ALANizer: Design and validation of experimental lighting rig for studying artificial light at night in ecosystems

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Author contributions

Daphne Chevalier, Juli Carrillo, and Quentin Geissmann conceived the ideas and designed methodology, with insight from Nisa Chavez Molina on pitfall trap placement. Daphne

Chevalier and Nisa Chavez Molina collected the data; Daphne Chevalier, Juli Carrillo, and Quentin Geissmann analysed the data; Daphne Chevalier led the writing of the manuscript. All authors contributed critically to the drafts and gave final approval for publication.

Availability

Software, firmware, and documentation are on Github at github.com/chevalierid/alanizer. Data are available at Zenodo (10.5281/zenodo.15170657).

1 Abstract

Over the past few centuries, human activity has introduced astoundingly bright light to the environment at a rapidly accelerating pace. Artificial light at night (ALAN) has detrimental effects on a wide range of organisms, including arthropods. To minimise impact, we must understand how different organisms are affected and whether certain lights are less perturbing. We designed a novel tool for introducing and monitoring different types of ALAN, called ALANizer, composed of open-source software and inexpensive, widely-available hardware. We describe the design and assembly of ALANizer, as well as a feasibility study where we installed 12 ALANizers in hedgerows and monitored arthropod activity using pitfall traps. We found that ALAN presence increased the total biomass of captured arthropods, the number of arthropods captured, and the total biomass divided by total count (average specimen weight per pitfall trap). Across these three metrics, we observed similar results under white and amber ALAN. Understanding ALAN's impacts on ecosystems only grows more pressing as LED technology proliferates. As an effective, low-cost, and scalable tool for introducing and monitoring ALAN in ecosystems, ALANizer can help advance this key area of research.

2 Introduction

To protect biodiversity, we urgently need to better understand the effects of artificial light at night (ALAN) on ecosystems [1]. Despite copious evidence linking ALAN to negative biological impacts on individual species, little is known about its role in disrupting ecological communities; meanwhile, ALAN continues to intensify and spread [1]. Emerging

recommendations suggest that amber-coloured LEDs may be less harmful than white-coloured LEDs, but supporting evidence is lacking, especially for arthropods [2].

Experimental ecology requires controlled perturbations of the natural environment that can be monitored with effects quantified [3]. Although the scientific community has developed effective methods for manipulating many environmental variables, there is not yet a standardised and widely-available approach for introducing artificial light to field settings [2]. Studies featuring existing light installations, such as streetlights, can be useful, yet are limited by confounding variables, such as noise, heat, and increased human activity, and primarily provide observational data, which precludes causal links [4]. Correlative approaches also require equipment to measure important covariates, such as light intensity.

It is difficult to know to what extent ALAN has already affected ecosystems and biodiversity. However, we can perform field experiments in areas that are still relatively ALAN-naïve (without histories of artificial lighting), introducing light at a small scale and observing ecological consequences. Although some groups have designed and deployed mobile experimental lighting rigs in these settings, suitable experimental sites often lack the required infrastructure (e.g., a power grid). In addition, costly setups limit the number of experimental replicates [5].

Experimental lighting rigs must introduce light on a schedule, vary their colour and/or intensity, and monitor lighting conditions in the environment. Most light metrics, especially those derived from lumens, are tailored to human vision. In ecological research, it is especially important to measure light from the perspectives of other vision systems [6].

Consequently, some researchers have suggested concurrent monitoring of intensity and spectral characteristics [7, 8].

In this article, we address the need for an autonomous, scalable, and controllable device to study ALAN in the field. First, we describe ALANizer, a novel open-hardware and open-source tool. Then, we present an experiment to illustrate ALANizer's usefulness for exploring ALAN's effects on terrestrial arthropods. We found significant changes in terrestrial arthropod activity under LED lights compared to darkness, and no differences between activity under white and amber LED lights.

3 Application overview

ALANizer consists of hardware and firmware components, whose operation and performance were validated in-lab and experimentally. First, we detail ALANizer's hardware components (Fig. 1). We then describe firmware components, including programs to schedule the light timing and to collect data from the light sensors. We report validation steps and results (Fig. 2). Finally, we describe an experimental deployment in real-world field conditions (Fig. 3).

