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Review

Impacts of artificial lighting on bats: a review of challenges and solutions

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ABSTRACT

Light pollution is a major emerging issue in biodiversity conservation, and has important implications for policy development and strategic planning. Although research is now addressing the negative impacts of anthropogenic noise on biota, less attention has been paid to the effects of light pollution. Changes in lighting technology have led to a diverse range of emerging low energy light types and a trend towards the increased use of white light. Light pollution affects ecological interactions across a range of taxa and has adverse effects on behaviours such as foraging, reproduction and communication. Almost a quarter of bat species globally are threatened and the key underlying threat to populations is pressure on resources from increasing human populations. Being nocturnal, bats are among the taxa most likely to be affected by light pollution. In this paper we provide an overview of the current trends in artificial lighting followed by a review of the current evidence of the impacts of lighting on bat behaviour, particularly foraging, commuting, emergence, roosting and hibernation. We discuss taxon-specific effects and potential cumulative ecosystem level impacts. We conclude by summarising some potential strategies to minimise the impacts of lighting on bats and identify key gaps in knowledge and priority areas for future research.

Shedding light on the challenges – how important is light pollution?

Global increases in urbanisation (Grimm et al., 2008) and human development have led to a dramatic rise in both the extent and intensity of artificial lighting throughout the 20th and 21st centuries (Cinzano, 2000, 2003; Cinzano et al., 2001; Hölker et al., 2010a). Light pollution affects every inhabited continent; electric lighting has increased nocturnal sky brightness by 20% (Hendry, 1984). Worldwide, artificial lighting is increasing by around 6% per annum (Hölker et al., 2010b), and there was a 24% increase in light pollution in the UK between 1993 and 2000 (CPRE, 2003). Traditionally street lights consisted of sodium discharge lamps which generate light via electric discharges through a gas or vapour. The most common lights used were Low Pressure Sodium (LPS) and High Pressure Sodium (HPS). LPS lights are narrow spectrum, emitting an orange-based light with a correlated colour temperature (CCT) of 1807 Kelvin (K), and an absence of ultraviolet (UV) light. HPS are broad spectrum generating a pinkish light with a CCT of 2005–2108 K, with some light emitted in the UV spectrum. Trends in lighting technology have led to changes in the spectral content of artificial lighting (Davies et al., 2013a; Frank, 1988; Massey and Foltz, 2000) from predominantly orange sodium-based lighting in the 1960s and 1970s (Gaston et al., 2013) to broader wavelength lights such as high-brightness light-emitting diodes (LEDs). Today a variety of light types are used globally each with differing CCT and wavelengths (Table 1, Fig. 1). LEDs produce monochromatic radiation and their colour tone is defined by the dominant wavelength (Fig. 2), so LEDs can be a variety of CCTs from "warm white" similar to LPS to "blue white" similar to metal halogen. LEDs had a 31% growth in market share in 2010 (Steele, 2010) and are expected to represent 60% of the market share by 2020 (Peters, 2011).

Ecological impacts of lighting

Global levels of light pollution are set to increase as human populations rise and become more urbanised. There has been increasing awareness of the ecological impacts of light pollution associated with urbanisation (Davies et al., 2013b; Gaston et al., 2012, 2013; Harder, 2002; Hölker et al., 2010a, 2010b; Longcore and Rich, 2004; Navara and Nelson, 2007; Smith, 2009). Light pollution affects ecological interactions across a range of taxa and negatively affects critical animal behaviours including foraging, reproduction and communication (for reviews see Gaston et al., 2013; Longcore

