Kim Taylor/naturepl.com

In an artist's composite, a brown long-eared bat (*Plecotus auritus*) hunts for insects attracted to an outdoor lamp. Bat species that forage near streetlights may be displacing those that don't.

night, INTERRUPTED

BY MARY-RUSSELL ROBERSON

Humans thrive in light. We move about during the day and sleep at night, third-shift workers and newborns notwithstanding. Sunshine helps us see, produce vitamin D, and regulate our sleeping patterns and moods. In the immortal words of John Denver, sunshine on our shoulders makes us happy.

When the sun goes down, we retreat into buildings flooded with artificial light. To ease nighttime travel and keep shadows at bay, we light our streets and yards as well. A few hours later, we turn off the bedside lights to sleep the rest of the night away.

From our diurnal point of view, nighttime is no time, a time for non-doing. We forget that for many of the world's creatures, nighttime is when the action happens. Fireflies signal to each other at dusk. Owls wake up to hunt. Frogs begin their chorus. Bats leave their roosts. Felines go on the prowl. Animals that are active at night have evolved diverse strategies for finding food and mates, avoiding predators, and communicating with each other under cover of darkness.

So what happens to these animals when the cover of darkness begins to fray?

Dietmar Nill/naturepl.com

The effects of artificial lighting on the nocturnal behaviors of animals, such as this west European hedgehog (*Erinaceus europaeus*), are not fully understood. Some species' foraging and breeding habits are severely hampered by a lack of natural darkness.

Night Light

In the absence of artificial light, illumination at night varies from inky darkness to a soft glow from the moon and stars. Moon phases are usually the most significant variables in nighttime illumination. Light from the sun bounces off the surface of the moon and shines back toward Earth; the percentage of the moon's face that appears lit up varies during the month as the Earth, moon, and sun change position relative to each other. Nights are darkest during a new moon, when the moon is between the Earth and the sun, and brightest during a full moon, when the Earth is between the sun and the moon.

Weather conditions and topography also affect nighttime illumination. Heavy cloud cover blocks light from the moon and stars. Snow on the ground reflects it, increasing illumination; patchy clouds can do the same. A mountaintop above tree line is brighter than a valley whose steep sides block light.

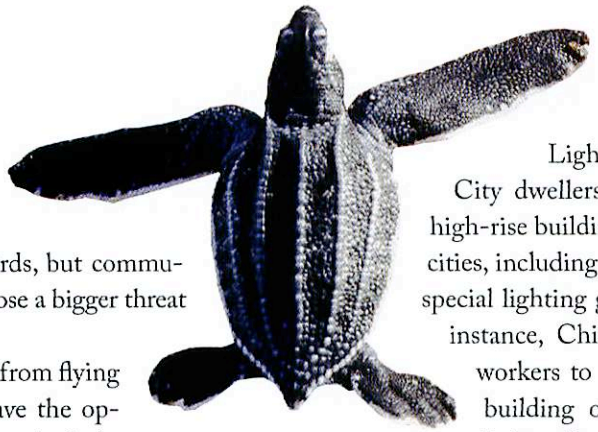
This natural ebb and flow of illumination is washed out by artificial nighttime lighting in many developed parts of the world. Almost two-thirds of the United States is at least ten percent brighter at night than it would be without artificial lighting. Most Americans can no longer see the Milky Way from where they live.

Light pollution can be divided into three categories—direct glare, sky glow, and intermittent variations. Direct glare is light shining directly on an object from a particular source, such as an unshielded street light or a backyard floodlight. Sky glow occurs when light shines skyward from the Earth, reflects off particles of dust and water vapor in the atmosphere, and bounces back to Earth. Low clouds increase sky glow by providing more reflective surfaces in the form of water vapor. When the night sky is lit up in the direction of a city that's too far away to see, that's sky glow. Glitzy Las Vegas produces sky glow that extends for more than 100 miles. Intermittent variations are brief flashes of light, such as those caused by the headlights from a passing car.

Most light pollution is caused by electric lights, so light pollution is primarily a problem in or near urban areas in developed nations. However, there are other sources as well—flares from offshore oil wells light up parts of Nigeria, North Africa, and Siberia. Lights from commercial fishing ships illuminate the night in the Sea of Japan. Wildfires overpower moonlight wherever they burn large enough.

All this nighttime light creates a problem for astronomers, who must build their telescopes in increasingly remote locations where light pollution does not obscure the stars. It also creates problems for animals.

