The Effects of Artificial Night Lighting on the Nocturnal Activity of the Terrestrial Red-backed Salamander, *Plethodon cinereus*

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Abstract

As human development encroaches into natural habitats, artificial light at night increasingly becomes an additional stressor for wildlife. Nocturnal animals are especially vulnerable to artificial night lighting, as physiology and behavior of these species have evolved in dark, nocturnal environments. Studies exposing amphibians to constant bright light provide evidence for changes to normal metabolism, growth, and behavior, but few of these studies have used treatments of artificial night lighting comparable to that found in affected habitats. We examined the effect of artificial night lighting on the nocturnal activity of the terrestrial Red-backed Salamander, *Plethodon cinereus*. Previous work using transects in a forested habitat found that salamanders emerged from under cover objects later at night when exposed to artificial night lighting than under naturally dark conditions. In a controlled laboratory setting, salamanders (N = 16) housed in plastic test chambers with cover objects were randomly exposed to nocturnal illuminations of 10^{-4}lx, 10^{-2}lx, or 1 lx using a repeated-measures design: each salamander was exposed to each illumination for 10 d, and then the behavior of the salamander was observed using infrared cameras for one night. We predicted that salamanders would delay emergence from the cover objects and exhibit less activity in the test chambers under higher nocturnal light levels than under lower light levels. Based on the results of this study and previous research, salamanders delayed emergence when subjected to artificial night lighting, suggesting a negative impact of artificial night lighting on time available for activities such as foraging and breeding.

Introduction

Artificial light at night affects many animal species living in and around urban environments (Rich and Longcore, 2006), including reptiles and amphibians (Perry et al., 2008). In amphibians, artificial night lighting has been shown to affect behavior, reproductive cycles, development, hormones, and metabolic rates (Buchanan, 2006; Wise and Buchanan, 2006). The potential impact of artificial night lighting on amphibians is of particular concern, as amphibian populations are declining at an alarming rate (Alford and Richards, 1999; Stuart et al., 2004). Thus, studies on the affects of night lighting on amphibians have become important in understanding how urban development may be affecting these animals.

Salamanders are found in urban, suburban, and rural areas and are frequently exposed to artificial night lighting in parks, residential areas, areas around roadways, and bodies of water (Perry et al., 2008). The Red-backed Salamander (Fig. 1) is common in forested areas of the eastern U.S. and Canada. Red-backed salamanders are nocturnal and emerge from under cover objects on the forest floor approximately 1 h after dark (Perry et al., 2008) and seem to forage actively above the surface until satiated, the leaf litter dries, or light levels increase at dawn (Jaeger, 1978; Buchanan and Wise, unpublished data). Any reduction in above-ground activity could lead to a reduction in time available for foraging.

Figure 1. Adult Red-backed Salamander, *Plethodon cinereus*. Fifteen salamanders were collected from Frankfort, NY in September 2008, housed in individual Petri dishes on a 12L (100 lx):12D (10^{-5} lx) photoperiod, and fed *Drosophila* ad libitum until tested.

Buchanan and Wise (Perry et al., 2008; unpublished data) constructed lighted (10^{-2} lx at ground level) and unlighted (10^{-4} lx) transects in a forested habitat at Mountain Lake Biological Station, Virginia. They found fewer salamanders active on the forest floor 1-2 h after dark in lighted transects than in naturally dark transects, suggesting that emergence from the forest floor was delayed, possibly due to negative phototaxis (Sugalski and Claussen, 1997) and/or the alteration of the light cue that triggers emergence from refugia. Such delayed emergence would result in fewer salamanders active on the forest floor early at night during their foraging period, but the impact on total time spent active is unknown.

Hypotheses

We examined the impact of artificial night lighting on the emergence and activity of Red-backed Salamanders using a controlled laboratory study. We tested the following alternative hypotheses:

1. Time to emerge from under cover objects is delayed in salamanders exposed to artificial night lighting compared to darker, control conditions.
2. Time to emerge from under cover objects affects the amount of time salamanders are active outside of cover objects, i.e. delayed emergence results in less time spent active outside cover objects.
3. Salamanders have reduced activity (time spent active outside of cover objects) when exposed to artificial night lighting compared to darker, control conditions.