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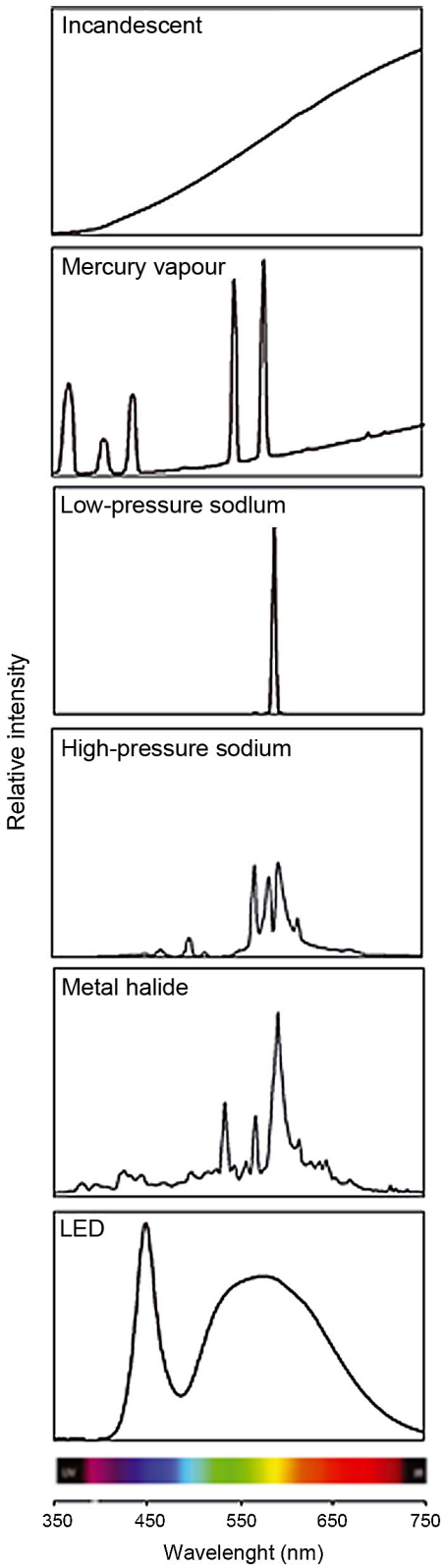

Fig. 1. Spectral composition of common street light types.
Source: Gaston et al. (2013).

and Rich, 2004; Rich and Longcore, 2006). Light pollution is now recognised as a key biodiversity threat and is an emerging issue in biodiversity conservation, with important implications for policy development and strategic planning (Hölker et al., 2010b). Being nocturnal bats are among those species most likely to be affected

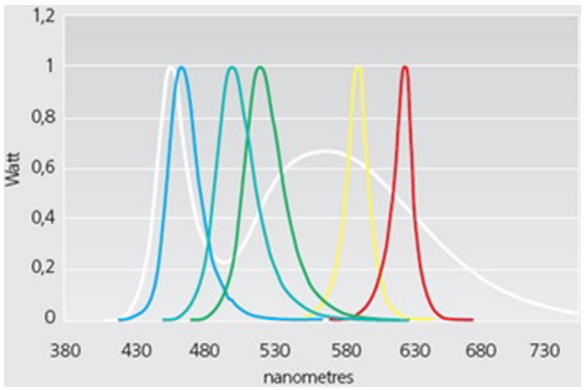

Fig. 2. Spectra of coloured and white LEDs.
Source: Anon (2005).

Table 1
Common light types and colour temperatures.

Light type	Colour	Correlated colour temperature (K)
Low pressure sodium (LPS/SOX)	Yellow/orange	1807
High pressure sodium (HPS/SON)	Pinkish/off white	2005–2108
Compact fluorescent	Warm white	2766–5193
Metal halide (MH)	Blue-white	2720–4160
Light emitting diode (LED)	White/warm-white	2800–7000

Source: Gaston et al. (2012).

by lighting, although artificial light can have an impact on a wide range of taxa and behaviours.

Impacts of artificial lighting on bats

As the second most species-rich mammalian order in the world (Wilson and Reeder 2005) bats represent a significant contribution to global biodiversity (Altringham, 1996; Racey and Entwistle, 2003). Bats make effective bio-indicators, capturing the responses of a range of taxa and reflecting components of biological diversity such as species richness and biodiversity (Jones et al., 2009). Due to their high niche diversity bats are also effective ecological indicators reflecting responses over a range of trophic levels and highlighting effects of environmental degradation on specific ecological processes that are key to ecosystem functioning. Bats are potentially effective bio-indicators for conservation biologists measuring the human impact on the environment, including the impacts of light pollution as their relative abundance, species richness, and vulnerability to disturbance can be relatively easy to monitor over successive years (Fenton et al., 1992).

Bats are therefore critical to ecosystem functioning and should be included in conservation plans aimed at preserving the integrity of ecosystems (Kalka et al., 2008). Declining bat populations may compromise important ecosystem services, so understanding their conservation needs is vital (Williams-Guillén et al., 2008). Urbanisation and development affect bat habitats, either through direct loss or disturbance from light and noise pollution or human activities. Connectivity of habitat and foraging areas to roosts is fundamental to the survival of many bat populations (Verboom and Huitema, 1997). Linear landscape features such as hedgerows, river banks and canals are important for bats, often being used for foraging and commuting (Limpens and Kapteyn, 1991; Verboom et al., 1999; Park, 2015). Changes in habitat affect the quantity, quality and connectivity of foraging, drinking and roosting resources available to bats.