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The Biological Basis for the Canadian Guideline for Outdoor Lighting 5. Impact of the Scheduling of Light

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Abstract

Nightfall keeps the circadian rhythm of plants and animals in synchrony with their natural activity and the environment. For humans, the threshold for the blue light of twilight is roughly a few times the brightness of the full Moon and somewhat less for some other species. Altering the night's brightness and its spectrum changes the natural cues for the onset of night that will shift or delay the biological benefits of night by changing or disabling some aspects of the organism's biochemistry.

There have been many diverse studies into the impact of artificial (anthropogenic) light at night (ALAN) on various aspects of wildlife. These highlight the dependence on the extent and brightness of the light and its spectrum. Scheduling or timing the use of light is the fourth attribute that has a profound impact on the biology of the night (Navara and Nelson 2007), but the timing of ALAN need not be exact.

Animals have a natural plasticity in their behaviour and biochemistry that can tolerate some shifts in the natural time of night (Reebs 2002, Wong 2015). This can be used to determine a schedule for outdoor lighting that will reduce its impact on the ecology, yet will accommodate human activity.

Introduction

Predators need illumination to hunt and forage, so some species take advantage of twilight and moonlight to extend the photoperiod. The activity of the prey may also require light, though this varies with species and habitat. Some nocturnal animals (porcupines for example) rely on smell because of their poor vision, but raccoons use both. With these limited examples, light generally benefits the predator.

The leaves of some plants become a liability as winter approaches. The lengthening nights message the need to retract the flow of nutrients and let the leaves dry and fall. Also, an early snowfall shortens the time for foraging animals to prepare for winter. It covers vegetation making foraging difficult for herbivores and will put these species, and those that rely on them, at risk.

To avoid procrastination, we will not wait until the threshold luminances for all, or even most species have been determined. We can assign lighting limits by monitoring activity of species when subjected to, for example, the different phases of the Moon and the range in the severity of seasons. The limits may be revised as new information becomes available, however more than a dozen years of additional research has not significantly changed our qualitative and quantitative understanding of sensitivities to ALAN presented in our first published work on this subject in 2008 (Dick 2008).

Behavioural Plasticity

The first three key attributes to ALAN have been discussed in the three preceding papers (Dick 2020b, Dick 2020c, and Dick 2020d). The fourth attribute, timing of when ALAN may be used that will have minimal ecological impact, is not as precise as we may wish.

Organisms benefit from being able to adapt their behaviour to the state of the environment—daily temperature, rainfall, food availability, the seasons, and the first snowfall, for examples. It can reduce stress from the changes experienced during long migrations, and it can also promote long-term evolution (West-Eberhard 1989) by allowing survival to bridge across an evolving environment.

This biological and behavioural "plasticity" makes precise timing of animal sensitivity to ALAN almost impossible. However, we need not wait for complete knowledge before we start protecting wildlife and humans from the effects of artificial light at night. Not all animals may share the same tolerance, but it is a beginning.

This "plasticity" has its limits. It may only involve a few traits (Bhat 2015), ALAN may be used where plasticity is demonstrated, but not depended on as a panacea for purposefully changing the environment.

Length of Night as a Cue

What duration of ALAN in the evening (and morning) can be used that will not significantly affect the ecology? As complex as this may be, we suggest it can be reduced to relatively simple analyses, especially in the temperate and northern latitudes of Canada where seasonal contrasts make change more apparent.

Snowfall is important to the survival of foraging herbivores (Jones 2000). Even relatively shallow snow packs can significantly affect the food intake of animals, which can force a change of diet (Goodson 1991). The sooner animals begin to prepare for winter the greater their chance of survival, however preparing too early may not significantly improve their prospects, as it may reduce available food that might be gathered in winter and later in spring. Since animals do tend to survive seasonal change—with its range in natural severity—the natural cues to seasonal change seem to be sufficient.

