

Resources and References that helped inform Sierra Club's Light Pollution Policy Update

(Last updated 3/7/2021)

Over 70 resources and references (including websites, articles, publications, and reports) were reviewed during Sierra Club's March 2021 update to its light pollution national policy. The list is only provided to document resources used during policy development. Inclusion of any given resource in this list should *not* be construed as an endorsement by Sierra Club. The main resources consulted are listed below, organized by a relevant category. Several resources cover multiple issues, but each is only listed once.

Sierra Club Advocacy

Sierra Club AddUp Petition to City Mayors: Protect the Night Against Light Pollution (started in Feb 2018)

<https://addup.sierraclub.org/campaigns/protect-the-night>

Sierra Club Articles

On the Hunt for Stars: In Search of a Truly Dark Night Sky. Heather Smith, Feb 27, 2018. SIERRA magazine, March/April 2018 edition. <https://www.sierraclub.org/sierra/2018-2-march-april/feature/hunt-for-stars-dark-skies-preserves-and-parks>

Reclaiming the Night. SIERRA magazine. Katie O'Reilly. <https://www.sierraclub.org/sierra/slideshow/reclaiming-night>

General Educational Resources

National Park Service Night Skies, www.nps.gov/subjects/night skies

Light pollution - a global discussion. Schulte-Römer, N., Dannemann, E., Meier, J. (2018): Helmholtz Centre for Environmental Research - UFZ, Leipzig, 248 pp.

<http://www.lightpollutiondiscussion.net>

The Right to Dark Skies, 2016, United Nations Educational, Scientific and Cultural Organization (UNESCO Mexico)

<https://unesdoc.unesco.org/ark:/48223/pf0000246131>

Our nights are getting brighter, and Earth is paying the price, by Nadia Drake, National Geographic, published April 3, 2019

<https://www.nationalgeographic.com/science/2019/04/nights-are-getting-brighter-earth-paying-the-price-light-pollution-dark-skies/>

Treat artificial light like other forms of pollution, say scientists. Jonathan Watts, The Guardian. Nov 2, 2020.

<https://www.theguardian.com/environment/2020/nov/02/treat-artificial-light-form-pollution-environment>

Excerpt: "What stands out is how pervasive the effects are. The effects were found everywhere – microbes, invertebrates, animals and plants," said the lead author, Kevin Gaston, a professor at the university's Environment and Sustainability Institute. "We need to start thinking about lighting in the way we think of other big systemic pressures like climate change."

Light pollution – extent, effects and approaches. TAB-Fokus no. 25, Jun 2020, Office of Technology Assessment at the German Bundestag. Christoph Schröter-Schlaack, et al.

<http://www.tab-beim-bundestag.de/en/news/20200828.html>

Summary: In addition to the intended effects, the increasing use of artificial outdoor lighting also entails a number of undesirable side effects referred to as light pollution. Artificial lighting can disturb the circadian rhythms of humans and animals, which are controlled by the change of day and night, and is suspected of being involved in the development of various diseases. Moreover, the increasing illumination of the night influences the natural behaviour of animals. Besides habitat changes, the consequences are ranging from changes in hunting or reproductive behaviour to the deadly attraction effect of light sources, e. g. for insects. However, the longterm consequences of these changes for entire populations, communities or landscapes are still poorly understood. Options for reducing light pollution exist both technologically and in terms of regulation and approval of lighting installations.

Light Pollution Is Taking Away Our Night Skies. Here's Why That Matters. 11/13/2019. HuffPost. By Kyla Mandel

https://www.huffpost.com/entry/city-light-pollution-night-sky-star-protection_n_5dc9d1fee4b00927b2381233

Some cities and states are trying to protect our night sky "for the health and wellbeing for all living things."

Light Pollution Trends

Artificially lit surface of Earth at night increasing in radiance and extent, by Christopher C. M. Kyba, Theres Kuester, Alejandro Sánchez de Miguel, Kimberly Baugh, Andreas Jechow, Franz Hölker, Jonathan Bennie, Christopher D. Elvidge, Kevin J. Gaston, and Luis Guanter. *Science Advances* 22 Nov 2017: Vol. 3, no. 11, e1701528, DOI: 10.1126/sciadv.1701528
<http://advances.sciencemag.org/content/3/11/e1701528>

Abstract: A central aim of the “lighting revolution” (the transition to solid-state lighting technology) is decreased energy consumption. This could be undermined by a rebound effect of increased use in response to lowered cost of light. We use the first-ever calibrated satellite radiometer designed for night lights to show that from 2012 to 2016, Earth’s artificially lit outdoor area grew by 2.2% per year, with a total radiance growth of 1.8% per year. Continuously lit areas brightened at a rate of 2.2% per year. Large differences in national growth rates were observed, with lighting remaining stable or decreasing in only a few countries. These data are not consistent with global scale energy reductions but rather indicate increased light pollution, with corresponding negative consequences for flora, fauna, and human well-being.

The new world atlas of artificial night sky brightness. Falchi, F., Cinzano, P., Duriscoe, D., Kyba, C.C.M., Elvidge, C.D., Baugh, K., Portnow, B.A., Rybnikova, N.A., & Furgoni, R. (2016). *Science Advances*, 2:e1600377.
<https://advances.sciencemag.org/content/2/6/e1600377>

Abstract: Artificial lights raise night sky luminance, creating the most visible effect of light pollution—artificial skyglow. Despite the increasing interest among scientists in fields such as ecology, astronomy, health care, and land-use planning, light pollution lacks a current quantification of its magnitude on a global scale. To overcome this, we present the world atlas of artificial sky luminance, computed with our light pollution propagation software using new high-resolution satellite data and new precision sky brightness measurements. This atlas shows that more than 80% of the world and more than 99% of the U.S. and European populations live under light-polluted skies. The Milky Way is hidden from more than one-third of humanity, including 60% of Europeans and nearly 80% of North Americans. Moreover, 23% of the world’s land surfaces between 75°N and 60°S, 88% of Europe, and almost half of the United States experience light-polluted nights.

Light pollution in USA and Europe: The good, the bad and the ugly. F. Falchi, R. Furgoni, T.A. Gallaway, N.A. Rybnikova, B.A. Portnov, K. Baugh, P. Cinzano, C.D. Elvidge, *Elsevier Journal of Environmental Management*, Volume 248, 2019, 109227, 15 October 2019
<http://www.sciencedirect.com/science/article/pii/S0301479719309296>

Abstract: Light pollution is a worldwide problem that has a range of adverse effects on human health and natural ecosystems. Using data from the New World Atlas of Artificial Night Sky Brightness, VIIRS-recorded radiance and Gross Domestic Product (GDP) data, we compared light pollution levels, and the light flux to the population size and GDP at the State and County levels in the USA and at Regional (NUTS2) and Province (NUTS3) levels in Europe. We found 6800-fold differences between the most and least polluted regions in Europe, 120-fold differences in their light flux per capita, and 267-fold differences in flux per GDP unit. Yet, we found even greater differences between US counties: 200,000-fold differences in sky pollution, 16,000-fold differences in light flux per capita, and 40,000-fold differences in light flux per GDP unit. These findings may inform policy-makers, helping to reduce energy waste and adverse environmental, cultural and health consequences associated with light pollution.

Global Trends in Exposure to Light Pollution in Natural Terrestrial Ecosystems. Bennie, J.; Duffy, J.P.; Davies, T.W.; Correa-Cano, M.E.; Gaston, K.J. *Remote Sens.* 2015, 7, 2715-2730.
<https://www.mdpi.com/2072-4292/7/3/2715>

Abstract: The rapid growth in electric light usage across the globe has led to increasing presence of artificial light in natural and semi-natural ecosystems at night. This occurs both due to direct illumination and skyglow - scattered light in the atmosphere. There is increasing concern about the effects of artificial light on biological processes, biodiversity and the functioning of ecosystems. We combine intercalibrated Defense Meteorological Satellite Program’s Operational Linescan System (DMSP/OLS) images of stable night-time lights for the period 1992 to 2012 with a remotely sensed landcover product (GLC2000) to assess recent changes in exposure to artificial light at night in 43 global ecosystem types. We find that Mediterranean-climate ecosystems have experienced the greatest increases in exposure, followed by temperate ecosystems. Boreal, Arctic and montane systems experienced the lowest increases. In tropical and subtropical regions, the greatest increases are in mangroves and subtropical needleleaf and mixed forests, and in arid regions increases are mainly in forest and agricultural areas. The global ecosystems experiencing the greatest increase in exposure to artificial light are already localized and fragmented, and often of particular conservation importance due to high levels of diversity, endemism and rarity. Night time remote sensing can play a key role in identifying the extent to which natural ecosystems are exposed to light pollution.

