The Effects of Artificial Lights at Night from Digital Billboards:

A Compendium of Studies







SCENIC AMERICA

Table of Contents

Executive Summary **1**

Consequences of Artificial Light at Night on Animals **2**

Wildlife and Behavior 2
Physiological Changes 13
Ecosystems, Communities, and Species Interactions 15
Plant Life 30
Reviews, Metanalyses, and Opinions 33

Human-ALAN interaction **43**

Measurement of ALAN **46**

Consequences of Artificial Light at Night on Humans **50**

Disclaimer: *Findings, Methods, Response, and Mechanism sections contain language drawn directly from the cited studies. Summaries are written by Scenic America.*

Executive Summary

The proliferation of digital billboards across America has significantly contributed to a rise in light pollution or artificial light at night (ALAN). The high brightness displays used in digital billboards rely on LED technology. This technology emits blue light that has outsized biological effects on both humans and wildlife. ALAN poses a serious risk to public health. In fact, an estimated 83% of the world's population lives under light-polluted skies. ALAN is also an underrecognized environmental hazard.

In 2026, Scenic America conducted a compendium study on the effects of ALAN from digital billboards. A total of 54 studies published between the years 2006 and 2025 were reviewed. These studies covered the impacts of ALAN on animals and plant life including wildlife behavior, physiological changes, and ecosystem and species interactions. The review also covered studies on the measurement of ALAN, human-ALAN interaction, and the impacts of ALAN on humans. Collectively, these studies found a wide range of negative effects of ALAN from digital billboards on both wildlife and humans that should not be ignored.

Research across multiple species reveals that ALAN exposure alters biological processes and modifies behavioral patterns. Some effects include the desynchronization of nocturnal activity, sleep disruption, shifts in feeding behavior, as well as changes in migration patterns, invertebrate composition, and aviators' singing behavior. ALAN also negatively impacts species interaction through shifts in nocturnal pollination and foraging behaviors that lead to a decline in species diversity. These effects, along with the disruption of habitat selection, seed aggregation, and reproductive processes, ultimately lead to a loss of biodiversity.

Although people generally view nighttime light as a positive, and LED has been touted as environmentally friendly, ALAN has serious human health implications. These include the disruption of endocrine systems which alter circadian rhythms, affect melatonin secretion, and increase cortisol levels. Disruption to these systems may increase the risk of developing sleep disorders, cardiovascular disease, type 2 diabetes, obesity, depression and anxiety, as well as thyroid, breast and colorectal cancer. Overall, exposure to ALAN is a public health issue that is well-documented and must be addressed.

Consequences of Artificial Light at Night on Animals

Wildlife and Behavior

Title: 'Determining the effects of artificial light at night on the distributions of Western Snowy Plovers (*Charadrius nivosus nivosus*) and California Grunion (*Leuresthes tenuis*) in southern California'

Year Published: 2022

Author(s): Simons, A. L., K. L. M. Martin, and T. Longcore

Subject: Animals (birds)

Scope: Coastal birds of conservation concern

Design: Species distribution models using observational data and remote sensing.

Response: Disruption of behaviors related to reproduction, roosting, and spawning.

Mechanism: Increased predation risk

Summary: Even faint light pollution was enough to drive conservation-sensitive shorebirds away from otherwise suitable habitat.

Key Findings: "Exposure to ALAN was the most important environmental factor influencing distribution of grunion runs and second-most important factor for plover roosts. Significant declines were found in the likelihood of plovers roosting in locations where exposure to ALAN exceeded illuminance levels equivalent to that produced by approximately one half a full moon and for grunion spawning at one full moon."

Citation: Simons, A. L., K. L. M. Martin, and T. Longcore. 2022. Determining the effects of artificial light at night on the distributions of Western Snowy Plovers (*Charadrius nivosus nivosus*) and California Grunion (*Leuresthes tenuis*) in southern California. *Journal of Coastal Research, 38(2), 302–309. https://www.jstor.org/stable/48656955.*

Title:	'Light Pollution Modifies the Expression of Daily Rhythms and Behavior Patterns in a Nocturnal Primate'
Year Published:	2013
Author(s):	Thomas Le Tallec, Martine Perret, Marc Théry
Subject:	Animals (primate)
Scope:	Grey mouse lemur *Microcebus murinus*
Design:	Lab experiment where Male mouse lemurs were exposed 14 nights to moonlight treatment and then exposed 14 nights to light pollution treatment.
Response:	Light pollution was demonstrated to modify daily rhythms of locomotor activity and core temperature
Mechanism:	Phase delays and increases in core temperature.

Summary: Light pollution causes daily desynchronization of nocturnal activity, feeding behavior, and thermoregulation, in grey mouse lemurs.

Methods:

- Recorded chronobiological parameters related to locomotor activity and core temperature using telemetric transmitters.
- At the end of each treatment, nocturnal and feeding behaviors were explored using an infrared camera.
- Throughout the study, body mass and daily caloric food intake were recorded.

Key Findings:

- Nocturnal activity and feeding behaviors patterns were modified negatively.
    - Negative impact on thermoregulation and potentially energy balance through changes in patterns of daily torpor bouts.
- This study suggests that light pollution induces daily desynchronization of biological rhythms and could lead to seasonal desynchronization with potential deleterious consequences for animals in terms of adaptation and anticipation of environmental changes.

Citation: Thomas Le Tallec, Martine Perret, Marc Théry. 2013. Light Pollution Modifies the Expression of Daily Rhythms and Behavior Patterns in a Nocturnal Primate. *PLoS ONE 8(11): e79250. https://doi.org/10.1371/journal.pone.0079250*

Title:	'Anthropogenic noise and light pollution additively affect sleep behaviour in free-living birds in 2 sex- and season-dependent fashions'
Year Published:	2022
Author(s):	Andrea Grunst, Melissa Grunst, Thomas Raap, Rianne Pinxtena, Marcel Eensa
Subject:	Animal (bird)
Scope:	Great tit (*Parus major*)
Design:	Field observational

Summary: The combined effects of noise and light pollution effects on sleep in great tits resulted in differences in sleep duration.

Methods: Measured noise and light levels at nest boxes and used infrared video30 recording to assess sleep behaviour.

Key Findings:

- Noise pollution and ALAN were both independently related to variation in sleep behaviour
- In late fall through early spring, birds woke up and left the nest box ~35 min earlier relative to sunrise on territories with the lowest, but not the highest, light levels (range: 0.01-8.5 lux), such that the seasonal difference in sleep duration was dampened on light polluted territories
- ALAN could interfere with birds' ability to sense and respond to increasing daylength

Citation: Andrea Grunst, Melissa Grunst, Thomas Raap, Rianne Pinxtena, Marcel Eensa. 2022. Anthropogenic noise and light pollution additively affect sleep behaviour in free-living birds in 2 sex- and season-dependent fashions. *Environmental Pollution Volume 316, Part 1, 2023, 120426, ISSN 0269-7491, https://doi.org/10.1016/j.envpol.2022.120426.*

Title:	'Apparent Effects of Light Pollution on Singing Behavior of American Robins'
Year Published:	2006
Author(s):	Miller, Mark W.
Subject:	Animal (bird)
Scope:	American robin
Design:	Comparative observational

Summary: Artificial Light at night led to changes in singing behavior in Robins.

Methods: Compared song timing observations among sites and against historical studies.

Key Findings: Proliferation of artificial nocturnal light may be strongly affecting singing behavior of American Robins.

- Robin populations in areas with large amounts of artificial light frequently began their morning chorus during true night.
- Robin choruses in areas with little, or presumably little, artificial light have almost never begun during true night, instead appearing to track the onset of civil twilight.
- Robins initiate their morning chorus earlier in areas with high levels of artificial light, and that robins in areas with little artificial light continue to initiate song at approximately the same time, relative to civil twilight, as did robins historically.
- Cloud cover and mist appear to amplify the effect of artificial light by trapping that light near the ground in urban areas, making the night even brighter and prompting robins to initiate song even earlier.

Citation: Miller, Mark W. 2006. Apparent Effects of Light Pollution on Singing Behavior of American Robins. *The Condor: Ornithological Applications*, Volume 108, Issue 1, 1 February 2006, Pages 130–139, https://doi.org/10.1093/condor/108.1.130.

Title:	'Seasonal associations with light pollution trends for nocturnally migrating bird populations'
Year Published:	2021
Author(s):	Frank A. La Sorte, Kyle G. Horton, Alison Johnston, Daniel Fink, Tom Auer
Subject:	Animals (birds)
Scope:	42 species of nocturnally migrating birds
Design:	Cluster analysis
Response:	Abundance

Summary: ALAN causes the nocturnal migration of birds to be more energetically expensive and increases the risk of mortality.

Methods: intersect ALAN annual trend estimates (1992–2013) with weekly estimates of relative abundance for 42 nocturnally migrating passerine bird species that breed in North America using observations from the eBird community science database for the combined period 2005–2020

Key Findings:

- Encountering ALAN during nocturnal migration expands the cost of the migration journey in terms of time and energy expenditures, enhances the risk of mortality through collisions with illumined structures and impedes the selection of optimal stopover habitat.
- Reversing ALAN trends in Central America during migration, especially in the spring, would benefit the most individuals of the greatest number of species.
- Reversing ALAN trends in southeastern North America during the breeding season and Central America during the nonbreeding season would generate the greatest benefits outside of migration.

Citation: Frank A. La Sorte, Kyle G. Horton, Alison Johnston, Daniel Fink, Tom Auer. 2021. Seasonal associations with light pollution trends for nocturnally migrating bird populations. Ecosphere https://doi.org/10.1002/ecs2.3994.

Title:	'Relative importance of intensity and spectrum of artificial light at night in disrupting behavior of a nocturnal rodent'
Year Published:	2024
Author(s):	Travis Longcore, Sophia Anne Marie B. Villanueva, Kyle Nguyen-Ngo, Cristina A. Ghiani Benjamin Harrison, and Christopher S. Colwell
Subject:	Animals (rodent)
Scope:	Nocturnal rodent *Mus musculus*
Design:	Lab Experiment
Response:	Activity levels
Mechanism:	LED illumination system for nocturnal exposure of all combinations of four intensity levels and three correlated color temperatures.

