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Distribution of Endangered Owlet Moths Provides Evidence for Adverse Effects of Light Pollution on Some Lepidoptera (Lepidoptera: Noctuidae)

Erik Tihelka

Abstract

The past decades have seen an increase in night time light pollution with serious ecological impacts. Previous experimental studies have demonstrated adverse effects of photopollution on moth reproduction, oviposition, dispersal, foraging, pheromone production, development and susceptibility to predation. The present study examines the distribution of endangered owlet moths (Noctuidae) in the Czech Republic in relation to light pollution.

Key words: Lepidoptera; Noctuidae; artificial light; Czech Republic; distribution; faunistics; light pollution; moth; owlet moth; photopollution

Zusammenfassung

In den letzten Jahrzehnten konnten wir eine Zunahme der nächtlichen Lichtverschmutzung beobachten, mit enormen ökologischen Folgen. Frühere Studien haben nachteilige Auswirkungen von Lichtverschmutzung gezeigt, insbesondere bei der Entwicklung von Motten und deren Flugaktivität, sowie bei Pheromon-Produktion, Eierlegung und Entwicklung. Die Studie befasst sich mit der Verbreitung des Eulenfalters in Relation mit der Lichtverschmutzung in einigen Gebieten der Tschechischen Republik.

Introduction

Moths are a diverse group of Lepidopterans distributed over the world. As such, moths have a vast potential as bioindicators (Šafář 2010). Recently, declines of moth populations in some parts of Western Europe were recorded (Conrad et al. 2004; Conrad et al. 2006; Mattila et al. 2006; Groenendijk & Ellis 2011; Fox et al. 2014). The reasons for these declines remain obscure but climate change, habitat loss, land use change, chemical pollution, non-native species, agricultural intensification and others have been suggested as possible reasons for the trend (Conrad et al. 2006; Groenendijk & Ellis 2011; Fox 2013; Fox et al. 2014). These declines may have far reaching consequences on entire ecosystems (Groenendijk & Ellis 2011) that remain to be quantified.

One of the suggested reasons for the declines are adverse effects of light pollution during night (Fox 2013). Humans have attempted to illuminate outdoor structures for centuries, but it was not until the last hundred years that the intensity of night time light pollution escalated rapidly. Although night time illumination is generally linked with a lower crime rate and greater safety in general, it was shown to have serious ecological impacts in urban and sub-urban areas (Longcore & Rich 2004; Hölker et al. 2010a; b; Stone et al. 2012; Gaston et al. 2013). Photopollution affects all continents and it is estimated that 18.7% of Earth´s terrestrial surface is exposed to astronomical light pollution (Cinzano et al. 2001). Many organisms are sensitive to disruptions of the day-night cycle. Artificial night time illumination was shown to profoundly affect orientation, reproduction, predation, communication and competition in a number of animals including fish, mammals, birds as well as invertebrates (Longcore & Rich 2004). Since Ancient Roman times, light traps were used to control pest Lepidopterans (Steiner 1991). But it was not until recently, that experimental studies identified negative effects of light pollution on moths.

Light pollution was shown to affect reproductive capacities of moths (van Geffen et al. 2015b). This may be because exposure of moths to artificial light negatively affects the quality and quantity of their sex pheromone (Sower et al. 1970; van Geffen et al. 2015a). Photopollution affects moth oviposition (Nemec 1969) and causes moths to lay eggs in unsuitable locations near sources of artificial light (Brown 1984). In addition, Geffen et al. (2014) demonstrated a negative effect of light on the development of moths. Furthermore, moths are often attracted to light sources (Altermatt et al. 2009), where they can be predated (Rydell 1992; Acharya & Fenton 1999). Additional research has shown that light pollution increases the susceptibility of moths to predation by bats (Svensson & Rydell 1998). This increases moth mortality and may lead to changes in the genetic structure and the total biomass of the population (Hölker et al. 2010a). Artificial night time light pollution may disturb the valuable pollination service moths provide and may seriously affect their vision (Macgregor et al. 2015). Given the amount of research into responses to light pollution in moths compared with the whole insect order, moths can be considered an invertebrate model for studying environmental impacts of light pollution.

