Introduction

BANES is declaring a Climate and Ecological Emergency: this is timely in view of the Final Report of the Dasgupta Review published today, 2.2.21. Bath Starlit Skies believes that in view of the above, and as part of B&NES's forthcoming Local Plan Partial Update, BANES should review its Lighting Plan as there is now substantial evidence of the harm by high Correlated Colour Temperature (CCT), blue-rich lighting to eco-systems and to human health. The Commission for Dark Skies also urges action: "Given the current urgent need to save energy as our planet warms, and the evidence that waste light is a contributory factor to the rapid decline in biodiversity (www.sciencedaily.com/releases/2018/06/180619122456.htm), we should be urging all administrations, both local and national, to save energy and reverse biodiversity decline by tackling waste light." (Chapter 3, https://britastro.org/dark-skies/pdfs/CfDS_booklet_Rev07.pdf).

It appears that all living organisms, including plants, have inherent bio-rhythms. These organisms (ranging from the smallest plankton through to Man) have evolved over hundreds of millions of years to adapt to the natural rhythm of light and dark. Night and daylight act to fine-tune these bio-rhythms which govern essential health maintenance systems.

Thomas Edison produced the first commercial electric light bulb just over a hundred years ago. Since then, Man has been increasingly lighting the night-time. There is an advantage: light at night allows us to extend the day and so our activities. However, there is increasing evidence that artificial light at night (ALAN) is harmful to both the environment and human health. Particularly disruptive is blue-rich light which is being increasingly installed outdoors in the form *inter alia* of high CCT (over 3000K) street lights and commercial parking areas.

The United Nations report **Light Pollution impact on the bio-environment** (UNOOSA conference Dark and Quiet Skies for Science and Society, October 2020) https://owncloud.iac.es/index.php/s/WcdR7Z8GeqfRWxG#pdfviewer

is summarised below. The findings are supported by some 300 peer-reviewed research papers. A further and separate list of supporting references is attached.

1. The Natural Rhythm of Light & Dark

The natural light/dark rhythm is important for flora and fauna (including Man). Many vertebrates and invertebrates, including vital pollinating insects, are nocturnal. Darkness at night is essential for them to thrive: they rely on circadian, lunar and seasonal rhythms of light for foraging, migration, pairing and reproduction. Artificial light at night over-rides these natural rhythms and high CCT, blue-rich light (i.e. over 3000K) is particularly disruptive. Its effects cascade through the eco-system, affecting day-time organisms and their ecological function as well (Hölker et al. 2010a, Hölker et al. 2010b, Longcore 2010, Gaston et al. 2013; Bennie et al 2015). Artificial light at night is an additional, but avoidable stressor, on already stressed bio-systems. It should properly be considered a form of pollution but one that, fortunately, it is easy to address.

2. Fauna and Flora

About 30% of all vertebrates and 60% of all invertebrates known today are nocturnal. More than 60% of all known mammals have adapted to low light conditions at night and can be directly affected by artificial light at night. (Hölker et al. 2010b). Many mammals migrate at night-time to avoid predation, using the Moon, stars (Foster et al, 2018) and Earth's magnetic field to find their way. ALAN can disrupt migration by attracting, repulsing and disorientating species. Circadian, lunar and seasonal rhythms of light are also important for pairing and reproduction. ALAN blurs the circadian and seasonal signals for reproduction (Grubisc et al. 2019; Le Tallec et al. 2013).

ALAN and its associated skyglow affect *inter alia* :

Plants

ALAN affects plants' perception of seasonal changes and their associated physiological responses.

- Bud burst and leaf fall are occurring a week earlier and a week later in a pattern that cannot be explained by greater temperature in cities (ffrench-Constant et al. 2016; Briggs 2006; Bennie et al. 2016; Škerinová et al. 2017; MacGregor et al. 2017)
- Delays plant maturity (Briggs et al. 2006; Sinnadurai 1981)
- ALAN, particularly blue-rich, negatively impacts on the seed production of wild flowers (MacGregor et al. 2019)
- Plants use starch supplies at night to sustain metabolism and growth (Scialdone et al, 2015) and increase immune defences before dawn at the time of day when infection is most likely (Wang et al. 2011). ALAN acts to blur the light/dark signals making plants more vulnerable to disease.
- preliminary experiments show that carbon assimilation is lower in trees exposed to continuous night lighting (Skaf et al. 2010). This stress response could be critical given the importance of trees in balancing CO_2 emissions.

