



No Creature Comfort

Artificial light at night robs us of more than the stars.



Give a lot of talks about light pollution and its effects on things other than our view of the stars. Everyone working in light pollution generally has a story about dark skies and being inspired by the aurora borealis (or australis) or a first view of the Milky Way. The threat of light pollution to that experience is easy to explain, visceral.

But many people have never experienced the Milky Way firsthand. Those billions of people growing up in cities around the world, often without the personal capital to travel outside the surrounding glow, have no experience with, let alone connection to, the night sky.

One of the ways in which I try to connect with such urban audiences is to talk about the effects of light pollution on things more familiar to them. These include human health — everyone has experience with sleep disrupted by lights, sooner or later — and wildlife that they may know and care about.

It should come as no surprise that anthropogenic light at night (that is, light from human sources) affects living organisms. And yet, it *does* surprise people. It also surprises them that many creatures in the marvelous landscapes surrounding us are falling prey to the effects of nighttime lighting, and that they themselves may suffer the medical consequences of long-term exposure.

For all of evolutionary history, the major patterns of light and dark were defined by Earth's rotation, the Moon reflecting the Sun's light back at us, and the stars and other glowing phenomena of the sky. Daily, monthly, and seasonal patterns were so predictable that they became the metaphor for predictability — like clockwork.

As a result of this predictability, many events in life are

◀ **CAPTIVATED** Thousands of moths swarm around floodlights at the Newcastle United Jets home game at EnergyAustralia Stadium (today, McDonald Jones Stadium) in Newcastle, Australia, on October 1, 2005.

tied to light levels. Birds begin their dawn song when the light levels increase to a certain point. Gerbils come out to search for food when moonlight is low and darkness provides a refuge. Moth-pollinated flowers open as dusk falls. Some plants set seed as daytime shortens. Humans (usually) sleep at night. All of these rhythms are tied to light levels that had billions of years of predictability.

In nature, whenever there are predictably variable resources available in an environment, species will evolve to specialize and divide up those resources. Some birds specialize in looking for food in the highest branches of trees, some in the lowest branches, some on the ground, and some wherever they can (this last group is known as *generalists*). Over the long arc of the history of life on this planet, species have evolved to exploit all the different conditions of darkness — and, in doing so, have come to rely on those conditions for their survival. The darkest nights of the month, the *crepuscular* period between night at day, and the full Sun of noon are all unique conditions to which species have adapted. The generalists may be able to persevere if part of that natural variation is curtailed, but the specialists will not. So it is that light pollution, through simplifying the physical environment and eliminating certain conditions, threatens some species' persistence.

In any given system, although generalists may be numerous in terms of individuals, the number of specialist species can be equal or greater. A world without the species that need the natural patterns of light and darkness would be depauperate indeed.

The effects of light at night on the natural world fall into three main categories: 1) movement, including attraction, disorientation, and resulting fragmentation; 2) disruption of ecologi-



MOTHS AT NIGHT LIGHT: FAIRFAX MEDIA / GETTY IMAGES; MOTH ILLUSTRATIONS: ARTOPHOTODESIGN STUDIO / SHUTTERSTOCK.COM; SEA TURTLE ILLUSTRATION: TANVIR AHMED SIDDIQUE / SHUTTERSTOCK.COM

cal interactions between species; and 3) disruption of those daily, lunar, and seasonal rhythms, which also encompasses the effects light at night has on humans.

Movement and Its Consequences

Influences on animal movement are some of the most well-known effects of light at night, because they can leave dead bodies on the ground. Sea turtles are one familiar example. Female sea turtles normally lay their eggs in nests they excavate on sandy beaches. Once the baby turtles hatch, they emerge from the nest and head for the ocean. Before the advent of electric lighting, the hatchlings simply crawled away from the darkest horizon — which was always the landward dune and vegetation — to find the water.

Coastal and offshore development and lighting have altered these patterns. Lights disorient and misorient the hatchlings, so that they are much less likely to reach the ocean. Recent studies have shown that even skyglow (scattered light in the atmosphere from artificial lighting) can be bright enough to confuse hatchling turtles. Female turtles will also not lay on beaches that are brightly lit, reducing the area of habitat available to them.

Although some jurisdictions have enacted lighting limitations to protect nesting sea turtles, there remain many tropical beaches around the world where anthropogenic lights threaten these animals.

