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Nature's nocturnal services: Light pollution as a non-recognised challenge for ecosystem services research and management

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ABSTRACT

Research focusing on ecosystem services has tackled several of the major drivers of environmental degradation, but it suffers from a blind spot related to light pollution. Light pollution caused by artificial night-time lighting is a global environmental change affecting terrestrial, coastal and marine ecosystems. The long-term effects of the disruption of the natural cycles of light and dark on ecosystem functioning and ecosystem services are largely unknown. Even though additional research is clearly needed, identifying, developing and implementing stringent management actions aimed at reducing inadequately installed, unnecessary or excessive lighting are well justified. This essay argues that management is hampered, because ecosystem services from nocturnal nature are increasingly underappreciated by the public due to shifting baseline syndrome, making most people accustomed to constantly illuminated and light-polluted night environments. Increased attention from scientists, managers and the public is needed in order to explicate the best options for preserving the benefits from natural darkness.

1. Introduction: Artificial light as a neglected environmental stressor

Humanity has succeeded in its enduring endeavour to illuminate the night. Electric light has permeated industrialised societies since the introduction of the incandescent light bulb in the late 19th century and especially since the Second World War (Fouquet and Pearson, 2006). Because of the increase in artificial light causing sky glow, more than two-thirds of the population of the United States, about half of the population of the European Union and one-fifth of the world population has lost the possibility of seeing the Milky Way from their place of residence (Cinzano et al., 2001).

Despite the repeated warnings by professional and amateur astronomers, the trend towards brighter nights is likely to continue. Cheap and energy-effective lighting technologies such as Light Emitting Diodes (LED) are becoming more widespread and new energy production methods such as solar-based, small-scale photovoltaic systems allow the electrification of distant locations. Safe and reliable illumination undoubtedly increases the well-being of those currently suffering from the lack of lighting needed for education, work and social life. However, there are ecological and health risks related to night-time outdoor lighting that have often been neglected or underappreciated (Chepesiuk, 2009; Falchi et al., 2011; Longcore and Rich, 2004; Lyytimäki et al., 2012). Furthermore, the loss of night sky persists as a profound aesthetic issue. We are losing the mesmerising view of the deep night sky that has fascinated all preceding civilisations.

Seasonal, lunar and circadian photoperiodic cycles have guided evolution for millions of years. The physical conditions of the Earth have not allowed the evolution of any species that would live under constant daylight, but there exists a huge variety of species that have adapted to a life devoid of sunlight, ranging from our intestinal microbes to largely uncharted deep sea and subterranean organisms. Almost a third of all known vertebrate species and nearly two-thirds of invertebrate species are nocturnal (Hölker et al., 2010). In addition, day-active species, such as humans, are dependent on ecosystem services produced, in part, under natural darkness. In fact, the distinction between diurnal and nocturnal phases of biological processes is largely artificial, since photosynthesis and most other biological processes active under bright daylight include important nocturnal phases.

Ecosystem services have been proposed as a useful concept for understanding and managing the environmental challenges in coupled socio-ecological systems (Daily, 1997; MEA, 2005). Ecosystem services are defined as the benefits that people obtain from ecosystems (MEA, 2005). Not all functions of ecosystems are perceived as benefits. Those functions that are perceived as negative for human well-being can be labelled ecosystem disservices (Lyytimäki and Sipilä, 2009). These include economic

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Table 1
Examples of potential nocturnal ecosystem services and disservices. The typology builds on the general level classification used in the Millennium Ecosystem Assessment (MEA, 2005) and employs the notion of ecosystem disservice (Lyytimäki et al., 2008; Lyytimäki and Sipilä, 2009).

	Type of ecosystem service			
	Supporting	Regulating	Provisioning	Cultural
Ecosystem services from natural darkness	Nocturnal processes related to nutrient cycling, soil formation, primary production, etc. (Daily, 1997; Potts et al., 2011).	Nocturnal processes related to disease regulation, pollination, water purification, etc. (Martinell et al., 2010; Potts et al., 2011).	Goods harvested at night-time, e.g., nocturnal birds for exploitation and fish from night-time fishing (Hamilton et al., 2012).	Nocturnal nature watching and recreation, including observing celestial objects from nature (Marín andJafari, 2007).
Ecosystem disservices resulting from lack of darkness	Disruption of supporting processes, e.g., nutrient cycling in lakes due to impact of light on vertical movement of plankton (Moore et al., 2000).	Disruption of regulating processes, e.g., increase in vector-borne diseases and health problems resulting from disruptions of circadian cycles (Barghini and de Medeiros, 2010; Frick and Tallamy, 1996).	Reduction of goods harvested during the night and lower yields of goods harvested in the daytime (Potts et al., 2011; Fox, 2012).	Deprivation of human experiences (Marín andJafari, 2007).

losses, health and security risks and nuisances caused by floods and fires, pests and vector-borne diseases, and invasive or unwanted species (Bixler and Floyd, 1997; Table 1). Both ecosystem services and disservices often originate from ecosystems that are modified or indirectly influenced by human actions.

