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Street lighting changes the composition of invertebrate communities

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Artificial lighting has been used to illuminate the nocturnal environment for centuries and continues to expand with urbanization and economic development. Yet, the potential ecological impact of the resultant light pollution has only recently emerged as a major cause for concern. While investigations have demonstrated that artificial lighting can influence organism behaviour, reproductive success and survivorship, none have addressed whether it is altering the composition of communities. We show, for the first time, that invertebrate community composition is affected by proximity to street lighting independently of the time of day. Five major invertebrate groups contributed to compositional differences, resulting in an increase in the number of predatory and scavenging individuals in brightly lit communities. Our results indicate that street lighting changes the environment at higher levels of biological organization than previously recognized, raising the potential that it can alter the structure and function of ecosystems.

Keywords: artificial light pollution; community composition; ground-dwelling invertebrates; high pressure sodium; street lights

1. INTRODUCTION

The continuing spread of artificial night-time lighting has resulted in a widespread loss of naturally unlit habitat around the world [1,2]. Yet, there is only limited understanding of the impact that light pollution has on the structure and functioning of ecosystems. Many organisms have evolved to take advantage of natural light regimes in terms of intensity [3,4], periodicity [5,6] and spectral characteristics [7,8]. Artificially illuminating the nocturnal environment changes the predictability of these regimes, potentially affecting foraging, navigation, communication and the regulation of daily and seasonal cycles in a plethora of species [9,10]. Current knowledge of the ecological impact of light pollution is largely limited to its effects on organism physiology [11,12], behaviour [13,14], reproduction [15] and predator–prey interactions [16,17]. No study has yet addressed whether the effect of artificial light pollution on organisms has consequences for higher levels of biological organization, such as changing the abundances of species within communities (community composition). In this study, we asked whether artificial street lighting changes the composition of ground-dwelling invertebrate communities, identified major invertebrate groups whose distributions are affected by street lighting and describe the consequences of such changes for the trophic equilibrium of these communities.

2. MATERIAL AND METHODS

To establish the effect of street lighting on communities of ground-dwelling invertebrates, pitfall traps were deployed on grassy vegetation directly under (19.29 ± 1.31 s.e. lux at ground level) and between (3.02 ± 0.14 s.e. lux) 14 high-pressure sodium (HPS) street lights that were 35 m apart (28 traps in total) for three days and three nights on 5–8 August 2011 (a month of peak annual invertebrate abundance) in the town of Helston, Cornwall, UK (50°06′09.06″ N, 5°15′29.83″ W). Cloudy conditions resulted in an intermittently visible first quarter moon during the nocturnal sampling periods (average hourly cloud cover was 7.8, 4.5 and 4.4 oktas on the first, second and third sampling nights, respectively). To test whether proximity to street lighting affected community composition, and did not simply affect species distributions at night, we sampled in a two-way crossed design that compared the nocturnal and diurnal (factor 'time') invertebrate communities under and between street lights (factor 'space'). The contents of the traps were collected 30 min prior to sunrise and sunset, so that nocturnal and diurnal components of the invertebrate community could be identified and enumerated separately for each trap. A non-significant interaction between 'space' and 'time' indicated that any effect of street lighting was independent of whether communities were sampled during the day or the night, leading to the conclusion that street lighting was affecting invertebrate community composition.

Differences in invertebrate abundance (measured as the total number of individuals caught per pitfall trap over the three day sampling period) between patches sampled from under street lights and between street lights were tested using a two-way crossed analysis of variance (ANOVA) conducted on untransformed data. Differences in community composition were tested by conducting a two-way crossed multivariate analysis of variance (MANOVA) on the Bray–Curtis dissimilarity matrix calculated from species abundance data that were square root transformed to reduce leverage by dominant taxa (CRAN package: vegan). The same analysis was applied to vegetation per cent cover data (estimated within a 50×50 cm quadrat at locations adjacent to the pitfall traps) to establish whether street lighting could have indirect effects on invertebrate communities by changing the composition of the plant community that the invertebrates inhabit.