Summary: Intensity and spectral composition independently influence circadian-linked activity.

Methods: Multiple Linear Regression

Key Findings: need to account for light spectrum in circadian studies of behavior, and confirm that spectral controls can mitigate some, but certainly not all, of the effects of light pollution on species in the wild.

- Experimental evidence that both intensity and spectral composition independently influence circadian-linked activity.

Citation: Travis Longcore, Sophia Anne Marie B. Villanueva, Kyle Nguyen-Ngo, Cristina A. Ghiani Benjamin Harrison, and Christopher S. Colwell. 2024. Relative importance of intensity and spectrum of artificial light at night in disrupting behavior of a nocturnal rodent. *J Exp Biol (2024) 227 (14): jeb247235*. doi: https://doi.org/10.1242/jeb.247235

Title:	'Light pollution is greatest within migration passage areas for nocturnally-migrating birds around the world'
Year Published:	2018
Author(s):	Sergio A. Cabrera-Cruz, Jaclyn A. Smolinsky & Jeffrey J. Buler
Subject:	Animals (birds)
Scope:	298 nocturnally migrating bird species
Design:	Geospatial analytics
Response:	Migrants will slow down their flight speed, start circling the light source, call more frequently near the lights, and collide with buildings .
Mechanism:	Disruption of circadian rhythms and disorientation during flight.

Summary: Migratory birds are exposed to ALAN during migration, affecting stopover habitat selection during an energetically expensive time.

Methods: Evaluated the association of the annual mean ALAN intensity over land within the geographic ranges of 298 nocturnally migrating bird species with five factors: phase of annual cycle, mean distance between breeding and non-breeding ranges, range size, global hemisphere of range, and IUCN category of conservation concern.

Key Findings: Migratory birds may be subject to the effects of light pollution particularly during migration, the most critical stage in their annual cycle.

- Many long distance migratory birds are exposed to more extensive ALAN in areas they traverse while aloft during migration, a period of great selective pressure when birds must repeatedly locate stopover habitats where they can safely rest and refuel and contend with weather to fly long distances to reach their destinations in a timely manner.

Citation: Sergio A. Cabrera-Cruz, Jaclyn A. Smolinsky & Jeffrey J. Buler. 2018. Light pollution is greatest within migration passage areas for nocturnally-migrating birds around the world. *Sci Rep* 8, 3261. https://doi.org/10.1038/s41598-018-21577-6

Title: 'Light pollution disrupts sleep in free-living animals'

Year Published: 2015

Author(s): Thomas Raap, Rianne Pinxten, & Marcel Eens

Subject: Animals (birds)

Scope: Suburban nest-box population of Great tits *Parus major* in the surroundings of Wilrijk, Belgium.

Design: Field experiment

Response: Changes in sleep patterns

Mechanism: Sleep disruption

Summary: ALAN causes great tits to sleep less, with potential fitness effects.

Methods: Recording individual sleep behaviour of great tits, Parus major, that were roosting in dark nest-boxes and were exposed to light-emitting diode light the following night. Their behaviour was compared to that of control birds sleeping in dark nest-boxes on both nights.

Key Findings: Artificial lighting caused experimental birds to wake up earlier, sleep less (–5%) and spent less time in the nest-box as they left their nest-box earlier in the morning. Experimental birds did not enter the nest-box or fall asleep later than controls. Although individuals in lit nest-boxes did not wake up more often nor decreased the length of their sleep bouts, females spent a greater a proportion of the night awake. Our study provides the first direct proof that light pollution has a significant impact on sleep in free-living animals, in particular in the morning, and highlights mechanism for potential effects of light pollution on fitness.

Citation: Thomas Raap, Rianne Pinxten, & Marcel Eens. 2015. Light pollution disrupts sleep in free-living animals. *Sci Rep* 5, 13557. https://doi.org/10.1038/srep13557.

Physiological Changes

Title:	'Long-Term Effects of Chronic Light Pollution on Seasonal Functions of European Blackbirds (Turdus merula)'
Year Published:	2013
Author(s):	Davide M. Dominoni, Michael Quetting, Jesko Partecke
Subject:	Animals (birds)
Scope:	European Blackbirds (*Turdus merula*)
Design:	Field observational (chronic exposure comparison between urban light-polluted and darker sites)
Response:	Reproductive physiology, molt and locomotor activity
Mechanism:	Testicular, gonadal, and testosterone cycles, prolongation in photorefractory state, chronic stress

Summary: Chronic exposure to low-intensity ALAN resulted in physiological changes to European Blackbirds.

Methods: Field measurements of Testicular measurement and hormone analysis, body mass and molt, and Locomotor activity; analyzed with Monte Carlo Markov Chain.

Key Findings: Chronic low intensities of light at night can dramatically affect the reproductive system.

- Chronic exposure to low-intensity ALAN was associated with altered timing of gonadal development, testosterone cycles, and seasonal physiological transitions.

Citation: Davide M. Dominoni, Michael Quetting, Jesko Partecke. 2013. Long-Term Effects of Chronic Light Pollution on Seasonal Functions of European Blackbirds (Turdus merula). PLoS ONE 8(12): e85069. https://doi.org/10.1371/journal.pone.0085069.

Title: 'The effects of light pollution on biological rhythms of birds: an integrated, mechanistic perspective'

Year Published: 2014

Author(s): Davide M. Dominoni

Subject: Birds

Scope: Physiological and biochemical mechanisms that underlie changes in birds' behavior

Design: Narrative Review

Response: Modification to daily cycles & annual cycles

Mechanism: Photoreception (photopigments, opsins, phototransduction, retinal ganglion cells, pineal gland), light and circadian rhythm (suprachiasmatic nuclei, molecular mechanisms)

Summary: Investigation of the physiological and biochemical mechanisms that govern how ALAN influences changes in biological rhythms (e.g., singing and reproduction).

Key Findings:

- In studies that control for other environmental factors such as noise, light pollution can clearly alter the onset and offset of daily singing in a variety of species, and that the annual development of dawn and dusk chorus is accelerated under artificial lights.
- Several bird species advance their timing of reproduction in relation to urbanization.
- Have a limited understanding of the fitness consequences of the phenological shifts recorded in birds breeding under artificial lights.

Citation: Davide M. Dominoni. 2014. The effects of light pollution on biological rhythms of birds: an integrated, mechanistic perspective. *J Ornithol* 156 (Suppl 1), 409–418 (2015). https://doi.org/10.1007/s10336-015-1196-3.

Ecosystems, Communities, and Species Interactions

Title:	'Artificial light at night erases positive interactions across trophic levels'
Year Published:	2019
Author(s):	Elena Maggi, Lucia Bongiorni, Debora Fontanini| Antonella Capocchi, Martina Dal Bello, Andrea Giacomelli, Lisandro Benedetti-Cecchi
Subject:	Microbes
Scope:	Marine high-shore ecosystems
Design:	Field Experiment
Response:	Organism density and biomass
Mechanism:	Artificial extension of photoperiod, Artificial extension of photoperiod

Summary: ALAN impacts restructures lower-level species interactions in marine high-shore ecosystems.

Methods: Performed in situ nocturnal manipulations of a direct source of white LED light and presence of herbivores in a Mediterranean high-shore habitat, we assessed the interactive effects of light pollution and grazing on two key functional components of the epilithic microbial community.

Key Findings: Overall, direct and indirect effects on ALAN resulted in a significant increase in the diversity of the photoautotrophic component and a decrease in the heterotrophic.

- ALAN may represent a threat for natural systems through the annihilation of positive interactions across trophic levels in coastal ecosystems.

Citation: Elena Maggi, Lucia Bongiorni, Debora Fontanini| Antonella Capocchi, Martina Dal Bello, Andrea Giacomelli, Lisandro Benedetti-Cecchi. 2019. Artificial light at night erases positive interactions across trophic levels. *British Ecological Society Functional Ecology. https://doi.org/10.1111/1365-2435.13485*.

Title:	'Artificial light at night as a new threat to pollination'
Year Published:	2017
Author(s):	Eva Knop, Leana Zoller, Remo Ryser, Christopher Gerpe, Maurin Hörler & Colin Fontaine
Subject:	Plants and animals
Scope:	Plant–pollinator communities
Design:	Field Experiment
Response:	Significantly lower number of flower visits and species of flower visitors on illuminated sites.
Mechanism:	Altered behavior of nocturnal flower visitors, such as attraction to an artificial light source at night, as is known for many moth species, and/or to a physiological reaction of flower visitors.

Summary: ALAN disrupts nocturnal pollination networks and negatively impacts plant reproduction.

Methods: set up mobile streetlamps on ruderal meadows not previously exposed to ALAN

- Sampled nocturnal interactions between plants and flower visitors and analysed how ALAN affects the structure of the interaction networks.
- Analyzed the number of interactions and species, and two network metrics known to affect the stability of plant–pollinator communities: species generalism and network nestedness.
- To test whether the negative impact of ALAN on night-time pollinators
    - Translates into a lower pollination function, conducted a fruit set experiment using the model plant *Cirsium oleraceum*.

Key Findings: Artificial light at night disrupts nocturnal pollination networks and has negative consequences for plant reproductive success.

- Nocturnal visits to plants were reduced by 62% compared to dark areas.

- Overall, 13% reduction in fruit set of a focal plant even though the plant also received numerous visits by diurnal pollinators.
- Facilitate the spread of the negative consequences of disrupted nocturnal pollination to daytime pollinator communities predicted to lead to the decline of diurnal pollinator populations.

Citations: Eva Knop, Leana Zoller, Remo Ryser, Christopher Gerpe, Maurin Hörler & Colin Fontaine. 2017. Artificial light at night as a new threat to pollination. *Nature* 548, 206–209 (2017). https://doi.org/10.1038/nature23288.