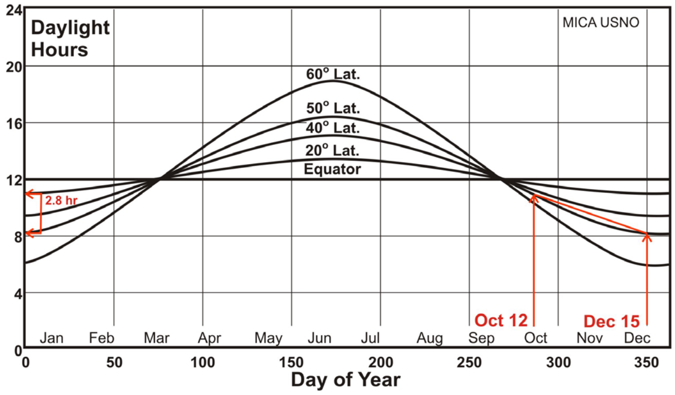

Figure 1 — Annual variation in length of daylight (sunrise to sunset) for latitudes typical of North America. In Ontario, significant snowfall may first occur as early as October or December—and even later. This corresponds to a range in the length of day of about 3 hours - 1.5hr (am) and +1.5hrs (pm). This might vary even more for other regions of the country. (Based on data from MICA-USNO)

Figure 1 shows the length of day throughout the year for temperate latitudes. Based on anecdotal reports from eastern Ontario (about +45 degrees latitude), a permanent snowpack may arrive as early as mid-October, or as late as the end of December. This has a significant impact on wildlifes' preparation for winter. These dates result in a difference in day length of 3-hours. Since the animals have apparently survived this natural variation, it demonstrates an acceptable range in behavioural plasticity to the length of day and corresponding length of night.

After the first snow falls, it suddenly becomes harder for active, foraging animals to dig for and find food. In this respect, survivability is affected by the snowfall, which is not well predicted by the preceding temperatures. In the temperate latitudes there is episodic cooling toward winter—warm

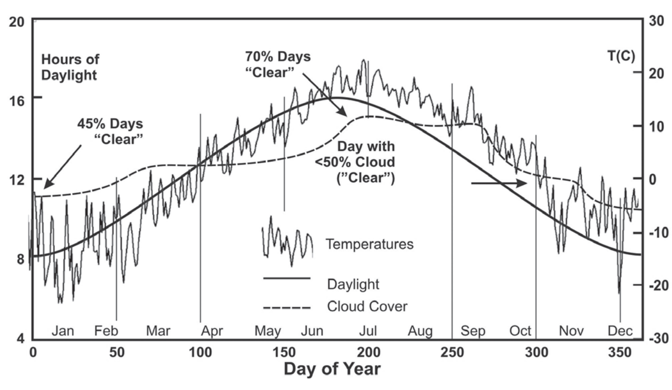

Figure 2 — Daylight, clouds, and average temperatures. The hours of daylight for Ottawa (2019) are from MICA-USNO. Cloud cover is from A. Danko, Ottawa Clear Sky Chart (SE direction between 2006 and 2020) based on average sky cloudiness with a sky <50% cloud). And, the temperatures are from www.wunderground.com/history/monthly/ca/ottawa/CYOW. Only long-term trends (monthly) are good indicators for seasonal change. Daily and weekly temperature trends are too variable from week-to-week and year-to-year to be used as reliable indicators.

periods are followed by cooler ones—and this cycle continues but with declining average temperatures (see Figure 2). Therefore, a more reliable indicator for animal survival, in the long term, is the length of daylight, or night.

Figure 2 focuses on the City of Ottawa and plots the length of daylight, average temperatures, and percentage of clear skies with the maximum range from 0 (cloudy) to 100% clear. These plots demonstrate there are several contributing factors to daytime heating and resulting challenges for animal survival.

This length of daylight has a direct effect on the accumulated solar heating, which is a function of the time the Sun is above the horizon, the angle the sunlight hits the ground,and the clarity of the atmosphere—all of which are not constant. Cloud cover and forest canopies will reduce the daytime solar heating and illumination level but will increase night temperatures in winter by reducing heat loss through radiation to the night sky.

After sunset the ambient illumination on a clear evening is halved about every 5 minutes—extending the apparent daylight by perhaps 30–35 minutes. However, the dimming effect of clouds reduces illumination from about 130,000 lux down to about 10,000 lux (about a 90% reduction). It is interesting to observe that the length of day (length of night) indicator shifts the autumn cue by about a month ahead of the typical temperature indicators, providing animals with extra time for preparation.

These variables complicate the light cues (brightness and spectra) that are used by wildlife. However, awareness of the shortening daylight is delayed by ALAN by extending daylight, and twilight ALAN —several hours might impact the animal's perception of seasonal change by up to an additional month.

These natural variations have been combined to define an approximate 2-hour dawn and 2-hour dusk tolerance or plasticity for ALAN.

