

EFFECTS OF ARTIFICIAL LIGHT AT NIGHT ON ACTIVITY OF LOCAL BATS

A field study from Slottsskogen Park, Gothenburg



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Vespertilio murinus, Photography by Magnus Gelang.

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Abstract

Artificial light at night (ALAN) is a pressing issue on global biodiversity. Particularly sensitive are nocturnal animals such as bats. In this study, attempts were made to evaluate the effect of ALAN on the nightly activity of bat species who inhabit the area of Slottsskogen Park in central Gothenburg, Sweden. With the cooperation of Gothenburg City, the streetlights in six suitable sites within the park got a weekly alternating schedule of being lit and unlit, lasting four weeks. During this period, one bat detector was installed at each site, recording any passing bat sounds. The recordings were then analysed in BatSound, where each distinct individual per recording was marked down as a registration for the identified species. Activity was measured as the number of registrations per species and was then compared between light statuses. In total, six bat species were identified but only three of them had enough observations to be statistically tested reliably, those being *Eptesicus nilssonii*, *Vespertilio murinus* and *Pipistrellus pygmaeus*. The data of *E. nilssonii* and *V. murinus* showed a trend of preference for unlit sites, while the data of *P. pygmaeus* showed near equal activity levels for lit and unlit sites. However, testing showed nonsignificant effects of light status on the activity of any of the three species, possibly due to lacking sample sizes. While the results for *E. nilssonii* and *P. pygmaeus* match with pre-existing knowledge of these species, *V. murinus* appearing avoidant towards artificial light goes against the common notion that it, like most fast-flying bats, is relatively light-tolerant. Further research on the topic, and particularly on *V. murinus*, may have significant implications for conservational work.

Introduction

Artificial light at night

Artificial light at night (ALAN), human made illumination such as streetlamps that brighten the nightly environment, has become an increasingly extensive feature of urban landscapes globally (Cinzano, et al., 2001) due to the rapid expansion of cities and infrastructure (United Nations, Department of Economic and Social Affairs, 2025). While benefiting humans with visibility and perceived safety, ALAN also serves as a major source of disruption for biodiversity (Hölker, et al., 2010). A group of animals particularly sensitive to artificial light are the winged mammals in the Chiroptera order, bats. Nearly all bat species are nocturnal, having adapted to the cover of the night together with their predators and prey (Rydell & Speakman, 1995). When exposed to ALAN, these species may be forced to alter their behavioral patterns (Zou, et al., 2024), and the typical interactions between them and their prey may be disrupted (Li & Wilkins, 2022). The results of multiple field experiments show these ALAN-driven changes, with disruptions in bat flight patterns and reductions in bat activity (Stone, et al., 2009; Seewagen & Adams, 2021). However, the extent of these effects is not uniform across all bat species (Voigt, et al., 2021). Fast-flying bats that forage in edge spaces, semi-cluttered environments such as forest borders and tree canopies, typically use long range echolocation pulses for detection of prey. Species that fit in this group, such as the soprano pipistrelle (*Pipistrellus pygmaeus*) and the common pipistrelle (*Pipistrellus pipistrellus*) (Denzinger & Schnitzler, 2013), appear more tolerant to illuminated areas, and may even exploit the gathering of flying insects around streetlamps as feeding opportunities (Rydell, 1992). On the other hand, the relatively slow-flying, narrow space foraging species that utilize short range detection strategies, such as species of *Myotis* and *Plecotus* species, seem to avoid illuminated areas (Denzinger & Schnitzler, 2013; Rydell J. , 1992).

Species composition in study area

In Sweden there are 19 recognized species of bats belonging to seven different genera: *Myotis*, *Pipistrellus*, *Nyctalus*, *Eptesicus*, *Vespertilio*, *Barbastella* and *Plecotus* (Naturvårdsverket, 2026) , all of which belong to the family Vespertilionidae (Mammal Diversity Database, 2021). In the area chosen for this study, Slotsskogen Park located in central Gothenburg, eight of these species have been verified or observed (Gelang, 2025):