Other creatures also go toward the light. Many groups of insect species are attracted to lights, so much so that their behavior has been woven into the imagery of language (“like a moth to a flame”). Insects are essential to the functioning of the natural world — think pollination and decomposition

Outdoor light that penetrates into bedrooms in a major city can be more than double that of a full Moon — within the same order of magnitude as the melatonin suppression threshold.

— but are in global decline. Some locations have seen upwards of 75% fewer insects in the last three decades, leading to fears of an “insect apocalypse.” We suspect light pollution is one of the causes, because lights can draw insects significant distances away from their natural habitats and into areas dangerous for them.

Some insect species flee light instead, while others simply become quiet and do not move at a time when they would normally be active. The degree of such effects is often related to the contrast between the light and the ambient conditions, such that even a dim light in an environment with little light pollution is highly attractive to insects.

Birds, too, are attracted to light, through mechanisms that researchers have not yet fully been able to explain. People have used fire and lights to hunt birds for centuries, and great masses of birds have been recorded at light sources such as lighthouses, lightships, communication towers, buildings, ceilometers (beams of light directed at the sky to measure cloud height), and light displays erected for aesthetic purposes. The annual 9/11 Tribute in Light in New York, for instance, draws around 160,000 birds to its beams in a single night. Very often the species attracted by lights are normally



WILDFLOWERS: NIKIFORONAK / SHUTTERSTOCK.COM; STATIS: SOURCE: C. A. HALLEMAN ET AL. / PLOS ONE 2017

active during the daytime but migrate at night. These birds may die when they collide with lit structures, especially glass windows as day breaks.

Research with weather radar, which is sensitive enough to detect individual birds, has shown that birds are indeed attracted to lighted areas from even kilometer-scale distances and that anthropogenic light influences the distribution of birds across the landscape during their migration. In these cases, the birds aren't choosing their stopover habitats because the locations are the highest quality but because they're lured by lights. As a consequence, migrating birds are exposed to the excess dangers associated with urban conditions.

A major consequence of animals changing their movement patterns in response to lights can be the fragmentation of landscapes into smaller pieces. Lights themselves can create a barrier to movement, acting alone or in concert with other features such as roads. In aquatic environments, for example, bridge lights can prevent young salmon from migrating downstream, even without a physical barrier in their way. Young salmon naturally move during darkness, and when under lights they will hunker down like it's daytime. Some species of bats commuting from their roosts will avoid lighted areas and consequently must fly around them. Researchers think these behaviors are attempts to avoid being seen by predators.

In other instances, nocturnally active species avoid lights to reduce contact with humans. Several studies show that mountain lions keep to the darkest parts of the landscapes they are in and will avoid areas with lights. For this reason, controlling lights and creating dark pathways of approach is important for the design of wildlife-crossing structures for roadways.

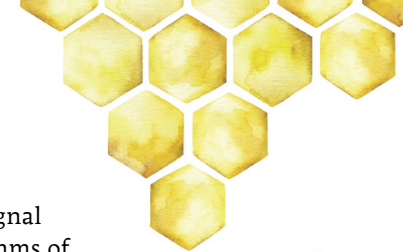
Physiology: A Matter of Timing

Artificial light also serves as a signal that affects the timing and rhythms of organisms, resulting in a wide number of physiological and behavioral changes. It is here where research on human health and on other species overlaps.

Nearly every organism that lives on Earth's surface (as opposed to in the abyss of the ocean or deep in caves) has intrinsic daily rhythms that are kept synchronized by light. Exposure to light at night, even at relatively low levels, can upset those rhythms. Researchers have extensively investigated this for humans, often using mice as a model organism. Exposure to light at night has been associated with a whole suite of diseases, most notably breast, prostate, and several other cancers, as well as diabetes, obesity, sleep disorders, depression, and stress.

For breast cancer, researchers think nighttime light exposure prompts disease by suppressing the production of the hormone melatonin. Melatonin serves many roles in regulating systems in the body, suppresses cancerous growth, and is produced only in the dark. Large studies consistently connect outdoor nighttime lighting levels measured by satellites with