Affect on Wildlife

The growth patterns of some plants, such as some cash crops, are not so closely tied to the actual length of day (Thomas and Vince-Prue 1997). Changes in the nocturnal lighting may help or hinder their growth depending on the species. Taking an urban landscape as an example, urban plants tend to be Long Day or Day Neutral plants, allowing them to tolerate the light-polluted urban environment. So the mix of urban species differs considerably from the mix of rural plants.

The departure times for migrating birds vary from year to year depending on not just the length of day but also the temperature and availability of food. Once on their journey, winds aloft will affect their progress and arrival times at their destina-

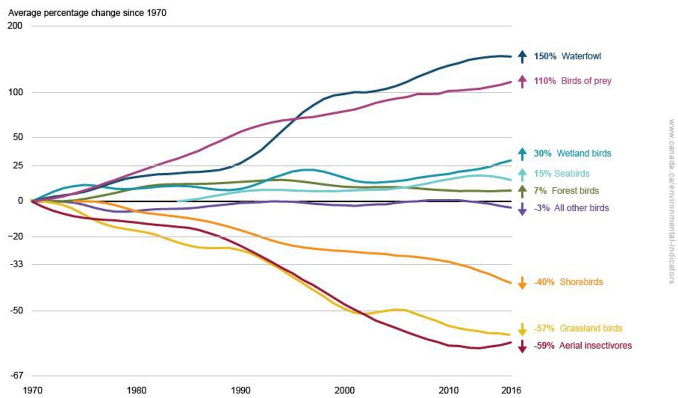

Figure 3 — Changes in bird populations over about 50 years. Not all these birds are migratory. Waterfowl and birds of prey are doing quite well at this time with the greatest declines in grassland birds and insectivores. (Canada A 2020)

tion. Given the long-term survival of the species, there appear to be some tolerance to their departure date and arrival time. Fortunately with these different cues, a cue that is at odds with the others will not rule the "fate of the fowl."

The ALAN in urban areas creates skyglow that extends over the countryside and combines with the increasing use of ALAN in rural areas. So the extended length of an urban day will have an additive effect on the local rural ALAN to delay migrations and other preparations for winter.

There is evidence for declines in some avian populations, and these patterns have been attributed to their sensitivity to urban development, and by extension ALAN. The success or failure seems due to the habitat of the species. In the migratory groups, the grassland and insectivores show the greatest decline (Figure 3 – Canada A and Figure 4 – Canada B). Factors other than the length of day or night probably affect the survival of birds but without a full understanding of this problem, for simplicity, we use a one-parameter calculation for animal plasticity (length of night) but this should be used as a "guide," not as a "rule."

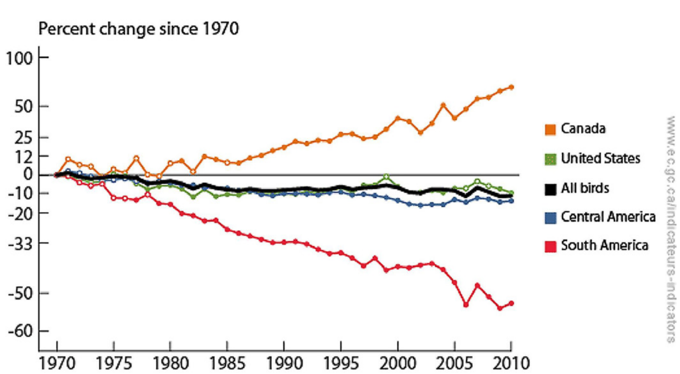

Figure 4 — Change in species by country over 40 years. The general increase in Canadian species may be due to the population concentration in relatively few urban areas. (Canada B 2020)

Human Schedule

When you go to bed and how long you sleep varies between individuals and their daily schedules, but there seem to be limits. These conclusions are based on chronobiology of many bodily functions and our circadian rhythm (Koukkari, Sothern 2006). As hunter-gatherers, our ancestors' activity was based on sunrise and sunset, and their "workday" was constrained by sunlight and did not differ very much from the animals they hunted.

In our modern society, the pattern of rural and urban activities is driven by two different priorities depending on whether the labour is outdoors (sunlight during the day and artificial light at night) or indoors (artificial light).

Urban activity is controlled only by "office hours" and is now virtually independent of the Sun. The workday is a cultural construct, which has become entrenched in our society. However, rural farm life bridges two worlds: urban and rural. It is still linked to the diurnal cycle of the Sun for planting, harvesting, and the tending of animals from before sunrise and after sunset due to their circadian rhythms.