While scientists have known for a long time that artificial lights disturb migrating birds and sea turtles, they have only recently started looking at the ecological effects of light pollution on other animals. Their data show that light pollution affects species in ways we are only beginning to understand.



Leatherback sea turtle hatchling.

Frans Lanting/franslanting.com

Wayfinding

As early as 1884, scientists documented the tendency of migrating birds to circle lighthouses in huge numbers at night. Today lighthouses still attract birds, but communication towers and lit-up skyscrapers pose a bigger threat because there are so many of them.

Towers are lighted to prevent aircraft from flying into them. Unfortunately, the lights have the opposite effect on some birds. Attracted to the lights, these birds sometimes circle the towers for hours and often have fatal collisions with other birds, the tower, or guy lines. Those birds that emerge from circling towers unscathed have wasted precious energy reserves needed for migration.

Charles Kemper, a retired physician, monitored a 1,000-foot-tall TV tower in Eau Claire, Wisconsin, every dawn during spring and fall migration seasons from 1957 until the late 1990s (he had a helper who filled in when he was unavailable). "I remember one night I was standing under the tower and birds were falling like raindrops," he says. "The engineer at the station came out and I talked him into turning the lights off for just a little while, and during this interval they quit. I didn't hear the collisions or [birds] hitting the ground."

One memorable September morning, he collected 11,000 birds at the base of the tower, all of which had died the night before. Kemper no longer monitors the tower, in part because he stopped finding significant numbers of dead birds there. He doesn't know why, but speculates that the increased number of communication towers in the area plays a part. Perhaps the bird collisions are spread out over the 30 or 40 towers that now stand in and around Eau Claire, not just concentrated at the one TV tower. It's also possible there are fewer migrating birds passing through the area.

Scientists aren't sure exactly why birds are attracted to lights, but have several theories. To fly in a straight path, birds may keep a constant angle between their flight trajectory and light rays from the moon; because the moon is far away, it does not appear to change position as the bird flies. But the same strategy used with a nearby artificial light would result in a trajectory that spirals in around the light source. Or it may be that artificial light somehow interferes with the inner magnetic compass that some scientists believe birds use for navigation during migration.

Sidney Gauthreaux, Jr., and Carroll Belser of the Clemson University Radar Ornithology Laboratory in Clemson, South Carolina, have observed lighted towers in the field and have found that birds are more attracted to red lights than to white, more attracted to constant lights than to strobes, and less likely to become "snared" by lights if they have a significant tailwind.

Lighted skyscrapers also pose a problem. City dwellers often find dead birds at the base of high-rise buildings on spring and fall mornings. Several cities, including New York, Toronto, and Chicago, have special lighting guidelines during migratory season. For instance, Chicago's program encourages downtown workers to turn off their office lights at night and building owners to turn off exterior decorative lights after 11 p.m.

Sea turtles, which have been studied extensively along Florida's east coast, are also disoriented by artificial lights. Loggerheads (*Caretta caretta*) routinely lay their eggs there; leatherbacks (*Dermochelys coriacea*) and green turtles (*Chelonia mydas*) do so less commonly. Beachside development has left precious few dark beaches on the east coast of Florida, and female turtles are much more likely to lay their eggs in the sand on these dark beaches. If baby turtles hatch from their nests when the sand is hot, as it usually is in the daytime, they remain still in their nests; they wait until the sand cools, primarily at dusk or at night, to tunnel out and crawl toward the water.

When the hatchlings reach the surface of the sand, instinct directs them to crawl away from tall dark silhouettes and toward a low, uniform, dimly lit horizon. On an undeveloped beach, this instinct sends them into the surf: Sand dunes appear as tall, dark silhouettes and the ocean looks like a low uniform horizon that is dimly illuminated by the reflection of moonlight or starlight. On a developed beach, however, sky glow or house and street lights often lure baby turtles away from the ocean and toward death by predation, exhaustion, or cars. Scientists estimate that hundreds of thousands of hatchlings die this way in Florida every year.

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Studies have shown that, as with birds, wavelength affects behavior of both mothers and hatchlings. In 1992, Blair Witherington of the Florida Marine Research Institute published the results of a field study of loggerheads in Florida and green turtles in Costa Rica that demonstrated that mercury vapor street lights (bright white) erected on the beach virtually eliminated nesting by females, while low-pressure sodium lights (yellow) had no effect on nesting rates as compared to a dark beach.