Myotis daubentonii - Daubenton's bat

Nyctalus noctula - Common noctule

Pipistrellus pygmaeus - Soprano pipistrelle

Pipistrellus pipistrellus - Common pipistrelle*

Pipistrellus nathusii - Nathusius's pipistrelle

Vespertilio murinus - Parti-coloured bat

Eptesicus nilssonii - Northern bat

Plecotus auritus - Brown long-eared bat

Being previously abundant in the park, Daubenton's bat (*Myotis daubentonii*) has recently only been observed a low number of times (Gelang, 2025). Furthermore, the local population of brown

* *Pipistrellus pipistrellus* typically appears very sparingly in southern Sweden. Within Slotsskogen, the species has only ever been recorded, not caught, making verification of the species more complex (Gelang, 2025; SLU, 2026).

long-eared bats (*Plecotus auritus*), a species with an established sensitivity towards light pollution, has seen a significant decline (Gelang, 2025; SLU, 2026).

Yearly bat activity in Europe generally starts to climb at the end of April and beginning of May, when most bat species start to emerge from hibernation (Masing & Lutsar, 2007). Bat activity then peaks over the summer, with some smaller surges in September and October before the hibernation season begins anew (Giuntini, et al., 2026). Some species are migratory, such as the Nathusius's pipistrelle (*Pipistrellus nathusii*) and the common noctule (*N. noctule*) (Fleming, 2010), some of which likely uses Slottsskogen Park as a stopover during migration (Gelang, 2025). The daily activity of bats typically starts at or soon after sunset, peaking 1-2 hours afterwards and then declining through the night, with some species showing a second smaller peak closer to dawn (Goodenough, et al., 2015; Perks & Goodenough, 2020). Since these periods of activity coincide with the hours when artificial light typically is active, the management of street lighting and other sources of ALAN may be of particular relevance to bat activity.

In this study, nightly bat activity was measured using static bat detectors, comparing the differences in activity between lit and unlit conditions. The chosen study area, Slottsskogen Park, Gothenburg, contains two types of streetlights: those that can only be managed manually and those that can be managed remotely via Gothenburg City's network (Ekelund, et al., 2026). By selecting sites that only contained remotely controlled lights, a lighting schedule that suited the experiment could be prepared. With the schedule, half of the sites were lit up normally while the other half were turned off. Every week for four weeks, the sites switched light status. The expectation of this experiment was that bat activity would generally be higher in unlit conditions. However, it was also expected that the effect of light status on bat activity would differ, for instance between species with different foraging strategies. For fast-flying species that might take advantage of insects gathering around streetlights, the effect on activity may even be positive in sites that are lit up.

Research aim

The aim of this research is to further evaluate the impacts of ALAN on the activity of local bat species by comparing the nightly recorded activity of the species during dark and artificially lit periods.

Material and method

Site selection and preparation

Six sites within Slottsskogen Park were studied, prioritizing areas that are less used by people at night to create minimal disturbance to the public during data collection. Site 6 was part of a busier path (Figure 1), but since the site was partly illuminated by the nearby road lights it was deemed not to be disruptive to people to use the area for this study. The chosen sites only included streetlights that could be remotely controlled to minimize manual labor. Additionally, areas where bat activity was known to be relatively high were prioritized. The sites were split up into two groups with alternating light schedules. Sites 1, 2 and 4 were included in Group 1, and Sites 3, 5 and 6 in Group 2 (Figure 1). The data collection took place for four weeks, starting on the 4th of May, 2026 and ending on the 1st of June, 2026. The sites in Group 1 had their lampposts powered off completely during study week 1 and 3 and powered normally during week 2 and 4. The schedule of Group 2 was identical, but reversed.



Figure 1. Map of Slottsskogen Park with the six sites marked as either red lines (Group 1) or yellow lines (Group 2). Base map by Linda Thelin.

Data collection

To measure the activity of bats, PippyG static bat detectors (Apodemus, Netherlands) were used, which record full spectrum ultrasonic calls at a sampling rate of 384kHz. They were configured to record for five seconds any time a sound within the frequency range of 10-110 kHz was detected. Within this frequency range, all typical Swedish bat sounds (usually around 20-60 kHz) would be recorded (Fenton, et al., 1998). Any time a sound was recorded by a detector, it was automatically stored as a WAV-file with information about site number, date, and time of recording in the file name. The detectors were set up to start recording at sunset and end at sunrise. Detectors were covered with plastic bags for protection, with holes cut out where their microphones were located. The detectors were then tied up with string at their designated sites, one detector per site (Figure 2). Every 3-4 days, each detector was visited to refresh the batteries and to back up the data.

