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The effect of artificial light on wildlife use of a passage structure

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ABSTRACT

Barriers to animal movement can isolate populations, impacting their genetic diversity, susceptibility to disease, and access to resources. Barriers to movement may be caused by artificial light, which is known to disrupt bird, sea turtle, and bat behavior, but few studies have experimentally investigated the effects of artificial light on movement for a suite of terrestrial vertebrates. Therefore, we studied the effect of ecological light pollution on animal usage of a bridge under-road passage structure. On a weekly basis, sections of the structure were subjected to different light treatments including no light added, followed by a Reference period when lights were off in all the structure sections. Sand track data revealed use by 23 mammals, birds, reptiles and amphibians, nine of which had >30 tracks for species-level analysis. Columbia black-tailed deer (*Odocoileus hemionus columbianus*) traversed under unlit bridge sections much less when neighboring sections were lit compared to when none were, suggesting avoidance due to any nearby presence of artificial light. Similarly, deer mouse (*Peromyscus maniculatus*) and opossum (*Didelphis virginiana*) track paths were less frequent in the lit sections than the ambient. Crossing was correlated with temporal or spatial factors but not light for three of the other species. These findings suggest that artificial light may be reducing habitat connectivity for some species though not providing a strong barrier for others. Such information is needed to inform mitigation of habitat fragmentation in the face of expanding urbanization.

1. Introduction

Artificial light is used pervasively at night in conjunction with the built environment, creating 'ecological light pollution' (Longcore and Rich, 2004) that can alter behavior and physiology and disrupt habitat connectivity (Bennie et al., 2014, Gaston et al., 2014, 2015 and Rotics et al., 2011). Light provides key information to organisms by enabling their vision, regulating circadian cycles and phenological events (Gaston et al., 2012). Even so, few studies have investigated the effects of artificial light on movement patterns, especially in an experimental setting, for terrestrial vertebrate communities (Gaston et al., 2015, and Longcore and Rich, 2004). Such information is needed to inform mitigation of habitat fragmentation in the face of expanding urbanization.

Artificial light can affect foraging, reproduction, communication and other critical behaviors (Bird et al., 2004, Kempenaers et al., 2010, Longcore and Rich, 2004, and Rotics et al., 2011). For example, it disrupts migratory behavior in birds, sea turtles, bats, and other species (Sella et al., 2006, Rich and Longcore, 2005, and Rodrigues et al., 2012). It also alters movement and foraging patterns, creating an underexploited temporal niche that may promote invasion by less light-sensitive species (Rotics et al., 2011). Responses to artificial light vary among species, however, ranging from increased orientation (van Langevelde et al., 2011) to disorientation (Riley et al., 2013) and from attraction (Polak et al., 2011) to avoidance of light (Beier, 1995, and Bird et al., 2004).

Organisms vary widely in their sensitivities to light and this sensitivity is highly dependent on design and size of the animal's eye (Gaston et al., 2012). Mammals in particular are theorized to be most affected behaviorally by artificial light because of the physical structure of the mammalian eye (Davies et al., 2013). Thus, some species will be more affected by certain types, intensities, and directionality of light than others.

Wildlife populations depend on the ability to traverse habitats, but for some species artificial lighting impacts these movements, fragmenting habitats and disrupting connectivity (Beier, 1995, Coelho et al., 2012, Grigione and Mrykalo, 2004, and Threlfall et al., 2013). Barriers to connectivity on the landscape, especially roads, can isolate populations, reducing their ability to maintain genetic diversity, increasing their susceptibility to disturbance and disease, and limiting their access to resources (Clark et al., 2010, Dixon et al., 2006, and Shepard et al., 2008). Many of the barrier effects of roads may be at least partially mitigated by under- or over-road passages, which increase safe animal movement across roads (Clevenger et al., 2001). Given the cost associated with constructing crossing structures, it is important that we ensure they are as effective as possible. Increasingly, crossing structures are proposed for use by foot or bike traffic as well as for wildlife. Structures

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built for human use typically include artificial light for safety. However, studies have yet to examine the effect of artificial light on wildlife passage use. Examining wildlife response to artificial light in the context of an under-road passage allows for efficient sampling and separates out the effect of illumination from traffic volume and many other barrier effects of roads. Hence, examining artificial light in passages informs the larger question about the role of artificial light on connectivity as well as the specifics about passage structures.

We conducted an experimental study on the effect of light pollution on animal usage of an under-road passage structure in an urbanizing environment. This study aims to determine the effect of artificial light on wildlife use of passage structures by investigating if the presence of light influences use of a crossing structure by species in the local community of terrestrial vertebrates. We hypothesized that the presence of artificial light would decrease use of an under-road crossing structure, especially for mammals, and that higher intensity light would elicit a greater response.

2. Methods

2.1. Site description

We conducted the light-level experiment in a wetland portion of the Boeckman Road Extension, which was recently constructed (2006–2008) in Wilsonville, Oregon, USA (45.316245, −122.783933). Wilsonville lies at the edge of Portland's urban growth boundary. The Extension spans diverse land uses including wetlands, forests, farms, industrial land, and housing. Maintaining animal passage was an important goal of this Extension project because this area was deemed important for habitat connectivity between the Willamette River and the Rock Creek Unit of the Tualatin River National Wildlife Refuge for the area's diverse animal community.

