predator/nuisance species management plan and the proposed education program.

The DEIR maintains that suitable habitat for the salt marsh harvest mouse does not exist within the project boundaries. However, the 2022 Biological Resources Technical Report for the Mowry Village Project (Technical Report) acknowledges that:

> "Recent studies have also shown that salt marsh harvest mice are more flexible in habitat use and, in their diet, than previously thought (Smith and Kelt 2019). Salt marsh harvest mice will use non-native plant species, such as rabbitsfoot grass (*Polypogon monspeliensis*), in their diet (Smith and Kelt 2019) in addition to other native species and are not tied exclusively to pickleweed dominated wetlands but will also use other mixed vegetation wetlands (Sustaita et al. 2011). This shows that salt marsh harvest mice may use mixed vegetation salt marsh habitat (Sustaita et al. 2011; Smith et al. 2014)."

While it is unlikely that SMHM habitat exists within the current developed Pick-n-Pull facility, the undeveloped 10 acres of the project site may provide transition zone and upland escape habitat during periods of flooding. The Technical Report also states, "…no surveys have been conducted on the site for this species." Again, it is unlikely that SMHM occur within the developed Pick-n-Pull site, but based on the information presented in the Technical Report, how can the DEIR determine that SMHM does not exist within the undeveloped 10 acres?

The fact that the undeveloped portion of the site does support pickleweed habitat does not rule out the possibility that the undeveloped portions of the site provide suitable upland escape habitat for the SMHM. Nor does the fact that the undeveloped portions of the site are "disced does not rule out

[23] Weston MA, JA Fitzsimons, G Wescott, KK Miller, KB Ekanayake, T Schneider. 2014. Bark in the park: A review of domestic dogs in parks. Environmental Management 54:373-382.

the possible occurrence of SMHM. Smith[24] reported that SMHM were trapped in high management treatment habitats after the area had been recently disced.

3.7 Geology and Soils

The DEIR is unresponsive to Geology and Soils issues identified in CCCR's scoping comments, specifically, the DEIR does not consider the synergistic/exacerbating impacts of sea level rise and groundwater rise for issues such slope stability and protection of infrastructure:

> "The issues of how the project will be constructed under increasing rates of sea level and groundwater rise are issues that must be discussed in the DEIR, as there could be resulting direct and indirect impacts to the environment from project construction. For example, if more fill is required to raise the project out of potential sea level rise, storm frequency, groundwater rise flooding potential, there could be an increase in the amounts of fill that might be required to remove the flood risk, increased greenhouse gas emissions due to increased numbers of truckloads of fill that are required, changes in the geotechnical mitigation measures that need to be employed, changes in the techniques that may be required to ensure the fill slopes are stabilized, changes in the methodology required to protect required infrastructure, changes in how below ground surface contaminants may need to be dealt with, etc. Any of these design features could also result in indirect impacts to the surrounding environment including the Line D, adjacent wetlands, Mowry Slough and Mowry Avenue. All of these issues should be disclosed within the DEIR." [emphasis added]

The geotechnical report, "*DUE DILIGENCE GEOTECHNICAL ASSESSMENT PROPOSED RESIDENTIAL DEVELOPMENT PICK-N-PULL – 7400 MOWRY AVENUE NEWARK, CALIFORNIA For INTEGRAL PARTNERS FUNDING, LLC,*" dated *April 1, 2019,* prepared by Berlogar Stevens & Associates.

Liquefaction

The DEIR description of the analysis of the potential for liquefaction and lateral spread does not seem to include an assessment of the liquefaction potential under conditions of rising groundwater. This is a reasonably foreseeable phenomenon and maps depicting the potential for groundwater rise can been accessed through the Out Coast Our Future
(https://ourcoastourfuture.org/hazard-map/).

Page 8 of the Borlogar April 1, 2019 states:

> "Current practice in liquefaction evaluation now includes sands, silty sands and gravels, as well as silts and even some clay soils. In general, soils consisting of plastic silts or clays, do not generate excess pore water pressure to the same extent or as quickly as relatively clean sands. Thus, silty and clayey soils tend to be less susceptible to liquefaction-type behaviors than sandy soils. Primary factors affecting the potential for a soil to undergo liquefaction include: depth to groundwater, soil type, relative density of granular soils, moisture content

[24] Smith, Katherine. *Emerging Perspective on Salt Marsh Harvest Mouse Conservation and Management – Ducks, Dikes and Demographics.* 2014. California Department of Fish and Wildlife, UC Davis. Bay Delta Science Conference. *https://scienceconf2014.deltacouncil.ca.gov/sites/default/files/uploads/2014-10-30-306PM1-SMITH.pdf*

> and Plasticity Index of fine-grained soils, initial confining (overburden) pressure, and intensity and duration of ground shaking. The impact of liquefaction to surface structures is generally limited to liquefaction of soils within about 50 feet of the ground surface."

And page 9 of that same document states, "liquefiable soil may experience differential settlement through reconsolidation of the liquefied soil" and, "…The liquefaction calculation results indicate that the sand, silty sand and sandy silt layers at the adjacent sites have a moderate to high potential to liquefy during the design earthquake."

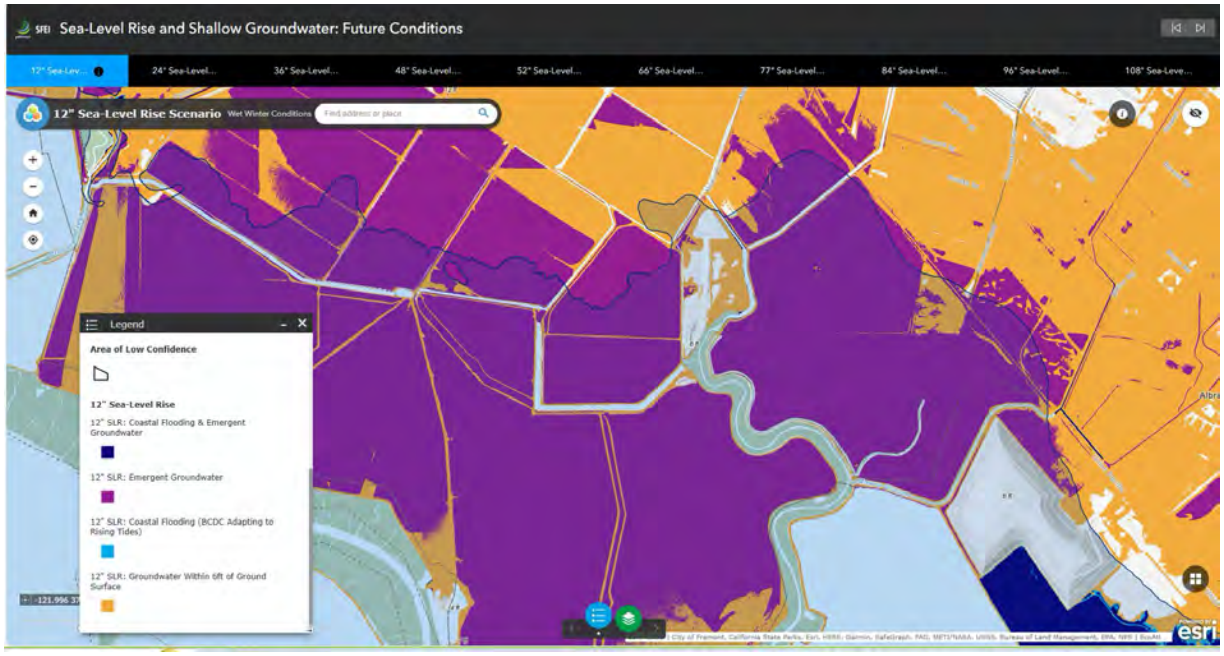
The DEIR states:

> "Loose sands and peat deposits, along with recent Holocene age deposits, are more susceptible to liquefaction, while older deposits of clayey silts, silty clays, and clays deposited in freshwater environments are generally stable under the influence of seismic ground shaking.
>
> Based on the analysis conducted for the design level geotechnical report, the liquefaction induced settlement potential at the project site was found to range between 1.6 and 2.8 inches. The analyses showed that the predominant contributor to the settlement potential was a sand layer at depths between 30 and 40 feet. Based on the analyses and geologic setting of the site, the design level geotechnical report estimates a liquefaction induced differential settlement of up to 0.5 inch across 100 feet (Berlogar Stevens and Associates 2021)." [emphasis added]

The DEIR description of the analysis of the potential for liquefaction and lateral spread, as well as the geotechnical appendices, do not appear to include an assessment of the liquefaction potential for the site under conditions of rising groundwater, due to sea level rise.

Rising groundwater level in response to sea level rise, is a reasonably foreseeable phenomenon and maps depicting the potential for groundwater rise can been accessed through the Out Coast Our Future (*https://ourcoastourfuture.org/hazard-map/*). The San Francisco Estuary Institute (SFEI) has also mapped potential groundwater rise in response to sea level rise. The SFEI mapping of groundwater rise under differing levels of sea level rise can be explored at: *https://sfei.maps.arcgis.com/apps/instant/portfolio/index.html?appid=2ab0c998497f4f7398aa54f176a6fb26*

The map below depicts the potential for groundwater rise with 12” of sea level rise.



May et al[25]authored a report focusing on the response of shallow groundwater to rising sea levels. One of the issues discussed includes the impacts of groundwater rise on liquefaction:

> “The areas most at risk of liquefaction are generally located along the Bay shoreline and Bay tributaries in former floodplains, marshplains, wetlands, mudflats, and open water areas that were filled for development (Witter et al., 2006). <u>These same areas are at risk of rising groundwater, and as the groundwater table rises, the liquefaction risk is likely to increase</u> (Grant et al., 2021; Quilter et al., 2015; Risken et al., 2015).[emphasis added]”

Dong et al[26]state:

> “The degree of saturation is a decisive factor that influences the liquefaction potential. With the rise of sea levels, the groundwater level may increase in some coastal areas, causing unsaturated sand soil and silt layers to become saturated. In this case, the effective stress of the sand would thus decrease, leading to an increase in the excess pore water pressure, which is needed to achieve a liquefaction state [95,96]. For this reason, areas with higher groundwater levels are more easily liquefied compared with areas with lower groundwater levels when they experience the same-intensity earthquake. Sea-level rise can influence underground water levels in two ways. Firstly, when sea levels rise, the water head of underground water to seawater decreases, thus leading to an underground runoff decrease. Second, sea-level rise also increases the intensity of tidal action in estuary areas, which also decreases the underground runoff. When the tidal level surpasses the underground water

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[25] May CL, Mohan A, Plane E, Ramirez-Lopez D, Mak M, Luchinsky L, Hale T, Hill K. 2022. “*Shallow Groundwater Response to Sea-Level Rise: Alameda, Marin, San Francisco, and San Mateo Counties*.” Prepared by Pathways Climate Institute and San Francisco Estuary Institute. doi.org/10.13140/RG.2.2.16973.72164

[26] Dong, L.; Cao, J.; Liu, X. “*Recent Developments in Sea-Level Rise and Its Related Geological Disasters Mitigation: A Review.*” J. Mar. Sci. Eng. 2022, 10, 355. *https://doi.org/10.3390/jmse10030355*

level, a great deal of seawater flows back into the underground water and increases underground water levels."

And:

> "<u>As the sea level rises, the original site conditions are changed, resulting in an increased risk of liquefaction of sand in coastal cities. In this case, it is necessary to consider the risk of liquefaction in coastal areas</u> [97,98]. By comparing liquefaction hazard maps before and after the sea-level rise, Murakami, Yasuhara [99] described a procedure for liquefaction hazard mapping, which shows that sea-level rise can expand the liquefaction areas." [emphasis added]

The potential for groundwater rise to exacerbate the potential and magnitude of liquefaction across the proposed development footprint is an analysis that must be incorporated into the geotechnical review of the site geology and soils, and for determination of the adequacy of any proposed mitigation measures. *See*, 14 C.C.R. § 15126.2.

MM GEO-2: Mitigation of Liquefaction-Induced Impacts on Buildings:

> "Prior to issuance of grading permits, the Applicant shall be required to incorporate all mitigation measures and design recommendations relating to liquefaction contained within the preliminary and design level geotechnical reports prepared by Berlogar Stevens and Associates in 2019 and 2021 into relevant project plans and specifications.
>
> … The project site plans, with all geotechnical design measures incorporated, shall be submitted to the City and reviewed as part of the development review process."

The public's ability to ascertain whether the mitigation measures described in **MM GEO-2** are adequate because the impacts of rising groundwater on the liquefaction potential of the soils found within the project boundary have not been discussed in the DEIR or geotechnical appendices, nor is it possible with the available information, whether there could be additional impacts of the proposed project on the environment.

Fill Slope Stabilization

The DEIR fails to describe how the fill slopes will be stabilized post construction to ensure the project does not result in adverse impacts to adjacent habitats. **MM GEO-2** identifies the need to acquire a Stormwater Pollution Prevention Plan (SWPPP) from the San Francisco Bay Regional Water Quality Control Board (Water Board) to comply with the National Pollution Discharge Elimination System (NPDES) due to potential of "exposing unprotected soils to stormwater runoff," that could result in erosion and loss of topsoil, as well as impacts to waters of the U.S. and state.

There is however, no description of how the fill slopes will be stabilized post-construction. This information is crucial to informing the public and decision-maker's understanding of potentially significant and adverse impacts of the project on the environment. For example, how will the fill slopes be stabilized to prevent rilling and erosion during heavy rainstorms, which could have adverse impacts to water quality and waters of the U.S. and state, and to biological resources and beneficial uses.

DEIR also fails to described how the fill slopes will be protected from potential wave action as sea levels rise. The DEIR acknowledges the reasonably foreseeable exposure of the proposed development to flood inundation and sea level rise, but fails to provide any information on how the development slopes would be protected and stabilized. The techniques employed could have adverse impacts to biological resources and should be identified, analyzed and mitigated. As an example, if riprap were to be utilized, there could be adverse impacts to adjacent wetlands under flood inundation conditions, such as scour of adjacent wetlands from wave reflection[27]. Riprap of the fill slopes could also provide attractive habitat for nuisance species such as Norway and roof rats, which in turn could pose adverse impacts to wildlife and human health. It is imperative that the DEIR disclose how the fill slopes will be stabilized so any potential adverse impacts that result from the technology employed can be analyzed and mitigated.

For example, as mentioned above, riprap is known to attract nuisance species. Claffey et. al[28] reported a "widespread infestation of oceanfront riprap by roof rats (*Rattus rattus*) during the summer months of 1979 in Ventura County.

Along the edges of San Francisco Bay, the San Mateo County Mosquito & Vector Control District[29] advises "Norway rats use underground burrows and may be found on creek banks, shorelines, and sewer systems. They should be suspected if rats are seen entering burrows or tunnels in the ground."

Breaux[30] reported:

> "Rats which are found in San Francisco Bay marshes are more likely to be roof than Norway rats (Jurek, pers. comm.). Where urbanization abuts natural marshes as it does in many areas of the South Bay, and garbage provides a food supply, Norway rats are likely to find the marsh habitats quite hospitable. In 1927, DeGroot noted that reclaimed land behind dikes along the San Francisco Bay shoreline was responsible for an increase in rats and a decrease in native California clapper rails (*Rallus longirostris obsoletus*): "No sooner is a dyke constructed than Norway rats appear in great numbers. Large gray fellows they are, on a dark night appearing to be as large as small cotton-tail rabbits....The Clapper Rail has no more deadly enemy than this sinister fellow" (DeGroot 1927)." [emphasis added]

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[27] Berman, M.R., Nunez, K., Killeen, S., Rudnicky, T., Bradshaw, J., Hendricks, J., and Hershner, C.H. 2018. New Kent County, Virginia -Shoreline Inventory Report: Methods and Guidelines, SRAMSOE no. 469. Comprehensive Coastal Inventory Program, Virginia Institute of Marine Science, College of William and Mary, Gloucester Point, Virginia, 23062

[28] Claffey, Daniel P., Madon, Minoo B., Smith, Randall T. *An Integrated Pest Management Approach to Roof Rat Control in Oceanfront Riprap, Ventura County, California.* 1986. *Proceedings of the Twelfth Vertebrate Pest Conference (1986).*

[29] *Identification and Information.* San Mateo County Mosquito & Vector Control District. https://www.smcmvcd.org/rodent-identification-info

[30] Breaux, Andrée. Non-Native Predators: Norway Rat and Roof Rat *Rattus norvegicus* and *Rattus rattus* Goals Project. 2000. Baylands Ecosystem Species and Community Profiles: Life histories and environmental requirements of key plants, fish and wildlife. Prepared by the San Francisco Bay Area Wetlands Ecosystem Goals Project. P.R. Olofson, editor. San Francisco Bay Regional Water Quality Control Board, Oakland, Calif.

And:

> "Control of rats has not been implemented and continues to be a problem in the South Bay for endangered species, such as clapper rails and, quite possibly, salt marsh harvest mice (*Reithrodontomys raviventris*). Additional threats to other target species selected by this project as representative of wetland species in the San Francisco Bay region (e.g., California voles (*Microtus californicus*), ornate shrews *(Sorex ornatus californicus*), salt marsh wandering shrews *(Sorex vagrans haliocoetes*), and amphibians, reptiles, terrestrial invertebrates in general, and some ground nesting birds) probably occur."

Sufficient evidence exists to warrant concerns regarding the impacts of riprap installation on the endangered salt marsh harvest mouse and other adjacent wildlife such as nesting waterbirds. One such adverse impact is the difficulty in controlling nuisance species once they gain a foothold in an area. Breaux[31] states:

> "Control measures are difficult, since there is no poison specific to rats that is safe for endangered mammals, such as the salt marsh harvest mouse. Given the difficulties in any control programs (e.g., public outcry against removing feral cats and the difficulty of trapping or shooting these large rodents) the most effective control measure at this time is to protect marshes with large buffers, and to keep shelter and garbage far from the wetland edge."

As mentioned by Breaux, there is no control measure that would be specific to rats, that would not adversely impact small mammals, such as the endangered salt marsh harvest mouse, raptors, owls, and domestic pets that do not observe the prohibition against free-roaming pets. If the project proponent is proposing to incorporate the use of riprap into stabilization of the fill slopes, the public must have the opportunity to review and provide comments on the direct and indirect impacts that may result.

3.9 Hazards and Hazardous Materials

Emergency Response or Evacuation Plan (HAZ-6) Page 3-161 and Emergency Access (TRANS-4) Page 3-272

The project proposes to have a single point of ingress/egress at the existing at-grade crossing of the UPRR tracks at Mowry Avenue, for vehicles, bicyclists, and pedestrians. The potentially significant and adverse impacts of this single point of ingress and egress has not been identified, analyzed, and adequately mitigated. The public safety concerns regarding the single point of access are magnified by the fact that Mowry Avenue has an at-grade crossing of the UPRR tracks. This results in potential safety issues and potentially increases the time it will take for first responders (police, fire and medical professionals) to reach the proposed Mowry Village residents when the trains are crossing Mowry Avenue, or even longer delays when the trains are blocking the tracks while using the switching yard located just to the north of Mowry Avenue. No secondary or emergency access route is planned. The emergency response section of the DEIR fails to provide sufficient site details for a full analysis of the adequacy of emergency response or evacuation plan. The DEIR does not fully describe

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[31] Ibid.

the existing site conditions nor does it take into consideration the current and reasonably foreseeable future level of passenger (based upon the 2040 California Rail Network Vision[32]) and freight trains crossing Mowry Avenue.

The DEIR analysis concludes that the project complies with the General Plan's policies for grade-separated crossings despite the fact that it increases automobile, bicycle and foot traffic over the only point of ingress and egress, the existing at-grade crossing of the UPRR rail lines. The DEIR does not identify the two rail improvement plans proposed in the area or the 2040 California Rail Network Vision. These plans include the possibility of double or triple tracking and raising the tracks to adapt to sea level rise in the segment located 4,000 feet north of Mowry Avenue in Newark to Gold Street in Alviso to allow for expanded train service on the Union Pacific rail line crossing Mowry Avenue. The plan calls for increasing commuter rail traffic (Capitol Corridor and Altamont Commuter Express) to one trip every 30 minutes, in addition to the existing Amtrak passenger (Coast Starlight) and freight rail traffic traveling over Mowry Avenue. These train improvements must be identified and factored into the analysis of the impacts of the proposed project on public safety and the effectiveness of Mowry Avenue serving as the only point of ingress/egress to the 203 housing units. The three plans include – the Capitol Corridor South Bay Connect Study[33] exploring the rail corridor from San Jose to Oakland, the Alviso Wetland Railroad Adaptation Alternatives Study[34] evaluating the rail corridor from Santa Clara to Newark and the 2040 California Rail Network Vision.

The Alviso Wetland Railroad Adaptation Alternatives Study states,

"The Coast Subdivision traverses a low-lying, environmentally sensitive wetland area between the City of Newark and the community of Alviso that is subject to inundation with even a moderate amount of sea-level rise (please see Figure ES-1 below). Because the Coast Subdivision is the only passenger rail route connecting Alameda County with Santa Clara County, inundation of the rail line would disrupt passenger rail service between these counties, affecting thousands of travelers each day and causing train delays throughout the larger Northern California rail network.

Moreover, between Newark and Santa Clara, the majority of the Coast Subdivision consists of a single track, which limits the number of trains that can traverse this area. Additional tracks would be required to enable more passenger trains to operate on this section of the Coast Subdivision.[35]"

The Hazards and Hazardous Materials section of the DEIR fails to identify the site conditions at the Mowry crossing. The at-grade railroad crossing is described in the Transportation section of the DEIR which notes, "The crossing is a public, at-grade crossing with three tracks. Based on Federal Railroad Administration (FRA) data, about 24 trains use the tracks on a typical day, with a maximum speed of 60 mph." The three sets of tracks at the Mowry crossing lead into the switching area at the Newark Yard located immediately north of Mowry Avenue. The trains entering the switching yard sometimes block the Mowry Avenue crossing under current operations. The emergency access analysis in the

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[32]California State Rail Plan Connecting California. https://dot.ca.gov/-/media/dot-media/programs/rail-mass-transportation/documents/rail-plan/0-executive-symmarycsrpfinal.pdf
[33] Capitol Corridor South Bay Connect. https://www.southbayconnect.com/
[34] Capitol Corridor. The Alviso Wetland Railroad Adaptation Alternatives Study. https://images.capitolcorridor.org/wp-content/uploads/2020/02/CCJPA_Alviso-Wetland-Railroad-Adaptation-Alternatives-Study-Report_2020-02-10.pdf
[35] Capitol Corridor Joint Powers Authority. 2021. The Alviso Wetland Railroad Adaptation Alternatives Study

Transportation section focuses solely on the two vehicular access points, west of the railroad tracks, off of Mowry Avenue that extend into the actual development, **but fails to acknowledge that only one road, Mowry Avenue, links the proposed development to the rest of the City of Newark, and that road must cross the Union Pacific railroad tracks at-grade.** The fact that there is a single point of ingress and egress, that is frequently blocked by railroad traffic, is never mentioned in the emergency access discussion. The DEIR must identify and analyze the impacts on emergency access and response times that will result from constructing a housing development that has a single point of access, crossing railroad tracks at-grade.

In 2009, the Public Utilities Commission recommended a pedestrian overcrossing of the rail line. A pedestrian overcrossing does not solve the issue of (emergency) vehicle access but does solve the issue of safety for pedestrians and bicyclists traveling between the proposed Mowry Village development and all other areas in the City of Newark. The Mowry Village project makes no such pedestrian and bicycle improvements. Instead, the project relies solely on a new pedestrian crossing arm at the tracks.

The DEIR analysis must include these important site characteristics in the environmental setting, evaluate existing and future train trips crossing Mowry Avenue and analyze whether adequate police, fire and medical emergency response times can be achieved with only one access to this proposed development. The DEIR must also further consider the impacts of the proposed project on the safety of pedestrians and bicyclists crossing the existing triple tracks with the proposed increased rail service.

