Hazard or Hope? LEDs and Wildlife

The introduction and widespread uptake of LEDs as outdoor lighting has caused no small amount of concern amongst conservation biologists. The prevailing impression that LEDs are always blue-white is well founded as adoption of LEDs for streetlights were invariably high color temperatures and with the deterioration of phosphors the blue wavelengths penetrated even more. But LEDs do have characteristics that differentiate them from other light sources and may allow for the reduction of environmental effects of lighting on species and habitats: direction, duration, intensity, and spectrum. Travis Longcore, Assistant Professor at the University of Southern California's School of Architecture, sheds light on all these aspects.

Outdoor lighting sources that have been in use for the better part of a century or more are rapidly being phased out in favor of LEDs. The industry has delivered consistent improvements in efficiency extending across a wide spectral range and with control capabilities unimaginable to previous generations of lighting designers. Yet, the introduction and widespread uptake of LEDs as outdoor lighting has caused no small amount of concern amongst conservation biologists. Leading bat researchers wondered if LEDs were "conserving energy at the cost of biodiversity" [1]. Another group investigating insects declared "LED lighting increases the ecological impact of light pollution" [2]. A horizon scan of threats to urban ecosystems listed LEDs and the associated profusion of bright white light [3]. Most of these concerns, however, are based on the experience of the general public that LEDs used in outdoor lighting can only be blue-white - or on studies of instances where the switch to LEDs is in fact to high color temperature whites [4,5]. The prevailing impression that LEDs are always blue-white is well-founded. Early adoption of LEDs for streetlights was invariably high color temperatures as a result of their higher efficiency during that phase of technological development. As these products aged and the phosphors deteriorated, the blue wavelengths penetrated even more. It is no surprise that the public, and wildlife researchers included, perceived high color temperatures to be an inherent attribute of LEDs. This misconception continues today, even though a wider range of spectral configurations of LEDs are competitive and installed across the world.

It seems possible, as well, that LED professionals are unfamiliar with the concerns about the effects of outdoor lighting that motivate conservation biologists to regard LEDs with suspicion. The purpose of this essay is to reconcile these two realms by addressing the question of whether LEDs pose a risk or opportunity to wildlife conservation. LEDs do have characteristics that differentiate them from other light sources. The influence of these characteristics fall into the four major attributes that have been identified as important to reducing environmental effects of lighting on species and habitats: direction, duration, intensity, and spectrum [6].

Figure 1:
A hatchling loggerhead sea turtle crawls toward a high-pressure sodium luminaire on the Florida coast (Photo Credits: Blair Witherington)

Direction

LEDs as currently deployed in street lighting tend to be quite directional, casting most light on the ground and little light at the horizontal or higher. In this regard they can be an improvement over other lamp types that have drop lenses resulting in more light scattering to locations where it is not useful. With the use of microlens arrays, the focus of LED streetlights on the street and adjacent pedestrian zones could be nearly perfect [7]. So long as lights are not pointing downward into a sensitive habitat (e.g., a wetland [8]), the directionality of LED streetlights can be an improvement in terms of wildlife impacts. Bulb-type LED lamps, however, offer no such benefit and their deployment in unshielded fixtures presents the same challenges as previous technologies.

Duration

One of the most effective ways to reduce the unintended adverse effects of lighting is to turn lights off when they are not needed. For most lamp types previously used for municipal outdoor lighting, turning the lamp on and off comes with an energetic penalty or warmup period. In contrast, LEDs can easily be extinguished and illuminated without delay. Consequently, LEDs are suited to the use of controls that use either timing or motion/heat detection to extinguish lights when they are not needed.

Intensity

Intensity of light is easily controlled in LEDs, they are dimmable without difficulty. So from the perspective of reducing lighting levels to the minimum needed for required tasks, they are ideal. Yet, the tendency is for designers and end users to use more light with LEDs because they are so energy efficient [9]. This phenomenon is well-known in environmental economics, known as the "rebound effect" [10]. It seems that users find that it is preferable to use a brighter bulb when the energy savings are great. LEDs represent an era of cheap light and when a product is inexpensive, the tendency is to overconsume. Just as cheap (fast) food has resulted in an obesity epidemic in the United States and elsewhere [11], cheap light has the potential to result in unnecessarily bright nights.

Spectrum

The flexibility of LEDs when it comes to spectrum, contrasts dramatically with the perception that LEDs used for outdoor lighting are intrinsically bluish white. Rather, the rapid development of a range of spectral combinations offers many possible options that could be exploited to reduce impacts on wildlife and the environment.