A series of independent tests were performed on the total number of individuals caught within higher taxonomic groupings. Species abundances were pooled into higher taxonomic groupings in order to reduce the high number of zero counts recorded for many species (table 1). Species abundances were also pooled into trophic groups (herbivores, predators, scavengers, detritivores and parasites) to establish how these responded to changes in the distribution of major taxonomic groups. Differences in the abundance of invertebrates within the assigned taxonomic or trophic groups were tested using ANOVA, or zero-adjusted Poisson (ZAP) or zero-adjusted negative binomial (ZANB) regression (CRAN package: pscl) where data displayed high zero inflation or failed to meet the assumption of homogeneity of variances necessary to perform ANOVA. ZAP is typically used for overdispersed zero inflated data, whereas ZANB is used where data display extra overdispersion. A likelihood ratio test (CRAN package: lrtest) was used to determine whether ZANB provided a significantly improved fit to the data compared with ZAP and therefore should be used for the interpretation of results (table 1) [18].

3. RESULTS

A total of 1194 ground-dwelling invertebrates representing 60 taxa were collected during the study. Invertebrates were more abundant within close proximity to street lighting independently of whether communities were sampled during the day or during the night (ANOVA, 'space' × 'time': $F_{1,52} = 0.40$, $p = 0.529$), with pitfall traps which had been deployed under street lights catching an average of 24 ± 2 s.e. individuals over the three-day period, which was significantly higher than pitfall traps deployed in patches between the lights (19 ± 2 s.e. individuals; ANOVA, 'space': $F_{1,52} = 7.68$, $p = 0.008$). The

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Table 1. The effect of HPS street lighting on the spatial distribution of taxonomic and trophic groups of ground-dwelling invertebrates. *n* denotes the number of individuals caught within each group. Term (dashes) was excluded from the analysis owing to no data occurrences within all possible space × time combinations. Significant results are italicized.

		time (nocturnal versus diurnal)		space (under lights versus between lights)		time × space interaction	
	n	χ^2 or *F*	*p*	χ^2 or *F*	*p*	χ^2 or *F*	*p*
Taxonomic groups							
harvestmen (Opiliones)[a]	138	15.03	*<0.001*	9.69	*0.008*	2.31	0.315
wolf spiders (Lycosidae)[b]	72	26.62	*<0.001*	0.54	0.763	3.18	0.204
money spiders (Linyphiidae)[b]	96	11.98	*0.003*	1.03	0.597	6.53	*0.038*
crab spiders (Thomisidae)[a]	19	5.32	0.070	1.13	0.567	2.22	0.330
ground beetles (Carabidae)[b]	107	0.57	0.752	15.35	*<0.001*	4.72	0.094
rove beetles (Staphylinidae)[a]	18	3.71	0.156	0.23	0.890	0.07	0.965
ants (Formicidae)[c]	189	9.99	*0.003*	7.43	*0.009*	0.38	0.540
slugs and snails (Gastropoda)[b]	136	0.06	0.972	1.38	0.502	0.58	0.747
mites (Acari)[a]	67	0.86	0.649	2.66	0.264	2.34	0.311
springtails (Collembola)[b]	305	5.21	0.074	0.14	0.264	2.10	0.349
woodlice (Isopoda)[a,d]	19	4.22	0.121	9.59	*0.008*	—	—
amphipods (Amphipoda)[a,d]	16	4.91	0.086	13.66	*0.001*	—	—
grasshoppers and crickets (Orthoptera)[a,e]	12	—	—	0.82	0.664	—	—
Trophic groups							
predators[c]	450	1.75	0.191	6.54	*0.014*	2.44	0.124
scavengers[c]	189	9.99	*0.003*	7.43	*0.009*	0.38	0.540
grazers[c]	148	0.32	0.576	0.97	0.329	0.22	0.641
detritivores[c]	390	0.86	0.358	0	0.964	0.03	0.868
parasites[a]	17	0.45	0.799	1.01	0.601	2.24	0.326

[a]Results are presented from analysis performed using either zero-adjusted Poisson regression (ZAP).
[b]Zero-adjusted negative binomial regression (ZANB).
[c]Analysis of variance.
[d]Individuals did not occur between street lights during the day preventing an interaction term between time and space being included in the analysis.
[e]Individuals did not occur during the night preventing a test of peak daily activity (time), and therefore a test of an interaction between time and space.

composition of invertebrate communities in patches under the lights was also significantly different from patches between the lights (MANOVA, 'space': $F_{1,52} = 3.95$, $p = 0.001$) independently of whether communities were sampled during the day or during the night (MANOVA, 'space' × 'time': $F_{1,52} = 0.81$, $p = 0.613$). This result indicated that street lighting had a more permanent effect on the composition of invertebrate communities than simply attracting certain species to brightly lit areas at night, which then re-dispersed during the day. The composition of plant communities did not vary with proximity to lighting (one-way MANOVA, 'space': $F_{1,31} = 1.33$, $p = 0.239$), indicating that street lights were having direct effects on invertebrate communities as opposed to indirect effects by re-structuring their habitat.