Title: 'Using citizen science data to investigate annual survival rates of resident birds in relation to noise and light pollution'

Author(s): Lauren D. Pharr, Caren B. Cooper, Brian Evans, Christopher E. Moorman, Margaret A. Voss, Jelena Vukomanovic, Peter P. Marra

Year Published: 2023

Subject: Non-migratory birds

Scope: 7 species, 20-year band-resight data at 242 sites in Washington, DC.

Design: Geospatial analytics

Response: Survival and species-specific interactions

Mechanism: Interaction of noise and light pollution

Summary: Changes in avian survival and reproduction due to light pollution depending on species' traits.

Key Findings:

- Gray Catbird (Dumetella carolinensis) and House Wren (Thryothorus aedon) survival decreased and American Robin (Turdus migratorius) survival increased with greater amounts of anthropogenic light.
- Life-history trade-offs between survival and reproduction may account for differences in species-specific effects of light pollution: If artificial light is a stressor that negatively affects reproduction, it is possible that bird populations compensate with greater survival. If artificial light is a stressor that negatively affects survival, then it is possible that birds compensate with greater reproduction.

Citation: Lauren D. Pharr, Caren B. Cooper, Brian Evans, Christopher E. Moorman, Margaret A. Voss, Jelena Vukomanovic, Peter P. Marra. 2023. Using citizen science data to investigate annual survival rates of resident birds in relation to noise and light pollution. *Urban Ecosyst* 26, 1629–1637. https://doi.org/10.1007/s11252-023-01403-2.

Title: ‘Light pollution in complex ecological systems’

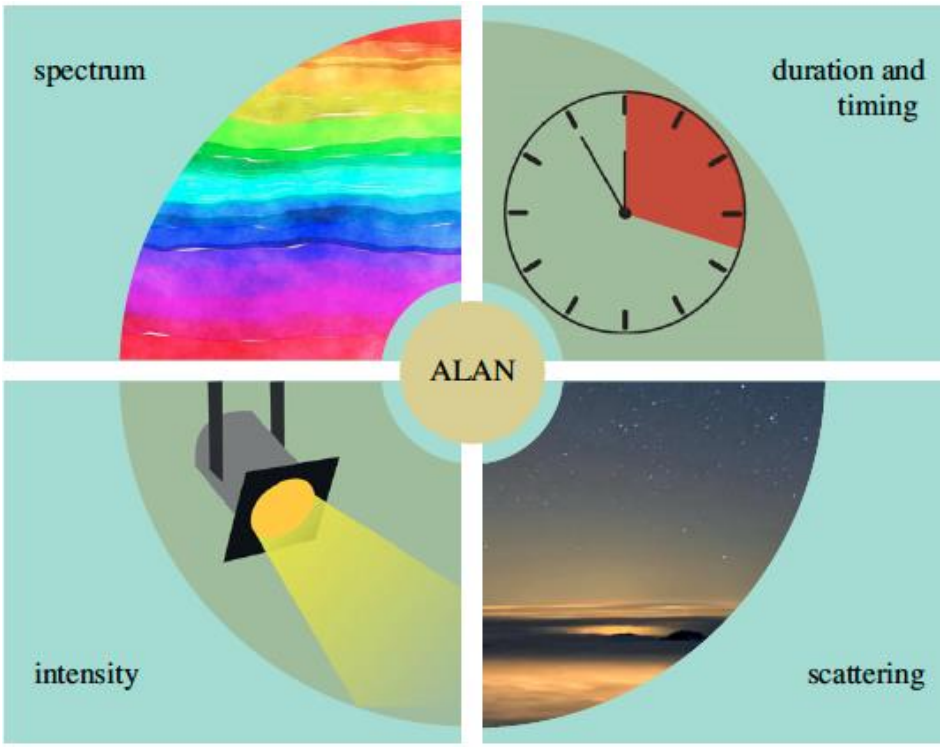
Year Published: 2023

Author(s): Hirt et al

Subject: Ecological Communities

Design: Review

Mechanism: Interplay between light pollution, ecological dynamics and humans in a world increasingly impacted by anthropogenic lighting.



Summary: Overview of how the properties of light impact ecosystems.

Key Findings: Explore the effects of light pollution on complex ecological systems by bridging various realms and scaling up from individual processes and functions to communities and Networks.

- Details ecologically relevant characteristics of ALAN
- Shed light on species interaction effects

Citation: Myriam R. Hirt, Darren M. Evans, Colleen R. Miller, Remo Ryser. 2023. Light pollution in complex ecological systems. *Phil. Trans. R. Soc. B* 378 (1892): 20220351. https://doi.org/10.1098/rstb.2022.0351.

Title:	'A framework for untangling the consequences of artificial light at night on species interactions'
Year Published:	2023
Author(s):	Seymoure et al
Subject:	Plants and animals
Scope:	Community-level species interactions
Design:	Literature review
Response:	Enhancements and reductions of species interactions were equally documented.
Mechanism:	ALAN alters and destroys natural light cycles responsible for temporal niches and nocturnal spatial niches.

Summary: ALAN changes how species interact with one another, including pollination activity, abnormal inactivity at night of nocturnal species, aggregation around light sources at night, and foraging extension.

Key Findings: Seventy-five of 79 studies found ALAN altered species interactions.

- Many studies revealed ALAN affecting species' interactions spatially, but few revealed temporal alterations.

- 
    - Potential altered species interactions due to ALAN. (a) Dusk: crepuscular species such as bees may shift their activity and pollinate flowers later at night and/or earlier in the morning. (b) Early night: many nocturnal species, such as bats and rodents, may remain inactive at night under the presence of ALAN [9,66]. (c) Night: nocturnal species may aggregate around artificial light sources at night owing to non-homogeneous lighting, such as bats and moths aggregating around artificial light [67,68]. (d) Dawn: diurnal predators may extend their foraging to earlier in the morning owing to the presence of ALAN and thus increase predation on insects as a result of an extended temporal niche [69–71].

Citation: Brett Seymoure, Anthony Dell, Franz Hölker, Gregor Kalinkat. 2023. A framework for untangling the consequences of artificial light at night on species interactions. *Phil. Trans. R. Soc. B.* 378 (1892): 20220356. https://doi.org/10.1098/rstb.2022.0356.

Title: 'Insect communities under skyglow: diffuse night-time illuminance induces spatio-temporal shifts in movement and predation'

Author(s): Dyer et al

Year Published: 2023

Subject: Animals (insects)

Scope: Nocturnal invertebrate communities

Design: Manipulative Experiment

Response: Shifts in community-level movement activity from daytime to night-time (Q1) as well as shifts in habitat use from vegetated habitat patches to open habitat at night (Q2).

Mechanism: Skyglow

Summary: ALAN, specifically skyglow, results in movement, spatial, and predation changes in nocturnal insects.

Methods: Quantify their movement activity and predation rates during simulated Moon cycles across a gradient of diffuse night-time illuminance including the full range of observed skyglow intensities and quantified predation rates using prey dummies.

Key Findings: Even low-intensity skyglow causes a temporal shift in movement activity from day to night, and a spatial shift towards open habitats at night.

Citation: Dyer et al. 2023. Insect communities under skyglow: diffuse night-time illuminance induces spatio-temporal shifts in movement and predation. *Phil. Trans. R. Soc. B.* 378 (1892): 20220359. https://doi.org/10.1098/rstb.2022.0359

Title: 'Long-term exposure to experimental light affects the ground-dwelling invertebrate community, independent of light spectra'

Year Published: 2023

Author(s): Spoelstra et al

Subject: Animals (insects, arachnids, molluscs, millipedes, woodlice, and worms)

Scope: Ground-dwelling invertebrate

Design: Manipulative field experiment

Response: Diversity and community composition after 3 or 4 **Year**s of continued nightly exposure to experimental ALAN with three different spectra (white-, and green- and red-dominated light), as well as for a dark control, in natural forest-edge habitat.

Mechanism: Species interactions

Summary: Light pollution, regardless of light color, had an almost immediate effect on composition of invertebrates.

Methods: Pitfall traps

Key Findings: Invertebrate community composition, however, was significantly affected by the presence of light. Keeping lights off during single nights did show an immediate effect on the composition of trapped invertebrates compared to illuminated nights.

- Light colour may not be a solution to mitigate effects on community composition.
- Leaving lights off had immediate significant effects, which indicates a direct response of species.

Citation: Spoelstra et al. 2023. Long-term exposure to experimental light affects the ground-dwelling invertebrate community, independent of light spectra. *Phil. Trans. R. Soc. B.* 378 (1892): 20220364. https://doi.org/10.1098/rstb.2022.0364.

Title:	'Spectral composition of light-emitting diodes impacts aquatic and terrestrial invertebrate communities with potential implications for cross-ecosystem subsidies'
Year Published:	2023
Author(s):	Elizabeth Parkinson, Scott D. Tiegs.
Subject:	Animals (insects)
Scope:	Aquatic and terrestrial insect communities
Design:	Manipulative field experiment
Response:	Biomass changes
Mechanism:	Taxa-specific responses—both attraction and avoidance—to particular colors of light.

Summary: Artificial light color affected the presence of different insect species heterogeneously.

Methods: Experimentally elevated ALAN levels by installing replicated light treatments in the littoral zone and adjacent riparian habitat.

Key Findings: Variation in wavelength from LEDs may impact the flux of resources between systems, as well as the communities of insects that are attracted to particular spectra of LED lighting.

- Community composition differed among colour treatments both across and within the littoral and riparian habitats.

Citation: Elizabeth Parkinson, Scott D. Tiegs. 2023. Spectral composition of light-emitting diodes impacts aquatic and terrestrial invertebrate communities with potential implications for cross-ecosystem subsidies. *Phil. Trans. R. Soc. B*. 378 (1892): 20220361. https://doi.org/10.1098/rstb.2022.0361.

Title: 'Does artificial light at night alter moth community composition?'

Year Published: 2023

Author(s): Kylee Grenis, César Nufio, Gina M. Wimp, Shannon M. Murphy

Subject: Animals (insects)

Scope: Moths communities from prairie fragments in Colorado, USA

Design: Field experiment

Response: Community composition

Mechanism: Surveys of light and bait traps

Summary: Sky Glow decreases moth diversity, potentially through increases in moth predation.