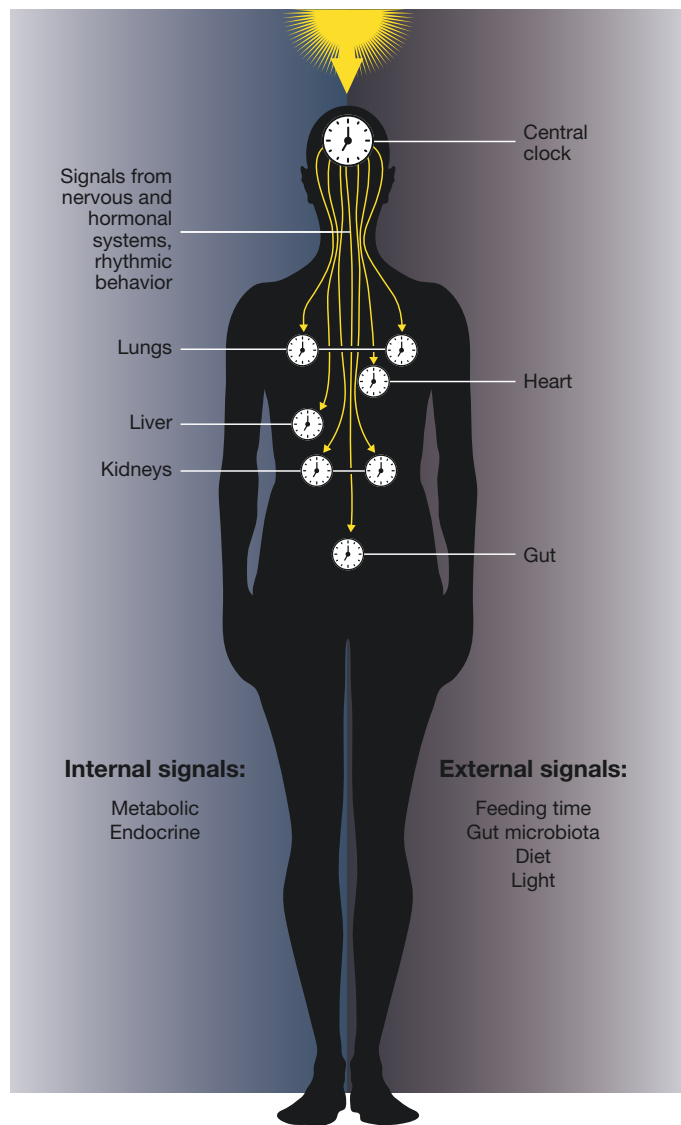
▼ **SOYBEANS** This drone photo of a soybean field in Fairview, Alabama, shows how the crop's behavior changes when exposed to artificial light at night. Under normal conditions, the soybeans mature, die, and dry out (brown areas), after which they're harvested. But near the streetlight, the plants stay green. Note the long brown strip inside the green area: This is where the pole's shadow blocked light from reaching the plants, enabling them to mature naturally.



elevated rates of breast cancer. Of course, much of the light that humans are exposed to at night is self-directed (indoor lighting, devices, computers, televisions), but outdoor lighting is still highly correlated with risk.

My own preliminary research with my students indicates that outdoor light that penetrates into bedrooms in a major city can be more than double that of a full Moon — within the same order of magnitude as the melatonin suppression threshold (about 5 lux, similar to civil twilight). Individuals vary enormously in their sensitivity to light at night, though, with some people being up to 50 times more sensitive than others.

The association between increased outdoor light and sleep disruption is quite strong. In a recent study, my colleagues



▲ **CIRCADIAN RHYTHM** Light exposure sets the master clock in the brain. The brain in turn sets clocks in various organs via nervous and hormonal signals. External and internal factors influence these peripheral clocks, too: Internal signals include metabolic and endocrine sources (such as body temperature and hormones), and external signals include light, feeding time, gut microbiota, and diet composition.

and I showed that light at night is a significant influence even when considering other stressors like noise, air pollution, and lack of green space. Sleep disruption is associated with cardiovascular disease, diabetes, and cancer. But because our study was based on survey results, we could not conclusively tie the effects to melatonin suppression.

Wildlife species can be up to 1,000 times more sensitive to melatonin suppression by light than humans, so they must be experiencing the adverse effects of light at night in their most basic inner workings. Birds are one example.

Lights, as a signal of seasonal timing, induce birds to lay eggs. This was noted first in London in the 1920s, where starlings were ready to breed earlier when they lived close to streetlights. Poultry growers harnessed this technique, stimulating decades of research on the timing and types of light to maximize not only egg production but growth for human consumption. To this day, the industry uses lights to keep the billions of hens around the world laying as desired.

Even plants react to artificial lighting. Under normal circumstances, soybeans set seed when the number of daylight hours dwindles. Once they set seed, they die and can be harvested. But under streetlights and in fields affected by lights, soybeans never set seed — they don't know that summer has ended, because the artificial lights make it seem as though the daylight levels remain the same.