Toxics:

The DEIR notes that in some areas, "Additionally, contaminated groundwater was detected at the project site. Soil gas samples were planned to be collected for the preparation of the Phase II ESA; however, soil gas samples could not be collected at the site due to the presence of perched groundwater (page 2-34)." It is obvious from the soil and groundwater tests pits excavated in January 2019 (a drought year), the wetland vegetation on the adjacent parcels, the proximity of the tidal slough and the ponded water that appears on the adjacent parcels in the winter that groundwater levels are shallow and are modeled to become emergent as sea levels rise. How will rising groundwater impact the geotechnical mitigation measures proposed for building foundations, utilities and legacy toxins remediation?

3.10 Hydrology and Water

3.10.1 Environmental Setting - Flooding

The DEIR states that, "*Flood hazard zones are identified on official Flood Insurance Rate Maps issued by the Federal Emergency Management Agency. The project site is designated as Zone X and Zone X (Shaded). The northern part of the project site is within an area of minimal flood hazard (Zone X); however, the majority of the project site is located in an area with a 0.2 percent annual chance of shallow flooding of less than one foot (Zone X Shaded) (FEMA 2021) (*page 3-163)." When checking the Flood Insurance Rate Maps on the FEMA website it appears as though the last time the map was updated for the project area was August 3, 2009 (Effective date 8/3/2009 for map 06001C0443G).

Many FEMA maps do not reflect the current realities of the changing climate and resulting severity of flooding. What is the effective date of the map used for analysis in the DEIR? Is this map suitable to use as the basis for the DEIR analysis? The most current mapping available must be used for assessing for assessing flood impacts?

3.10.1 Environmental Setting - Sea Level Rise

The DEIR states that "According to the Areas 3 and 4 Specific Plan RDEIR, the most currently available estimates for sea level rise by 2050 range from 0.3 foot to 1.5 feet, and by 2100 from 0.6 foot to 4.8 feet (page 3-164)." Please note that the Areas 3 and 4 Specific Plan RDEIR was prepared in 2009, certified in 2010, and later set aside by the courts. The RDEIR was recirculated in 2014 and certified in 2015. However, the majority of the baseline and analysis in the RDEIR dates back to 2009, fourteen years ago. Because the RDEIR evaluated a specific plan that will not be built – the proposed project would require significant Specific Plan amendments – the RDEIR analysis of environmental effects cannot be relied upon for the proposed project.

The 2022 State Agency Sea-Level Rise Action Plan for California states "***SLR adaptation planning should include pathways to resiliency to 3.5' by 2050 and 6.0' by 2100.*** *These numbers represent a set of consistent targets for the minimum of SLR planning and preparation. They demonstrate an elevated risk scenario that should be considered for long-term and large-scale planning but may not be applicable for every localized planning or project design. Best available science, such as the State Sea-Level Rise Guidance, should be consulted to determine which sea-level rise scenarios are most appropriate, which is context dependent. While the 3.5' and 6.0' targets may not be feasible for all situations, planners should consider adaptation pathways to this level of resiliency, as a way to prepare for all predicted SLR impacts. Critical infrastructure (highways, bridges, water treatment plants, etc.) should consider higher SLR scenarios, as appropriate, based on State Guidance.* ***New and redevelopment in the coastal zone should utilize these targets as consistent minimum criteria for planning for the impacts of SLR (page 6).[36]"*** See https://www.opc.ca.gov/webmaster/_media_library/2022/02/Item-7_Exhibit-A_SLR-Action-Plan-Final.pdf

The Ocean Protection Council's most recent state guidance for planning for sea level rise was released in 2021 indicating that, *"Sea level rise poses a significant threat to the state's infrastructure located within and near the coast. Based on the current best available science, the Ocean Protection Council's State of California Sea-Level Rise Guidance and the California Coastal Commission Sea Level Rise Policy Guidance recommend evaluating the expected impacts to critical infrastructure that would be caused by approximately 10 feet of sea level rise by 2100 (using what is known as the extreme risk or "H++" scenario) along with other sea level rise scenarios. In addition, in May 2020, the Commission adopted Making California's Coast Resilient to Sea Level Rise: Principles for Aligned State Action (State SLR Principles)* ***which calls for addressing a minimum of 3.5 feet of sea level rise in the next 30 years.[37]"*** These state recommendations differ significantly from those used in the RDEIR.

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[36] Sea-Level Rise Leadership Team. (January 2022). State Agency Sea-Level Rise Action Plan for California.

[37] The California Coastal Commission's Critical Infrastructure at Risk: Sea Level Rise Planning Guidance for California's Coastal Zone was unanimously adopted by the California Coastal Commission on November 17, 2021.

The guidance further states that, *"Because of the uncertain timing but very significant consequences of extreme rates of sea level rise, the State of California Sea-Level Rise Guidance (OPC 2018) recommends analyzing the H++ scenario for* ***"projects with a design life beyond 2050 that have little to no adaptive capacity, would be irreversibly destroyed or significantly costly to relocate or repair, or would have considerable public health, public safety, or environmental impacts.[2]"*** The Mowry Village development is hopefully planned to have design life beyond 2050 (homes should last more than 27 years as a typical mortgage is written for 30 years) and would indeed have no adaptive capacity to be moved inland.

It should also be noted in the baseline site conditions that the 29-acre site is situated at the confluence of Alameda County Flood Control & Water Conservation District (ACFC&WCD) Line B and Line D and Mowry Slough. These three watercourses are located on three sides of the proposed development. This area is subject to stormwater flooding flowing down Lines B and D and tidal flooding extending from SF Bay into Mowry Slough. In January 2023 Line D overtopped and flooded the city owned lands adjacent to the Pick-n-Pull site. The San Francisco Estuary Institute recently identified this site for groundwater emergence with as little as 12 inches of sea level rise[38]. See https://sfei.maps.arcgis.com/apps/instant/portfolio/index.html?appid=2ab0c998497f4f7398aa54f176a6fb26

It is critical that in evaluating suitability of the land to support development, and the sustainability of the development to fulfill the design life of a residential project, that all factors influencing site hydrology be explored collectively. OPC's guidance also identifies the hazards associated with sea level rise. "*Sea level rise is expected to increase storm flooding, coastal erosion, tidal inundation, submergence of nearshore lands, groundwater rise, and seawater intrusion. Figure 1 provides examples of how sea level rise can exacerbate these coastal hazards. While each is discussed separately below, when hazards cooccur in space and time, as is often the case along the shoreline, vulnerabilities can increase significantly.[2]*" The project site is located in an existing FEMA floodplain subject to storm flooding, surrounded by watercourses on three sides and ponded water in the winter months, and overlays shallow groundwater. The flood inundation threat posed by each and all of these factors will be magnified as sea levels continue to rise. The DEIR must evaluate the co-occurrence of these hazards and the projections for sea level rise at the Mowry Village site to identify impacts and to develop feasible mitigation measures to hydrology, geology and soils and hazardous materials. *See*, 14 C.C.R. § 15126.2.

Project Inundation (HYD-4) and Expose People or Structures (WF-4)

The DEIR states that:

> "The proposed project would use clean imported fill to elevate the proposed pad grades for the homes and would have a minimum pad elevation of 13.0 feet NGVD and an average pad elevation of 14.2 feet NGVD. Therefore, the proposed project would be above the FEMA 100-year flood plain elevation of 9.3 feet which would provide the project site with flood damage

[38] May, C. L.; Mohan, A.; Plane, E.; Ramirez-Lopez, D.; Mak, M.; Luchinsky, L.; Hale, T.; Hill, K. 2022. Shallow Groundwater Response to Sea-Level Rise: Alameda, Marin, San Francisco, and San Mateo Counties. Pathways Climate Institute and San Francisco Estuary Institute.

> protection. The proposed pad grades would exceed the City's standards for residential structures located in a flood hazard zone which requires a minimum pad elevation of 11.25 feet and would be above the BCDC minimum pad elevation recommendation for sea level rise guidance of 12.2 feet." [emphasis added]

The DEIR acknowledges that the proposed project is located in an area that will be subject to a reasonably foreseeable risk of flood inundation and proposes to mitigate the threat to public safety by raising the building pads to "ensure that the proposed project would not be inundated by potential sea level rise anticipated to affect the area in the future (page 3-178)." However, there is no proposal to raise the only roadway serving the development. Mowry Avenue is to remain at the existing elevation ranging from approximately 8 to 11 feet. The reasonably foreseeable inundation of Mowry Avenue and impacts to public safety are not evaluated or mitigated within the DEIR. How will residents access or leave their homes in the event of flooding, tidal inundation or groundwater emergence? Note, that storm-related flood waters will eventually recede, but rising sea levels will not. The DEIR fails to identify, analyze or mitigate the potential flooding of Mowry Avenue and the impacts to public safety. *See*, *Cal. Bldg. Indus. Ass'n. v. Bay Area Air Quality Mgmt. Dist*., 62 Cal. 4th 369, 392 (2015).

Project Inundation (HYD-3) – Impede or Redirect Flood Flows/Loss of Flood Accommodation Space

A 2021 study, "Economic evaluation of sea-level rise adaptation strongly influenced by hydrodynamic feedbacks" (Hummel et al.)[39] suggests that the impacts of removing flood accommodation space or building seawalls or levees in one region of SF Bay may increase flood risk and associated economic costs in other Bay Area communities. As sea levels rise, the study's authors point out that building new flood walls to protect development (existing and proposed) from sea level rise can significantly alter where water can move — and could result in flooding not only in adjacent communities, but all the way across the Bay.

In particular, the study examined the loss of flood accommodation space through the placement of fill or building of flood walls in Newark within the Mowry (Slough) Operational Landscape Unit (OLU). It would lead to increased flooding throughout the Bay, with as many as 14 different sections of San Francisco Bay experiencing increased flooding, with a price tag of $194 million in increased flooding damages.

The DEIR has failed to assess whether creating a fill pad on the 29-acre site that raises the elevation of the project to 14.2' NGVD will displace floodwaters to other areas of Newark or to adjacent communities, or wetlands. The DEIR fails to identify, analyze and mitigate the potential to displace floodwaters that results from importing approximately 252,000 CY (page 2-35) of fill to raise the building pad elevations.

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[39] Hummel, M. A., Griffin, R. , Arkema, K. , & Guerry, A. D. (2021). Economic evaluation of sea-level rise adaptation strongly influenced by hydrodynamic feedbacks. Proceedings of the National Academy of Sciences. https://www.pnas.org/doi/10.1073/pnas.2025961118

The Hummel et al study also points out that in strategic locations, if Bay waters are allowed to move inland, flooding around the rest of the Bay can be minimized as sea levels rise. It is critical that Newark consider "nature-based solutions" to rising sea levels that include maintaining the Newark baylands as accommodation space for floodwaters and rising sea levels. The lands west of the UPRR tracks are noted in the study for the ability to reduce flood risk for the immediate community as well as other regions of the Bay. The study specifically highlights the Mowry OLU in which Pick-n-Pull is located as a key location for allowing Bay waters to move inland, saying, "strategic flooding in these areas could provide substantial regional benefits," and that the idea of walling off this section of the shoreline (such as with new development) is "difficult to justify from a regional economic perspective." The impacts resulting from the creation of an elevated fill pad for the proposed development is similar to the creation of a flood wall as the fill pad will result in the redirection of flood flows and the loss of flood accommodation space.

Project Inundation (HYD-3), Growth Inducing Impacts (Section 6.1) and Coastal Squeeze

The Mowry Village project proposes the extension of utilities (electrical, water, sewer and broadband services) and the placement of significant fill into the Newark baylands. Will the Mowry Village project induce growth, more development, that would bring along with it more fill placed on the 100-year floodplain, and further reduce the potential of the Newark baylands to accommodate floodwaters and sea level rise? The extension of utilities into an area currently without services, the widening of Mowry Avenue, and the placement of fill have the potential to both induce growth and exacerbate coastal squeeze, the loss of natural habitats or deterioration of their quality arising from anthropogenic structures or actions which prevent the landward transgression of those habitats that would otherwise naturally occur in response to sea level rise in conjunction with other coastal processes. The DEIR must identify, analyze and mitigate the grow inducing impacts and identify and evaluate the loss of flood accommodation space on coastal squeeze. The DEIR's reliance on the RDEIR for this analysis is improper, since the RDEIR evaluated a different number and location of development units than the proposed Project.

Groundwater

The DEIR acknowledges "Historically high groundwater at the project site has been reported at 5 feet below ground surface (bgs) and based on the preliminary investigations and borings conducted at the project site, groundwater is estimated to be at a depth of 4 to 8.5 feet bgs (Berlogar, Stevens, and Associates 2019). Groundwater could be encountered during excavation activities and require dewatering (page 3 – 173)." The San Francisco Estuary Institute recently identified this site for groundwater emergence with as little as 12 inches of sea level rise[40]. See https://sfei.maps.arcgis.com/apps/instant/portfolio/index.html?appid=2ab0c998497f4f7398aa54f176a6fb26

The DEIR also recognizes "The proposed project is identified to be located in an area where there is potential for liquefaction and expansive soil hazards (page 3-121)." How will rising groundwater levels

[40] May, C. L.; Mohan, A.; Plane, E.; Ramirez-Lopez, D.; Mak, M.; Luchinsky, L.; Hale, T.; Hill, K. 2022. Shallow Groundwater Response to Sea-Level Rise: Alameda, Marin, San Francisco, and San Mateo Counties. Pathways Climate Institute and San Francisco Estuary Institute.

impact the potential for liquefaction? The DEIR fails to disclose if Mitigation Measures Geo-1, Geo-2 and Geo-3 incorporated an analysis of rising groundwater impacts on the feasibility and effectiveness of these mitigation measures.

Groundwater Management (HYD-2) and Unstable Geologic Unit Soil (GEO-3)

As noted above, the DEIR acknowledges "Historically high groundwater at the project site has been reported at 5 feet bgs and based on the preliminary investigations and borings conducted at the project site, groundwater is estimated to be at a depth of 4 to 8.5 feet bgs (Berlogar, Stevens, and Associates 2019). Groundwater could be encountered during excavation activities and require dewatering (page 3 – 173)." As such the DEIR calls for "Mitigation Measure GEO-3 which requires the preparation and implementation of a dewatering plan in accordance with the waste discharge requirements of the RWQCB (page 3 – 173)." Dewatering activities could impact the wetlands immediately south and east of the site, and yet the DEIR has no analysis of the potential impacts to wetlands and provides no information as to whether any potential impacts would be mitigated through the RWQCB dewatering plan. Additionally, no information is provided in the DEIR on the anticipated duration of the dewatering process needed to support cleanup of groundwater contaminants and construction of the project.

Surface and Groundwater Quality (HYD-1)

"In accordance with the Corrective Action Plan issued for the proposed project, the impacted groundwater would be exposed via remedial excavation and treated with the rapid chemical oxidizing agent PersolfOx as well as a time-released oxygen release compound (ORC) to treat residual levels of benzene, toluene, ethylbenzene, and xylenes (BTEX) after the excavation has been backfilled. ORC will be added to any remedial excavation that extends to groundwater elevation. Benzene in soil gas would be released during the remedial soil excavation process (page 2-34)." What impact could PersulfOx as well as a time-released oxygen release compound (ORC) have on the Niles Cone Aquifer and the nearby Newark Desalination Facility which draws from and treats brackish groundwater to create drinking water? Have these chemicals been used in or near a drinking water aquifer? What is the anticipated persistence and degradability of these chemicals? Have these chemicals been used in a drinking water basin? The site is part of the Niles Cone Aquifer and the Newark Desalination Facility, which treats brackish groundwater, is located at Cherry Street and Central Avenue. Would these chemicals interfere with the reverse osmosis system at the Newark Desalination Facility? The DEIR fails to identify and analyze the potential for impacts from the groundwater remediation plan to the aquifer and nearby drinking water facility.

3.11 Land Use and Planning
Conflict with Plans, Policies, or Regulations (LU-2)

The DEIR indicates that "The proposed project lies within Sub Area D of Area 4 and is designated for a golf course or other recreational uses. The proposed project is not consistent with the land use mapping identified by the Areas 3 and 4 Specific Plan (page 3-183)." The DEIR also states that "The project site is zoned as Park. The project is proposing to rezone the project site from Park to PD-RS-6000 (page 3-181)." The project proposes to rezone the 29-acre site to low density residential. As stated in the DEIR, the Superior Court of the State of California in and for the County of Alameda ruled that all references to the 2013 General Plan Tune Up Program EIR shall refer to the Newark Areas 3 and 4 Specific Plan Project Recirculated Environmental Impact Report, including all references to the Areas 3 and 4 Specific Plan EIR for the purposes of environmental baseline, environmental analysis and mitigation measures. The Mowry Village project is inconsistent with the current land use and zoning for park and recreation, and Newark will lose 29 acres of future park or open space land if the project is constructed.

Goal LU-7 Southwest Newark and Policy LU-7.6 Open Space Amenities requires including a major open space and recreation amenity. The DEIR states the Mowry Village project is consistent with this policy as it provides 4.89 acres of open space that would provide limited recreational opportunities to the residents of the project (page 3-189). There is no basis for this DEIR conclusion and it cannot be substantiated. **In fact, the loss of 29 acres of public park and recreational land – "a major open space and recreational amenity" – is inconsistent with these specific land use policies and represents a significant and unavoidable impact from the Mowry Village project.**

Let us be clear, these 4.89 acres do not equal the 29 acres that will be lost. It is also disingenuous to even identify these 4.89 acres as public open space as required in the current Specific Plan. On Page 3-248, the DEIR states "A majority of the on-site open space would be provided through private open space, provided as a rear yard for each home. However, the proposed project includes the development of 0.94 acres of common open space through the construction of a pocket park, landscaping, and bioretention areas." On Page 2-13 the DEIR reads "The proposed project would also provide a rear yard for each home, resulting in a total of 172,120 square feet (3.95 acres) of private open space." Backyards, required bioretention areas and adjacent landscaping do not create usable park or open space land for Newark residents. The Mowry Village project costs Newark 29 acres of future park or open space land. These details found in other sections of the DEIR should be used in the analysis of the land use goals and policies. Mowry Village is not consistent with the previously approved Newark Areas 3 and 4 Specific Plan Project Recirculated Environmental Impact Report. Mowry Village results in the irretrievable loss of 29 acres of future park or open space lands.

Furthermore, the environmental review of the impacts of the Area 3 & 4 Specific Area Plan tied its determination of consistency, of the proposed Specific Area Plan to the General Plan, on a project description that included a 120-acre golf course or other recreational facility. The DEIR analyzes the impacts of the proposed development on parks/open space within the 29-acre footprint but fails to analyze the consistency of the project with the Specific Area Plan that is reliant upon the incorporation of a 120-acre golf course or other recreational facility (100-acres of the 120-acres is within an area entitled Sub Area D, which includes all of the Mowry Village site) in its determination of consistency between the Specific Area Plan and the General Plan.

FREIR Area 3 & 4 Specific Area Plan (Land Use):

> "Policy LU-1.9 Park and Recreation Expansion.
>
> Expand park and recreational lands and facilities to keep pace with population growth and support the leisure time needs of Newark residents.

The Specific Plan proposes park and recreational facilities including a golf course and preserved open spaces within Area 4 and a nine-acre school/park site in Area 3. The City of Newark has an adopted Parkland Dedication Ordinance, which requires that new residential development either dedicate sufficient space to serve new residents, or pay fees calculated to offset the increased costs of providing new park facilities for new development.

Development within the Specific Plan would meet the requirements for the Parkland Dedication Ordinance on-site. The project is consistent with this policy." [emphasis added]

DREIR p. 301 (Parks and Recreation):

"Area 4 of the Specific Plan includes approximately 2.5 acres of park and trails and approximately 120-acre for a golf course."[emphasis added]

"3.11.4 Conclusion
The project will incrementally increase the demand for public services in the project area. The project would not, however, result in substantial adverse physical impacts associated with a need for new public safety, recreational or educational facilities in order to maintain acceptable levels of service. (Less than Significant Impact)" [emphasis added]

DREIR p. 381 (Additional Economic Growth):

"The proposed development would generate tax revenues for the City of Newark. The project will require services that would increase expenditures for City departments. The project would not require the construction of new community facilities. As discussed in Section 3.11 of this document, all of the public facilities are adequate to serve the proposed Specific Plan. The City of Newark will provide police and fire protection. The proposed project would include recreational facilities, which will reduce the residential development's demands on local parks and recreation." [emphasis added]

DREIR p. 55 (Land Use):

"Policy LU-7.6 Open Space Amenities – Include a major open space and recreational amenity within the Southwest Newark Residential and Recreational Project boundary. The preferred amenity is an 18-hole golf course with clubhouse. The former solid waste disposal site at the west end of Mowry Avenue should be considered for inclusion in the Golf Course site. In the event a golf course is deemed infeasible, then another recreational use that is acceptable to the city shall be provided through developer fees. In addition, development in this area shall provide for neighborhood parks consistent with the ratios established by the General Plan.

In the event a golf course is developed, its design should minimize disturbance of sensitive natural resources. To the extent feasible, the golf course should contain natural habitat such as native grassland and native trees rather than non-native grass and non-native vegetation.

Consistency - The Specific Plan proposes a golf course, open space areas, and parks and trails on the southwestern side of the city. The golf course will be designed to protect the natural resources, particularly sensitive habitats and include unmaintained native grasses in the outer roughs that require very little water and infrequent mowing. If a golf course is found infeasible, then another recreational use that is acceptable to the City, and undergoes environmental analysis, shall be provided as part of the Specific Plan development. The project is consistent with this policy." [emphasis added]

DREIR p. 64 (Land Use):

Policy PR-2.2: Parks in New Development. Require new parks to be provided within largescale new development. Where the provision of an on-site park is infeasible, require the payment of an in-lieu fee for parkland acquisition to serve that development.

Consistency - The Specific Plan includes a minimum of five acres of public recreational uses, including parks and trails, throughout Areas 3 and 4. Additional public recreational space, such as playfields, would be provided at the Area 3 school site. The Specific Plan also includes an approximately 120-acre golf course, or if that is infeasible, another recreational facility. The project will comply with the City's adopted Parkland Dedication Ordinance, which requires that new residential development either dedicate sufficient space to serve new residents, or pay fees calculated to offset the increased costs of providing new park facilities for new development. Development within the project would meet the requirements for parkland dedication ordinance on-site." [emphasis added]

As stated above, the determination of consistency between the Areas 3 and 4 Specific Plan and the General Plan was based upon a project description that included a "120-acre golf course or other recreational facility." The Mowry Village DEIR must analyze its impacts not only on the impacts to park and recreational facilities based on development of the 29-acre project site, but also within the larger context of the impacts to the consistency determination between the Areas 3 and 4 Specific Plan and the General Plan.

Policy LU-7.1 Southwest Newark – The DEIR indicates the Mowry Village project will require a Specific Plan Amendment and rezoning to allow the project site to be developed with residential uses and provide additional residential units above the holding capacity specified in the Newark Areas 3 and 4 Specific Plan (Page 3-189). Mowry Village cannot be deemed consistent with the Specific Plan if the project requires amendments and rezoning to modify the Specific Plan previously adopted by the City Council. It is also unclear why the holding capacity of 1,260 housing units must be increased. The Area 3 site is fully developed at 386 units and the Area 4 plan is listed in the 2023-2031 Housing Element Update at 431 units. Even if the 6-acre school site in Area 3 were to develop as low medium residential (8.7 to 15 units/acre) thus adding another 90 homes to Area 3 the total units constructed or proposed in Areas 3 and 4 would be 907. The 203 units proposed with Mowry Village would bring the 1,110 units far short of the 1,260. The DEIR should clarify why the 1,260 "holding capacity" must increase by 203. Insofar as a Specific Plan amendment is necessary, and undertaken by the City, then the Specific Plan would be inconsistent with the General Plan, which specifically states that "The residential holding capacity of this area **shall be** 1,260 units" (emphasis added). *See*, Napa Citizens for Honest Government v. Napa County Bd. Of Supervisors (2001) 91 Cal.App.4th 342, 389 ["If the Updated Specific Plan is inconsistent with the General Plan, the Updated Specific Plan is invalid; but the General Plan is unaffected"].) Any inconsistency with the General Plan renders the proposed

Project Specific Plan amendments invalid. *See*, Lesher Communications, Inc. v. City of Walnut Creek (1990) 52 Cal.3d 531, 541 ["The general plan is the charter to which the ordinance must conform."])