Data analysis

After the four weeks of data collection, the recorded WAV-files were analysed in BatSound 4.7 (Pettersons Elektronik AB). Species identification of every recording followed the methods in Russ (2021). The species identification was relatively simple, as the recordings for each species typically fit within the consequent parameters of certain features, such as frequency range, time between calls, and the trajectory of calls on a spectrogram. The identification of *P. pipistrellus*, being specially tricky since its calls are similar to those of *P. pygmaeus* and *P. nathusii*, was defined by the parameters of 46-48 kHz and <100 ms between calls, since their calls are consequently within these intervals. Recordings with no distinguishable bat calls were marked as noise and disregarded from analysis. Each WAV-file with an identified species generally equaled one registration for that species. In the events that multiple individuals could be identified in one file, each identification then equaled one separate registration. Registrations are

not a measurement of the number of individuals, but rather a measurement of activity. In addition to species registrations, the site number, date, week and light status (0 = off, 1 = on) was noted for the WAV-files. Data of the daily air temperature in Gothenburg at 23:00 during the study period was downloaded from the open meteorological database of the Swedish Meteorological and Hydrological Institute (SMHI, 2026).

Bat activity with light status was analysed using Poisson generalized linear mixed-effects models (GLLMs) (Bolker, et al., 2009) in R (R Core Team, 2025) using RStudio (Posit Team, 2025). GLLMs were appropriate for this study since they allowed for assessment of the effects of light status and temperature on bat activity while accounting for differences between sites. GLLMs were fitted on all recorded species separately; however, due to the low number of observations for some species, the models could not be fitted reliably for all species. The response variable for each model was the number of sounds recorded for the corresponding species. Light status (on or off) and temperature (C °) at 23:00 were included as fixed effects, while the site was added as a random effect. The threshold set on p-values for significant effects was 0.05.



Figure 2: One of the bat detectors set up at its designated recording site, protected from moisture and other disturbances by a plastic bag and cover. Photograph by Magnus Gelang.

Results

Overall, 2452 registrations were identified from six bat species (Table 1; Figure 4). The three most common species in order were *Eptesicus nilssonii*, *Vespertilio murinus* and *Pipistrellus pygmaeus*, with the rarest being *Nyctalus noctula*. No registrations of *Myotis daubentonii* or *Plecotus auritus* were identified. The sites with the most registrations in total were Site 5 (1393 registrations) and Site 3 (656 registrations), while the other sites ranged from 30 to < 200 registrations (Figure 3). Technical issues with the bat detectors caused some of them to fail to record certain days, particularly during the first half of the study period. The affected sites/days with missing data were excluded from analysis, while data recorded by functioning detectors from the same days was retained. (Figure 5).

Mixed model results

A generalized linear mixed-effects model with a Poisson error distribution was used to test the effects of light status and temperature on bat activity, with the site as a random effect. Due to low numbers of observations for *Nyctalus noctula*, *Pipistrellus nathusii* and *Pipistrellus pipistrellus*, generalized linear mixed-effects models on the effect of light status and temperature on bat activity could only reliably be fitted for the species *Eptesicus nilssonii*, *Vespertilio murinus*, and *Pipistrellus pygmaeus*. Model estimates are represented as $\beta \pm \text{SE}$ (standard error). The model for *E. nilssonii* did not show a significant effect of light status on activity ($\beta = -0.138 \pm 0.080$, $z = -1.72$, $p = 0.085$), although activity tended to be lower during illuminated nights compared to dark nights (Table 1; Figure 4). For *V. murinus*, the effect of light status was also non-significant ($\beta = -0.016 \pm 0.223$, $z = 0.07$, $p = 0.944$), although they in total had considerably more recordings in dark sites (Table 1; Figure 4). *Pipistrellus pygmaeus* had the least significant effect ($\beta = -0.003 \pm 0.126$, $z = -0.024$, $p = 0.981$) and did not show any indication of preference to either light status (Table 1; Figure 4). Temperature did not significantly affect any of the three species (*E. nilssonii*: $\beta = 0.009 \pm 0.021$, $z = 0.42$, $p = 0.675$; *V. murinus*: $\beta = 0.049 \pm 0.044$, $z = 1.11$, $p = 0.267$; *P. pygmaeus*: $\beta = 0.002 \pm 0.020$, $z = -0.12$, $p = 0.906$) (Figure 5).

