



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 Bats are often useful bioindicators for ecosystem health and are disproportionately affected by sources of night light. Changes in bat behavior may manifest in two different ways: 1) some bats are light-exploiting and therefore attracted to areas with light sources, and 2) some are light-shy, traveling far out of their way to avoid lit areas. Grand Teton National Park provides an excellent natural system to study the effects of lights on bat behavior, as the park supports a large community of over a dozen species, as well as sizeable human infrastructure that generates night light. From June to August 2018 we used passive acoustic monitoring and radiotelemetry to study the activity and space use of bats in Colter Bay Village, specifically in the large parking lot at the center of the village and the adjacent naturally dark areas. We recorded 98,238 echolocation call sequences from 11 species, with the vast majority (~ 69,000) occurring in lit areas. Further, we recorded 4,665 location fixes from 32 tagged individuals from three species and, similarly, most location fixes (2,970) were in lit areas. All day roosts were found within buildings. We discuss the importance of these results and our work moving forward.

Introduction

Bats are one of the most successful mammalian groups on the planet, and are second only to rodents as the most-specious order in the class (Altringham, 2011). Nocturnality, powered flight, and echolocation have allowed bats to occupy the widest niche breadth of any mammalian order (Altringham and Senior, 2005). Further, bats provide important ecological (Lacki et al., 2007) and economic (Maine and Boyles, 2015) services, and fill keystone roles in some habitats (Jones et al., 2009). Insectivorous bats are a primary consumer of nocturnal insects, eating up to 100% of their bodyweight each night (Lacki et al., 2007). The importance of bats, along with their susceptibility to habitat perturbations and disease, make them excellent bioindicators for assessing habitat quality (Jones et al., 2009).

Two significant issues currently threaten North American bats: 1) the rapid spread of White-nose Syndrome (WNS; Blehert et al., 2009), and 2) human-induced changes to roosting and foraging areas (Tuttle, 2013). WNS, caused by the fungal pathogen *Pseudogymnoascus destructans*, results in depleted fat reserves and eventual starvation by hibernating bats through increased winter arousals (Reeder et al., 2012). WNS has caused the death of millions of bats in North America since its arrival in 2006 and continues to spread westward at a rapid pace (Coleman and Reichard, 2014). Further, bats have been profoundly influenced by urbanization and anthropogenic changes to their habitat (Russo and Ancillotto, 2015); both anthropogenic light (Stone et al., 2009) and sound (Schaub et al., 2008; Siemers and Schaub, 2011) significantly alter bat behavior, and while some species appear to be tolerant to the ef-

fects of urbanization, these settings may be acting as ecological traps (Russo and Ancillotto, 2015) through increased rates of predation and conflicts with humans (Streicker et al., 2013).

The rapid increase of anthropogenic light at night (ALAN; Falchi et al., 2016) is having profound impacts on both diurnal and nocturnal species worldwide (Hölker et al., 2010; Gaston et al., 2013), including bats (Stone et al., 2015). ALAN has been shown to affect free-flying bats in two ways: fast-flying bats forgo their usual foraging areas to feed on the insects drawn to lights, and slow-flying bats avoid lit areas completely, likely for fear of owl predation (Stone et al., 2015). However, these alternative travel routes may cause increased energy expenditure due to longer flight times or exposure to predation via non-optimal vegetation cover (Stone et al., 2009). Moreover, ALAN has been found to cause significant decreases in nocturnal insect abundances by drawing insects from adjacent dark areas for wide distances (Eisenbeis, 2006; Perkin et al., 2014), potentially decreasing the food availability in dark foraging areas for light-shy species. This comes at a time when massive reductions (over 75%) in flying insect biomass have been observed in protected areas worldwide (Hallmann et al., 2017).