In this section, we detail ALANizer's specifications, components, operation, and validation. We identified several key specifications for our system by reviewing a range of ecological studies centred around ALAN. Justifications for these benchmarks can be found in "Components," below.

We wanted ALANizer to operate off-grid (through battery power) with enough capacity to produce light over at least five consecutive nights, and emit light in two colours (white and amber), at a luminous flux of approximately 1000 lumens (equivalent to a 75 watt incandescent bulb). Additional needs included the ability to schedule when ALANizer's light turned on and off each day, in advance of deployment, and the ability to monitor overall light intensity and spectral character between 350 and 1000 nanometres. These data needed to be retrievable without exposing the device's electronics to the elements. Lastly, ALANizer needed to be robust and weatherproof, keeping internal components dry during months outside.

4 Components

4.1 Hardware overview

ALANizer (illustrated in Fig. 1) hardware allows users to introduce and monitor light in the field. This is done by supplying power to the unit ("power source", see "Supplementary information") which activates the experimental light source ("light box") which can be cycled through light settings and measured via the "controller box." We provide detailed schematics on the ALANizer GitHub repository (see Availability section).

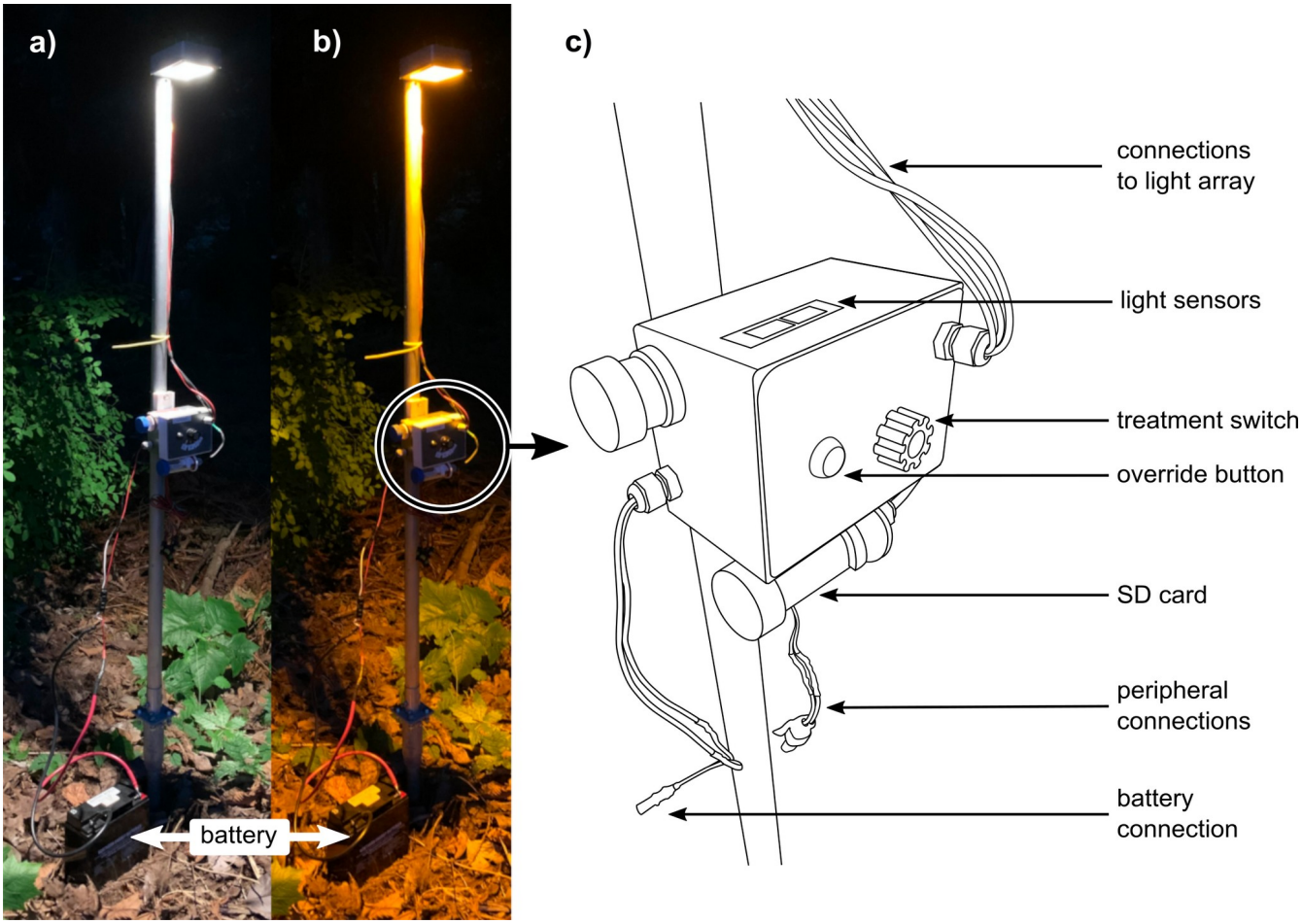

Figure 1: ALANizer overview. Deployed device can be set to white-light treatment (a) and amber-light treatment (b), displayed alongside diagram of ALANizer's controller box (c). The treatment switch toggles between unlit, white-light, and amber-light treatments. The override button powers the light array (if the treatment switch is set to a lit treatment) regardless of schedule, which allows the user to check that the device is outputting the correct treatment at any time. The SD card saves light sensor data every 5 minutes. It is stored in an external tube and can be removed without opening the controller box. The peripheral connections can power other sensors or tools.

4.1.1 Light box

The ALANizer light box must emulate realistic light sources for both amber and white lights, be low-power enough to rely on batteries, and operate without producing unmanageable heat. We therefore designed a printed circuit board (PCB) with two parallel strings of high-efficiency LEDs in series, connected to a low-side treatment switch. Although LEDs are more efficient than other lamp types, high-intensity LEDs require thermal management. The LED array PCB incorporates many thermal vias and a solid copper pour on the back. In our implementation, we bolted the PCB to an aluminum enclosure with a layer of thermal paste between the solid copper pour and enclosure, turning the enclosure into a large heat sink.

4.1.2 Controller box