Table 1: Total count of activity events of bats listed by species under dark or light treatments.

Species	Dark	Light	Total
<i>Eptesicus nilssonii</i>	809	265	1074
<i>Vespertilio murinus</i>	817	58	875
<i>Nyctalus noctula</i>	14	14	28
<i>Pipistrellus nathusii</i>	23	30	53
<i>Pipistrellus pipistrellus</i>	46	37	83
<i>Pipistrellus pygmaeus</i>	160	179	339
Total	1869	583	2452

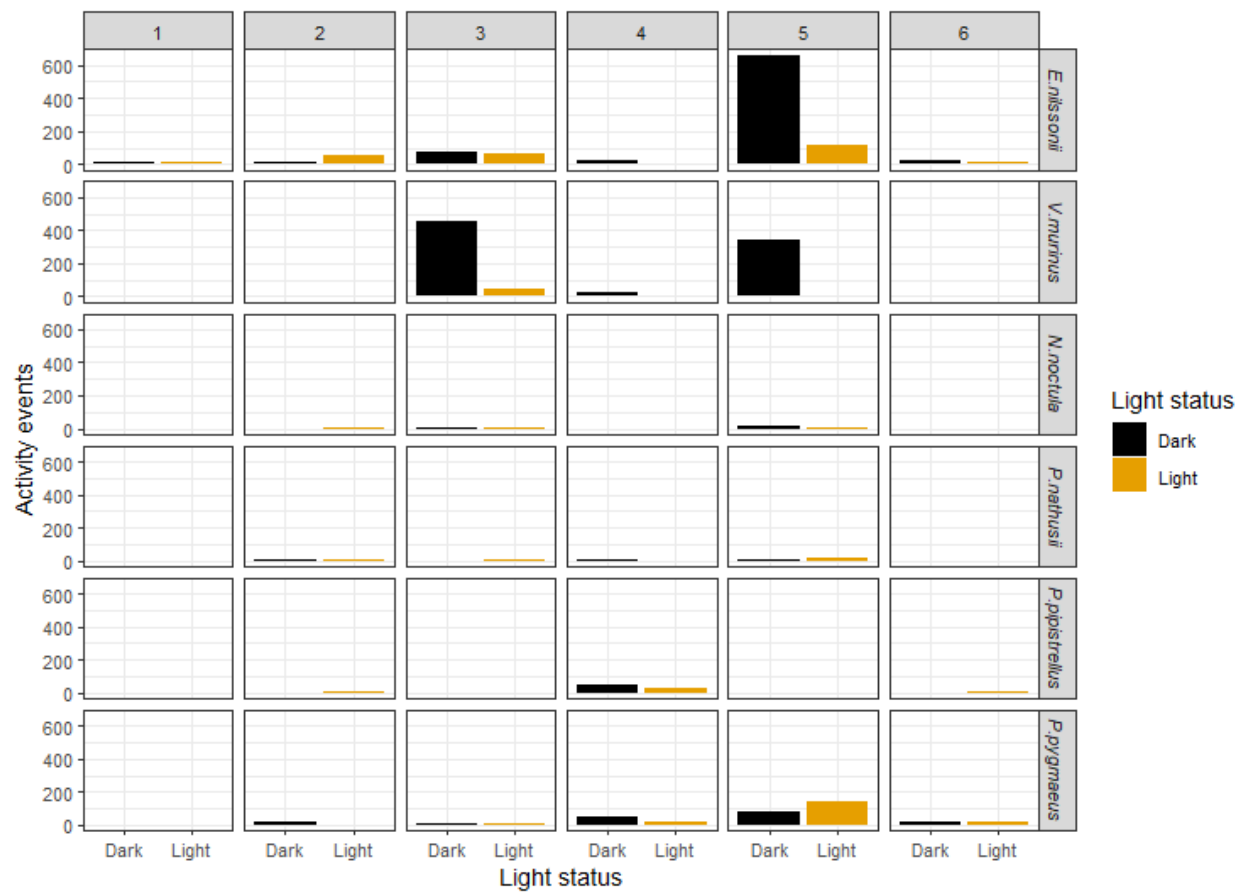


Figure 3: Recorded registrations in dark and light treatments, divided into groups of species and sites (1-6).

