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 under-appreciated 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 (Chepessyuk, 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 (Höcker 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...
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; Holker 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

<table>
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<th>Type of ecosystem service</th>
<th>Supporting</th>
<th>Regulating</th>
<th>Provisioning</th>
<th>Cultural</th>
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<tr>
<td>Ecosystem services from natural darkness</td>
<td>Nocturnal processes related to nutrient cycling, soil formation, primary production, etc. (Daily, 1997; Potts et al., 2011).</td>
<td>Nocturnal processes related to disease regulation, pollination, water purification, etc. (Martinell et al., 2010; Potts et al., 2011).</td>
<td>Goods harvested at night-time, e.g., nocturnal birds for exploitation and fish from night-time fishing (Hamilton et al., 2012).</td>
<td>Nocturnal nature watching and recreation, including observing celestial objects from nature (Marín and Jafari, 2007).</td>
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<tr>
<td>Ecosystem disservices resulting from lack of darkness</td>
<td>Disruption of supporting processes, e.g., nutrient cycling in lakes due to impact of light on vertical movement of plankton (Moore et al., 2000).</td>
<td>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).</td>
<td>Reduction of goods harvested during the night and lower yields of goods harvested in the daytime (Potts et al., 2011; Fox, 2012).</td>
<td>Deprivation of human experiences (Marín and Jafari, 2007).</td>
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have been widely studied, but these approaches are largely isolated from environmentally oriented research addressing light as potential pollutant (e.g., Ekirch, 2005).

Ecologists have studied light pollution predominantly as a stress factor to natural species. Some direct individual-level consequences of light pollution, such as bird collisions with lighted obstacles both on land (Longcore et al., 2008) and at sea (Bocetti, 2011; Merkel and Johansen, 2011) can be estimated with reasonable accuracy, but indirect consequences are difficult to assess (Rich and Longcore, 2006). A well-known effect of light pollution is disorientation of sea turtle hatchlings, which causes them to turn towards land. Despite decades of research, profound uncertainties remain. For example, recent research has suggested that differences in the visual behaviour among different populations of sea turtles of the same species may exist (Fritsches, 2012).

Important effects on biodiversity and ecosystem services probably occur through various indirect functional and behavioural effects that are elusive and difficult to assess. Furthermore, in most cases it is not possible to reliably determine the importance of light pollution in relation to other risks. Light pollution typically occurs together with other environmental stressors caused by human activities such as physical disturbance, noise, chemical pollution and fragmentation of habitats.

Not all species suffer from light pollution. Diurnal species capable of exploiting artificial light may extend their foraging into nocturnal hours and predators may more easily detect the prey. For example, light pollution may improve the foraging conditions of intertidal areas for waders relying primarily on visual cues (Santos et al., 2010). The improved short-term success of species may lead to long-term effects that cascade through food webs and potentially decrease the resilience of the ecosystem.

Artificial light can also be used as a tool for ecosystem management, as shown by experiences from fisheries management (Johnson et al., 2005). However, this use of light may also produce unwanted consequences. For example, ultraviolet light insect traps targeted at biting flies or other nuisance insects can be lethal for other insects that are predators or parasites (Frick and Tallamy, 1996). Hence, the use of these traps may lead to a decrease in regulating ecosystem services. Artificial lighting that attracts insects may also increase the risk of vector-borne diseases. Relationships between increasing artificial illumination and vector-borne diseases are complex, since night lighting promotes new lifestyles that may lead to new modes of disease transmission (Barghini and de Medeiros, 2010; Dunn, 2010).

To summarise, the potential effects of light pollution on ecosystem services are complex and varied (Table 1). The changes in species composition and loss of light-sensitive species and genotypes may lead to a decrease in supporting and regulating ecosystem services (Höcker et al., 2010). This in turn can lead to a decrease in provisional services. The generation and consumption of cultural ecosystem services is mainly determined by the value of nocturnal ecosystem services. People surrounded by constant artificial night lighting lack the possibilities for direct contact with natural ecosystems and may experience natural darkness as unnatural, unpleasant and unsafe (Bixler and Floyd, 1997; Ekirch, 2005). For example, street and road lighting is often considered a ‘natural’ part of urban and semi-urban scenery, even at times when traffic is absent (Lyytimäki et al., 2012). Urban lifestyles are characterised by the extensive use of electric light and an increased amount of time spent in indoor spaces, as well as increased exposure to information delivered through information and communication technologies (Fig. 1; Pilgrim et al., 2008; Kahn et al., 2009; Lyytimäki, 2012). Importantly, the modern entertainment industry – from horror movies to TV series and computer games – regenerates the evolutionary rooted cultural connotations of natural darkness as something untamed, unsafe, evil and even devilish (Packer et al., 2011). At the same time, the use of lighting in urban design, advertising, art works, decorating and celebration creates connotations of safety and security, prosperity, pleasure and brilliance (Jakle, 2001; Ekirch, 2005; Koslofsky, 2011).

3. Shifting baseline of night experience

Almost forty years ago, based on the results from the mapping of light pollution situation in Ontario, Canada, astronomer Richard Berry lamented that, ‘Light pollution is so prevalent, in fact, that many amateurs of high school age have never seen a non-degraded sky and react to rather badly degraded skies with great excitement.’ (Berry, 1976, p. 111). More recently, Cinzano et al. (2001) estimated that about 40% of the population of the United States and almost 20% of that of the European Union live in areas where the average human eye is incapable of developing night vision. In other words, a significant proportion of the population is unable to directly sense natural darkness.