Direct measurement of the contribution of street lighting to satellite observations of nighttime light emissions from urban areas. Kyba, C, et al. *Lighting Research & Technology*. October 2020.
<https://doi.org/10.1177/1477153520958463>

Abstract: Nighttime light emissions are increasing in most countries worldwide, but which types of lighting are responsible for the increase remains unknown. Also unknown is what fraction of outdoor light emissions and associated energy use are due to

public light sources (i.e. streetlights) or various types of private light sources (e.g. advertising). Here we show that it is possible to measure the contribution of street lighting to nighttime satellite imagery using ‘smart city’ lighting infrastructure. The city of Tucson, USA, intentionally altered its streetlight output over 10 days, and we examined the change in emissions observed by satellite. We find that streetlights operated by the city are responsible for only 13% of the total radiance (in the 500–900 nm band) observed from Tucson from space after midnight (95% confidence interval 10–16%). If Tucson did not dim their streetlights after midnight, the contribution would be 18% (95% confidence interval 15–23%). When streetlights operated by other actors are included, the best estimates rise to 16% and 21%, respectively. Existing energy and lighting policy related to the sustainability of outdoor light use has mainly focused on street lighting. These results suggest an urgent need for consideration of other types of light sources in outdoor lighting policy.

Anthropogenic Light Disrupts Natural Light Cycles in Critical Conservation Areas, Seymoure, B, et al. (August 19, 2019).

<https://ssrn.com/abstract=3439670>

Abstract: Anthropogenic lighting drastically alters nocturnal environments, threatening a wide range of species by disrupting light regimes that regulate fundamental biological processes such as reproduction, foraging, and predator defense. We translate satellite measures of anthropogenic light radiating from the earth to a biologically relevant measurement – the amount of light scattered back to the earth (horizontal illuminance). Anthropogenic light exceeding the natural level produced by stars, galactic light, and airglow on a clear moonless night (i.e., new moon conditions) affects 22.9% of the Earth’s terrestrial surface, as well as 51.0% of Key Biodiversity Area units, 77.1% of Global Protected Area units, and approximately 20% of the most biodiverse areas for mammals, birds, and amphibians. Thus, due to anthropogenic sources, these environments experience at least double the levels of natural illuminance during half of the night hours in a year. To facilitate biological interpretation of these levels of anthropogenic illuminance observed globally, we undertook a systematic literature review of animal responses to changing nocturnal light levels. Known biological effects from the current anthropogenic illuminance levels range from behavioral and physiological alterations to increased mortality, which have been documented in 117 species from 23 orders and 8 classes. These findings provide a biological perspective on global light pollution, and they identify regions where reductions in anthropogenic illuminance would yield the greatest benefits for conserving biodiversity.

Effects of the COVID-19 Lockdown on Urban Light Emissions: Ground and Satellite Comparison. Bustamante-Calabria, M, Sánchez de Miguel, A, et al. Remote Sensing. Jan 2021, Vol 13, Issue 2, 258.

<https://www.mdpi.com/2072-4292/13/2/258>

Abstract Excerpt: ‘Lockdown’ periods in response to COVID-19 have provided a unique opportunity to study the impacts of economic activity on environmental pollution (e.g., NO₂, aerosols, noise, light)... Here, to analyze the effect of lockdown on urban light emissions, we use ground and satellite data for Granada, Spain, during the COVID-19 induced confinement of the city’s population from 14 March until 31 May 2020. We find a clear decrease in light pollution due both to a decrease in light emissions from the city and to a decrease in anthropogenic aerosol content in the atmosphere which resulted in less light being scattered. A clear correlation between the abundance of PM₁₀ particles and sky brightness is observed, such that the more polluted the atmosphere the brighter the urban night sky.

Environmental and Social Justice

Light pollution inequities in the continental United States: A distributive environmental justice analysis. Nadybal S.M., Collins T.W., Grineski S.E.. Environmental Research, Vol 189, 2020, 109959.

<http://www.sciencedirect.com/science/article/pii/S0013935120308549>

Abstract: Excessive exposure to ambient light at night is a well-documented hazard to human health, yet analysts have not examined it from an environmental justice (EJ) perspective. We conducted the first EJ study of exposure to light pollution by testing for socially disparate patterns across the continental United States (US)... We found evidence of disparities in exposures to light pollution based on racial/ethnic minority and low-to-mid socioeconomic statuses. Americans of Asian, Hispanic or Black race/ethnicity had population-weighted mean exposures to light pollution in their neighborhoods that were approximately two times that of White Americans... neighborhoods composed of higher proportions of Blacks, Hispanics, Asians, or renter-occupants experienced greater exposures to ambient light at night. Stratified analyses indicated that those patterns of inequity did not substantially vary based on urban-rural context. Findings have implications for understanding environmental influences on health disparities, raise concerns about the potential for a multiple environmental jeopardy situation, and highlight the need for policy actions to address light pollution.

An incandescent truth: Disparities in energy-efficient lighting availability and prices in an urban U.S. county. Reames, Tony G., Michael A. Reiner, and M. Ben Stacey. (2018) Applied Energy 218:95-103.

<https://www.sciencedirect.com/science/article/abs/pii/S0306261918302769>

Abstract Excerpt: In the U.S. lighting represents about 9% of the average household's primary energy consumption and 20% of the average household's energy bill. Lighting in U.S. homes is in a state of transition with steady growth in the adoption of more energy-efficient lighting technology, such as, compact florescent lamps (CFL) and light-emitting diodes (LEDs). However, the adoption of energy-efficient lighting is not equitably distributed across socioeconomic groups, with poorer households less likely to adopt than higher-income households... We found that (1) energy-efficient bulbs were less available in high-poverty areas and

smaller stores; (2) energy-efficient bulbs were more expensive in high-poverty areas and smaller stores; (3) upgrade costs from incandescent and halogen lamps (IHLs) to CFLs or LEDs were higher in high poverty areas; and (4) both poverty and store type were significant predictors of LED availability, while store type was the most significant predictor of LED price variability. We suggest several ways that the development and implementation of energy efficiency policies and programs may consider these disparities that affect access and affordability, in order to achieve a more just energy-efficient transition.

Up in smoke: Characterizing the population exposed to flaring from unconventional oil and gas development in the contiguous US. Cushing Lara J, et al. Feb 2021. Environmental Research Letters. Vol. 16, No 3.

<https://iopscience.iop.org/article/10.1088/1748-9326/abd3d4>

Abstract Excerpt: The disposal of waste gas via intentional combustion (flaring) from unconventional oil and gas (UOG) development has also been on the rise, and may expose nearby residents to toxic air pollutants, light pollution and noise... We found that three basins accounted for over 83% of all UOG flaring activity in the contiguous US over the 8 year study period. We estimated that over half a million people in these basins reside within 5 km of a flare, and 39% of them lived near more than 100 nightly flares. Black, indigenous, and people of color were disproportionately exposed to flaring.

Light Pollution in San Antonio, TX: An Environmental Justice Issue. Alvarez, V, et al. May 2020. Environmental Studies Student Works. Trinity University.

https://digitalcommons.trinity.edu/env_studocs/2

Abstract Excerpt: the environmental justice movement often overlooks the issue of light pollution, even though light pollution is higher in urban low-income areas. There is a lack of studies examining how light pollution varies between communities on a regional, state, or municipal scale... The mid-income neighborhoods had the greatest median and maximum light pollution levels, while high-income neighborhoods had the lowest median illuminance. These results indicate that mid-income neighborhoods are subject to the greatest amount of light pollution by area and intensity.

Ecological, Wildlife and Human Impacts

Ecological light pollution. Longcore, T. and Rich, C. (2004), *Frontiers in Ecology and the Environment*, 2: 191-198.