Grand Teton National Park (GTNP) sits at a nexus for serious bat conservation concerns for both susceptibility to WNS infection and for changes in foraging and roosting behavior in relation to anthropogenic stressors. While the park ostensibly provides an intact habitat refuge, it supports a sizeable infrastructure that generates anthropogenic light pollution, and some species may therefore be excluded from primary habitats by the presence of night lighting. 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. How anthropogenic factors influence the bats of GTNP is unknown. In this study we examine how one of the most significant sources of night light in GTNP – the parking lot of Colter Bay Village – affects the activity and space use of the bats that inhabit the area.

Methods

Study location

This work was completed between June 6 and August 29, 2018, in Colter Bay Village (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 consisting of 14 older orange high-pressure sodium streetlights and 18 newer white LED lights. 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.

Acoustic monitoring

We deployed 19 Wildlife Acoustics Song Meter 4 (SM4) acoustic-monitoring units nightly throughout the parking lot in roughly equal proportions of areas lit by white light ($n = 5$), orange light ($n = 4$), gradient lighting (i.e. transition areas bordering lit and unlit areas; $n = 4$), and naturally dark areas ($n = 6$). 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.

Bat call recordings were classified to the species level using SonoBat v. 4.2.1 (SonoBat Inc., Arcata, CA). Acceptable call quality was set to 0.8, and the sequence decision threshold to 0.9. A maximum of 16 calls were considered per sequence for classification purposes, and only sequences where three or more calls were used for species classification were retained in the final species tally.

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 capture

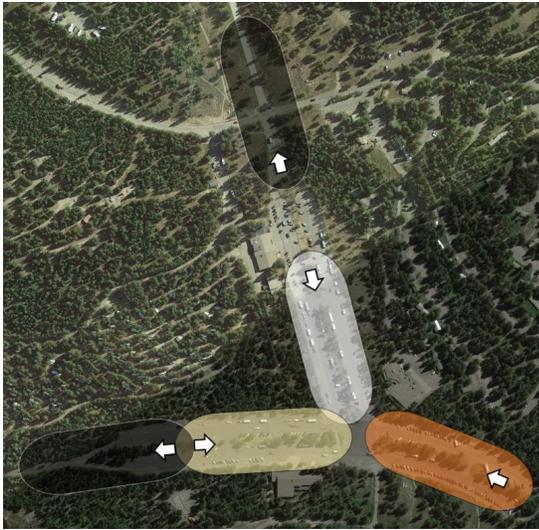


Figure 1. Study site and telemetry methods from Colter Bay Village, Grand Teton National Park. Map shows locations of telemetry dataloggers and orientations of Yagi antennas (arrows), and polygons represent the approximate area and color of lighting treatment that they monitored (yellow represents the mix of white and orange lights).

individuals using Perma-type Surgical Glue (Perma-Type Company Inc., Plainville, CT, USA). In total, we captured 32 individuals from four species – *Myotis lucifugus* ($n = 27$), *Myotis evotis* ($n = 1$), *Eptesicus fuscus* ($n = 3$), and *Lasionycteris noctivagans* ($n = 1$). Transmitters were programmed with a 10-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 and Brigham, 1988).

We deployed three Lotek SRX800 dataloggers (Lotek Engineering, Newmarket, ON, Canada) on a nightly rotating schedule throughout CBV, monitoring for tagged bats in areas described by four lighting regimes: natural darkness, white lights, orange lights, and a mix of white and orange lights (Figure 1). Further, we used active telemetry during the day to locate the day roosts of transmitted individuals; observers with handheld receivers used a close approach method to determine the exact structures that individuals were roosting within.

Insect sampling

Insect types and abundances are a largely predictive of bat activity (Rydell et al., 1996; Fukui et al., 2006) and may also be influenced by anthropogenic light levels (Rydell, 2006; Eisenbeis, 2006). Thus, we used malaise traps to quantify the nocturnal insect community of CBV throughout the 2018 field season. We hung traps approximately 3-5 m in the air, suspended either from a light post (lit areas) or a tree branch of a comparable height (dark areas). One malaise trap was hung in each of four treatment types per sampling night: dark, gradient, white light and orange light. There were 2-4 sampling sites per treatment and we rotated through them randomly within each treatment type.