Harvestmen, ants, ground beetles, woodlice and amphipods were each more abundant in patches under street lights compared with patches between street lights (figure 1 and table 1). This effect was independent of the time of day for harvestmen, ants and ground beetles (figure 1 and table 1), indicating that the distribution of these groups was not limited to the attraction of individuals to street lights at night. We could not test whether differences in the abundance of woodlice and amphipods were independent of sampling time, as no individuals were caught in traps deployed between street lights during the day in each of these groups. However, considering that individuals from these groups were present under street lights during the day, their absence from traps deployed between street lights during the day was in itself a strong indication that the effect of street lighting on the distribution of these groups was similar during the day to that observed at night (figure 1).

Patches under the street lights contained on average significantly more individuals belonging to the two carnivorous groups: the predators and scavengers, compared with patches located between street lights (figure 2 and table 1). This effect was independent of the time of day (figure 2 and table 1), indicating that predatory and scavenging individuals were always more abundant in close proximity to street lights, as opposed to being transiently more abundant around street lights at night.

4. DISCUSSION

The results presented here provide the first evidence that street lighting changes the composition of communities. In addition, while the attraction of aerial invertebrates to artificial lighting is a well-documented phenomenon [13,14], this study is the first to document the effect of street lighting on ground-dwelling invertebrates. Ground beetles, harvestmen, ants, woodlice and amphipods were all more abundant in close proximity to HPS street lights, resulting in communities that contained more predatory and scavenging individuals.