The controller box contains hardware for scheduling, adjusting, and monitoring the light treatment. We used an Arduino Mega as the controller, which interfaced with two light sensors (and, optionally, other peripherals). We connected an external real-time clock (RTC) circuit to keep time, which allowed us to schedule the light's on and off periods and to timestamp sensor data.

We wanted to monitor both light intensity and light colour (spectral character) following best practices suggested by Seymoure et al. [7]. We integrated a light intensity sensor (Adafruit TSL2591, which measures wavelengths between 400 and 1100 nm, with a dynamic range of 188 µlux-88,000 lux) and a spectral sensor (Adafruit AS7341, which measures wavelengths between 415 and 680 nm) into the enclosure, pointing upward toward the light. We mounted a piece of frosted acrylic over the sensors as a diffuser, reducing error by scattering incoming light in a uniform manner [9].

We added a rotary switch to allow the user to toggle between the light's different states, which are "control" (light off), white light treatment, and amber light treatment. We also added an override switch, through which the user can override schedule and turn the light on during the daytime, which is useful for ensuring the device works.

To keep the SD card accessible, we placed the SD module in a 50mL centrifuge tube (Falcon™) attached to the outside of the controller box (see "Supporting information"). We replaced the tube's conical tip with a 3D-printed piece, securely attached with "gasket maker" (Permatex™). This piece's integrated cable gland kept the SD module connected to the controller while maintaining a watertight seal. The tube's threaded lid provided access to the SD card.

4.2 Firmware

ALANizer's firmware can be separated into pre-deployment and post-deployment utilities. Before deployment, the user needs to generate a list of timestamps for turning the light on and off based on sunset and sunrise times given geolocation and time of year, which is then stored on the SD card (see "Initialisation and setup" for instructions). The user also needs to synchronise all RTCs to real-time (see the Github repository for details).

After deployment, ALANizer's controller collects sensor data every 5 minutes and stores it on an SD card. The controller also turns on an LED in the enclosure if it enters an error state (e.g., cannot communicate with a peripheral). The controller saves sensor data into a new file every hour, which prevents significant data loss from interrupted transmission but requires the user to later concatenate all data.

5 Operation

As mentioned in the firmware section above, operating ALANizer involves a few initialisation steps, followed by regular maintenance.

The ALANizer's Arduino microcontroller must be programmed with the length of each day and night between light-switching events, which will be specific to season and location. We used the `suncalc` package in R (see "`scheduling.R`" in the ALANizer Github repository) [10, 11].