Preliminary Results

Acoustic monitoring

We recorded 98,238 call sequences from 11 species in total. Species recorded consisted of the Yuma myotis (*M. yumanensis*), California myotis (*M. californicus*), Western small-footed myotis (*M. ciliolabrum*), long-legged myotis (*M. volans*), little brown myotis (*M. lucifugus*), long-eared myotis (*M. evotis*), fringed myotis (*M. thysanodes*), big brown bat (*Eptesicus fuscus*), silver-haired bat (*Lasionycteris noctivagans*), hoary bat (*Lasiurus cinereus*), and pallid bat (*Antrozous pallidus*). Of these, *E. fuscus*, *M. lucifugus*, *M. yumanensis*, and *Lasionycteris noctivagans* have been confirmed as susceptible to WNS or have been found carrying the fungus linked with the disease. Although *M. evotis* has not yet been documented with WNS, its eastern counterpart – the northern long-eared myotis (*M. septentrionalis*) – has been (Knudsen et al., 2013), suggesting that *M. evotis* is likely to be affected by WNS as the disease spreads westwards.

Preliminary analysis of the acoustic data shows a clear distinction between lighting types: monitors under white lights recorded 42,953 calls, those at orange light recorded 25,999 calls, 16,455 in the gradient between lit and unlit areas, and 12,831 in dark areas (Figure 2a). Further, there were clear differ-