Insects

- Insects represent more than half and potentially 90% of known living organisms (Novotny et al 2002; Chapman 2006)
- a review of 150 insect studies (Owens et al. 2020) concluded that artificial light at night is a significant cause of insect loss. Decline in insect populations have been observed under long time exposure to ALAN (van Grunsven et al. 2019) Insect population collapse is occurring across the globe. This is a clear threat to Nature's eco-systems and ultimately to the global food supply.
- 60% of all insects are nocturnal and moths are amongst our most vital pollinators (Walton et al. 2020).
- Ultra-violet and blue-rich light is highly attractive to insects (Eisenbeis 2006, Frank 2006, van Langevelde et al. 2011, Barghini and de Medeiros 2012). ALAN exerts a 'vacuum cleaner' effect (Eisenbeis, 2006), drawing insects from their natural environment and behaviours (Meyer and Sullivan 2013)
- such insects, include moths, lacewings, beetles, bugs, caddisflies, crane flies, midges, hoverflies, wasps (Sustek 1999, Kolligs 2000, Eisenbeis 2006, Longcore et al 2015), are already a vital food source for other animals such as bats, birds, toads and spiders. Light sources attract insects away from their normally wide distribution and, by being

concentrated, are at increased risk of predation. Numbers and distribution are consequently affected (Blake et al. 1994, Frank 2006) as is pollination.
The attraction of moths to light alters foraging habits. For example, bats that normally prefer beetles and other small insects, will consume more moths. A Common Pipistrelle can consume more than 3,000 moths in one night (BANES : Bath's Bats - Young People's Page; Bat Conservation Trust)

- moths are particularly attracted to blue-rich light. They account for nearly 95% of all Lepidoptera and, along with bees, are vital pollinators (Pro Natura, 2019). They often die of exhaustion, predation or because they are trapped by fittings (Frank 1988, 2006).
  Pollination activity of moths has been found to be reduced in the presence of street lights (Macgregor et al. 2017, Knop et al. 2017). A Swiss study also noted a 62% decrease in pollination in the presence of ALAN (Knop et al, 2017).
  The carcasses of dead insects seem to attract an increase in phytosanitary pests (slugs, snails, spiders and rats etc) (Davies et al. 2012; Manfrin et al. 2018; van Grunsven et al. 2018)
- ALAN affects reproduction: moths use scent to find a partner and can travel many kilometres to find a mate. (Pro Natura 2019); however, the quality and quantity of the pheromone in female moths exposed to street lighting has been found to be reduced in those exposed to high CCT lighting (van Geffen et al. 2014); the bioluminescence of female glow-worms is found to fall in the presence of street lighting (Elgert et al. 2020). Mayflies emerge and look for polarized light. They find it in asphalt and other surfaces which resemble water. However, eggs laid on asphalt die, thus reducing the mayfly population (Szas et al. 2015).
- insects are a vital food source for many organisms; bats, which in natural conditions rather catch beetles, will consume more moths (Cravens et al. 2017), which in turn leads to decreased nocturnal pollination
- blue-rich light is highly attractive to insects and is driving insect declines (Owens et al. 2020 https://www.sciencedirect.com/science/article/pii/S0006320719307797?via%3Dihub)

Bats

Bath is part of the Bath and Bradford-on-Avon Special Area of Conservation. BANES Lighting Policy D8 cites Bat Conservation Trust guidance 2009. This has been replaced by ILP/Bat Conservation Trust Guidance Note 8 (2018) Bats and Artificial Lighting in the UK which sets an upper limit for outdoor/streetlighting of 2700K. BS5489-1 2013 has recently been updated (2020).

- there are 18 different species of bat, 15 of which can be found in and around Bath Bristol Regional Environmental Records Centre | NBN Atlas)
- they are protected species
- responses of different types of bat to ALAN are complex (Rydell 2006; Voigt et al. 2018). Manoeuverable species may be attracted to high prey abundance around light (*see* **Insects** *above*); slower species will be repulsed by ALAN
- light near roosts can deter bats from emerging to forage (Boldogh et al. 2007) and can lead them to abandon roosts (Stone et al. 2015b). This in turn affects health and reproduction which is important as most bats only have one pup a year.
- occurrence and activity is affected more by ALAN than imperviousness of land by development. (UNOOSA 2020)