Insect attraction to LEDs is lower across the board when compared with lamps that emit ultraviolet light. Both "warm" and "cold" LEDs have been compared with metal halide and mercury vapor lamps and found to attract less than a tenth of the number of insects, a finding that is attributable to the difference in ultraviolet emissions [12]. Conversely, most broad spectrum LEDs used in outdoor lighting do have a potential to adversely impact the perception of daylength (and thus seasonality)

Figure 2: Relationship of modeled effect of lamps on different wildlife species or groups (juvenile salmon, Newell's shearwater, sea turtles, insects, and their average) with Correlated Color Temperature (CCT) of the lamps. Data from [14]

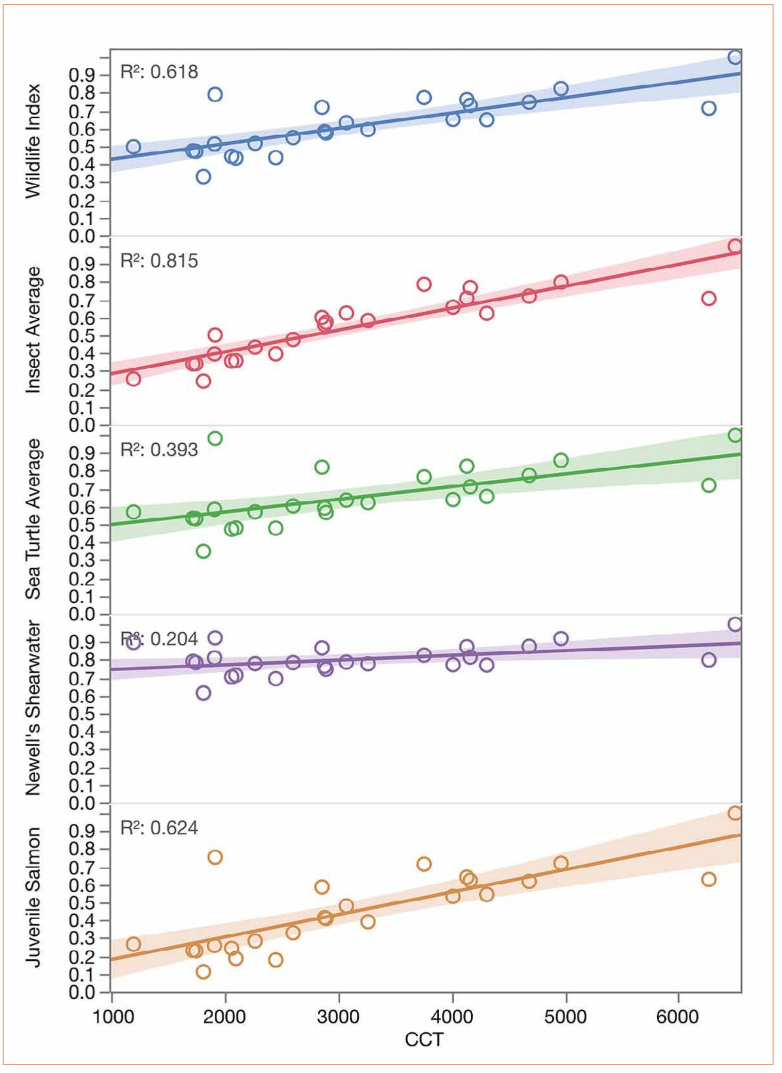
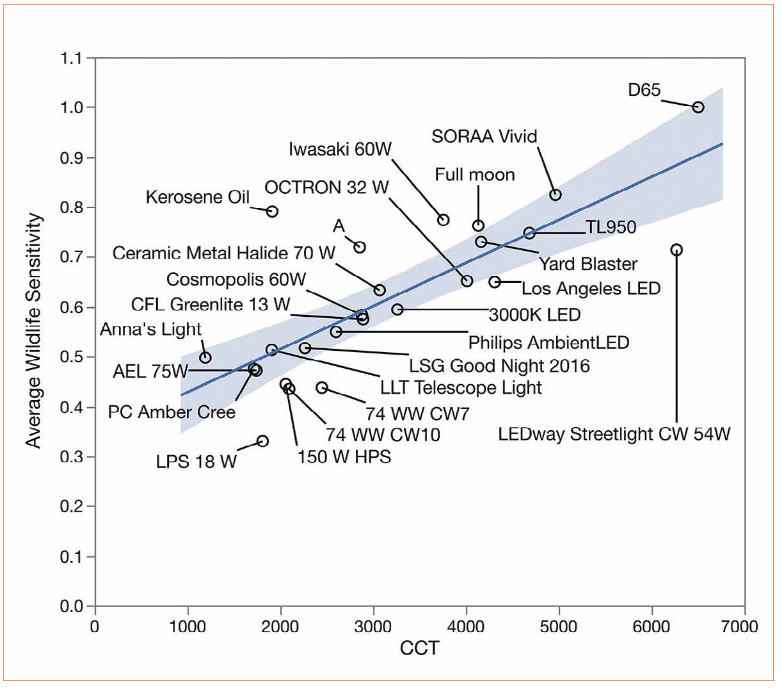


