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Lights, bats, and buildings: investigating the factors influencing roosting sites and habitat use by bats in Grand Teton National Park

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Abstract Free-flying bats are highly affected by artificial night lighting, causing individuals to either 1) gather in unnaturally high densities around the light sources to exploit insects, or 2) travel increased distances to avoid light exposure. Similarly, nocturnal insects are disproportionately attracted to night lighting, trapping them until they die of exhaustion. The advent of new lighting technology which may decrease the impacts of night lighting on bats and insects by primarily producing light at wavelengths these animals are not sensitive to (i.e. in the red portion of the spectrum) is promising, however no studies have shown this at a large scale, and not in North America. Similarly, many studies on the effects of lights on bats, in general, have been on European species, and thus our overall understanding of how North American species are affected is limited. Grand Teton National Park, Wyoming, provides an excellent natural system to study the effects of lights on bat behavior, as well as to test possible mitigation methods, as the park supports a large community of over a dozen species, as well as sizeable human infrastructure that generates night light. From June through September, 2019, we undertook a large-scale, blocked experiment examining bat activity and space use in Colter Bay Village under both traditional street-lighting, as well as new "bat friendly" street lighting. Using both passive echolocation records and radiotelemetry, we collected data that will allow us to examine the ability of red LED streetlights to mitigate artificial light's negative impacts on bats and insects.

Introduction

Artificial light at night (ALAN) is pervasive across the world (Falchi et al., 2016), and is used increasingly as LED technology makes it cost-effective to do so (Stone et al., 2012). While ostensibly a tool, ALAN's benefits are tempered by numerous disadvantages to wellbeing, and it has been linked to numerous deleterious effects on humans (e.g. Lewy et al., 1980; Stevens, 2009; Obayashi et al., 2013). Further, it has been demonstrated to affect both invertebrates and vertebrates in terrestrial and aquatic ecosystems, and has been named as one of the greatest threats to biodiversity worldwide (Hölker et al., 2010). Some of the greatest threats are experienced by nocturnal animals, as these evolved with only moonlight as their primary source of night lighting.

Two groups that are of increasing conservation concern and that are threatened by ALAN are bats and nocturnal insects. Insects serve as the foundation of the world's food webs and are vital to pollination and nutrient cycling, but several recent studies have shown alarming worldwide collapses in insect biomass (Fox, 2013; Vogel, 2017; Hallmann et al., 2017). The spread and ubiquity of ALAN is likely playing a large role in these declines, as ALAN has a "vacuuming" effect on light-dispersing insects, drawing

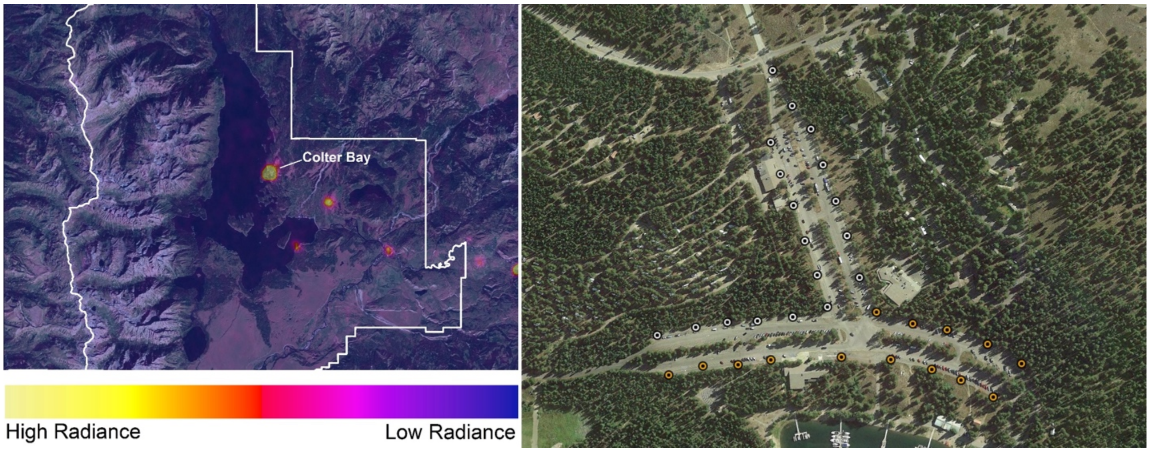

Figure 1. Left: Surface radiance (i.e. light exposure) within Grand Teton National Park, delineated by the white border (source: VIIRS satellite data and Google Earth imagery). Right: satellite imagery of the Colter Bay Village parking lot, displaying the locations of the 32 streetlights (18 white LEDs [white circles] and 14 orange high-pressure sodium streetlights [orange circles]) present in the parking lot prior to our 2019 season (source: Google Earth imagery).