There are relatively few people engaged in farming, but farms are expansive, and the flat, treeless fields allow light to shine for several kilometres—indeed it is limited only by the clarity of the air and the curvature of the Earth. Thus rural lighting can have wider impact on the ecology than urban lighting that is concentrated into smaller regions and is mostly shielded by tall buildings.

Urban lighting is also used by businesses to attract customers and advertise their services even after most offices are closed. This policy extends urban lighting well beyond the biological limits of the human species. It serves only motorists and pedestrians who are out to visit businesses well into the night. Regardless of the promoted popularity of late-night shopping, Figure 5 paints a different story. It is more reasonable to use the distribution of vehicle traffic density as a proxy for the need of ALAN.

The traffic records show a clear pattern of vehicle activity. Figure 5 shows the bimodal shape of the traffic density, reflecting the morning and evening rush hours. London, UK was selected for this figure because its latitude and sunset times are more similar to most of Canada than Toronto, Ontario, which shows similar patterns, as does New York, NY.

The after-hour traffic is about 1/4 that of the peak periods. Further analysis of this figure shows that for most of the year rush hour is in daylight. Anecdotal reports from residential areas indicate much less vehicle traffic and very few people walking about after 22:00. People consider this to be the end of their day and are more sedentary. Therefore even human activity abides by the 2-hour after–sunset guideline – but with an amendment.

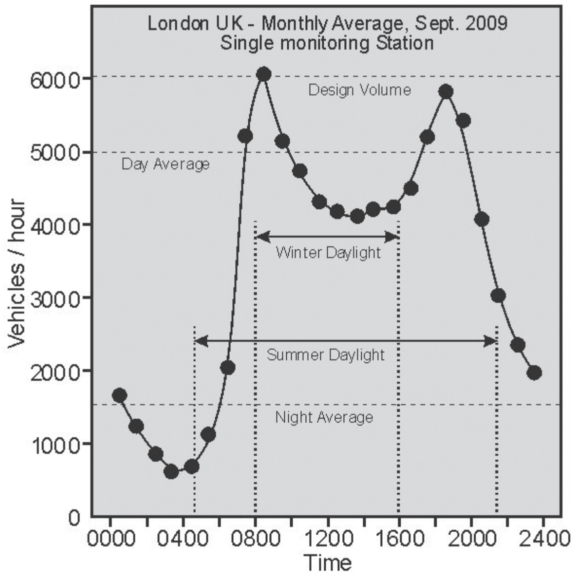

Figure 5 — Traffic pattern for a major city. Vehicle traffic shows a similar pattern in most cities. Two "rush hours" are separated by a relatively low congestion period. Before 06:00 and after 22:00, the traffic density wanes to below 1/4 peak levels. Rush hours in the northern temperate latitudes are in daylight. Therefore, ignoring car headlights, streetlights are only needed at full intensity from late autumn to early spring. (UK Gov. 2012)

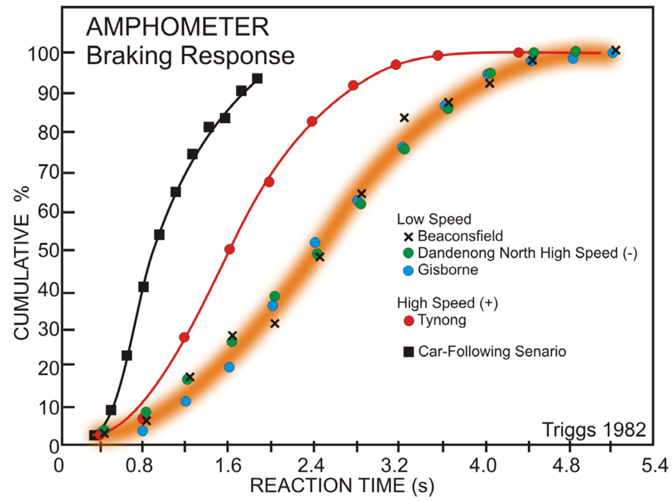

Figure 6 — Reaction times at low and high driving speeds. Arguments for increasing ALAN include the reduction of reaction times. However studies show that at low (urban) and highway speeds, reaction times are typically 2.5 seconds. It is interesting to observe that this study shows drivers travelling at much greater than the highway speed limit react faster than those going the legal speed. The study suggests this is because the drivers are being more alert. This seems supported by the "car-following scenario" that has much shorter reaction times. (Triggs 1982)

Instead of nature's sunrise and sunset, human activity is based on the workday, which is typically 8 a.m. to 6 p.m. So the 2-hour after-sunset guideline could be applied to these limits regardless of the Sun-time. The only time when there is a significant departure from the natural guideline will be in winter when nature's activity is low and the workday extends through twilight.

