Potential effects of PC-amber on the activity of common pipistrelles (*Pipistrellus pipistrellus*)

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Abstract: Artificial light at night (ALAN) is known to have an impact on the environment. Adapted to the dark, nocturnal animals are likely to be strongly influenced by ALAN. For bats this means potential effects on the functionality of roosts, flight paths and foraging areas. When conducting construction work, a certain amount of light is required to ensure a safe working environment for humans. To limit the potential negative effects of ALAN on the environment colour spectrum light solutions have been implemented in the past. There is a trade-off between environmental impact, safety and costs. In this study, in close proximity to a specific construction site, we were interested in the effect of phosphor converted (PC) amber on the activity of common pipistrelles (*Pipistrellus pipistrellus*). PC-amber is cheaper and more energy-efficient than amber light and gives people more visibility. We conducted an experiment with four different light regimes: PC-amber, amber, white and natural darkness as a control, and measured the activity of common pipistrelles. We included several environmental variables in the analyses and used a negative binomial mixed-effect regression model with a log-link function. Neither colour treatment nor distance to the light source significantly explain the observed variation in common pipistrelle activity. The variance in data is partly explained by environmental factors as bat activity significantly decreased with precipitation, increasing wind speed and increasing moon illumination. Based on this experiment, no firm conclusion can be drawn on the effect of PC-amber coloured light on the activity of common pipistrelles. To be able to make a statement with more certainty, more replicates on multiple locations are needed.

Keywords: common pipistrelle, *Pipistrellus pipistrellus*, Chiroptera, Anabat, light experiment, Amber, PC-amber, bat friendly lighting, ALAN.

Introduction

Bats are nocturnal animals and as such are affected by artificial light at night (ALAN). Bats can experience nuisance from ALAN and in the course of spatial developments the degree of disadvantageous effects of light must be assessed and mitigated if necessary. Bats avoid light on flight paths (Verboom & Huitema 2010, Voigt et al. 2018, 2021). However, some light tolerant bats are also attracted by potential increased prey availability in proximity of lights. Different bat species show differences in response towards light. Common pipistrelles (*Pipistrellus pipistrellus*) are considered quite light tolerant species, however openness and light can have negative effects on flightpaths (Jansen & Limpens 2012, Jansen et al. 2014, Hale et al. 2015).

To have safe conditions for humans to work in the dark there must be a certain amount of light. On the other hand, the impact on nocturnal animals has to be reduced. At the same time the aim is to save costs by using energy efficient technologies. In other words, there is a trade-off between security and environmental impact. The background of this study

Table 1. Overview of test set-up and expectations regarding bat activity at positions 1 to 5 for the different light treatments. Detector 3 refers to the position of the lamp, i.e. the light source. A higher number of '+' means more activity. The symbols indicate the expected relative activity to the other treatments or positions; they do not indicate absolute differences.

	detector 1 far	detector 2 close	detector 3 light source	detector 4 close	detector 5 far
Dark	+/-	+/-	+/-	+/-	+/-
PC-amber	+	++	+	++	+
Amber	+/-	+	+/-	+	+/-
White	++	+++	+	+++	++

was a specific case of construction work close to the Beatrixsluis in Nieuwegein (Province of Utrecht, the Netherlands) (exemption FF/75C/2014/0294). The use of conventional bat-friendly light (Philips Clearfield) in the whole area would lead to a high cost in energy, an alternative option could be a more broadband, energy efficient PC-amber (Veltman 2018). Based on expert judgement, mitigation with PC-amber lights was considered a practical solution for this situation where safety and costs are balanced with limited negative effects of light on wildlife. However, empirical data of PC-amber light on bat activity was lacking. Spoelstra et al. (2017) suggested that white and green light should be avoided in order to limit the negative impact of light at night on bats. In this study we tested the effect of different light regimes on common pipistrelle activity in a field experiment and compared four light regimes: darkness, white, amber and phosphor converted amber (hereafter PC-amber). Our hypotheses are summarized in table 1, which shows the expected effects on bat activity in different light conditions and distances to the light source. The assumption is that common pipistrelles are, as a consequence of a balance of energy uptake and predation risk, ambivalent toward light. They will avoid illuminated flightpaths, but also hunt the insects that are attracted to the light. However they will not stay in the light cone, hence we expect bigger effects on intermediate distance to the light source (see hypotheses table 1). A light spectrum that is supposed to attract less insects (amber and PC-amber) is assumed to have less effects on hunting bats than white light.

