Bats and lighting — six years on

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Abstract

Since my 'Bats and lighting' review (Fure 2006), there has been interesting comment from a number of sources: bat workers, entomologists and those from ophthalmic fields; lighting professionals from the UK and Europe; and natural light campaigners (CPRE and the Campaign for Dark Skies, CfDS). There has also been an increase in studies, reviews, publications and guidance. Topics range from bat ecology, bat physiology, bats v. illumination and insects v. illumination, and as prey species, rendering the initial review out of date. All beg for a swift and positive intervention to change the way that we light the environment.

Introduction

Recent increases in the levels of illumination have met with detailed responses from many sources including

- The Royal Commission on Environmental Pollution reporting on the negative ecological consequences of illumination for most species (Lawton 2009)
- Research on the effects of illumination on bats: at their roost (Boldogh et al. 2007), along commuting routes (Stone et al. 2009, 2012) and foraging areas (Fure and Wedd 2010), and widely reviewed (Eurobats 2010)
- The publication of the 'Ecological Consequences of Artificial Night Lighting', a summary of the negative influences of illumination on mammals, birds, reptiles, fish, insects and plants (Rich and Longcore 2006)
- Research on the effect of increasing urbanization and the 'tipping point' for pipistrelle bats (Hale et al. 2012)
- Unpublished research on the monitoring of insect abundance and bat activity whilst manipulating light levels (Evens 2012)
- Comprehensive reviews on insects, which form the prey species of all bats on the British list and the effects of illumination (Eurobats 2010, Bruce-White and Shardlow 2011).

The Buglife review (Bruce-White and Shardlow 2011) was a turning point, highlighting the scale of disruption to many ecological processes, as well as 'termination by lamp', of a complex and beautiful life cycle. In order successfully to mitigate the effects of artificial illumination on bat populations, it is essential to understand the interactions of bats and insects and the effect of lighting. The following focuses on the London region, a champion for light pollution (LP) and is aimed particularly at the fieldworker charged with balancing the sociological and ecological, with regional values and norms, using data gleaned from an armoury of scientific instruments. It gives examples of the most accessible research (post-2006) and attempts to answer the two most often asked questions: why do bats feed around lights and what are the maximum acceptable lux values at important bat commuting and foraging habitat. There is comment on guidance and policy measures to see if they are adequate or whether it is poor enforcement or sheer lack of will that has led to uncontrolled illumination blotting out the night sky in our region. The report ends by sharing measures which have been usefully employed on projects with varying degrees of success. It hopes for an 'Olympic' legacy: to ensure that from this point on, each successive year will not only see a reduction in illumination (especially along our rivers and canals) but a diminution of our tolerance of unnecessary lighting, viewing it as a form of anti-social behaviour.

Many London councils are increasingly acting as commissioning bodies, with a reduced role in service delivery. Councils are extending the opportunity to local interest groups to take over the management of parks and open spaces. It is these groups who are in the front line when protecting their local sites from character-changing planning applications, or the use of protected areas as theme parks or sports stadiums. In my own borough, there is an application to incorporate 218 light units into an area featuring a Daubenton's bat *Myotis daubentonii* maternity colony, one of only four recorded in the region in as many years. This indicates the need for a louder message, achieved by more conduits from scientific papers to grass roots, in order to disseminate information to those in the frontline. Anthropogenic in nature, LP issues cannot be separated from politics, economics and culture.

What follows is largely London-centric. It does not necessarily seek to repeat advice expounded by the Bat Conservation Trust (BCT), the Institute of Lighting Professionals (ILP) or the Campaign for Dark Skies (CfDS), which all offer invaluable guidance. It is worth stating at the outset that the author is in accord with a strapline of the ILP 'Lighting where needed and when necessary'. It is beyond the scope of this report to comment on light dimming or part-night lighting where it has been invoked (Leicestershire, Norfolk etc.). This has been done not as a protection measure for nocturnal wildlife or the night sky, but as a cost-cutting measure, as councils collectively spend £529 million on street lighting, which accounts for 5–10 per cent of each council's carbon emissions.

Studies

A limitation of Fure (2006) arose from a lack of published material examining the physiology of bat retinas. It has been believed that the retina of microchiropteran bats contained predominantly rods, the photoreceptors at the basis of 'scotopic' vision (vision of the eye under low light conditions) and that bats lack cones. Recently it has been demonstrated how at least some species (common pipistrelle bats *Pipistrellus pipistrellus* and greater horseshoe bats *Rhinolophus ferrumequinum*) possess a significant number of cones (Kim et al. 2008, Müller et al. 2009). Nevertheless, the size and shape of eyes, photoreceptor organization, and colour sensitivity differ dramatically depending upon an animal's specific needs and photic environments, and the arrangement of cones has not yet been established in *Myotis* bats. Bat vision has been shown to be best in low ambient lighting, due to the high proportion of rods compared with cones. Having eyes sensitive to low light levels (more sensitive than human eyes) a bat confronted with artificial light may be an annoyance and possibly painful (Limpens et al. 2012).