2.2. Passage structure & light treatment design

A variety of species cross under the structure we used for this experiment, a bridge at the Boeckman site (de Rivera and Bliss-Ketchum, 2009). The bridge ranges from 1.5 to 2.7 m tall, spans 122 m, and is 18 m wide. We used only a portion of the bridge at its east end, three consecutive 25 m long sections separated by ~1 m of support pylons topped by concrete supports perpendicular to the span (Fig. A1a,b). We established a sand pad (0.6 m wide, 0.025 m deep, 73 m long) spanning the midline of the three sections for wildlife tracking (Fig. A1c). The terrain leading up to the bridge is similar across sections (Fig A1d).

We added lights under the bridge in the three sections used in our experiment. Light treatments were rotated weekly (Table A1) and consisted of High (172 lx), Low (54 lx), or Zero (<1 lx) light level treatments. Street lighting standards adopted by Portland, Oregon list 32 lx as the average acceptable horizontal illumination (Portland, 1984); however, measurements of street and parking garage lighting ranged from 65 to 646 lx (Bliss-Ketchum, unpublished data). During these treatments, lights were on for 24 h a day to avoid startling, temporary blindness, or other effects of sudden illumination from the lights turning on in the evening. Before the experiment started each year and at the end of each 3-week experimental light-manipulation period, we turned off the lights in all sections for a week-long unlit reference period (herein referred to as "Reference"). This pattern was repeated throughout the 18 weeks of the study period for a total of 13 samples each of the High, Low and Zero treatments and 15 samples of the Reference period.

To provide artificial light to the experimental area under the bridge, three Lithonia Lighting 2-Light Wall-Mount Outdoor Floodlight housings (Model #OFTH300PR120PWHM12) were mounted to the ceiling in each of the three sections, equally spaced across the span of each section. Each light housing supported two halogen flood lights. For the High light treatment, six Phillips 100 watt 130 V halogen PAR38 flood light bulbs (1750 lm, warmth 2730 K) were used; for the Low treatment six, Philips 45 watt 120–130 V halogen PAR38 Flood light bulbs were used (470 lm, warmth 3000 K). All bulbs in the given bridge section were removed for the Zero treatment and all bulbs in all sections were removed during the Reference. All treatments were exposed to ambient lighting, including from moonlight and shielded streetlights on the roadway above. Lights were directed at the sand tracking pad (Fig. A1c). An Extech Instruments Foot-Candle/Lux Light Meter model 401,025 with a minimum resolution of 1 lx was used to measure light levels in each section and to verify that artificial light from one section was not detectable across the boundary between sections. It should be noted that a full moon on a clear night can produce illumination ranging from 0.27 to 1.0 lx and so this light meter would mostly likely not be able to detect illumination from moonlight in the passages (Bunning and Moser, 1969).

At the end of each week, wildlife track data were recorded to determine use by terrestrial vertebrates. Data were collected August–October 2011 and July through October 2012, for a total of 18 weeks when water levels were low enough to collect sand track data (Table A1). We collected data once per week to minimize our presence; our pilot data showed this week-long interval was suitable for detecting all tracks in summer, the dry season. Tracks were identified in the field using Sheldon (1997) track identification guide. Tracks were measured and photographed for later identification if the identity of the species was in question. We consider a set of footprints leading across the pad in one direction as a track. After all sand tracks were recorded, the sand tracking beds were re-graded. Then, the light treatments were rotated or, in the case of a Reference period, all lights were removed.

2.3. Data analysis

Data collected during Reference treatments were compared to the Zero light treatments for each of the nine species that created at least 30 tracks. If more (>95% CI) tracks were left during the Reference period than during the Zero treatment we concluded that the species avoided the bridge undercrossing during light treatments and the bridge sections were not functioning independently; if, however, the number of tracks was similar between the Reference periods and Zero treatments, we also analyzed the effect of light on usage within the bridge sections. Species detections were analyzed for eight of the nine most commonly detected species (all but deer) using Generalized Linear Models (GLM) and a quasi-Poisson error distribution. These analyses examined the effects of light level, passage section, year, week nested within year, and average moon phase for the week on species detection (Table A2). We used diagnostic plots to ensure the data met the assumptions of the statistical tests. Analyses were conducted using R statistical software (version 2.15.2, R Development Core Team, 2012).

3. Results

Track data documented 23 species (Table A3) and over 1500 tracks. Detections of individual species varied from a minimum of one to a maximum of 459 tracks during the study.

The crepuscular Columbia black-tailed deer (*Odocoileus hemionus columbianus*) showed sensitivity to even nearby artificial light, crossing much less even in the Zero level treatment (4.15 ± 3.08, Mean ± 95% CI) than in the Reference period (14.2 ± 7.3) when all under-passage lights were off (Fig. 1). Deer mouse (*Peromyscus maniculatus*) crossings also showed sensitivity to light with significantly more crossings in the Zero treatment (11.62 ± 5.91) than lit sections (Low: 1.0 ± 1.09; High: 0.23 ± 0.33; GLM: Low vs. Zero: $t = -0.433$, $p < 0.001$; High vs. Zero: $t = -3.24$, $p < 0.001$; Fig. 2; Table A2). Similarly, opossum (*Didelphis virginiana*) tracks were significantly more numerous in Zero (3.0 ± 1.87) than High treatments (1.08 ± 0.81; $t = -2.46$, $p = 0.02$). No other species left significantly more tracks in Zero than lit sections, though the number of tracks left by Bullfrogs (*Lithobates catesbeianus*) was affected by temporal and spatial factors (Fig. 2; Table A2).