Methods: Experimental Design

Red-backed salamanders were placed into clear plastic dishes lined with moistened white paper towels and containing a black cover object with a single entrance/exit. Lids with an opening covered with black window screen were placed on the dishes creating a relative humidity range from 76-100%. Salamanders were fed fruit flies (*D. virilis*) ad libitum while in the test dishes. Each salamander was tested under each of the three nocturnal treatments (10^{-4} lx, 10^{-2} lx, or 1 lx) in random order in light-safe test chambers (Fig. 2). The salamanders were recorded using infrared video for at least 18 hrs (3 h before lights off, 12 h scotophase, and 3 h after lights turned on) following a 10-d acclimation period. Video recordings were reviewed to observe the nocturnal behavior of the salamanders.

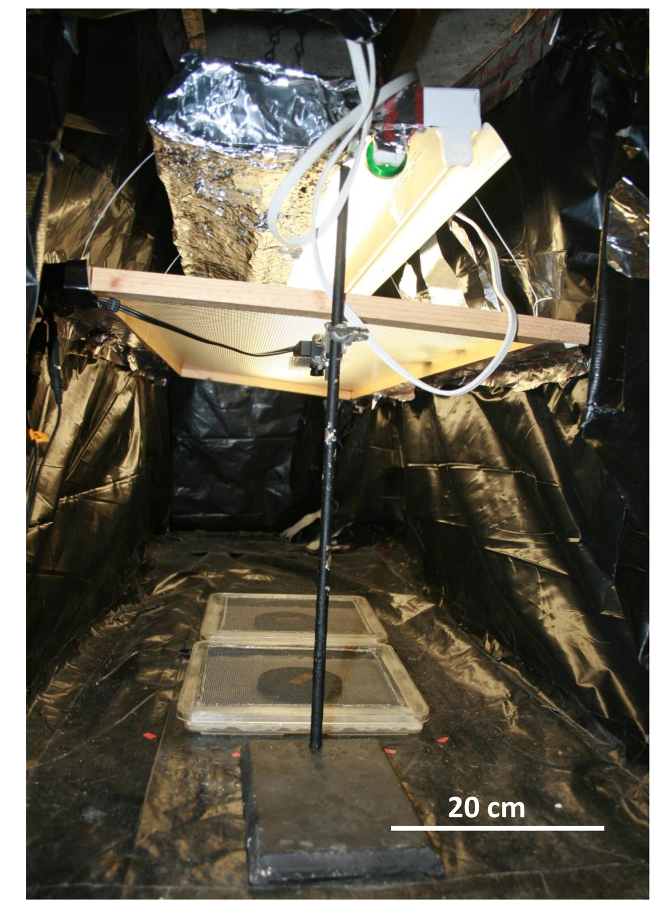

Figure 2. Light-safe test chamber with two dishes for housing salamanders during tests. Fluorescent lamps produced illuminations of 100 lx during photophase, and masked lamps created nocturnal illuminations of 10^{-4} (0.0001) lx, 10^{-2} (0.01) lx, or 1 lx (nine chambers were each randomly assigned each lighting treatment, N=3 for each treatment). A diffuser under the lights created even lighting throughout the chamber.

Methods: Response Variables

We determined time to emergence and time spent active for each salamander. Time to emergence was defined as when the head, trunk, and limbs (front and hind) were first visible (not under cover object) relative to initiation of the dark phase (0-720 min). Salamanders that did not emerge during the dark period were recorded as emerging at 720 min. Salamanders already active at dark were recorded as emerging at 0 min. Activity was defined as the total time the salamander was observed out from under the cover object during the dark phase (12 h).