It is therefore worth restating at the outset that emergence times from roosts appear to act as an indication of the differing light tolerance through the range of species. Those bats which emerge late in the evening, such as *Plecotus* and *Myotis*, particularly the Natterer's bat *Myotis nattereri*, have a reduced tolerance to lighting. But as intensity of light increases, even relatively light-tolerant species are delayed in emergence from their roosts. Larger, high-flying species such as noctule *Nyctalus noctula* are not as affected by illumination. They will often fly during the daytime and feed above installations employing security lights. LP, either direct or indirect (from sky glow) is increasing in London and may eventuate in outstripping the tolerance of *Myotis* species. Daubenton's bats have been declining on London's waterways (Briggs et al. 2007).

Since the 2006 review, researchers have demonstrated the conservation consequences for bats from illuminated roosts, feeding after a delayed emergence (Boldogh et al. 2007). Mothers from illuminated maternity roosts produced juveniles with smaller forearm and body mass measurements than the young from unlit roosts. This is after the peak availability of insects, leading to inferior foraging opportunities for bats.

The effect of illumination on commuting bats has been measured at linear features. These can be energy saving for bats, offering reduced exposure from weather conditions, such as wind and rain, and also reduce predation exposure (Stone et al. 2009). The researchers installed high-pressure sodium lights to mimic the intensity and light spectra of street lights along commuting routes of lesser horseshoe bats *Rhinolophus hipposideros*. Bat activity was reduced dramatically and the onset of commuting behaviour was delayed in the presence of lighting (with no evidence of habituation). The results of the study demonstrated that illumination has a significant impact on the selection of flight routes of bats.

Subsequent studies demonstrated little difference in both the magnitude and nature of the impact of LEDs on lesser horseshoe bats *R. hipposideros* and *Myotis* species, causing a significant reduction in activity along lit hedgerows (Stone et al. 2012). Researchers found that even the lowest light levels (3.6 lux) had an effect on behaviour. They stated that lower levels of illumination may not be suitable for human use.

Kuijper et al. (2008) placed a light source along existing commuting routes which clearly disturbed the behaviour of another *Myotis* species, commuting pond bats *Myotis dasycneme*. Foraging behaviour, expressed as the percentage of feeding buzzes, was reduced by 49–84 per cent during the four nights along Workumertrekvaart with experimental light compared to nights without light. The highest proportion of bats turned between fifteen and ten metres distance from the light source at light levels of approximately 0.6–3.2 lux. This indicates that light levels slightly above natural light values (in this example moonlit nights were given as 0.12 lux) along commuting routes may have disturbing effects. If these disturbing effects take place on a large scale, they may have negative effects on the fitness of individual bats, particularly lactating females. The aim should therefore be to keep light away from the feature of interest (as well as reducing sky glow). Perhaps there is no acceptable illuminance level at a feature, especially when we have technology to prevent it.

Bat Groups occasionally undertake surveys on the effect of illuminating water on the foraging behaviour of Daubenton's bats. During studies of water bodies, Daubenton's bats were negatively influenced by the addition of artificial lighting and foraging activity was reduced (Surrey and Lancashire Bat groups; see Fure 2006). This type of study is repeatable on a large scale and the effect of relatively small changes in light levels created by different moon phases is apparent.

Twenty-one surveyors from the London and Hertfordshire & Middlesex Bat Groups along with the London Borough of Redbridge Ranger Service, participated in a Moon Phase Survey at eight sites (Fure and Wedd 2010). Bat counts were made at open areas around water bodies during 'No Moon' on 10 August 2010 and the 'Full Moon' on 24 August 2010. Standing at a spot in an open area, participants counted the number of Daubenton's bat passes obtained, using a torch. When the number of passes was compared, it was found that activity was reduced by almost two thirds (63 per cent) (at sites where data were obtained) during the full moon (Table 1). The results can be used to inform light threshold information as a full moon at its peak can be as low as 0.25 lux in the London region (0.1–0.3 under clear conditions elsewhere; Rich and Longcore 2006). A clear relationship between bat activity and light has been noted during surveys. As light levels increase bat activity decreases or changes. Daubenton's bats were not found *routinely feeding* above 0.1 lux (Fure 2006). *Myotis* species are associated with dark river conditions created by overhanging riparian vegetation in urban areas.

An unpublished study (Evens 2012) considers the vacuum effect of insect attraction to a light source which 'left the light shy *Myotis* species with reduced insect prey at their preferred foraging areas' (the water surface). Evens carried out insect sampling, using a net attached to a handle. Metal stakes positioned

TABLE 1. To show the number of Daubenton's bat passes during different moon phases.

	Number of Daubenton's bat passes during 'No Moon' 10 August 2010	**Number of Daubenton's bat passes during 'Full Moon' 24 August 2010**
Oakmere Lake, Potters Bar 3 stations	83	31
	273	103
	370	187
Pen Ponds, Richmond 3 stations	260	0
	60	0
	160	119
Total	**1,206**	**440**

two metres apart were used as a guide to conduct ten sweeps progressing from ground level to a height of three metres. Insects were divided into five size classes, between 0–1.9 mm and 20+ mm. Insect sampling occurred between the lamp and the riverbank at each study site. The study concludes that even a relatively low level of illumination can have significant impacts not only upon bats but also insect activity and leads to changes in species assemblage, giving a competitive advantage to pipistrelle bats and reduction in foraging success of *Myotis* species.

