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Long-term dim light during nighttime changes activity patterns and space use in experimental small mammal populations[☆]

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ABSTRACT

Artificial light at night (ALAN) is spreading worldwide and thereby is increasingly interfering with natural dark-light cycles. Meanwhile, effects of very low intensities of light pollution on animals have rarely been investigated. We explored the effects of low intensity ALAN over seven months in eight experimental bank vole (*Myodes glareolus*) populations in large grassland enclosures over winter and early breeding season, using LED garden lamps. Initial populations consisted of eight individuals (32 animals per hectare) in enclosures with or without ALAN. We found that bank voles under ALAN experienced changes in daily activity patterns and space use behavior, measured by automated radio-telemetry. There were no differences in survival and body mass, measured with live trapping, and none in levels of fecal glucocorticoid metabolites. Voles in the ALAN treatment showed higher activity at night during half moon, and had larger day ranges during new moon. Thus, even low levels of light pollution as experienced in remote areas or by sky glow can lead to changes in animal behavior and could have consequences for species interactions.

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1. Introduction

Life on earth is strongly influenced by natural rhythms, with day length used as a *zeitgeber* for diurnal and seasonal patterns in many biological systems (Thomas and Vince-Prue, 1996; Bradshaw and Holzapfel, 2007). Under natural light conditions, the change of the dark-light cycle is transduced into a biochemical signal. In mammals, melatonin is secreted into the blood during the night while secretion is inhibited by light (Reiter, 1993). Thereby, the photoperiod is used by many animals to synchronize their circadian rhythm through endogenous biological clocks (Challet, 2015). Many prey species, especially small nocturnal mammals, use the photoperiod and moonlight as cues to adjust their foraging behavior to avoid increased risks of predation in illuminated time periods (Clarke, 1983; Daly et al., 1992; Mougeot and Bretagnolle, 2000; Perea et al., 2011; Navarro-Castilla and Barja, 2014).

However, in recent decades the spread and intensity of artificial light at night (ALAN) has increased steadily on a global scale

(Hölker et al., 2010b; Bennie et al., 2014). ALAN can act as an environmental pollutant on many taxa and rhythms such as on activity in mammals (Rotics et al., 2011), foraging in amphibians (Buchanan, 1993), dispersal in fish (Riley et al., 2015), melatonin pattern in birds (Dominoni et al., 2013), mating in insects (van Geffen et al., 2015) and flowering in plants (Bennie et al., 2015).

In consequence of the extensive spread of ALAN, its negative effects on different aspects of the environment in general and on animal behavior and physiology in particular increase rapidly. In rodents, a distinct change in activity in response to differing intensities of ALAN has been demonstrated (Blair, 1943; Clarke, 1983; Kotler et al., 1991). Subsequently, masking of the natural dark-light regime by ALAN can cause the circadian cycle to drift out of phase (Redlin, 2001). This is often a result of the suppression of the hormone melatonin (Brainard et al., 1984; Falchi et al., 2011).

There is accumulating evidence through laboratory experiments that under ALAN the proportion of food intake in rodents increases during the day, which leads to an increase in body mass although total food intake remains the same (Fonken et al., 2010, 2013). Fonken et al. (2012) also found elevated corticosterone levels in Nile grass rats subjected to dim artificial light in the laboratory. In contrast, Bedrosian et al. (2013) found that Siberian hamsters did not show a typical diurnal pattern of cortisol concentrations under

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similar night light conditions.

Meanwhile, the majority of studies, especially regarding the physiological changes induced by ALAN, have been conducted under laboratory conditions. It is unknown how these findings translate into natural environments and natural populations. Further, in many studies the exposure to light is rather short so that long-term effects and adaptations to light cannot be investigated. Additionally, most experiments concentrate on rather high levels of direct light exposure, while light pollution often consists of low light intensities on a wide spatial scale, e.g. sky glow around a city.

The aim of this study was to investigate how chronic dim ALAN influences behavior and body condition of mammals. We used experimental bank vole populations (*Myodes glareolus*) in semi-natural grassland in a replicated design of illuminated and non-illuminated enclosures. The bank vole is a common and widespread microtine rodent in Eurasia. It is short-lived and iteroparous, usually surviving only one reproductive season (Tkadlec and Zejda, 1998). Bank voles show an ultradian rhythm with a polyphasic activity pattern throughout the year (Ylönen et al., 1988; Halle, 2006). This ultradian rhythm is controlled by the circadian clock so that short activity bouts keep their position in relation to sunrise and sunset during a seasonally changing photoperiod (Halle, 2006). So far, there is no knowledge on the effects of ALAN on animals that display an ultradian rhythm. As bank voles partially forage on insects (Hansson and Larsson, 1978), they might increase their activity during night under ALAN to exploit those insects that are drawn to the light sources. Thus, they potentially can be influenced by ALAN through several direct and indirect ways.