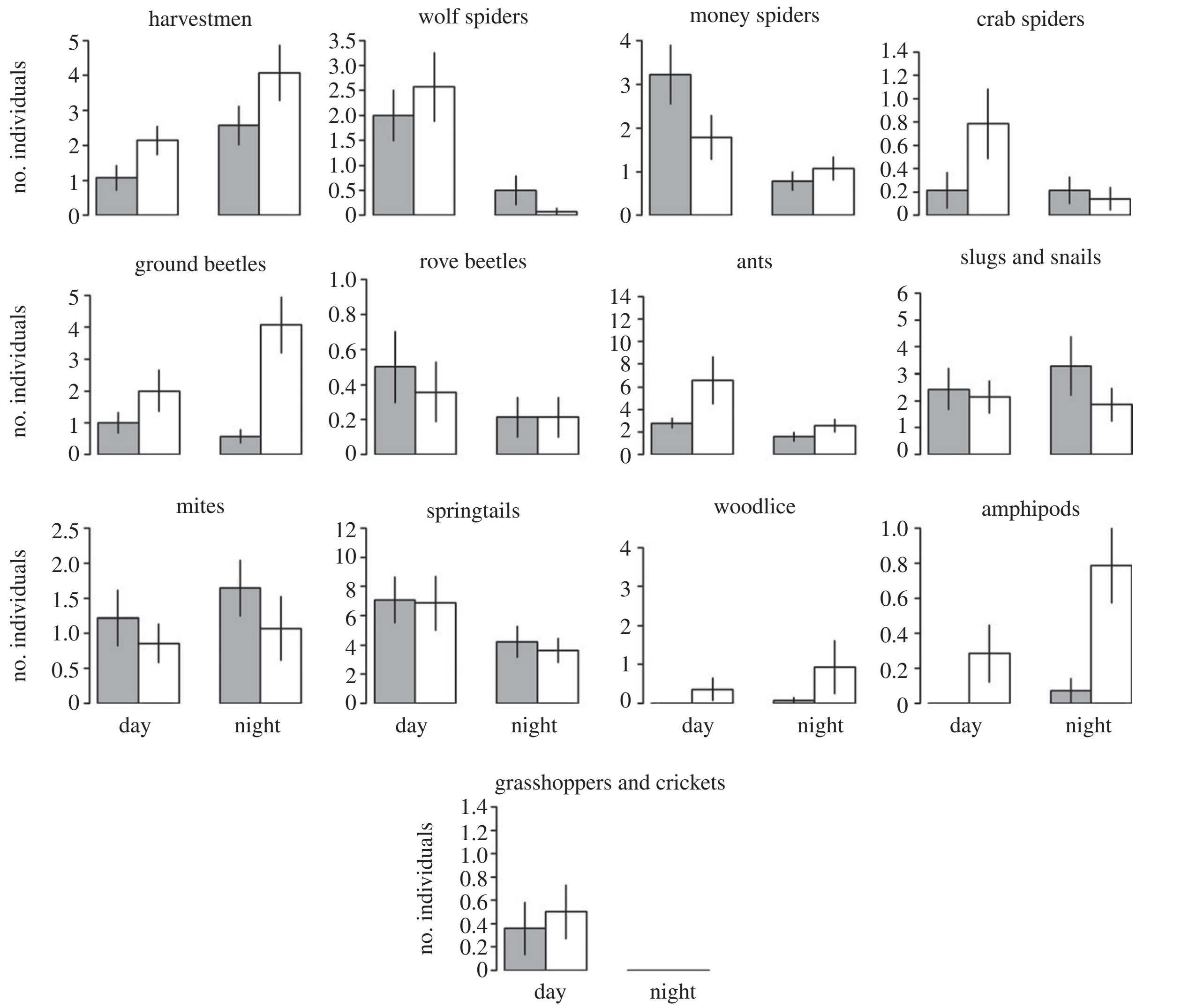

Figure 1. The effect of high-pressure sodium street lighting on the abundance of individuals within taxonomic groups of invertebrates. Bars represent the average total number of individuals in each group collected from pitfall traps deployed under street lights (open bars) and between street lights (grey bars). Error bars represent s.e.

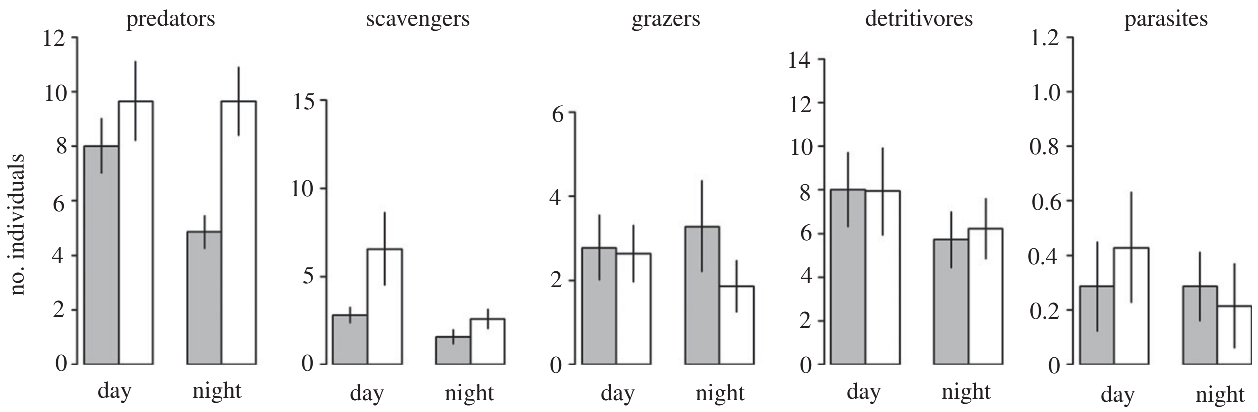

Figure 2. The effect of high-pressure sodium street lighting on the abundance of individuals within trophic groups of invertebrates. Bars represent the average total number of individuals in each group collected from pitfall traps deployed under street lights (open bars) and between street lights (grey bars). Error bars represent s.e.

Recent estimates suggest that artificial lighting is increasing at a rate of 6 per cent per year globally [1]. Given this, the resulting loss of naturally lit habitat may be affecting the composition of communities of organisms on a broad scale. Whether such changes affect the functioning of ecosystems, and the services they provide to humanity is unknown. However, the observed concentration of predators and scavengers around street lights in the current study raises the potential that ecosystem services may be altered through cascading effects from higher to lower trophic levels. Future research should therefore address how light pollution affects trophic interactions in complex food webs as well as the physiology, behaviour and mortality of species. Ongoing changes in technology towards broader spectrum lighting may further compound the threat posed by artificial light pollution [14,19]. This study highlights that a widespread lighting technology (HPS lighting) can affect the composition of communities of organisms. The future introduction of broader spectrum light technologies, such as metal halide or light-emitting diodes may further exacerbate any effects which artificial lighting has on the environment because these technologies emit light over a broader range of wavelengths to which organisms are sensitive. The paucity of information available on the environmental impacts of artificial light pollution does not currently reflect the potential scale of this problem.

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