In laboratory studies carried out by Kristen Nelson and Susan Tuxbury at Florida Atlantic University in Boca Raton, hatchlings crawled toward lights designed to simulate standard street lights; some lights were clearly more attractive to the turtles than others. A higher percentage of hatchlings were attracted to mercury vapor lights than to high-pressure sodium lights (orange), and a higher percentage were attracted to high-pressure sodium than to those same lights equipped with "turtle-friendly" filters that decreased

MOONLIGHT NO DELIGHT FOR OCELOTS

We get it on most every night
when that moon gets big and bright
it's a supernatural delight
everybody's dancin' in the moonlight.

–Sherman Kelly,
"Dancin' in the Moonlight"

I see the bad moon arising.
I see trouble on the way.

–J.C. Fogerty,
"Bad Moon Rising"

James Carmichael/Bruce Coleman Inc.

To most of us, the idea of dancing in the light of a full moon is a romantic delight. For ocelots, a full moon is more like "the bad moon arising."

That was the tentative conclusion of a study by Louise Emmons, research associate at the Smithsonian's Museum of Natural History, and her colleagues, published in 1989 in the book ***Advances in Neotropical Ecology***, in a paper entitled "Ocelot Behavior in Moonlight." These biologists were studying ocelots (***Leopardus paradalis***) in Peruvian tropical rainforest. Ocelots are primarily nocturnal hunters but may be active day or night; as many cats do, they walk along trails and visit beaches while hunting their rodent prey. On trails and beaches, ocelots can walk more quietly and easily and see prey from farther away than if they were plowing through vegetation. But they do not use trails or visit beaches during the day, even when they are active, sticking to the cover of vegetation.

Emmons also found that ocelots generally avoid trails and beaches on nights with full moons, even though they are active just as many hours and walk just as far as they do on darker nights. It appears that the predators keep off brightly moonlit trails and stick to traveling under the darker cover of vegetation to look for a meal. In turn, their primary prey, nocturnal spiny rats (***Proechimys*** spp.), follow a similar pattern: They are more often seen on trails on dark nights than on bright nights, although they are equally active under both conditions.

Other evidence suggests, however, that ocelots are no more, and probably less, successful hunters when confined to vegetation, which likely hampers their ability to see prey, sneak up on it undetected, and pounce on it amid the undergrowth. Spiny mice and other small rodents, in contrast, probably avoid moonlit trails to decrease their risk of predation by birds of prey, which may be better able to see small animals when the night is bright. This forces the ocelots into the bush to find something to eat. It is also possible that avoiding trails and beaches during the day and full moons reduces the chances of ocelots themselves becoming the prey of jaguars (***Panthera onca***), pumas (***Puma concolor***), or harpy eagles (***Harpia harpyja***).

Other things being equal, a few days a month of eating a few less spiny mice is probably not a huge hardship for ocelots. But what if artificial night light forces them to stay under the cover of vegetation all the time? Or worse, what if there is no vegetation at all?

A small, endangered population of ocelots is clinging to survival in south Texas, in two refuges near or bordering the Rio Grande, which forms the international boundary between the U.S. and Mexico. These refuges do not form a large contiguous protected area; rather, protected tracts are linked by unprotected corridors that often lack vegetation. This probably makes it difficult for ocelots to move between the protected tracts. Making matters worse, to combat illegal immigration across the Rio Grande, the U.S. Immigration and Naturalization Service's Border Patrol burns and mows vegetation along the border and has installed miles of lights that brightly illuminate the border at night.

This concerns Melissa Grigione, a professor in the University of South Florida's Department of Environmental Science and Policy and cofounder of the Border Cats Working Group, which also focuses on the conservation of jaguars and jaguarundis (***Puma yagouaroundi***), which too are barely hanging on along the U.S.–Mexico border.

In a 2004 paper published in the journal ***Urban Ecosystems*** called "Effects of Artificial Night Lighting on Endangered Ocelots and Nocturnal Prey Along the United States-Mexico Border," Grigione and her colleague Robert Myrkalo reviewed existing studies, including Emmons', to assess what might happen to the Texas ocelots. They suggest that loss of vegetation in which ocelots can find cover while hunting or traveling between protected areas, and nocturnal artificial illumination that may alter the activity or abundance of rodents and reduce ocelot foraging success, may be serious threats to the recovery of these ocelots. Further, both night light and little cover may prevent them from moving across the Rio Grande to join populations in Mexico, and vice versa.