Recent Dutch studies have attempted to find a wavelength with the least effect on bat behaviour and various colours have been trialled. Green LEDs have been used in Assen, Netherlands, to illuminate cycle paths along natural areas, although effects on bat behaviour can still be observed (Glazenborg et al. 2010) and R. Meijer (pers. comm., July 2012). The search for solutions and a desire to lessen the impact of lighting on the environment means that green-coloured street lighting can be seen illuminating roads at several municipal locations. There are no empirical studies supporting the use of this wavelength for bats but it probably originates from the work on oil rigs and birds (Poot et al. 2008).

The Dutch Mammal Society has demonstrated that bats cannot see amber-coloured lights. In a field experiment on a flight path of pond bats *Myotis dasycneme* following a forest canal in 2010 where no artificial light was present (Limpens et al. 2012), different light treatments were compared: darkness, amber, traditional white street lamps and a green. Five units of floating automatically recording stereo HET detectors were positioned in the canal. The results showed a lower total of bat passes when white and green were used as compared to darkness, and no difference between darkness and amber, suggesting avoidance of white and green. A paper with details of a 'bat friendly colour spectrum' will be given by Limpens et al. at the Irish Bat conference in September 2012. Examples of the use of narrowband amber LEDs are found in the section on case studies.

A four-year study led by the Netherlands Institute for Ecology at Wageningen and Wageningen University is looking at the effect of four different coloured-light treatments, which include the spectra used in Philips ClearField and Clearsky lamps (K. Spoelstra 2012, and pers. comm.). The study is taking place in the Veluwe nature reserve, through a forest edge gradient. Four rows of street lighting columns with luminaires containing green, white and red LEDs (along with a control for no light) have been temporarily erected at 150-metre intervals. The columns are placed twenty-five metres apart and monitored by bat-detection equipment positioned on nearby trees (Figures 1 and 2). These will record the species and number of bat passes at each station, while camera traps monitor additional mammal species, whilst bird groups study birds nesting in the vicinity at each light treatment. Moths are collected with Heath traps; changes in plant community and phenology are monitored. It is possible for independent researchers to study the effects of the different lamps on species from their fields of interest by arrangement with the project leader.

The extent and density of urbanized land-use is increasing, with implications for habitat quality, connectivity and city ecology. Little is known about 'densification' thresholds for urban ecosystem function and the response of nocturnal mammals is poorly studied (Hale et al. 2012). In this study, common pipistrelle activity exhibited a non-linear relationship with the area of built land cover and was much reduced beyond the threshold of about 60 per

FIGURE 1. A monitoring station. *Photo: A. Fure*

FIGURE 2. Lighting columns, Veluwe. *Photo: K. Spoelstra, July 2012*

cent built surface, implying the existence of a threshold or tipping point. Protecting and establishing tree networks may improve the resilience of some bat populations to urban densification. The researchers argue for further study of the impacts of lighting, roost availability and the abundance of insect prey to explain these results. Their work continues to map nocturnal landscapes from the air and, with the aid of very high-resolution images, analyse lighting installations across the city of Birmingham and elsewhere.

Moth species have declined by 75 per cent in recent years (Bruce-White and Shardlow 2011). As the wavelength of light decreases, the attractiveness to insects increases. As low-pressure sodium light has wavelengths in the region of 555 nm it does not attract insects. High-pressure sodium does attract some insects, but on average 57 per cent fewer insects than mercury-vapour light source (Patriarca and Debernardi 2010). A popular theory for the flight-to-light response is whereby insects mistake light sources as the moon, upon which they rely for nocturnal orientation (Frank 2006). This positive 'phototaxis' can lead to demographic insect losses and a third of the insects that fly around light will damage themselves or die.

The effect of illumination on organisms in the water column could compound the disadvantages of illumination for Daubenton's bats. Light pollution, or the sky glow produced by inefficient outdoor lighting, can affect water quality because zooplankton grazing influences water quality and the depth distribution of many organisms is affected by light. A field experiment manipulating underwater light intensity at night was performed in a suburban lake bordering a large metropolitan area. Diurnal vertical migration of *Daphnia* was significantly reduced in both amplitude (2 m. lower) and magnitude (10–20 per cent fewer individuals) by urban illumination of a suburban lake. Reduced algal grazing by zooplankton at night in the upper layers could potentially contribute to enhanced algal biomass in lakes and coastal waters near urban areas, thereby lowering water quality (Moore et al. 2000).