3.19 Utilities and Services – Water Supply (UTIL-2)

The DEIR states, "The 2020 – 2025 UWMP identified that under normal year water supply conditions, ACWD would have sufficient supplies to meet projected water demands and that during these conditions, ACWD would have sufficient supplied available in excess of the projected demands for placing into groundwater storage for later use in the area in dry years (ACWD 2021a). During critically dry and multiple dry years, the ACWD service area may be facing water supply shortages. Because the Areas 3 and 4 Specific Plan's demands are already factored into the UWMP, the development of these 203 homes would not result in increased shortages, during normal and dry years, beyond those which are already factored into ACWD's planning under current and foreseeable conditions (City of Newark 2014) (page 3-282)."

The Areas 3 and 4 Specific Plan water supply was based on 1,260 housing units and a golf course. The golf course was to be supplied by existing on-site wells and recycled water which did not draw from the potable water allotment identified for the Specific Plan project. The Mowry Village DEIR states "the development of the proposed project's 203 residential units would not be within the Specific Plan allocated residential units of 1,260 units and would be above the allowed number of units for the Specific Plan area (page 2-7)." This contradicts the statements made in the Water Supply section. The 203 residential units are not in the WSA and the golf course was never intended to be part of the potable water demand. The DEIR must address this contradiction and analyze the impact on the water supply.

Cumulative Impacts:

As we stated earlier, the Mowry Village Project will exacerbate coastal squeeze, the loss of natural habitats or deterioration of their quality arising from anthropogenic structures or actions which prevent the landward transgression of those habitats that would otherwise naturally occur in response to sea level rise in conjunction with other coastal processes. The proposed project will also result in the loss of flood accommodation space. The DEIR must identify, analyze and mitigate the individual and cumulative coastal squeeze impacts of the project, as well as the individual and cumulative impacts of the proposed project on flood accommodation space.

"The cumulative impact from several projects is the change in the environment which results from the incremental impact of the project when added to other closely related past, present, and reasonably foreseeable probable future projects." *Golden Door Props., LLC v. Cty. of San Diego*, 50 Cal. App. 5th 467, 527 (2020), quoting CEQA Guidelines § 15355, subd. (b). "'[C]onsideration of the effects of a project or projects as if no others existed would encourage the piecemeal approval of several projects that, taken together, could overwhelm the natural environment . . . . This would effectively defeat CEQA's mandate to review the actual effect of the projects upon the environment.' The agency must interpret this requirement to 'afford the fullest possible protection of the environment.'" *Id.*, quoting *Las Virgenes Homeowners Fed'n v. Cty. of L.A.*, 177 Cal. App. 3d 300, 306 (1986); *Friends of the Eel River v. Sonoma Cty. Water Agency*, 108 Cal. App. 4th 859, 868 (2003).

Further, "[t]he greater the existing environmental problems are, the lower the threshold should be for treating a project's contribution to cumulative impacts as significant." *Cmtys. for a Better Env't v. Cal. Res. Agency*, 103 Cal. App. 4th 98, 120 (2002).

The DEIR must analyze the impacts of the project both individually and cumulatively on the availability of low-lying flood accommodation space that provides flood storage and potential for tidal wetlands to move inland as sea levels continue to rise. The adverse impacts associated with coastal squeeze are the impacts of the project on the environment, as the proposed project will directly limit tidal marsh migration space due to the elevation of 29-acre project site through the import of 252,000 cubic yards of fill. Areas that can support the inland movement of Bay habitats as sea levels continue to rise, are scarce within the South Bay.

Silva et al[41], define coastal squeeze as "…a process in which rising sea levels and other factors, such as hard infrastructure, cause loss of space in both directions – land and sea – and where the ecosystems no longer have the necessary conditions to maintain the essential functions."

Borchert et al[42] open their scientific paper regarding the potential of coastal wetlands to adapt to sea level rise by migrating landward and the challenges posed by coastal squeeze, with the following statement:

> "Climate change adaptation efforts are particularly important in low-lying coastal regions that are threatened by rising seas (Hinkel et al., 2014; Nicholls, Hoozemans, & Marchand, 1999; Titus et al., 2009). As global temperatures continue to increase, warming oceans coupled with melting ice sheets and glaciers are expected to accelerate the rate of sea level rise (Church et al., 2013; Sweet et al., 2017). Coastal and estuarine ecosystems are particularly vulnerable to accelerated sea level rise (Ellison, 2015; Kirwan & Megonigal, 2013; Nicholls & Cazenave, 2010; Scavia et al., 2002; Thorne et al., 2018). <u>Climate-smart conservation efforts along the coast can increase the adaptive capacity of valuable coastal ecosystems and also protect coastal communities from the harmful impacts of sea level rise</u> (Arkema et al., 2013; Duarte, Losada, Hendriks, Mazarrasa, & Marbà, 2013; Spalding et al., 2014; Stein et al., 2014)." [emphasis added]

The authors go on to explain why the loss of coastal wetlands to coastal squeeze is concerning:

> "Coastal wetlands are highly productive ecosystems that provide many benefits to society, including erosion control, coastal protection during storms, water filtration, flood reduction, carbon sequestration, recreational opportunities and maintenance of productive coastal fisheries (Barbier et al., 2011; Costanza et al., 2014; Morgan, Burdick, & Short, 2009; Sutton-Grier, Wowk, & Bamford, 2015)."

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[41] Silva, R., Martínez, M. L., van Tussenbroek, B. I., Guzmán-Rodríguez, L. O., Mendoza, E., & López-Portillo, J. (2020). A framework to manage coastal squeeze. *Sustainability*, *12*(24), 10610.

[42] Borchert, S. M., Osland, M. J., Enwright, N. M., & Griffith, K. T. (2018). Coastal wetland adaptation to sea level rise: Quantifying potential for landward migration and coastal squeeze. *Journal of applied ecology*, *55*(6), 2876-2887

The authors then state:

> "To maximize the adaptive capacity of coastal wetlands, there is a pressing need in many estuaries to better identify, manage and protect low-lying, undeveloped lands that could facilitate the landward migration of these ecosystems (Ellison, 2015; Lester & Matella, 2016; Rogers, Saintilan, & Copeland, 2014; Wigand et al., 2017)." [emphasis added]

The 2022 San Francisco Estuary Partnership (SFEP) "*2022 Estuary Blueprint*,"[43] (Estuary Blueprint) also known as the "*Comprehensive Conservation and Management Plan*," (CCMP) was developed to "establish priorities and guide decisions to address a range of environmental issues for the Estuary." The San Francisco Estuary Partnership was "established in 1988 by the State of California and the U.S. Environmental Protection Agency under the Clean Water Act's National Estuary Program when the San Francisco Estuary was designated as an estuary of national significance." SFEP is a "collaboration of local, state, and federal agencies, NGO's, academia, and business leaders working to protect and restore the San Francisco Bay-Delta Estuary."

One of the Action Items identified in the Estuary Blueprint, is that tidal marsh habitat be protected, restored, and enhanced. Task 10-3 states:

> "Protect San Francisco Bay historical Baylands (including both tidal marsh and non-tidal wetlands and waters within the historical Bay margins) to preserve and enhance tidal habitats and adjacent habitats to allow for migration with sea level rise."

Under the Overview of this Action Item, the Estuary Blueprint states, "Tidal marshes offer diverse ecosystem services to the San Francisco Estuary and its communities through their abilities to provide habitat for wildlife, stabilize shorelines, prevent erosion, absorb stormwater, and store carbon."

Action Item 11 of the Estuary Blueprint - "Protect, restore, and enhance estuarine-upland transition zones and adjacent upland ecosystems" is as the title explains – focused on transition zones and adjacent upland areas. The description provides further explanation of this Action Item:

> "Include protection of adjacent upland ecosystems and diked historic baylands where feasible and appropriate. Integrate transition zones and adjacent upland ecosystems into restoration and enhancement projects in the Estuary to provide both migration space and high water refugia."

Task 11-2 states:

> "Protect transition zones, adjacent upland areas, and diked historic baylands for wetland migration space, based on identified needs and opportunities, through acquisition of fee title, partnerships to develop conservation easements, or other management agreements."

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[43] 2022 San Francisco Estuary Blueprint (Comprehensive Conservation and Management Plan for the San Francisco Estuary). San Francisco Estuary Partnership: San Francisco, CA.

The San Francisco Bay Joint Venture (SFBJV), is a "public-private partnership with a mission to protect, restore, increase, and enhance habitats throughout the San Francisco Bay region for the benefit of birds, other wildlife, and people. The opening remarks to "*Restoring the Estuary*"[44] note:

> "…we are at a time of rapid change, emerging challenges and an ever-increasing need to respond with urgency. How we approach the next 10-15 years will be pivotal in determining the health and resilience of the San Francisco Estuary much further into the future.
>
> This framework outlines a well-researched and achievable vision for the restoration of the Estuary and other important habitats throughout the SFBJV region. It embraces and expands upon the 2015 Baylands Ecosystem Habitat Goals Update, while working in concert with other regional plans like the 2022 Estuary Blueprint to provide needed guidance to those in and beyond our partnership who will be carrying on this work in the years ahead." [emphasis added]

"*Restoring the Estuary*" similar to the Estuary Blueprint, recognizes the critical need to protect low-lying, adjacent upland areas for tidal marsh migration space, and that such areas are crucial to the current and future resilience of the Bay ecosystem and for our communities. *"Restoring the Estuary*" sets as a goal, the protection of adjacent uplands:

> "…adjacent uplands are being explicitly called out for their important role in long-term estuarine resilience to sea level rise. Specifically, these uplands provide potential spaces for marshes to move landward as sea levels rise, also referred to as "marsh migration space." Under higher rates of sea level rise, these uplands may be the few remaining places where marsh habitat can persist."[emphasis added]

The Mowry Village DEIR dismisses the need to analyze the contribution of the project to coastal squeeze. The DEIR states:

> "The proposed project could have the potential to exacerbate coastal squeeze which is defined as the loss of natural habitats or deterioration of their quality arising from placement of structures along the shoreline, preventing the landward transgression of those habitats that would naturally occur in response to sea level rise. However, given the baseline condition of the project site as already developed with existing structures, development of the proposed project would not exacerbate potential coastal squeeze impacts beyond what is already present. Therefore, this would not be a driving impact for the proposed project."

The baseline condition for a portion of the project site is indeed developed; however, the entirety of the site is currently at the proper elevation to provide tidal marsh migration space if the site were restored, thereby providing ecosystem and resilience benefits such as carbon sequestration and flood accommodation. The DEIR must evaluate the individual and cumulative impacts of the project and of past, current, and reasonably foreseeable projects that will result in the loss of tidal marsh migration space that will exacerbate coastal squeeze and squander the opportunity to provide resilience benefits for the existing community.

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[44] San Francisco Bay Joint Venture. 2022. Restoring the Estuary - A Framework for the Restoration of Wetlands and Wildlife in the San Francisco Bay Area. Richmond, CA.

Closing Remarks:

Based upon our review of the information provided in the DEIR and its technical appendices, we find that the DEIR is flawed, and there are many substantive issues that must be addressed. These issues must be rectified prior to issuance of a final environmental impact report (FEIR). However, there is a significant and overarching concern that the project location is simply not suitable for development. On September 18, 2023, a Joint Comment Letter was submitted by local and regional environmental groups regarding the unsuitability of the proposed project site for construction of housing due to the threat of flooding posed by sea level and groundwater rise, and because of the proximity of the site to significant wildlife habitat. We urge the City to give due consideration to these concerns and consider an alternative location that is located closer to transit hubs and will not be susceptible to rising sea and groundwater levels.

The DEIR acknowledges the reasonably foreseeable flood inundation that could occur with rising sea levels, but fails to analyze the impacts of elevating the building pads of the proposed development to 14.2’ NGVD, while the single point of ingress and egress will remain at an average elevation of 9’ NGVD.

The proposed project is inconsistent with current state guidance that states “SLR adaptation planning should include pathways to resiliency to 3.5’ by 2050 and 6.0’ by 2100 (page 8).”[45] The proposed project will place new residents in harms’ way and add to the regional economic burden of providing protection for areas vulnerable to sea level rise.

A 2023 document released jointly by the Metropolitan Transportation Commission (MTC), Association of Bay Area Governments (ABAG) and San Francisco Bay Conservation and Development Commission (BCDC), “Sea Level Rise Adaptation Funding and Investment Framework Final Report” utilizes a Total Water Level of 4.9’ (1.4’ permanent sea level rise plus a figure of 3.5’ above MHW for a 100-year storm) by 2050 to “identify adaptation vulnerability and protection (page i).”[46] Based upon a Total Water Level of 4.9’ by 2050, the agencies have estimated the cost of protecting existing development and infrastructure would cost approximately $110 billion. **Putting new development in areas that will be at risk and require additional protection does not make sense.**
https://mtc.ca.gov/planning/resilience/sea-level-rise-adaptation-funding-investment-framework

Finally, protecting and restoring the Newark baylands is in alignment with numerous state goals and priorities. These include the Ocean Protection Council’s 2020-2025 Strategic Plan which has a goal to protect, restore or create 10,000 acres of coastal wetlands by 2025, and Governor Newsom’s “30x30” Executive Order (N-82-20) to preserve at least 30% of California’s lands and coastal waters by 2030 in a manner that protects biodiversity, builds climate resilience, reduces risk from extreme climate events and contributes to the State’s effort to combat climate change.

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[45] Sea-Level Rise Leadership Team. (January 2022). State Agency Sea-Level Rise Action Plan for California.

[46] Metropolitan Transportation Commission / Association of Bay Area Governments and the San Francisco Bay Conservation and Development Commission. 2023. Sea Level Rise Adaptation Funding and Investment Framework Final Report.

We have learned through the Shoreline Levee process in Alviso just how financially costly that may be. The 2015 cost estimate for the 5 Reaches of the Phase I levee construction was $194 million, with the Non-Federal Sponsors share estimated to be $104.4 million. Fast forward to the 2021. The estimates for Reaches 1-3 are now $545 million and the Non-Federal share of construction costs has more than doubled to $265 million. Is Newark prepared to pay its Non-Federal cost share for future mitigation resulting from the construction of housing units placed along the Bayshore? Communities along the edges of San Francisco Bay are living in an era of rising sea and groundwater levels and planning must be adjusted to ensure that we do not put more residents, development and infrastructure at risk. It is just too costly to continue to put new development and residents in harm's way.

The City of Newark should prioritize supporting the clean-up and restoration of the Pick-n-Pull site for future park space as planned and as part of a climate resilience and conservation vision for the baylands as we face the impacts of climate change.

Thank you for the opportunity to provide comments.

Respectfully submitted,

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A bid to commercialize a rare natural blue—ethically p. 1100

Beryllium bonding in a crystalline compound pp. 1106 & 1147

Changing transcription over the life span of *Drosophila* p. 1145

Attachment 1

Science

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LIGHT POLLUTION

LOSING THE DARKNESS

By **Keith T. Smith**, **Bianca Lopez**, **Sacha Vignieri**, and **Brad Wible**

For most of history, the only lights made by humans were naked flames. Daily life was governed by the times of sunrise and sunset, outdoor nighttime activities depended on the phase of the Moon, and viewing the stars was a common and culturally important activity. Today, the widespread deployment of outdoor electric lighting means that the night is no longer dark for most people—few can see the Milky Way from their homes. Outdoor lighting has many legitimate uses that have benefited society. However, it often leads to illumination at times and locations that are unnecessary, excessive, intrusive, or harmful: light pollution.

This special issue examines the effects of light pollution on the natural world, human health, and the night sky. It discusses how the level of light pollution can be measured and what could be done about it.

Both the amount of light pollution and its geographic extent are increasing rapidly, causing worsening impacts on the environment. This wasted light emission consumes vast amounts of electricity, with associated financial costs and greenhouse gas emissions. Although streetlights are the most obvious form of outdoor lighting, light pollution often arises from buildings, vehicles, advertising, sports facilities, and many other sources.

Fortunately, light pollution does not accumulate in the environment; it can be halted by simply turning off the lights, although that is not always practical. Often, those responsible for poor lighting do not realize that it is causing pollution that harms the environment. Careful design, appropriate use of technology, and effective regulation can ensure that we retain the benefits of artificial light at night while minimizing its harmful effects. If we fail to do so, we will lose what little darkness remains.

10.1126/science.adi4552

POLICY FORUM

REVIEWS

RELATED ITEM PODCAST

PHOTO: JIM RICHARDSON

The city of Chicago, seen from above through scattered clouds with the shoreline of Lake Michigan at the bottom. Extensive light pollution is visible from sources including streetlights, commercial buildings, vehicles, and leisure facilities. The light escaping into the sky performs no useful function but is bright enough to reveal the layout of the city and penetrate through the clouds.

A national law regulating artificial light affects many Koreans, particularly in cities such as Seoul, where local authorities have power to impose fines.

POLICY FORUM

Regulating light pollution: More than just the night sky

Impacts on ecology, health, energy, and climate are critical

By **Martin Morgan-Taylor**

Artificial light at night (ALAN), or light pollution, causes a broad spectrum of problems. Emerging scientific research describes energy waste exacerbating the climate emergency, and harm to human (*1*) and ecological health (*2*). Despite these broad effects, the problems of light at night are usually couched in terms of the loss of the night sky in the media, leading the public to believe that light pollution is an issue primarily concerning astronomy and star gazing, rather than being more immediately relevant to the average person through broader adverse effects. This public perception may be contributing to the relatively modest priority thus far placed on addressing ALAN in many jurisdictions. Yet all of these issues warrant regulation, which is evolving in response to research findings, across the world. We examine below the types of regulation in existence, and their merits, then offer suggestions to aid the call for further regulation.

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The types of regulation that exist today vary depending on the source of the law, and how it goes about regulation. Sources vary from “hard law”—binding law from supranational, national government, or regional bodies—to “soft law,” which may take the form of non–legally binding guidance. Laws explicitly dedicated to light pollution may be drafted, or ALAN-oriented elements may be “bolted on” to existing legislation that is not ALAN specific. Regulation may act proactively to stop problems in the first place—by, for example, preventing the sale of or use of certain types of lighting—or limit light outputs or spill. Or it may act reactively to lighting problems once they exist, such as light shining into windows. It is possible to combine a hard law core with soft law supporting guidance, involving a mix of the above. Notably, any regulation requires enforcement, which in turn requires the resources for and the buy-in of the bodies tasked with enforcement.

Policy-makers must view regulation as worthwhile, and this means that voters must see the value. The burden imposed by regulation must be set against the negative effects of ALAN. So, regulation must be based on a full understanding of how the benefits and disadvantages of light at night might be effectively balanced. It must cover the spectrum of problems caused by light at night and be enforced in practice. And it must be as simple, easy to understand, and as cheap as possible to enforce. Underpinning this is a need for a proper understanding of the problems and practical solutions, which may be aided with scientific evidence. A general understanding is required of the wider problems that ALAN may cause us all, not just the loss of the night sky. Perceptions of need and economics, in the eyes of the public, policy-makers, and enforcement bodies, are all critical.

EXAMPLE REGIMES

Supranationally, the United Nations Environment Programme has recently published draft light pollution guidance for birds and bats (*3*). Also, a growing number of nations are adopting national laws, with France and the Republic of Korea serving as excellent examples of jurisdictions that have adopted hard law approaches. Some US states have hard law, and other jurisdictions, such as those in the UK, have adopted “bolt on” approaches. We will examine initiatives in the European Union (EU), France, Korea, and the UK as examples.

European Union

Light pollution was on the agenda of the Czech Republic Presidency of the EU in 2022. An outline of European initiatives was commissioned (*4*), listing 18 out of 32 European nations as having some form of national legislation, and the emerging underlying physical, ecological, social, and health scientific research that states the case for regulation. Light pollution is also beginning to be addressed by the EU block itself; the EU’s Green Public Procurement Criteria for Street Lighting and Traffic Signals provides street-lighting recommendations, which includes addressing light pollution (*5*), for policy-makers and lighting professionals. This report recommends dimming and selective switching off, subject to the EN13201 lighting standard. Primarily designed to save energy, these standards also serve to reduce all other negative effects of ALAN. The Zero Pollution Action Plan of the European Green Deal names light pollution as an emerging pollutant for monitoring (*6*). Similarly, light pollution is named as a cause of pollinator decline in the EU Pollinators Initiative (*7*). Although such recognition is good, progress is slow in actually reducing light pollution. Continuing scientific research of these fields will support calls for further regulation.

PHOTO: FOTOVOYAGER/ISTOCK.COM

France

France adopted a decree in 2018 that covers the broad spectrum of ALAN problems, including disturbing humans, fauna, and ecology, as well as cutting energy waste and protecting the night sky. Framed in terms of energy waste and the environment, this decree can appeal to businesses and the public as a response to financial, energy, and climate challenges. The decree augments France's existing environmental code, as well as commitments to buildings and town planning, and broader commitments to the Paris agreement and the EU Green Deal. It also defines and gives extra protection to 11 astronomically important areas. Aiming to be preventive, the decree provides a scheme of design and use, for all lighting, but does not cover the sale of lighting. Unlike its 2013 precursor, it applies to private consumer lighting as well as that from the commercial and public sectors. It is built on a review and understanding of the underlying scientific research into the broad problems, provided by the French astronomical community.

The decree includes curfews on external and internal lighting, which are easy to understand and to enforce; limiting blue-rich light at night (implicated in harm to human and ecological health) to a color temperature of 2400 to 3000 K; and banning laser lights that exceed 100,000 lumens in many areas. The decree also limits upward light into the night sky and cutting glare, which will reduce astronomical light pollution and intrusive light, and limits "excessive intrusive light into dwellings" from all lights, including domestic "security" lights. But "excessive" is not defined, leaving tension over the right to self-determination.

Republic of Korea

The Republic of Korea has also adopted a dedicated law (*8*), mainly to cut energy waste and nuisance lighting, especially from billboards. It uses metrics based on the International Commission on Illumination's international standard (CIE 150). These metrics are clear and transparent, and because they set maximum lighting levels, provide less scope for subjective judgments about what is reasonable. This is good for lighting designers and commercial users as it helps minimize enforcement conflict that might arise as a result of uncertainty and ambiguity. The transparency means that consumers have access to metrics to determine whether they have a case, rather than risk financial resources on uncertain legal action. However, metrics require the use of light meters, which provides a cost and training burden on regulators, and this law does not prevent the sale of certain lighting types. As such this is not a fully preventive law.

The metrics classify areas into four environmental zones (E zones) ranging from E1 (the darkest) to E4 (the brightest, city areas). This law is likely to be seen as directly relevant to many city-dwelling Koreans, such as those facing illuminated billboards shining into their windows. A disadvantage of a zone-based policy is that like noise, light travels across different zones. This can be a particular problem in densely populated countries, such as many in Europe and Korea. Similarly, cities include mixed-use areas containing both commercial and residential buildings. These areas often have illuminated billboards. The Korean law uses the same maxima recommended under CIE 150 (*9*). However, it is possible that the law could in time also adopt the curfews used by the French law, so that illuminated billboards and other lights must be switched off. Such a law would combine the best elements of the curfew and metrics system.