Nevertheless, currently no causal relationship between light pollution and moth decline was identified, so the true impact of light pollution on moths remains unexplored (Fox 2013). Earlier analyses were unable to determine if light pollution really negatively affects moth distribution (Conrad et al. 2006). This study aims at elucidating whether moth distribution is actually affected by light pollution under field conditions and if yes, to what extent. It was hypothesised that less common moths may be more sensitive to light pollution. Therefore, faunistic data for endangered owlet moths (Noctuidae) in the Czech Republic (Farkač et al. 2005) were compiled. Their distribution was related to the level of light pollution at each of the localities.

Material and Methods

Light Pollution and Owlet Moth Distribution

Czech Republic is a landlocked country in Central Europe. Since it is situated in the middle of Europe, it can be assumed that its fauna represents the continent as a whole (Konvicka et al. 2003). The family Noctuidae has some 475 species in the Czech Republic (Laštůvka 1998), 13% of these are included in the Red List of Threatened Species (Farkač et al. 2005). The following species are considered endangered by the Red List: *Actinotia radiosa* (Esper, 1804), *Callopistria juventina* (Stoll, 1782), *Calyptra thalictri* (Borkhausen, 1790), *Conisania leineri* (Freyer, 1836), *Diachrysia zosimi* (Hübner, 1822), *Lygephila ludicra* (Hübner, 1790), *Lamprotes c-aureum* (Knoch, 1781), *Euchalcia consona* (Fabricius, 1787), *Euchalcia modestoides* Poole, 1989, *Euchalcia variabilis* (Piller, 1783), *Eremobia ochroleuca* (Denis et Schiffermüller, 1775), *Heliophobus kitti* (Schawerda, 1914), *Litophane consocia* (Borkhausen, 1792), *Litophane lamda* (Fabricius, 1787), *Lycophotia molothina* (Esper, 1789), *Luperina nickerlii* (Freyer, 1845), *Polia serratilinea* Ochsenheimer, 1816, *Polychrisia moneta* (Fabricius, 1787), *Polymixis flavicincta* (Denis et Schiffermüller, 1775), *Protolampra sobrina* (Duponchel, 1843), *Schinia cognata* (Freyer, 1833), *Xestia ashworthii* (Doubleday, 1855), *Xestia sincera* (Herrich-Schäffer, 1851), *Xanthia gilvago* (Denis et Schiffermüller, 1775) and *Yigoga forcipula* (Denis et Schiffermüller, 1775). These species were chosen as a subject for the study since distribution data for them would be easier to compile from nature conservation agencies.

A method needed to be chosen that would assure equal representation of every species. For this reason, the distribution data were searched using the Google search engine, Google scholar scientific paper database and the Czech Natural Bibliography, a database of Czech natural history papers. For each species, the searches "[genus name]" and "[species name] Czech Republic" were performed. Most of the time, the searches yielded scientific papers and distribution maps from the Nature Conservation Agency of the Czech Republic (AOPK ČR). Where scientific papers cited other studies, these were consulted too. Only distribution data from the last 15 years were considered. As a result, a representative dataset of owlet moth distribution was produced that would allow for comparisons to be made between species.

The place where the specimen was reported from was plotted on the Map of light pollution (http://www.lightpollutionmap.info/). Localities with radiance between 0 to 0.40 10-9 W/cm2 were considered as low light pollution, localities with radiance between 0.40 to 3 10-9 W/cm2 were considered moderate, 3 to 20 10-9 W/cm2 elevated, 20 to 40 10-9 W/cm2 high and 40 10-9 W/cm2 and over very high. The percentage of occurrences in each category of light pollution was recorded. The results are displaced in Tab. 1. The preference of owlet moths for each of the light pollution levels was analysed further.