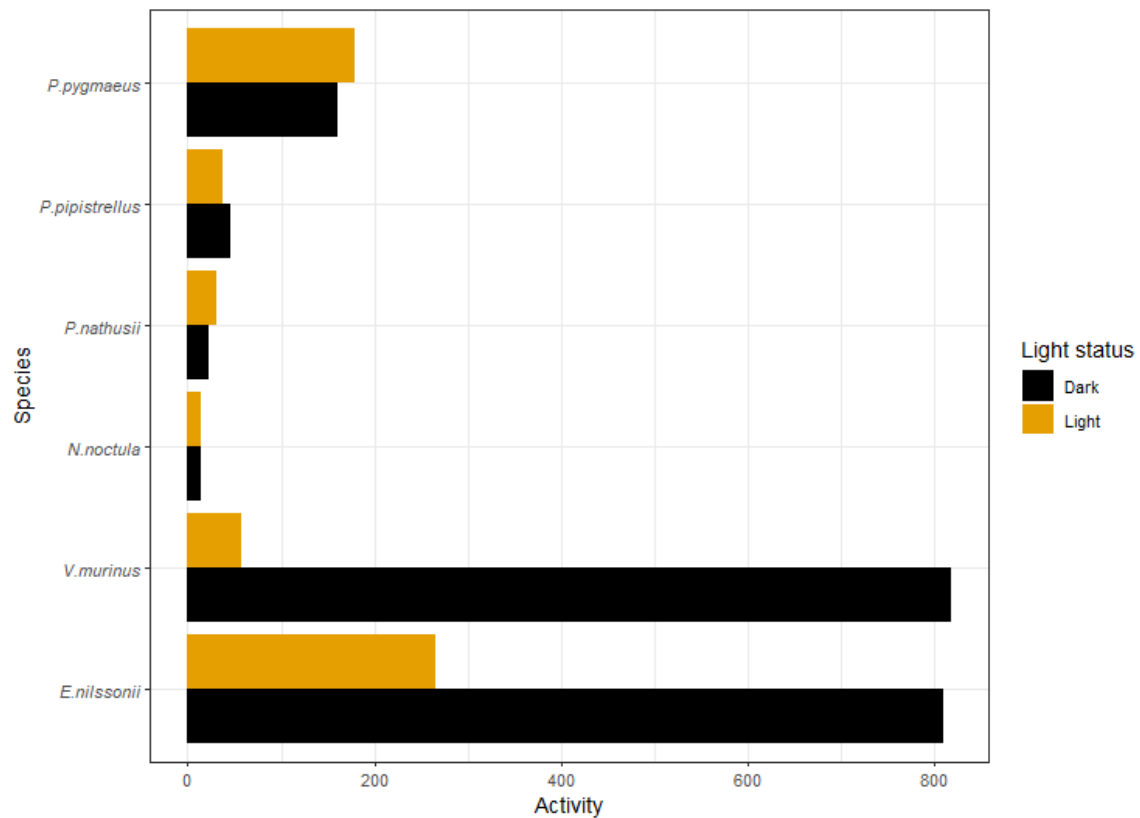


Figure 4: Registrations for all recorded species, divided into dark and light treatments.