While experiments to test these ideas have not yet been conducted, Grigione says the prudent thing would be to eliminate artificial lighting or increase vegetation so ocelots and their prey have sufficient cover to shield them from artificial lights. Thus far, however, neither action is being taken.

–Susan Lumpkin

the amount of illumination by eliminating all but the amber wavelengths.

A field study at a beach near Boca Raton, Florida, examined the effectiveness of eliminating overhead street lights altogether and replacing them with light-emitting diodes embedded in the roadway. Lesley Bertolotti of the Broward County Department of Planning and Environmental Protection and Michael Salmon of Florida Atlantic University showed that the embedded light-emitting diodes were much less disruptive to hatchlings than conventional street lights equipped with the "turtle-friendly" amber filters. The embedded lights proved to be sufficient for the wayfinding needs of drivers, cyclists, and pedestrians, without interfering with the wayfinding needs of the baby turtles.

Eating and Being Eaten

Adding artificial light to habitats at night can disrupt nocturnal animals' strategies for eating and avoiding being eaten. An intriguing study led Robert Fisher, a research biologist with the United States Geological Survey, seems to have uncovered an example of this. Fisher has spent years surveying wildlife reserves in southern California. These pockets of wilderness are large enough to support a wide variety of biodiversity, but close enough to urban areas to be awash with sky glow. "In the coastal area where you've got low ceiling clouds at night, it's so bright there's no escaping it," Fisher says. The reserves are mostly coastal shrub and desert, so there is no significant tree cover to block sky glow from reaching the ground.

After extensive surveying, much of it done in collaboration with Ted Case, a retired professor at the University of California at San Diego, Fisher found that some nocturnal species that were previously documented in these reserves are now missing. For example, the glossy snake (*Arizona elegans*) and the western long-nose snake (*Rhinocheilus lecontei*) are gone. Their primary prey, which includes the nocturnal San Diego banded gecko (*Coleonyx variegatus abbotti*) and the Pacific pocket mouse (*Perognathus longimembris pacificus*), are also gone. "Some of these things are really inconspicuous and they are not things you'd expect to be declining based on the size of preserves and intactness of the habitat," Fisher says. "Why is this tiny mouse missing when all these bigger species of mammals, like bobcat and mountain lion, are still here?"

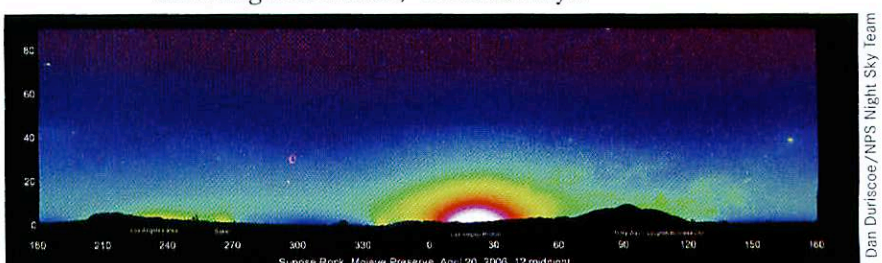
The mouse, gecko, and snakes still live in some darker parts of coastal southern California, such as the U.S. Marine Corps base Camp Pendleton and El Monte Canyon, which are both within 40 miles of San Diego. Fisher studied long-nose snakes' behavior in the field and discovered that they are most active on dark nights and least active around the full moon, when visibility is better for predators such as owls and cats.

Gopher snakes, which are ecologically similar to glossy and long-nose snakes except that they are active during the day, are flourishing in the southern California reserves.

Fisher has concluded that light pollution is the most likely culprit in the demise of the glossy and western long-nose snakes. "There are a whole bunch of questions, but the pattern seems pretty clear: Certain species that might be tracking the lunar cycle are gone," Fisher says. "We know that as soon as you get away from the brighter areas those species still exist." Fisher speculates that nocturnal snakes living in light-polluted areas don't come out to forage often enough, fall victim to predators more frequently, or suffer when their nocturnal prey dies out. "Brightness is going to affect a [nocturnal] species' ability to find prey or evade predators," he says.

On the opposite coast, Sharon Wise and Bryant Buchanan at Utica College in upstate New York are studying how sky glow affects the foraging behavior of nocturnal red-backed salamanders (*Plethodon cinereus*). Red-backed salamanders have no lungs; they absorb oxygen through their skins, which must stay moist. During the day, they seek shelter under leaf litter in the forest, and on wet nights, they come out to forage.