Humans also can exhibit seasonal and monthly patterns in response to the light environment. At high latitudes, humans show a seasonal pattern of melatonin production, with more produced during the winter and less during the summer. Urban residents, however, who are exposed to more artificial light at night, do not show this pattern. Recently, researchers have also shown that human sleep in the absence of electric light shows a monthly pattern that tracks the illumination from the Moon. A similar but smaller lunar influence was found in the sleep patterns of a nearby village that did have electric lights, and it was still detectable in college students in a highly urbanized North American city. Whether the lunar patterns' weakening results from illumination in the urban environment remains to be proven, but the patterns' presence indicates how much human sleep is influenced by the environment.

Spectrum Matters

The effects of light pollution are amplified or reduced by the light's color. Outdoor lighting often involves broad-spectrum white lights, which emit a wide range of wavelengths. This light triggers both humans' daytime (color) and nighttime (monochromatic) vision. But other species form images using light at wavelengths outside the sensitivity of human vision. Many non-human species, including some insects, spiders, birds, reptiles, amphibians, and mammal species, see very short wavelengths in the ultraviolet range, while humans generally do not because we filter these wavelengths out in our corneas. Insects in particular are attracted to ultraviolet light, making them vulnerable to lamps that emit in this range.



116 minutes
Time before civil dawn when robins began singing in a light-polluted town

48 minutes
Time before civil dawn when robins began singing in a rural area

9 minutes
Time before civil dawn when robins began singing in a dark-sky area

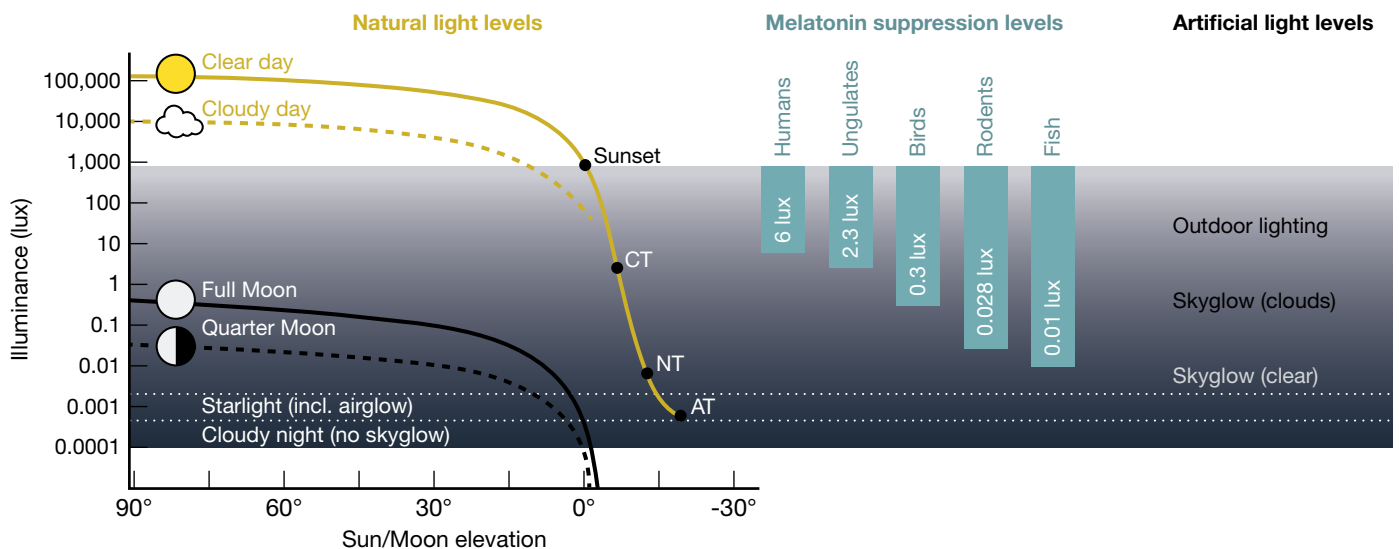
I recently compiled and digitized visual sensitivity information for a wide array of terrestrial wildlife species, pulling from published studies dating from the middle of the 20th century to today. I was looking for similarities in the degree to which different groups of animals respond to different light colors, to find out which areas of the spectrum we should avoid. It was not a new idea: Estimates of the degree to which moths are attracted to short (ultraviolet, violet, and blue) and long (red and yellow) wavelengths have been around since the 1960s, and several research groups have suggested using color to mitigate the ecological and health effects of light pollution.