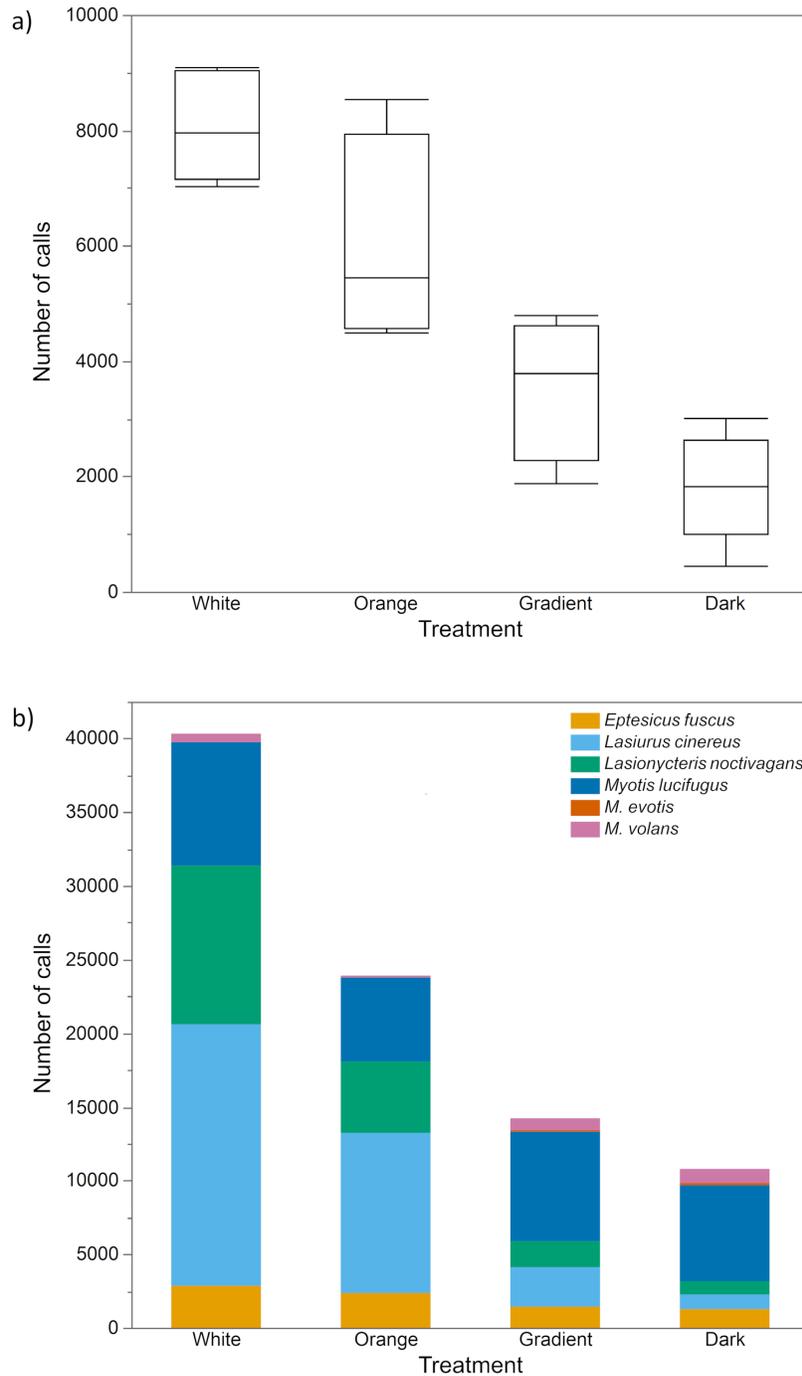


Figure 2. Echolocation calls recorded across 19 sites and four lighting treatments in Colter Bay Village, Grand Teton National Park. a) Range of total echolocation calls recorded in each lighting treatment, with box plots showing the 25% and 75% quartiles (boxes), medians (lines in the boxes) and outermost values within the range of 1.5 times the respective quartiles (whiskers), and b) the proportion of calls made in each treatment by the top six recorded species.

ences between the proportion and types of species recorded in each treatment. For example, both *Lasionycteris noctivagans* and *Lasiurus cinereus* were recorded more often in both lit conditions than either gradient or dark conditions, whereas *M. lucifugus* was found in roughly equal numbers throughout (Figure 2b).

Radiotelemetry

Passive telemetry dataloggers recorded 4665 location fixes from three species (*M. lucifugus*, *E. fuscus*, and *Lasionycteris noctivagans*). While this data is currently being analyzed to determine individual-specific space use, there were clear differences at the gross scale. Contrary to acoustic monitoring data, transmittered individuals were detected most frequently in dark ($n = 1695$ fixes) and orange-lit areas ($n = 1749$ fixes) compared to white ($n = 626$ fixes) and orange-white ($n = 595$ fixes) areas (Figure 3a). Further, activity patterns differed between treatments (Figure 3b), with white and orange-white treatments experiencing peaks of activity relatively early in the night, dark treatments experiencing bimodal peaks in activity (no location fixes recorded after 4 AM), and the bulk of activity occurring near morning in orange-lit areas.

We located 65 day-roosts for radiotagged individuals from the four species in six locations. All day roosts were located within buildings, including two visitor cabins, a generator building, the CBV visitor center, the marina, and a park office. Roosting within buildings is a rare behavior for *Lasionycteris noctivagans*, but our tagged individual day-roosted within a visitor cabin during every roost check.

Insect sampling

Our trapping protocol resulted in 165 trap nights across the 2018 season, however these samples have yet to be analyzed.

Conclusions

Our work provides some of the first evidence that North American bat species are affected by ALAN. Further, these effects appear to be species (and light-

ing type) specific, with some avoiding lit areas, and others appearing to be disproportionately attracted to those same areas. Light type also had differential effects on bat activity, with individuals leaving dark areas earlier, and staying in areas lit by high-pressure sodium lighting longer.