them from the surrounding dark habitat and leaving them at risk of death via predation and exhaustion at lights (Eisenbeis, 2006). Similarly, bats are of global conservation risk, and the arrival of White-Nose Syndrome (WNS) to North America in 2006 has resulted in the death of tens of millions of the continent's bats (Turner et al., 2011). ALAN has been shown to broadly affect free-flying bats in two ways. First, fast-flying species forgo their usual foraging areas to feed on the insects attracted to lights, potentially drawing them into ecological traps (Rydell, 2006; Russo and Ancillotto, 2015). Second, slow-flying species avoid lit areas completely, likely for fear of owl predation (Stone et al., 2012). However, these alternate routes may result in increased energy expenditure and/or risk of predation. Thus, ALAN contributes to the cumulative effects acting on at-risk bat communities and may affect recovery from WNS.

Grand Teton National Park (GTNP) sits at a nexus for conservation concerns for bats; while it houses one of the largest western bat communities yet unaffected by WNS (although the disease's introduction is likely imminent), and provides a habitat refuge, it also supports a sizeable infrastructure that generates ALAN. If the foraging behaviors of WNS-susceptible species are altered by the presence of night lights, the ability of survivors to recover from infection may be compromised.

The parking lot of Colter Bay Village (CBV) includes 32 streetlights, and is the source of the greatest night light in the entirety of GTNP (Figure 1). Our work from the 2018 season has shown that bat activity and space use are greatly affected in this area relative to the adjacent naturally dark habitat (see previous report, Toth and Barber, 2018). For the 2019 season, we sought to test a promising new method to mitigate the effects of ALAN on bats and their insect prey: the use of recently developed "bat friendly" lighting (Spoelstra et al., 2017). These LED streetlights (ClearField luminaires developed by Signify) that have been shown to return lit areas to naturally dark habitat for both bats and nocturnal insects (Spoelstra et al., 2015, 2017) by predominantly emitting light of longer wavelengths (Figure 2), which neither bats nor insects are sensitive to (Müller et al., 2009), while matching the intensity of traditional streetlights (Figure 2). These lights have even been adopted for widespread use by the town of Nieuwkoop, Netherlands, following trials demonstrating their effectiveness (Figure 2). However, ClearFields have not been implemented in North America, or tested on North American bats/insects.

In this study we tested the effectiveness of this promising new technology by undertaking a block-design experiment in CBV. We switched lighting regimes in CBV between traditional white LED light-