- dark crossing routes need to be protected for sensitive species. Best practice suggests that lighting levels should be congruent with the least lit area https://www.britastro.org/dark-skies/pdfs/CfDS_booklet_Rev07.pdf. This is particularly important for bats.
- *Pipistrellus spp* can be attracted especially to white and green lights (Spoelstra et al. 2017) and be distracted from their migration routes (Voigt et al. 2017)
- The best bat-friendly lighting is red with a CCT of around 1000K – 1500K (seen here in Worcestershire https://www.worcesternews.co.uk/news/17870050.innovative-bat-friendly-lighting-project-installed-warndon/ and Holland https://www.smartcitiesworld.net/news/news/dutch-town-installs-bat-friendly-lighting-2998)
- "If the city is good for wildlife like bats, then it will be delivering real benefits for people too." (BANES, River Avon Bat Project). Truer words were never spoken.

Birds

- ALAN affects diurnal species as well as nocturnal species. It affects the timing of dawn and dusk song, seasonality of reproduction, mate choices and can extend diurnal activity into the night, thus affecting nocturnal species (Stracey et al. 2014)
- Approx. 40% of birds migrate and an estimated 80% of them do so at night to avoid predation. They, along with other migratory species, use the moon, stars and the earth's magnetic field to navigate (Foster et al. 2018). Light sources can confuse and blind them. There is danger of collision with natural structures, lighting towers and buildings (Telfer et al. 1987; Rodriguez & Rodriguez 2009; Miles et al. 2010; Rodriguez et al. 2014, 2015; Longcore et al. 2012, 2013, Gehring et al. 2009). Collision can be reduced by warmer spectra and lighting densities (Rodriguez et al. 2017; Rebke et al. 2019)
- They are disproportionately attracted to ALAN in urban areas. This takes them away from rural habitats and higher food availability (MacLaren et al. 2018)
- Low levels of light (0.3lx) can move reproductive seasonality of songbirds by a month and cause irregular moult progression (Dominoni et al. 2013a, Dominoni et al. 2013b). Altered seasonality has obvious consequences for the availability of food for fledglings.
- Streetlighting is known to alter the timing of the dawn chorus of songbirds, affecting mating choices and in turn fitness (Kempenaers et al. 2010) In fact, many songbirds seem to be active at night when they should be resting, keeping warm and conserving energy.
- Roosting habits are also affected (Tillmann 2009) and night-time activity of diurnal species can result in higher susceptibility to infection (Ouyang et al. 2017)

Non-flying mammals

Permanent outdoor lighting can erode connectivity for wildlife species (Stone et al. 2009). The existence of the lights themselves, whether shielded or not, is sufficient to influence wildlife movement (Beier 1995, 2006).

The activity, movement and food consumption of even small mammals in low levels of artificial light (0.1lux) is reduced (Clarke 1983, Brillhart and Kaufman 1991, Vasquez 1994, Falkenberg and Clarke 1998, Kramer and Birney 2001)

Lit habitats are often lost to use by nocturnal wildlife and are often not used by day-time organisms. (Longland 1994; Rotics et al. 2011; Le Tallec et al. 2013; Ciach et al. 2019). These areas become 'blind ecological spots' which can become vulnerable to invasive species more adapted to man-made disturbances. Pollination activity is reduced in areas where plants are exposed to streetlight (MacGregor et al. 2017)

Aquatic organisms

- The drift of insect larvae is impaired in illuminated flowing waters (Henn et al. 2014, Perkin et al. 2014)
- The nocturnal vertical migration of zooplankton and small fish is suppressed (Moore et al. 2000); paired with the observation of altered periphyton growth and changed phytoplankton community structures in freshwater bodies (Grubisic et al. 2017, 2018; Poulin et al. 2014) this could potentially trigger algae blooms and significantly decrease the quality of water in freshwater systems
- The horizontal migration of migratory fish (i.e. salmon, eels) is impaired around illuminated crossing structures such as bridges and weirs (Cullen & McCarthy 2000; Lowe 1952; Nightingale et al. 2006)

3. Human Health

Concern has been raised about possible retinal damage from blue-rich lighting (Kanterman 2009, Pauley 2005; Marie et al 2010; Behar-Cohen et al 2015, Jin-Xin Tao et al 2019). Low intensity light can cause retinal damage over time in animal models and therefore, theoretically, it may accelerate age-related macular degeneration (Walls 2011, Marquioni-Ramella 2015, Nowak 2014, Paskowitz 2006). This is a particular consideration for the very young and older individuals (Grimm 2013, Marie et al 2018). Paradoxically, intermittent exposure may cause greater visual cell-damage than continuous exposure (Organisciak 1989)

The following considers the role of ALAN in melatonin suppression and its association with diabetes, obesity, cancer and depression. It should be borne in mind that the purpose of street lighting is to increase overall safety of people and traffic, not compromise vision, safety and public health.