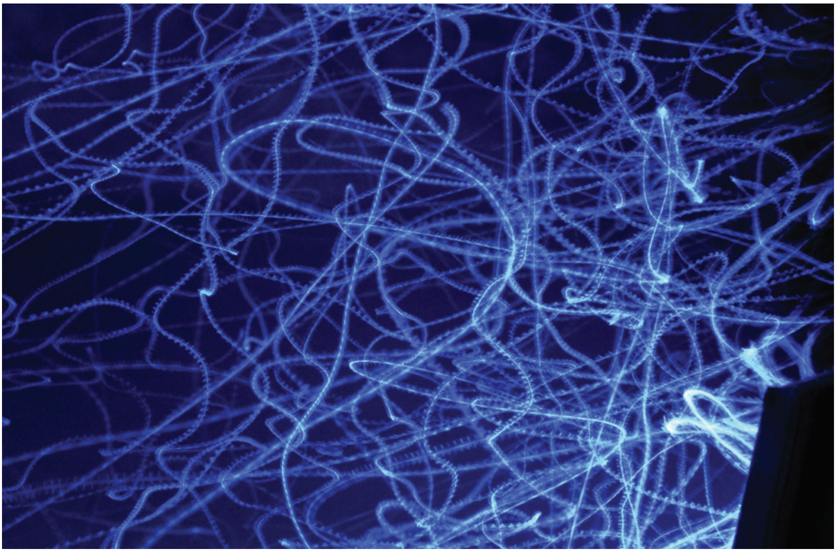

FIGURE 3. Insects attracted to light. *Photo: P. Waring, 2012*

Why do some bat species feed around lights? — (the majority of UK bat species do not). The most well-known effect of artificial light at night is its attraction of insects, especially to high UV content (Figure 3). When attracted to artificial light sources, insects deviate from their natural habitats and from their natural behaviour and also this can lead to demographic losses. Lights could be providing 75 per cent of the insect food resource in an area, as they are drawn from habitat patches to feed around lights (Bruce-White and Shardlow 2011). The draw of insects to artificial lighting has been termed the 'vacuum effect' (Eisenbeis 2006). This insect attraction leads to a reduction in insect density in the environs, leaving light-shy bat species at a significant foraging disadvantage. With the insects removed from the park, cemetery or water body and concentrated in a particular way, is it not surprising that bats will opportunistically feed on a concentrated resource in the same way that dippers will leave streams to feed on blackberries; dormice will eat from bird tables (National Dormouse Monitoring Scheme data); dolphins will feed at the strandline (Duffy-Echevarria et al. 2008); and bears will take fridge stuff. These are high-risk strategies, performed away from areas where these animals **routinely forage**.

Legislation, guidance, policy and good practice

Amendments were made to The Conservation of Habitats Regulations (HR) (2010) to strengthen the protection of features of importance that protected species are reliant upon (should include the effect of LP on waterways, treelines and other linear features that bats are using). This includes **any** disturbance to bats or a disturbance affecting:

- The ability of a group of animals of that species to survive, breed, rear or nurture their young
- In the case of migratory species, impair their ability to hibernate or migrate, or
- The local distribution or abundance of the species.

This may preclude fragmentation of corridors caused by illumination, and a useful discussion of this is provided by Garland and Markham (2007) who attest that although the Bat Mitigation Guidelines (Mitchell-Jones 2004) state that bat 'foraging areas and commuting routes are not legally protected', that there is a legal basis for the protection of these features within the HR, The Natural Environment and Rural Communities Act (NERC 2006) planning policy, and international treaties. They argue that ecological consultants should be putting forward a legal argument for the protection of bat foraging and commuting habitat, rather than solely relying on convincing developers and local planning authorities of the merits of good practice. They give an example of floodlit sports pitches (marinas and roads) illuminating at the same time as bats become active. Should bat movement along these corridors be inhibited by lighting, then this could constitute illegal disturbance.

In a recent High Court judgment in the case of Crystal Palace (Keith 2012), two members of the Crystal Palace Community Association (CPCA) challenged the Secretary of State's (SoS) approval of a planning application. It was accepted by the court that a small impact to a secondary commuting route is a disturbance, which may require a licence, as it causes bats to deviate from their normal flight route (it follows that other similarly mentioned impacts such as lighting, could also be a disturbance). It can be concluded that the courts and legal counsel accept that disturbance means changes to important activities such as foraging/commuting for a bat colony. This might be at odds with what appears to be the accepted view that disturbance involves something likely to lead to harm and should be tied to a roost. By attempting to demonstrate harm we may be creating more work than we need to. We (those concerned to conserve bat populations) only need to demonstrate a disturbance to engage the Regulations.

Dutch Agencies' interpretation of the Directive may be more related to conservation principles and licences are necessary where impacting on flight paths or foraging areas (not tied to roosts). It may be it is the Dutch interpretation that has led to innovative solutions such as the 'bat-lamp'. Licences ensure that flight paths remain functional (e.g., are not illuminated) during and after construction works, or are compensated before existing paths would be affected. Dutch licence applications are in the public domain and open to consultation. In 2009, public pressure caused the competent authorities to decide that no permits were needed in cases where all negative effects would be mitigated. However, in March 2012 a judge decided that this is a wrong interpretation of the Flora and Fauna Act (V. Loehr 2012, and pers. comm.).