<https://esajournals.onlinelibrary.wiley.com/doi/abs/10.1890/1540-9295%282004%29002%5B0191%3AELP%5D2.0.CO%3B2>

Abstract: Ecologists have long studied the critical role of natural light in regulating species interactions, but, with limited exceptions, have not investigated the consequences of artificial night lighting. In the past century, the extent and intensity of artificial night lighting has increased such that it has substantial effects on the biology and ecology of species in the wild. We distinguish “astronomical light pollution”, which obscures the view of the night sky, from “ecological light pollution”, which alters natural light regimes in terrestrial and aquatic ecosystems. Some of the catastrophic consequences of light for certain taxonomic groups are well known, such as the deaths of migratory birds around tall lighted structures, and those of hatchling sea turtles disoriented by lights on their natal beaches. The more subtle influences of artificial night lighting on the behavior and community ecology of species are less well recognized, and constitute a new focus for research in ecology and a pressing conservation challenge.

Ecological consequences of artificial night lighting. Rich, C. and T. Longcore. (eds.). 2006. Island Press, Washington, D.C.

<https://www.urbanwildlands.org/ecanlbook.html>

The first book to consider the environmental effects of the intentional illumination of the night. It brings together leading scientists from around the world to review the state of knowledge on the subject and to describe specific effects that have been observed across a full range of taxonomic groups, including mammals, birds, reptiles and amphibians, fishes, invertebrates, and plants... provides a scientific basis to begin addressing the challenge of conserving the nighttime environment. It cogently demonstrates the vital importance of this until-now neglected topic and is an essential new work for conservation planners, researchers, and anyone concerned with human impacts on the natural world.

Light Pollution Is a Driver of Insect Declines, by Owens, A, et al. (April 26, 2019)

<https://ssrn.com/abstract=3378835>

Abstract: Insects around the world are rapidly declining. Concerns over what this loss means for food security and ecological communities have compelled a growing number of researchers to search for the key drivers behind the decline. Habitat loss, pesticide use, invasive species, and climate change all have likely played a role, but we posit here that artificial light at night (ALAN) is another important — but often overlooked — bringer of the insect apocalypse. We first discuss the history and extent of ALAN, and then present evidence that ALAN has led to insect declines through its interference with the development, movement, foraging, and reproductive success of diverse insect species, as well as its positive effect on insectivore predation. We conclude with a discussion of how artificial lights can be tuned to reduce their impacts on vulnerable populations. ALAN is unique among anthropogenic habitat disturbances in that it is fairly easy to ameliorate, and leaves behind no residual effects. Greater recognition of the ways in which ALAN impacts insects can help conservationists reduce or eliminate one of the major drivers of insect declines.

A meta-analysis of biological impacts of artificial light at night. Nature Ecology & Evolution (2020), Dirk Sanders, Enric Frago, Rachel Kehoe, Christophe Patterson & Kevin J. Gaston

<https://doi.org/10.1038/s41559-020-01322-x>

<https://datadryad.org/stash/dataset/doi:10.5061/dryad.wpzgmsbjn>

Abstract: Natural light cycles are being eroded over large areas of the globe by the direct emissions and sky brightening that result from sources of artificial night-time light. This is predicted to affect wild organisms, particularly because of the central role that light regimes play in determining the timing of biological activity. Although many empirical studies have reported such effects, these have focused on particular species or local communities and have thus been unable to provide a general evaluation of the overall frequency and strength of these impacts. Using a new database of published studies, we show that exposure to artificial light at night induces strong responses for physiological measures, daily activity patterns and life history traits. We found particularly strong responses with regards to hormone levels, the onset of daily activity in diurnal species and life history traits, such as the number of offspring, predation, cognition and seafinding (in turtles). So far, few studies have focused on the impact of artificial light at night on ecosystem functions. The breadth and often strength of biological impacts we reveal highlight the need for outdoor artificial night-time lighting to be limited to the places and forms—such as timing, intensity and spectrum—where it is genuinely required by the people using it to minimize ecological impacts.

Longer photoperiods through range shifts and artificial light lead to a destabilizing increase in host–parasitoid interaction strength. Kehoe, R, Sanders, D, Cruse, D, et al. Journal of Animal Ecology. 2020; 89: 2508–2516.

<https://doi.org/10.1111/1365-2656.13328>

Excerpts: Many organisms are experiencing changing daily light regimes due to latitudinal range shifts driven by climate change and increased artificial light at night (ALAN). Activity patterns are often driven by light cycles, which will have important consequences for species interactions... Here we demonstrate that ALAN impact interacts with daylength and temperature by changing the interaction strength between a common day-active consumer species and its host in a predictable way. Our results further suggest that range expansion or ALAN-induced changes in light regimes experienced by insects and their natural enemies will result in unstable dynamics beyond key tipping points in daylength... Finally, the strong response of a diurnal host–parasitoid system reported here also emphasizes the importance of focussing on the impact of ALAN not just on nocturnal species but also on those that are chiefly diurnal, on which the effects of ALAN may be just as profound, if not as intuitive.

Artificial nightlight alters the predator–prey dynamics of an apex carnivore. Ditmer, MA, et al. (2020). Ecography

<https://doi.org/10.1111/ecog.05251>

Abstract Excerpts: Our results indicate that deer used the anthropogenic environments to access forage and were more active at night than their wildland conspecifics. Despite higher nightlight levels, cougars killed deer at the wildland–urban interface, but hunted them in the relatively darkest locations. Light had the greatest effect of all covariates on where cougars killed deer at the wildland–urban interface. Both species exhibited functional responses to light pollution at fine scales; individual cougars and deer with less light exposure increasingly avoided illuminated areas when exposed to greater radiance, whereas deer living in the wildland–urban interface selected elevated light levels. We conclude that integrating estimates of light pollution into ecological studies provides crucial insights into how the dynamic human footprint can alter animal behavior and ecosystem function across spatial scales.

Coral Gametogenesis Collapse under Artificial Light Pollution. Ayalon et al. Current Biology. Nov 2020

<https://doi.org/10.1016/j.cub.2020.10.039>

Excerpts: Marine organisms, including coral reefs in particular, rely on the natural light cycles of sunlight and moonlight to regulate various physiological, biological, and behavioral processes. Here, we demonstrate that light pollution caused delayed gametogenesis and unsynchronized gamete release in two coral species, *Acropora millepora* and *Acropora digitifera*, from the Indo-Pacific Ocean... With the global transition toward LED lighting, which tends to have higher emissions in the blue spectrum, more coral reefs could be affected by artificial light, as blue light penetrates deeper into the water column. This spectral shift is expected to be amplified by the current rapid population growth in coastal regions... Our experimental results are corroborated by *in situ* observations, which have shown disruption of gametogenesis and loss of spawning synchrony in corals occurring at sites that are heavily polluted by artificial lights. These results demonstrate that artificial light must be considered in conservation plans for coral reefs near areas of human activity.

Sensory pollutants alter bird phenology and fitness across a continent. Senzaki, M., Barber, J.R., Phillips, J.N. et al. Nature 587, 605–609 (2020)

<https://doi.org/10.1038/s41586-020-2903-7>

Abstract: Expansion of anthropogenic noise and night lighting across our planet is of increasing conservation concern. Despite growing knowledge of physiological and behavioural responses to these stimuli from single-species and local-scale studies, whether these pollutants affect fitness is less clear, as is how and why species vary in their sensitivity to these anthropic stressors. Here we leverage a large citizen science dataset paired with high-resolution noise and light data from across the contiguous United States to assess how these stimuli affect reproductive success in 142 bird species. We find responses to both sensory pollutants linked to the functional traits and habitat affiliations of species. For example, overall nest success was negatively correlated with noise among birds in closed environments. Species-specific changes in reproductive timing and hatching success

in response to noise exposure were explained by vocalization frequency, nesting location and diet. Additionally, increased light-gathering ability of species' eyes was associated with stronger advancements in reproductive timing in response to light exposure, potentially creating phenological mismatches. Unexpectedly, better light-gathering ability was linked to reduced clutch failure and increased overall nest success in response to light exposure, raising important questions about how responses to sensory pollutants counteract or exacerbate responses to other aspects of global change, such as climate warming. These findings demonstrate that anthropogenic noise and light can substantially affect breeding bird phenology and fitness, and underscore the need to consider sensory pollutants alongside traditional dimensions of the environment that typically inform biodiversity conservation.