To retrieve data, we replaced the SD cards each cycle and backed them up using `robocopy` or `rsync`. During these visits, we also replaced system batteries.

6 Validation

We validated ALANizer via several in-lab unit tests and a longer-term field deployment, which are detailed below.

6.1 Quality control (in-lab)

We tested the devices' waterproofness by standardised engineering procedure (see "Supplementary information"). We then tested basic functionality to ensure the sensors, data collection and storage, light scheduling, and toggling between settings functioned as expected.

6.2 Experimental deployment

To validate ALANizer's functionalities, we introduced ALANizer into the environment and quantified differences in terrestrial arthropod activity dependent on experimental light conditions, across 12 sites. We chose sites located along hedgerows at an experimental research farm at the University of British Columbia's Vancouver campus, at least 50 metres apart. A map of the sites can be found in "Supporting information." We deployed an ALANizer at each site from the end of June to the end of November, 2023.

Underneath each ALANizer, we deployed in-ground insect pitfall traps (Vernon Pitfall Traps™, Intko Supply Ltd., Chilliwack, BC, Canada) to capture arthropods that may be differentially affected by different light treatments. We treated pitfall trap capture as a proxy for overall ground-dwelling arthropod activity. Traps had barriers to exclude small vertebrates and contained sample cups with ~50mL of low-toxicity antifreeze (propylene glycol) to hasten the deaths of captured invertebrates and preserve them until collection. We placed two traps at each site, one directly below the light and one 5 metres away. We estimated that the trap 5 metres away received at most 22.5% of the light received by the trap directly under the ALANizer [12]. We collected pitfall trap samples and performed ALANizer maintenance every 5 days.

During deployment, each ALANizer cycled through treatment settings (white light, amber light, or no light (control)) in a 20-day sequence split into four phases, where each phase lasted 5 days. All the lights followed the same pattern, where lit phases alternated with control phases, switching between white and amber treatments during alternating lit phases. We staggered

schedules for different sites, so that at any given time, six sites were set to control, three were set to the white treatment, and three were set to the amber treatment.

As expected, light intensity was higher in lit phases than in dark control phases and light colour changed depending on whether the white or amber light was on. We observed the fluctuations shown in Figure 2, which matched our expectations, confirming that ALANizer introduced distinct wavelengths to the environment according to our experimental cycle.