Wise and Buchanan set up 12 transects, each of which was 16 meters long and two meters wide. Six of the transects were each illuminated by one strand of small, white, electric holiday lights about one meter off the ground that simulated sky glow. "Our lights were very comparable to something between a full moon and twilight in a forest," Buchanan says.

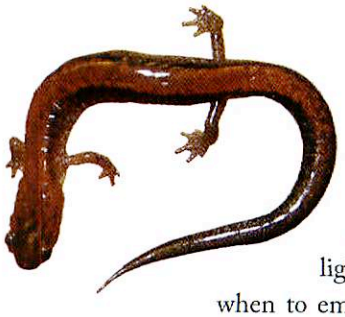


Dan Duriscoe/NPS Night Sky Team

This composite photo was taken at the Mojave National Preserve in California and enhanced with false color to show distant sources of artificial light. The Los Angeles area, which is about 185 miles to the southwest, is represented by the small yellow glow toward the left of the horizon, while the Las Vegas area, about 65 miles to the northeast, is represented by the large, multicolored semicircle near the horizon's center.

The scientists surveyed all transects for foraging red-backed salamanders. Between one and two hours after dark, they found significantly fewer in the illuminated transects. Later in the night, they found no difference between transects that were illuminated and those that weren't, in terms of the number of salamanders out foraging. Because of difficulties with weather and logistics, they collected data only one night. Wise says, "In the next year or two we will try to set up some of these transects again so we can run [the study] over multiple nights and over a complete summer."

In the meantime, Wise and Buchanan have been working in



Red-backed salamander.

Sharon Wise

the laboratory to untangle the relative importance of the different cues—temperature, rainfall, and light—that salamanders use to decide when to emerge from the leaf litter to forage. "Light is obviously important," Wise says. "If you go out on a rainy day and look for red-backed salamanders, they're not out. If you go out on a rainy night, you'll see them being active. What we're trying to determine is the level of light that is important." If it turns out that sky glow does inhibit salamanders from coming out to forage, that could have negative implications for their survival. On the other hand, Wise points out, there are confounding factors. "Lights may give them less time to forage," she says, "but if the lights are attracting insects, there may be more for them to forage on."

Other species also take advantage of insects' attraction to light to snare an easy meal. For example, frogs, geckos, and bats congregate at streetlights to forage on clouds of insects that swarm the lights. But Buchanan says, "Even if it superficially looks good for the frog, it might not be. It really does potentially expose the animals to a great increase in traffic-induced mortalities."

Insects are attracted to mercury-vapor lights and high-pressure sodium lights. Both of these emit some ultraviolet wavelengths, whereas low-pressure sodium lights give off a nearly monochromatic yellow light that contains no ultraviolet wavelengths and does not attract insects. Scientists surveying for bats with ultrasound detectors find increased concentrations of bats near mercury-vapor and high-pressure sodium lights.

In some cases, there is evidence that bats that take advantage of insect-attracting streetlights may be displacing species that don't. In several valleys in Switzerland, lesser horseshoe bats (*Rhinolophus hipposideros*) disappeared after streetlights were installed. At the same time and in the same areas, populations of common pipistrelle bats (*Pipistrellus pipistrellus*) increased. The two species are similar in size and diet, but pipistrelles eat at streetlights and lesser horseshoe bats don't.

Mating and Life Cycle

Most anurans (frogs and toads) are nocturnal. In the spring and summer, as daylight fades, male anurans begin their chorus to attract mates. Buchanan, who studies both anurans and salamanders, found that his outdoor enclosure of frogs was silent on nights when the nearby football stadium was lit up. The frogs would not chorus unless he shielded the enclosure with black plastic. Frogs that don't sing don't attract mates.

The football stadium observation is anecdotal, but Buchanan and Wise, along with Utica College undergraduates Heidi Savage and Kaylyn Bingel, performed controlled laboratory experiments showing that increased light levels at night have measurable effects on tadpole development in African clawed frogs (*Xenopus laevis*). They reared clawed frog tadpoles under controlled-temperature and varied nighttime-light conditions. "It appears that even light levels as dim as twilight will delay metamorphosis," Buchanan says. "That's potentially a real hardcore message for tadpoles." African clawed frogs live in water permanently, so perhaps there's no disadvantage to spending more time as a tadpole. However, if this finding holds true for tadpoles that develop in ephemeral ponds, nighttime light could pose a significant liability. "A lot of species have to metamorphose before the pond dries up," he says. "Delaying metamorphosis can prevent you from getting out of the pond."