The Royal Commission on Environmental Pollution, led by Sir John Lawton (2009) reported on the nuisance caused by badly designed lighting and the effects of artificial light on nature and ecosystems. It stated that lighting should be reviewed on motorways and could be removed from urban parks. Local authorities should attend to the outcome of the trials to examine the impact of reducing or turning off lighting in quieter areas, where there is insignificant use of the roads. The commission concluded that there was a need for government to recognize that artificial light in the wrong place at the wrong time is a pollutant, which can harm the natural environment.

A statement by the Bat Conservation Trust (2011) on 'Lighting and Mitigation for Bats' resolved that smarter lighting, rather than less lighting, is key to mitigating the effects of light pollution. Light should only be erected where it is needed, illuminated during the time period it will be used, and at levels that enhance visibility. Any bare bulbs and any light pointing upwards should be eliminated. The spread of light should be kept near to or below the horizontal. Narrow-spectrum bulbs should be used to lower the range of species affected by lighting and light sources that emit ultraviolet light must be avoided. Reducing the height of lighting columns as light at a low level reduces ecological impact. For pedestrian lighting, low level lighting that is as directional as possible should be used and below 3 lux at ground level.

Central police advice is that pedestrians should not be drawn by the use of lighting, into an area where there are high crime levels (PC Ike Gray, pers. comm., March 2008). Joint policy guidelines issued by the Metropolitan Police and British Waterways (Anon. 2008) state that, 'whilst waterside lighting may be an operational requirement in locations such as lock sides, encouraging access to the waterway after dark may increase levels of criminal activity that would not otherwise occur. Lighting should be used to draw pedestrians away from urban watercourses at night.

During a presentation entitled A Legal Update on Light Pollution, Morgan-Taylor (2012) suggested that paragraph 125 in the National Planning Policy Framework (NPPF), creates an obligation on local authorities to tackle light pollution and introduces the concept of 'good lighting design', which, if clarified for local authorities, may help foster a uniform approach. The benefits in the revised ILP 'Guidance Notes for the Reduction of Light Pollution' and the draft BRE (Building Research Establishment) light-pollution guidance are worth examination.

As mentioned, the European situation varies between countries and may be more tightly controlled in France, Netherlands and Belgium. Neon signs can be no brighter than street lighting (see Appendix 1 for a copy of the legislation). The Flemish 'Control of Nuisance Legislation' requires that open-air light sources should be limited to 'necessities related to operation and safety'. Lighting must be conceived in such a way that 'non-functional emission of light' to the surrounding area is limited. For example, if accent lighting is installed at an historic building, legislation requires that only the building/feature should be lit and not the surrounding areas (or vegetation). Note that some London boroughs are now refusing new applications to up-light buildings (recent increase due to marketing and fashion) and any new lighting of waterways, where there is no existing lighting.

There are courses aimed at those who would like to learn more about lighting in relation to bats (aimed at those with existing experience of bat surveys and mitigation) as it focuses on specific aspects which are often overlooked or not given sufficient consideration. They are based in north Lancashire, Snowdonia and Wiltshire (Waring 2012), and if sufficient demand, can be extended to cover London.

The courses content includes sessions on:

- Artificial lighting and measuring light levels
- Bats and lighting — what we know
- Bats and lighting — what we think is the case
- Implications for bat surveys and mitigation.

Enabling participants to take measurements of light levels; make confident judgements about lighting and impacts on bats as well as make detailed comments on lighting scenarios in relation to impacts on bats.

The legislation, guidance and policy section is stronger and longer (Fure 2006) so why is LP a bigger issue, with new lights appearing in parks, along waterways and up-lighting the most nondescript of buildings. There was a 24 per cent increase in LP in the UK between 1993 and 2000. The South-East is the worst area of Britain for LP, with only 1 per cent of land being classed as a 'truly dark' area (CPRE 2009). In the last five years so-called lighting improvements have been implemented on many of the rivers and canals in the region. Light levels along the Thames and Grand Union Canal are probably the highest, in contrast there are some stretches along the Regent's Canal, still unaffected by illumination (Fure and Wedd 2006, 2007) as well as stretches of the Lee Navigation (Fure and Chipchase 2006–2007). Lighting along London's rivers, especially the Thames, can be seen by clicking on the link in the reference list (Figure 4, courtesy of the Dutch astronaut, André Kuipers and ESA/NASA 2012).

In summary: even moonlight will alter bat behaviour. Lighting of commuting routes and foraging areas will ensure a reduction in activity. The Habitats Regulations is sufficient to restrict illumination onto some natural features used by bats. Illumination falling onto a feature or a commuting route used by a maternity colony to nurture their young is illegal. Bat Conservation Trust

FIGURE 4. Lighting along the Thames (Kuipers 2012). *Photo: A. Kuipers*

Guidelines are changing, converging with other organizations. A joint leaflet with Buglife warns of the undesirable effects of too much lighting in the environment, appeals for reductions in light levels, hours of use and restrictions on the use of ultraviolet light. This is the strongest advice yet giving the subject the clarity it deserves and should be consolidated by new guidance awaited, some of which may target illumination along rivers. Hopefully it will be stronger on the licensing issue in the future. In the meantime, ecologists should be leading on this issue. Waterways should remain dark to prevent adverse effects on insect resources, whilst safeguarding the potential for nocturnal wildlife. Is our legislation too complex to be enforceable, or are we too embarrassed to fight for beauty or protect that 'Site of Special Scientific Interest' that is the night sky (Mirzon 2012). To be effective, policy objectives need to consider the cultural, social, energetic, economic and ecological impacts of future lighting technologies (Stone et al. 2012).