Key Findings: Increased sky glow decreased moth abundance and species richness and shifted community composition.

- **Sky glow is significant**: ALAN from streetlights and other local light sources has different impacts on communities than wide ranging, pervasive ALAN across degraded night skies.
- ALAN has significant effects on moth communities and that local light sources have contrasting effects on moth community composition compared to sky glow areas with increased sky glow received indirect light because they were adjacent to areas with high numbers of artificial lights but did not actually contain as many of these point sources of light. These areas may have suffered decreased diversity because indirect light at these sites may make moths more visible to predators or disrupt circadian development and reproductive behaviors, with cascading effects on reproductive fitness.

Citation: Kylee Grenis, César Nufio, Gina M. Wimp, Shannon M. Murphy. 2023. Does artificial light at night alter moth community composition?. *Phil. Trans. R. Soc. B.* 378 (1892): 20220365. https://doi.org/10.1098/rstb.2022.0365.

Title:	'Nearby night lighting, rather than sky glow, is associated with habitat selection a top predator in human-dominated landscapes'
Year Published:	2023
Author(s):	Rafael Barrientos et al
Subject:	Mountain lions
Scope:	102 mountain lions in a light-polluted region in California
Strength:	Moderate
Design:	Statistical modeling of radio-collared mountain lions
Response:	Avoidance of lights associated with humans but some preference towards sky glow areas.
Mechanism:	Human settlements are important sources of non-natural mortality.

Summary: Some mountain lions avoided areas with high upwards radiance (nearby lights) as compared to skyglow and natural moonlight.

Methods: Modelled their distribution relative to environmental and human-disturbance variables, including upward radiance (nearby lights), zenith brightness (sky glow) and natural illumination from moonlight.

Key Findings: mountain lion probability of presence was highly related to upward radiance, that is, related to lights within approximately 500 m. Despite a general pattern of avoidance of locations with high upward radiance, there were large differences in degree of avoidance among individuals.

Citation: Rafael Barrientos, Winston Vickers, Travis Longcore, Eric S. Abelson, Justin Dellinger, David P. Waetjen, Guillermo Fandos, Fraser M. Shilling. 2023. Nearby night lighting, rather than sky glow, is associated with habitat selection by a top predator in human-dominated landscapes. *Phil. Trans. R. Soc. B.* 378 (1892): 20220370. https://doi.org/10.1098/rstb.2022.0370.

Title: 'How artificial light at night may rewire ecological networks: concepts and models'

Year Published: 2023

Author(s): Dirk Sanders et al

Subject: Ecological communities

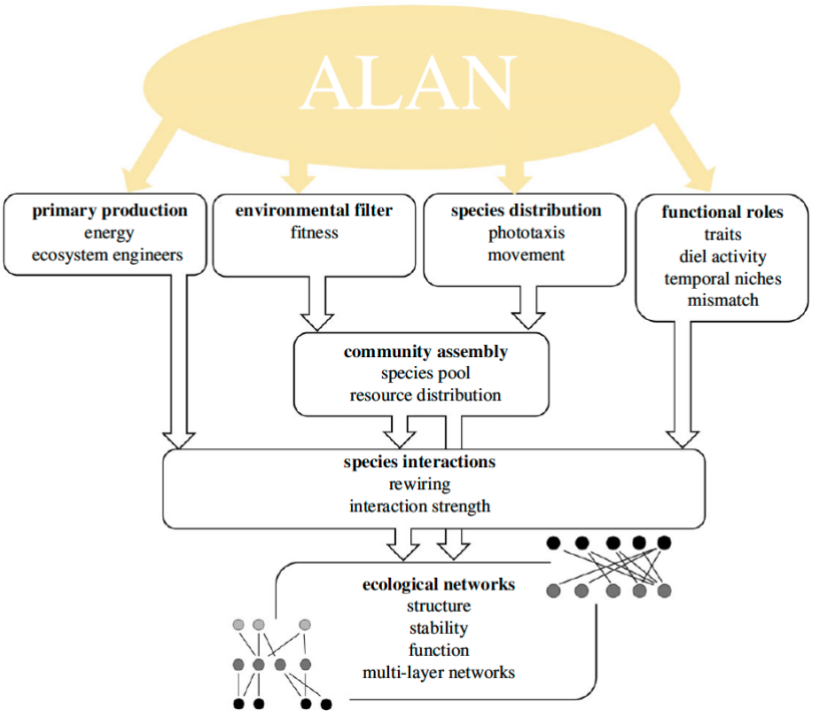
Scope: Diurnal, nocturnal and crepuscular species

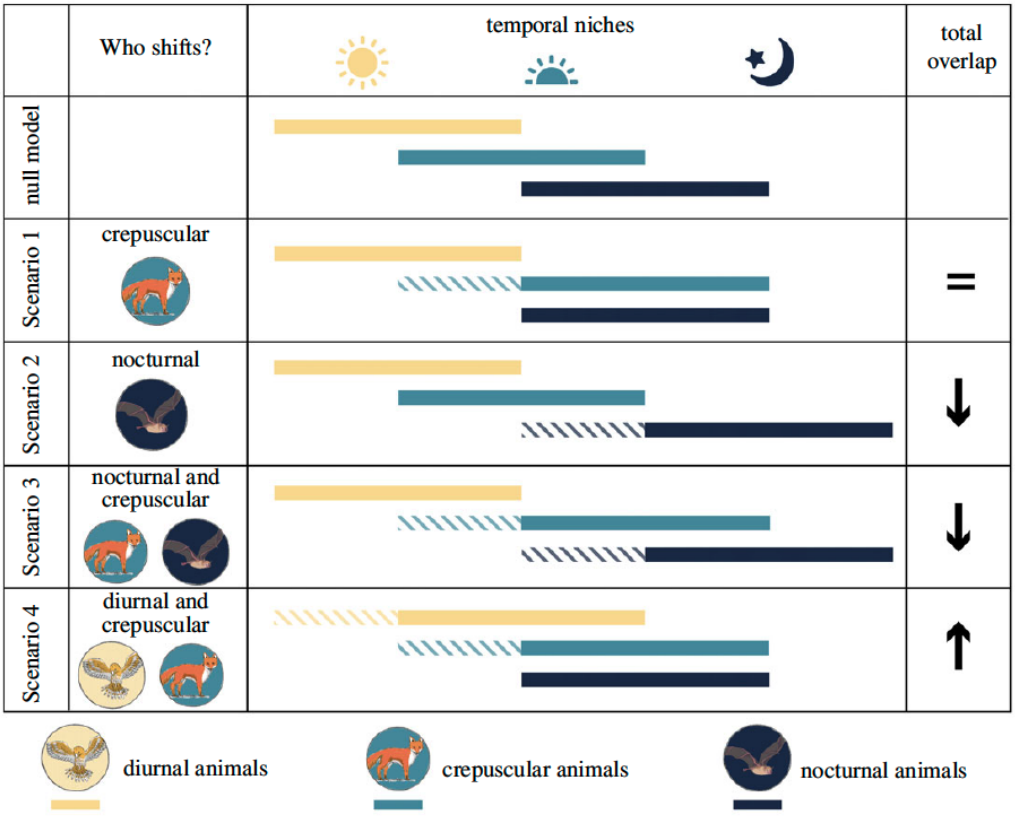
Strength: Strong

Design: Statistical modeling

Response: Food web stability

Mechanism: ALAN may affect ecological interaction networks by (i) impacting primary production, (ii) acting as an environmental filter affecting species survival, (iii) driving the movement and distribution of species, and (iv) changing functional roles and niches by affecting activity patterns.





Summary: Overview of how ALAN may affect complex ecological interactions, ultimately leading to biodiversity loss.

Methods: Allometric–trophic network model

Key Findings: Models indicate that diel niche shifts can severely impact community persistence by altering the temporal overlap between species, which leads to changes in interaction strengths and rewiring of networks.

- ALAN can thereby lead to biodiversity loss through the homogenization of temporal niches.

Citation: Dirk Sanders, Myriam R. Hirt, Ulrich Brose, Darren M. Evans, Kevin J. Gaston, Benoit Gauzens, Remo Ryser. 2023. How artificial light at night may rewire ecological networks: concepts and models. *Phil. Trans. R. Soc. B.* 378 (1892): 20220368. https://doi.org/10.1098/rstb.2022.0368.

Plant Life

Title:	'Ecological effects of artificial light at night on wild plants'
Year Published:	2016
Author(s):	Jonathan Bennie, Thomas W. Davies, David Cruse and Kevin J. Gaston
Subject:	Plants
Design:	Narrative review
Response:	Phenology (budburst, leaf retention, flowering), Growth and resource allocation, Physiological pathways (phytochrome, cryptochrome, photoperiodism), Plant–animal interactions (herbivory, pollination), Stress recovery (e.g., ozone damage interaction)
Mechanism:	Photoreceptor pathways (phytochrome, cryptochrome, phototropins); photoperiod disruption; spectral sensitivity; interaction with other stressors.

Summary: ALAN, through disruption of seasonal light cues, may lead to foliage dropping in trees.

Key Findings:

- Disruption of seasonal light cues by artificial light, population level changes or aggregation of individuals could modify interactions including herbivory, pollination and seed dispersal.
- Loss of leaves: Certain tree species appear to be more sensitive to direct illumination than others, but it is a common phenomena in several species planted as urban roadside trees.

Citation: Jonathan Bennie, Thomas W. Davies, David Cruse and Kevin J. Gaston. 2016. Ecological effects of artificial light at night on wild plants. *J Ecol, 104: 611-620. https://doi.org/10.1111/1365-2745.12551*.

Title:	'Artificial light at night outweighs temperature in lengthening urban growing seasons'
Year Published:	2025
Author(s):	Lvlv Wang , Lin Meng, Andrew D. Richardson, Franz Hölker, Huidong Li, Jiafu Mao , Travis Longcore, Jun Xia,& Dunxian She
Subject:	Plants
Scope:	428 Northern Hemisphere cities from 2014-2020
Design:	Remote Sensing
Response:	Phenological shifts

Summary: ALAN, especially near urban centers, may lengthen the growing season.

