**Blue Lighting**

Bat Conservation Trust. 'Artificial lighting and wildlife. Interim Guidance: Recommendations to help minimise the impact of artificial lighting.' http://www.bats.org.uk/pages/bats\_and\_lighting.html

Miles, James (2016) 'What sort of harmful effects are your lighting designs potentially having on bats? Lighting Journal April 2016 pp28-30. https://issuu.com/matrixprint/docs/lighting\_journal\_april\_2016

Edet, D. I, Oladele, A. T and Bekom R (2012) The impact of coloured lights on night-time colony management of the African honey bee (Apis mellifera adansonii) Agriculture & Biol J N Am 3(12): 506-509.

African honey bees were shown to be more active at night when disturbed in the presence of blue and white light compared to red or green.

International Dark-Sky Association: 'Visibility, Environmental, and Astronomical Issues Associated with Blue-Rich White Outdoor Lighting' May 4, 2010 http://www.ida.darksky.org/assets/documents/Reports/IDA-Blue-Rich-Light-White-Paper.pdf

Conclusions: There is a suite of known and likely detrimental effects to the ecosystem, to the enjoyment of the night sky, to astronomical research, and possibly to human health from blue-rich white outdoor lighting.

The science of photobiology indicates that blue-rich light at night is more likely to alter circadian rhythm and photoperiod, the evidence being widely scattered across the animal kingdom. The ecological differences between light rich in blue and light devoid of blue can be several-fold for some critical species.

The advantages of blue light in the daytime are diminished and overwhelmed by the disadvantages accrued at night, including glare, delayed dark adaptation, pupil constriction, and factors associated with the aging eye.

The blue portion of the spectrum is known to interfere most strongly with the human endocrine system mediated by photoperiod, leading to reduction in the production of melatonin, a hormone shown to suppress breast cancer growth and development.

Dark-adapted eyes observing a sky contaminated with artificial sky glow are more sensitive to blue-rich light; this light will appear 3–5x as bright when observed from nearby. Blue-rich light will greatly exacerbate visible sky glow close to the light source and retain greater impacts to very large distances.

The physics describing the interaction of light with the atmosphere is long-established science and shows that the increased blue light emission from white lighting sources will increase visible sky glow and detrimental effects on astronomical research through increased scotopic sensitivity and scattering.

The blue portion of the spectrum is known to interfere most strongly with the human endocrine system mediated by photoperiod, leading to reduction in the production of melatonin, a hormone shown to suppress breast cancer growth and development. A direct connection has not yet been made to outdoor lighting, nor particularly to incidental exposure (such as through bedroom windows) or the blue component of outdoor lighting, but the potential link is clearly delineated.

Concerning effects on other living species, little research has examined spectral issues; yet where spectral issues have been examined, the blue component is more commonly indicated to have particular impacts than other colors (e.g., on sea turtles and insects). Much more research is needed before firm conclusions can be drawn in many areas, but the evidence is strong enough to suggest a cautious approach and further research before a widespread change to white lighting gets underway.

The application of such corrections [increased blue] has achieved official recognition in Britain (see, for example, BS 5489- 2:2003 “Code of practice for the design of road lighting”). In the case of blue-rich light, such weighting functions increase the apparent efficacy of the associated lighting and fundamentally alter the economics of those systems.

The spectral output of white light sources stands in contrast to the most common highintensity discharge (HID) source used for area and roadway lighting for the last several decades, high-pressure sodium (HPS). Thus these sources represent a substantial change in outdoor lighting practice because they produce a larger amount of radiation in the bluer portions of the spectrum than HPS. Most HPS emission falls between 550 nm and 650 nm; the ratio of radiant output shorter than 500 nm to the total output in the visible spectrum (here defined as 400 nm to 650 nm) is 7%; for fluorescent (including induction fluorescent) and metal halide (MH) sources the ratio is about 20% to 30%; and for white LED sources this ratio is in the range of 20% to 50% (see Figure 1). LED manufacturers have indicated that the ratio is expected to be less as LED technology develops and, indeed, some manufacturers have already announced “reduced-blue” LED products for outdoor lighting. But if more white light, regardless of light source type, is used for outdoor lighting, the amount of blue-rich light emitted into the environment will also rise substantially. [Concern that increasing white LED lights will increase blue-rich light emitted into the environment]