Methods

Acoustic data was collected using automatic bat recorders (Anabat Swift) in the summer of 2019 (15 May – 29 June) from 30 minutes before sundown until 30 minutes after sunset. The study was conducted in close proximity of the Beatrix locks situated between the cities of Nieuwegein and Houten, on the east bank of the canal named 'Lekkanaal' (52.0329°N, 5.1149°E). Five poles with an automatic bat recorder were placed along the vegetation with 25 metre intervals, the light source was located at a height of approximately 8 metres, near the central pole (figure 1). The light regime changed every night using a Latin square scheme to select the colour treatment: white (*Philips Mini Luma,* with a correlated colour temperature (CCT) of 4000 K), amber (*Innolumnis Nicole,* CCT 2200 K), PC-amber (*Holophane V-Max,* CCT 2900 K) or the control condition: darkness (Veltman 2018). Acoustic data was analysed by a trained ecologist using the program 'bat classify' with a certainty threshold of at least 90%.

Data analyses

In total, 39 nights were used for the analy-

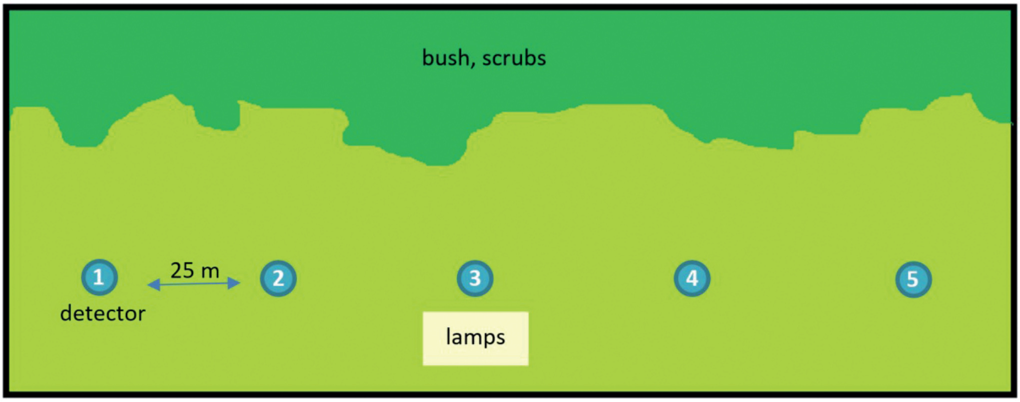

Figure 1. Schematic experimental set-up: Five poles with an automatic bat detector in a row (numbered 1–5 from north to south). With the light source at the centre (pole 3), two at an intermediate distance of 25 m (pole 2 and 4) and two further away from the light source at a distance of 50 m (pole 1 and 5).

ses. Some nights had to be removed from the analyses due to technical malfunctioning and unfavourable weather conditions. A filter was used to select common pipistrelle recordings, from now on referred to as 'bat activity'. The final data frame contained 195 recordings of bat activity (sum of detections per night) and nine predictor covariates. The response variable, i.e. the sum of bat activity per night, had a variance far exceeding the mean (647 >> 48). Frequency distributions of covariates were assessed, and none of the covariates were problematic in terms of a strongly unbalanced design. Collinearity was checked by calculating pair-wise correlations among the predictors, without detecting any problems.

To account for this over dispersion we used a negative binomial regression model. All data analyses were performed using R version 4.0.3 (R Core Team 2020). To investigate the effect of light treatment and distance to the light source on bat activity in dependence of other environmental confounders, we used negative binomial mixed-effect regression models with a log-link in R package lme4 (Bates et al. 2015). The final model had the following structure: fm1 = glmer.nb (bat.activity ~ treatment * DisTreat + wind.speed + moon.phase + temperature + night.duration + night.duration² + rain + (1|detector.ID)). The ID of the detector was included as a random intercept term. This accounts for systematic differences between the detector poles. The model fit was validated by plotting residuals vs. expected values and assessed the normal distribution of the random intercepts. Predicted model effects are visualized by producing conditional effect plots, using the effects library to average predictions across factor levels (Fox & Weisberg 2019).

Results

There was no significant difference in bat activity between light treatments, nor did we find a significant effect of the distance to the light source or the interaction of the two (table 2). There were trends indicating higher bat activity at distances 'intermediate' and 'far' from the light source and differences in the effect pattern of distance between light types, in particular the colour 'amber'; however, the associated variance was large (figure 2). Bat activity significantly decreased with wind speed and increasing moon phase. A negative effect of temperature was almost significant (table 2). There was a significantly lower activity during nights with rainfall. There was a significant non-linear effect of night duration,

Table 2. Model results of the negative binomial mixed-effect model explaining bat activity at detector poles as a function of light, distance to light as well as other environmental confounders. Coefficient estimates, associated standard errors and *P*-values are provided. Note that the category combination of 'no light' with 'at the light source' and 'no rain' are contained in the model intercept.