Effective regulation needs enforcement powers with penalties for violators. Under the Korean law, local authorities have enforcement powers to fine and/or impose a compliance order. Fines rise with the severity of the breach, and the number of offences, ranging from roughly USD$50 to roughly USD$1000. Increasing fines is an effective way to ensure compliance. It remains to be seen whether local authorities will allocate resources to the lowest levels of breach.

United Kingdom

The UK is not a single jurisdiction, but rather consists of several "home countries" with autonomy in specified areas, including the environment (devolution). The law in England will be discussed here, as it has the highest population (*10*). All UK jurisdictions have adopted the bolt-on approach, rather than dedicated laws, because it was the quickest, cheapest method, and possibly because it was not deemed to warrant the time and cost of a dedicated law. Consideration of light pollution has been added to the planning stage requirements for new buildings, and for the nuisance effects under statutory nuisance laws. These methods offered the best fit to existing laws. There has been a Royal Commission in 2009 (*11*), and there is a current all-party parliamentary group (APPG for Dark Skies) (*12*), with both recommending regulatory changes. These were in response to representations from the astronomical community, including star counts showing the impact on the night sky, and so do not reflect the full spectrum of the problems with ALAN, which might explain the lack of a dedicated law.

Light pollution is now a factor for consideration when applying for planning permission for land development under the National Planning Policy Framework, to "limit the impact of light pollution from artificial light on local amenity, intrinsically dark landscapes and nature conservation." However, this framework tends to highlight dark landscapes and nature conservation, which may conflict with the aims of the lighting to address safety and security, commercial interests, and so on. So this measure is not especially helpful in tackling the broader problems of light at night.

This bolt-on approach has weaknesses, as it tries to incorporate light pollution into an existing framework for something else, which may reduce effectiveness. For example, planning law only covers "development," which is limited to lighting in existing buildings that affects daytime visual appearance. This is because the planning system is interested in the visual appearance of the light fittings, rather than the problems they might cause.

Supplementary guidance from the lighting industry and other environmental interest groups can also play a substantial role in bolt-on regulation. For example, the UK's Institution of Lighting Professionals regularly updates its Guidance Notes for the Reduction of Obtrusive Light (GN01, 2021), with clear guidance on avoiding overlighting, and provides diagrams on how to design and install light fittings correctly. This guidance is well respected in the UK.

ALAN was added to the list of possible statutory nuisances in 2006. These are criminal offences to protect society generally, but it requires an act or omission that is either "prejudicial to health" or a "nuisance," under the Environmental Protection Act 1990. Scientific evidence clearly indicates that harming sleep harms human health, and the emerging research indicates that exposure to light at night might harm sleeping. So the health element might cover loss of sleep caused by light shining into bedroom windows. However, the most fundamental problem with bolting light onto existing nuisance legislation is that light pollution causes problems far wider than the narrow scope of the nuisance regime's second (nuisance) element. This only covers interference relating to everyday use of land, not the broader environmental ecological or night sky concerns that ALAN may cause. So, nuisance has had little effect in combating light pollution.

A WAY FORWARD

Light pollution is an issue that can elicit a response in favor of light at night that is just as emotional as the response to the problems that it can cause. This may to some degree be because a lot of the emotion derives from myths and misconceptions, or rests on beliefs not necessarily borne out by the evidence. These issues may center on an emotional fear of the dark and a belief that light offers safety and security. In this view, more light is always better, possibly explaining instances in which residents object to the dimming or switching-off of some streetlights. Moreover, it might be that light is regarded as an intrinsic part of liberty, where one is entitled to string up as many security lights as desired. The perception that light is good has led to the common interpretation of "well lit" to mean brightly lit. Concerns over attempts to reduce lighting may also center on the safety of women at night. These all are very valid concerns. And this state of affairs may explain the somewhat piecemeal regulatory response to light pollution. Continued research can help support or refute these beliefs.

One notable gap in the literature is the lack of recent, reliable economic analyses of the financial costs of light pollution. Such analyses could better inform the levels and timescales of change required, and consideration of possible financial incentives such as subsidies. A 2010 paper indicates that ALAN cost USD$7 billion annually in the US alone (*13*). But what is "waste" light? Recent satellite mapping research has mapped upwardly escaping light, but not as yet quantified its cost. Nevertheless, greater understanding and awareness of the long-term savings offsetting the costs of retrofitting lighting is possible. For example, in 2002, Calgary retrofitted its streetlighting to "full cut off lights" (which do not emit light above the horizontal), and recouped the costs within 6 to 7 years, before saving roughly USD$2 million a year (*14*).

Calls for regulation often center on the night sky. For example, a leading international body in raising awareness and pushing for change (including excellent templates and guidance for regulation) is named the International Dark-Sky Association. The UK All-Party Parliamentary Select Committee is named the APPG for Dark Skies. Although the night sky is clearly the most graphic victim of ALAN, the average person may be unlikely to prioritize it among the reasons to light in the first place. Hence, a night-sky focus may be limiting public awareness and political will. An unintended consequence of the growing number of well publicized dark-sky accredited places has led to suggestions that if the night sky is protected in reserves, then there is no need to protect it in city and urban areas, with their perceived higher lighting needs for safety, security, commerce, and so on.

A slight change in tactics might better put ALAN on the radar of the general public (and so the politicians and regulators). The issue could be reframed around aspects more relevant to the lives of the general public. Education can describe how addressing light pollution is a readily achievable balance between the competing interests of the need to light against the adverse consequences, not simply a call to turn off all the lights to look at the night sky. Education could emphasize how this involves cutting energy waste and carbon emissions in a time of an energy and climate crisis, may reduce harm to human and ecological health, and may aid safety and security by cutting glare. "Well lit" might come to be understood not to mean brightly lit, but instead the use of more suitable and efficient lighting, aiming to light to a level actually required and that is on when, and only illuminating where, needed. These are issues that society is more likely to see as relevant to everyday life, and more worthy of action; and the night sky gets protected as a direct consequence.

What sort of regulation is likely to be the most effective? Dedicated laws, specifically drafted to address light pollution, such as in France and Korea, offer the most effective control. These could be supported by bolt-on laws where relevant. However, light pollution also needs preventive, guidance, and educational elements. Lighting should be considered at the design and build stage, to avoid light pollution from occurring in the first place, which in turn reduces the regulatory need and cost. Design and build also should be based on a full understanding of the entire light pollution problem, particularly the levels of lighting, the color spectra, light spill controls, and the way that the lighting can be installed physically (to avoid direct glare and upwardly escaping light).

Education is critical so that all light users and regulators are cognizant of the problems of ALAN and how a balance may be struck. Ownership of the balance may be best placed in the hands of stakeholder interest groups on all sides, who can contribute to the debate, to the creation and evolution of regulation, and to the drafting of guidance that might supplement hard law. There is also a need for further research to address the myths and misconceptions surrounding light at night. Education must break down preconceptions such as "the brighter the better" and "well lit" means brightly lit. Or that lighting is always needed, all the time, and that any form of lighting control is an unjustifiable fetter on personal autonomy. These attitudes could be replaced with understanding, namely, "the right amount of light, of the right type, where needed, when needed." Education should also lead to ALAN issues being taken more seriously by enforcement bodies. Education may help to shift some existing attitudes to lighting shown by the public and commerce. For example, changing recognition of the cost and value of lighting should lead to changing purchasing habits, for example, reducing the demand for lighting such as ultrabright floodlighting. The International Dark-Sky Association offers a wealth of excellent exemplar ordinances and underpinning education for regulators (*15*).

The public and regulators must recognize the benefits and value of the restrictions and burden that come with regulation. To this end, the most fruitful approach might be to lead on the adverse effects of light at night that are most relevant to everyday life, rather than the loss of the night sky. This needs to be bolstered with ongoing interdisciplinary research and active co-operation with stakeholders. In particular, education and research might center on the emotive matters that promote the use of light at night, such as the belief that light at night always cuts crime, and so the more light the better. Estimating the financial and carbon cost of light pollution would be beneficial as well. The result will be an evidence-based, and not an emotion-based, use of lighting. ■

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REVIEW

Measuring and monitoring light pollution: Current approaches and challenges

Miroslav Kocifaj[1,2]*, Stefan Wallner[1,3], John C. Barentine[4]

Understanding the causes and potential mitigations of light pollution requires measuring and monitoring artificial light at night (ALAN). We review how ALAN is measured, both from the ground and through remote sensing by satellites in Earth orbit. A variety of techniques are described, including single-channel photometers, all-sky cameras, and drones. Spectroscopic differences between light sources can be used to determine which are most responsible for light pollution, but they complicate the interpretation of photometric data. The variability of Earth's atmosphere leads to difficulty in comparisons between datasets. Theoretical models provide complementary information to calibrate experiments and interpret their results. Here, we identify several shortcomings and challenges in current approaches to measuring light pollution and suggest ways forward.

Preserving the environment and ensuring sustainability are worldwide challenges. They include the phenomenon of light pollution caused by artificial light at night (ALAN). Light pollution primarily consists of misdirected light emission, illuminating outdoor areas not intended or required to be lit. It also includes overillumination—the use of lights with much higher brightness than necessary—and the use of harmful light colors, such as lighting that emits radiation at short optical wavelengths (blue light). Light pollution produces "light domes" visible in the night sky near cities, brightening the sky over wide areas and reaching into otherwise dark areas, such as protected natural spaces (*1*). The adverse consequences of light pollution include detrimental effects to flora and fauna and to human health (*2*–*4*). Increased night sky brightness (NSB) also impairs astronomical observations of celestial objects (*5*, *6*).

Reducing the negative impacts of light pollution requires environmentally responsible urban development. This is often taken to include the widespread conversion of lighting systems from inefficient incandescent or high-intensity gas discharge lamps to light-emitting diodes (LEDs) (*7*, *8*). However, current trends in the spatial and temporal distribution of ALAN show that switching to LEDs has been counterproductive for light pollution, with observations showing continuous growth in illuminated areas and upward-directed radiance worldwide, both being ~2% per year (*9*). In inhabited locations, the rate of increase can be even higher, with contemporaneous citizen-science data pointing to an increase in observed NSB of nearly 11% per year (*10*). Mapping NSB across the globe provides a baseline for investigating the worldwide emergence of lighted areas (*11*).

It is necessary to identify sources and quantify the impact of ALAN, particularly to guide regulations and other mitigation strategies (*12*, *13*). A multitude of measurement techniques are available, providing either single snapshots of lighting conditions and influences or long-term monitoring and remote sensing of ALAN. Many measurement devices are available, all of which have advantages and shortcomings (*14*–*17*). We review the methods behind quantifying light pollution and ALAN, focusing on the diverse functions. We consider current challenges in determining light pollution influences at arbitrary places and predicting how it will change over time. We also provide recommendations on how the measurements can be used more comprehensively in the future.

"...outdoor lighting design should minimize the amount of blue light emitted..."

Quantifying light pollution

Light pollution research uses a large variety of measurement techniques and devices. The right method, instrument, and analytical approach must be chosen for each application in analyzing ALAN and its effects.

Some light pollution parameters can be measured directly from the night sky itself. The enhancement of NSB caused by ALAN is generally called skyglow (Fig. 1A), most commonly occurring in and around densely inhabited areas. A clear night sky background without any ground-based light pollution has a luminance of ~200 μcd m^{-2} (*15*), equivalent to a value of 22.0 mag arc sec^{-2} in astronomical magnitudes (an inverted logarithmic scale) (*18*). Observations that include luminous celestial objects within the instrumental field of view show appreciably higher figures; for example, the brightest parts of the Milky Way are ~2.5 times as bright as the surrounding night sky (*19*). Although the highest NSB values are measured within the light domes above cities, absolute measurements are highly dependent on the distance from (and proliferation of) individual light sources as well as the observed field of view on the night sky. The zenith—the point on the sky directly overhead—is often used as a local reference direction to characterize the approximate sky quality.

Figure 2 shows a comparison of different NSB measurement techniques. Photometric measurements are usually one-dimensional, having no angular resolution (*20*), and may be either portable for single readings or permanently installed as part of monitoring networks (*21*, *22*). Figure 2 includes an illustration of an NSB measurement process using devices with a specified field of view directed toward the zenith to collect continuous NSB data throughout a night. This technique is widespread—used by researchers and activists—because of its generally low data-acquisition cost and high accuracy. However, to collect information about the entire night sky rather than small fields of view, additional techniques are required to analyze skyglow. Two methods predominate. First, the horizontal illuminance of the overall radiation field can be measured using a simple light-to-frequency counter. Second, all-sky imaging techniques measure the entire hemisphere of the sky simultaneously (*23*, *24*) (also illustrated in Fig. 2). All-sky imaging has the advantage of not only measuring any NSB increases over time but also identifying the spatial distribution and relative contributions of individual light domes around the horizon. Combined with calibration software (*25*, *26*), the resulting night sky luminance matrices provide sufficient information to identify light pollution sources and the night sky quality at the time of observation.

ALAN directed toward the sky (directly or indirectly) can also be measured by spaceborne instruments (Fig. 1B). Whereas the ground-based techniques discussed above provide data on local conditions, satellite observations probe much larger spatial scales (*27*, *28*). Satellite remote sensing measures upward-directed radiance from light sources on Earth's surface (Fig. 2) with the goal of analyzing whole cities, countries, or other large areas. These data are particularly useful for studying extensive conversions of existing lighting systems, including potential changes in their total luminous flux, radiation angles, and other properties (*29*). They can also identify the type of lights installed on the ground (*30*).

Returning to smaller observational scales on the ground, ecological light pollution is widespread. The techniques used to study it depend on both the light source and the organism or ecosystem being investigated. When these conditions are clearly defined, light pollution

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measurements can be used to assess impacts on selected species of flora and fauna, caused by either single or multiple light emissions into the nighttime environment (*31*, *32*) (Fig. 1C). These measurements must consider the specific detector parameters required, for example, to provide analogs of animal eyes and the sensitivity to radiation of different origins (*33*, *34*). Light traps are often used to observe ground-based wildlife, and unmanned aerial vehicles (drones) are used to recreate the influence of ALAN on flying animals (*35*) (Fig. 2).

In urban management, outdoor lighting is a tool used to improve safety, provide orientation, and improve wayfinding. However, its use is not usually subject to meaningful public oversight. During the planning process, luminance and illuminance analyses (Fig. 1D) can be used to determine how to achieve those goals (*36*). Parameters, including the spatial distribution and illuminance, are adjusted as needed for site-specific requirements. However, influences such as light scattering effects and nonideal construction of light fixtures potentially lead to unexpected results and can cause light pollution. Therefore, determining luminance and illuminance is necessary in urban engineering. Within cities, individual light fixtures can be optimized on the basis of such analyses (*37*), and in dark areas, ecological light pollution can be explored using the same approach (*38*).

The impact of ALAN on the environment depends not only on its luminous flux but also its spectral power distribution. Exposure to short-wavelength (blue) light at night has negative consequences for many organisms (*3*, *39*). Even at very low illuminances, blue light disrupts the human sleep-wake cycle and suppresses secretion of the hormone melatonin, whose dysregulation is associated with metabolic diseases and certain cancers (*40*). To minimize potential harm, outdoor lighting design should minimize the amount of blue light emitted wherever possible. There are two approaches for quantifying this aspect of light pollution. First, individual lamps are characterized by their spectra (Fig. 1E), and the emission at shorter wavelengths is analyzed. Second, skyglow retains information about the light sources on the ground that generated it, which allows spectrographic measurements of ALAN (Fig. 2).

To forecast changes in light pollution, or its effect under varying ground-based conditions (e.g., lighting conversions and meteorological changes), theoretical modeling is applied. Several computational methods have been developed (*25*, *41*, *42*) to simulate ALAN and its spatial and temporal distribution at arbitrary locations and chosen input parameters. The accuracy of these models is limited by the (typically) large number of lights in cities, which differ in lumen outputs, spectral compositions, directional emissions, and spatial distributions, resulting in a nontrivial cumulative light emission pattern. Modeling of the angular distribution of urban photons has sometimes used a simple analytical formula, combining direct upward emissions with an assumed fraction of ground-reflected light (*43*). This approach has been improved by adding an extinction factor that accounts for light-blocking obstacles near the horizon (*44*). Although this approach works for some cities, the angular distribution of emitted light is generally more complex, requiring a combination of several model functions (*11*). The spectral composition of light escaping an urban area changes with direction as a result of the variety of light sources. These limitations in modeling source emissions affect NSB across the modeling domain.

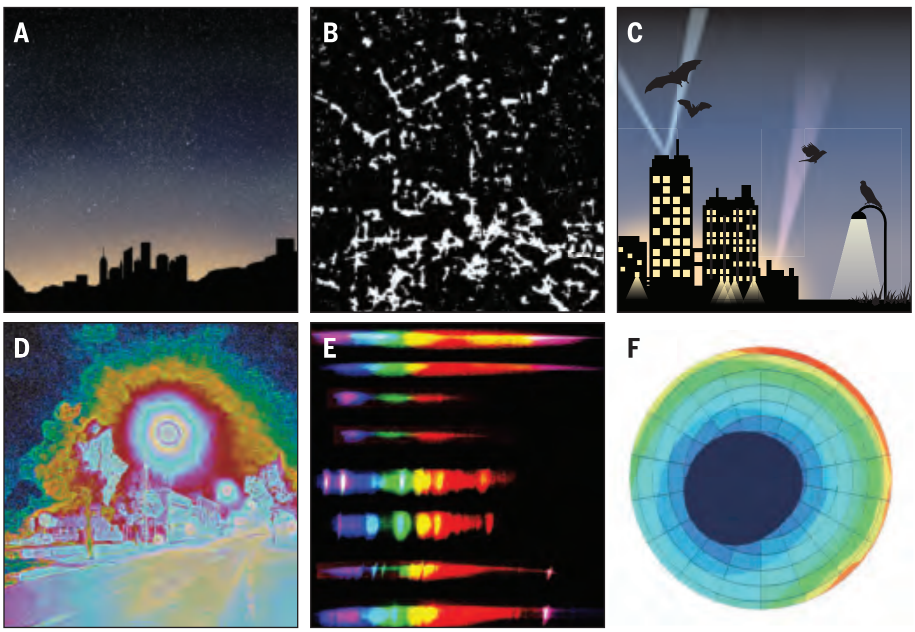

Fig. 1. Topical areas that require quantification of light pollution. Six areas that quantify the impacts of ALAN are illustrated: (**A**) Higher levels of NSB, also called skyglow. (**B**) Satellite remote sensing of upward-directed radiance from Earth's surface. (**C**) Ecological light pollution. (**D**) Surface illuminance resulting from individual light sources—the colors indicate the brightness levels on an illuminated building. (**E**) Emission spectra of individual lighting fixtures. (**F**) Computational modeling. For each application, different techniques and analysis methods are necessary.

CREDIT: (A) AND (C) K. HOLOSKI/*SCIENCE*; (B) DATA DOWNLOADED FROM NOAA; (E) THOMAS POSCH/UNIVERSITY OF VIENNA

Current challenges in measuring light pollution

Although there are many different methods of quantifying the impact of ALAN, they each have shortcomings. Despite the variety of instruments available to observe skyglow, radiance, or other characteristics, there are several common problematic aspects. Because light pollution is affected by the scattering of light in the lower atmosphere, it is influenced by the spatial and temporal instability of the atmosphere. Each night is potentially different from its predecessor or successor, depending on atmospheric and meteorological conditions, so measurements obtained on different dates might not be directly comparable. This primarily affects long-term analyses from monitoring stations because both NSB and atmospheric conditions must be recorded simultaneously and considered together. This applies to all measurement techniques; for example, fog affects satellite remote sensing as well as ground-based illuminance measurements of a single lighting fixture. Ecological light pollution studies are particularly affected because the atmospheric conditions change the spatial distribution of ALAN (*45*). Solutions to this problem can use data from atmospheric monitoring stations, if present near the measurement sites, but those are usually not available, so researchers must rely heavily (or solely) on theoretical models (*46*).

Other factors also cause light pollution measurements to vary. The types and flux density of lighting sources change over time—even during a single night, as lights are switched on and off—and vary spatially as a result of the influence of local topographical features. Parameters, including the albedo of the illuminated surface and shadowing by physical obstructions, affect the resulting light pollution and its analysis (*47*). These variations can be incorporated into a mathematical description known as the emission function (EF) (*48*). It is not possible to obtain sufficient data to determine the EF completely, but it is commonly used as an input for data analysis and processing. Several approaches have been developed to approximate the EF of urban areas (*49*, *50*).

Technical limitations of available devices also affect light pollution measurements. The

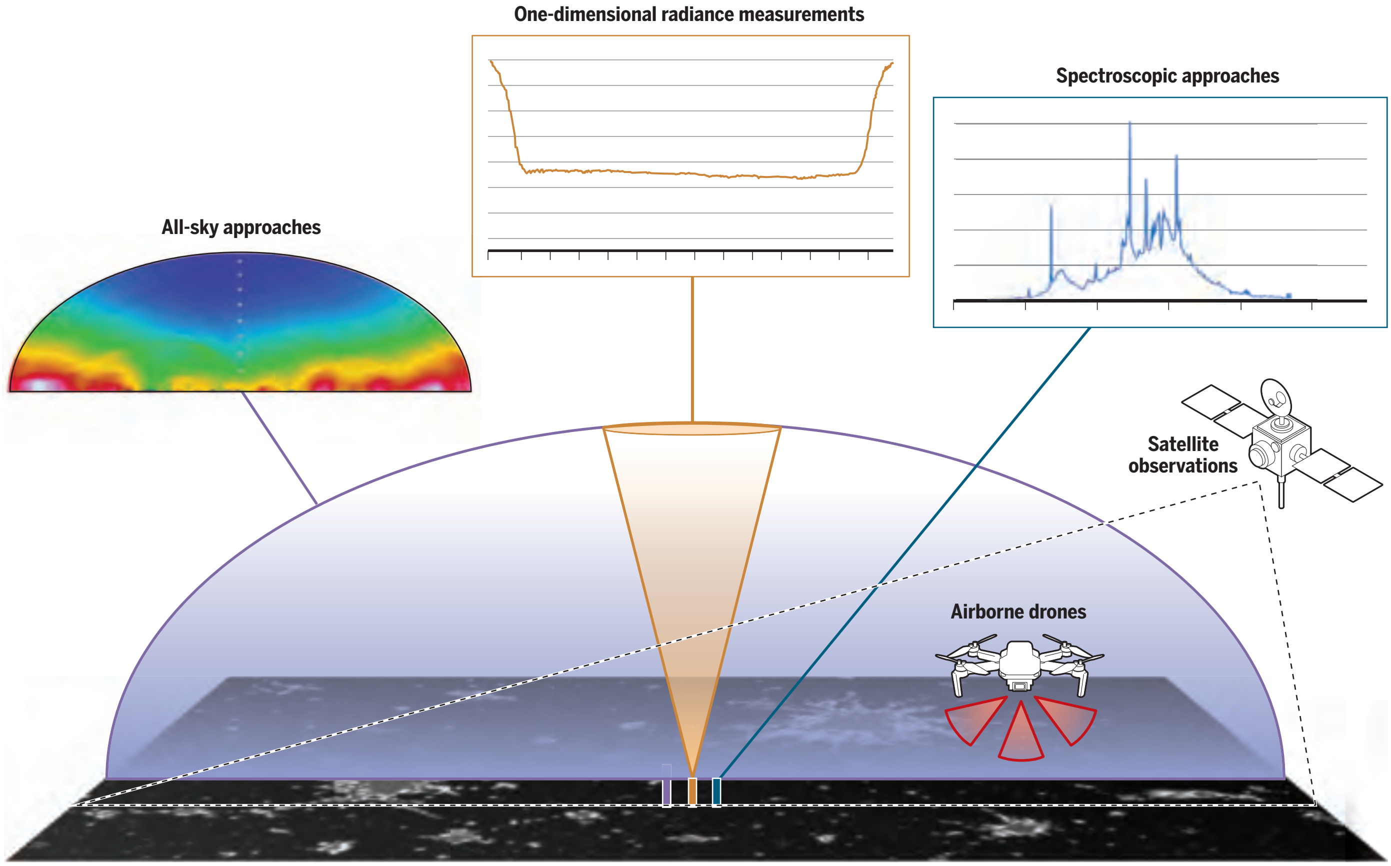

Fig. 2. Illustration of available measurement techniques for light pollution analyses. The variety of methods for measuring light pollution, their domains of applicability, and related observables are shown. All-sky approaches (purple semicircle) collect information originating in the upper hemisphere; spectroscopic approaches (blue line) provide information on the wavelengths of light; one-dimensional radiance measurements (orange cone) typically sample a small region around the zenith; satellite observations (black dashed lines) observe radiance from sources on the ground escaping to space; and airborne drones (red triangles) measure (spectral) radiance and irradiance in multiple directions.

differing spectral sensitivities of different devices combine with the potentially varying spectral power distributions of light sources (discussed above) in complex ways that affect the measurement. If the types of ground-based light sources are unknown and not included as a variable in the analysis, then the measurement conditions before and after a lighting conversion might not be directly comparable (*51*). This is also true for comparisons between different instruments. Satellite observations are particularly affected by this issue. For example, the main source of orbital ALAN data, with global coverage and nightly temporal cadence, is insensitive to light with wavelengths shorter than 500 nm (*52*). Space-based measurements are also influenced by the emission angle of ground-based light sources. Ground-based measurements have shown that zenithal observations can differ substantially from those obtained at low elevation angles (*53*, *54*). The lower signal-to-noise ratio of measurements taken in low-light environments makes them less reliable than locations with high levels of light pollution, and complex corrections because of natural night airglow are required (*55*). Portable instruments, such as cameras or drones, can be easily maintained, but permanently installed devices are susceptible to meteorological conditions, such as rain and snow. Solar radiation during the daytime has been shown to affect the optics of instruments, causing an aging effect that influences nighttime measurements (*56*).

