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Conservation biology

Shedding light on moths: shorter wavelengths attract noctuids more than geometrids

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With moth declines reported across Europe, and parallel changes in the amount and spectra of street lighting, it is important to understand exactly how artificial lights affect moth populations. We therefore compared the relative attractiveness of shorter wavelength (SW) and longer wavelength (LW) lighting to macromoths. SW light attracted significantly more individuals and species of moth, either when used alone or in competition with LW lighting. We also found striking differences in the relative attractiveness of different wavelengths to different moth groups. SW lighting attracted significantly more Noctuidae than LW, whereas both wavelengths were equally attractive to Geometridae. Understanding the extent to which different groups of moth are attracted to different wavelengths of light will be useful in determining the impact of artificial light on moth populations.

1. Introduction

Much of the world is artificially illuminated at night [1] and the amount of lighting is increasing by approximately 6 per cent annually [2]. This increase is accompanied by changes in the abundance of nocturnal Lepidoptera. Recent analyses have highlighted declines in the populations of larger (macro) moths in the UK and Europe, with population trends varying among species [3–7]. These declines are probably due to a combination of factors, including habitat loss and anthropogenic climate change [8]. Another suspected driver, however, is light pollution [3,4,8]. Two of the largest sources of artificial light are street lighting and sports fields [9], and studies have shown that different types of widely used light vary with regards to how many insects they attract; light with shorter wavelengths and higher UV content is generally more attractive [10–15]. Artificial light has the potential to affect moths in many ways, including disrupting their foraging, dispersal, breeding and interspecific interactions [16,17], as well as increasing their risk of predation [10,18]. However, what specific impact artificial light has on different groups of macromoths is largely unknown.

Given the important role insects play in ecosystem functioning [8], it is important to determine whether artificial light is having an impact on moths at the population level. Further, an understanding of the different degree to which moth families or species are attracted to different types of widely used lighting will be useful in trying to determine whether artificial lighting is contributing to the decline of specific groups. To address this need, here, we compare the attractiveness of shorter and longer wavelength lights to UK moth populations across a full field season.

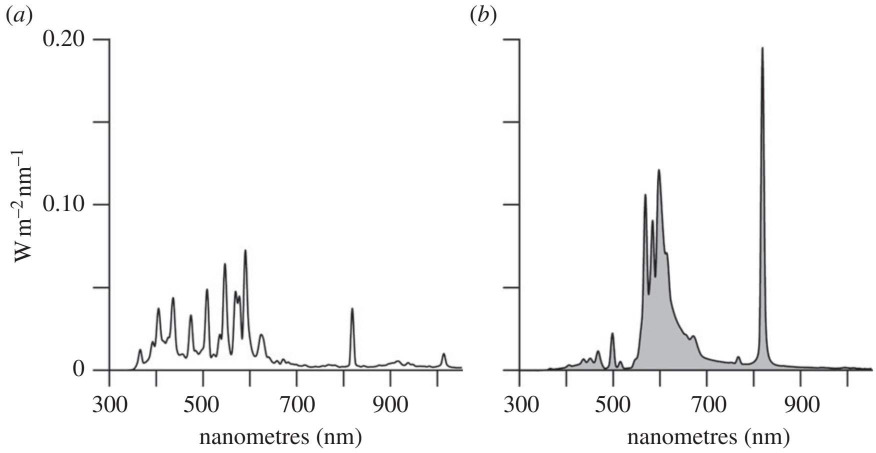

Figure 1. Spectral energy distribution for lights used in this study; (*a*) shorter wavelength light (weighted-mean wavelength = approx. 583 nm) and (*b*) longer wavelength light (weighted-mean wavelength = approx. 656 nm). Spectral energy data were measured using an Ocean Optics Maya 2000 spectrometer.

2. Material and methods

(a) Study area and lighting

Experiments were performed in the Walled Garden, Tremough Campus, Penryn, UK (grid reference no: SW76975 34609) between 26 June 2012 and 10 October 2012. The site was chosen as it is a representative of the suburban habitats in the UK likely to be affected by street lighting. To compare lights of longer and shorter wavelength, four lamp-post structures were mounted on a wall overlooking the site. From each of the lamp-post structures were suspended two adjacent lights, a high-pressure sodium floodlight (150 W, 15 000 lm, FL150SON/L) characterized by yellowish 'longer wavelength' light, and hereafter termed 'LW', and a metal halide floodlight (150 W, 12 000 lm, FL150HQI/C) characterized by 'shorter wavelength' white light or 'SW' (see figure 1 and electronic supplementary material, picture S1). Lighting type was selected on each lamp-post with a switch. The lamp-posts were positioned approximately 14.5 m apart and the lights were angled at approximately 45°. The average total height of the lights was 5.65 ± 0.13 s.d.m, although they remained only 3.1 ± 0.33 s.d.m above the ground from behind the wall (see the electronic supplementary material, picture S2).