Covariate	Estimate	SE	z-value	*P*-value
(Intercept)	3.38423	0.17918	18.887	<0.001
treatmentAM	0.25332	0.20815	1.217	0.223595
treatmentPC	-0.11481	0.25331	-0.453	0.650375
treatmentW	0.13212	0.21971	0.601	0.547596
DisTreat-far	0.23005	0.19196	1.198	0.230767
DisTreat-intermediate	0.26038	0.19131	1.361	0.173490
wind.speed	-0.15465	0.04145	-3.731	0.000191
moon.phase	-0.15038	0.06518	-2.307	0.021054
temperature	-0.10041	0.05218	-1.924	0.054340
night.duration	-0.22879	0.07229	-3.165	0.001552
night.duration^2	0.28499	0.07266	3.922	<0.001
rain-Yes	-0.38424	0.10092	-3.807	0.000140
treatmentAM:DisTreat-far	-0.07680	0.25206	-0.305	0.760613
treatmentPC:DisTreat-far	-0.11324	0.30876	-0.367	0.713802
treatmentW:DisTreat-far	-0.06930	0.26516	-0.261	0.793821
treatmentAM:DisTreat-intermediate	-0.17809	0.25200	-0.707	0.479736
treatmentPC:DisTreat-intermediate	-0.03440	0.30841	-0.112	0.911187
treatmentW:DisTreat-intermediate	-0.03610	0.26478	-0.136	0.891564

with more bats recorded during short and long nights, and fewer in between (figure 3).

Discussion

This study was conducted in a relatively open habitat, therefore weather conditions could have had a relatively big impact on bats. Also, recent changes in the surrounding of the study site included an increase of light and a more open vegetation structure, which is likely to have altered the behaviour of the bats. Furthermore, it is likely that the spatial context had a significant influence. The design could be improved by taking into account behaviour and the different functional habitats so that it is possible to disentangle effects on flightpaths and foraging area.

All manufacturers were asked to supply a lamp with a luminous output of 3185 lumen. Although all three manufacturers indicated to comply with this, during the experiment a control illuminance measurement indicated differences between the light treatments. In future experiments we would recommend to control for this.

Conclusions

The current experiment does not allow to draw a firm conclusion on the effect of PC-amber coloured light on the activity of common pipistrelles compared to white light or darkness in general. We found no significant difference between the treatments. Weather conditions (most notable windspeed and rainfall) and moon phase had a significant effect.

The lack of significance of the light treatment can be due to the large associated variance. In other words, there were large differences in how many bats flew over the recorders each night, inflating the confidence intervals

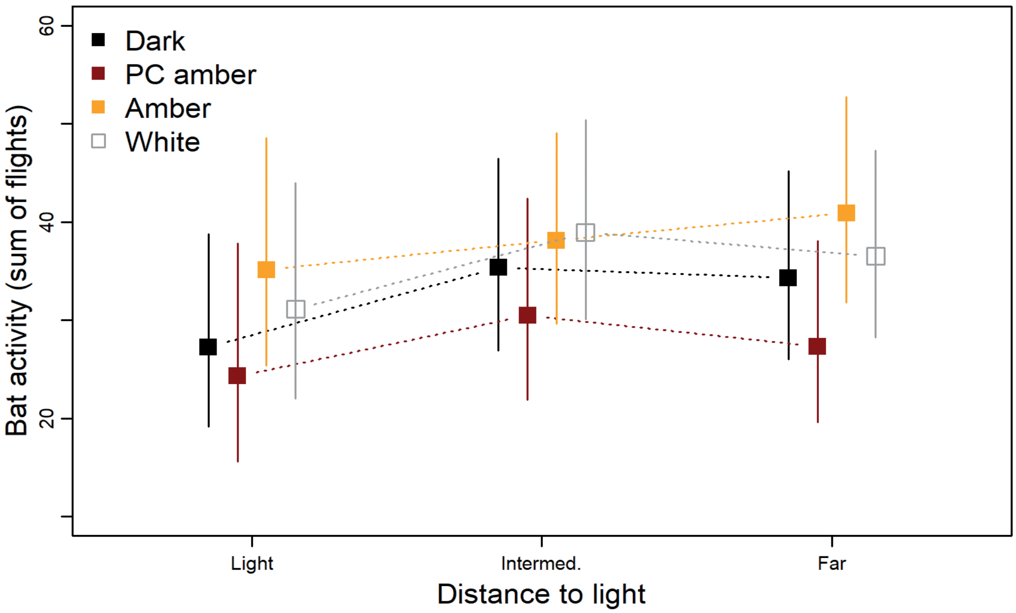

Figure 2. Conditional effect plots of the interaction term between distance to the light source and light treatment as predicted by the final model. Effects were obtained by averaging across the remaining covariates.