Light to Reduce Reaction Times

Road illumination levels are based on aesthetics through colour rendering and to improve safety by shortening the reaction time of motorists. Reaction times lengthen as illumination decreases, so busy areas require brighter levels of lighting. However, the connection between light and safety is not necessarily this clear cut (Triggs 1982).

It is generally understood that our blue- and green-sensitive scotopic vision results in slower reaction times—roughly 0.6 seconds. Our green-red-sensitive photopic vision provides shorter reaction times that extend to about 0.2 seconds. The difference is significant, so typical roadway lighting is designed for our photopic range (>5 lux).

However, Figure 6 indicates that driver attention, or distraction, has a greater impact on our reaction times than the difference between our scotopic and photopic vision. In most emergency situations when fast reactions are needed, drivers are generally distracted by the "art of driving" and roadside signage. Therefore traffic and roadway design should be based on addressing the "less-attentive situation," which delays reaction times to longer than 1 second. This renders as "academic" the need for lighting to be based on our photopic vision. It is more critical to reduce the illumination of distracting features (non-driving related signs and lighting) than to increase illumination levels that will increase the visibility of distractions.

Other Constraints on Duration of ALAN

The foregoing evidence covers the direct effects of ALAN through the night. However there are other, more indirect effects that stem from data not strictly related to light pollution. Because of the unusual nature of these studies, there has been little follow-up work. The following example is presented to show that we need to think "outside-the-box" when faced with new, and old, problems.

The Sun illuminates and heats the ground and oceans. Beyond this most obvious effect it was not clearly demonstrated until 1859 that the Sun affected the Earth's magnetosphere ("Carrington Event," Wikipedia). In the 20th century, light pollution was considered to be too tenuous to create more than a visual display at night. Yet in the 21st century, light pollution was found to profoundly affect the environment and undermine its ecological integrity.

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Into the second decade of this century, ALAN has now been implicated in exacerbating the long-standing problem of air pollution (Stark 2010). The loss of solar radiation after sunset allows molecules to form that help destroy air pollution during the night. However the spectra of ALAN carries sufficient energy to reduce the formation of these cleansing molecules, allowing air pollution to accumulate day-after-day. This suggests that dimming or turning off ALAN in the late evening when it is less important will help improve the urban environment in ways we did not expect until a decade ago.

Summary

We have the responsibility to take measures that minimize the impact of ALAN by "critically" assessing when it is used. We must not apply more weight to our "want" of light than to the evidence for its ecological impact.

Similar to the Hippocratic Oath, "primum non nocere" (Wikipedia) (first, do no harm), the onus should not be to prove there would be harm, but to ensure harm shall not be done—to the best of our current knowledge. City and lighting officials are not doctors but we believe the ethical message is applicable—especially in the profession of engineering. With the preceding and referenced research and the publishing of these papers, it cannot be said, "no one could have known." In addition, our society is increasingly respectful of the well-being of non-human species, so it is fitting that this ethic apply to our treatment of nature.

Wildlife does not require ALAN. Therefore only light used for human activity should be used. We can now estimate when peak illumination is necessary and minimize its use at all other times when there is low human activity.

Developing a schedule for lighting must include a number of factors: natural biology and behaviour, and the human need for ALAN. In this paper we have taken into account behavioural plasticity, records of several environmental factors and animal survival during extreme weather, and contemporary records of human activity at night.

The timing and flexibility of animal behaviour has been found to closely match critically assessed human activity. We have found that by limiting ALAN to 2 hours before sunrise and 2 hours after sunset, or before and after the workday, it will satisfy most human activity with reduced ecological impact. In winter and early spring, people will still require ALAN into the evening, but the activity of wildlife is also low during this time of year.

Scheduling of ALAN is important but it must be coupled with the other three attributes: brightness (luminance and illuminance), extent (shielding), and colour (spectrum).

The last paper in this series combines these four attributes of light for populated suburbs, semi-rural, and rural areas, which cover most inhabited and recreational areas. It balances them into a practical specification for outdoor lighting, which will have low-ecological impact, and that will provide sufficient light at night for most human activity.

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