When to light

Along a 2.5-metre stretch of one small river in north London, there have been three floodlighting schemes in as many years, which bat reports are still supporting. Every year, each London borough receives planning applications for lighting projects (Planning Portal and author's data, 2006–2011) ranging from floodlighting for sports pitches, up-lighting of historic buildings as well as entirely new schemes for parks. How can this be when these areas are designated as wildlife corridors?

When considering an application, any proposal for illumination (both the rationale and the user/s), its use should be limited to fulfil that rationale or support that user. If the user is not present then the lighting should not be employed. For example, if security lighting is employed, there should also be a means of identifying and reacting to breaches in security. Another example relates to cyclists as users, their safety and night vision. There remain few unlit areas of towpath left in London, chiefly along stretches of the Lee Navigation and the Regent's Canal, where there is pressure to extend lighting to these areas. Human retinas have two types of receptor cells called rods and cones. Cones work in bright light and register detail. The rods see in black and white and do not discriminate colours. In a dim-light environment, with one or two bright pinpoint lights, a person sees with both the cones (for the bright light) and the rods (for the dim light). Prolonged viewing of a bright light in a dim field causes the pupils to close to smaller sizes and may desensitize the rods, temporarily reducing our ability to see in dim light. The issue is the chemical in the eye, rhodopsin, commonly called visual purple, which is broken down quickly by light. Once the bright light is gone, the pupils open up again and the rod cells resensitize, thus restoring night vision, although it takes time for true night vision to be recovered. This is about 10 minutes for 10 per cent, 30–45 minutes for 80 per cent. This clearly has implications for cyclists approaching and exiting a lit area, as this may have an adverse effect on their night vision.

In the case of lighting in response to rising crime levels, additional discussion with local police may reveal that a location earmarked for raised illuminance, is actually an exit point for criminals, **not the crime scene.** Police crime prevention design advisors, if consulted, may state that the existing lux spillage from multiple light sources is already fit for purpose. It is worth bearing in mind that even if users have been misidentified, changing established illuminance levels can be very difficult, even with the support of different user groups.

One method of demonstrating if footpath or towpath lighting is needed, is not necessarily by a survey of the bat activity. This is often requested, but in most cases does not make a difference to the outcome, unless it affects a nearby roost. If no bats are observed during surveys, negative survey results are often used to bolster an application. By surveying the existing illuminance, with a logging light meter and plotting the readout against grid references, it can be shown that night-time levels may already be adequate for safety standards (ref: police design advisors and BCT advisory). Council officers, not having had the benefit of night visits to these sites, may decide that lux levels presented are of sufficient magnitude. Illuminance onto water can be gleaned from a logging light meter mounted on a one-metre pole, projecting into the mid-stream. Boats can also be used for this purpose where there is no access to the towpath, but at greater cost (Table 2). If the light levels are 25 lux at the mid-stream, as in this example, then clearly something is wrong and there is a case to substantially reduce the light levels, not increase them.

TABLE 2. Illuminance (lux) recorded by boat along the Regent's Canal (Fure and Wedd, 31 August 2007).

Lux levels	GPS
25.7	TQ2837783933
25.4	TQ2843583992
24.5	TQ2837783933
6.1	TQ2837783933
2.0	TQ2837783933
2.0	TQ2837783933
1.6	TQ2837783933
1.5	TQ2837783933
0.0	TQ2843583992
0.2	TQ2843583992
1.4	TQ2845384002
1.5	TQ2845384002

Leaflet

There are many ways of directing light where it is needed and there is a wealth of guidance on bulb types, luminaire design, hoods and cowls and height of columns from BCT, Buglife and ILP, which is not repeated here. But where a river or canal is designated as a wildlife corridor and the public footway ends, **unmitigated light spillage onto the riparian vegetation and a potential bat flyway (from windows, security lights, accent or streetlights), should be seen as a form of discarded litter or anti-social behaviour.** Why does negative bat survey data suggest that lighting will have no impact on a bat species and therefore can continue. When, in fact, this approach guarantees that any potential for bat activity will be removed forever. Various leaflets are in preparation specific to bats and LP/watercourses. By the time this is printed one should be available to download from my website, specific to south-west London, available for use or adaptation.

LED case studies

Lighting schemes attempting to address the protection of dark corridors sometimes use LEDs. LEDs do not produce UV, but can have strong emissions in the blue region of the spectrum (especially the ‘cool white’ type). Preliminary results from a survey regarding insects and LED lamps have been released and show a low insect attractiveness, which can be compared to that of the low-pressure sodium lamps (Eisenbeis 2010, Eurobats 2010). LED lighting which has a negligible UV component may be of benefit to bat populations (Morrison 2009) although not if it illuminates a feature used by bats to travel (Stone et al. 2012).