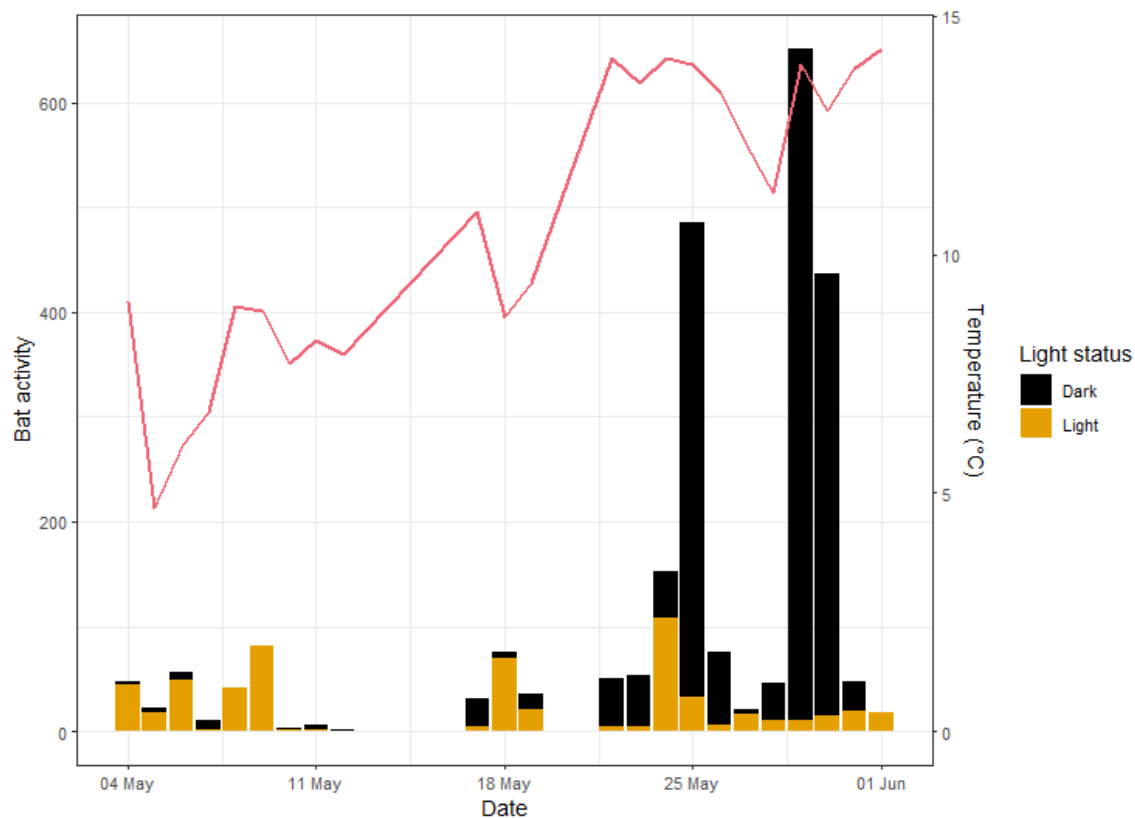


Figure 5: Total bat activity events for every recorded date, with the daily temperature at 23:00. During the first half of the study period, technical issues with the bat detectors caused missing data in some or all of the sites, depending on the date.

Discussion

The main aim of this study was to evaluate the effect of artificial light at night (ALAN) on the activity of bat species in Slottsskogen Park. The results indicated some species-specific trends in different light treatments. Activity of *Eptesicus nilssonii* and *Vespertilio murinus* tended to decrease in illuminated conditions, while light treatment showed little to no effect on *Pipistrellus pygmaeus* activity. However, the generalized linear mixed-effects models did not detect any statistically significant effects of light status on any of the species. The three other recorded species did not have enough observations to detect any visible trends. Surprisingly, this study's observations on *V. murinus* contrast with the commonly reported notion that the species is relatively tolerant towards artificial light. In this study, *V. murinus* shows a tendency to have lower activity in illuminated areas, suggesting that the species may exhibit greater light avoidance than is generally expected. Species-specific studies on the effect of artificial light at night (ALAN) on *V. murinus* are limited in number, and the species is commonly grouped with other fast-flying species who are relatively light tolerant. The results from this study may indicate that the response of *V. murinus* towards ALAN is more complex than previously assumed. Further species-specific studies are needed to determine if *V. murinus* genuinely can be grouped as a light tolerant species, or if their response to artificial light varies depending on other factors.

Biological and ecological interpretations

Eptesicus nilssonii and *V. murinus* largely avoided illuminated areas, in contrast to *P. pygmaeus*. However, previous studies have shown that all three species may choose to forage in illuminated areas where flying insects aggregate (Voigt, et al., 2021; Denzinger & Schnitzler, 2013). One possible explanation is that the two generally larger species, *E. nilssonii* and *V. murinus*, may be less willing to forage in illuminated areas, preferring darker parts of the park. *Eptesicus nilssonii* and *V. murinus* may rely less on such insect aggregations, choosing different foraging strategies

instead. Differences in habitat use and flight behavior may also be contributing factors to the contrasting responses between the species. The reduced activity of the two generally larger species may then indirectly benefit the smaller *Pipistrellus* species by reducing competitive pressure close to streetlights, allowing them to more efficiently exploit these areas for foraging.