After compiling results from 175 measurements scattered across nearly as many studies, I found considerable variation. But on average, the light sensitivity of terrestrial species' eyes follows a double-peaked wave: We have one peak of sensitivity to ultraviolet light, relatively high sensitivity to blue, another peak in response to green light, declining sensitivity to yellow, and then lowest sensitivity to red. Importantly, the peak sensitivity of human color vision is offset to longer wavelengths from the peak sensitivity of most other species, suggesting that the use of lights that are yellow and red instead

of white could provide visibility for humans while reducing their apparency to other species.

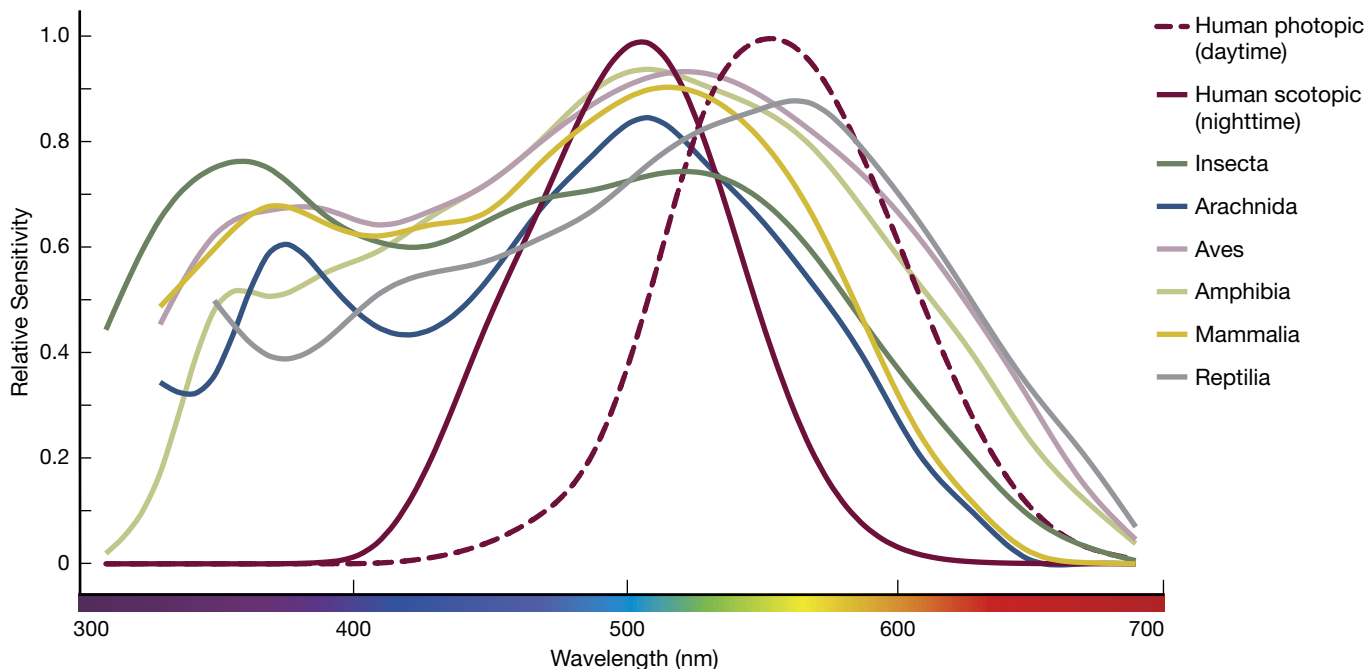
The lower effect of amber and red will come as no surprise to amateur and professional astronomers, who have long relied on red-hued lights to preserve their night vision. But the benefits go far beyond detecting faint fuzzies in telescopes. Light that is more visible to a given species should have a larger impact on behaviors that arise from its visual perception. With this new database, I could calculate the likely effect of lights with different color compositions for groups of organisms — birds, mammals, amphibians, reptiles, insects, and spiders. To do this, I used a technique my colleagues and I had previously developed to compare the light from different real-world sources based on their *correlated color temperature* (CCT), which describes the proportions of different wavelengths in the light.