Bright lights in the big cities: migratory birds' exposure to artificial light. Horton, KG., Nilsson, C., et al, 2019. *Frontiers in Ecology and the Environment*, April 2019.

<https://doi.org/10.1002/FEE.2029>

<https://www.youtube.com/watch?v=gXSN2GmI8M>

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

High-intensity urban light installation dramatically alters nocturnal bird migration. Van Doren BM, Horton KG, et al. *Proceedings of the National Academy of Sciences*, Oct 2017, 114 (42) 11175-11180

<https://www.pnas.org/content/114/42/11175>

Abstract Excerpt: Billions of nocturnally migrating birds move through increasingly photopolluted skies, relying on cues for navigation and orientation that artificial light at night (ALAN) can impair... We studied effects of ALAN on migrating birds by monitoring the beams of the National September 11 Memorial & Museum's "Tribute in Light" in New York, quantifying behavioral responses with radar and acoustic sensors and modeling disorientation and attraction with simulations... When the installation was illuminated, birds aggregated in high densities, decreased flight speeds, followed circular flight paths, and vocalized frequently... However, behavioral disruptions disappeared when lights were extinguished, suggesting that selective removal of light during nights with substantial bird migration is a viable strategy for minimizing potentially fatal interactions among ALAN, structmelures, and birds. Our results also highlight the value of additional studies describing behavioral patterns of nocturnally migrating birds in powerful lights in urban areas as well as conservation implications for such lighting installations.

The ecological impacts of nighttime light pollution: a mechanistic appraisal. Gaston, K. J., Bennie, J., Davies, T. W. and Hopkins, J., *Biological Reviews*, Vol 88, Issue 4, 2013, Cambridge Philosophical Society

<https://onlinelibrary.wiley.com/doi/full/10.1111/brv.12036>

Abstract: The ecological impacts of nighttime light pollution have been a longstanding source of concern, accentuated by realized and projected growth in electrical lighting. As human communities and lighting technologies develop, artificial light increasingly modifies natural light regimes by encroaching on dark refuges in space, in time, and across wavelengths. A wide variety of ecological implications of artificial light have been identified. However, the primary research to date is largely focused on the disruptive influence of nighttime light on higher vertebrates, and while comprehensive reviews have been compiled along taxonomic lines and within specific research domains, the subject is in need of synthesis within a common mechanistic framework. Here we propose such a framework that focuses on the cross-factoring of the ways in which artificial lighting alters natural light regimes (spatially, temporally, and spectrally), and the ways in which light influences biological systems, particularly the distinction between light as a resource and light as an information source. We review the evidence for each of the combinations of this cross-factoring. As artificial lighting alters natural patterns of light in space, time and across wavelengths, natural patterns of resource use and information flows may be disrupted, with downstream effects to the structure and function of ecosystems. This review highlights: (i) the potential influence of nighttime lighting at all levels of biological organisation (from cell to ecosystem); (ii) the significant impact that even low levels of nighttime light pollution can have; and (iii) the existence of major research gaps, particularly in terms of the impacts of light at population and ecosystem levels, identification of intensity thresholds, and the spatial extent of impacts in the vicinity of artificial lights.

Light Pollution, Circadian Photoreception, and Melatonin in Vertebrates. Grubisic M, Haim A, Bhusal P, Dominoni DM, Gabriel KMA, Jechow A, Kupprat F, Lerner A, Marchant P, Riley W, Stebelova K, van Grunsven RHA, Zeman M, Zubidat AE, Hölker F. *Sustainability*. 2019; 11(22):6400.

<https://www.mdpi.com/2071-1050/11/22/6400>

Abstract: Artificial light at night (ALAN) is increasing exponentially worldwide, accelerated by the transition to new efficient lighting technologies. However, ALAN and resulting light pollution can cause unintended physiological consequences. In vertebrates, production of melatonin—the “hormone of darkness” and a key player in circadian regulation—can be suppressed by

ALAN. In this paper, we provide an overview of research on melatonin and ALAN in vertebrates. We discuss how ALAN disrupts natural photic environments, its effect on melatonin and circadian rhythms, and different photoreceptor systems across vertebrate taxa. We then present the results of a systematic review in which we identified studies on melatonin under typical light-polluted conditions in fishes, amphibians, reptiles, birds, and mammals, including humans. Melatonin is suppressed by extremely low light intensities in many vertebrates, ranging from 0.01–0.03 lx for fishes and rodents to 6 lx for sensitive humans. Even lower, wavelength-dependent intensities are implied by some studies and require rigorous testing in ecological contexts. In many studies, melatonin suppression occurs at the minimum light levels tested, and, in better-studied groups, melatonin suppression is reported to occur at lower light levels. We identify major research gaps and conclude that, for most groups, crucial information is lacking. No studies were identified for amphibians and reptiles and long-term impacts of low-level ALAN exposure are unknown. Given the high sensitivity of vertebrate melatonin production to ALAN and the paucity of available information, it is crucial to research impacts of ALAN further in order to inform effective mitigation strategies for human health and the wellbeing and fitness of vertebrates in natural ecosystems.

Melatonin: a possible link between the presence of artificial light at night and reductions in biological fitness. Jones TM, Durrant J, Michaelides EB, Green MP. 2015, Phil. Trans. R. Soc. B 370: 20140122.
<https://royalsocietypublishing.org/doi/10.1098/rstb.2014.0122>

Abstract: The mechanisms underpinning the ecological impacts of the presence of artificial night lighting remain elusive. One suspected underlying cause is that the presence of light at night (LAN) suppresses nocturnal production of melatonin, a key driver of biological rhythm and a potent antioxidant with a proposed role in immune function. Here, we briefly review the evidence for melatonin as the link between LAN and changes in behaviour and physiology. We then present preliminary data supporting the potential for melatonin to act as a recovery agent mitigating the negative effects of LAN in an invertebrate. Adult crickets (*Teleogryllus commodus*), exposed to constant illumination, were provided with dietary melatonin (concentrations: 0, 10 or 100 µg ml⁻¹) in their drinking water. We then compared survival, lifetime fecundity and, over a 4-week period, immune function (haemocyte concentration, lysozyme-like and phenoloxidase (PO) activity). Melatonin supplementation was able only partially to mitigate the detrimental effects of LAN: it did not improve survival or fecundity or PO activity, but it had a largely dose-dependent positive effect on haemocyte concentration and lysozyme-like activity. We discuss the implications of these relationships, as well as the usefulness of invertebrates as model species for future studies that explore the effects of LAN.

Waters under Artificial Lights: Does Light Pollution Matter for Aquatic Primary Producers? Grubisic, M. (2018), Limnology and Oceanography Bulletin, 27: 76-81.
<https://aslopubs.onlinelibrary.wiley.com/doi/abs/10.1002/lob.10254>

Abstract: Bright night lights have become a symbol of development and prosperity in the modern world. But have you ever wondered how artificial light at night (ALAN) may be affecting living beings in our cities, and how it may be affecting us? As artificial illumination is transforming nocturnal environments around the world, light pollution associated with its use is becoming a topic of increasing interest in the scientific and public communities. Light pollution disrupts natural light regimes in many regions of the world, raising concerns about ecological and health impacts of this novel anthropogenic pressure. Most obviously, ALAN can influence night-active animals in urban and suburban areas, and most research in this growing field focuses on terrestrial organisms such as bats, birds, and insects. Effects on aquatic ecosystems are much less known. In particular, aquatic primary producers, such as microalgae, cyanobacteria, and plants, have rarely been studied despite their critical positioning in the base of aquatic food webs and the fundamental role that light plays in their ecology. For primary producers, light is a key source of both energy and environmental information; it influences their growth, production, and community structure. ALAN has therefore a large potential to influence their communities and induce bottom-up changes to aquatic ecosystems and ecosystem functions.