Pupillary Response Several studies have shown that pupil size is more strongly correlated to blue light intensity (e.g., Barbur et al., 1992) than to photopic luminance, with the effect becoming more prominent at lower luminance levels. Blue-rich light causes incrementally smaller pupil sizes than yellower light. Although it is sometimes assumed to be mediated by rod cell (scotopic) response, research indicates that pupil size may be dependent on bluesensitive S-cones (Kimura and Young, 1999), a combination of rod and cone cell response with peak sensitivity at 490 nm (Bouma, 1962), or a L-cone minus M-cone mechanism (Tsujimura et al., 2001). At lower luminances, a smaller pupil size and the resultant lower retinal illumination may reduce visual performance for tasks more closely related to foveal vision or photopic luminance. Pupil size is an important covariable that should be examined using a range of performance tasks, not just reaction time, and the ramifications of a lower retinal illumination on foveal vision tasks have not been adequately addressed.

The timing and duration of the eye’s adaptation between photopic and scotopic modes is also critically important (e.g. Stockman and Sharpe, 2006). In particular, exposure to blue light increases the adaptation time required for maximum scotopic sensitivity (Bartlett, 1965; Brown et al., 1969). This relationship of dark adaptation to lighting color is commonly utilized by military personnel and astronomers who use red lighting to preserve scotopic vision.

Thus, while scotopic response is most sensitive to blue light at low intensities, higher intensities of blue light, including intensities in the mesopic range, inhibit dark adaptation and appear to suppress scotopic response. The implications in a real world setting with glare sources, poor uniformities, harsh transitions, wide-ranging illumination levels and adaptation time scales are important to consider and remain poorly understood. The vision advantages of blue light shown in laboratory experimental settings with dark adapted subjects or in simplified roadway designs does not translate well for some applications.

Blue light in the 350–430 nm range has also been shown to cause the lens of the eye to fluoresce (Zuclich et al., 2005), resulting in intraocular veiling luminance.

However, since blue-rich sources produce relatively more discomfort glare and older people are more sensitive to glare, blue-rich outdoor lighting is presumed to impact the elderly more than other groups.

The human circadian rhythm is mediated by non-visual photoreceptors in the retina, with a response function peaking near 460 nm in the blue portion of the spectrum (see Figure 3); exposure to light at night, particularly blue-rich light, suppresses the production of melatonin (Brainard et al., 2001). Melatonin is found in animals and humans, and even some plants. In humans this hormone mediates the sleep-wake cycle, and plays a role in the immune system.

Many laboratory and epidemiological studies show that suppressed melatonin production can lead to increased incidence of or growth rates for breast cancer. Further, evidence indicates that people living in illuminated urban environments suffer increased breast cancer rates while suffering no more than average rates of lung cancer, which is not linked to melatonin levels. All potential compounding factors have not been ruled out, and crucial research concerning realistic incidental exposure to outdoor lighting, as well as the spectral characteristics of such lighting, has not been published. However, the effects of blue-rich light on melatonin production, and the effects of melatonin on human cancer growth in certain laboratory experiments, are uncontroversial. Stevens concludes: “The level of impact [of lighting] on life on the planet… is only now beginning to be appreciated. Of the many potential adverse effects from LAN and circadian disruption on human health, the most evidence to date is on breast cancer. No single study can prove cause and effect, as neither can a group of studies of only one of the factors cited above. However, taken together, the epidemiologic and basic science evidence may lead to a ‘proof’ of causality (i.e. a consensus of experts). If so, then there would be an opportunity for the architectural and lighting communities, working with the scientific community, to develop new lighting technologies that better accommodate the circadian system both at night and during the day inside buildings.” While a firm connection between outdoor lighting and cancer has not yet been established, if true it is clear that the blue component of such light would be a greater risk factor.

Environmental Effects Artificial lighting is intended to serve only human needs, but once introduced outdoors it radiates freely into the environment where it may have unintended consequences to wildlife (e.g., Longcore and Rich, 2004; IESNA, 2008).

There are several examples where shorter wavelength light has been linked to ecological problems (e.g. Frank, 1988; Witherington and Martin, 2000; Nightingale et al. 2006),.... the increased scattering of blue light in the atmosphere, the sensitivity of many biological systems to blue light, and deeper penetration of blue light into aquatic environments (Clarke and Oster, 1967) means that increased use of blue-rich light sources is likely to produce greater environmental consequences.