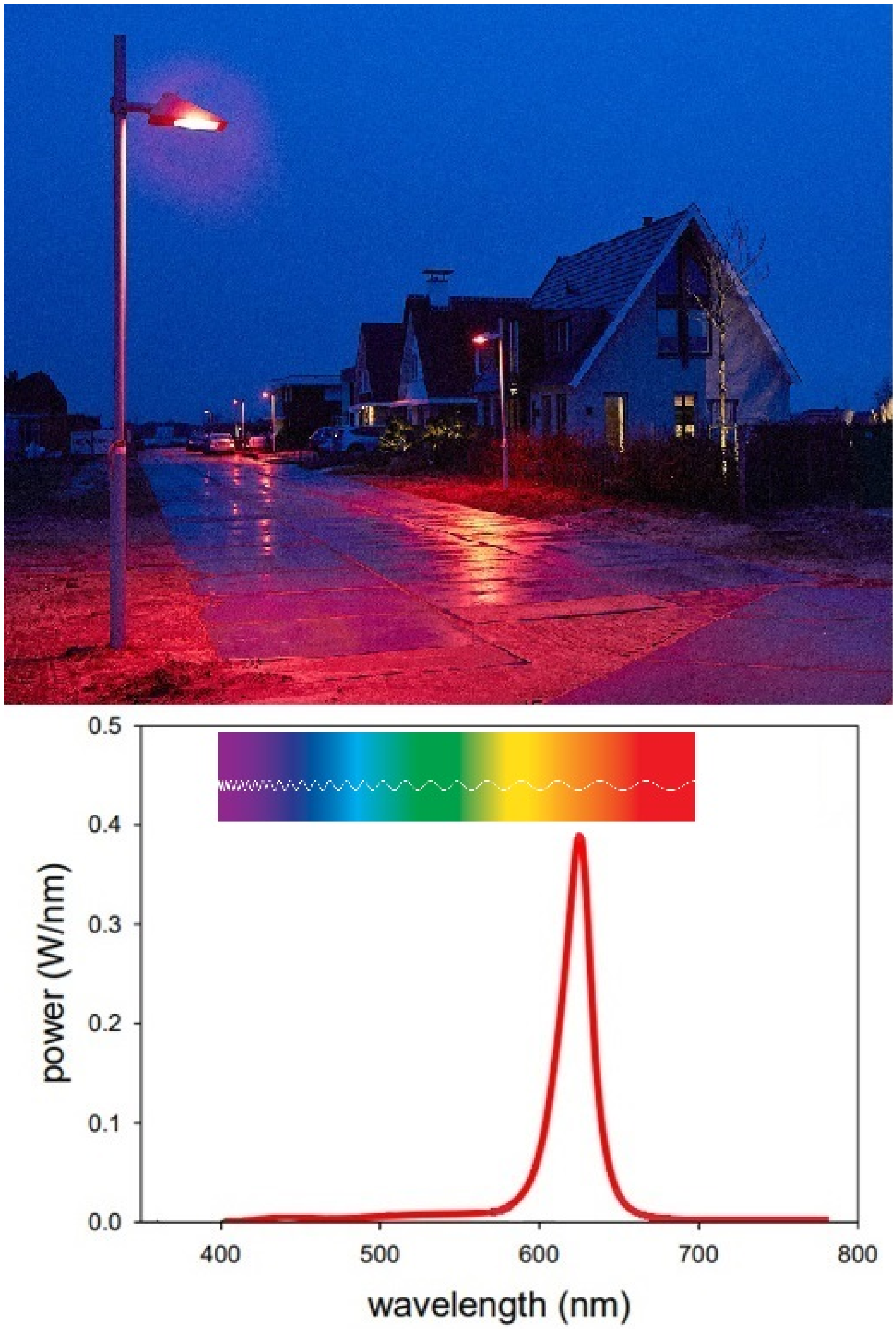

Figure 2. Above: Signify ClearField streetlights in use in the town of Nieuwkoop, Netherlands (source: Signify), a similar model to those employed in Colter Bay Village. During the red phase of the experimental blocks, we hypothesize that light-shy bats will no longer be excluded from the area (showing similar levels to dark areas), while light-exploiting bats will no longer have increased activity levels relative to dark areas. We further predict that the abundances of nocturnal insects will equalize between lit and unlit areas, negating the "vacuum effect" demonstrated in lit areas. Below: The spectral properties of the ClearField luminaires (adapted from Spoelstra et al., 2017). The lights attenuate the wavelengths that bat eyes are most sensitive to, as well as the wavelengths that attract nocturnal insects.

ing and red, "bat-friendly" lighting in three-day blocks between June 25 and September 24. We concurrently assessed bat activity and space use, and the abundance of nocturnal insects in the area to elucidate the effectiveness of this possible mitigation measure. We hypothesize that during the red-lit periods, activity levels of bats and abundances of nocturnal insects would return to levels observed in naturally dark areas.

Methods

Study location

This work was completed between June 25 and September 24, 2019, in CBV (43.9040°, -110.6418°). CBV is a developed area consisting of 250 RV campsites, a marina, a visitors' center, several businesses, and 208 log and tent cabins. CBV received over 400,000 visitors in 2017, making it an ideal location to study the human-wildlife interface in GTNP. The village is serviced by a large, central parking lot, originally consisting of 14 older orange high-pressure sodium streetlights and 18 newer white LED lights (Fig 1). The area is bordered by Jackson Lake to the west, Highway 89 to the east, and natural areas (forest, ponds, and meadows) to the north and south.

Light switching

Throughout the 2019 field season, both the color and intensity of the experimental streetlights used in this study were manipulated. Every 3 days, the color of the lights was changed between red and white. The season was blocked into six day blocks, each capturing the entirety of both a red and a white lighting color treatment. Each six day block was assigned a lighting intensity (i.e., 60% maximum wattage).