London’s Arcadia was granted funding to implement a lighting scheme, which could have less impact on nocturnal species than the existing arrangement. The old lighting system was a mixture of different luminaries, columns and distances between lights, which caused light spillage onto the riparian vegetation and the water surface. The Arcadia Project implemented consultation with the local community and the lighting system was designed by Philips. Illumination is at 20 lux ambient light level (lower than the standard 55 lux). The LEDs are 30 watts (street lights about 70 watts). When used along the Warren Footpath, light spillage was removed from the River Thames, whilst directing the lighting to the footpath, where needed. Figures 5 and 6 show how light trespass falls short of riparian vegetation. The view south from Richmond Bridge (Figure 6) demonstrates the darker right hand side as opposed to the left hand side, which suffers illumination (note the value of vegetation screening). The lights have a flexible Control Management System (CMS) which allow luminaires to be remotely monitored and individually controlled. Bespoke dimming regimes can be installed or selected luminaires switched off and the lamps reduced to 5–1 lux at times of predicted low usage: the key is in the ability to control and dim them and thereby remove any impacts from wildlife features. The system works but only because it is dynamic in nature and spillage can be directed away from the feature. The light can still be seen by bats and will alter their behaviour.

The same company recently developed amber-coloured LED street lights with a wavelength of 600 nm, used in some areas of Holland (Gilze, south Netherlands) with good success as the lights allow humans to see whilst minimizing disturbance to bats, although bats can still see this light. In this country similar lamps are marketed by Philips as ClearField, which include

FIGURE 5. Richmond bridge, view north. *Photo: A. Fure*

FIGURE 6. Richmond bridge, view south. *Photo: A. Fure*

FIGURE 7. Narrowband amber handrail lights over the A74 bridge at Tegelen, Netherlands. *Photo: H. Limpens*

FIGURE 8. Narrowband LED street lights at Tegelen, Netherlands. *Photo: H. Limpens*

small amounts of light at frequencies in the green and blue spectrum. Beware of the aggressive marketing of other companies, as some LEDs have a phosphorous content (wavelength 590 + 80 nm) and there are no empiricle studies supporting their use for bats at present.

There is a difference between the ClearField lamp, created by Philips and the Amber lamp created by the Dutch company LEDexpert, the Dutch Mammal Society and the Dutch Road Agency. The Amber LED 'Bat Lamp' is a narrowband amber colour (590 +/- 20) patented by the Dutch Roads Agency, for use by all. The Amber LEDs are installed under licence as mitigation, at the national highway A74 at Ulingsheide, Tegelen, where a parallel road abuts a larger green bridge and important bat flight paths. Narrowband Amber is employed along with a dynamic lighting system, reacting on pedestrians or cyclists, but ignoring cars. Narrowband Amber handrail lighting is installed over the A74 bridge at Tegelen (Figure 7) and as street lighting (Figure 8). A monitoring scheme to test the overall effectiveness of the 'bat lamp' is being prepared (V. Loehr 2012, and pers. comm.).

Note: The amber LED was not patented by the Dutch Roads Agency (it has existed for about ten years), but its use in a lamp to avoid any effect on bats is new, hence the name 'bat-lamp'. There is only a minor price difference between conventional LED illumination and bat-lamps.

New lighting along waterways is **not** recommended where not currently provided, especially where light-shy species are known. Where illumination is already present and causing spillage onto areas where it is unwanted, it may be mitigated by other means. Louvres have been specially manufactured to replace less-effective shields on high-pressure sodium (HPS) lamps, creating a light corridor in a dark area, without encroaching onto the canal (Grand Canal Dublin, Naper 2010).

Light pollution from windows and security lights has transformed the Grand Union, Regent's and Hertford Union Canals, where warehouses are now converted to grand apartments. Industrial buildings were once dark and undisturbed at night but the new apartments have an array of light sources, much of it from windows. Windows on the canal-side could have window film or low transmittance glass or built with ready installed blinds. Pilkington Optifloat can be used for this purpose and grey has the lowest light transmittance of 39 per cent, this means that 61 per cent of the out-coming light will be absorbed. Size of windows over a watercourse (or protected area) can be reduced by 50 per cent to reduce light spill. Residual light spillage will attenuate quickly in these circumstances and have less impact on foraging bats.

Light curfews for sports pitches, even when subject to planning conditions, will not be enforced so don't ask for them unless annual compliance checks are included. Post-development monitoring is where mitigation measures tend to fail as there is no independent system of compliance checking. At a recent conference (DMU) there was said to be a surprisingly poor compliance between lighting schemes and planning permission (Lummis 2012). Luminaires could be of a totally different type to those agreed at the planning stage, columns were higher or lower or of different materials.