There is a wide range of instrumental and environmental influences that affect light pollution measurements, which must be considered during data processing. The wide range of techniques can be advantageous for tackling different research goals, but the lack of measurement standards contributes to difficulty in comparing results and the need for complex interpretations. Yet, measurements made consistently with well-designed protocols over long periods of time can yield information of distinct value to light pollution researchers and dark-sky activists alike. Provided that data are obtained with care and the instrumental limitations are understood, light pollution measurements can be confidently applied to situations involving urban planning, land management, natural resource conservation, and more.

Using data more comprehensively

There is great potential for extracting more information from measurement data than is typical at present, for example, through long-term observations of NSB, which are scarce and generally only consist of zenith radiance data. Monitoring networks routinely operate single-channel optical instruments to gather time series of zenith radiance for trend analysis (*57*). However, such data contain more information than is inferred from simple trend statistics. Exploiting more of the information content of zenith radiance measurements has been demonstrated in nighttime monitoring of atmospheric aerosols using differential photometry (*58*). Zenith radiances obtained in rough or irregular terrain, from two measuring stations separated in elevation, have been used to characterize the turbidity of the atmospheric layer between the stations. Conventional measurements, when taken under suitable configurations or spatial arrangements, can therefore provide additional information about the nighttime environment (*58*).

Aerosols—tiny particles suspended in the air—are a large source of uncertainty in quantifying the impacts of ALAN. Several measuring techniques and tools for retrieving aerosol properties have been developed to determine the aerosol optical depth (AOD), a parameter used in, for example, modeling the influence of ground-based light sources. Multiple techniques are in use to determine AOD, but only a few of them are applicable at night, and most are difficult for inexperienced experimentalists to use. One method useful for light pollution measurements relies on an empirical relationship between the zenith brightness and AOD; it can be implemented with low-cost optical devices during moonless nights (*21*).

Simple measurement techniques are preferable for use in monitoring programs at many locations. As discussed above, local atmosphere data are highly advantageous to interpret light pollution measurements, but the instrumentation for measuring atmospheric conditions is not present at most sites. For example, ceilometers—devices that use lasers or other light sources to determine the height of a cloud ceiling or cloud base—can provide useful information on local atmospheric conditions that can be used as inputs for light pollution analyses and skyglow modeling (*59*). When systematically used, measurements of cloud base altitude and backscatter from aerosols provide complementary information to light pollution data.

Spectral data are usually required to characterize light sources (*60*) and to quantify light field distributions for a broad range of atmospheric conditions (*61*). Such measurements are rarely available. Ground-based spectral measurements are infrequent (*62*) because optical systems with the required sensitivity are expensive. Space-based spectral measurements require highly sensitive detectors with high spectral and spatial resolutions. Orbital remote sensing of ALAN mostly uses the Day-Night Band—part of the Visible Infrared Imaging Radiometer Suite (VIIRS) instrument aboard the Suomi spacecraft (*16*)—which can be used to map directional outputs from cities for a range of zenith viewing angles (*63*). The collective effect of the whole-city lights (i.e., its cumulative angular emission pattern) is a required input for, for example, ecological light pollution measurements or forecast approaches, but is difficult to determine experimentally. Exploitation of satellite data for this purpose is a challenge for both experimentalists and theorists. VIIRS does not have a multispectral capability with both sufficient sensitivity and panchromatic response in the optical range. Multiple-angle remote sensing could be used for extended diagnosis of the atmosphere and artificial lights (*53*).

Conclusion and outlook

Experiments and theoretical studies are equally useful to investigate light pollution because they provide complementary information about the nighttime environment. Field experiments can never be performed under fully controlled conditions; the data gathered by optical systems are therefore not free of errors or the effects of other physical phenomena. Measurements are only possible in discrete locations because data acquisition in an arbitrary spatial pattern is impractical. Theoretical studies are required to address these issues. Models are also useful in determining the isolated effect of single parameters on the light field, improving our understanding of their impacts on the measured quantities. However, the models are accurate only within the limitations of the theories used. Experimental data and theoretical models are complementary, providing incomplete information if isolated from each other. Theories can fill data gaps, whereas experimental data are necessary to test the theories.

The development of new models and experimental techniques should go hand in hand because the outcome of one drives progress in the other and can generate new applications. Understanding the processes of light emission and propagation allows for more-specialized field experiments that more fully use the information content of nighttime light measurements. For example, the polarization of light at night is largely unexplored in light pollution research.

Light pollution has drawn increasing attention from the scientific community in recent decades, and we expect that trend to continue. There is a need for more-accurate devices, data acquisition, and study management—all activities that have high technical demands. As the number and diversity of instruments available for field light pollution measurements continue to increase, we question whether a technical standard for absolute calibration of their data can be achieved. Given the need for more global collaboration in the interdisciplinary field of light pollution research, we feel that standardization of measurement protocols will be necessary.

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REVIEW

Effects of anthropogenic light on species and ecosystems

Annika K. Jägerbrand[1]* and Kamiel Spoelstra[2]

Anthropogenic light is ubiquitous in areas where humans are present and is showing a progressive increase worldwide. This has far-reaching consequences for most species and their ecosystems. The effects of anthropogenic light on natural ecosystems are highly variable and complex. Many species suffer from adverse effects and often respond in a highly specific manner. Ostensibly surveyable effects such as attraction and deterrence become complicated because these can depend on the type of behavior and specific locations. Here, we considered how solutions and new technologies could reduce the adverse effects of anthropogenic light. A simple solution to reducing and mitigating the ecological effects of anthropogenic light seems unattainable, because frugal lighting practices and turning off lights may be necessary to eliminate them.

Artificial light is ubiquitous in areas where humans are present and inevitably extends to our natural environment. This has far-reaching consequences for most species and their ecosystems. The ability of humankind to produce electric light has enabled us, a naturally diurnal species, to dispel darkness and extend our activities into the night. However, artificial light has serious side effects that are commonly referred to as light pollution. Light pollution is defined as the sum total of all of the adverse effects of artificial (hereafter referred to as anthropogenic) light (*1*). Ecological light pollution was originally defined as artificial light that alters the natural patterns of light and dark in ecosystems (*2*) that are caused by exposure to near and distant light sources and sky brightness. Light-polluted skies have become a global reality, affecting most of the world's economically developed areas (*3*). Sky brightness has increased over time, eroding natural darkness and encroaching on protected terrestrial and marine areas. Anthropogenic light not only worsens climate change through energy consumption but also poses serious challenges across species and ecosystems (*4*).

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Over the past 15 years, there has been a substantial amount of research on the ecological effects of anthropogenic lighting across the globe (*5*, *6*). Most of these studies have focused on direct light exposure. Research on broad-scale spatial patterns has become possible by combining remote sensing data on light emitted upward with digitalized biological data such as information on species occurrence and migration routes.

The deleterious effects of anthropogenic light have been reviewed for several species groups, including bats (*7*), insects (*8*–*11*), seabirds (*12*), fish (*5*), vertebrates (*13*), and marine, shoreline, and estuarine species (*14*–*16*). Effect sizes for numerous species have also been reviewed (*6*). These reviews line up numerous studies that have led to substantially more knowledge about the effects on different species groups, the diverse nature of such effects, and how they manifest across trophic levels, thereby increasing awareness about this environmental problem.

Commonly recommended solutions to mitigating the ecological effects of anthropogenic light include reductions or adaptations in light intensity, distribution, spectra, and duration. New technologies, such as light-emitting diodes (LEDs), can aid in reducing the effects of anthropogenic light on the natural environment. However, these solutions have limitations and may not safeguard against deleterious effects on all species.

Herein, we review the ways in which anthropogenic light affects species and ecosystems, discuss the research progress made in recent years, and describe various light pollution management solutions.

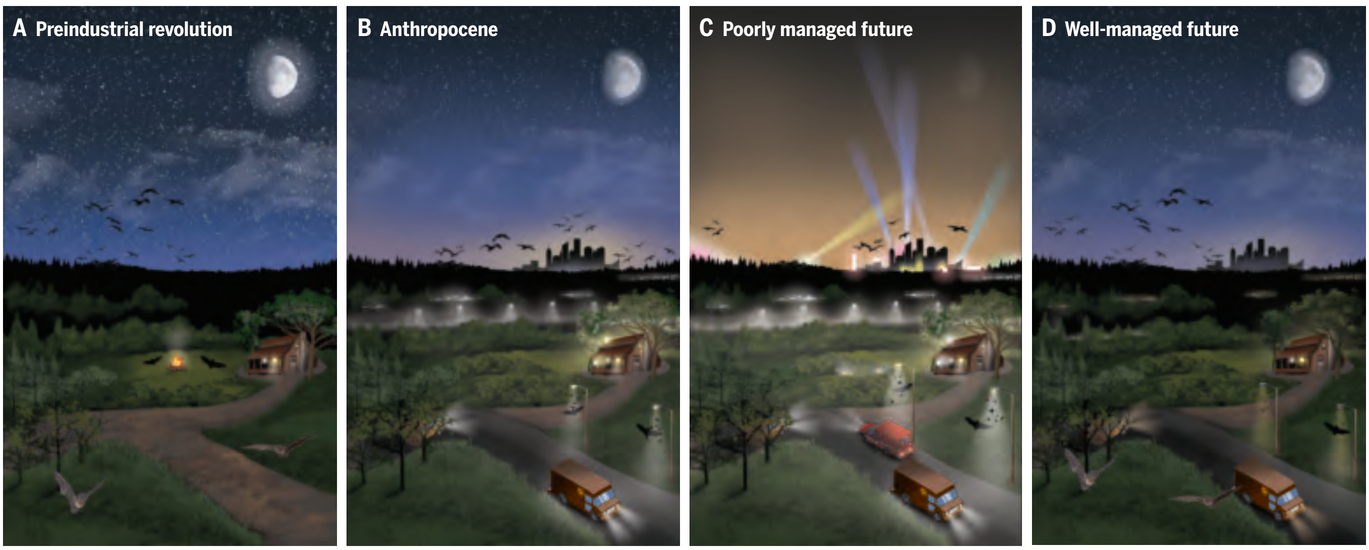

Fig. 1. Anthropogenic light through history and possible futures. (**A**) During the preindustrial revolution, few light sources were used for outdoor activities during darkness. Natural light sources dominated the natural environment, bats foraged and commuted along forest edges, migrating birds were undisturbed by strong light sources, and there was no sky glow from cities. (**B**) In the Anthropocene, anthropogenic lighting is used where it is needed to enhance human activities, attracting insects, migrating birds, and foraging bats and causing visible sky glow. (**C**) As anthropogenic lighting is increasingly used, light pollution will also increase and result in higher mortality in insects and migrating birds, habitat loss for light-repelled bats, and increased foraging opportunities for synanthropic bats. Barrier effects and fragmentation of dark ecosystems will decrease habitat quality. (**D**) A well-managed future conserves dark areas and limits light use in several ways, thereby minimizing the effects of anthropogenic light on birds, insects, and bats and numerous other species.

ILLUSTRATION: K.HOLOSKI/*SCIENCE*, BASED ON ANNIKA K. JÄGERBRAND AND KAMIEL SPOELSTRA

Effects of anthropogenic light on species groups

Birds

One of the most established effects of anthropogenic light on birds is their response to it during migration (Fig. 1). Many birds, including otherwise diurnal species, migrate at night. They are attracted to light and disoriented by it, especially strong light sources and bright spots in dark areas. This attraction to light can not only cause them to collide with buildings, lighthouses, oil rigs, and ships (*17*), but may also divert them from suitable stopover locations (*18*). Migratory routes are often close to illuminated urban areas (*19*). In areas with dark surroundings, such as islands, light sources attract seabird fledglings (*12*). These effects can directly result in high mortality and exhaustion. Many other effects are less pervasive but still problematic; for example, light may induce stress and disturb sleep (*20*, *21*). Many bird species in temperate zones depend on the accurate seasonal timing of breeding and the accurate daily timing of song activity and foraging, so light disturbance of this temporal organization is problematic [(*22*, *23*); Fig. 2].

Mammals

Most bat species are highly nocturnal and respond strongly to light. This response is driven by the fear of predators or the foraging ecology. For example, fast-flying, agile bats are less frightened by light and forage on accumulated insects around light sources, whereas slow-flying bats stay in sheltered locations (*24*) (Fig. 3). Bats are particularly vulnerable because they use linear landscape elements such as forest edges, hedgerows, and streams to guide them in foraging and commuting. Light along commuting and foraging routes can act as a barrier, thereby amplifying its negative effects by fragmenting habitat networks. Anthropogenic light in or near bat roosting sites can lead to delayed emergence or roost abandonment, which has negative consequences for the survival of populations (*7*).

A commonly accepted assumption is that, like bats, other nocturnal mammal species' responses to light are driven by fear of predators. A decrease in the activity of nocturnal species by light at night has been reported in numerous laboratory experiments. Many mammal species reduce activity in response to moonlight (*25*, *26*) and show a comparable response to anthropogenic light (*27*). Likewise, anthropogenic light can change the spatial behavior of rodents (*28*) and, even in the absence of predation, reduce longevity and reproduction (*29*). Larger mammal species such as deer and predators may also change their spatial activity (*30*). On a larger scale, the deterrent effects of light on infrastructure may have far-reaching effects because mammals may stop using passage structures (*31*). As is the case with many other species, anthropogenic light can have profound effects on mammals' daily and seasonal rhythms of activity, physiology, and reproduction (*32*).

Invertebrates

The attraction of insects to light is a well-known phenomenon (Fig. 1). In naturally dark environments, insects can be attracted to low light intensities (*33*), and the extent of attraction to a light source depends on the presence of surrounding lights (*34*). Insect's flight-to-light may be a maladaptive response to the original orientation toward moonlight (*35*) and is related to color composition. Blue light (<500 nm) attracts more insects than the yellow and red parts of the spectrum (*36*). The attraction of insects to anthropogenic light may cause mortality and exhaustion, which may play a substantial role in global insect declines. This has been corroborated by the fact that phototactic nocturnal species that fly toward light have shown strong population declines (*37*). Indeed, light posts have been found to affect local moth caterpillar abundance (*38*). Moreover, insect declines can be caused by the negative effects of light on reproduction and development (*10*). Insects that depend on bioluminescent signaling, such as fireflies, are especially vulnerable to anthropogenic light and are directly impaired in reproduction (*11*). Anthropogenic light deprives insects such as aquatic insects and dung beetles of their ability to use light cues for orientation (*39*). For several other invertebrate groups, the effects of light are well documented, including opportunistic foraging around light sources by spiders (*40*) and slugs (*41*). Finally, anthropogenic light can change species composition in invertebrate communities (*42*).

Amphibians

Early field observations have provided evidence that anthropogenic light affects the reproduction, visual performance, and activity patterns of amphibians (*2*). In toads, exposure to anthropogenic light has been found to cause reduced activity levels, altered energy allocation, and decreased juvenile growth and metamorphic duration (*13*). Anthropogenic light can also alter breeding behavior and reduce the fertilization success of toads (*43*). In frogs, although mate choice behavior appears to be unaffected by anthropogenic light, it has been shown to shorten the calling season and shift the daily calling period (*13*).

Reptiles

Knowledge about the impact of anthropogenic light on reptiles in general is limited, but its effect on marine turtle populations is widely known. Hatchlings are highly susceptible to disorientation caused by light when crossing the beach to reach the sea, leading to high mortality rates. Furthermore, even at low levels, anthropogenic light can disrupt the on-beach orientation of turtles, resulting in suboptimal selection of nesting sites (*14*). Turtle nests have declined in lit areas across several species, with turtles using lit beaches less frequently or avoiding them altogether (*15*). Some diurnal reptiles, such as geckos, are able to forage at night in the presence of anthropogenic light (*44*). Likewise, green anole lizards (*Anolis carolinensis*) express part of their normal daytime foraging and display activity during the night (*45*).

Fish

Compared with terrestrial organisms, fish have received less attention in studies investigating the effects of anthropogenic light (*5*). Such light may affect fish populations through changes in survival rates, spawning, hatching success, and physiology, and can alter the temporal and spatial activity of fish and increase their energy expenditure. This can stimulate various behaviors such as nest-guarding activity, higher nocturnal activity, overall activity during both day and night, increased time spent in open areas, and maintaining position in an area. Fish species can be attracted or repelled by light. For example, positive phototaxis can lead to the aggregation of smaller fish around lighting, thereby providing easy prey for predatory fish. Some species may benefit from foraging under brighter conditions, but whether the benefits outweigh the costs over time is still being determined (*5*). Very low light levels can have effects on fish behavior. For example, rainbow trout (*Oncorhynchus mykiss*) are attracted to low levels of bridge illumination, which further depends on various environmental factors, making it a complex issue (*46*).

Plants

Although the effects of anthropogenic lighting on commercially grown plants are well documented, there is a gap in the knowledge about its effects on plants and plant-mediated responses in the natural environment. Lighting close to trees can lead to increased photosynthesis and morphological changes through the relocation of biomass from roots to leaves (*47*). In deciduous trees, exposure to anthropogenic light advances the emergence of leaf buds and, together with temperature, delays the coloring of leaves (*48*). Species-specific variations in responses to anthropogenic light have also been demonstrated in herbs and grasses (*49*).

Ecosystem effects of anthropogenic light

Nocturnal environments are dominated by moonlight because it is the strongest and most abundant natural light source. Light from anthropogenic sources differs from natural light in magnitude, color composition, and temporal and spatial presence. Moonlight intensities at midlatitudes can be as high as 0.2 lux depending on the position above the horizon and the amount of cloud cover (*50*). In many areas, however, the amount of anthropogenic light surpasses moonlight.

Anthropogenic light sources usually have a spectral composition that differs substantially

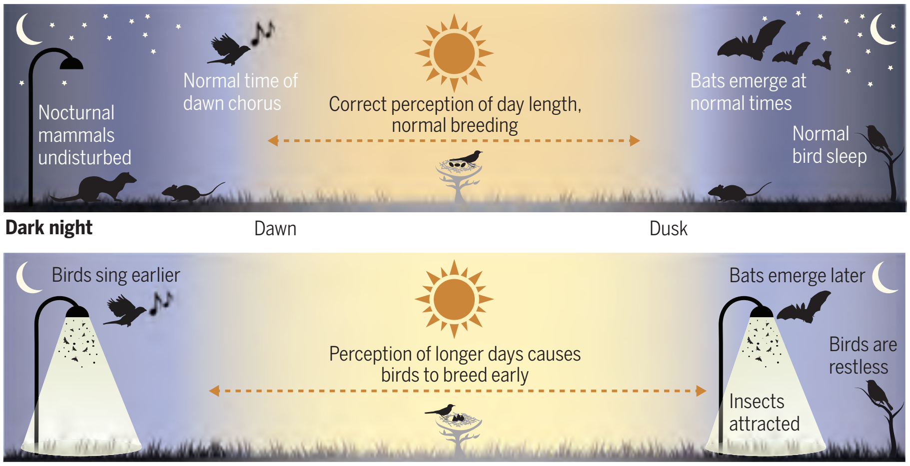

Fig. 2. Examples of disturbance of daily and seasonal rhythms by anthropogenic light. Nocturnal rodents are less active, and diurnal species can be restless in illuminated nights. Birds advance their dawn song, and bats delay emerging until the evening. Light at night can disrupt the perception of day length in birds, causing them to breed earlier in spring.

from natural nocturnal light: Outdoor LEDs typically have a peak in the blue spectral range, resulting in a cooler, white light compared with the yellowish light of the moon. Traditional light sources, such as high-pressure or orange low-pressure sodium lamps, are different from natural light because they have very little or no blue light. The intensity and distribution of natural nocturnal light vary as the night progresses and are also influenced by changes in the lunar phases and weather conditions. By contrast, anthropogenic light is often constant and concentrated around human settlements.

Terrestrial landscapes vary in topography and in the heights of physical objects, which result in variations in light distribution and exposure to organisms.

Forest ecosystems are generally darker as light is filtered through and absorbed by the vegetation, and only a small proportion of ambient light reaches the ground. Species that inhabit forests are believed to have adapted to darker nocturnal environments (*51*). In open environments, light can propagate far from the source, and even a single strong light can be a conspicuous element in the landscape, resulting in glare and difficulties in seeing details in the surroundings and stars in the night sky. In general, open environments are perceived as brighter when larger parts of the naturally lit sky and the ground can be viewed. Low-growing and light-green vegetation such as grasses, bushes, and herbs can reflect a high proportion of light, which increases the luminance of the landscape.

In aquatic ecosystems, anthropogenic light is reflected on water surfaces and thus has a high probability of propagating widely over open water and may affect large areas.

Many human structures in or near aquatic ecosystems, such as ports, ships, and oil rigs, use high-intensity lighting with insufficient restrictions, often resulting in large amounts of light spilling into the surroundings. In water, light changes with depth. Water and its particulates absorb and scatter light, reducing light intensity, altering color composition, and changing the degree of polarization. Clear ocean waters absorb ultraviolet, red, orange, and yellow wavelengths at the top of the water column, allowing blue light to penetrate the deepest, which results in a bluer color at greater depths. Coastal and freshwater systems often contain suspended particulates and phytoplankton, which selectively absorb the light, causing the water to appear more yellow-green, orange, or brown in color. Aquatic species have adapted their eye morphology to natural variations in intensity and color composition with photoreceptors that match the color of light, thereby increasing photon absorption (*52*). For example, deep-sea fishes have a visual pigment that matches the color of downwelling oceanic light, whereas fish species found in yellow-green coastal waters and inland freshwater lakes have photoreceptors with absorption peaks at longer wavelengths. Because light diminishes with depth, organisms in the mesopelagic zone have adapted to more dim light conditions with larger eye size and wider pupils. Aquatic species are expected to be vulnerable to anthropogenic light at night because of their high photosensitivity at low illuminance (*53*), which is an adaptation to decreased light intensity as light is filtered out by water.