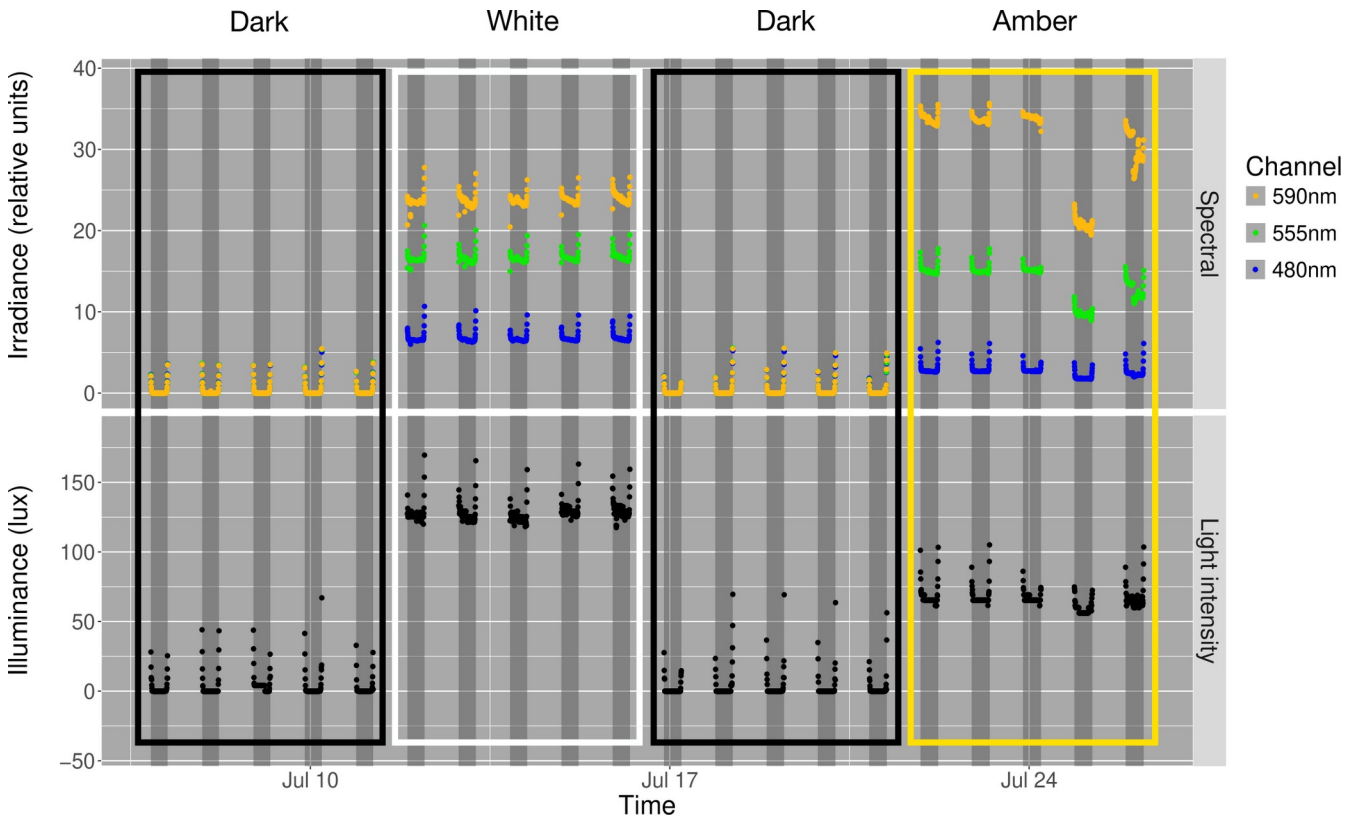

Figure 2: Example light sensor measurements from ALANizer. Plots of nighttime spectral and intensity measurements as light is turned on and off in a scheduled manner, for white/amber/control settings (taken from Site 6). Irradiance units are relative while illuminance is displayed in lux. Dark grey bands represent civil night (i.e., when the sun is ≥ 6 degrees below the horizon). We measured very little light during dark settings. The white treatment

exhibited more green (555nm) and blue (480nm) light and higher overall light intensity than amber light.

6.3 Statistical modelling

To determine how the presence and type of light influenced insect activity, we modelled the biomass of insects caught in pitfall traps as a function of experimental light treatment using a generalised linear model with the `glmmTMB` package in R [11, 13]. The primary objective of this model was to test whether ALANizer had a measurable environmental effect through biomass captured in pitfall traps, not to draw ecological conclusions on ALAN's effects on arthropods. In addition, our experimental design distributed and regularly rotated all possible light treatments across sites during each sampling period. We therefore kept our model extremely simple and did not account for time of year of sample collection.

We used the DHARMa package to assess goodness of fit, choosing the Tweedie distribution based on the right-skew, non-integer characteristics of our response variable [14]. We included trap distance as a fixed factor. We expected trap distance to affect biomass under treatment but not control conditions. Consequently, we introduced an interaction effect between distance and treatment.

We added a random factor for site effects. We also added a random factor that nested trap distance within each site, since vegetation presence and density varied across sites, which allowed the faraway trap at some sites to receive more light than at other (more vegetatively dense) sites.

We were interested in exploring the effect of each treatment (white and amber) on biomass. To do this, we first performed a Type III Analysis of Variance (ANOVA) test to check the significance of treatment, trap distance, and their interaction. We used z-tests to check whether each light treatment had a significant interaction term with trap distance. A significant interaction term indicated that a specific light treatment's effect on biomass changed with respect to trap distance.

We then examined the model's estimated marginal means to determine whether ALAN treatments increased biomass, and whether these effects might be mediated by trap distance from light.

7 Results

We analysed a total of 216 pitfall samples, with 108 samples collected under no-light (control) conditions, 52 under white light, and 56 under amber light. Since each lit period was followed by an unlit period, we had approximately double as many control periods as white or amber periods. Any other discrepancies in the number of treatment periods are due to technical issues with ALANizer units, largely regarding weatherproofing and water ingress, which are avoidable with proper sealing (see "Supplementary information").

As expected, we found that light treatments increased captured biomass compared to the no-light condition (control) (Table 1). We also found a significant interaction between each of the white and amber light treatments and the trap distance (Table 1). Biomass did not differ across white and amber treatments.