Light Pollution and Habitat Disturbance

Although even protected landscape areas have considerable levels of light pollution (Aubrecht et al. 2010), it could be argued that light pollution acts as a proxy of habitat disturbance. In other words, unnatural or semi-natural locations may logically have higher levels of light pollution. In order to account for this factor, a total of 32 localities in the Czech Republic were randomly selected and the level of light pollution and was related to the average percentage of natural habitats at the location. The map of habitat disturbance of the Czech Republic produced by Divíšek et al. (2014) was used. The map of habitat disturbance is a statistical landscape classification that takes into account the proportion of natural habitats in a studied locality. Since the low resolution of this map, a less detailed map of light pollution was used for this analysis (http://svetelneznecisteni.cz/). Four categories of light pollution were established. If the ratio between natural and artificial light was between 0.33 to 1, this was understood as low light pollution, 1 to 3 as medium, 3 to 9 as high and 9 to 27 as very high.

Statistical analysis

Before analysis, all data were subjected to a normality test. P≤0.05 was set as the significance level (α). All statistical analyses were carried out in R.

Results

Light Pollution and Owlet Moth Distribution

Unfortunately, for four species, no recent distribution records were found and so these species were excluded from the analysis. A Shapiro-Wilk normality test revealed that the data did not follow the normal distribution curve (p= 2.621e-13). A Friedman rank sum test rejected the null hypothesis (p=6.223e-11). The data were analysed post-hoc using a Wilcoxon significant rank test, the results are displayed in Tab. 2. A significant difference was detected between localities with low and elevated light pollution (p=0.0017), localities with low and high light pollution (p=0.0017), moderate and elevated light pollution (p=0.0049), moderate and high light pollution (p=0.0052) and very high and low light pollution (p=0.0013). Therefore, the results show that a light pollution value of 3 10-9 W/cm2 can be understood as a threshold value that limits the distribution of owlet moths studied in the present work.

The results suggest that some species may be more sensitive to light pollution than others. The examination of Tab. 1 reveals some interesting patterns. *Euchalcia variabilis*, *Heliophobus kitti*, *Polia serratilinea*, *Polychrisia moneta*, *Polymixis flavicincta* and *Xanthia gilvago* occur exclusively in areas with low light pollution and could therefore be categorised as sensitive to artificial photopollution. On the other hand, species such as *Callopistria juventina* occur even at localities with higher levels of light pollution. This may be a result of broader ecological preferences of the species. Specifically, *Callopistria juventina* is recently expanding its range in the Czech Republic (Vrabec & Lehečka 2007).

Light Pollution and Habitat Disturbance

Next, the connection of landscape disturbance and light pollution was analysed (Fig. 2). A Shapiro-Wilk normality test revealed that the data did not follow a normal distribution curve (Low: p=0.0001865; Medium: p=0.005872; High: p=0.02301; Very high: p=0.0004194). A Kruskal-Wallis rank sum test did not reject the null hypothesis (p=0.1357).

Discussion and Conclusion

Distribution data from the past 15 years reveal that endangered Czech owlet moths (Noctuidae) have clearly determined preferences for the levels of light pollution. As a general rule, the majority of owlet moths occurred at localities with a low or moderate light pollution, but were rare at localities with higher night time illumination (Fig. 1). A value of 3 10-9 W/cm2 can be considered a threshold that limits owlet moth distribution. This threshold is however not universal, since individual species vary in their light pollution preferences.

Patterns of species distribution are often determined by complex interactions. It could be suggested that localities with lower human disturbance also logically have lower levels of light pollution. The present study identified no significant difference between the levels of light pollution at locations with various levels of habitat disturbance. Therefore, light pollution can be understood as a key driver of the trends observed herein.

While the present research identified some interesting patterns in Noctulidae distribution, many unresolved questions remain. In many studies on moth distribution in the Czech Republic and in many other countries, light trapping is used. However, there are many factors that influence the outcomes of light trapping (Knight & Light 2005). Moth capture rates may differ between localities with different levels of light pollution. In fact, in areas with high light pollution, less moths may be attracted to UV-moth traps because of the competition between light sources. However, light trapping is not the only method used to collect moths. Manual netting, beating vegetation and visual inspections are also popularly used by moth collectors (Leraut 2009), and these methods would likely be less subjected to biases resulting from light pollution. A priority for future research will be the development of harmonized methods for light trapping so that the trend outlined in the present paper can be tested further. Future research should also explore responses of taxa other than owlet moths to light pollution.