Effects of anthropogenic light on temporal organization

Light is the key driver of the most important temporal niches in nature. The contrast between high light levels during the day and low levels at night enables species to share the same habitat within a 24-hour cycle. For most species, photic conditions are essential for their ability to survive (*24*). Organisms need to optimally schedule activity, rest, and sleep in (species-specific) natural light conditions.

The disturbance of rhythms in natural systems by light at night has attracted increasing interest (*54*), particularly in laboratory studies. For example, great tits (*Parus major*) exposed to low light levels during the dark phase of the light cycle were found to advance the start of their daily activities [e.g., (*55*)]. Rhythms in laboratory mice were shown to be weakened by dim light at night, and their hormonal rhythms were affected (*56*). Light at night has also been shown to disrupt circadian gene expression in great tits (*57*). In the field, an advanced onset of dawn song has been observed for several bird species, and individual blackbirds (*Turdus merula*) exposed to higher levels of anthropogenic light begin their activity earlier in the day (*58*). By contrast, nocturnal species respond to light by delaying their activity. For example, least horseshoe bats (*Rhinolophus pusillus*) emerge later, when their roost is illuminated (*59*). Bird species that normally start their dawn song relatively early during still low light levels, such as the robin (*Erithacus rubecula*), respond more strongly to the presence of artificial light compared with other birds (e.g., the blue tit, *Cyanistes caeruleus*) that start dawn song later in the morning [(*23*); Fig. 2].

In temperate zones, anthropogenic light interferes with the annual cycle of species. Trees delay shedding leaves from branches close to streetlights (*60*). Anthropogenic light can advance reproduction in birds (*22*), delay reproduction in mammals (*61*), and prolong yearly reproduction in insects (*62*).

Anthropogenic light affects interactions and trophic levels

Changes in the population of a species caused by anthropogenic light inevitably cause changes in the food web. Light can facilitate foraging for predators by concentrating prey species, such as for synanthropic bat species that catch light-attracted flying insects (Fig. 3) (*63*). Such changes in the predator–prey interaction may, however, be part of a trade-off for bats because they need to prevent exposing themselves too much (*64*). Foraging may be further facilitated by providing better visual detection of prey, as was shown for burrowing owls (*Athene cunicularia*), which could expand their foraging habitat into urbanized areas using the presence of anthropogenic light (*65*). Conversely, prey species may avoid illuminated, otherwise suitable habitat or change foraging behavior. Such changes have been shown in jerboas (*Allactaga sibirica*), which spend less time searching for food in illuminated conditions (*66*). Likewise, in aquatic systems, light at night can counteract the benefits of shelter material for amphipods (*Gammarus fossarum*) seeking shelter from the predatory Eurasian perch (*Perca fluviatilis*) (*67*).

ILLUSTRATION: N.CARY/*SCIENCE*, BASED ON ANNIKA K. JÄGERBRAND AND KAMIEL SPOELSTRA

Complex effects have been reported about the interaction of urbanization with the response to light. In urban areas, mule deer (*Odocoileus hemionus*) use illuminated foraging grounds but are then exposed to predation by cougars (*Puma concolor*) (*30*), which potentially results in an ecological "trap" in which species may do worse in an ostensibly beneficial situation.

Trophic interactions can form the basis of key ecosystem services such as pollination by insects. Nocturnal pollination is strongly affected by anthropogenic light, and reduced nocturnal pollination rates are compensated for by diurnal insects (*68*). The disturbance of trophic interactions by light at night in plant–herbivore communities can be complex and depend on species and color composition (*69*). To understand ecosystem-wide changes, a better understanding of trophic interactions is essential.

Anthropogenic light affects species at different time scales

The attraction of animals to light is a well-known direct response. Anyone who is attentive will notice the accumulation of insects around light sources. Attraction has been reported in many other species groups, such as marine turtles, birds, and amphibians, and often has direct consequences for survival (*8*, *12*, *17*) and subsequently for populations. Because the removal of light sources is very rare, it is important to assess effects that may only manifest after a long period of time. Several studies have shown indirect effects of anthropogenic light on many insect species (*9*). Adult fireflies survive light sources in proximity but fail to attract mates (*70*), which eventually results in population decline. Moth species, in addition to the agony of being trapped near light sources, are burdened by impaired reproduction and development (*38*). Light at night affects gonadal growth in blackbirds, which manifests only during the second year of exposure (*71*). Ultimately, light at night may cause adaptive changes, but evidence is limited to just a few studies (*9*). These include the examples of potential adaptation in spiders (*Larinioides sclopetarius*) with the innate preference for building webs around anthropogenic light sources (*40*) and in urban moths that show reduced flight-to-light behavior compared with rural conspecifics (*72*).

The way forward

Given the varied and substantial impacts of anthropogenic light, there are no simple solutions for its reduction and mitigation in natural systems. Continued increases in the nocturnal use of anthropogenic lighting will exacerbate its impact on our natural environment (Figs. 1C and 4, A to E), causing major changes to ecosystems, such as further declines in insect populations, loss of habitats of nocturnal mammals, and disruption of food web interactions. These changes will lead to the loss of biodiversity and potential feedback effects, including impaired ecosystem services such as the pollination of crops. Keeping natural areas dark, limiting light emissions from near and distant light sources, and thereby reducing sky brightness are therefore of utmost importance. Strategies to prevent light emissions into nature conservation areas are therefore proposed to be urgently implemented to ensure the long-term survival of protected species, preferably by combinations of different light mitigation measures (*53*, *73*). To effectively implement these measures, both national and international collaborations are essential. In protected areas, the aim should be to reduce light emissions from anthropogenic light sources to natural nocturnal light conditions. Current international guidelines, such as the "Guide on the limitation of the effects of obtrusive light from outdoor lighting installations" (*74*), can be used as the first step in ensuring that light emissions are below the recommended threshold values in protected areas.

Several technical and practical adaptations of lighting designs can be used to reduce their effects on local ecosystems (*53*, *73*). These include luminaire shielding, time-restricted and adaptive lighting, light intensity reductions, and tuning color composition.

Luminaire shielding or special optics can be used to prevent light being emitted in unwanted directions (*53*). Standardization to restrict spill light is urgently needed to prevent the negative effects of upward light and light outside of intentionally lit areas in vulnerable and exposed ecosystems such as open and aquatic environments (Fig. 4, A and B). Natural barriers, such as dense vegetation, can also be used to hinder light emission. The ecological benefit of time-restricted lighting may be limited, because the human demand for light during the first part of the night coincides with the peak activity of many nocturnal species. For example, bats are particularly active after dusk, reducing the potency of part-night lighting schedules (*75*). Adaptive road lighting is a promising solution to reduce ecological effects, but it is most effective for roads with low traffic. However, dedicated lighting schedules in more unique situations can be highly effective, for example, the intermittent off-switching of the lighting setup at the National 9/11 Museum's "Tribute in Light" in lower Manhattan to release thousands of light-trapped migratory birds (*17*). Decreasing light intensity is essential to preventing its ecological effects because many species are highly photosensitive even at extremely low illuminance levels due to their adaptation to dark nocturnal ecosystems. However, little is known about the intensity thresholds of many species, which may vary according to exposure duration, life history stages, and habitat structure. The installation of dimmable LED lighting is therefore very important because light levels can be adjusted after installation. A good example is the city of Rotterdam in the Netherlands, where all 100,000 light posts are currently fitted with LED fixtures that can be remotely adjusted for light intensity at any time of night. Because of the problematic identification of threshold light intensity levels, a pragmatic approach may be to keep light levels below lower moonlight illumination levels, which range from 0.05 to 0.1 lux (*76*). Finally, the color composition of light sources must be carefully chosen because it can modulate ecological

Fig. 3. Light at night drives species interactions. Many species are nocturnal because of fear of predators, for example by barn owls (*Tyto alba*). The middle and right species (Natterer's bat, *Myotis nattereri*, and the brown long-eared bat, *Plecotus auritus*) are examples of slow-flying bats that need to be extra wary of predators. These bats thrive in darkness, emerging late in the evening and foraging in sheltered places. The common pipistrelle (*Pipistrellus pipistrellus*) avoids light as well, but has a more agile flight and dares to forage on accumulated insects close to street lights.

ILLUSTRATION: K.HOLOSKI/*SCIENCE*, BASED ON ANNIKA K. JÄGERBRAND AND KAMIEL SPOELSTRA

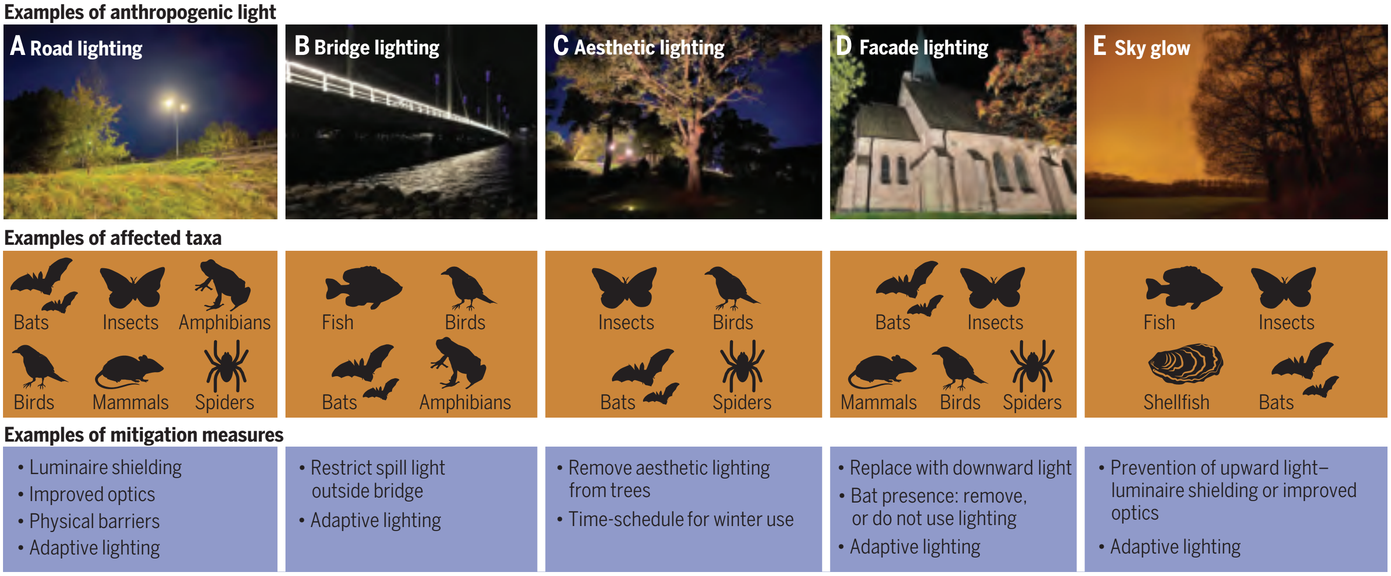

Fig. 4. Examples of anthropogenic light, affected taxa, and mitigation measures. (**A**) Terrestrial species can be affected by road lighting, which can be reduced through various measures to control light spill. (**B**) Bridge lighting can affect both aquatic and terrestrial species, and light spill outside the bridge should therefore be restricted. (**C**) Aesthetic lighting on trees can affect species that use trees for habitats or foraging, so this lighting should be removed or time restricted. (**D**) Upward façade lighting on buildings can affect several terrestrial species, and downward lighting should be used instead unless bats are present. (**E**) Even low levels of sky glow—reflected light from remote anthropogenic light sources—can affect species in natural habitat.

PHOTOS: (A) TO (C) ANNIKA JAGERBRAND. (D) KAMIEL SPOELSTRA; ILLUSTRATIONS: N.CARY/*SCIENCE*

consequences. The current worldwide transition to LED lighting poses both challenges and opportunities. White LED lamps often contain a high proportion of blue light (~450 nm) and, although the responses of species are diverse, there is a general tendency to caution against the high emission of blue light. By utilizing diodes that produce different colors, and with the application of phosphor conversion techniques, the amount of blue light in a light source can be reduced. This is effective in protecting animal species because the red part of the color spectrum attracts fewer insects (*36*) and has a less disturbing effect on the activity of bats (*63*). Highly adapted spectra should, however, be used cautiously because they may create ecological traps for species that are unable to sense the light and therefore think they are in a safe environment. In addition, technical and practical lighting design adaptations presumably need adjustments to better compensate for variations in ecosystem properties and topography.

International initiatives have been formed to establish policy frameworks aimed at reducing light pollution, such as the Convention on the Conservation of Migratory Species of Wild Animals (CMS). Work is underway in the International Commission on Illumination (Commission Internationale de l'Eclairage, CIE) to develop guidelines for minimizing the effects of anthropogenic lighting on the natural environment. Furthermore, some countries have implemented national guidelines aimed at reducing ecological light pollution. Currently, outdoor lighting is not included in the 2030 Agenda for Sustainable Development, which has been adopted by all the members of the United Nations. This is very unfortunate because many Sustainable Development Goals are markedly affected by outdoor lighting and light pollution. For ecological sustainable development, it should be an urgent priority to keep naturally dark environments dark and to protect species from the adverse effects of anthropogenic light. This should be a strong motivator for national and local governments to include effects of anthropogenic lighting in planning and decision making toward a sustainable future.

Future recommendations for ecological protection should aim to establish numerical threshold values on the basis of illuminance or luminance of current light sources and technologies. This will facilitate the translation of new research findings into practical guidelines for lighting design and the upgrading of existing lighting systems. Given the variation in species responses to both spectral differences and intensities, a simple solution to mitigating the effects of anthropogenic light on all species may be challenging. Therefore, investigating different types of mitigation measures and their effectiveness in different species and environments is an important mission for future research.

It is important to recognize that even when the most advanced current technologies are used, light can still spill into the natural environment and sky because of reflections from surfaces. This reflected light may affect aerial species and contribute to sky glow (Fig. 4E). However, guidelines for outdoor lighting or light pollution rarely address restrictions on reflected light. Given the difficulty of effectively reducing the ecological effects of anthropogenic light, it may be necessary to adopt more frugal lighting practices and, in some cases, turn off lights altogether, despite the potential discomfort to humans that this may cause.

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REVIEW

Reducing nighttime light exposure in the urban environment to benefit human health and society

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Nocturnal light pollution can have profound effects on humans and other organisms. Recent research indicates that nighttime outdoor lighting is increasing rapidly. Evidence from controlled laboratory studies demonstrates that nocturnal light exposure can strain the visual system, disrupt circadian physiology, suppress melatonin secretion, and impair sleep. There is a growing body of work pointing to adverse effects of outdoor lighting on human health, including the risk of chronic diseases, but this knowledge is in a more nascent stage. In this Review, we synthesize recent research on the context-specific factors and physiology relevant to nocturnal light exposure in relation to human health and society, identify critical areas for future research, and highlight recent policy steps and recommendations for mitigating light pollution in the urban environment.

Nighttime outdoor lighting provides many important functions in urban societies including aiding wayfinding, supporting feelings of safety and security, enabling outdoor activities, revealing historical and architectural heritage, and promoting economic development by bringing people together (*1*). At the same time, cycles of light and darkness are important physiological cues for key bodily functions. Exposure to too much light in the evening and nighttime has the potential to disrupt circadian physiology, suppress melatonin secretion, impair sleep, and stress the visual system (*2*).

With 4.4 billion humans currently living in cities, nighttime lighting is rising worldwide, especially in urban environments, and it is now visible even in remote locations. A recent study shows that the extent of electrical light at night has increased by almost 10% annually over the past 12 years—much more than previously thought (*3*). It is known that electrical light from local and more distant sources produces light pollution, i.e., outdoor light levels that differ from those occurring naturally. This results in over-illumination, urban sky-glow, light trespass, and glare, all of which have been linked to adverse effects on various living organisms, including humans (*2*, *4*).

"...nighttime light can disrupt circadian rhythms..."

The Commission Internationale de L'Eclairage (CIE, or International Commission on Illumination), an organization that sets standards for the lighting industry and lighting professionals, describes light pollution as "the sum total of all adverse effects of artificial light" (*5*). Effects on flora, fauna, human health, and society comprise this "sum total," so a more comprehensive definition may be warranted. Light emitted by any type of electrical light source has the potential to contribute to light pollution. The introduction of light-emitting diodes (LEDs) in the early 2000s continues to transform outdoor lighting, as traditional high-pressure sodium and metal halide lamps for street and area lighting are changed to LED light sources, because of their promised energy-saving potential and longevity. As with earlier light sources, the overuse of lighting, as well as poor luminaire design and placement, can elicit unwanted adverse effects.

In this Review, we synthesize recent research on the context-specific factors and physiology relevant to nocturnal light exposure and their impact on human health and society. We also identify critical areas for future research and highlight recent policy steps and recommendations for mitigating light pollution to benefit human health and well-being.

Nighttime light exposure and human health

Demographic shifts toward increasingly urban living mean that most humans are exposed to higher levels of light at night. Behaviorally, humans have considerably extended their daytime and consequently shortened their nighttime. We experience increased nighttime light exposure from lighting in the home before bedtime, from computers, mobile phones, and television screens, as well as from light entering the home from street lighting, security lighting, externally illuminated buildings, and brightly illuminated advertisements. Excessive light exposure in the evening and nighttime can be problematic as it strains the eyes, stresses the visual system, and can cause circadian, neurobehavioral, and neuroendocrine problems such as circadian desynchrony, sleep disruption, and suppression of melatonin secretion from the pineal gland (*2*, *6*–*8*).

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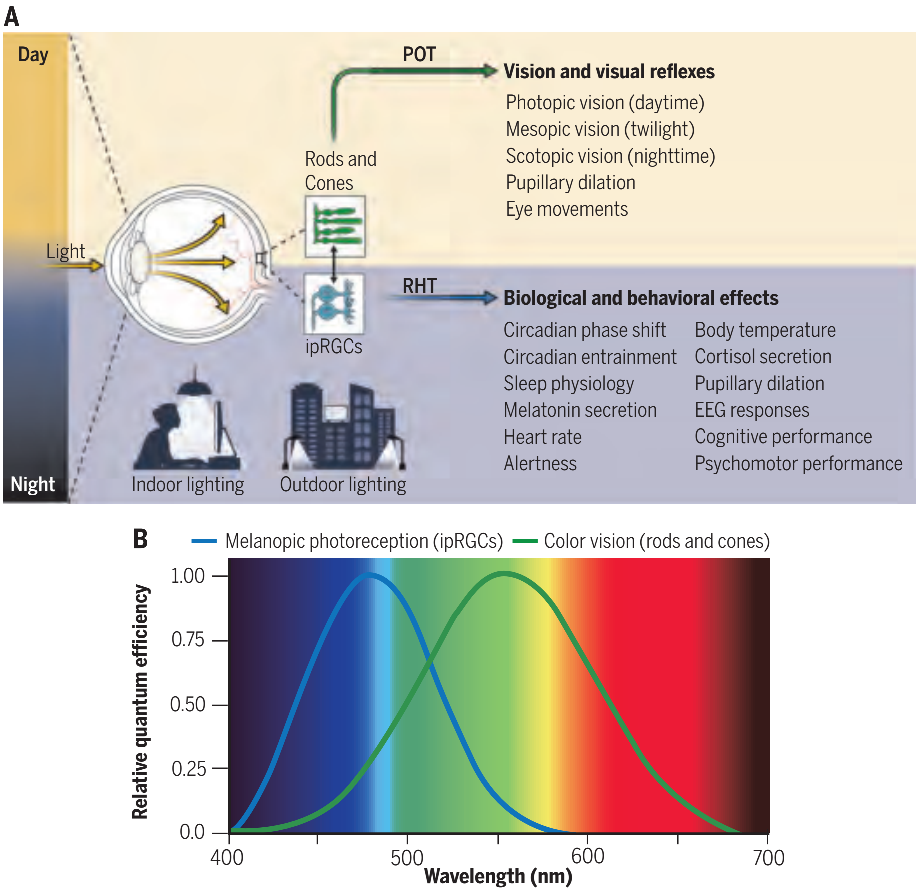

Fig. 1. The human eye has two distinct, interconnected sensory systems. (**A**) Simplified diagram illustrating that the human eye supports two distinct photoreceptive pathways. The primary optic tract (POT) delivers information about environmental light to regions of the brain involved in vision and visual reflexes. The retinohypothalamic tract (RHT) delivers information about light and darkness to nuclei in the brain that regulate circadian, neuroendocrine, and neurobehavioral effects of light. ipRGCs have the capacity to influence certain visual responses, and rods and cones have the ability to contribute to biological and behavioral responses. The list of effects is not comprehensive. (**B**). Graph illustrating the relative quantum efficiency of the photopic visual system for color vision (with a peak at ~555 nm) versus the melanopsin ipRGC system (with a peak at ~480 nm), which supports circadian, neuroendocrine, and neurobehavioral regulation in humans.

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Light stimuli are detected by two sensory systems in the eye (Fig. 1A). Classically, human light perception has been thought to be mediated exclusively by rod and cone photoreceptors. These form the entire photoreceptor layer of the retina and detect visible light to support the sensory capacity of vision and visual reflexes (Fig. 1A). In addition, there is a set of intrinsically photosensitive retinal ganglion cells (ipRGCs), which contain the photopigment melanopsin (*9*, *10*). The ipRGCs play roles in visual responses such as contrast detection, and, just as rods and cones, can contribute to physiological responses (*6*, *9*). Numerous human and animal laboratory studies have quantified the impact of light on circadian phase shifting, melatonin regulation, and pupillary light reflex, as well as sleep, alertness, and mood responses (*6*, *9*–*12*). Recently, a study showed that melatonin suppression and circadian phase shifting appear to have a strong cone input at the start of a 6.5-hour light exposure, but over most of the exposure, ipRGCs are the primary photoreceptors for circadian and neuroendocrine light detection (*13*).

Early research on human exposure to light at night came from individual-level studies of night workers. This work showed that nighttime light can disrupt circadian rhythms, thereby increasing breast cancer risk (*14*). Today, the effects of individual nighttime light exposure on the circadian system and physiology central to chronic disease and the immune system are well demonstrated (*15*–*17*). Indeed, in nighttime workers, exposure to light at night has been described not only as a likely cause of cancer, but also as a risk factor for cardiovascular disease, type 2 diabetes, hypertension, obesity, depression, and more (*8*). Additionally, evidence reveals more immediate adverse effects of night work, ranging from sleep problems to work errors and injuries.

Researchers have attempted to identify health impacts of ambient outdoor light pollution. Images of nighttime light emissions (the extent of sky glow and overlighting) in the outdoor environment can be obtained through satellite-based remote sensing (Fig. 2), and this has been used in some epidemiological studies. Most of these studies on light pollution from outside the home are either purely ecological or multilevel, when prospective cohorts with individual-level data are investigated but light exposure is used as an aggregate measure. These studies have yielded mixed findings, with some showing a higher risk of breast cancer, obesity, diabetes, cardiovascular diseases, and sleep problems or disorders (*15*, *17*–*19*). Support is also still mixed about the physiological effects of excess ambient nighttime light exposure on melatonin levels, perhaps in part due to inherent variability in individuals' sensitivity to light (*4*, *20*, *21*).

Unlike night worker studies, in which metrics capturing the intensity and duration of night work exposure tend to provide a more viable estimate reflective of circadian misalignment, light pollution studies using light exposure as an aggregate measure are currently fraught by their broad and imprecise measurements. For example, it has remained difficult to ascertain if the nighttime light pollution measured outdoors results in consistent lighting conditions in the bedrooms of exposed individuals, considering that individuals vary in their use of shutters and curtains to block light, additional indoor lighting exposure, and whether and when they sleep (*22*). It is challenging to obtain composite assessments of evening and nighttime interior lighting across a whole community, and only a few examples exist in which indoor nighttime light measurements have been attempted using, e.g., self-reported ambient light levels in private bedrooms while sleeping or portable light meters, linking this data with breast cancer and depressive symptoms (*23*, *24*).