Methods: Multiple satellite observations of 428 Northern Hemisphere cities from 2014 to 2020 to analyze phenological patterns along a gradient from rural to urban.

Key Findings: We found that ALAN increased exponentially toward urban centers, and exerted stronger influence than air temperature in lengthening the urban growing season, especially by delaying its end, although the effects varied across climate zones. Our findings demonstrate that ALAN is a critical driver of vegetation dynamics in cities, one we should consider during urban management and development.

Citation: Lvlv Wang , Lin Meng, Andrew D. Richardson, Franz Hölker, Huidong Li, Jiafu Mao , Travis Longcore, Jun Xia, Dunxian She. 2025. Artificial light at night outweighs temperature in lengthening urban growing seasons. *Nat Cities* 2, 506–517 (2025). https://doi.org/10.1038/s44284-025-00258-2.

Title:	'Artificial light at night decreases plant diversity and performance in experimental grassland communities'
Author(s):	Franziska Bucher et al
Year Published:	2023
Subject:	Plants
Scope:	Grassland communities
Strength:	Strong
Design:	Manipulative experiment
Response:	Plant community composition, biomass, functional treaits
Mechanism:	Light serves as a fundamental resource for photosynthesis and as a key source of information for plants to time growth and recovery, as well as life-history events such as the onset of flowering or hardening in winter and the production of plant biomass.

Summary: Plants are sensitive to ALAN, decreasing plant diversity and physical performance such as leaf area.

Methods: Assessed individual plant performance by measuring 10 leaf plant functional traits that indicate whether plants benefit from the additional light or are stressed

Key Findings: Biomass was reduced by 33% in the highest ALAN treatment compared to the control, Shannon diversity decreased by 43% and evenness by 34% in the first harvest. Some species failed to establish in the second harvest.

- Specific leaf area, leaf dry matter content and leaf hairiness responded to ALAN.

Citations: Franziska Bucher et al. 2023. Artificial light at night decreases plant diversity and performance in experimental grassland communities. *Phil. Trans. R. Soc. B.* 378 (1892): 20220358. https://doi.org/10.1098/rstb.2022.0358.

Reviews, Metanalyses, and Opinions

Title:	'Exposure to Artificial Light at Night and the Consequences for Flora, Fauna, and Ecosystems'
Year Published:	2020
Author(s):	Jack Falcón, Alicia Torriglia, Dina Attia, Françoise Viénot, Claude Gronfier, Francine Behar-Cohen, Christophe Martinsons, and David Hicks
Subject:	System (Flora, Fauna, Ecosystem)
Scope:	Multi Taxa
Design:	Narrative Review
Mechanism:	Neuroendocrine + circadian

Summary: ALAN alongside other anthropogenic pressures can exacerbate phototaxis, circadian rhythm, and behavior in all living organisms.

Methods: Overview of the tremendous variety of light detection strategies which have evolved in living organisms - unicellular, plants and animals, covering chloroplasts (plants), and the plethora of ocular and extra-ocular organs (animals) to explain how their perturbation underlies much of the disruptive effects of ALAN.

Key Findings: Synergistic harmful effects resulting from the impacts of ALAN combined with other anthropogenic pressures, which often impact the neuroendocrine loops in vertebrates.

- There is no longer any doubt that ALAN affects phototaxis and circadian rhythms, and consequently any ensuing functions and behaviours.
- Thus, artificial light either during daytime or night-time, is not the only anthropogenic pressure on wildlife, and the question arises as to what is the impact of simultaneous and/or successive actions of these factors, since many of these targeting the same organs or associated and interconnected organs as is the case for the neuroendocrine system of vertebrates.
    - ALAN together with other external cues and disruptors often target the same neuroendocrine areas in vertebrates.

Citation: Jack Falcón, Alicia Torriglia, Dina Attia, Françoise Viénot, Claude Gronfier, Francine Behar-Cohen, Christophe Martinsons, and David Hicks. 2020. Exposure to Artificial Light at Night and the Consequences for Flora, Fauna, and Ecosystems. *Front. Neurosci. 14:602796. doi: 10.3389/fnins.2020.602796.*

Title:	'The impacts of artificial light at night on the ecology of temperate and tropical reefs'
Year Published:	2023
Author(s):	Emily Fobert et al
Subject:	Animals
Scope:	Coral reef communities
Strength:	Strong
Design:	Literary Review
Mechanism:	Reef species have evolved in response to low-light nocturnal environments.

Summary: ALAN impacts reef ecosystems through physiology, activity patterns, and reproduction.

Key Findings: Changes in physiological function, fitness and survival; primary production; Biological timings: early brood spawners, spawning synchrony, Diel activity patterns; light-based movement; landscape of fear (temporal niche partitioning between predators and prey); functional diversity collapse; source-sink dynamics; Disruption of diel vertical migrations.

Citation: Emily Fobert et al. 2023. The impacts of artificial light at night on the ecology of temperate and tropical reefs. *Philosophical Transactions of The Royal Society B Biological Sciences. 378. 20220362. 10.1098/rstb.2022.0362.*

Title:	'A meta-analysis of biological impacts of artificial light at night'
Year Published:	2020
Author(s):	Dirk Sanders et al
Subject:	24 microbial communities, 143 plants, 388 invertebrates, 746 vertebrates
Scope:	126 papers, 1304 effect sizes
Design:	Metanalysis
Response:	Physiology, population/community dynamics, activity patterns, phenology, life history traits
Mechanism:	Predation changes, disorientation/cognition, offspring number, early onset activity pattern

Summary: Across microbes, plants, invertebrates, and vertebrates, ALAN, even at extremely low levels, can cause disruptions to predation, activity, phenology, and species traits.

Key Findings: Exposure to artificial light at night induces strong responses for physiological measures, daily activity patterns and life history traits.

- 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 sea finding.
- Marked biological impacts of ALAN occur across a wide range of intensities including very low lighting levels (below 1 lx).

Citation: Dirk Sanders et al. 2020. A meta-analysis of biological impacts of artificial light at night. *Nat Ecol Evol* 5, 74–81. https://doi.org/10.1038/s41559-020-01322-x.

Title:	'Impacts of Artificial Light at Night on Biological Timings'
Year Published:	2017
Author(s):	Kevin J. Gaston et al
Subject:	Animal and Plants
Scope:	Biological timings
Design:	Review
Response:	Circadian rhythms, photoperiodism
Mechanism:	Disruption of light cycles due to illuminance, skyglow, spectrum

Summary: Different types of ALAN, including illuminance, skyglow, spectrum, can impact biological behaviors across animals and plants.

Key Findings: Impacts on biological events

- Singing
- Foraging
- Sleep
- Dark Repair and Recovery
- Growth
- Reproduction
- Migration
- Budburst and Flowering
- Leaf Loss

Citation: Kevin J. Gaston, Thomas W. Davies, Sophie L. Nedelec, Lauren A. Holt. 2017. Impacts of Artificial Light at Night on Biological Timings. *Annual Review of Ecology, Evolution, and Systematics* 48:49-68. https://doi.org/10.1146/annurev-ecolsys-110316-022745.

Title: 'Pervasiveness of Biological Impacts of Artificial Light at Night'

Author(s): Kevin J. Gaston et al

Year Published: 2021

Subject: ALAN

Design: Literature review

Summary: ALAN is likely much more pervasive globally than previously thought, with rural light, low light levels, skyglow, and long distances having indirect biological effects through movement and the combination of other anthropogenic pressures.

Key Findings: The proportion of the earth over which ALAN occurs at levels at which it is likely to have such impacts is marked.

- The global extent of ALAN is likely itself commonly underestimated, as a consequence of limitations of available remote sensing data sources and how these are processed.
- More isolated (rural) and mobile (e.g., vehicle headlight) sources of ALAN may have both very widespread and important biological influences.
- The occurrence and impacts of ALAN in marine systems and other remote settings need much greater consideration.
- There is growing evidence for important biological impacts of ALAN at low light levels, from skyglow, and over long distances (because of the altitudes from which it may be viewed by some organisms), all of which would increase the areas over which impacts are occurring.
- ALAN may exert indirect biological effects that may further expand these areas, because it has a landscape ecology (modifying movement and dispersal and so hence with effects beyond the direct extent of ALAN), and because ALAN interacts with other anthropogenic pressures on the environment.
- Finally, ALAN is not stable, but increasing rapidly in global extent, and shifting toward wavelengths of light that often have greater biological impacts.

Citation: Kevin J Gaston, Simone Ackermann, Jonathan Bennie, Daniel T C Cox, Benjamin B Phillips, Alejandro Sánchez de Miguel, Dirk Sanders. 2021. Pervasiveness of Biological

Impacts of Artificial Light at Night. *Integrative and Comparative Biology*, *Volume 61*, *Issue 3 Pages 1098–1110. https://doi.org/10.1093/icb/icab145*.

Title: 'The effects of light pollution on migratory animal behavior'

Year Published: 2022

Author(s): Carolyn S. Burt et al

Subject: Animals

Scope: Migratory animals

Design: Literature review

Response: Mortality

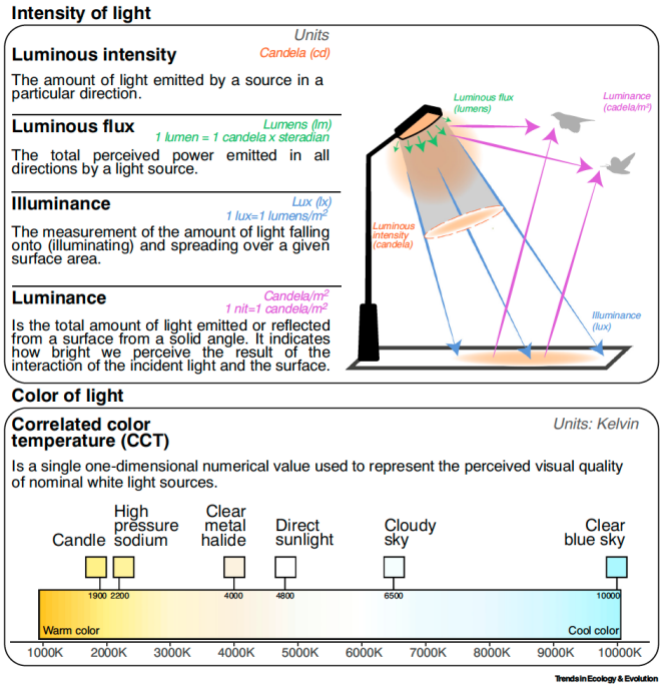
Mechanism:

- Macro scale: sky glow and potential exposure to light pollution.
- Regional scale: distribution and abundance of migrants in the air and on the ground, decreased connectivity.
- Local scale: collisions with windows and building structures.