The present research identified that some moth taxa are more tolerant towards light pollution then others. This is in line with other studies that show differential response of various moths to light (Somers-Yeates et al. 2013; Merckx & Slade 2014). In this regard, future research should address light pollution tolerance in moth species that are not endangered and thus may be less sensitive to environmental stressors. Given the fact, that photopollution significantly affects owlet moth ecology, data on light pollution can be useful for designing future species (niche) distribution models.

A limit of the present study is that only endangered moths have been subjected to study. This is because endangered species traditionally enjoy much more attention from amateur and professional entomologists as well as nature conservation agencies, so that distribution data are more readily available. Data on the distribution of some common owlet moths in the Czech Republic appear to be more incomplete (E. Tihelka, pers. observ.). This is a pity, because it makes comparing the responses to light pollution in endangered and common taxa difficult. Endangered taxa often have very specific habitat requirements (for example, *Dichagyris forcipula* is specialized on warm areas exposed to the sun, while *Litophane* *consocia* occurs in wetland areas). This could make them more sensitive to environmental stressors such as light pollution on their small and isolated localities. On the other hand, common species with a wider environmental tolerance could simply avoid areas with higher levels of light pollution. This problem is currently under study.

In light of the present findings, lowering artificial night time photopollution is an emerging priority of insect conservation. There are several possibilities to reduce the ecological impacts of night time light pollution. These include preventing areas from being lit, reducing the duration and intensity of outdoor lightning and altering the spectral composition of light (Gaston et al 2012). Implementing these changes will require persuading landowners, authorities and policy-makers to change their current practices. Further evidence on the effects of light pollution on animals will thus be vital.

In conclusion, previous studies highlighted that light pollution has a negative impact on moth foraging, dispersal, reproduction, oviposition, mortality and intraspecific interactions (Nemec 1969; Sower et al. 1970; Brown 1984; Svensson & Rydell 1998; Hölker et al. 2010a; Geffen et al. 2014; van Geffen et al. 2015a; b). It has the potential to disturb nocturnal moth pollination as well as vision (Macgregor et al. 2015). However, the true impact of light pollution on a larger scale remains elusive (Conrad et al. 2006; Fox 2013). This study investigated the occurrence of endangered owlet moths in the Czech Republic. Light pollution on each of the localities were the moths have been recorded were listed and analysed. The results show that that endangered Czech owlet moths (Noctuidae) occur significantly less at localities with a light pollution of more than 3 10-9 W/cm2. Different species show various tolerance to light pollution, which is in line with other experimental studies that demonstrated that different taxa of moths react differently to light (Somers-Yeates et al. 2013; Merckx & Slade 2014). Habitat disturbance did not significantly affect the level of light pollution. It is thus possible, that light pollution is a key factor that limits the distribution of endangered Czech owlet moths. The results highlight light pollution as a priority in insect conservation.

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Author's address:

Erik Tihelka
The Prague British School
K Lesu 558/2, 142 00
Prague 4
CZECH REPUBLIC
E-mail: erik@yourbeehouse.cz

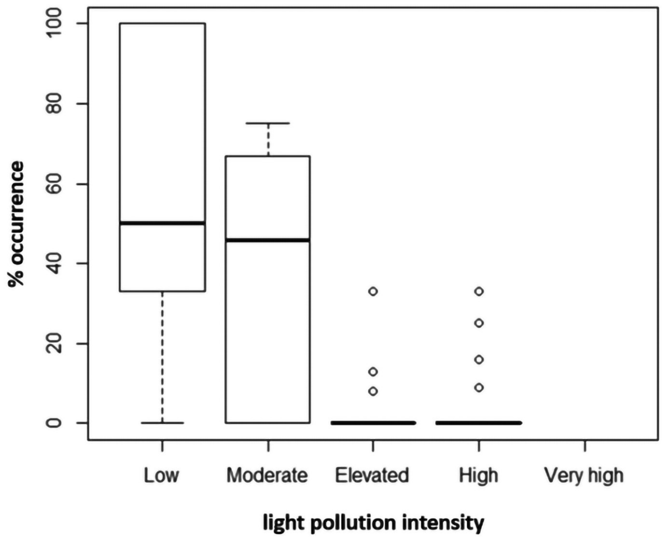

Fig. 1: Distribution of Czech owlet moths (Noctuidae) in localities with varying intensities of light pollution.