Our results also highlight the need for the complimentary methodological approaches of both passive acoustic monitoring and radiotelemetry to examining bat behavior in these complex habitat matrices, as each only tells a portion of the story. While most echolocation call sequences were found within areas lit by white light (and the least in dark areas), the majority of location fixes were recorded in orange-lit and dark areas, with less than half in white-lit areas. This may reflect changes in behavior in these areas (e.g. individuals may not produce as many echolocation calls), and/or the habitat preferences of individual bats.

Lastly, many of the individuals caught and transmittered in CBV also roosted in the immediate area, and all located day roosts were within buildings. Whether ALAN promotes roosting within nearby buildings (by creating high-quality foraging areas) remains to be seen.

Our work highlights the wildlife-urban interface in CBV, and presents an important first step in demonstrating the importance of ALAN in influencing the nocturnal (and potentially diurnal) behaviors of North American bat species. How these alterations to behavior affect the survivability and/or transmission probability of WNS is currently unknown and requires further research.

Future Work

In addition to continuing the analysis of our current dataset, we are excited to build upon this work in important ways moving forward in 2019 and beyond. This includes expanding our monitoring area to a 170-ha landscape matrix that includes the entirety of CBV and the surrounding natural habitats. We will use a grid-based approach to the placement of SM4s and telemetry dataloggers, and their locations will reflect a number of habitat characteristics (both