Statistical significance

No statistical significance of bat activity with light status was detected with generalized linear mixed-effects models. Even though trends were visible in the dataset, the relatively low sample size of recordings prevented statistical significance. With a different experimental setup, such as using more sites or a longer sampling period, one could increase statistical power substantially.

Methodological limitations

Detector setup

Before data collection, a smaller pilot study with the detectors would have been beneficial. This would have allowed for optimization of settings and would give time to identify any practical issues before any data is lost, which would have increased the consistency of the data.

Weather protection

The microphones of the PippyG detectors are sensitive to moisture. During the sampling period, there were at least two instances of heavy rainfall in the local area. This resulted in two detectors being damaged and unusable. Having more waterproof protection, for instance custom 3D-printed cases, for the detectors would decrease the risk of such damage.

Theft

Two detectors disappeared during the study period, a risk that was well known from the beginning as Slottsskogen Park is a popular place for locals, especially during spring and summer. This made an impact on the dataset and was something that could have been better prevented. Finding better concealed spots for the detectors or using a locking or tracking system could have reduced the risk of theft.

Future studies

A suggestion for a future study would be to extend the recording period from early to late summer. This would provide a more complete insight into how bats may respond to artificial light throughout their active season. Bat activity typically changes remarkably during this time, with the progression of reproductive cycles, juveniles foraging independently for the first time and seasonal migration altering bat communities (Dietz, et al., 2009). As a consequence, the effect of ALAN might also vary across one active season and should therefore ideally be estimated across a larger part of it. It could also be beneficial to extend the light/dark periods to multiple weeks or even a month at a time, depending on how the total study period is set up. This could reduce the potential stress effect of lights switching on and off every week, allowing the bats more time to adjust to the shifting light status. In addition, it may be of interest to expand the study area by either increasing the number of sites, expanding the area of each site or doing both. Using more than one detector on each site could then be beneficial to capture a more accurate measurement of activity.

Conservational implications

The results of this study show some evidence of species-dependent changes in bat activity in artificially illuminated areas compared to naturally dark ones, coinciding with the results of some previous studies (Russo, et al., 2019; Seewagen & Adams, 2021). To mitigate this effect and potentially benefit light-sensitive bats, municipalities who manage public areas like Slottsskogen Park may choose to reduce unnecessary illumination. For instance, lights may be dimmed or even switched off on selected paths during periods of lower human activity. Some studies also suggest

that switching from green and white lights to red lights has potential to reduce ecological impacts for bats (Spoelstra, et al., 2017; Voigt, et al., 2017). The results of one study revealed how *Myotis* and *Plecotus* species in North America interact with different light spectra, showing evidence of significantly reduced activity for both species in white and green, while retaining activity in red light (Spoelstra, et al., 2017). In another study that measured the activity of migratory bats around green lights close to a shoreline, a significant increase in activity for *Pipistrellus nathusii* and *Pipistrellus pygmaeus* was observed during lights-on treatments. Here, it was argued that green light attracted these species not because of potential foraging possibilities, but because they get disoriented by the light and therefore head towards it, potentially luring them off course (Voigt, et al., 2017). Consequently, the choice of light spectra for urban areas may be of high conservational importance.

Conclusion

The aim of this study was to evaluate the impact of artificial light at night on local bat species. Although no statistically significant results were found, species-specific trends indicate different responses towards artificial light. The observed decrease in activity for *Eptesicus nilssonii* and *Vespertilio murinus* in illuminated sites contrasts with the neutral response for *Pipistrellus pygmaeus*, emphasizing the differential relationship between bat species and artificial light. The unexpected observations of *V. murinus* activity, contrasting with the common notion of the species, is something that deserves to be further studied. Continued research with larger sample sizes and prolonged data collection periods will provide better understanding of this complexity and may contribute to improved conservation strategies in urban areas.

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