Buchanan says more research is needed to untangle the ways in which light affects hormone levels, foraging, predator-prey relationships, and other factors. He adds, "One thing that is certain is that increasing light in a natural habitat will affect the ecology of the organism one way or the other. It's almost unfathomable that it wouldn't."

Communication

Fireflies are masters of the art of nighttime communication. There are thousands of species of fireflies worldwide, most of which are nocturnal and use self-generated bioluminescence to communicate. There are perhaps a couple of dozen species living in and around Washington, D.C.

In the last several decades, there has been a dramatic decline in the number of fireflies worldwide. James Lloyd, a retired professor of entomology at the University of Florida at Gainesville, says, "I've probably spent well over 2,000 nights in the field. I can't find a lot of species locally that I found 35 or 40 years ago." No one knows the cause, but possible culprits include loss of habitat (particularly wetlands), overuse of pesticides, overcollection for research and medicine, and light pollution.

The vast majority of flashing fireflies on summer evenings are males advertising for a mate. However, both males and females use their flashes in many other situations as well. For example, they may flicker when trapped in spider webs, or when landing or taking off. Females of some species mimic the flashes of other species, then eat males that respond.

Las Vegas lights blaze at night.

Fireflies have evolved specific adaptations to send and receive these lighted communications in the dark. Some species' light is yellow, while other species' light is green. For the most part, yellow species come out earlier at night than green species. Fireflies' vision has evolved in concert with their flashes, perhaps putting them at

Craig Mayhew and Robert Simmon/NASA GSFC

A composite of satellite images from 2000 shows artificial light usage around the world.

risk for behavioral changes as they respond to artificial lights in particular spectral ranges.

While there have been few studies that quantify the effect of artificial nighttime light on fireflies, a number of studies have shown ways in which the behavior of fireflies is finely tuned to light levels. On clear days, *Photinus pyralis* males come out at twilight and begin signaling for mates, but on cloudy days, or in shady areas, they start signaling earlier. Another species, *Photinus collustrans*, adjusts the height of its flight depending on light levels. Soon after sunset, it flies near the ground; as darkness deepens, it flies higher. Like many insects, fireflies are also attracted and "trapped" by streetlights and porch lights.

"How disturbing is the light we put into the habitat, either directly from point sources or indirectly bouncing off the clouds?" Lloyd asks. "I think it's devastating."

How disturbing is the light we put into the habitat, either directly from point sources or indirectly bouncing off the clouds?

Turning Down the Lights

The International Dark-Sky Association has long worked to curb light pollution in the interest of star-gazing and astronomy. Now, others are beginning to spread the word that light pollution hurts animals. Catherine Rich and Travis Longcore of The Urban Wildlands Group in Los Angeles, California, recently edited a book called *Ecological Consequences of Artificial Night Lighting* and are currently putting together best lighting management practices for national parks.

Their recommendations to homeowners for putting a lid on light pollution? "Use the minimum necessary for security, and have it be fully shielded and pointing downward to the place where light is necessary," Rich says. "Have a motion detector—then you're only lighting when there's something going by that needs to be illuminated. Don't uplight your trees or house." Longcore adds, "Stay away from lights that have ultraviolet or [are at the] blue end of the spectrum. Stay away from metal halide and mercury vapor. Use yellow lights [that won't attract bugs]."

Many communities, particularly in desert areas, have adopted light ordinances. A typical ordinance might include requirements that outdoor lighting be fully shielded (so that light rays go down, not up); that lights at playing fields be properly shielded and be turned off at 10:30 or 11 p.m.; that billboards and other signs be lit from the top, not bottom; that businesses turn off parking-lot lights 30 minutes after closing; and that searchlights and laser lights not be used for advertising.

"One of the big challenges is that there is no silver bullet," Longcore says. White strobe lights on towers might be best for migrating birds, but are more annoying to humans living nearby. Yellow lights might not bother nesting sea turtles, but they disorient hatchlings. Lights that point down don't contribute to sky glow, but they might adversely affect tadpoles in a ditch below them.

"The best thing we can do with any natural habitat," he says, "is keep it dark."

—Mary-Russell Roberson is a contributing editor to ZooGoer. *She wrote about animal song in the May/June issue.*