Figure 3: Relationship of correlated color temperature to average wildlife sensitivity with lamps and illuminants labelled. Data from [14]



in plants, because the peak sensitivity of the phytochromes that detect daylength are in range of LED peak emissions for most full-spectrum LEDs.

Beyond these two examples, the combination of tunable LEDs, filters combined with LEDs, and colored LEDs such as PC Amber offer unique opportunities. Spectrum can be controlled by combining different colored diodes in many configurations (red, blue, green, and perhaps also white, amber with white). The number of combinations far outstrips previous technologies, where the spectral output of high pressure sodium, low pressure sodium, metal halide, xenon, fluorescent, and incandescent lamps were well-known and inflexible.

Choosing Spectrum to Reduce Wildlife Disruption

To take advantage of the range of possibilities from LEDs, the quantal flux at different wavelengths can be compared with the behavioral responses of wildlife across those wavelengths. A generalized response curve for all insects was just published [13] and curves exist for other species [14]. The intersection of the response curves with the spectral power distribution of the lamps (converted to photons) can be compared with the same calculations for an equal lux of a standard illuminant to provide a comparison of the effects of different light sources [14]. Response curves for insects (averaging three curves in the literature), sea turtle (averaging three curves in the literature), juvenile salmon, and a visual response curve for the endangered seabird Newell's Shearwater were used to construct a composite metric of wildlife impacts and compared with a range of lamp types and standard illuminants. Plotting the results relative to Correlated Color Temperature (CCT) reveals two characteristics of the impacts of lights (Figure 2). First, on average and for each species or group, lower CCTs had lower predicted effects. Second, the slope of the relationship between CCT and wildlife influence was greater for some groups than others, indicating that spectrum could be a more effective tool to reduce impacts on insects and juvenile salmon than on Newell's Shearwater.