Global climate change and invariable photoperiods: A mismatch that jeopardizes animal fitness. Walker, WH, Meléndez-Fernández, OH, Nelson, RJ, Reiter, RJ. Ecol Evol. 2019; 9: 10044–10054.
<https://onlinelibrary.wiley.com/doi/full/10.1002/ece3.5537>

Abstract: The Earth's surface temperature is rising, and precipitation patterns throughout the Earth are changing; the source of these shifts is likely anthropogenic in nature. Alterations in temperature and precipitation have obvious direct and indirect effects on both plants and animals. Notably, changes in temperature and precipitation alone can have both advantageous and detrimental consequences depending on the species. Typically, production of offspring is timed to coincide with optimal food availability; thus, individuals of many species display annual rhythms of reproductive function. Because it requires substantial time to establish or re-establish reproductive function, individuals cannot depend on the arrival of seasonal food availability to begin breeding; thus, mechanisms have evolved in many plants and animals to monitor and respond to day length in order to anticipate seasonal changes in the environment. Over evolutionary time, there has been precise fine-tuning of critical photoperiod and onset/offset of seasonal adaptations. Climate change has provoked changes in the availability of insects and plants which shifts the timing of optimal reproduction. However, adaptations to the stable photoperiod may be insufficiently plastic to allow a shift in the seasonal timing of bird and mammal breeding. Coupled with the effects of light pollution which prevents these species from determining day length, climate change presents extreme evolutionary pressure that can result in severe deleterious consequences for individual species reproduction and survival. This review describes the effects of climate change on plants and animals,

defines photoperiod and the physiological events it regulates, and addresses the consequences of global climate change and a stable photoperiod.

Effects of street lighting technologies on the success and quality of pollination in a nocturnally pollinated plant. Macgregor, C. J., M. J. O. Pocock, R. Fox, and D. M. Evans. 2019. *Ecosphere* 10(1):e02550
<https://esajournals.onlinelibrary.wiley.com/doi/abs/10.1002/ecs2.2550>

Abstract: Artificial light at night (ALAN) is an increasingly important driver of global change. Lighting directly affects plants, but few studies have investigated indirect effects mediated by interacting organisms. Nocturnal Lepidoptera are globally important pollinators, and pollen transport by moths is disrupted by lighting. Many street lighting systems are being replaced with novel, energy-efficient lighting, with unknown ecological consequences. Using the wildflower *Silene latifolia*, we compared pollination success and quality at experimentally lit and unlit plots, testing two major changes to street lighting technology: in lamp type, from high-pressure sodium lamps to light-emitting diodes, and in lighting regime, from full-night (FN) to part-night (PN) lighting. We predicted that lighting would reduce pollination. *S. latifolia* was pollinated both diurnally and nocturnally. Contrary to our predictions, flowers under FN lighting had higher pollination success than flowers under either PN lighting or unlit controls, which did not significantly differ from each other. Lamp type, lighting regime, and distance from the light all significantly affected aspects of pollination quality. These results confirm that street lighting could affect plant reproduction through indirect effects mediated by nocturnal insects, and further highlight the possibility for novel lighting technologies to mitigate the effects of ALAN on ecosystems.

Cascading effects of artificial light at night: resource-mediated control of herbivores in a grassland ecosystem. Bennie J, Davies TW, Cruse D, Inger R, Gaston KJ. 2015. *Phil. Trans. R. Soc. B* 370: 20140131.
<https://royalsocietypublishing.org/doi/10.1098/rstb.2014.0131>

Abstract: Artificial light at night has a wide range of biological effects on both plants and animals. Here, we review mechanisms by which artificial light at night may restructure ecological communities by modifying the interactions between species. Such mechanisms may be top-down (predator, parasite or grazer controlled), bottom-up (resource-controlled) or involve non-trophic processes, such as pollination, seed dispersal or competition. We present results from an experiment investigating both top-down and bottom-up effects of artificial light at night on the population density of pea aphids *Acyrtosiphon pisum* in a diverse artificial grassland community in the presence and absence of predators and under low-level light of different spectral composition. We found no evidence for top-down control of *A. pisum* in this system, but did find evidence for bottom-up effects mediated through the impact of light on flower head density in a leguminous food plant. These results suggest that physiological effects of light on a plant species within a diverse plant community can have detectable demographic effects on a specialist herbivore.

Artificial night light alters ecosystem services provided by biotic components. Singhal, R.K., Chauhan, J., Jatav, H.S. et al. *Biologia Futura* (2021).
<https://doi.org/10.1007/s42977-020-00065-x>

Abstract Excerpt: This review highlights the impact of ALAN on the ecosystem and its living and non-living components, emphasizing to the terrestrial and aquatic ecosystem. Further, we summarize the means of minimizing strategies of ALAN in the environment, which are very crucial to reduce the further spread of night light contamination in the environment and can be useful to minimize the drastic impacts on the ecosystem.

City lights and urban air. Stark, H., Brown, S., Wong, K. et al. *Nature Geoscience*, Vol 4, Nov 2011.
<https://doi.org/10.1038/ngeo1300>
https://s3.amazonaws.com/wbez-assets/curiouscity/ngeo_1300_NOV11_auproof2.pdf
<https://cires.colorado.edu/news/bright-city-lights-affect-air-pollution>

Here we show that city lights can also alter the concentration of nitrate radicals, an important atmospheric oxidant. These alterations have potential — albeit small — consequences for pollution levels the following day... We converted satellite data on light intensity into nitrate radical loss, using our aircraft measurements, and show that the influence of city lights on nitrate radical loss can be large in regions outside Los Angeles... We also find that satellite-derived estimates of light levels tend to correlate positively with independent satellite-derived estimates of nitrogen dioxide. We therefore suggest that city lights are likely to influence nitrogen dynamics in other regions of the globe.

Nighttime photochemistry: nitrate radical destruction by anthropogenic light sources. Stark, H, et al. CIRES, NOAA. 2010.
https://www.academia.edu/23527679/Nighttime_photochemistry_nitrate_radical_destruction_by_anthropogenic_light_sources
Abstract extract: show airborne and ground measurements of absolute light intensities from anthropogenic and natural light sources (e.g. industrial and street lighting, full moon) as a newly discovered NO₃ loss process. This loss process has implications for nighttime pollutant levels and next-day ozone production.

Light Flicker from LED Lighting Systems-An Urgent Problem to Solve. GIES, T.H. (2016).

https://www.led-professional.com/resources-1/articles/lighting-flicker-from-led-lighting-systems/LpR53_p50-p59.pdf

Recent research has shown that fluctuations of short wavelength emissions are perceived to a higher extent and light flicker may have a huge influence on the well-being of end users.

Blue light excited retinal intercepts cellular signaling. Ratnayake, K., Payton, J.L., Lakmal, O.H. et al. Scientific Reports 8, 10207 (2018).

<https://doi.org/10.1038/s41598-018-28254-8>

Photoreceptor chromophore, 11-cis retinal (11CR) and the photoproduct, all-trans retinal (ATR), are present in the retina at higher concentrations and interact with the visual cells. Non-visual cells in the body are also exposed to retinal that enters the circulation. ... we uncovered that blue light-excited ATR and 11CR irreversibly change/distort plasma membrane (PM) bound phospholipid; phosphatidylinositol 4,5 biphosphate (PIP2) and disrupt its function. ... The change in PIP2 was followed by an increase in the cytosolic calcium, excessive cell shape change, and cell death... These findings suggest that retinal exerts light sensitivity to both photoreceptor and non-photoreceptor cells, and intercepts crucial signaling events, altering the cellular fate.

Blue light from phone screens accelerates blindness, study finds. The Guardian. 8/9/2018

<https://www.theguardian.com/society/2018/aug/09/blue-light-from-phone-screens-accelerates-blindness-study-finds>

Research... has revealed that prolonged exposure to blue light triggers poisonous molecules to be generated in the eye's light-sensitive cells that can cause macular degeneration – an incurable condition that affects the middle part of vision. Blue light, which has a shorter wavelength and more energy compared with other colours, can gradually cause damage to the eyes.

How the marvel of electric light became a global blight to health. Dr. Richard G 'Bugs' Stevens. Aeon. August 3, 2018.