Research on ecosystem services typically focuses on daytime provision and – less often – human consumption of ecosystem goods and services (MEA, 2005). This focus originates from ecological studies that have predominantly focused on individuals and ecosystems of terrestrial daylight (Rich and Longcore, 2006; Hölker et al., 2010). In this essay, I argue that specific attention should be paid to nature's nocturnal services both by scholars, managers, decision-makers and the public.

In the following chapter I briefly review some of the light pollution research related to ecosystem services. The review aims not to give an exhaustive overview but rather to identify focal areas for further research. In the next chapter I discuss the challenges for the research and management of nocturnal ecosystem services from the perspective of the shifting baseline syndrome (Kahn and Friedman, 1995; Pauly, 1995) making most people in urbanised or affluent regions accustomed to light-polluted night environments. I conclude with a call for transdisciplinary studies and immediate action.

2. Complex and various effects of light pollution

Artificial illumination causes light pollution of various kinds, including sky glow, light trespass, glare and light clutter. Ecological light pollution has been defined as artificial light that alters the natural patterns of light and dark in ecosystems (Longcore and Rich, 2004). It has various physiological and behavioural implications, such as disorientation, attraction or repulsion, enhancement or distortion of communication, disruption of periods of rest, changes in patterns of intra- and inter-species competition and predation, reproductive failures in animals and disruption of photoperiodism in plants (Rich and Longcore, 2006). It appears that no safe level of artificial light can be determined since very low levels of artificial light can disturb nocturnal species. Exposure and effects are dependent on the timing, intensity and spectra of the artificial light, as well as the environmental conditions. For example, cloud coverage amplifies the reflection of artificial light back to the ground from the sky (Kyba et al., 2011). Ecological light pollution is closely related to polarised light pollution that results from the reflection of natural or artificial light from built surfaces (Horváth et al., 2009).

The implications of light pollution for ecosystem services are poorly addressed by the research. In a search conducted in October 2012, only two peer-reviewed journal articles were found from the Thompson Reuters Web of Science by using the key words 'light pollution' and 'ecosystem service'. These particular studies included a review that mentioned light pollution as a potential threat to pollination services by beetles (Potts et al., 2011) and a review of the relationship between human well-being and ecosystem services (Summers et al., 2012). Both of these studies discussed light pollution only fleetingly. However, there are several studies of light pollution that deal with ecosystem services without mentioning the term (e.g., Martinell et al., 2010). An early example is the seminal review of 'photopollution' by Verheijen (1985). Since the publication of the review by Longcore and Rich (2004) and the subsequent book by Rich and Longcore (2006) in particular, an increasing amount of studies have been published. Web of Science identifies 324 studies with the search string 'light pollution' (October 2012). More than 80% of these studies have been published since the millennium. Most of the ecological or biological research papers focusing on light pollution are empirical case studies describing the effects of increased light levels on certain species.

Various individual-level effects of light pollution have been convincingly demonstrated, but studies focusing on the population or ecosystem level are largely absent (Navara and Nelson, 2007; Rich and Longcore, 2006). In particular, little is known about the effects on the insect populations, which are important providers of ecosystem services and may be vulnerable to light pollution. For example, moths are a species-rich taxon that includes pollinators, consumers and prey items for other taxa (Fox, 2012). It has been suspected that the size-dependent attraction to artificial light by moth species may lead to cascading effects for biodiversity and ecosystem services (van Langevelde et al., 2011). However, light pollution remains uninvestigated as a possible cause of population-level change in moths (Fox, 2012).

The species studied most thoroughly is undoubtedly *Homo sapiens*. Disruption of natural circadian rhythmicity caused by artificial light may lead to several health effects, such as elevated risk of breast or prostate cancer, obesity, depression, diabetes and sleep disorders (Kloog et al., 2009; Stevens et al., 2007). The melatonin suppression effect of light exposure is well known, but many other effects and resulting health risks are still poorly understood, especially regarding long-term cumulative effects. Discerning the effect of light pollution among many confounding factors is a constitutive problem, partly because it is difficult to find reference groups with no exposure to artificial light at night. The challenge is further complicated because in some cases, exposure to artificial light can serve as an antidote to ecosystem 'disservices' provided by the unfavourable natural pattern of light. Medical researchers have intensively studied the effects of light therapy provided for seasonal affective disorder (Golden et al., 2005). Psychological, social and cultural implications of lighting