Summary: ALAN affects migratory animals across scales, from local (collisions with lit structures) to regional (stopover site selection) to macroscale (skyglow and altered phenology).

Key Findings: Light pollution can affect nocturnal and diurnal animal migrants by disrupting their movements at various scales: at local scales through collisions with lit structures, at regional scales by altering stopover sites and the aerial connectivity of the night sky, and at macroscales through exposure to sky glow and altered phenology.

- Extinguishing and dimming lights is a first priority to reducing ecological impacts, but light can be modified when needed across multiple dimensions, including correlated color temperature or more holistic color spectra. Responses to light color and intensity are not uniform across taxonomic groups.
- In 2019, massive waves of grasshoppers (primarily Trimerotropis pallidipennis) were observed leaving vegetated areas as the sun set and taking flight in the direction of the brightest US city, Las Vegas, Nevada, USA [74]. More than 45 million grasshoppers were on the move on a single night, and city lights acted as a broad ecological trap that reshaped the regional distribution of biomass.



Citation: Carolyn S. Burt, Jeffrey F. Kelly, Grace E. Trankina, Carol L. Silva, Ali Khalighifar, Hank C. Jenkins-Smith, Andrew S. Fox, Kurt M. Fristrup, Kyle G. Horton. 2022. The effects of light pollution on migratory animal behavior. *Trends in Ecology and Evolution. https://doi.org/10.1016/j.tree.2022.12.006.*

Title: 'Light pollution prolongs avian activity'

Year Published: 2025

Author(s): Brent S. Pease, Neil A. Gilbert

Subject: Animal (birds)

Scope: 583 species

Design: Acoustic Metanalysis

Response: Activity duration

Mechanism: Light-sensitive vocal timing

Summary: ALAN prolongs vocal activity and decreases resting time in birds by 50 minutes, with potential consequences including increased foraging time and reproductive output or conversely increased physiological demand.

Methods: Used a global acoustic dataset of more than 60 million detections, representing 583 diurnal bird species, to synthesize effects of light pollution on avian vocalization.

Key Findings:

- Light pollution prolonged vocal activity by 50 min.
- Light pollution responses were strongest for species with large eyes, open nests, migratory habits, and large ranges and during the breeding season.
- Substantial breeding season effects likely arises because birds naturally vocalize earlier in the morning during the breeding season relative to the nonbreeding season, heightening exposure to light pollution.
- Prolonged activity may confer negative, neutral, or positive fitness effects
    - May represent a substantial loss of resting time, particularly during the breeding season, which is an already demanding period for birds.
    - May lead to positive fitness effects if they facilitate increased foraging time or reproductive output.

Citation: Brent S. Pease, Neil A. Gilbert. 2025. Light pollution prolongs avian activity. *Science* 389, 818-821. DOI: 10.1126/science.adv9472.

Human-ALAN interaction

Title: 'Artificial Light at Night (ALAN), a New Anthropogenic Pollutant: A Narrative Review'

Year Published: 2026

Author(s): Machnowska & Skwarlo-Sonta

Subject: Humans, plants, animals

Design: Literature review

Summary: ALAN is difficult to fight against because people generally view nighttime light as positive.

Key Findings: Public awareness of its existence is exceptionally weak, as the presence of light is usually perceived as a good thing, generating safety and beauty, and it is difficult for people to understand that excess of light may turn against us.

- Human benefits and threats of ALAN
- ALAN as pollution
- Adverse effects of LP
    - Astronomy and Night Sky Observations
    - Human Health and wellbeing: Circadian rhythm, melatonin, desynchronization

Citation: Skwarlo-Sonta, Krystyna. 2026. Artificial Light at Night (ALAN), an Anthropogenic Pollutant: A Narrative Review. Pollutants. 6. 11. 10.3390/pollutants6010011.

Title: 'Why artificial light at night should be a focus for global change research in the 21st century'

Year Published: 2017

Author(s): Thomas W. Davies & Tim Smyth

Subject: Human–environment interrelationships

Design: Literature review, opinion

Response:

- A range of intra- and interspecific interactions could be affected including foraging (e.g. seeking nectar-rich flowers), predation (ability to locate and successfully capture prey), sexual communication (ability to locate, identify and assess the fitness of conspecifics through visual displays) and camouflage (ability to avoid detection by predators).
- Nocturnal species may find themselves competing for resources with diurnal species where such interactions had previously not existed (MacGregor et al., 2014), and differences in the sensitivity of animal visual systems to white LED light spectra could change the balance of species interactions.
- Short wavelength peak: melatonin response
- Thirdly, because LEDs illuminate a broad range of wavelengths, they have the potential to affect a greater variety of biological responses that are sensitive to specific wavelengths of light.

Mechanism:

- LEDs are poised as environmentally friendly, reducing CO2 emissions, but solutions"), environmental scientists and human health experts have raised concerns about the broad-spectrum light and prominent short wavelength peak
    - The broad range of wavelengths emitted by white LEDs likely enables organisms to perform colour-guided behaviours at night that were previously only possible during the day.
- Evolutionary novelty: Organisms have evolved with large-scale fluctuations in atmospheric CO2, climate temperatures and ocean pH throughout history while sudden changes to natural light regimes are unprecedented over evolutionary time scales.

- Many organisms are extremely sensitive to natural light, utilizing light cues as dim as the moon and the Milky Way to orientate themselves, navigate landscapes and identify conspecifics and resources at night.

Summary: Broad-spectrum light with short wavelength peak such as LEDs may cause significant ecological impacts despite being touted as environmentally-friendly.

Key Findings: Growing use of night-time lighting will continue to raise numerous ecological, human health and cultural issues, but that opportunities exist to mitigate its impacts by combining novel technologies with sound scientific evidence.

- The ecological impacts of climate change — like light pollution — are therefore likely to be spatially heterogeneous for organisms with low mobility, but more widespread for taxa that depend on large-scale movements for their survival and reproduction.
    - A growing number of documented responses to white LEDs in marine systems where species are both adapted to utilize short wavelengths that penetrate deeper in seawater and are incredibly sensitive to natural light.
- While LEDs are often advocated for their potential to reduce global CO2 emissions and the ability to tailor their spectra to avoid unwanted environmental impacts, environmental scientists and human health experts have raised concerns about the broad-spectrum light and prominent short wavelength peak.

Citation: Thomas W. Davies & Tim Smyth. 2017. Why artificial light at night should be a focus for global change research in the 21st century. *Global Change Biology https://doi.org/10.1111/gcb.13927*.

Measurement of ALAN

Title: 'Ecological Aspects and Measurement of Anthropogenic Light at Night'

Year Published: 2023

Author(s): Eric Abelson, Brett Seymoure, Andreas Jechow, Elizabeth K. Perkin, Hannah Moons, Christopher C. M. Kyba, Franz Hölker, Jeremy White, Travis Longcore

Design: Narrative Review

Summary: Because light pollution is so pervasive in its ecological effects, it is imperative to measure light at night in biologically meaningful ways to understand true effects.

Key Findings: Suggest that light measurements should both match the mechanism of influence and the unique photoreceptor system of the organism being studied.

Citation: Eric Abelson, Brett Seymoure, Andreas Jechow, Elizabeth K. Perkin, Hannah Moons, Christopher C. M. Kyba, Franz Hölker, Jeremy White, Travis Longcore. 2023. Ecological Aspects and Measurement of Anthropogenic Light at Night. http://dx.doi.org/10.2139/ssrn.4353905.

Title:	'Direct measurement of the contribution of street lighting to satellite observations of nighttime light emissions from urban areas'
Year Published:	2020
Author(s):	Kyba et al.
Subject:	Light measurement
Scope:	Tucson, Arizona
Design:	Remote Sensing
Response:	Which types of lighting are responsible for current increases in ALAN, uncovering the contributions of public (e.g. streetlights) relative to private light sources (e.g. advertising, sports lighting).
Mechanism:	Fraction of the radiance detected by space is due to those sources.

Summary: Outdoor advertising is often overlooked in ALAN studies but contributes to a significant amount of light pollution.

Methods: Dim streetlights and remotely sense fraction of emissions that come from streetlights and measure the relationship between lamp lumen output and radiance detected from space.

Key Findings: 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.

- 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.

Citation: Kyba et al. 2020. Direct measurement of the contribution of street lighting to satellite observations of nighttime light emissions from urban areas. *Lighting Research and Technology*, *Volume 53*, *Issue 3*, *Pages 189 – 211*. https://doi.org/10.1177/1477153520958463.

Title: ‘Citizen Science illuminates the nature of city lights

Year Published: 2025

Author(s): Team Nachtlichter

Scope: German city centes

Design: Citizen Science

Summary: Outdoor advertising is a major contributor to light pollution compared to street lighting, despite street lighting being more commonly targeted in light pollution mitigation measures.

Methods: Citizen scientists used the Nachtlichter app to count and classify 234,044 light sources.

Key Findings: In German city centers, more total light sources are used for advertising and aesthetic purposes than for street lighting.

- In dense urban areas (that is, continuous urban fabric and industrial and commercial areas, we find that lights used for advertising outnumber streetlights
- Streetlights represent a minority of total light emissions from cities

Citation: Team Nachtlichter. Citizen science illuminates the nature of city lights. Nat Cities 2, 496–505 (2025). https://doi.org/10.1038/s44284-025-00239-5

Title: 'Aerial survey and spatial analysis of sources of light pollution in Berlin, Germany'

Year Published: 2012

Author(s): Helga U. Kuechly et al.