Furthermore, some elements of light pollution cannot be quantified with satellite data owing to lack of resolution, failure to detect shorter wavelengths of light, complex three-dimensional structure of light sources, and cloud cover in the Northern Hemisphere (*25*). More recent studies of nighttime light pollution have made a greater distinction between indoor and outdoor lighting (*26*). They show that exposure to outdoor light at night with light rich in the blue-appearing spectrum is associated with increased breast, prostate, and colon cancer risk. Future empirical studies on the physiological and health effects of outdoor nighttime lighting should incorporate these considerations.

The direct impact of outdoor lighting has rarely been measured. One study with a small sample size examined car drivers, pedestrians, and people exposed to light trespass from streetlamps. Each group was exposed to solid-state light sources with differing spectral emissions. The spectrum of the light sources tested at recommended roadway exposure levels did not statistically affect salivary melatonin levels (*20*). In another study, scientists measured light exposure and wrist temperature among residents of an urban area and noted circadian effects on wrist temperature linked to the timing of environmental light exposure, although the contribution of outdoor light sources after dark was minimal (*27*). Glare from bright light sources such as unshielded LEDs is a growing public concern (*7*). Recently, a new approach for evaluating the discomfort glare of pedestrian-scale applications has been developed (*28*). A more in-depth study of temporal light modulation (flicker) at frequencies that may have adverse health effects is needed (*29*). There remain sparse direct, empirical measurements of the capacity of urban street, building, outdoor sport facility, and illuminated advertisement lighting to evoke detrimental visual, circadian, neuroendocrine, or neurobehavioral responses in healthy humans under naturalistic outdoor conditions.

The physiological effects of light exposure have been shown to be dependent on light spectrum, quantity, length of exposure, and the time of day (*6*, *9*, *15*). In addition, differences between individuals influence their susceptibility to developing disease when exposed (i.e., variation in “shift work tolerance” in night workers). Important determinants of such variability include age, gender, chronotype, and ethnicity (*15*). Although evidence is currently inconclusive, there is some suggestion that there are stronger effects of light on sleep in younger persons. An important recent study showed that a >50-fold variability exists between individuals regarding their sensitivity to evening light, suggesting that future studies should take interindividual differences into account (*30*).

Recently, other potentially relevant effects of light on human physiology have been described. These relate to daily oscillations of the gut microbiome, the relative abundance of gut microbes under normal conditions, and altered composition under modified dark-cycle conditions, including dim light at night (*31*). It is increasingly recognized that gut microbiota are involved in human physiology, affecting metabolism, neurodegeneration, and mental health, and interventions that modulate gut microbiota may mitigate the impact of light exposure on health outcomes associated with nighttime light (*31*). During the COVID-19 pandemic, studies showed that people became infected more often, more severely, and for longer periods of time when they were sleep deprived and/or worked at night or they resided in areas that had high levels of outdoor electrical light emissions at night (*32*, *33*).

Owing to the pronounced effects of nocturnal light on flora and fauna, indirect effects on human health, although even more difficult to measure, are practically inevitable (*34*). Urban light at night can attract and repel animals and cause changes in their behavior, potentially providing more opportunities for vector-borne diseases to spread to humans, including through zoonoses. In addition, light at night has been implicated in the recently observed insect die-off, because of decreased reproduction and a fatal attraction to car headlights, streetlights, or other lighting (*35*). Insect decline has numerous downstream effects that are detrimental to human health, as insects control pest species, help decompose waste, and pollinate more than a third of our food (*35*).

Typically, light that supports human vision in daylight is quantified inside and outside of buildings in terms of photopic illuminance or lux. Information about light and darkness is also detected by photosensitive ipRGCs and transmitted to nuclei in the brain that regulate circadian, neuroendocrine, and neurobehavioral effects (Fig. 1A). Quantifying light that regulates human physiology, however, requires a different method of measurement.

“...there are better ways to manage light pollution for the benefit of public health and society in the urban environment...”

Scientific consensus and an international standard, balloted by the CIE, selected the measurement of melanopic equivalent daytime illuminance (melanopic EDI) at eye level as a better means than photopic lux for quantifying light relative to the regulation of human physiology, and ultimately, health and well-being (*6*, *9*, *36*). Because this is an emergent field and the relative contribution of rods, cones, and ipRGCs remains unknown, the CIE recommends assessing and reporting all five α-opic photoreceptor values (*36*). Different spectral sensitivities of the photopic visual system versus the melanopic ipRGC photoreceptor have been demonstrated (Fig. 1B).

Social burden of light pollution

Understanding the drivers and consequences of light pollution is critical to moving society toward a humanity-centered (supporting the rights of all of humanity and the entire ecosystem) and sustainable lighting approach. Although there are numerous needs for nighttime lighting, some social and cultural misconceptions can contribute to poorly executed lighting, which, in turn, can lead to unnecessary light pollution.

Such misconceptions include the notion that increased electric light outdoors is seen as a sign of wealth and prosperity. Economic growth, for example, has been estimated through satellite imagery of Earth at night to record visible illumination and correlated to gross domestic product (GDP), even though most relevant activity actually occurs during the day, thereby reducing the accuracy of these estimates (*37*).

The fear of darkness and the associated perception that bright lighting provides safety and security have limited research support (*38*). In fact, unshielded, glary lighting can be momentarily blinding, making it more difficult to identify objects and potential threats, navigate the terrain, and adjust to low-contrast surrounding, consequently decreasing safety (*7*).

An absence of lighting, as well as poorly executed lighting, also can be a sign of social injustice in terms of wealth prospects and opportunities (*39*). In the rural populations of developing, low-income countries worldwide, there is no electricity in most schools and households, but without education it is difficult to escape poverty. Basic lighting relies on unsustainable sources of energy, e.g., wood, coal, or kerosene, and these can negatively affect wide-ranging aspects of children’s health, such as respiratory problems or chemically related pneumonia from kerosene lamps, eye disease, or accidents from using candles while learning in bed. To avoid this, children often gather in publicly lit areas with streetlights to study and do homework. By contrast, in the Western world, the introduction of lower illuminance levels is seen as a sign of commitment to environmental protection and sustainability (*40*, *41*). In recent decades, affluent citizens (who generally live in safe neighborhoods) have enjoyed more natural darkness and considerably less light pollution from well-designed lighting on their own properties or in nearby natural park areas, compared to people in less affluent suburbs. Indeed, studies have emerged that highlight light pollution inequities, with more disparate exposure to light at night based on race and socioeconomic status (*42*). Moreover, in mixed-use urban developments that encompass two or more types of land uses (e.g., residential, commercial, retail), light trespass from outdoor lighting might include street lighting, media architecture, or LED advertisements shining through bedroom windows (*43*). This can disrupt sleep, requiring people to sleep in another room to escape light pollution, and in some cases, residents have even had to move to another apartment—an affordable option, however, only for a certain segment of the population.

How a lack of night sky visibility might contribute to the lack of healthy urban living has been studied in the past (*44*). Urban residents have been disconnected from nature and the cosmos such as major constellations, planets, and the Moon, with the Milky Way being hidden from more than one-third of humanity (Fig. 2) (*45*). Other studies also indicated that stargazing can be a stress reliever, possibly reducing anxiety and depression (*46*).

Another concern is that light pollution has increasingly obscured the celestial culture of Indigenous communities, many of whom rely on visual celestial clues that are supported by stories passed down across generations (*47*). Some have even expressed concern that the eradication of starlore and the disconnection from the heavens as a result of light pollution could contribute to the decline of entire groups by impeding their history and culture (*47*).

Every citizen should have the right to access darkness and quality, responsible outdoor lighting for improved health and well-being, a better social life, and nocturnal sustainability (*48*). To help facilitate positive change, more empirical evidence is required to determine the amount, and also the quality of outdoor lighting necessary to ensure visibility, safety, and the confidence of end users (*49*).

Current actions and recommendations for managing and regulating light pollution

Countries such as the Czech Republic, France, Germany, South Korea, and Slovenia are taking regulatory and policy measures against light pollution by adopting laws, regulations, and action plans to protect human health, the environment, and biodiversity (*50*). Despite such encouraging initial steps, most countries have no regulatory infrastructure to monitor or regulate light emissions at night.

Furthermore, there are currently no recommendations for urban outdoor lighting standards that specifically address circadian, neuroendocrine, and neurobehavioral effects of light, nor are there properly developed frameworks for assessing the health effects of light pollution (*40*). A scientific consensus position published in 2014, which evolved into an internationally balloted CIE standard in 2018, provides guidance to the lighting and scientific communities on how best to quantify light exposure in an SI-compliant system for regulating human physiology and ultimately health (*6*, *36*). Based, in part, on an analysis of 19 published studies, a consensus view was published in 2022, with target lighting recommendations of melanopic EDI levels for indoor ocular light exposures measured at the eye, to best support physiology, sleep, and wakefulness in day-active healthy adults (*9*, *51*). Specific melanopic EDI values were given for daytime minimum amounts, as well as evening and nighttime maximum exposures (*9*). These last two elements are relevant for outdoor electrical lighting at night. Studies on the effects of outdoor nighttime light exposure on human health would be best served by characterizing the spectral power distribution (SPD) of the light and all five α-opic EDI values for rods, cones and ipRGCs (*6*, *9*, *36*). Although several metrics for quantifying outdoor lighting exist (e.g., photon flux, irradiance, luminance, photopic and scotopic illuminance, and sky brightness factor), to understand whether and how light pollution affects human neurophysiology, it is important to measure all five α-opic EDI values. The published recommendations for evening and nighttime light exposures described above could be considered as preliminary guidance for limiting outdoor light trespass into residences or other indoor spaces (*9*). Notably, studies with nocturnal rodents show circadian and neuroendocrine sensitivities well below 1 melanopic lux, and there are indications that the same may be true for humans (*52*).

Rather than providing assistance in establishing plans or restrictions for electric light in terms of quantity, spectrum, timing, geometry, and the duration of exposure, current guidelines instead focus on energy efficiency. In fact, there are better ways to manage light pollution for the benefit of public health and society in the urban environment, including the driver-pressure-state-impact-response (DPSIR) framework, which is based on work of the European Environment Agency (Fig. 3). It provides a structure of the indicators needed to enable feedback for policy-makers on light pollution, public health, and the resulting impact of current or future political choices.

Recent changes in the SPD of street lighting sources have sparked an intense debate over the possible ill effects of LED lighting. The American Medical Association (AMA) produced two reports: one that details the impacts of inappropriate exposure to excessive light at night with a call for more research, and another, more recent document that recommends the use of roadway lighting with lower correlated color temperature lamps (<3000 K, which emit fewer short wavelengths of light) to minimize potential harmful effects to human health (*53*, *54*). The more recent AMA recommendation resulted in a strong reaction from the lighting industry and the US government, which disagreed with elements of that policy (*55*). Several initiatives, measures, and policies have subsequently evolved as a means to prevent

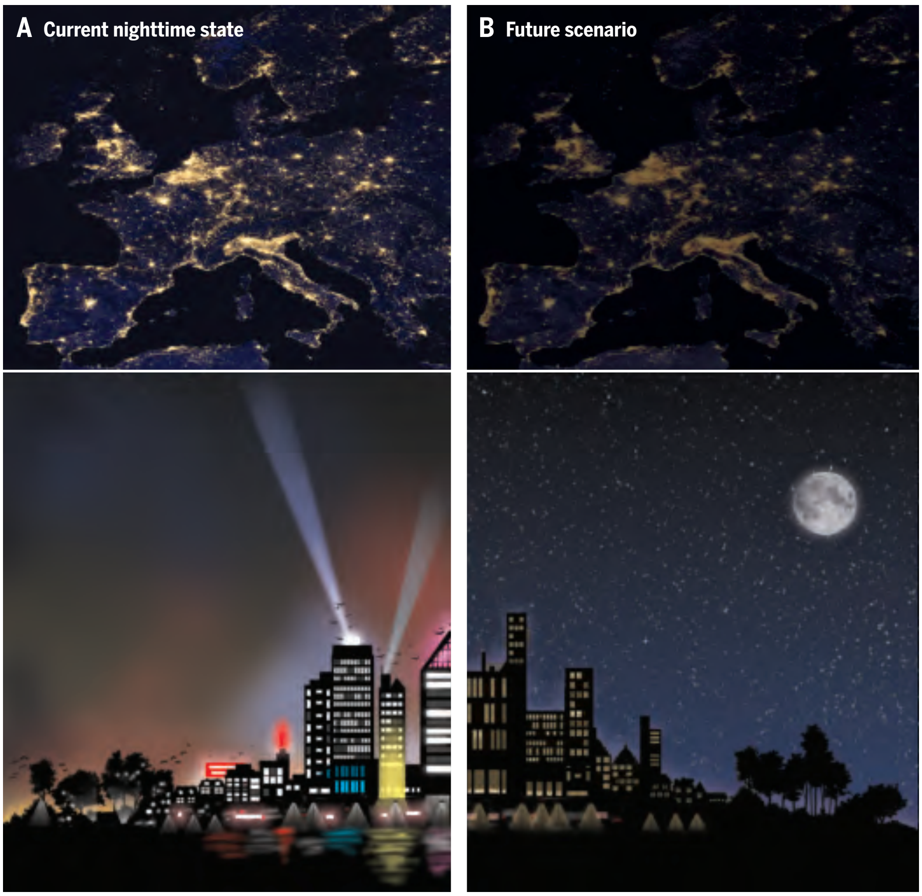

Fig. 2. Exposure to excess light at night has the capacity to influence human health, other organisms, and ecological systems. (**A**) Image of Europe from space at the current nighttime state shows increased light pollution typical of many urban areas across the globe. Sky glow above cities caused by over-illumination affects not only humans but also the migration and behavior of various animal species. Excess nighttime lighting can have an indirect impact on animals and plants and may contribute to insect decline and the emergence of zoonoses. (**B**) A future scenario in which anthropogenic light pollution is reduced to improve human, animal, and environmental health. Protecting ecosystems in urban areas can reduce humanity's environmental footprint, improve quality of life, and provide a cultural connection to the night sky.

CREDIT: K.HOLOSKI/*SCIENCE* BASED ON KAROLINA M. ZIELINSKA-DABKOWSKA AND SEREN DINCEL the excessive use of electrical light at night, and many are still being enacted and developed. Data-driven design recommendations have been developed to match illumination levels to the needs of vehicle users, reducing extraneous light while maintaining a level of safety for pedestrians and residents (*56*).

Because of the energy crisis, many cities have begun to change their energy policies and introduce lighting curfews. Even if saving energy is the main driver behind the switch-off of lighting rather than the goal of minimizing the other impacts of exposure to light, these actions are a positive example for other governments to follow. CIE recommendations to limit light trespass on properties (e.g., windows) exist; however, these may not be effective enough. For maximum values of vertical illuminance including the sum of all area lighting installations in well-inhabited urban and rural settlements (medium district brightness, environmental lighting zone E3), there is an allowance of 10 lux (pre-curfew) and 2 lux (post-curfew) (*41*). For town and city centers including other commercial areas (high district brightness, lighting zone E4), there is an allowance of 25 lux (pre-curfew) and 5 lux (post-curfew) (*41*). Additionally, an evidence-based consensus should be developed on the maximum light levels allowed in outdoor urban residential areas for limiting light trespass.

With the many problems faced by the world's urban inhabitants, it is common for city authorities to wonder how to improve the quality of life and health of citizens. Human-generated light pollution, which affects people in the evening and at night, however, has often been omitted even in the forward-looking development strategies proposed by the World Health Organization, such as Healthy Cities (*57*). Therefore, proposed and implemented well-balanced responsible urban lighting strategies and masterplans that allow for the integration of dimming and/or the temporary switching off of street, area, and decorative lighting could improve the existing situation (*40*). The City of London's recently adopted lighting strategy is a step toward a new approach to urban lighting and nocturnal sustainability for the built environment. Prior to this, the brightness of decorative and advertisement illumination of buildings was not properly regulated in terms of the adverse impact of light trespass on the health and well-being of residents (*43*).

Contrary to widespread outdoor light pollution, which a single person cannot change, over-lighting can easily be reduced and prevented in the home. Individuals can take action by either changing their light sources—e.g., to amber or warm white (with fewer short wavelengths light)—or by using only red light at night (with zero short wavelengths of light), or by turning lights off or dimming them in the evening using sensors and/or timers on their balconies, in gardens, and on façades. They can also become active members of various citizen groups, such as one advocating for a thorough investigation into the evidence of the impact of outdoor illumination (*58*). Recently, such citizens' actions resulted in an inquiry into the effects of electrical light on human health by the UK House of Lords (*59*).

In 2020, citizens, active members of the International Dark-Sky Association (IDA), and lighting professionals representing the Illuminating Engineering Society (IES) joined forces to protect the night from light pollution, and a consensus was reached between these stakeholders. This alliance created the Five Principles for Responsible Outdoor Lighting, which were adopted by the board of directors of both organizations (*60*). Another recent initiative, the Responsible Outdoor Lighting at Night (ROLAN) Manifesto, has further expanded and applied this knowledge (*61*). It provides 10 core principles for external illumination

1 ANTHROPOGENIC DRIVERS
Anthropogenic light pollution connected to human activities that influence environmental change and public health via:

- Over-illumination
- Urban sky glow
- Light trespass/light spill
- Glare

2 PRESSURES
Stressors that human activities (light pollution) place on the environment and public health

3 STATE
The state of the environment and socioeconomic status

The condition of the environment and public health and well-being

4 IMPACTS
Effects on public health and society

5 RESPONSES
Responses by society to the environmental/public health situation

- Light pollution laws, regulations and action plans
- Lighting impact assessments
- Outdoor lighting standards and guidelines
- Responsible urban lighting masterplans and lighting strategies
- Public inquiries/surveys
- Five Principles for Responsible Outdoor Lighting (IES/IDA)
- Responsible Outdoor Lighting at Night (ROLAN) Manifesto

Fig. 3. DPSIR framework for nighttime light exposure based on work by the European Environmental Agency, modified to benefit public health and society in the urban environment. This effective tool consists of five indicators that interreact with human activities in a closed loop of action, encouraging society or individuals to change their practices regarding the use of light at night. Appropriate responses (5) by society to anthropogenic drivers (1) such as light pollution can prevent or minimize their occurrence. Moreover, these behaviors can alleviate pressure (2) by reducing the extent of light pollution from excessive lighting, as these responses strive to understand the factors affecting this environmental change and impact on public health. By using appropriate tools such as public surveys that are based on expert interviews, testimony and evidence can be gathered along with adequate evidence of conditions so that the state (3) of the nighttime environment as well as public health and well-being can be partially restored to what it was before the use of electrical outdoor lighting. Lastly, impacts (4) in the form of public health and societal effects can be adapted to environmental conditions through the introduction of appropriate regulatory frameworks and the application of recommendations in the form of light pollution laws, lighting standards, guidelines, and other tools.

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with easy-to-follow actions to minimize the impact of outdoor nighttime lighting on human health and well-being, and also to preserve darkness and humanity's access to the stars at night. It has been adopted by leading international professional lighting bodies such as the International Association of Lighting Designers (IALD) and the IES, which demonstrates that dark sky protection is starting to be accepted.

Effective reductions in light pollution ultimately require more comprehensive regulatory controls. Therefore, of utmost importance is that all concerned stakeholders understand the consequences of excess light exposure at night and work together to develop measures that standardize urban lighting.

Conclusion

Detailed scientific knowledge of how overexposure to light at night affects individuals on the physiological, population, and community levels is complex and incomplete. Further research is required to facilitate the prevention and management of light pollution and to develop best practices for safer and healthier nighttime outdoor illumination.

There is a critical need for field studies on the physiological impact of nighttime electrical outdoor light to validate the concepts discussed above. These studies should (i) achieve an improved characterization of the SPD of both indoor and outdoor light, and the melanopic EDI measured at eye level; (ii) identify the minimum levels of illuminance and luminance affecting human vision as well as other organisms and ecological systems; (iii) differentiate between the health consequences of excess nighttime light exposure, air pollution, and other environmental exposures; (iv) resolve factors that contribute to, or are a consequence of, individual variations in physiological responses to nighttime light such as sleep timing, the duration and timing of outdoor light exposure, and genetic variations; and (v) investigate health-related societal impacts of light pollution.

Furthermore, a collaboration between the research community and the lighting profession is essential so that relevant issues can be effectively identified to guide future research. Resultant findings can then be integrated into outdoor illumination projects, as well as into regulatory frameworks. In addition, it is essential to foster evidenced-based lighting design approaches and technological solutions including light sources, luminaire design, lighting controls, and measurement methods that support the health and well-being of humans and entire ecosystems, as well as Indigenous and cultural astronomy. It is hoped that this Review provides helpful guidance for lighting professionals and for addressing gaps in light pollution research, as well as for the organizations that set lighting standards. An approach that integrates the needs of all stakeholders opens the door to improve outdoor lighting to promote and support the long-term welfare of humanity.

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REVIEW

The increasing effects of light pollution on professional and amateur astronomy

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The starry sky has been a source of inspiration throughout human history. Astronomy has been a common element in all cultures and civilizations, being used to establish calendars, navigate and discover new lands, and drive numerous scientific and technical breakthroughs. This Review discusses how it is becoming increasingly difficult for professional and amateur astronomers to observe the night sky because of light pollution. Artificial light at night, radio interference, and the deployment of satellite constellations are all rapidly increasing and are having adverse impacts on astronomical observations, limiting scientific discoveries, cultural connections to the night sky, and opportunities presented by astrotourism. Potential mitigation strategies to preserve the night sky are discussed.

Since ancient times humans have illuminated their settlements using fire for safety or nighttime activities such as travel or trade. These were later replaced by longer-lasting oil lamps and wicks. Public electric lighting was developed in the late 19th century and soon spread around the world. These early forms of lighting (fire, then incandescent bulbs) emitted light with an approximately black body spectrum and low color temperature, consisting mostly of red light and very little blue content.

During the 20th century, street lighting adopted high-intensity discharge lamps and then metal vapor lamps, powered by electric discharge tubes containing metals such as mercury or sodium. These produce visible light with discrete emission lines, which contaminate observations of those lines (or others with similar wavelengths) in astronomical sources. In the 21st century, these technologies are being replaced by more efficient light-emitting diode (LED) lighting, which produces a broader spectrum with substantial blue content (*1*). These developments in lighting technology affect the amount of light pollution produced.

Increasing levels of light pollution

In recent decades the increasing global population, economic growth, and reduction of illumination costs due to the use of LEDs and the bluer light they emit are all contributing to rapidly increasing impacts on the natural night sky. The improvements in lighting efficiency have indirectly led to increased light pollution.

Outdoor lighting in cities alone consumes 19% of global electricity (predicted to reach 27% by 2040), costing 30 to 50% of a typical city's energy bill (*2*). Generation of that electricity produces greenhouse gas emissions, which contribute to climate change. Global lighting accounts for emissions equivalent to 1471 million tons of CO_2 per year, equivalent to 18% of total emissions in China or 27% in the US, the two countries with the highest greenhouse gas emissions (*3*). There is little public awareness of the link between lighting and CO_2 emissions.

Overillumination—the deployment of lighting that is unnecessary, brighter than required, or switched on at inappropriate times—has become widespread, affecting most towns and cities worldwide. This wasteful overuse of lighting causes unjustified energy consumption, needless economic expense, and excess emission of greenhouse gases.

83% of the world's population lives under light-polluted skies (*4*); 23% of the world's land surface between 75°N and 60°S is light-polluted (*4*), and this number is growing at 2% per year, i.e., doubling in about 35 years (*5*). By 2050 the world population is predicted to reach 9.6 billion people, of which 68% are expected to live in urban areas (*6*). Currently 733 million people lack electricity supply and another 2.4 billion do not have access to clean cooking fuels and technologies (*7*). If current lighting practices are continued, the combination of population increase and economic development will lead to rapid increases in the levels of light pollution.