<https://aeon.co/ideas/how-the-marvel-of-electric-light-became-a-global-blight-to-health>

Excerpts: Light at night constitutes a massive assault on the ecology of the planet, including us... The electric light bulb is touted as one of the most significant technological advancements of human beings... But as with any new and spectacular technology, there are invariably unintended consequences... The current 'lightmare' traces back to the 1950s, when a road-building frenzy, including construction of the Interstate Highway System, aimed to solve the problem of congestion in the United States. But the roads turned out to increase congestion and pollution, including light pollution, too... More efficient energy-production and use, without concerted public education on reduction of use, can make the pollution problem worse... The hyper-aggressive marketing of bright, white LED street lighting to cities and towns has advanced to a breathtaking level. The US Department of Energy (DoE) and a group of international partners have launched an effort called 'Rise and Shine: Lighting the World with 10 Billion LED Bulbs' in 'a race to deploy 10 billion high-efficiency, high-quality and affordable lighting fixtures and bulbs (like LEDs) as quickly as possible'... In response to this relentless attack on night, the American Medical Association (AMA) stepped up and adopted an official policy statement in 2016... The reaction from the DoE and the Illuminating Engineering Society of North America (IES) was swift and highly critical of the AMA's audacity, asserting that the AMA was not qualified to make any statements on lighting. But this reaction was disingenuous because without the AMA statement, the nationwide retrofit would have continued unabated without regard to the environment or human health. Electric light can be a great benefit to people when used wisely. To get to the 'used wisely' part requires all the science happening now. But there must also be a desire for effective use of electric lighting on the part of government and the public... few people will leave the faucet running much longer than necessary. Yet some people think nothing of using more electricity than they actually need... In the life of the planet, destruction of night is as important an issue as the poisoning of water and air.

Artificial Light at Night (ALAN): A Potential Anthropogenic Component for the COVID-19 and HCoV's Outbreak. Khan ZA,

Yumnamcha T, Mondal G, et al. Frontiers in endocrinology. 2020;11:622. Published 2020 Sep 10.

<https://www.frontiersin.org/articles/10.3389/fendo.2020.00622/full>

Abstract Excerpt: In this article, we tried to focus on the possible influence of this anthropogenic factor in human coronavirus (HCoV) outbreak. The relationship between the occurrences of coronavirus and the ascending curve of the night-light has also been delivered. The ALAN influences the physiology and behavior of bat, a known nocturnal natural reservoir of many Coronaviridae. The "threatened" and "endangered" status of the majority of bat species is mainly because of the destruction of their proper habit and habitat predominantly through artificial illumination. The stress exerted by ALAN leads to the impaired body functions, especially endocrine, immune, genomic integration, and overall rhythm features of different physiological variables and behaviors in nocturnal animals. Night-light disturbs "virus-host" synchronization and may lead to mutation in the genomic part of the virus and excessive virus shedding. We also proposed some future strategies to mitigate the repercussions of ALAN and for the protection of the living system in the earth as well.

Light pollution linked to preterm birth increase. Jan 25, 2021. Lehigh University. Science Daily.

<https://www.sciencedaily.com/releases/2021/01/210125191821.htm>

Scientists conducted the first study to examine the fetal health impact of light pollution based on a direct measure of skyglow, an important aspect of light pollution. Using an empirical regularity discovered in physics, called Walker's Law, a team found evidence of reduced birth weight, shortened gestational length and preterm births.

Association of Outdoor Artificial Light at Night With Mental Disorders and Sleep Patterns Among US Adolescents. Paksarian D, Rudolph KE, Stapp EK, et al. *JAMA Psychiatry*. 2020;77(12):1266–1275.
<https://jamanetwork.com/journals/jamapsychiatry/article-abstract/2767698>
<https://edition.cnn.com/2020/07/08/health/night-light-pollution-disrupt-sleep-wellness/index.html>

In this study, area-level outdoor ALAN was associated with less favorable sleep patterns and mood and anxiety disorder in adolescents. Future studies should elucidate whether interventions to reduce exposure to ALAN may positively affect mental and sleep health.

Astronomy Impacts

Light Pollution In California And Arizona. Walker, Merle F. *Publications of The Astronomical Society of The Pacific*, Vol. 85, No. 507, 1973, pp. 508–519. *Jstor*
<http://www.jstor.org/stable/40675430>

The present and future effect of artificial illumination on ground-based optical astronomical observations in California and Arizona is discussed. It is concluded that the effectiveness of all major observatories in these states is presently or potentially limited by light pollution. Consequently, it is essential that immediate efforts be undertaken to: (1) Control outdoor illumination to lengthen the useful life of existing observatory sites, and (2) Identify and protect the best remaining sites both within and outside the United States. The characteristics and probable locations of the best sites for ground-based optical astronomical observations are discussed.

Light Pollution: Outdoor lighting is a growing threat to astronomy. Riegel, Kurt W. *Science*, Vol. 179, No. 4080, Mar 1973, pp. 1285–1291.

<https://pubmed.ncbi.nlm.nih.gov/17835929/>

Abstract Excerpt: The level of skylight caused by outdoor lighting systems is growing at a very high rate, about 20 percent per year nationwide. In addition, the spectral distribution of man-made light pollution may change in the next decade from one containing a few mercury lines to one containing dozens of lines and a significantly increased continuum level. Light pollution is presently damaging to some astronomical programs, and it is likely to become a major factor limiting progress in the next decade... Some is due to promotional campaigns, in which questionable arguments involving public safety are presented. There are protective measures which might be adopted by the government; these would significantly aid observational astronomy, without compromising the legitimate outdoor lighting needs of society.

Flagstaff's Battle for Dark Skies. Portree D.S.F. Oct 2002, *Griffith Observer*, Vol 66 No 10

<http://www2.lowell.edu/users/wes/GriffithObserver/crop.pdf>

<http://www.flagstaffdarks skies.org/international-dark-sky-city/flagstaffs-battle-for-dark-skies/>

Public Safety

Blinded by the Lights: Levi's Stadium Lights May Be Airport Safety Hazard. By Stephen Stock, Michael Bott and Jeremy Carroll. NBC Bay Area. Sept 22, 2015

<https://www.nbcbayarea.com/news/local/blinded-by-the-lights-levi-stadium-lights-may-be-airport-safety-hazard/102234/>

Some pilots say powerful lights above and around the new Levi's Stadium can cause safety hazards for flights in and out of San Jose Mineta International Airport.

Why Lighting Claims Might Well Be Wrong, Paul Marchant, *International Journal of Sustainable Lighting*: Vol. 19 No. 1 (2017)

<http://lightingjournal.org/index.php/path/article/view/71/79>

This paper gives some background to claims of benefit from road lighting and why large beneficial claims may be suspect.

Feeling Safe in the Dark: Examining the Effect of Entrapment, Lighting Levels, and Gender on Feelings of Safety and Lighting Policy Acceptability. Boomsma C, et al. *Environmental and Behavior*, Vol 46 Issue 2, pp 193-212. Sept 2012.

<https://journals.sagepub.com/doi/10.1177/0013916512453838>

Importantly, as hypothesized, perceived safety mediated the effect of lighting on acceptability levels, suggesting that people can accept lower lighting levels when social safety is not threatened.

The effect of reduced street lighting on road casualties and crime in England and Wales: controlled interrupted time series analysis. Steinbach R, Perkins C, Tompson L, et al, *J Epidemiol Community Health* 2015;69:1118-1124.

<https://jech.bmj.com/content/69/11/1118>

Conclusions: This study found little evidence of harmful effects of switch off, part-night lighting, dimming, or changes to white light/LEDs on road collisions or crime in England and Wales.

Light Pollution Mitigation

National Light Pollution Guidelines for Wildlife Including Marine Turtles, Seabirds and Migratory Shorebirds, Commonwealth of Australia, Jan 2020

<https://www.environment.gov.au/biodiversity/publications/national-light-pollution-guidelines-wildlife>

Audubon's Lights Out program

<https://www.audubon.org/conservation/project/lights-out>

LoNNe, Loss of the Night Network

<http://www.cost-lonne.eu/recommendations/>

Human and Environmental Effects of Light Emitting Diode (LED) Community Lighting, 2016, American Medical Association, CSAPH Report 2-A-16, Policy H-135.927

<https://policysearch.ama-assn.org/policyfinder/detail/H-135.927?uri=%2FAMADoc%2FHOD-135.927.xml>

<https://www.ama-assn.org/sites/ama-assn.org/files/corp/media-browser/public/about-ama/councils/Council%20Reports/council-on-science-public-health/a16-csaph2.pdf>

supports the proper conversion to community-based Light Emitting Diode (LED) lighting, which reduces energy consumption and decreases the use of fossil fuels.. encourages minimizing and controlling blue-rich environmental lighting by using the lowest emission of blue light possible to reduce glare... should be properly shielded to minimize glare and detrimental human and environmental effects, and... utilize the ability of LED lighting to be dimmed for off-peak time periods.