Subject: Light measurement

Scope: Berlin, Germany

Design: Aerial

Response: Identification of sources of light pollution

Summary: Advertising was a major source of light pollution in Berlin.

Methods: Area-independent 'brightness factor' is introduced that allows direct comparison of the light emission from differently sized land use classes, and the percentage area with values above average brightness is calculated for each class.

Key Findings: The largest source of zenith directed light comes from areas categorized as streets (31.6%), which includes direct and scattered light from lamps, automobile headlights, advertising lights located in the street area, and to some extent light from building facades.

- The areas with the next largest light emission are industrial/commercial/service and public service areas, accounting for 15.6% and 9.6% of the total light, respectively.

Citation: Helga U. Kuechly, Christopher C.M. Kyba, Thomas Ruhtz, Carsten Lindemann, Christian Wolter, Jürgen Fischer, Franz Hölker. 2012. Aerial survey and spatial analysis of sources of light pollution in Berlin, Germany. *Remote Sensing of Environment*, *Volume 126*, *Pages 39-50*, *https://doi.org/10.1016/j.rse.2012.08.008*.

Consequences of Artificial Light at Night on Humans

Title:	'A case-referent study: light at night and breast cancer risk in Georgia'
Year Published:	2013
Author(s):	Bauer, S. E., S. E. Wagner, J. Burch, R. Bayakly, and J. E. Vena.
Subject:	Humans
Scope:	34,053 BC cases and 14,458 lung cancer referents
Design:	Case-referent study using Georgia Comprehensive Cancer Registry data (2000–2007)
Response:	Examined the co-distribution of light at night (LAN) and breast cancer (BC) incidence in Georgia, with the goal to contribute to the accumulating evidence that exposure to LAN increases risk of BC.
Mechanism:	Disruption of melatonin by LAN can promote BC development.

Summary: LAN may increase breast cancer risk.

Key Findings: Positive associations between LAN and BC incidence, especially among whites.

Citation: Bauer, Sarah & Wagner, Sara & Burch, Jim & Bayakly, Rana & Vena, John. 2013. A case-referent study: Light at night and breast cancer risk in Georgia. *International journal of health geographics. 12. 23. 10.1186/1476-072X-12-23.*

Title:	'Association of the Built Environment With Childhood Psychosocial Stress'
Year Published:	2020
Author(s):	Franklin et al.
Subject:	Humans
Scope:	2290 Southern California Children's Health Study participants residing in 8 densely populated urban communities.
Design:	Survey
Response:	Investigate associations between components of the built environment with personal and home characteristics in a large cohort of children who were assessed for perceived stress.
Mechanism:	The mechanism by which LAN acts on stress is likely through the hypothalamus-pituitary-adrenal axis, which is important to the physiologic regulatory system.

Summary: LAN may increase stress in children through the hypothalamus-pituitary-adrenal axis.

Key Findings: Children's exposure to smoke at home in addition to residential exposure to ALAN and near-roadway air pollution were associated with increased perceived stress among young adolescent children. These associations appeared to be partially mitigated by more residential green space. The findings may support the promotion of increased residential green spaces to reduce pollution associated with the built environment, with possible mental health benefits for children.

Citation: Franklin, M., X. Yin, R. McConnell, and S. Fruin. 2020. Association of the Built Environment With Childhood Psychosocial Stress. *JAMA network open 3:e2017634-e2017634*.

Title: 'Association Between Outdoor Light-at-night Exposure and Colorectal Cancer in Spain'

Year Published: 2020

Author(s): Garcia-Saenz et al.

Subject: Humans

Scope: 661 incident histologically verified colorectal cancer cases and 1,322 controls from Barcelona and Madrid, 2007–2013

Design: Odds ratio

Response: Association between exposure to ALAN according to light spectrum and colorectal cancer among Subjects who had never worked at night.

Mechanism: Circadian disruption may be associated with an increased risk of colorectal cancer.

Summary: Exposure to blue light may cause increases in colorectal cancer incidence.

Key Findings: Exposure to blue light spectrum was positively associated with colorectal cancer.

Citation: Garcia-Saenz, A., A. S. de Miguel, A. Espinosa, L. Costas, N. Aragonés, C. Tonne, V. Moreno, B. Pérez-Gómez, A. Valentin, and M. Pollán. 2020. Association between outdoor light-at-night exposure and colorectal cancer in Spain. *Epidemiology 31:718-727*.

Title:	'The relationship between obesity and exposure to light at night: cross-sectional analyses of over 100,000 women in the Breakthrough Generations Study.'
Year Published:	2014
Author(s):	McFadden et al
Subject:	Humans
Scope:	100,000 women in the Breakthrough Generations Study, a cohort study of women aged 16 years or older who were living in the United Kingdom and recruited during 2003–2012
Design:	Multinomial logistic regression

Summary: LAN led to increased obesity rates.

Key Findings: The odds of obesity, measured using body mass index, waist:hip ratio, waist:height ratio, and waist circumference, increased with increasing levels of LAN exposure ($P < 0.001$), even after adjustment for potential confounders such as sleep duration, alcohol intake, physical activity, and current smoking.

Citation: McFadden, E., M. E. Jones, M. J. Schoemaker, A. Ashworth, and A. J. Swerdlow. 2014. The relationship between obesity and exposure to light at night: cross-sectional analyses of over 100,000 women in the Breakthrough Generations Study. *Am J Epidemiol 180:245-250.*

Title:	'Exposure to light at night and risk of depression in the elderly'
Year Published:	2013
Author(s):	Obayashi et al.
Subject:	Humans
Scope:	516 elderly individuals (mean age, 72.8).
Response:	Nighttime light exposure is a powerful suppressor of melatonin secretion through activation of the SCN of the hypothalamus; therefore, melatonin is hypothesized to be one of the major contributors to the association between LAN exposure and mood impairments.
Mechanism:	LAN exposure is associated with circadian misalignment. • Completely understood, possible mechanisms are suggested by data regarding circadian phase delay and impaired sleep quality.

Summary: LAN exposure in home settings is associated with depression in elderly people.

Methods: We measured the intensities of nighttime bedroom light and ambulatory daytime light along with overnight urinary melatonin excretion (UME) Depressive symptoms were assessed using the Geriatric Depression Scale.

Key Findings: LAN exposure in home settings is significantly associated with depressive symptoms in the general elderly population.

Citation: Obayashi, K., K. Saeki, J. Iwamoto, Y. Ikada, and N. Kurumatani. 2013. Exposure to light at night and risk of depression in the elderly. *J Affect Disord 151:331-336.*

Title:	'Association between light exposure at night and insomnia in the general elderly population: The HEIJO-KYO cohort'
Year Published:	2015
Author(s):	Obayashi et al.
Subject:	Humans
Scope:	857 elderly individuals (mean age, 72.2 years).
Design:	Cross-sectional community-based study
Response:	Insomnia
Mechanism:	Chronic circadian misalignment between the internal and environmental rhythms, which is typically related to night-shift work and clock-gene variants, is associated with disruption of suprachiasmatic nucleus function and increased risk of insomnia.

Summary: ALAN exposure in the home leads to decreased sleep quality in elderly people.

Key Findings: ALAN exposure in home settings is significantly associated with both subjectively and objectively measured sleep quality in a community-based elderly population.

Citation: Obayashi, K., K. Saeki, and N. Kurumatani. 2014. Association between light exposure at night and insomnia in the general elderly population: the HEIJO-KYO cohort. *Chronobiol Int 31:976-982.*

Title:	'Association of outdoor artificial light at night with mental disorders and sleep patterns among US adolescents'
Year Published:	2020
Author(s):	Paksarian et al.
Subject:	Humans
Scope:	10 123 adolescents
Design:	Cross-sectional, nationally representative survey
Response:	Mood and anxiety disorders
Mechanism:	Sleep regulation

Summary: ALAN led to later bedtimes and increased mood and anxiety disorders in adolescents.

Key Findings: Higher levels of outdoor artificial light at night, were associated with later weeknight bedtimes; those in the lowest quartile of nighttime light reported the longest weeknight sleep durations. Adolescents in areas with greater levels of nighttime light also had higher prevalence of past-year mood and anxiety disorders.

Citation: Paksarian, D., K. E. Rudolph, E. K. Stapp, G. P. Dunster, J. He, D. Mennitt, S. Hattar, J. A. Casey, P. James, and K. R. Merikangas. 2020. Association of outdoor artificial light at night with mental disorders and sleep patterns among US adolescents. *Jama Psychiatry 77:1266-1275*.

Title: 'High sensitivity and interindividual variability in the response of the human circadian system to evening light'

Year Published: 2019

Author(s): Phillips et al

Subject: Humans

Scope: Fifty-five participants (aged 18–30)

Design: Characterized individual-level dose–response curves to light-induced melatonin suppression using a within subjects protocol.

Response: Circadian disruption

Mechanism: Melatonin suppression

Summary: ALAN has variable effects on circadian rhythm across individuals, implying different health outcomes.

Key Findings: Same evening-light environment is registered by the circadian system very differently between individuals. This interindividual variability may be an important factor for determining the circadian clock's role in human health and disease.

- Interindividual differences in light sensitivity may explain differential vulnerability to circadian disruption and subsequent impact on human health.

Citation: Phillips, A. J. K., P. Vidafar, A. C. Burns, E. M. McGlashan, C. Anderson, S. M. W. Rajaratnam, S. W. Lockley, and S. W. Cain. 2019. High sensitivity and interindividual variability in the response of the human circadian system to evening light. *Proceedings of the National Academy of Sciences 116:12019–12024.*

Title:	'Outdoor light at night and autism spectrum disorder in Shanghai, China: A matched case-control study'
Year Published:	2022
Author(s):	Xie et al
Subject:	Humans
Scope:	Children aged 3–12 years in Shanghai, China
Design:	Multi-stage sampling survey on ASD conducted between June 2014 and October 2014
Response:	Autism
Mechanism:	Melatonin suppression and circadian rhythm disruption

Summary: Brighter LAN exposures after and before birth were results in a higher risk of ASD.