(b) Lights alone or in competition

It has been suggested that moths only exhibit a phototactic preference to certain lighting types under conditions of light 'competition', where two or more lighting types are operated simultaneously in close proximity [19]. Although a previous study found results contrary to this idea [11], we investigated this hypothesis by testing the SW and LW lighting either alone (only SW or LW lights on all night) or in competition (SW and LW lighting alternating along the same transect). On any given night, both types of light (LW and SW) were alternated along the four lamp-posts in direct competition with each other. The order of the alternation was then changed on each consecutive night of trapping so as to control for the variation caused by the position of each of the lamp-posts. In the second, non-competitive configuration on any given night, all of the lamp-posts displayed the same lighting type. The lighting type was alternated on consecutive nights of trapping. For both experimental configurations, lights were turned on and off automatically by a photocell. Macromoths were trapped with safari moth traps suspended below each of the lights. A standardized number of seedling trays were used within the traps as refuge for the moths (see the electronic supplementary material, picture S2). The traps were checked at approximately 08.30 every morning. Moths were collected live and identified to species level where possible. Moth identification took place at the site, and identified individuals were released *in situ* (see the electronic supplementary material, S1 for justification of *in situ* release and removal of certain species for identification).

(c) Statistical analyses

For the competitive lighting configuration, the relationship between lighting type and overall moth abundance was analysed using a generalized linear-mixed effects model with a negative binomial error structure. Date of trapping and lamp-post position were incorporated into the model as random effects. Data collected from the non-competitive lighting configuration were pooled into nightly totals. A generalized linear-mixed effects model with negative binomial error structure, and date incorporated as a random effect, was used to test for differences in overall moth abundance between the two lighting types. This analysis was repeated separately for the two most abundant moth families and species. The number of species of moth attracted to the two lighting types was compared using the same statistical technique. The relationship between overall number of moths and number of species was tested using Spearman's rank correlation. Statistical analyses were carried out using R (v. 64 2.15.1), with glmmADMB (v. 0.7.2.12) for the generalized linear-mixed models.

3. Results

SW lighting attracted significantly more individuals than the LW lighting in both configurations (non-competitive, $\chi^2_1 = 7.1$, $p = 0.008$, $n = 40$; competitive, $\chi^2_1 = 12.2$, $p < 0.001$, $n = 56$; electronic supplementary material, figure S3*a*,*b*), with a catch ratio of SW : LW of about 2 : 1 (competitive 2.13 : 1; non-competitive 2.09 : 1, see the electronic supplementary material, figure S4). Also, significantly more species were attracted to SW than LW lighting (non-competitive, $\chi^2_1 = 6.2$, $p = 0.013$, $n = 40$). The number of species caught was positively correlated with the number of individuals caught (non-competitive, Spearman's correlation coefficient $r_S = 0.96$, $p < 0.001$, $n = 40$). However, the two most commonly caught moth families responded to lighting differently (figure 2*a*,*b*); significantly more noctuids were attracted to the SW lighting than the LW lighting (non-competitive, $\chi^2_1 = 10.2$, $p = 0.0014$, $n = 40$), but geometrids showed no significant difference (non-competitive, $\chi^2_1 = 0.042$, $p = 0.84$, $n = 40$). The two most commonly caught species, both noctuids, also responded to lighting differently. Significantly more *Ochropleura plecta* were attracted to the SW than the LW lighting (non-competitive, $p = 0.0022$, $n = 40$),