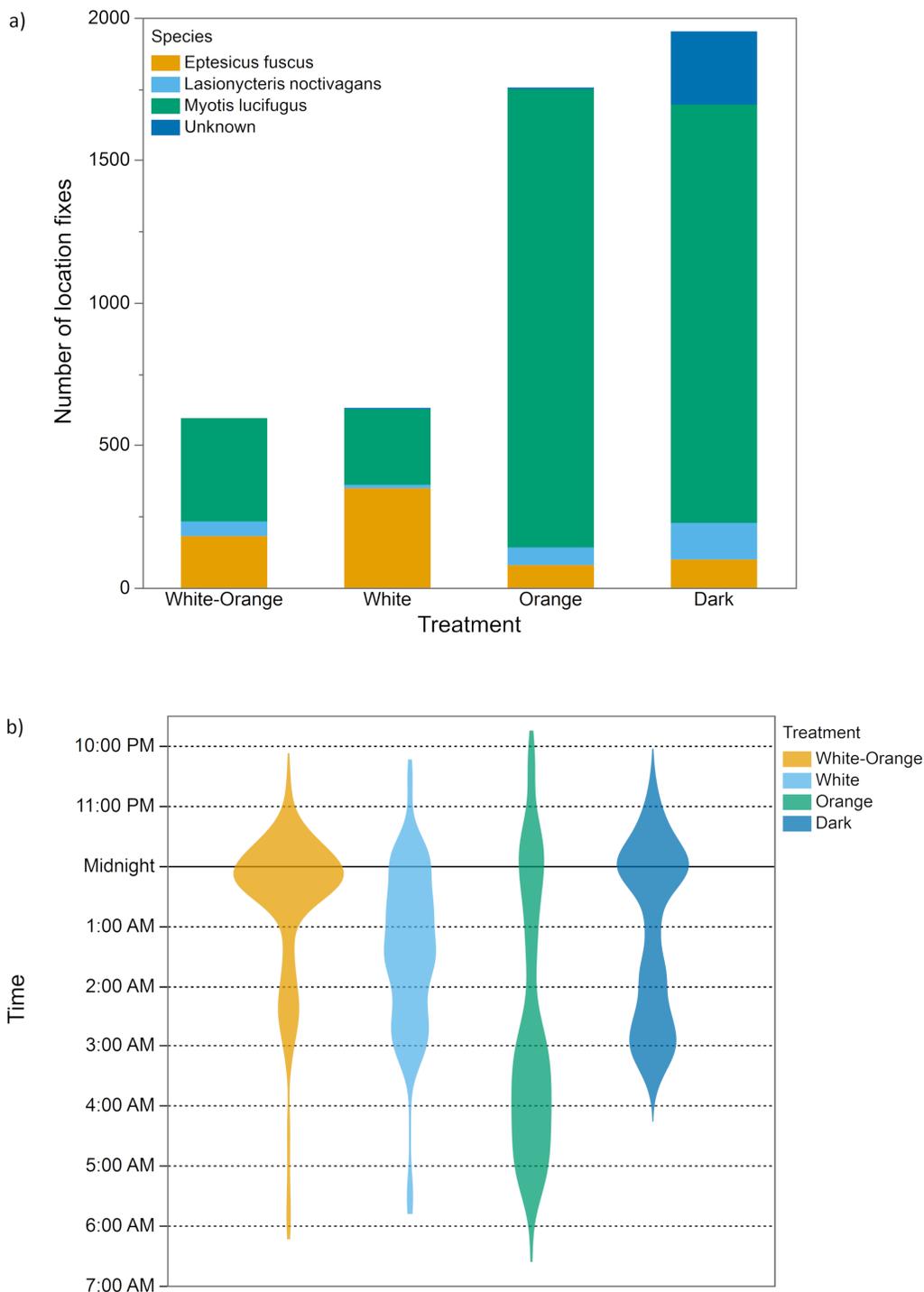


Figure 3. Telemetry results from five passive telemetry dataloggers placed throughout Colter Bay Village. a) the number of location fixes obtained for each lighting treatment per species, and b) the activity of bats across the night in each lighting treatment (thicker regions of the plot indicate more activity during that time period). In total, there were 4665 location fixes from three species (*M. lucifugus*, *Lasionycteris noctivagans*, and *E. fuscus*) between June 24 and July 31, 2018.

natural and urban) that may positively and/or negatively influence bat occurrence. We will use both activity (acoustic recording) and location (radiotelemetry) datasets to construct species distribution models, relating species observations to habitat variables to produce maps of the probability of occurrence. Once produced, these models can act in a predictive capacity and be applied park-wide to determine areas where bats are positively and negatively influenced by human activities.