During the seven-month study, we subjected animals to artificial illumination with light intensities lower than full moon using single-LED garden lights. Since voles are short lived, they were subjected to this dim ALAN over the longest part of their life span, during winter into the breeding season, to investigate the long-term effects of light pollution. We measured body mass, glucocorticoid metabolite levels, survival, day range and activity of individuals.

We hypothesize that dim ALAN has a negative influence on the physical condition of individuals. Circadian disruption can cause an increased concentration of glucocorticoids (Abilio et al., 1999). An elevated glucocorticoid level in turn can lead to a lowered body mass (Harris et al., 1998) which will, together with an increased visibility by predators, result in a lowered survival rate. Furthermore, we predict that ALAN leads to a change in activity patterns, potentially by masking of natural *zeitgebers*. We predict that prey animals have a higher perceived predation risk at illuminated nights as the perceived visibility to predators increases (e.g. Clarke, 1983). Since vigilant prey individuals may deplete their food patches less thoroughly, they may need to cover a larger area to forage sufficiently (Lagos et al., 1995). In consequence, we expect an enlargement of individual day ranges.

2. Materials and methods

2.1. Study subjects and experimental site

The study was conducted over a seven-month period from November 2012 to June 2013 in large (0.25 ha) grassland enclosures near Potsdam, Eastern Germany. Bank voles were the laboratory-born offspring of wild-captured individuals kept in standard rodent cages on a standard rodent diet until the experiment. For individual identification they were equipped with a passive integrated transponder tag (PIT; Trovan ID-100, 2.12 mm × 11.5 mm, 0.1 g). Each animal was tested repeatedly for its risk taking behavior as part of a project on animal personality, assuming that environments with ALAN would favor more risk

prone behavioral types. However, the tests developed to phenotype a related vole species (Herde and Eccard, 2013) turned out to yield too little variation in this species, and needed further refinement, therefore results are not reported here.

The experiment was conducted under the permission of the ‘Landesamt für Umwelt, Gesundheit und Verbraucherschutz’ (LUGV; reference number V3-2347-44-2011) investigating effects of animal personality on risk taking (here: ALAN). Animals were housed under the permission and control of the LUGV (reference number 3854-1-132).

We conducted the experiment in eight large outdoor enclosures with a size of 0.25 ha (50 × 50 m) each. Every enclosure was surrounded by a galvanized metal wall extending 1 m below and 0.5 m above ground. Voles were protected against terrestrial predators through an electrical veterinary fence surrounding all enclosures. Multicapture live traps (Ugglan special No2, Grahnbab, Sweden) were evenly distributed across each enclosure (N = 36, 6 × 6 grid). Traps were sheltered against wind and sun by metal boxes (30 × 20 × 20 cm) and a tile as cover.

2.2. Experimental design

For the ALAN treatment in half of the enclosures we used 85 small solar powered garden lamps with single-LEDs (light emitting diodes) per enclosure. Control enclosures were provided with the same amount of wooden dummies (same height and diameter) at the same locations to serve as controls for the potential effects of additional artificial structures on prey or predators of bank voles, which may affect their behavior. Lamps were 36 or 60 cm high and were above the grass layer in winter, but immersed in the grass layer later in spring. Each enclosure was illuminated by two similar lamp types that generated “white” light through one diode and contained a diffuser to scatter the light (Type A: Item-No. 57 21 29, Conrad Electronics, height = 60 cm, N = 60; Type B: Item-No. 1015021500/00158077, RTI, height = 36 cm, N = 35). Spectral measurements of lamp type A showed that the diode emits cold white light with a high proportion of blue light (color temperature = 7250 K). Diode and diffuser created a brighter zone surrounding the lamp (radius $r = 25$ cm, illuminance $i = 0.8$ lx) and a dimmer outer zone ($r = 2.5$ m, $i < 0.1$ lx, for details see Eccard et al., 2018 (in revision)). The integrated solar panel recharged a battery (1.2 V, 600 mAh) during daytime and an integrated sensor switched the diode on automatically at night. Duration of artificial illumination after sunset increased over the course of the season as daylight hours and temperatures increased to recharge and operate the batteries (Fig. 1) until in April the entire nighttime was

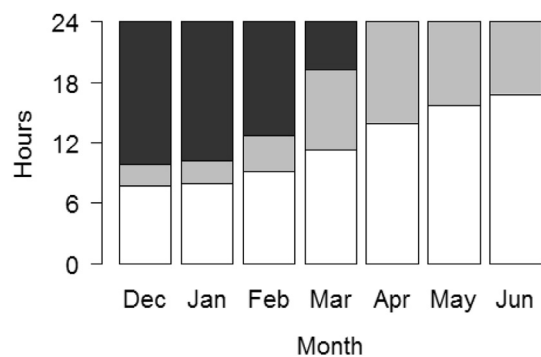


Fig. 1. Duration of daylight (white) and nighttime without (black) and with dim nighttime illumination (ALAN, grey) by solar garden lamps in 4 out of 8 enclosures. Duration of ALAN increased with progressing season due to increased solar charging during daytime.

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