Sales of LEDs had a compound annual growth rate of more than 18% between 2017 and 2022 and are estimated to grow by another 15% between 2022 and 2027, reaching 141 million USD per year (*8*). Many types of LED lighting involved in this market expansion are not compatible with preserving the night sky because they have inappropriate color temperatures that emit large fractions of blue light, which is more strongly scattered in the atmosphere.

Light pollution is increasing worldwide at an estimated rate of 9.6% per year (*9*), reducing darkness everywhere, even at the most remote observation sites. The increasing levels of light pollution produced by the glow of artificial light at night (ALAN) is erasing the stars from our visible skies. This deterioration will leave a legacy with scientific, cultural, environmental, and aesthetic repercussions. Over-lighting also causes glare—the decrease in visual capacity or distortion of perception due to the presence of high luminance—and spectral light pollution, the emission of light at wavelengths that are useless for the intended purpose. Figure 1 shows an example of light pollution on the night sky.

Light pollution at astronomical observatories

Astronomical observations require dark skies and any sky glow can overwhelm the faint signal from astronomical objects, preventing their

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Fig. 1. Example of light pollution. The night sky photographed from the island of Sálvora in northern Spain, part of the Atlantic Islands of Galicia National Park and a certified Starlight Tourist Destination. The Milky Way extends diagonally across the image. The bright sky glow in the lower left is produced by light pollution, mainly from the use of white and blue LEDs and poorly shielded light fixtures from the towns located on the mainland coast of Rías Baixas, Galicia. Compare the number of stars visible in the lower left and upper right parts of the image.

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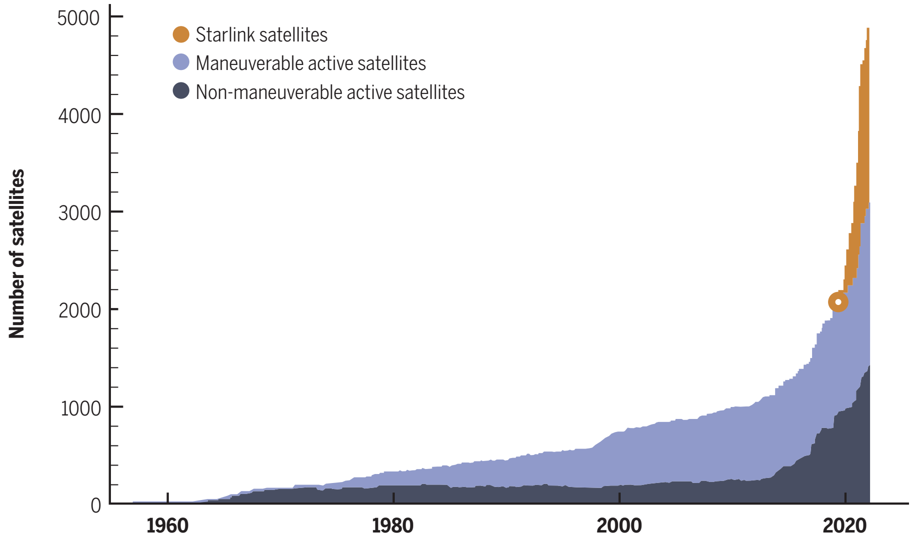

Fig. 2. Number of active satellites in orbit between 1957 and 2022. Data from (*18*). The number of maneuverable (blue) and nonmaneuverable (yellow) active satellites are plotted as a function of time. The pink circle indicates the beginning of the LEO communications constellation Starlink (pink). The three categories are additive. Between 2020 and 2022 the number of active satellites has grown by more than 50%.

detection. This problem becomes more acute for fainter astronomical objects or when observing with the naked eye. Because light pollution is generally worse in urban areas with high levels of economic development, dark skies are now mostly restricted to rural areas, often in more economically impoverished regions that are at risk of depopulation. In some of those places, access to dark skies is the basis for sustainable local economic development through star tourism, also known as astrotourism. Others have been chosen to host the large telescopes of professional observatories.

Even remote locations used for professional astronomical observatories or astrotourism no longer have pristine skies with natural levels of darkness. Light pollution is gradually encroaching everywhere as are radio signal interference and artificial changes to weather patterns caused by climate change and modifications to land use. Astronomical observations are also compromised by bright trails produced by increasing numbers of satellites orbiting Earth (discussed below). Two-thirds of major professional observatories are affected by light pollution at levels that exceed the target set by the International Astronomical Union (IAU) of 10% increase in radiance above the expected natural levels (*10*).

Ground-based astronomical observations continue to drive major, high-impact discoveries in astrophysics and fundamental physics. They are often essential to interpret observations from space-based telescopes. Ground-based optical telescopes can be built at a substantially larger size and roughly two orders of magnitude lower cost (per unit collecting area) than those launched into orbit. There are more than 40 ground-based optical telescopes with mirror diameters of 3 meters or larger, located in Australia, Chile, China, India, South Africa, Spain, Russia, and the United States, which constitute a substantial worldwide investment (*11*). The only space telescope of the same size is the James Webb Space Telescope (JWST), which took several decades to design, construct, and launch at a total cost of ~10 billion USD (*12*). The next generation of large ground-based optical telescopes currently under construction (the Giant Magellan Telescope, the Thirty-Meter Telescope, and the Extremely Large Telescope) will have apertures ranging from 3 to 6 times larger than JWST, are expected to be completed this decade, and have much smaller budgets (*12*, *13*).

Some types of astronomical data cannot be obtained from orbit, such as for planetary defense and space debris tracking. Arrays of light-collecting dishes similar in size to large radio antennas are deployed in remote locations (including in the United States, Namibia, Spain, and Argentina) to capture the faint flashes of blue Cherenkov radiation produced when high-energy gamma rays hit the top of Earth's atmosphere. These cannot be replaced with space-based telescopes.

Protecting sites for astronomy

Recognizing their importance for the local economy, some governments of regions that host astronomical observatories have introduced laws to limit light pollution, such as the 1988 Ley del Cielo (law of the skies) enacted by the Canary Islands to protect observatories on the islands of La Palma and Tenerife. Similar regulations have been introduced in other areas including Chile and Hawaii. However, the increasing impact of light pollution on observatories demonstrates that existing regulations are insufficient to halt the ongoing damage.

To do so, it is necessary to reduce, stop, and then reverse the growth of ALAN at its main sources (human population, agricultural, and industrial centers) within the next decade (*11, 12*). The IAU recommends that the total contribution of ALAN (quantifiable with sky glow measurement instruments and theoretical models) should be kept substantially below 10% of the natural dark sky level at an elevation of 45° in any azimuthal direction. Bluer photons are more strongly scattered in the atmosphere with the amount of scattering being inversely proportional to the fourth power of the wavelength. Therefore, reducing sky glow requires the reduction or removal of lighting that emits blue wavelengths: The blue light content (the amount of light emitted at wavelengths below 500 nm as a fraction of the total light emitted) should be as close as possible to zero (*11*). Recommended lighting sources should be quasi monochromatic and have their maximum radiant flux (in watts per nanometer) in the range of 570 to 605 nm (yellow-orange), similar to sodium vapor lamps (*11*). It is necessary for emissions to be at wavelengths longer than 555 nm—the astronomical *r*-band filter—which is already affected by emission lines as a result of oxygen and sodium that add to the natural night sky brightness.

Dark sky areas should be established around critical locations such as observatories and nature reserves, with zonal light output limits (similar to air quality zones). Close to these zones there should be no artificial light unless the need is clearly demonstrated. In this case, monochromatic illumination is strongly preferred (narrow-band amber), or when white light is required for safety LEDs, color temperatures of 1800 K should be used.

In addition to color, orientation and intensity also affect the amount of sky glow produced. Outside the area intended to be directly illuminated by the light source, the visible intensity should be as close as possible to zero even at low altitudes above the horizon (*14*). Light pollution could be further reduced by dimming lights, turning them off later in the night, or using motion sensors to increase brightness only when the lights are actually needed.

Wherever such regulations have been implemented, they have resulted in energy and economic savings as well as reductions in greenhouse gas emissions. Public administrations that host astronomical observatories are aware of the importance of protecting the night sky for science and to benefit the local economy.

The impact of satellite constellations

The deployment of large numbers of satellites in low Earth orbit (LEO) has had an unanticipated impact upon astronomy. Several communication providers have begun launching or are in advanced stages of planning networks of communications satellites referred to as constellations or mega constellations. Tens of thousands of these satellites are anticipated, orbiting at low altitudes from 400 to 1200 km (*15*). When a prototype batch of 60 satellites was launched in May 2019, astronomers were surprised by how bright they appeared from the ground. Between 5 and 10% of satellites are present above astronomical sites at any given time, with a proportion of those being illuminated by the Sun in a dark sky (*16*). With plans for up to 400,000 satellites in such constellations by 2030, thousands will be visible from any location at any time.

Although these constellations have legitimate goals of providing communication access even in remote areas, they have damaging effects for the astronomical community. The use of LEO means that even small satellites are bright enough to be observable with the naked eye, especially at low elevations above the horizon and during twilight (close to dawn and dusk). Satellites are illuminated by the Sun, remaining in sunlight for longer than the ground, with the resulting brightness also depending on the season and latitude of the observer. Satellites in lower altitude orbits generally appear brighter from the ground, whereas those in higher altitude orbits are illuminated for longer periods before and after twilight. Therefore, in general, constellations in higher orbits are expected to be more damaging to astronomical observations.

Figure 2 shows the number of active satellites in orbit since 1957. The number has increased rapidly, from 2200 in May 2019 to 5000 in May 2022, with another 58,000 satellites predicted to be launched by 2030. Including inactive satellites, this increases the total number in orbit to ~8000 in 2023.

Satellite constellations affect optical and infrared astronomy as a result of their brightness and the number of spacecraft involved. At optical wavelengths and viewed from the ground, each spacecraft appears as a moving source with apparent visual magnitudes (as perceived by the human eye, smaller magnitudes indicate brighter objects) of about +3 to +4 mag during the deployment process and +6.5 to +9 mag in their final orbits. Several thousand satellites have already been deployed (Fig. 2) and hundreds of thousands more are proposed. The number of satellites visible above the horizon from an observatory is anticipated to be ~1600 immediately after sunset, decreasing to 1100 at the end of astronomical twilight (*16*). Of those satellites, 85% would be close to the horizon (below 30° elevation) but that still leaves more than 100 across the higher elevations commonly used for astronomy. That study assumed 26 thousand satellites (*16*); since then the number of proposed LEO spacecraft has increased by more than a factor of 10. Satellite mega constellations also produce a diffuse sky brightening due to the scattering of sunlight from satellite debris. Assuming 65,000 satellites, this contribution has been estimated as ~0.5% of the dark sky, and the sunlight scattering of the upcoming satellites from the mega constellation into debris would create an additional ~10% over the dark sky brightness (*17*). This limit (~10%) was adopted in 1979 by the International Astronomical Union for the light pollution level not to be exceeded at the sites of astronomical observatories (*10*).

There is currently no regulation of the impact on astronomy by satellite mega constellations. The astronomical community did not become aware of the issue until spacecraft were already being launched. The impacts are expected to be particularly adverse for observations at low elevations or during twilight and automated surveys searching for moving objects (such as potentially hazardous asteroids) (*16*). Survey telescopes with wide fields of view will be severely affected. Twilight images taken with short exposure times (1 s) are essentially unaffected by satellite trails, but those with medium (100 s) or long (1000 s) exposures are contaminated by satellite trails in up to 0.5 and 1% of the

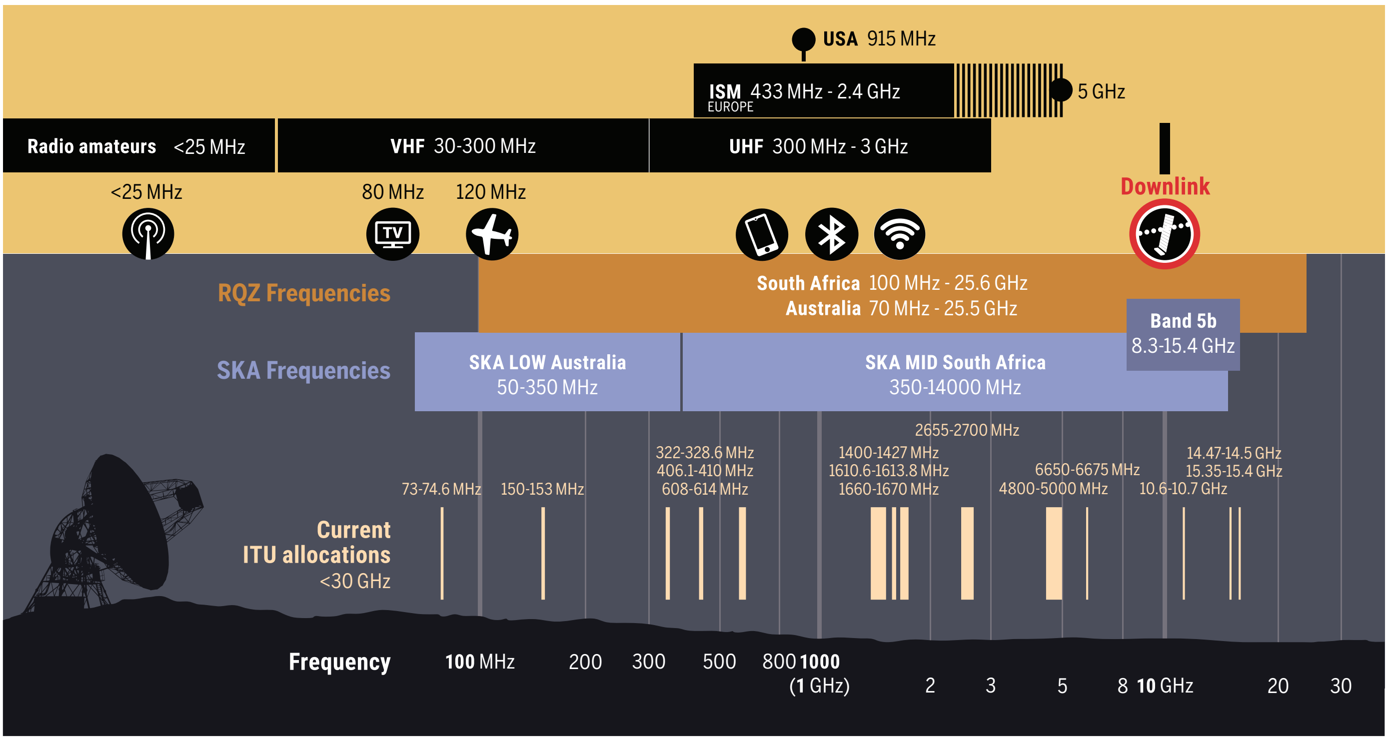

Fig. 3. Comparison of radio frequencies used for astronomy with sources of radio interference. Specific bands reserved for astronomy by the International Telecommunication Union (ITU) are shown up to 30 GHz, compared with observational ranges of the SKA and the radio quiet zones (RQZs) established by the host governments. Icons indicate the radio bands used for (from left to right) amateur radio, television, aviation, mobile telephony, bluetooth, wifi, 5b Band, and LEO satellites downlink. Black boxes indicate the frequency bands used for VHF (very high frequency) transmission, UHF (ultra high frequency) transmission, and ISM (industry, science, and medicine).

pixels, respectively (*16*). Up to 30% of wide-field exposures on a large telescope would be lost during the early evening pre-dawn hours, and nearly 50% of twilight exposures would be contaminated (*16*). The under-construction Vera C. Rubin Observatory, designed to perform wide-field surveys, is predicted to have up to 40% of its images be unusable due to satellite trails or saturation of the detectors (*16*). Even telescopes with smaller fields of view would have ~10% of images affected during twilight (*16*, *19*). Those studies considered the current satellite constellations so those rates will be higher if the anticipated numbers of spacecraft are launched.

Astronomical observations would greatly benefit if planned satellite constellations use as few spacecraft as possible (with the optimal number being zero), and to keep the satellite orbits low so that they enter the shadow of Earth soon after sunset. Astronomers and satellite operators have started to explore ways to mitigate their effects but there is an urgent need for national and international regulations. Several expert working groups (*11, 12*) have made more than 40 specific recommendations to various stakeholders (observatories, industry, astronomy community, science funding agencies, national and international policy-makers) for technical and political steps required to limit the impact on astronomy.

Radio interference impacts on radio astronomy

Radio astronomy involves observing the Universe at wavelengths that are also used by human-generated radio communications. The increasing bandwidth and transmission powers used by radio communications have led to increasing levels of radio frequency interference with astronomical observations. Satellite constellations also generate radio emissions. Some radio bands have been protected for astronomy by international agreements but transmitters always have some level of leakage into the protected bands, resulting in interference.

Radio quiet zones (RQZ) are regulatory zones around radio telescopes where human-generated radio emissions are controlled, established by local governments and the International Telecommunication Union (ITU) (*20*). These have been effective in reducing nearby radio emissions on the ground but do not protect against radio transmissions by spacecraft in orbit passing overhead. Until recently, satellite transmissions at frequencies between 10 and 80 GHz were generated mostly by satellites in geostationary Earth orbit (GEO), with lower contributions from LEO satellites. The deployment of LEO constellations will produce hundreds of fast-moving sources of bright radio interference, visible to radio telescopes at all times of day (*12*).

Figure 3 compares the radio frequency bands reserved for astronomy by ITU and those used by common sources of radio interference, both from ground-based technology and LEO satellites. For comparison, it also shows the observing ranges of the Square Kilometre Array (SKA), an international radio observatory currently under construction in Australia and South Africa, and the radio quiet zones that have been authorized at the telescope sites. This local ground-based protection of the observatory extends beyond the bands allocated by ITU for astronomy. However, it does not protect the observatory from radio interference produced by satellites. One exception is in Germany, where the government has an agreement with the Starlink satellite constellation to avoid the spacecraft transmitting while they pass over the Effelsberg radio telescope. Similar agreements will be necessary for other radio observatories.

Fig. 4. Photograph of Comet C/2020 F3 (NEOWISE) contaminated by satellite trails. The image was taken by Daniel López from Tenerife using amateur astronomer equipment. The comet is visible but so are numerous streaks generated by the passage of ~30 satellites through the field of view. Some of the streaks have gaps as a result of the multiple exposures that were stacked to produce the image.

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Amateur astronomy and astrotourism

Approximately one million people are active in amateur astronomy, two orders of magnitude larger than the number of professional astronomers (*21*). ALAN and LEO satellite constellations will also affect amateur astronomy, particularly in the areas of professional-amateur scientific research programs, astrophotography, and astrotourism.

Amateur astronomers discover comets, search galaxies for supernovae, perform variable star and meteor tracking campaigns, and confirm candidate exoplanets (*12*). These activities are particularly vulnerable to light pollution because amateur astronomers do not have access to the economic and technological resources required to mitigate its effects. Increasing levels of light pollution seriously compromise these activities, which will become practically impossible in the next decade if current trends continue.

The trails of LEO satellites affect amateur astrophotography. Figure 4 shows an image of Comet C/2020 F3 (NEOWISE) taken using a digital reflex camera. The photographer obtained a series of 30-second exposure images, then stacked them to reach sufficient depth to see the comet. However, 90% of the exposures showed satellite trails that contaminated the image. Amateur astronomers use cameras and telescopes with wider fields of view than large professional telescopes and so are more likely to have artificial satellite trails in their images.

Degradation of the night sky affects wider society, as the night sky has inspired developments in philosophy, art, culture, and religion. Cultural interpretations of the stars have been developed worldwide through generations, expressed in legends, folktales, stories, and other traditional practices; many of these are at risk of extinction (*22*).

The night sky is a resource to be safeguarded not only for science but also for its value to culture, the environment, biodiversity, human health and quality of life, and as a driver of sustainable economy through astrotourism (*23*). Astrotourism combines night- and day-time sky observations, outreach, and leisure activities related to astronomy. It is intended to be a sustainable form of tourism and is suitable for territories that are less economically developed, which often means less light-polluted (*24*).

Areas where dark night skies are legally protected are known as dark sky oases (*11*). Similar to physical oases, these locations are distinguished by the abundance of a resource surrounded by scarcity. Dark skies oases are intended to foster implementation of environmentally friendly and sustainable lighting solutions. There are currently more than 200,000 km^2 of territories (approximately the size of the UK) in more than 30 countries with protected skies (*11*, *25*), accredited by international institutions. These include areas designated as Biosphere Reserves, Natural or National Parks, Ramsar sites, World Heritage sites, etc. These areas are diversifying their economies and developing sustainable and responsible astrotourism. Astrotourism helps to disseminate an appreciation for astronomy and provides a tool against depopulation of undeveloped areas, providing jobs with technical and scientific skills (*26*).

Light pollution endangers the operation of infrastructure dedicated to astrotourism, such as tourist astronomical observatories, star parks, astronomical viewpoints, telescope farms, astronomy interpretation centers, and traveling planetariums. Many of these facilities receive hundreds of daily visits; collectively they provide employment opportunities to thousands of professionals. Over the last decade, hundreds of astrotourism companies have been established around the world. Many of their staff have backgrounds in amateur astronomy, who see their livelihood threatened by the growing levels of light pollution. Other astrotourism professionals come from the tourism sector (mainly from eco- and rural tourism) and the business sector, who regard astrotourism as a way to diversify their business (*24*). Therefore, light pollution affects not only amateur astronomy but also the business sector and local economic development. Demand for astrotourism certification and training has grown by more than 300% in the last five years (*26*), attracting tens of thousands of visitors and providing an economic return of over 100 million dollars in multiple territories. This growth is threatened by increasing light pollution.

Potential mitigation strategies

ALAN is regulated by local, regional, and national governments, some of whom have enacted legislation to control outdoor lighting specifically to reduce light pollution. Several international organizations work to protect the night sky for astronomy.

The United Nations Committee on the Peaceful Uses of Outer Space (COPUOS) of the UN Office of Outer Space Affairs (UNOOSA) is the institution responsible for regulating human activities in space. The effect of spacecraft on astronomy falls within the COPOUS remit and requires protection from the uncontrolled growth of artificial sky glow. However the impact of satellites on astronomy is essentially unregulated except for the protection of narrow radio bands by the ITU.

To discuss the impact of ALAN, satellite constellations, and radio frequency interference on astronomy, two workshops on Dark and Quiet Skies for Science and Society were held in October 2020 and 2021. The purpose was to establish recommendations for protecting the dark and (radio-)quiet skies as well as exploration of how to implement them. The workshops produced two reports (*11, 12*) that aimed to identify the technical and political actions required by the stakeholders and partners who would need to collaborate to preserve a dark and quiet sky. Similarly, two Satellite Constellations Workshops were held in July 2020 and 2021, which made recommendations of how to mitigate the negative impacts of satellite constellations on astronomy and the night sky (*15*, *19*).

The IAU set up a Centre for Protection of the Dark and Quiet Sky from satellite constellation interference in 2022 (*27*). Its goal is to propose mitigation strategies, policy, and regulatory measures to be implemented by local and national governments.

Preserving the skies has been proposed for inclusion in the 2030 Agenda for Sustainable Development, a revision of the UN sustainable development goals (*28*). Light pollution is related to sustainable development goals in the areas of poverty, inequality, climate, environmental degradation, prosperity, peace, and justice. "Sky Quality and Access to Starlight" has been proposed as sustainable development goal 18 (SDG18) and a public petition has been set up to promote it (*28*). The SDG18 proposal was submitted in March 2022; more than 2000 individuals and institutions from over 25 countries have supported it.

We are all made of stardust, literally and culturally. Astronomy is the oldest science, helping to drive scientific and technological discoveries. Having access to dark skies is necessary for many livelihoods and cultures. The starry sky is an opportunity for development and empowerment for many indigenous and local communities in rural locations. It is our duty to protect and safeguard it for present and future generations.

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