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References

- Aldridge, H., and R. Brigham. 1988. Load carrying and maneuverability in an insectivorous bat: a test of the 5% “rule” of radio-telemetry. *Journal of Mammalogy* **69**:379–382.
- Altringham, J. D. 2011. *Bats: from evolution to conservation*. 2nd edition. Oxford University Press, New York.
- Altringham, J. D., and P. Senior, 2005. Social systems and ecology of bats, Pages 280–302. *Sexual segregation in vertebrates: ecology of the two sexes*, Cambridge University Press, Cambridge, UK.
- Blehert, D. S., A. C. Hicks, M. Behr, C. U. Meteyer, B. M. Berlowski-Zier, E. L. Buckles, J. T. H. Coleman, S. R. Darling, A. Gargas, and R. Niver. 2009. Bat white-nose syndrome: an emerging fungal pathogen? *Science* **323**:227.
- Coleman, J. T. H., and J. D. Reichard. 2014. Bat white-nose syndrome in 2014: a brief assessment seven years after discovery of a virulent fungal pathogen in North America. *Outlooks on Pest Management* **25**:374–377.
- Eisenbeis, G., 2006. Artificial night lighting and insects: attraction of insects to streetlamps in a rural setting in Germany, volume 2 of *Ecological Consequences of Artificial Night Lighting*, Pages 191–198. Island Press, Washington, DC.
- Falchi, F., P. Cinzano, D. Duriscoe, C. C. Kyba, C. D. Elvidge, K. Baugh, B. A. Portnov, N. A. Rybnikova, and R. Furgoni. 2016. The new world atlas of artificial night sky brightness. *Science Advances* **2**:e1600377.
- Fukui, D. A. I., M. Murakami, S. Nakano, and T. Aoi. 2006. Effect of emergent aquatic insects on bat foraging in a riparian forest. *Journal of Animal Ecology* **75**:1252–1258.
- Gaston, K. J., J. Bennie, T. W. Davies, and J. Hopkins. 2013. The ecological impacts of nighttime light pollution: a mechanistic appraisal. *Biological Reviews* **88**:912–927.
- Hallmann, C. A., M. Sorg, E. Jongejans, H. Siepel, N. Hofland, H. Schwan, W. Stenmans, A. Müller, H. Sumser, and T. Hörrén. 2017. More than 75 percent decline over 27 years in total flying insect biomass in protected areas. *PLoS one* **12**:e0185809.
- Hölker, F., C. Wolter, E. K. Perkin, and K. Tockner. 2010. Light pollution as a biodiversity threat. *Trends in ecology & evolution* **25**:681–682.
- Jones, G., D. S. Jacobs, T. H. Kunz, M. R. Willig, and P. A. Racey. 2009. Carpe noctem: the importance of bats as bioindicators. *Endangered Species Research* **8**:93–115.
- Knudsen, G. R., R. D. Dixon, and S. K. Amelon. 2013. Potential spread of White-Nose Syndrome of bats to the Northwest: epidemiological considerations. *Northwest Science* **87**:292–306.
- Lacki, M. J., S. K. Amelon, and M. D. Baker, 2007. Foraging ecology of bats in forests, Pages 83–127. *Bats in forests: conservation and management.*, Johns Hopkins University Press, Baltimore, Maryland, USA.
- Maine, J. J., and J. G. Boyles. 2015. Bats initiate vital agroecological interactions in corn. *Proceedings of the National Academy of Sciences of the United States of America* **112**:12438–12443.
- Perkin, E. K., F. Hölker, and K. Tockner. 2014. The effects of artificial lighting on adult aquatic and terrestrial insects. *Freshwater Biology* **59**:368–377.
- Reeder, D. M., C. L. Frank, G. G. Turner, C. U. Meteyer, A. Kurta, E. R. Britzke, M. E. Vodzak, S. R. Darling, C. W. Stihler, and A. C. Hicks. 2012. Frequent arousal from hibernation linked to severity of infection and mortality in bats with white-nose syndrome. *PLoS One* **7**:e38920.
- Russo, D., and L. Ancillotto. 2015. Sensitivity of bats to urbanization: a review. *Mammalian Biology-Zeitschrift für Säugetierkunde* **80**:205–212.
- Rydell, J., 2006. Bats and their insect prey at streetlights, volume 2 of *Ecological Consequences of Artificial Night Lighting*, Pages 43–60. Island Press, Washington, DC.

- Rydell, J., A. Entwistle, and P. A. Racey. 1996. Timing of foraging flights of three species of bats in relation to insect activity and predation risk. *Oikos* **76**:243–252.
- Schaub, A., J. Ostwald, and B. M. Siemers. 2008. Foraging bats avoid noise. *The Journal of experimental biology* **211**:3174–3180.
- Siemers, B. M., and A. Schaub. 2011. Hunting at the highway: traffic noise reduces foraging efficiency in acoustic predators. *Proceedings of the Royal Society B: Biological Sciences* **278**:1646–1652.
- Stone, E. L., S. Harris, and G. Jones. 2015. Impacts of artificial lighting on bats: a review of challenges and solutions. *Mammalian Biology-Zeitschrift für Säugetierkunde* **80**:213–219.
- Stone, E. L., G. Jones, and S. Harris. 2009. Street lighting disturbs commuting bats. *Current Biology* **19**:1123–1127.
- Streicker, D. G., R. Franka, F. R. Jackson, and C. E. Rupprecht. 2013. Anthropogenic roost switching and rabies virus dynamics in house-roosting big brown bats. *Vector-Borne and Zoonotic Diseases* **13**:498–504.
- Tuttle, M. D., 2013. Threats to bats and educational challenges, Pages 363–391 . *Bat Evolution, Ecology, and Conservation*, Springer, New York.