For this reason it might be useful to create pro formas that a lay person could usefully employ to check the compliance of a lighting scheme against plans (Appendix 2). In a local authority situation a biodiversity officer might be able to undertake a compliance check, alone or with a local authority lighting engineer. Luminaires and cowl types, as well as other terminology can be obtained from the website of the ILP. The original proposed lighting scheme should be attached to the compliance check form. Height of columns can be checked with a laser measure. We can only access information about the success of the Mitigation Measures if this information is shared. Please log your success on the Yahoo Group. http://groups.yahoo.com/group/lightsandwildlife/

Light from multiple sources has blighted so much of our region that we have lost all control, and in some cases, we no longer have the ability to prevent unwanted illumination onto water courses, leading to spillage of 25 lux at the mid-stream of a so-called wildlife corridor. Given what we know about the effect of lighting on insect behaviour, bat foraging and commuting behaviour, the answer to the question 'how much lux onto an important feature used by bats (waterbody or treeline) is most appropriate?', the answer is determined to be 'none'. Where light provision will affect/change bat behaviour (no need to show harm) a licence should be sought and the disturbance effect should be mitigated. In our region there will always be lighting beyond control contributing to skyglow but if this standard is set for waterways then everything else should follow. There may be exceptions for operational reasons, but then lamps should only be illuminated when the user is present, not automatically programmed to operate 365 days a year, when only used once in that year. To achieve below 1 lux, a distance of several metres might be needed between the feature and a lighting unit, depending on the height of columns, unless mitigated, by the use of louvres on existing lights, narrowband amber LEDs when replacing existing lights, and the use of low-transmittance glass or window film on windows near water. The cumulative effects of lighting including the 'vacuum effect' is pushing bats and their prey nearer to the edge of existence in some areas of London, while for the majority of the time that these lights are burning, we rest safely in our beds.

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APPENDICES

APPENDIX 1. Order of the Flemish Government of 1 June 1995 concerning general and sectoral provisions relating to environmental safety

Chapter 6.3. Control of nuisance due to light.

Article 6.3.0.1. Without prejudice to other regulatory provisions the necessary measures must be taken to prevent light nuisance.

Article 6.3.0.2. The use and the intensity of light sources in the open air are limited to necessities related to operation and safety. The lighting must be conceived in such a way that the non-functional emission of light to the surrounding area is limited to the extent possible.

Article 6.3.0.3. Emphasis lighting may only be aimed at the establishment or parts thereof.

Article 6.3.0.4. Illuminated advertising may not exceed the normal intensity of public lighting.

APPENDIX 2. Post-installation compliance check — sample pro forma

Please use this to make choices about how you want to monitor lighting schemes. The greyscale is purely for guidance and as an aide-memoire. I will provide an adaptable version on request.

Section A: Scheme details		
Planning authority:	**Planning Application Ref. No: (if available)**	
Location:	Reference: *Guidance Notes for the Reduction of Obtrusive Light GN01:2011 ILP* (Includes new environmental zone, terminology, guidance and pictures of luminaire and cowl design).	
Protected species / BAP interests (where appropriate)		
Ecological consultant:	**Planning officer: (if known)**	
Section B: Details of USER		
User	Who is the user/observer	Action
Has the user been identified		
Has the observer been identified		

Section C: Details of LIGHT		
Height of column (use laser measure)	The lower the less travel	
Type of lamp	Low-pressure sodium lamps (SOX). These provide orange light. This light is emitted at one wavelength only, and contains no UV light. They are large and therefore the light is hard to direct. High-pressure sodium lamps (SON). These provide a pinkish-yellow light. Light is emitted over a moderate band of wavelengths including a small amount of UV. Insects are attracted to these and they are of medium size, making them easier to direct. Mercury lamps (MBF). These provide blue-white light and contain a large component of UV light. Insects are attracted to these in large numbers. Insects are attracted in large numbers to lamps emitting UV radiation (Wavelength 350–400 nm) Light-emitting diode (LED) lamps are long-lived and very efficient, produce a narrow beam and provide instant light. LED wavelength, and therefore their colour, can vary from the near-infrared, through visible to near-ultraviolet light. White LED lamps have a broad spectrum of light. Their wavelength peaks at 450 nm and they therefore emit much more blue light than high-pressure sodium lamps. Red, yellow and amber LED lamps each have a specific, narrower spectrum and have peak wavelengths between 590 and 660 nm.	
Full cut-off, louvres	If you can see the bulb there will be glare	
Glass (flat, bowl)	Shallow bowls provide efficient lighting due to their ability to allow light to pass out of the luminaire at high angles – therefore giving large distances between lighting columns. However, the disadvantage is that there is a small loss of control in that light is emitted sideways or upwards. Flat glass tends to be less efficient as light is reflected off the inside of the protector and absorbed back into the luminaire. The advantage is that there is no light emitted above 90 degrees and will best protect a feature.	
Glass protector	to reduce UV	
Sensors: trigger distance		
Summary of findings (if applicable) **Lux measurements on path 3 recommended by BCT** **Buffer width between light and feature (e.g. 1 metre)** **Illuminance levels on water surface**		
Section D: Mitigation Plan summary		
Summary of mitigation measures to be implemented		
Green wall to provide shield	e.g. Russian vine in gardens; old man's beard near open space	
Remedial works needed Will be affirmative if >0.25 (moonlight) light spillage reaches the feature	**YES**	**NO**