Light sources that have a strong blue and ultraviolet component are particularly attractive to insects (Frank, 1988), though even incandescent sources, broad-spectrum but not commonly thought of as blue-rich, are generally known to attract insects to residential porchlights. There is a dearth of published studies addressing the relative attractiveness of ultraviolet vs. blue light, though a few unpublished ones indicate that while UV has much greater attractiveness than blue light, blue light is more attractive than yellow. Insects in artificially lighted areas are frequently captured by phototactic fixation on lights, but lights also draw insects out of natural habitats into lighted areas, or present a barrier to migrating insects moving through an area (Eisenbeis, 2006). Thus, the distance to which a given light may affect insects can be quite large. Lights without substantial shortwavelength emission, from simple yellow-painted incandescent “bug” lights to lowpressure sodium, substantially reduce or eliminate this phototactic response.

Most bat species are insectivores and have long been observed to feed around lights at night. This results in a complex ecological change that is potentially harmful—the lights concentrate their food source outside of their normal habitat, may result in longer flights to feeding locations, change their diet, and alter the competitive balance between bat species (Rydell, 2006).

Circadian Disruption in Wildlife Photoperiod is one of the dominant cues in the animal kingdom; an animal’s response to it is commonly triggered by length of darkness as opposed to length of daylight. Light is a potent agent and is biologically active (Royal Commission on Environmental Pollution, 2009). As in humans, the circadian clock controls a complex cascade of daily and seasonal endocrine functions. These exert command over migratory, reproductive, and foraging behaviors (Rich and Longcore, 2006, Royal Commission, 2009). The tendency of blue-rich light to synchronize circadian function is common in mammals (Berson et al., 2002), and there is evidence for it in amphibians (Hailman and Jaeger, 1974; Buchanan, 2006) as well as plankton (Moore et al., 2000; Gehring and Rosbash, 2003).

Sky Glow, Astronomy, and the Natural Nightscape At sites near light sources, such as within and near urban areas, the increased scattering from blue-rich light sources leads to increased sky glow (Luginbuhl et al., 2010; Figure 4). The bluest sources produce 15% to 20% more radiant sky glow than HPS or lowpressure sodium (LPS). This effect is compounded for visual observation, as practiced by casual stargazers and amateur astronomers, by the shift of dark-adapted vision toward increased sensitivity to shorter wavelengths. In a relatively dark suburban or rural area, where the eyes can become completely or nearly completely dark-adapted (scotopic), the brightness of the sky glow produced by artificial lighting can appear 3–5 times brighter for blue-rich light sources as compared to HPS and up to 15 times as bright as compared to LPS.

In comparison to the impacts on scientific astronomical observation, which is affected most by increased artificial radiance in the upper portion of the sky (within about 70° of the zenith), impacts on the nightscape as viewed by human observers are strongly influenced by the interplay of the spectral sensitivity of human vision with the spectral content of light sources, and the appearance of light domes over cities. To the darkadapted human eye, the so-called “scotopic advantage” (or in this case disadvantage) of blue-rich light sources is fully realized.

As light domes from urban areas impinge on many rural and natural areas, including national parks (Duriscoe et al., 2007), increased use of blue-rich light sources will increase these impacts to distances of 100 km or more (Luginbuhl et al., 2010). The cultural impacts arising from the loss of a natural star-filled night are hard to quantify. Yet these impacts affect a much larger proportion of the population than commonly thought of when discussing the value of night skies (see e.g. Moore et al., 2010).

**Conclusions**

While there is substantial interest in using lighting that is richer in blue wavelengths, the complex interrelationships between visual performance and light source spectral distribution are not adequately understood, especially at mesopic luminance levels. Within the range of blue wavelengths, there are multiple opposing functions that may diminish or overwhelm the advantages of scotopic stimulation, including glare, delayed dark adaptation, pupil constriction, and factors associated with the aging eye. Also of special importance is the threshold of luminance where such benefits accrue. Most outdoor lighting levels lie in the high mesopic range; the benefits of blue-rich light found at low mesopic or scotopic levels should not be wrongly applied to brighter ranges.