- the retina contains 3 principal types of receptor cell: cones (that relate to day-time vision and colour); rods (that relate to night-time vision and are light-sensitive) and Intrinsically Photosensitive Retinal Ganglion Cells (ipRGCs). The latter were discovered as recently as 2002 and mediate the pathway of melatonin regulation. ipRGCs are particularly sensitive to blue wavelengths.
- under natural light/dark conditions, melatonin is produced at dusk and falls away again at dawn. Rising levels of melatonin induce sleepiness, body temperature drops, and hunger abates along with other responses. However, light at night suppresses melatonin production, disrupts circadian rhythm and compromises sleep and health. Good quality sleep is essential for the body to repair itself.
- ALAN suppresses normal melatonin production. Blue-rich light is 3 times more disruptive to circadian rhythms than high-pressure sodium (HPS) (Koo 2016, Falchi 2011, Lucas 2014)
- Circadian disruption is associated with increased cancer risk, diabetes, obesity and heart disease (Cappuccio 2010, Lunn 2017, Gangwisch 2009, Pietroiusti 2010, Masis-Vargas et al. 2020,)

- ALAN is associated with increased risk of breast cancer in female shift-workers (International Agency for Research on Cancer (IARC) studies). 4000K street lighting has more recently been associated with breast, prostate and colorectal cancer (Garcia-Saenz 2018, Garcia-Saenz 2020)
- White light during the 12-h dark phase has been shown to stimulate tumour growth (Anisimov 2004). Melatonin acts as a nocturnal anti-cancer signal: it has anti-proliferative and anti-oxidant properties (Brzezinski 1997, Korkmaz 2009, Reiter 2010). Anyone exposing themselves to light after dark or before dawn is overriding the natural light-dark pattern and the protective effect of melatonin (UNOOSA, 2020)
- a threshold has not been established for melatonin suppression in humans and the Precautionary Principle (Earth Charter) suggests that until the threshold is known, blue-rich light should be avoided.
- Russell Foster, Professor of Circadian Neuroscience in Oxford, has stated that sleep disruption and mental illness invariably co-exist. Satellite-measured light at night is associated with more insomnia drugs, even after other factors (BMI, alcohol, smoking etc) are taken into account.

Conclusion

A number of well-respected national and international organisations (such as the Commission for Dark Skies, CPRE – the Countryside Charity, All-Party Parliamentary Group on Dark Skies, Public Health England, American Medical Association, International Dark Sky Association, United Nations Office for Outerspace Affairs (UNOOSA), French Government, Mexican Government) are uniting to drive the move towards environmentally-responsible lighting. Light travels in straight lines and in urban and sub-urban areas it has a cumulative and pervasive effect that extends for many miles beyond the point of emission. Photons know no borders (Bará and Lima, 2018) and are reflected from the ground and cloud cover. There are many forms of pollution of which ALAN is a contributor. UNOOSA states : "Artificial light at night introduces into the atmosphere a huge number of photons that should not be there during night-time, and that give rise to detrimental consequences either by its own direct effects (e.g. by directly activating key physiological processes or distorting predator-prey relationships) or by reducing the spatial and temporal contrast of the natural night light cycles (e.g., erasing the monthly rhythm of natural illumination associated with the Moon)."

As a society we are increasingly aware of the complex ecological web on which Life on Earth depends. The natural alternation of night and day, light and dark are essential to many life forms and it is imperative that we start restoring more natural levels of lighting at night. It is not a question of being anti-LED but about recognising that all forms of life are connected. We are part of the ecosystem and depend on a healthy ecosystem for our well-being and survival. The issue is to refine our use of LEDs by making intelligent use of the available spectrum of CCTs and redirecting our choice towards 2700K and ideally 2200K not only for the sake of our starlit skies but also for the benefit of the bio-environment, our health and the well-being of future generations. As a UNESCO World Heritage site, Bath and its environs should be exemplars of responsible lighting practice.

The right light, at the right place, at the right amount, for the right duration

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Introduction

1. Dasgupta Review : Final Report. (02.02.2021) https://www.gov.uk/government/publications/final-report-the-economics-of-biodiversity-the-dasgupta-review

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