Table 1: Model summary. Generalised linear mixed model investigates the effects of light treatment and trap distance from light on biomass (grams) captured in pitfall traps, as well as fixed effects of the interaction between treatment colour and trap distance. Variance and standard deviation for the random effects of site and the interaction between site and trap distance reported.

Model	**Predictor variables**	**Estimate**	**S.E.**	**z-value**	**p-value**
GLMM of biomass	White light	0.635	0.159	4.00	**6.31e-5**
	Amber light	0.702	0.162	4.32	**1.55e-5**
	Distance	-0.379	0.232	-1.63	0.103
	White light × distance	-0.744	0.242	-3.07	**0.00211**
	Amber light × distance	-0.601	0.243	-2.48	**0.0133**
	Random variables			**Variance**	**S.D.**
	Site			0.1391	0.3729
	Site × distance			0.1879	0.4335

When modelling pitfall capture biomass in response to trap distance, treatment, and site, we found that distance, treatment, and their interaction all affected capture biomass (Table 2).

Table 2: Type III ANOVA. Generalised linear model investigates the effects of light treatment and trap distance from light on biomass (grams)captured in pitfall traps, as well as fixed effects of the interaction between treatment colour and trap distance.

Model	**Predictor variables**	**Chisq**	**Df**	**Pr(>Chisq)**
GLM of biomass	(Intercept)	213	1	**3.01e-48**

	Treatment	30	2	**3.08e-7**
	Distance	21.7	1	**3.22e-6**
	Treatment × distance	12.5	2	**0.00190**

Although our model describes higher biomass capture at near-to-light traps under both lit treatments when compared to the unlit condition, we did not find a difference between biomass capture under white and amber light, nor between any treatment conditions at traps 5 metres away from ALANizers (Fig. 3).