Methods: Data Analysis

Time to Emergence

We compared the time to emerge from cover objects for salamanders under each of the three nocturnal light treatments (10^{-4}, 10^{-2}, 1 lx) using a multivariate repeated-measures ANOVA, after testing for relatedness between lighting treatments (not significantly related: r = -0.160–0.358; P = 0.229-0.981). Because the data for all treatment groups did not meet the assumption of normality (P = 0.001–0.024) we analyzed outliers using stem-and-leaf plots. Two salamanders in the control treatment (10^{-4} lx) did not emerge during the 12-hr nocturnal period; these outliers and were removed from analyses (N =13). Because this deletion may bias the results, we removed all cases where salamanders did not emerge in all three lighting treatments (N = 8) and found similar results; thus, we present the analysis with the two outliers removed.

Emergence and Activity

We examined whether time spent active during the dark phase could be predicted by the time to emergence. For each nocturnal light treatment, we regressed the time (min) spent active on time to emergence from the cover object during that same dark period.

Time Spent Active

We compared the time salamanders spent active under each of the three nocturnal light treatments (10^{-4}, 10^{-2}, 1 lx) using a multivariate repeated-measures ANOVA, after testing for relatedness between lighting treatments (not significantly related: r = -0.021-0.324; P = 0.280- 0.949). The data for all but one treatment group met the assumption of normality using Shapiro-Wilks tests ($P_{0.0001}$ = 0.008; $P_{0.01}$ = 0.161; P_1 = 0.050) . There were no outliers for any of the treatment groups.

Results

Time to Emergence

We found a significant effect of light on time to emerge from the cover object (Wilks' λ = 5.173; df = 2,11; P = 0.026). Using post-hoc analyses using LSD (no correction) we found that salamanders emerged significantly sooner in the dark treatment than in the 10^{-2} lx light treatment (P = 0.024; Fig. 3) with a trend for salamanders to emerge sooner in the dark treatment than in the 1 lx light treatment (P = 0.054; Fig. 3). There was no significant difference in time to emergence between the 10^{-2} and 1 lx treatment groups (P = 0.718; Fig. 3).

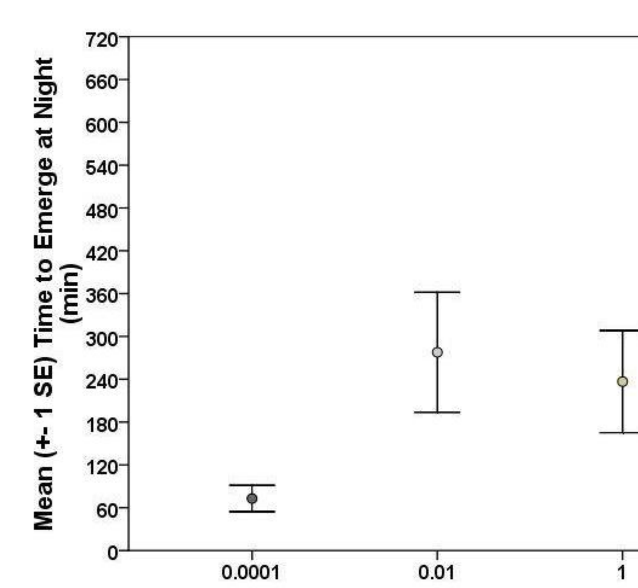

Figure 3. The mean (± 1 SE) elapsed time (min) since initiation of scotophase until salamanders emerged from the cover object at nocturnal light levels of 10^{-4} (0.0001: natural dark control), 10^{-2} (0.01), or 1 lx.

Emergence and Activity

We found no significant relationship between time spent active and elapsed time to emergence in the 10^{-4} lx (N = 13; R^2 = 0.139; P = 0.210) or 1 lx (N = 12; R^2 = 0.180; P = 0.169) treatments (Fig. 4), but there was a significant relationship for the 10^{-2} lx treatment group (N = 13; R^2 = 0.638, P = 0.001; Fig. 4). In these analyses, we removed salamanders if time to emergence was 720 min (did not emerge during the trial), as the time spent active would necessarily be 0 min in these instances.