Acoustic monitoring

We deployed Wildlife Acoustics SM4BAT FS passive acoustic monitoring units at 16 locations (9 in dark locations, and 7 in experimentally lit locations) throughout the 2019 field season to assess bat foraging activity patterns under different lighting treatments. These monitoring units automatically entered a detection phase at sunset each night, recording the echolocation calls of passing bats, and returning to sleep at sunrise.

Radiotelemetry

We used radiotelemetry to determine the response of individual bats to the light sources in CBV. We captured bats throughout CBV and the adjacent areas using a mix of single- and triple-high mist nets and attached radiotransmitters (NTQ nanotags, Lotek Engineering, Newmarket, ON, Canada) to captured individuals using Perma-type Surgical Glue (Perma-Type Company Inc., Plainville, CT, USA). In total, we radiotagged 52 individuals from 2 species – 2 *Myotis evotis* and 50 *Myotis lucifugus*. Transmitters were programmed with a 5-second burst rate, giving them an estimated lifespan of approximately 22-30 days. Further, we ensured that transmitters did not weigh more than 5% of each individual's mass prior to attachment (Aldridge, HDJN and Brigham, RM, 1988).

To assess bat habitat use patterns under different lighting treatments, we deployed 10 Lotek SRX800 data loggers throughout the Colter Bay Village area. Eight of these loggers (three in experimentally lit areas and five in unlit areas) were coupled with four-element Yagi antennas, while two other loggers (one in an experimentally lit area and one in an unlit area) were coupled with omnidirectional antennas.

Insect sampling

Insect types and abundances are often predictive of bat activity (Rydell et al., 1996; Fukui et al., 2006). Thus, we used flight intercept traps to quantify the nocturnal insect community of CBV throughout the 2019 field season. Each night approximately 1 hour before sunset, flight intercept traps with a dry killing agent placed in the traps' collection containers were suspended approximately 3 meters from the ground (below streetlights in lit areas and between trees in unlit areas). Insect trap deployments were terminated between sunrise and one hour after sunrise when samples were collected and sampling containers were removed from the traps.

Preliminary results

Acoustic monitoring

We recorded 597,954 potential call sequences in total. Of the acoustic monitoring data that has been processed with SonoBat, 12 species have been detected: *Antrozous pallidus*, *Eptesicus fuscus*, *Euderma maculatum*, *Lasiurus cinereus*, *Lasionycteris noctivagans*, *Myotis californicus*, *Myotis ciliolabrum*, *Myotis evotis*, *Myotis lucifugus*, *Myotis thysanodes*, *Myotis volans*, and *Myotis yumanensis*. Following processing of all recordings using SonoBat, we will manually inspect a portion of calls classified by SonoBat to validate species classifications and quantify species-level automated classification error rates.

Radiotelemetry

Passive telemetry data loggers recorded 63,033 location fixes, 62,570 of which were *M. lucifugus* detections, and 463 of which were *M. evotis* detections. These data are currently being analyzed to determine individual-specific space use.

Insect sampling

Our trapping protocol resulted in 359 trap nights. Insects collected are currently being identified to determine the effects of red light's ability to mitigate negative impacts of artificial lighting, as well as the effects of different lighting intensities for both red and white light.

Proposed analyses

To examine the effects of red and white light at various intensities on bat and insect habitat use, we will employ generalized linear mixed-effects models. For passive acoustic monitoring data, models will be constructed for each species, using the number of call sequences attributed to each species as response variables, light color and intensity when each call sequence was recorded, and whether the call sequence was recorded in a dark or lit area as predictors. Other predictors in these passive acoustic monitoring models will include landcover metrics for the area immediately surrounding passive acoustic monitors, moon phase, and nighttime temperature.

Radiotelemetry results will be analyzed similarly to passive acoustic monitoring results. For each species fitted with radiotags, the number of detections per night will be used as response variables, and the lighting conditions, weather, and surrounding landcover will be used as predictors.

Insect habitat use will be examined by constructing a model for each order of insect identified in samples, with the number of insects from each order captured per night as response variables. Predictor variables will include light color and intensity for each sampling night, as well as surrounding landcover metrics, moon phase, and nighttime temperature.

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