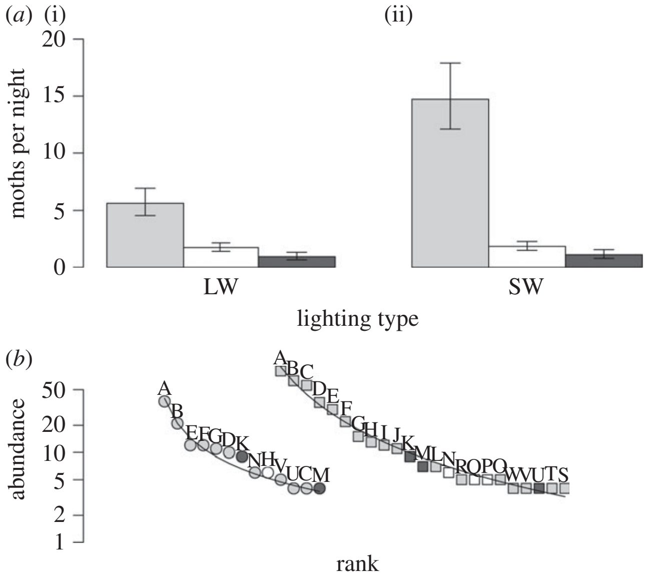

Figure 2. (*a*) Mean number of moths caught per night (± s.e.) in the two lighting treatments: (i) longer wavelength (LW) and (ii) shorter wavelength (SW). Noctuidae (light grey) $n = 570$, Geometridae (white) $n = 81$ and other (dark grey) $n = 68$. (*b*) Rank abundance curves for lighting treatments where overall species abundance greater than or equal to 4. Longer wavelength (circles) and shorter wavelength (squares). Noctuidae (light grey), Geometridae (white) and other (dark grey). A, *Noctua janthe*; B, *Ochropleura plecta*; C, *Noctua pronuba*; D, *Autographa gamma*; E, *Hoplodrina alsines*; F, *Mesapamea secalis* agg; G, *Xestia c-nigrum*; H, *Phlogophora meticulosa*; I, *Agrostis exclamationis*; J, *Agrostis puta*; K, *Eilema Griseola*; L, *Eilema depressa*; M, *Apamea monoglypha*; N, *Idaea biselata*; O, *Melanchra persicariae*; P, *Idaea aversata*; Q, *Ecliptopera silaceata*; R, *Abrostola tripartite*; S, *Cosmia trapezina*; T, *Noctua comes*; U, *Miltochrista miniata*; V, *Hydraecia micacea*; W, *Rivula sericealis*.

while there was no significant difference between the numbers of *Noctua janthe* (non-competitive, $\chi_1^2 = 2.2$, $p = 0.14$, $n = 40$).

4. Discussion

The results illustrate that the SW lighting attracts both greater numbers of species and individuals of moth than LW, attracting higher numbers of individuals whether the lighting types are in direct competition with each other or not (see the electronic supplementary material, figure S3). Catch ratios were similar, with the LW lighting attracting approximately 53 per cent fewer moths in the competitive lighting configuration and approximately 52 per cent fewer in the non-competitive configuration. This result agrees with that of Eisenbeis [11], and contradicts Scheibe's hypothesis [19] that moths only exhibit a phototactic preference for certain lighting types under conditions of light competition. Previous studies have shown that shorter wavelength light, and particularly UV light is more attractive to insects [11,12,15], however, further analysis of the two most numerous moth families illustrated that the difference in abundance of moths attracted to the two lighting types was driven predominantly by differences in the numbers of noctuids and there was no significant difference between the numbers of geometrids. The precise reason behind this is unclear, but it could be due to the higher sensitivity of geometrids to light of 597 nm (see van Langevelde *et al*. [12]), as the LW lighting used in this investigation emits more light of 597 nm than SW (figure 1). Alternatively, noctuids may be particularly attracted to the increased amounts of UV light emitted from SW, possibly mistaking the UV emission for a nectar source [20]. The increase in noctuids trapped is probably a function of a difference in their physiology, however, without visual evidence, we cannot rule out the potential importance of differences in strength of flight between noctuids and geometrids as a factor affecting ease of capture. There are also indications that individual species differ between SW and LW (figure 2*b*). The two most abundant species differed in terms of the degree to which they were attracted to the two lights. More research, further quantifying the degree to which moth families or species differ in terms of their attraction to wavelengths of light, and into the physiological or life-history traits that determine the different degrees of attraction, will be useful in assessing the impact of artificial light on moths. Assuming that increased attraction to light results in increased moth mortality, one might expect noctuid populations to decline more steeply in areas where the predominant source of artificial light emits more shorter wavelength and UV than in areas where the light emits less UV and more longer wavelength light, whereas geometrids would likely be similarly affected in both areas. Interestingly, of the 61 British macromoths that have declined by 75 per cent or more in recent years, 35 are Noctuidae compared with only 19 Geometridae [7].

In concordance with others [10,13,14], our results indicate that UV/shorter wavelength-rich lighting is likely to have a greater impact on moth populations, with potential effects at higher trophic levels [10], and support the advocacy of lighting types lacking such shorter wavelengths in ecologically sensitive situations.

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