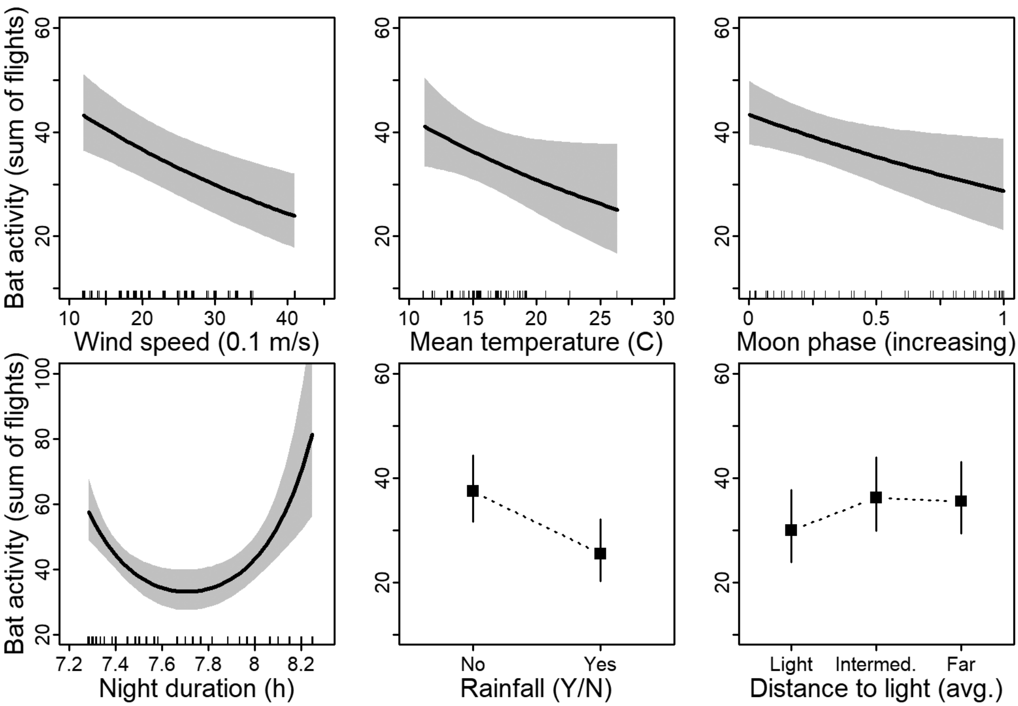

Figure 3. Conditional plots of the effects of additional covariates on bat activity as predicted by the final model. Effects were obtained by averaging across the remaining covariates. Note the different y-axes range for night duration. The single plot for distance to light (bottom right) was obtained by averaging across the colour treatments.

and leading to *P*-values exceeding the threshold. There is no clear signal in these results for the effect of the light treatment; to be able to make a statement with more certainty, more replicates on multiple locations are needed.

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Samenvatting

Het effect van breedbandig amberkleurig licht op de activiteit van gewone dwergvleermuis (*Pipistrellus pipistrellus*)

Verlichting kan invloed hebben op de functionaliteit van vliegroutes en foerageergebieden van vleermuizen. In het projectgebied bij de Beatrixsluizen gaat het over concrete vliegroutes en oversteekplaatsen van de gewone dwergvleermuis over het Lekkanaal en foerageergebied van deze soort. Toepassing van breedbandig amberkleurig licht ('phosphor converted (PC) amber') voor alle nieuwe verlichting in het gehele projectgebied biedt mogelijk een oplossing, omdat deze ten opzichte van wit licht mogelijk minder versto-

rend is op de functionaliteit van de omgeving voor vleermuizen, en een goedkoper (energiezuiniger) alternatief is voor amberkleurig licht. In dit experiment is gekeken naar de activiteit van gewone dwergvleermuizen bij de drie verschillende kleurenspectra, wit, amber en PC-amber ten opzichte van de controleconditie zonder verlichting. Tevens is er gekeken naar het effect van afstand tot de lichtbron. We vonden geen significant verschil in vleermuisactiviteit tussen de verschillende lichtbehandelingen. Er was een grote spreiding in de data, die deels verklaard kon worden door omgevingsfactoren zoals neerslag, wind en maanfase. De proefopzet bestond uit slechts *één locatie, waardoor de individuele variatie binnen deze locatie effecten kan hebben gemaskeerd.* Om meer zekerheid te krijgen adviseren we de proef te herhalen op verschillende locaties en gedurende meer nachten.

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