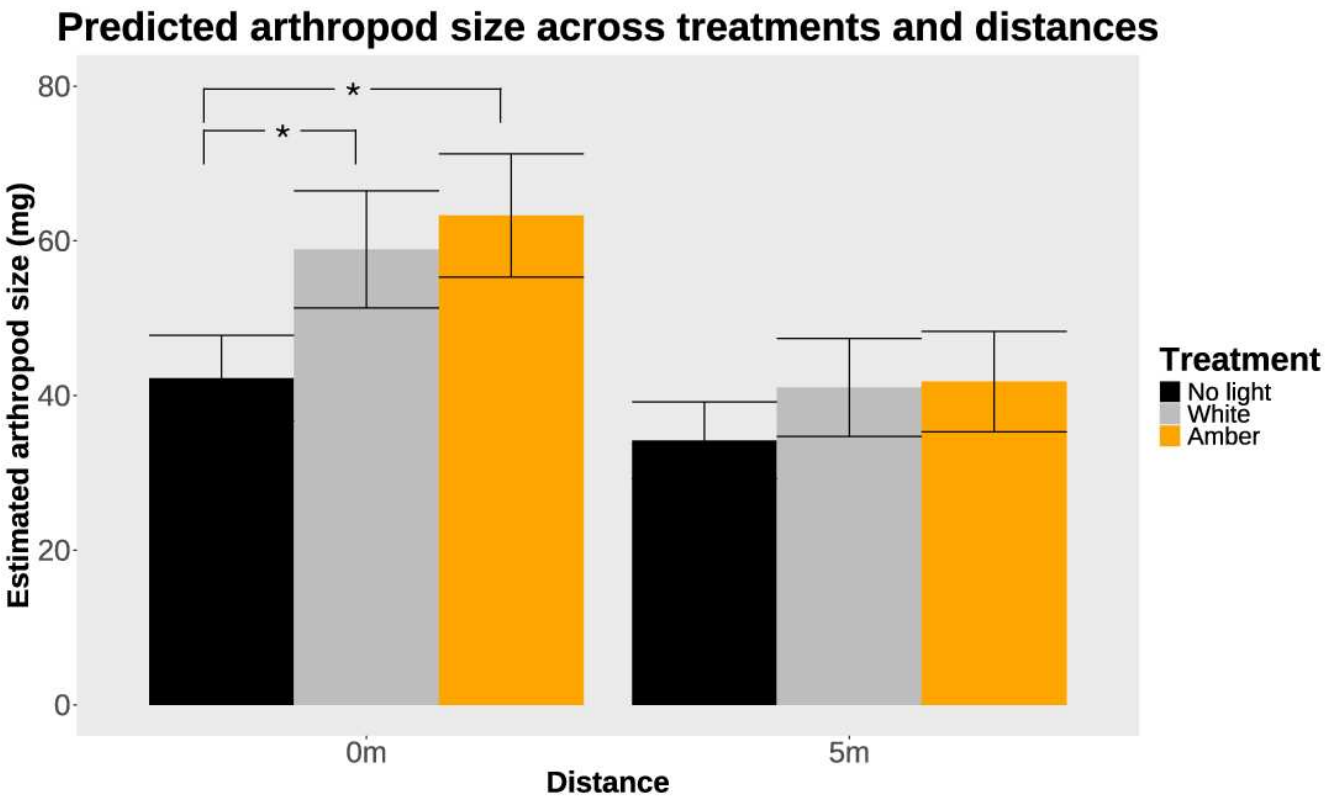

Figure 3: Estimated marginal means of biomass collected from each pitfall trap, comparing across treatments and distances. Asterisks indicate that according to our model, biomass was lower under no-light compared to lit treatments in traps directly underneath the lights ($p < 0.05$). Error bars represent standard error.

8 Discussion

We built ALANizer, a novel and open-source tool that contributes to the ALAN research community by allowing researchers to introduce inexpensive and scheduled light to an experiment. Its core components cost less than $200 CAD and are highly adaptable to a range of deployment contexts (light designs, sensor needs, sunrise and sunset times, etc.).

Using ALANizer, we successfully introduced white and amber light to a light-naïve environment while collecting data on light levels and arthropod activity. ALANizer successfully recorded higher levels of blue and green light under the white treatment condition relative to the amber treatment (Fig. 2). Additionally, we found that the light intensity of our white treatment condition matched that of a standard streetlight [15].

During field deployment, we observed larger biomass captures under both light treatments compared to a dark control, confirming the ability of ALANizer to induce changes in the natural environment. Our finding matches trends observed in other studies that compare ground-dwelling arthropod capture under light treatments [16, 17]. We did not observe any effects of ALAN on biomass in traps 5 metres away from ALANizer.

According to our model, we would expect on average an 89% increase in biomass upon introducing white light to the environment, and a 102% increase upon introducing amber light (see “Supporting information”). Biomass captures under these two light treatments did not differ. This matches the findings of Parkinson & Tieg [16], where biomass only differed across light colours for terrestrial insects. However, we sampled across relatively few study sites, and due to technical issues, there were a few sampling intervals where only a single site was

undergoing a given treatment. Although our model included a site-specific random factor, it is still possible that site factors were not fully accounted for, especially during times of scarcer data.

We identified several areas of improvement for ALANizer. Currently, ALANizer lacks wireless data transmission, requiring regular visits to experimental sites to download data. This may not be an issue for off-grid deployments, where batteries regularly need to be changed. However, it would be helpful for notifying the user when sensors are unexpectedly obstructed (i.e. by a fallen leaf), or when a peripheral device is unexpectedly disconnected. Additionally, retrieving and replacing the SD card without introducing water to the SD module can be challenging in heavy rain.

Many researchers have proposed guidelines and ideas for future ALAN studies [2]. These studies may be optimised by using lighting setups that are representative of real systems designed for human use. Future ALAN field experiments would benefit from assessing whether the lights being studied provide sufficient illumination for humans while mitigating effects on other organisms.

ALANizer’s low price, open-source documentation, and scalability make it well-suited to experimental ecology, which often requires many replicates to overcome the potential confounding effects of uncontrollable environmental variables.

ALAN’s acceleration shows no sign of stopping, making mitigation efforts increasingly crucial. To build effective policies and guidelines, we need high-quality evidence about its impacts,

which we know to be wide-ranging and profound. This work establishes ALANizer as a promising new tool in the rapidly growing field of ALAN research, facilitating further investigation of ecological impacts from new lighting installations.

9 Statement on Inclusion

Our study was performed on the traditional and ancestral territory of the xʷməθkʷəy̓əm (Musqueam) people. Our study involved input and participation from scientists and farm workers who work and live on and around the study area.

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