Advocating and Support for Light Pollution Control Efforts and Glare Reduction for Both Public Safety and Energy Savings, 2012, Policy H-135.937

<https://policysearch.ama-assn.org/policyfinder/detail/light%20pollution?uri=%2FAMADoc%2FHOD.xml-0-308.xml>

Our AMA: (1) will advocate that all future outdoor lighting be of energy efficient designs to reduce waste of energy and production of greenhouse gasses that result from this wasted energy use; (2) supports light pollution reduction efforts and glare reduction efforts at both the national and state levels; and (3) supports efforts to ensure all future streetlights be of a fully shielded design or similar non-glare design to improve the safety of our roadways for all, but especially vision impaired and older drivers.

International Dark-Sky Association, <https://darksky.org>, <https://darksky.org/light-pollution>

IDA Guidance for Electronic Message Centers (EMCs) – Digital billboards

<https://www.darksky.org/wp-content/uploads/2019/10/EMC-Guidelines-IDA2019-1.1.pdf>

IDA Criteria for Community-Friendly Outdoor Sports Lighting

<https://www.darksky.org/wp-content/uploads/2018/03/IDA-Criteria-for-Community-Friendly-Outdoor-Sports-Lighting.pdf>

Model Lighting Ordinances – Dark Sky Impacts, Flagstaff Dark Skies Coalition

<http://www.flagstaffdarks skies.org/model-lighting-ordinances-dark-sky-impacts/>

Led Lighting And Dark Skies: Are LEDs good for dark skies? Flagstaff Dark Skies Coalition.

<http://www.flagstaffdarks skies.org/led-lighting-dark-skies/>

Light Pollution and Lighting Codes: An Analysis of the Light Pollution Control Effectiveness of the IDA-IES Model Lighting Ordinance and the IDA Pattern Outdoor Lighting Code, Christian B. Luginbuhl, U.S. Naval Observatory Flagstaff Station, 15 January 2013

<http://www.flagstaffdarks skies.org/wp-content/uploads/2013/02/Lighting-Codes-and-LP-Luginbuhl-130115.pdf>

Excerpts: Under MLO standards, outside of MLO Lighting Zones 0 and 1, the total lumen allowances, direct uplight allowances, and amount of sky glow are notably greater than expected under POLC standards; in MLO Lighting Zones 3 and 4 they are dramatically greater. These lighting amounts and sky glow impacts are greater than what can be expected even when lighting is unregulated. The MLO Performance Method Option B provides notably poor control of direct uplight and therefore sky glow. Under the MLO Performance Method Option B there are no effective limitations on glare. MLO does not address lamp spectrum, and thus leaves this crucial aspect of light pollution unaddressed. Finally, the analysis shows that the MLO Prescriptive Hardscape Area and Performance Methods do not provide similar results in terms of total lumen amounts, uplight amounts, glare, or “offsite” impacts, an undesirable characteristic of a model regulation purporting to control light pollution. The Performance Method particularly allows for the most egregious forms of polluting lighting fixtures and designs. We find no evidence that communities adopting MLO can expect reduction in light pollution over that produced by typical unregulated lighting, despite the claims of MLO to be a method to “drastically reduce” light pollution.

Model Lighting Ordinance: Is the BUG rating method effective at limiting light trespass?, April/May 2012 issue of LEDs Magazine

<https://www.ledsmagazine.com/architectural-lighting/outdoor-lighting/article/16698628/model-lighting-ordinance-is-the-bug-rating-method-effective-at-limiting-light-trespass-magazine>

Excerpts: The MLO allows for the use of BUG ratings along with the performance method as long as there is no uplight used. This scenario would not only allow for more lumens on the site as compared to the prescriptive method, but also would allow for a greater amount of light spilling from the site than would be seen from sites that restrict the spill by using the calculation method. As proven from the studies done for this article, the BUG rating method cannot effectively control these extra lumens of spill light.

Hazard or Hope? LEDs and Wildlife. Longcore, Travis. (2018). LED Professional Review. 70. 52-57.

<https://www.led-professional.com/resources-1/articles/hazard-or-hope-leds-and-wildlife>

Conclusions: The efficiency benefits of LEDs and the resulting economic incentives will drive further conversion of outdoor and indoor lighting to the technology. If the tendency to light more when light is cheaper can be overcome, the other attributes of LEDs hold significant promise for reducing environmental effects. Realizing that promise requires designers and manufacturers to learn about and embrace the guidance that wildlife scientists can provide. In some instances it will be challenging - resisting the desire to up-light, using no more light than necessary, and educating clients on the benefits of spectral choices that do not look like daylight. In other contexts, environmental regulations are likely to dictate lighting choices and offer an opportunity if the industry is prepared to seize it. On each of the mitigation approaches - duration, direction, intensity, and spectrum - LEDs will inherently or can be designed to perform well. Whether they do in practice will be up to the LED professional.

Artificial Night Lighting and Protected Lands: Ecological Effects and Management Approaches (Revised August 2017).

Longcore, T., and C. Rich. Natural Resource Report NPS/NRSS/NSNS/NRR—2017/1493. National Park Service, Fort Collins, Colorado.

<https://irma.nps.gov/DataStore/DownloadFile/582058>

Artificial night lighting represents a growing challenge for managers of parks and protected lands. The disruption of natural patterns of light and dark, which have been more or less reliable for millions of years, has a range of adverse consequences for wildlife across taxonomic groups and landscape types. This document reviews effects of artificial night lighting by habitat type and discusses the approaches available to land managers to mitigate and avoid certain adverse effects of artificial night lighting.

Rapid assessment of lamp spectrum to quantify ecological effects of light at night. Longcore, T., A. Rodríguez, B.

Witherington, J. F. Penniman, L. Herf, and M. Herf. 2018. Journal of Experimental Zoology A 329:511-521.

<https://onlinelibrary.wiley.com/doi/abs/10.1002/jez.2184>

Abstract: For many decades, the spectral composition of lighting was determined by the type of lamp, which also influenced potential effects of outdoor lights on species and ecosystems. Light-emitting diode (LED) lamps have dramatically increased the range of spectral profiles of light that is economically viable for outdoor lighting. Because of the array of choices, it is necessary to develop methods to predict the effects of different spectral profiles without conducting field studies, especially because older lighting systems are being replaced rapidly. We describe an approach to predict responses of exemplar organisms and groups to lamps of different spectral output by calculating an index based on action spectra from behavioral or visual characteristics of organisms and lamp spectral irradiance. We calculate relative response indices for a range of lamp types and light sources and develop an index that identifies lamps that minimize predicted effects as measured by ecological, physiological, and astronomical indices. Using these assessment metrics, filtered yellow-green and amber LEDs are predicted to have lower effects on wildlife than high pressure sodium lamps, while blue-rich lighting (e.g., $K \geq 2200$) would have greater effects. The approach can be updated with new information about behavioral or visual responses of organisms and used to test new lighting products based on spectrum. Together with control of intensity, direction, and duration, the approach can be used to predict and then minimize the adverse effects of lighting and can be tailored to individual species or taxonomic groups.

The LED Paradox: How Light Pollution Challenges Experts to Reconsider Sustainable Lighting. Schulte-Römer, N.; Meier, J.;

Söding, M.; Dannemann, E.; Sustainability 2019, 11, 6160.

<https://www.mdpi.com/2071-1050/11/21/6160>

Abstract: In the 21st century, the notion of “sustainable lighting” is closely associated with LED technology. In the past ten years, municipalities and private light users worldwide have installed light-emitting diodes in urban spaces and public streets to save energy. Yet an increasing body of interdisciplinary research suggests that supposedly sustainable LED installations are in fact unsustainable, because they increase light pollution. Paradoxically, blue-rich cool-white LED lighting, which is the most energy-efficient, also appears to be the most ecologically unfriendly. Biologists, physicians and ecologists warn that blue-rich LED light disturbs the circadian day-and-night rhythm of living organisms, including humans, with potential negative health effects on individual species and whole ecosystems. Can the paradox be solved? This paper explores this question based on our transdisciplinary research project Light Pollution—A Global Discussion. It reveals how light pollution experts and lighting professionals see the challenges and potential of LED lighting from their different viewpoints. This expert feedback shows that “sustainable LED lighting” goes far beyond energy efficiency as it raises complex design issues that imply stakeholder negotiation. It also suggests that the LED paradox may be solved in context, but hardly in principle.