First, the atmosphere scatters shorter wavelengths to a much greater degree than longer wavelengths, and darkadapted eyes observing a sky contaminated with artificial sky glow are more sensitive to blue-rich light. As compared to HPS, blue-rich light sources scatter 1.1–1.2x more; to the dark-adapted eye this light will appear 3–5x as bright when observed from nearby. Thus, blue-rich light will greatly exacerbate visible sky glow close to the light source and retain greater impacts to very large distances.

Second, from the perspective of astronomical observation at distant observatories, shortwavelength emission from blue-rich lighting sources increases sky glow in the (naturally) relatively dark and unpolluted (by HPS and LPS) blue portion of the spectrum. The resultant decrease in contrast erodes the effectiveness of astronomical facilities.

The current state of knowledge regarding the health effects of light at night, and in particular blue-rich light at night, permits no firm conclusions. Yet, the clear linkage between short-wavelength emission, the blue-sensitive response of the photoreceptors involved in the human circadian system, and the suppression of melatonin production by short-wavelength emission, indicates at least that widespread use of blue-rich light sources at night should be considered with caution. There is an urgent need for further research in this area, due to the potentially grave impacts hinted at by much research.

The science of photobiology indicates that blue-rich light at night is more likely to alter circadian rhythm and photoperiod in the animal kingdom. With this field of study in its infancy, the evidence is widely scattered across the animal kingdom. Yellow-rich light, such as HPS, or even monochromatic yellow light, such as LPS, is environmentally preferred in many situations, but there are notable exceptions. However, the balance of evidence points to blue-rich light being more likely to impact wildlife than yellow light. The ecological differences between light rich in blue and light devoid of blue can be several-fold for some critical species.

The current trend toward blue-rich white outdoor lighting will result in a large increase in radiant flux being emitted below 500 nm. There is a suite of known and likely detrimental effects to the ecosystem, to the enjoyment of the night sky, to astronomical research, and possibly to human health.

.... lamps can be selected or filtered to limit emissions shorter than 500 nm. Such light would in general exhibit only a light yellow hue and still enable scotopic vision while decreasing deleterious effects.

Buchanan, B. W., 2006, “Observed and potential effects of artificial night lighting on anuran amphibians,” in Ecological consequences of artificial night lighting, Rich, C., and Longcore, T. (eds.), Island Press, Washington, D.C., pp. 192–220.

Eisenbeis, G., 2006, “Artificial night lighting and insects: attraction of insects to streetlamps in a rural setting in Germany,” in Ecological Consequences of Artificial Night Lighting, Rich, C., and Longcore, T. (eds), Island Press, Washington, D.C., pp. 281–304.

Gehring, W. and Rosbash, M., 2003, “The coevolution of blue-light photoreception and circadian rhythms,” Journal of Molecular Evolution, 57: S286–S289.

Rydell, J., 2006, “Bats and their insect prey at streetlights,” in Ecological Consequences of Artificial Night Lighting, Rich, C., and Longcore, T., (eds), Island Press, Washington, D.C., pp. 43–60.

The higher blue content in LED lighting is more subject to scattering in the atmosphere, especially by cloud cover, thus increasing skyglow. In addition, the blue spectra have a greater impact on melatonin production and could further disrupt sleep patterns in diurnal animals, including humans.

In the UK all 17 species of bats are protected: “This makes it illegal deliberately or recklessly to kill, injure, capture or disturb bats, obstruct access to bat roosts or damage or destroy bat roosts. Lighting in the vicinity of a bat roost that causes disturbance couldconstitute an offence, unless the local Statutory Nature Conservation Organisation has been consulted and allowed time to provide advice,” according to Miles.

“About a third of all vertebrates and two-thirds of invertebrates are nocturnal. For many of these animals, the introduction of artificial light probably represents the most drastic change human beings have made to their environment,” wrote Christopher Kyba, a light pollution researcher at the [Freie Universität Berlin](http://userpage.fu-berlin.de/~kyba/" \t "_blank). “Near cities, cloudy skies are now hundreds, or even thousands of times brighter than they were 200 years ago. We are only beginning to learn what a drastic effect this has had on nocturnal ecology.”

Like humans, other insects with apposition eyes, such as bees, become colour-blind in dim light10.

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attracted to different coloured light shown on white cloth mounted close to the beehive entrance at night. Results from the experiment showed the mean attraction figures in four weeks as white light (143.0), Blue light (122.5), Green light (97.8) and red light (85.0) as shown in Fig.1.