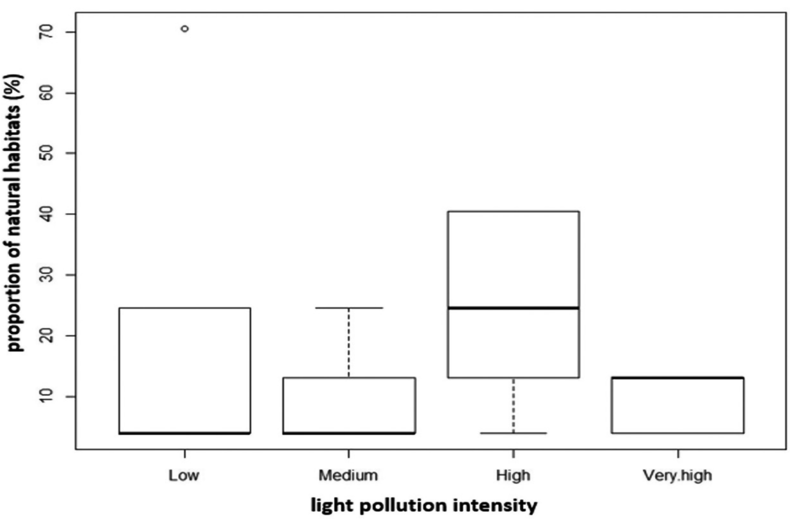

Fig. 2: The proportion of natural habitats (%) at localities with varying intensities of light pollution.

Tables

Tab. 1: The proportion of endangered Czech moths of the family Noctuidae occurring at localities with various intensities of light pollution.

Species	**Low light pollution**	**Moderate light pollution**	**Elevated light pollution**	**High light pollution**	**Very high light pollution**
Actinotia radiosa	45%	45%	0%	9%	0%
Callopistria juventina	31%	46%	8%	16%	0%
Calyptra thalictri	0%	75%	0%	25%	0%
Conisania leineri	33%	67%	0%	0%	0%
Diachrysia zosimi	33%	67%	0%	0%	0%
Lygephila ludicra	33%	33%	0%	33%	0%
Lamprotes c-aureum	-	-	-	-	-
Euchalcia consona	40%	60%	0%	0%	0%
Euchalcia modestoides	80%	20%	0%	0%	0%
Euchalcia variabilis	100%	0%	0%	0%	0%
Eremobia ochroleuca	25%	75%	0%	0%	0%
Heliophobus kitti	100%	0%	0%	0%	0%
Litophane consocia	33%	67%	0%	0%	0%
Litophane lamda	50%	50%	0%	0%	0%
Lycophotia molothina	0%	67%	33%	0%	0%
Luperina nickerlii	-	-	-	-	-
Polia serratilinea	100%	0%	0%	0%	0%
Polychrisia moneta	100%	0%	0%	0%	0%
Polymixis flavicincta	100%	0%	0%	0%	0%
Protolampra sobrina	63%	25%	13%	0%	0%
Schinia cognata	-	-	-	-	-
Xestia ashworthii	50%	50%	0%	0%	0%
Xestia sincera	-	-	-	-	-
Xanthia gilvago	100%	0%	0%	0%	0%
Yigoga forcipula	50%	50%	0%	0%	0%

Tab. 2: p-values of a Wilcox signed rank test comparing the proportion of endangered Czech owlet moths occurring at localities with varying degrees of light pollution.

	Elevated	**High**	**Low**	**Moderate**
High	0.7525	-	-	-
Low	0.0017	0.0017	-	-
Moderate	0.0049	0.0052	0.5034	-
Very high	0.5034	0.4014	0.0013	0.0049

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