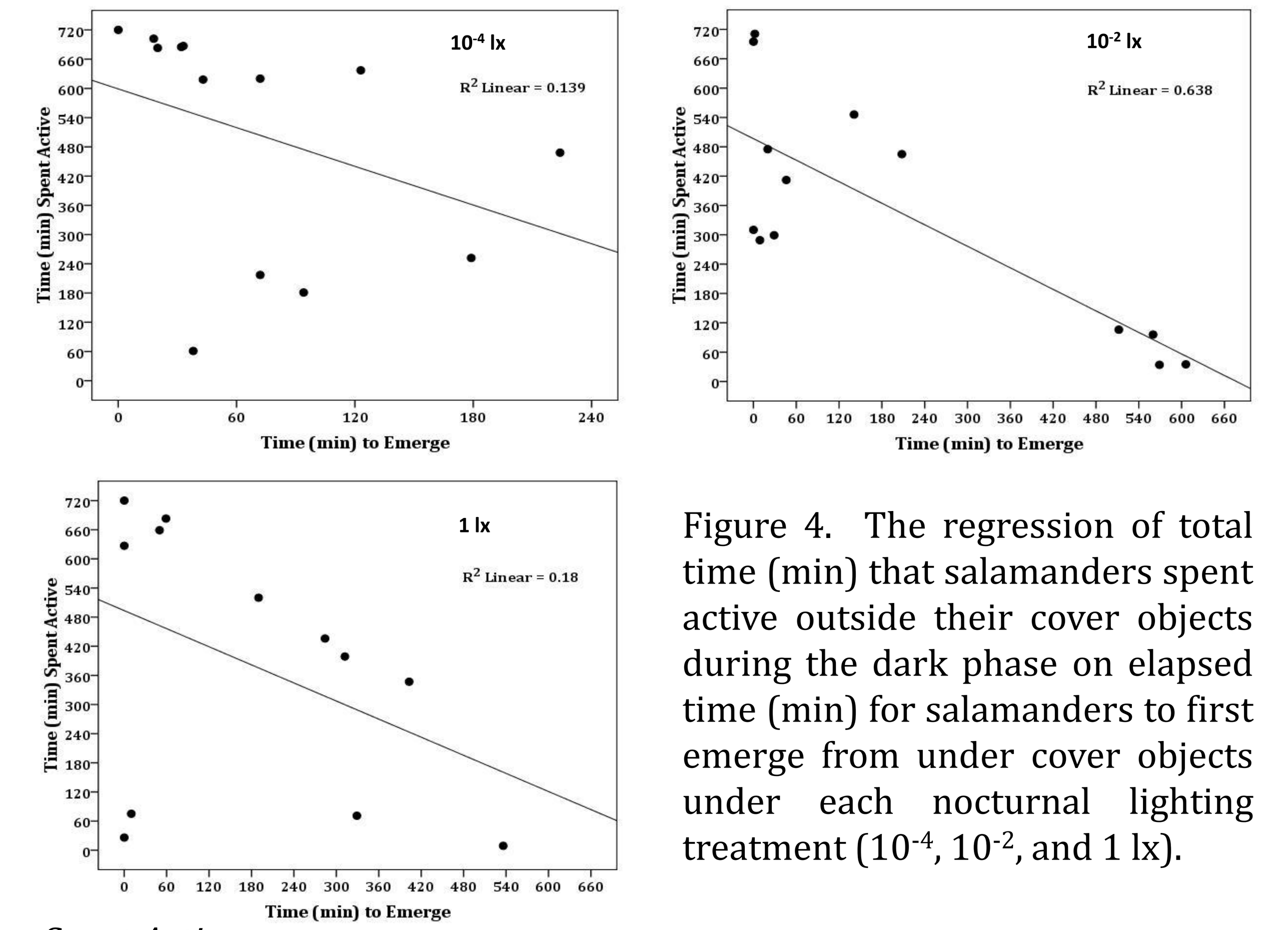

Figure 4. The regression of total time (min) that salamanders spent active outside their cover objects during the dark phase on elapsed time (min) for salamanders to first emerge from under cover objects under each nocturnal lighting treatment (10^{-4}, 10^{-2}, and 1 lx).

