Light Pollution as a Biodiversity Threat

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Letters

Light pollution as a biodiversity threat

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In a recent TREE article, Sutherland and colleagues [1] used horizon scanning to identify fifteen emerging issues in biodiversity conservation. They discussed both threats and opportunities for a broad range of issues, including invasive species, synthetic meat, nanosilver and microplastic pollution. We recognize that the article was not intended to be comprehensive, but feel they overlooked an emerging problem of great importance and urgency, namely that of light pollution. Although the widespread use of artificial light at night has enhanced the quality of human life and is positively associated with security, wealth and modernity, the rapid global increase of artificial light has fundamentally transformed nightscapes over the past six decades, both in quantity (6% increase per year, range: 0–20%) and quality (i.e. color spectra) [2,3]. Despite these significant increases, the impacts of artificial lighting on the biosphere, many of which are expected to be negative, are seldom considered.

Most organisms, including humans, have evolved molecular circadian clocks controlled by natural day–night cycles. These clocks play key roles in metabolism, growth and behavior [4]. A substantial proportion of global biodiversity is nocturnal (30% of all vertebrates and > 60% of all invertebrates, Table A1), and for these organisms their temporally differentiated niche has been promoted by highly developed senses, often including specially adapted eyesight. Circadian photoreceptors have been present in the vertebrate retina for 500 million years, and a nocturnal phase is thought to mark the early evolution of the mammals ago. It was only after the extinction of the dinosaurs that mammals radiated into the now relatively safe day niche [5,6]. Although unraveling 500 million years of circadian habituation is a difficult task, it seems that, with the exception of amphibians, the proportion of nocturnal species appears greater in recent radiations than in more ancient radiations (Figure 1). Nocturnality might therefore have been an important step in the evolution of vertebrates, and is currently threatened by the unforeseen implications of the now widespread use of artificial light.

Light pollution threatens biodiversity through changed night habits (such as reproduction and migration) of insects, amphibians, fish, birds, bats and other animals and it can disrupt plants by distorting their natural day–night cycle [7]. For example, many insects actively congregate around light sources until they die of exhaustion. Light pollution can therefore harm insects by reducing total biomass and population size, and by changing the relative composition of populations, all of which can have effects further up the food chain. Migratory fish and birds can become confused by artificial lighting, resulting in excessive energy loss and spatial impediments to migration, which in turn can result in phenological changes and reduced migratory success. Daytime feeders might extend their activity under illumination, thus increasing predation pressure on nocturnal species. For plants, artificial light at night can cause early leaf out, late leaf loss and extended growing periods, which could impact the composition of the floral community. Finally, it can be assumed that a population's genetic composition will be disturbed by light-induced selection for non-light sensitive individuals.

Furthermore, light pollution is considered an important driver behind the erosion of provisioning (for example, the loss of light-sensitive species and genotypes), regulating (for example, the decline of nocturnal pollinators such as moths and bats) and cultural ecosystem services (for example, the loss of aesthetic values such as the visibility of the Milky Way) [2,3,8,9]. As the world grows ever-more illuminated, many light-sensitive species will be lost, especially in or near highly illuminated urban areas. However, some species, in particular those with short generation times, may be able to adapt to the new stressor through rapid evolution, as is described for other human disturbances [10].

In summary, the loss of darkness has a potentially important, albeit almost completely neglected, impact on biodiversity and coupled natural–social systems. Thus, we

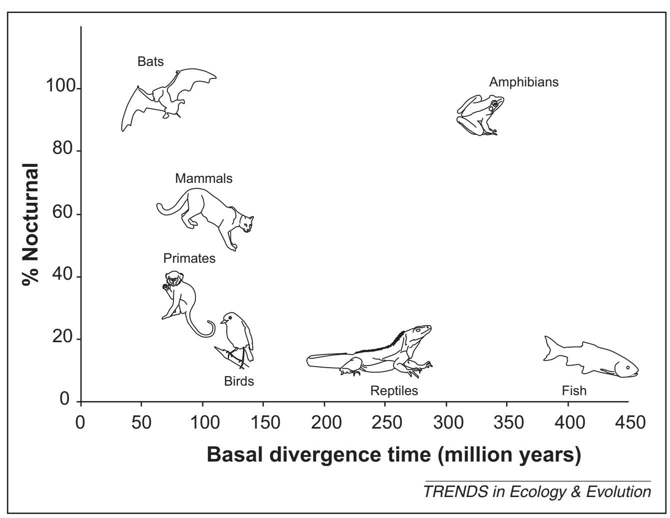

Figure 1. Percentage of extant nocturnal species within different vertebrate classes and orders. With the exception of amphibians, recent radiations have a higher proportion of nocturnal species than more ancient radiations (sources: [11,12]). This fact underlines the hypothesis that nocturnality is an important step in vertebrate evolution. Because the highly permeable skin of amphibians makes them susceptible to typical daytime stressors such as heat and light, the thresholds to radiate into the day niche are probably higher for amphibians than for other vertebrates. This reduced flexibility, in turn, could result in a higher vulnerability to adverse effects from light pollution at night, and could contribute to the recent amphibian declines.

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see an urgent need to prioritize research, and to inform policy development and strategic planning.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.tree.2010.09.007.

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Letters Response

Swarm intelligence in plant roots

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Swarm intelligence in animals and humans has recently been reviewed [1]. These authors posited that swarm intelligence occurs when two or more individuals independently, or at least partly independently, acquire information that is processed through social interactions and is used to solve a cognitive problem in a way that would be impossible for isolated individuals. We propose at least one example of swarm intelligence in plants: coordination of individual roots in complex root systems.

Plants develop extremely complex root systems, which colonize large soil areas. For example, calculations for one winter rye plant revealed 13 815 672 roots with a surface area of about 130 times that calculated for shoots [2]. Growing root apices show complex behaviour based on 'intelligent' decisions about their growth directions [3,4]. Moreover, growing roots show coordinated group behaviour that allows them to exploit the soil resources optimally. There are three possible communication channels for context-dependent information transfer among the numerous root apices of the same plant. Firstly, neuronal-like networks within plant tissues that support rapid electrical and slower hydraulic and chemical information transfer between the root apices [5,6]. Secondly, secreted chemicals and released volatiles allow rapid communication between individual roots. Thirdly, there is a possibility that the electric fields generated by each growing root [7] might allow electrical communication among roots. These electric activities and electric fields show maximal values [7,8] at the transition zone of growing root apices [3] which behaves as a 'brain-like' command centre [6,9]. Roots may use swarm intelligence for their navigation, coordination, cooperation, as well as for their 'war-like' aggressions [10]. It is important that every root has its own identity provided by its unique sensory history accumulated via its own command centre. Each root apex acts both as a sensory organ and as a 'brain-like' command centre to generate each unique plant/root-specific cognition and behaviour [3,6,9]. Recent advances in the emerging field of sensory plant ecology suggest that the sensory information collected by one plant is shared with neighbouring plants [11,12]. In the case of root apices, sensory information appears to be processed collectively in the root system to optimize root-mediated territorial activities [13–16]. These root apices solve cognitive problems such as where to grow and whether to grow at all, to fight or retreat in a face of competitive roots and root systems [10] and to enter symbiotic relationships with mycorrhiza fungi (and *Rhizobium* bacteria in the case of some species) [3–6,13–15]. So roots enjoy a rich 'social' life at the individual plant level and they continuously solve problems that could be called cognitive [4,13]. Swarm intelligence is essential for the evolutionary success of roots and, consequently, the whole plant. The accumulating data on the

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