Those calculations predicted greater effects for lights at higher color temperatures (bluer) and lower effects for lower color temperatures (more yellow and red). The predicted effect was more pronounced for some groups (mammals, insects, spiders) than for others, but it held true across all groups. For example, light-loving insects tend to be more



▲ **LIGHT AND MELATONIN** Natural light levels change throughout the day and month (left). When light levels rise to a certain threshold, animals stop producing the key hormone melatonin (center, minimum light levels shown). But typical artificial light at night (right) can exceed these thresholds. Human sensitivity to light varies widely — on average, 25 lux will suppress melatonin production by 50%, but some people are sensitive to much less, while others can handle 10 times more. CT = civil twilight, NT = nautical twilight, and AT = astronomical twilight.

ROBIN: MIS VECTOR / SHUTTERSTOCK.COM; STATS: SOURCE: M. W. MILLER / THE CONDOR 2006; MELATONIN GRAPH: BEATRIZ INGLESISSIS / S&T; SOURCE: M. GRUBISIC ET AL. / SUSTAINABILITY 2019; A. J. K. PHILLIPS ET AL. / PNAS 2019



▲ **SEEING THE LIGHT** Each class in the animal kingdom (six shown here) reacts in its own way to different wavelengths, although there are a lot of similarities. These average sensitivities have a similar peak to those of humans' day and night vision, but we are far less sensitive to short wavelengths than other animals are.

attracted to shorter wavelengths, and horses and related species shouldn't be disturbed by red light at night because it's at the edge of what they can see. This would also apply to most insect groups and some species of rodents, as well as bats.

The prospect of using color to reduce lights' impacts comes with some conspicuous exceptions and challenges. Bioluminescent species such as fireflies are often sensitive to the very yellow to amber wavelengths that are less harmful to other species. For these groups, which communicate using light, it is far better to avoid exposing them to stray light altogether. The other challenge is that some species are sensitive to light no matter where it is on the spectrum, so spectrum is not a "get out of jail free" card that allows indiscriminate use of light without adverse effects.

My work looked at color vision, which uses photoreceptors called cones; we also have rods, for dim light. But our eyes, as well as those of other species, also have daylight detectors that set our circadian rhythms yet don't contribute to vision. These photoreceptors are most sensitive to blue light, very close to the color of the blue sky, because before artificial light we only encountered bright bluish light during the day. The deleterious effect on our internal clocks — which govern our sleep patterns — gives another reason to avoid blue light at night.

Takeaways

We can conclude a few things from the research covered here. To minimize the impact on wildlife, plants, and even ourselves, we need to control both light levels and light colors in nighttime environments. We should avoid shorter wave-

lengths (ultraviolet through blue) in favor of yellow and red, to enable us to see at night while reducing adverse effects on other species.

But the best solution is to reduce light overall and direct it only where it is needed, when it is needed. From a technical perspective, this means shielding lights to make them "full cut-off," so that no light escapes upward, and directed, so that light falls on its target and not in nearby habitats.

For color, I recommend lights with a CCT less than 2200K, which looks like warm candlelight. Such lights are increasingly available from manufacturers who recognize the growing market potential, as awareness of the impacts of light pollution grows.

Once the harms of disrupting darkness are explained, people tend to intuitively understand them and are open to supporting better lighting. When I give presentations, I hear stories about sleep lost from a neighbor's light and hear wonder at the nuanced patterns of activity in response to light at night. Some places we should not light at all, but great strides could be made by simply lighting better — in a way that is less wasteful and aware of the natural rhythms of life on Earth.

■ **TRAVIS LONGCORE** is an adjunct professor at the UCLA Institute of the Environment and Sustainability and co-chair of the Environmental Science and Engineering (D.Env.) Program.

FURTHER READING: Catherine Rich and Travis Longcore, eds. *Ecological Consequences of Artificial Night Lighting*. Island Press. 2006.

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Los Angeles, California
LD 1934

I grew up in Orono, Maine and am now an adjunct professor in the Institute of the Environment and Sustainability at UCLA. I write to support LD 1934 introduced by Rep. Osher. The dark skies and northern lights of Maine were a formative part of my childhood, and I have dedicated a large part of my professional work to investigating and mitigating the adverse impacts of inappropriate lighting on species, habitats, and human health. As background please see the attached article I wrote for Sky and Telescope on these issues. If work session meeting times align with my schedule, I would be available to answer technical questions that may arise regarding the impacts of light pollution, the importance of darkness to the environment, and the many effective mitigation approaches available to protect and restore night skies.

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