Time Spent Active

We found no significant difference between treatment groups in mean total time that salamanders spent active using multivariate repeated-measures ANOVA (Wilks' λ = 0.632; F = 3.205, df = 2,11; P = 0.080; Fig. 5), although there was a trend toward more activity in the control treatment than in the other two treatment groups.

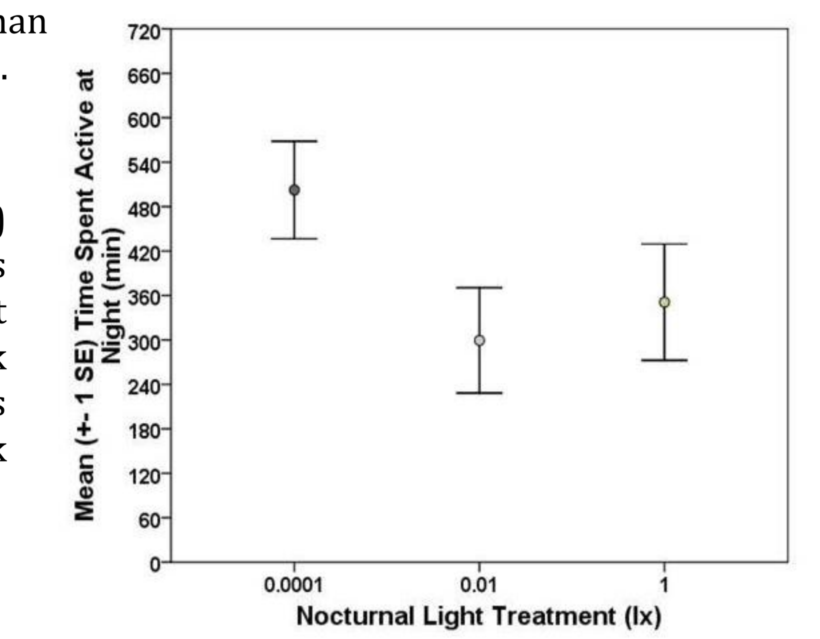

Figure 5. The mean (± 1 SE) total time (min) salamanders spent active outside their test chambers during the dark phase at nocturnal light levels of 10^{-4} (0.0001: natural dark control), 10^{-2} (0.01), or 1 lx.

Discussion

We found a significant effect of artificial night lighting on emergence times, such that salamanders emerged from under cover objects sooner during normal dark lighting conditions than under brighter nocturnal lighting. Although not significant, we also found a trend for reduced activity under brighter artificial night lighting. These results occurred despite a relatively weak link between emergence time and activity. These results provide preliminary support of our hypotheses that artificial night lighting influences the emergence and activity of red-backed salamanders.

The apparently weak relationship between emergence time and time spent active may be an artifact of our method of analysis and the test dishes in which the salamanders were housed. If the substrate is moist and humidity relatively high, salamanders may not be constrained in their level of activity; whereas in natural habitats, above ground activity may be limited by moisture. Although we attempted to reduce humidity by using dishes that were covered with screen, some salamanders remained active for the entire 720-min dark phase, providing evidence that time outside cover was not limited in our tests. Also, we removed salamanders from the analysis in which emergence time was 720 min (no emergence during scotophase) and time spent active was necessarily 0 min; thereby creating a more conservative analysis.

Foraging above-ground is especially important in providing salamanders with a positive energy budget (Fraser, 1976; Jaeger, 1978; 1980). Delays in emergence at night may limit time available for foraging and mating, which are activities that occur above-ground at night (Jaeger, 1978; Gergits and Jaeger, 1990). Thus, artificial night lighting may have subtle, but potentially important effects on nocturnal amphibians.

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