Tuning the white light spectrum of light emitting diode lamps to reduce attraction of nocturnal arthropods. Longcore Travis, Aldern Hannah L., Eggers John F., Flores Steve, Franco Lesly, Hirshfield-Yamanishi Eric, Petrincic Laina N., Yan Wilson A. and Barroso André M. 2015, Phil. Trans. R. Soc. B37020140125
<https://royalsocietypublishing.org/doi/abs/10.1098/rstb.2014.0125>

Abstract: Artificial lighting allows humans to be active at night, but has many unintended consequences, including interference with ecological processes, disruption of circadian rhythms and increased exposure to insect vectors of diseases. Although ultraviolet and blue light are usually most attractive to arthropods, degree of attraction varies among orders. With a focus on future indoor lighting applications, we manipulated the spectrum of white lamps to investigate the influence of spectral composition on number of arthropods attracted. We compared numbers of arthropods captured at three customizable light-emitting diode (LED) lamps (3510, 2704 and 2728 K), two commercial LED lamps (2700 K), two commercial compact fluorescent lamps (CFLs; 2700 K) and a control. We configured the three custom LEDs to minimize invertebrate attraction based on published attraction curves for honeybees and moths. Lamps were placed with pan traps at an urban and two rural study sites in Los Angeles, California. For all invertebrate orders combined, our custom LED configurations were less attractive than the commercial LED lamps or CFLs of similar colour temperatures. Thus, adjusting spectral composition of white light to minimize attracting nocturnal arthropods is feasible; not all lights with the same colour temperature are equally attractive to arthropods.

Evaluating Potential Spectral Impacts of Various Artificial Lights on Melatonin Suppression, Photosynthesis, and Star Visibility. Aubé M, Roby J, Kocifaj M (2013). PLOS ONE 8(7): e67798.

<https://doi.org/10.1371/journal.pone.0067798>

Abstract Excerpt: Artificial light at night can be harmful to the environment, and interferes with fauna and flora, star visibility, and human health. To estimate the relative impact of a lighting device, its radiant power, angular photometry and detailed spectral power distribution have to be considered. In this paper we focus on the spectral power distribution... In this paper we propose three new indices to characterize lamp spectra. These indices have been designed to allow a quick estimation of the potential impact of a lamp spectrum on melatonin suppression, photosynthesis, and star visibility. We used these new indices to compare various lighting technologies objectively. We also considered the transformation of such indices according to the propagation of light into the atmosphere as a function of distance to the observer. Among other results, we found that low pressure sodium, phosphor-converted amber light emitting diodes (LED) and LED 2700 K lamps filtered with the new Ledtech's Equilib filter showed a lower or equivalent potential impact on melatonin suppression and star visibility in comparison to high pressure sodium lamps. Low pressure sodium, LED 5000 K-filtered and LED 2700 K-filtered lamps had a lower impact on photosynthesis than did high pressure sodium lamps. Finally, we propose these indices as new standards for the lighting industry to be used in characterizing their lighting technologies.

Solid-State Roadway Lighting Design Guide: Volume 1: Guidance. National Academies of Sciences, Engineering, and Medicine. 2020. <https://doi.org/10.17226/25678>

Solid-State Roadway Lighting Design Guide: Volume 2: Research Overview. National Academies of Sciences, Engineering, and Medicine. 2020. <https://doi.org/10.17226/25679>

Assessment of Citizens' Actions against Light Pollution with Guidelines for Future Initiatives. Zielińska-Dabkowska, K.M.; Xavia, K.; Bobkowska, K. Sustainability. June 2020, 12, 4997.

<https://doi.org/10.3390/su12124997>

Abstract excerpt: This paper therefore investigates the various actions taken by citizens, as well as the challenges, methods, and tools involved, regarding good practices initiated by grass roots activism on how to reduce existing and potential light pollution. The results of a comparative analysis of 262 international case studies (lawsuits and online petitions) reveal that, since the 1990s, there has been an increase in the number of legal cases related to light pollution due to the rise in public awareness, the availability of scientific knowledge via the Internet, and the ability to take accurate lighting measurements and perform lighting simulations. Also, in the last decade a new tool for digital participation in the form of online petitions has established a new movement of citizen action to mitigate the effects of light pollution. Based on this information, a seven-step framework involving recommendations for citizen action has been developed. It is expected that this new knowledge will benefit those citizens planning future efforts involving the development, implementation, and monitoring processes of outdoor lighting. Additionally, it might support the evolution of planning and policy approaches that are sustainable and necessary to improve the application and installation of ecologically/biologically responsible illumination for towns, cities, and natural habitats.

Nevada Senate passes bill to form 'dark sky places' program. Feb 22, 2021. By Sam Metz, AP News

<https://apnews.com/article/legislature-nevada-light-pollution-coronavirus-pandemic-kate-marshall-e0f69ee3c5895b1f7dd4d89b1ea3ebc>

Nevada's state Senate took a step toward ensuring stargazers will continue to enjoy picture-perfect constellations on Monday, passing a bill to recognize "dark sky places" with unobstructed views of galaxies hundreds of thousands of light years away.

Urban Lighting Research Transdisciplinary Framework—A Collaborative Process with Lighting Professionals. Pérez Vega, C.; Zielinska-Dabkowska, K.M.; Hölker, F. *Int. J. Environ. Res. Public Health.* 2021, 18, 624.

<https://doi.org/10.3390/ijerph18020624>

Abstract Excerpt: Over the past decades, lighting professionals have influenced the experience of the night by brightly illuminating streets, buildings, skylines, and landscapes 24/7... a dual perspective on night-time was shaped and the visual enjoyment of visitors after dusk was prioritized over natural nightscapes (nocturnal landscapes). During this time, researchers of artificial light at night (ALAN) observed and reported a gradual increase in unnatural brightness and a shift in color of the night-time environment. As a consequence, ALAN has been identified as a relevant pollutant of aquatic and terrestrial habitats, and an environmental stressor, which may adversely affect a wide range of organisms, from micro-organisms to humans... This paper presents a framework to help reduce the existing gap of knowledge, because appropriate lighting applications depend upon it. Access to less light polluted nightscapes in urban environments is just as important as access to unpolluted water, food, and air.

On-line Workshop “Dark and Quiet Skies for Science and Society”, Report and Recommendations, Dec 2020, coordinated by the United Nations Office for Outer Space Affairs

https://unoosa.org/osa/en/ourwork/psa/schedule/2020/2020_dark_skies.html

to propose to COPUOS [United Nations Committee on the Peaceful Uses of Outer Space]... recommendations, to be acted upon either by local governments or agreed to at an international level... This report analyses all artificial interference that can have a negative impact on the visibility of the night sky. These interferences can be logically grouped into three categories... effect caused by the artificial emission of visible light during the night,... impact that the very large number of communication satellites in Low Earth Orbit... to the interference that radio broadcasting... have on observations by radio telescopes.

Grasping darkness: the dark ecological network as a social-ecological framework to limit the impacts of light pollution on biodiversity. Challéat, S., et al. 2021. *Ecology and Society* 26(1):15.

<https://doi.org/10.5751/ES-12156-260115>

Abstract excerpt: Artificial light at night (ALAN)... is increasingly recognized as a major threat to global biodiversity, which ultimately alters the amount, the quality, and the connectivity of available habitats for taxa... Here we present the concept of “dark ecological network.” We show this concept is able to grasp the effects of ALAN in terms of habitat disturbances and integrates temporal dimensions of ecological processes into biodiversity conservation planning... we propose a course of action that consists of building an interdisciplinary repertoire of contextualized knowledge (e.g., impacts on wildlife, human/lightscape relationship, existing legal tools, etc.), in order to deduce from it a number of practical supports for the governance of the dark ecological network in response to societal and ecological issues.