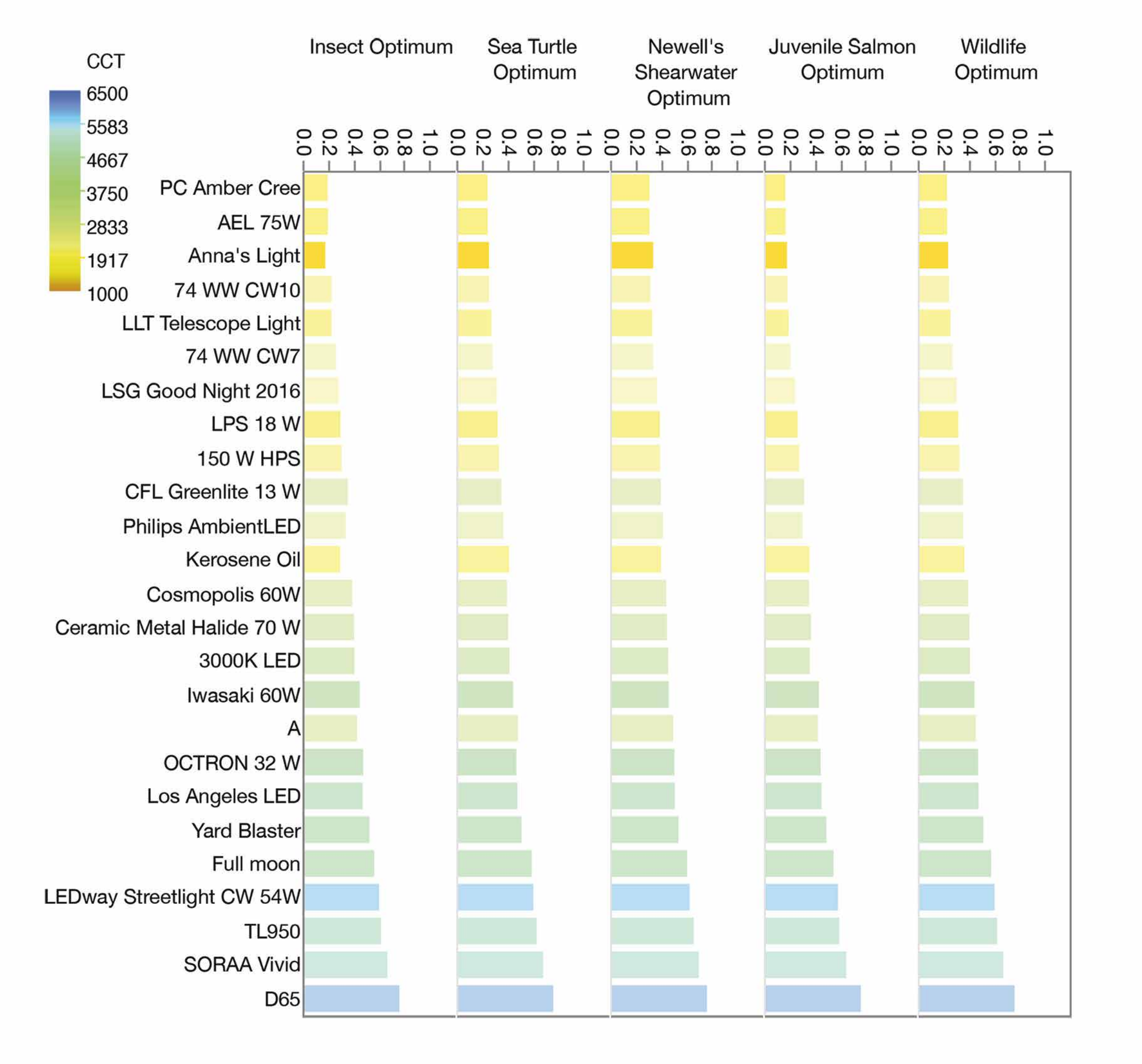


Figure 4: Ranking of lighting sources that equally weighs wildlife response, melanopic response, astronomical light pollution (Star Light Index [15]), and Color Rendering Index. Reprinted from [14]. Shorter bars represent a combination of lower wildlife responses and higher CRI

CCT is not a perfect predictor of effects on wildlife, but it is a reasonable rule of thumb that lower CCT will be less disruptive to wildlife (and we already know that it will be less disruptive for circadian rhythms and astronomical observation [15]). The lamps with the lowest projected influence on wildlife overall were low-pressure sodium (which is being phased out), high-pressure sodium, PC amber LEDs, and filtered LEDs (Figure 3).