Key Findings: Brighter LAN exposures after and before birth were significantly associated with higher risk of ASD.

Citation: Xie, Y., Z. Jin, H. Huang, S. Li, G. Dong, Y. Liu, G. Chen, and Y. Guo. 2022. Outdoor light at night and autism spectrum disorder in Shanghai, China: A matched case-control study. *Science of the Total Environment 811:152340*.

Title:	'Associations Between Artificial Light at Night and Risk for Thyroid Cancer: A Large US Cohort Study'
Year Published:	2021
Author(s):	Zhang et al
Subject:	Humans
Scope:	464,371 participants
Design:	Satellite data, Cox regression
Response:	Thyroid Cancer
Mechanism:	Melatonin suppression and circadian rhythm disruption

Summary: LAN may increase thyroid cancer risk.

Key Findings: LAN was positively associated with thyroid cancer risk. Future studies are needed to confirm this association and identify underlying biological mechanisms.

Citation: Zhang D, Jones RR, James P, Kitahara CM, Xiao Q. 2021. Associations Between Artificial Light at Night and Risk for Thyroid Cancer: A Large US Cohort Study. *Cancer*. 2021. https://doi.org/10.1002/cncr.33392.

Title: 'Outdoor Nighttime Light Exposure (light pollution) is associated with Alzheimer's Disease.'

Year Published: 2024

Author(s): Voigt, Ouyang, & Keshavarzian

Subject: Humans

Scope: Alzheimer's disease (AD) prevalence

Design: Satellite acquired outdoor nighttime light intensity and Medicare data.

Response: Evaluated the relationship between outdoor nighttime light exposure and AD prevalence in the United States

Mechanism: Faster cognitive decline

Summary: Higher outdoor nighttime light may lead to Alzheimer's Disease.

Key Findings: Higher outdoor nighttime light was associated with higher prevalence of AD

- Nighttime light was more strongly associated with AD prevalence than alcohol abuse, chronic kidney disease, depression, heart failure, and obesity.
- Startlingly, nighttime light exposure more strongly associated with AD prevalence in those under the age of 65 than any other disease factor examined.

Citation: Voigt, R. M., Ouyang, B., & Keshavarzian, A. (2024). Outdoor Nighttime Light Exposure (light pollution) is associated with alzheimer's disease. *Frontiers in Neuroscience*, *18*. *https://doi.org/10.3389/fnins.2024.1378498*.

Title:	'Exposure to artificial light at night: A common link for obesity and cancer?'
Year Published:	2022
Author(s):	Muscogiuri et al.
Subject:	Humans
Design:	Literature review
Response:	Summarizes human and basic studies pointing out the impact of ALAN exposure on health, mostly focusing on obesity and cancer.
Mechanism:	Among several multifactorial Mechanisms linking ALAN exposure and health risks, suppression of melatonin secretion plays a pivotal role leading to alterations in circadian rhythm patterns, that are detrimental in terms of appetite regulation, and dysfunctions in metabolic signaling and cell growth in cancer. In addition, gut dysbiosis, inflammation, hypovitaminosis D, imbalance in cytokine secretion and levels are responsible for the multiple relationship linking circadian dysregulation due to ALAN exposure and obesity, and cancer.

Summary: ALAN may may increase cancer and obesity rates due to a variety of mechanisms including melatonin secretion and disruption of circadian rhythm.

Key Findings: Impact of ALAN exposure on health, mostly focusing on obesity and cancer.

Citation: Muscogiuri et al. 2022. Exposure to artificial light at night: A common link for obesity and cancer? *European Journal of Cancer*, *Volume 173*, *Pages 263-275*. *https://doi.org/10.1016/j.ejca.2022.06.007*.

Title:	'Interaction of daytime and nighttime light exposure on objective sleep quality in patients with bipolar disorder: a cross-sectional analysis of the APPLE cohort'
Year Published:	2025
Author(s):	Esaki et al
Subject:	Humans
Scope:	Ambulatory individuals with bipolar disorder
Design:	Daytime illuminance and sleep were assessed using actigraphy over a seven-day period. In addition, a portable light meter was used to evaluate the illuminance levels in the bedroom during nighttime.
Response:	Sleep quality in bipolar patients
Mechanism:	Circadian rhythm

Summary: ALAN increases sleep disturbances in people with bipolar disorder, possibly exasperating symptoms.

Key Findings: Evening/nighttime indoor light intensities (from artificial light sources and light-emitting screens) are high relative to outdoor light at night, potentially leading to sleep disturbances.

Citation: Esaki et al. 2025. Interaction of daytime and nighttime light exposure on objective sleep quality in patients with bipolar disorder: a cross-sectional analysis of the APPLE cohort. *Transl Psychiatry* 15, 291 (2025). https://doi.org/10.1038/s41398-025-03549-3.

Title: 'Impact of artificial light at night and night shift work on brain functions and metabolism'

Year Published: 2025

Author(s): Korf et al.

Subject: Humans

Design: Narrative Review

Response: Brain function, metabolism

Mechanism: Endocrine systems (glucocorticoids, melatonin)

Summary: ALAN may disrupt critical brain and endocrine systems leadings to sleep disorders, cancer, cardiovascular disease, type 2 diabetes, obesity, and depression.

Key Findings:

- Proinflammatory responses in the brain which may make it more vulnerable to additional aversive stimuli.
- Acute continuous light impairs cognitive function and synaptic plasticity and leads to an increase in corticosterone, a stress hormone and an important mediator in the circadian system.
- Increased risk for sleep disorders, cancer, cardiovascular disease, type 2 diabetes, obesity, and depression.

Citation: Horst-Werner Korf, Nora Bittner, Svenja Caspers, Charlotte von Gall. 2025. Impact of artificial light at night and night shift work on brain functions and metabolism. *General and Comparative Endocrinology*, *Volume 373*, *114822*, *https://doi.org/10.1016/j.ygcen.2025.114822*.

Title: 'Artificial Light at Night (ALAN): A Potential Anthropogenic Component for the COVID-19 and HCoVs Outbreak'

Year Published: 2020

Author(s): Ahmad Khan et al

Subject: Humans, bats

Scope: COVID-19 Pandemic

Design: Review

Response: Human impairment, bat behavior

Mechanism:

- 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.

Summary: ALAN may lead to viral mutations in bats, possibly contributing to the COVID-19 pandemic.

Citation: Ahmad Khan et al. 2020. Artificial Light at Night (ALAN): A Potential Anthropogenic component for the COVID-19 and Human Corna Virus Outbreak. *Frontiers in Endocrinology* DOI: 10.3389/fendo.2020.00622.

Title:	'Light pollution: the possible consequences of excessive illumination on retina'
Year Published:	2016
Author(s):	Contín et al
Subject:	Humans
Scope:	Retinal disease
Design:	Narrative review
Response:	Photochemical damage of the retina, Bright light retinal damage, oxidative stress, circadian rhythm disruption
Mechanism:	Retina is adapted to capturing light photons and transmitting this information to other structures in the central nervous system. In mammals, light acts directly on the retina to fulfill two important roles: (1) the visual function through rod and cone photoreceptor cells and (2) non-image forming tasks, such as the synchronization of circadian rhythms to a 24 h solar cycle, pineal melatonin suppression and pupil light reflexes.

Summary: LED and prolonged ALAN exposure may cause eye diseases.

Key Findings: Excess of illumination may cause retinal degeneration or accelerate genetic retinal diseases.

- Cones, rods, retinal pigment epithelium, and intrinsically photosensitive retinal ganglion cells could be affected by high or prolonged light exposure induced by habits of modern life.
- Cumulative effects, long exposure by absence of profound experiences of dark during the night and high irradiance exposure by LED technology may affect the retinal physiology promoting cell death and the consequent blindness and desynchrony.

Citation: Contín, M., Benedetto, M., Quinteros-Quintana, M. *et al.* 2016. Light pollution: the possible consequences of excessive illumination on retina. *Eye* 30, 255–263. https://doi.org/10.1038/eye.2015.221

Title: 'Analysis of Exposure to ALAN (Artificial Light at Night) in the Urban Space of Madrid and Toledo (Spain) and Its Impact on Human Circadian Rhythms: "Circadian Neurolighting"'

Year Published: 2025

Author(s): Martinez & Lopez

Subject: Humans

Scope: Toledo (small, protected city with low urban lighting) and Madrid (high light, LED exposure)

Design: Comparative light measurements, surveys

Response: Circadian rhythm disruption

Mechanism: High emission of short-wavelength light produced by LED screens

Summary: LED exposure must be avoided in humans to avoid cortisol and circadian rhythm changes.

Key Findings: Humans must avoid unnecessary short-wavelength radiation that triggers increases in cortisol level.

- Important to consider not only lux levels when planning a lighting design but also the wavelength spectrum as well, as this can have a major impact on triggering cortisol levels, which are disruptors in our bodies at night.
- Additionally, a way to reduce short wavelength missions from LED screens is to position them at an appropriate distance from the observer in order to enable the dissipation of the short-wavelength light.

Citation: Martinez & Lopez. 2025. Analysis of Exposure to ALAN (Artificial Light at Night) in the Urban Space of Madrid and Toledo (Spain) and Its Impact on Human Circadian Rhythms: "Circadian Neurolighting". DOI: 10.20944/preprints202505.0089.v1.

Title: 'Artificial light at night and risk of mental disorders: A systematic review'

Year Published: 2022

Author(s): Tancredi et al

Subject: Humans

Scope: Nine eligible studies that assessed the link between indoor or outdoor artificial light at night and one or more mental disorders in human populations

Design: Literature review

Response: Depression

Mechanism: Disruption of circadian rhythm

Summary: LAN may lead to increased rates of depression.

Key Findings: Epidemiological evidence produced so far seems to support an association between LAN and risk of depressive disorders.

Citation: Stefano Tancredi, Teresa Urbano, Marco Vinceti, Tommaso Filippini. 2022. Artificial light at night and risk of mental disorders: A systematic review. *Science of The Total Environment*, *Volume 833*, *155185*, *https://doi.org/10.1016/j.scitotenv.2022.155185*.