Consequently, modern people are likely to suffer from a shifting baseline syndrome caused by lack of direct experiences of night environments free of light pollution. Shifting baseline syndrome refers to the changing human perceptions of biological systems due to loss of experience of past conditions (Kahn and Friedman, 1995; Pauly, 1995). Simply put, people may view the current situation as the typical or normal state, even when the ecosystem is considerably degraded compared to earlier states. Loss of the night sky is likely to cause both generational and personal amnesia (Kahn et al., 2009; Papworth et al., 2009). Generational amnesia occurs because younger generations have not experienced and are not aware of past environmental conditions. Personal amnesia occurs when individuals forget their own experiences.

Shifting the baseline of public (and professional) perceptions towards brighter nights has major implications for the management of nocturnal ecosystem services. People surrounded by constant artificial night lighting lack the possibilities for direct contact with natural ecosystems and may experience natural darkness as unnatural, unpleasant and unsafe (Bixler and Floyd, 1997; Ekirch, 2005). For example, street and road lighting is often considered a ‘natural’ part of urban and semi-urban scenery, even at times when traffic is absent (Lyytimäki et al., 2012). Urban lifestyles are characterised by the extensive use of electric light and an increased amount of time spent in indoor spaces, as well as increased exposure to information delivered through information and communication technologies (Fig. 1; Pilgrim et al., 2008; Kahn et al., 2009; Lyytimäki, 2012). Importantly, the modern entertainment industry – from horror movies to TV series and computer games – regenerates the evolutionary rooted cultural connotations of natural darkness as something untamed, unsafe, evil and even devilish (Packer et al., 2011). At the same time, the use of lighting in urban design, advertising, art works, decorating and celebration creates connotations of safety and security, prosperity, pleasure and brilliance (Jakle, 2001; Ekirch, 2005; Koslofsky, 2011).
Thus, modern urban lifestyles are prone to feeding public impressions of unlit green areas as sources of ecosystem disservices rather than services. This is likely to increase public demands for stronger illumination of streets, parks, squares, gardens and other outdoor areas, which, in turn, may induce demands for adding new lights in the remaining unlit areas (Fig. 1). This hampers the efforts aimed at kerbing the growth of light pollution, not to mention attempts to remove lights that are considered unnecessary or even harmful. Because of prejudices and misunderstandings, initiatives that incorporate restrictions on the use of light but which ultimately aim for less costly and safer, more efficient and enjoyable outdoor lighting, often face public criticism (Mizon, 2012).

To overcome the shifting baseline syndrome caused by ubiquitous artificial light at night, different forms of forgetting and unawareness should be taken into account (Lyytimäki et al., 2012). The question is partially about false awareness, referring to a situation where an actor believes that all relevant information is possessed, even though in reality the information is insufficient, inaccurate, outdated, misunderstood or erroneous. For example, children’s alienation from nocturnal nature provides opportunities for teachers to use darkness as an exciting resource in environmental education. The question is also about the perceived imbalance between the possibilities and the requirements to act (Lyytimäki et al., 2012). The changes needed may be considered too radical and the resources for inducing the changes too low. In particular, widely held positive perceptions towards lighting may prevent people from publicly stating any personal reservations about artificial lighting, even when badly designed or implemented lighting decreases human well-being.

4. Challenges of the nocturnal ecosystem management

The fundamental importance of natural darkness to ecosystem functioning and the widespread use of artificial night lighting suggests that light pollution should be considered one of the key global environmental changes. In order to manage this environmental change, the public, managers and decision-makers should be better informed about the key consequences of light pollution for ecosystem functions. Unfortunately, most of the existing knowledge is related to individual-level effects. Therefore, a call for scotobiology – the science of biological systems that depend upon darkness to function normally (Bidwell and Goering, 2004) – should be expanded towards a call for scotocology explicating long-term population-level consequences of light pollution and their relevance to ecosystem services.

Active outreach activities are needed, particularly in order to overcome the shifting baseline syndrome related to the widespread lighting of the night. Children born today face a double challenge caused by lifestyle changes related to increasing urbanisation and environmental changes, including light pollution (Fig. 1). However, producing and disseminating scientific information on the past situations and long-term ecosystem-level effects of light pollution is not enough. Public debate is needed because determining the characteristics of adequate, pleasant and safe illumination is partly a value-based question that cannot be solved by scientific insights alone. This calls for a transdisciplinary approach, taking into account not only knowledge from different disciplines but also integrating non-academic expertise (Hirsch Hadorn et al., 2008).

Natural darkness should be seen as an asset and a resource for the viability of ecosystems and human well-being. Examples of this appreciation are already seen in various dark sky preserves that serve both as nature protection areas and tourist destinations. Restoring the complete natural darkness into urban areas is, however, an unattainable and in most cases an undesirable goal. Instead, urban ecosystems should be understood and managed as novel ecosystems characterised by at least some impact from artificial light. However, urban areas do not need to be dominated by constant bright lights (Falchi et al., 2011; Mizon, 2012). The adverse implications of light pollution to human health and ecosystem services can be greatly alleviated through careful use of lighting technology and restrictions on the intensity, spectral quality and timing of the light.

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References