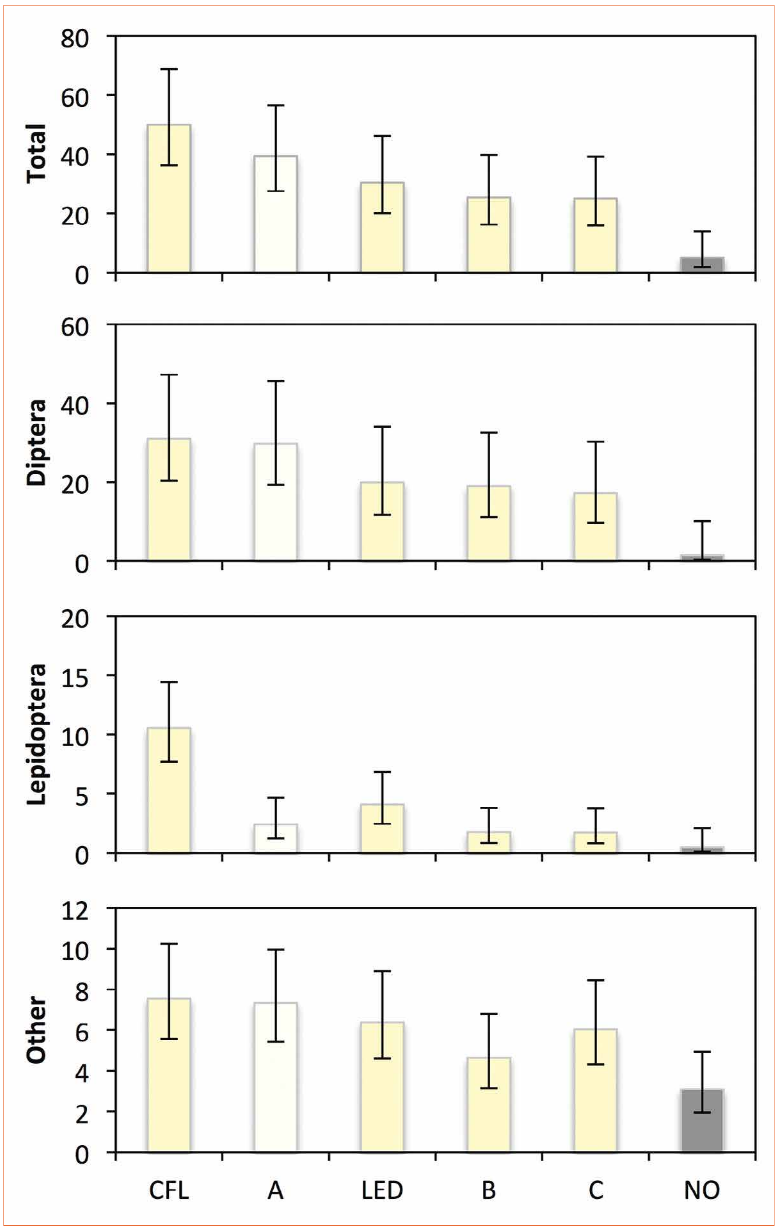
Figure 3: Thus far, the results represent the predicted effects of the lamps on wildlife. To account for preferences in outdoor lighting, another ranking was created that incorporated a penalty for low color rendering index (CRI). Any lamp with a CRI over 75 was assumed to have adequate color rendering, while those with lower CRI were penalized in the overall index. The resulting ranking of lamps is notable in that low pressure sodium ranks lower because of its extremely low CRI, while PC Amber and filtered LEDs rank the highest, balancing both lower wildlife impacts with reasonable if not high CRIs (Figure 4).

As a rule of thumb, CCT can be used as an indicator of wildlife effects, but this may not hold true across all applications. Migrating birds cannot orient under red light and therefore solid red lights are to be avoided on communication towers [16]. Green light has support for minimizing attraction of nocturnal migrant birds [17]. Other special cases exist and would require consultation with experts on a particular taxonomic group or species at risk.

Tuning Within the Same CCT

An additional useful feature of LED lamps is that they can be configured to produce the same CCT with different spectral outputs. To demonstrate this approach to minimize insect attraction, the spectral response curves for bees and moths were used to choose between configurations of two 2700 K LEDs (produced with a prototype tunable lamp with RGB diodes) and one 3000 K LED in a manner predicted to reduce insect attraction. The custom configurations were then compared in a field study with an off-the-shelf 2700 K LED and 2700 K fluorescent lamp [18].

The results of this field experiment showed that a tunable LED attracted 20-21% fewer insects than a similar LED not designed with minimizing



Figures 5: Comparison of attraction of insects, and subsets of flies (Diptera), moths (Lepidoptera), and other insects to 2700 K compact fluorescent (CFL), custom 3000 K LED (A), off-the-shelf 2700K LED, two custom 2700 K LEDs (B and C), and a control (NO). Average catch per night with 95% confidence intervals (see [18] for details)

insect attraction as an objective (Figure 5). This effect was large for moths, similar to the findings when comparing different CCT lamps. These results are especially important for the choice of indoor lighting in the tropics, where glass and screens on windows is not common. Using indoor light that provides adequate color rendering for work while reducing insect attraction would reduce the probability of exposure to phototactic insect vectors of disease [18]. LEDs offer this possibility because of the spectral flexibility in their design.

Certainly, conservation scientists have more work to do on spectral responses. The number of species response curves available needs to be increased, which requires experts across taxonomic groups to engage the topic. The relationship between light intensity and spectral responses is largely unknown and needs research across nearly all wildlife groups. Even the perception of light by different groups of wildlife species is not fully described and taxonomic-specific metrics of both radiance and irradiance are needed. Nevertheless, a "no regrets" approach can be taken to guide the choice of spectrum that LEDs make possible, which is to reduce blue content. With amber and filtered products on the market, low color temperatures ≤2200 K are feasible and desirable to minimize adverse impacts.

Conclusions

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

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