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How to reduce the impact of artificial lighting on moths: A case study on cultural heritage sites in Slovenia

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ABSTRACT

In an ever more artificially illuminated world, common moth behaviour, flight-to-light, causes declines in their abundance and diversity that can have severe impacts on ecosystems. To test if it is possible to reduce the number of moths attracted to artificially illuminated objects, the original lighting of 15 cultural heritage buildings in Slovenia was substituted with blue or yellow lighting. These three illumination types differed in the amount of luminance, percentage of UV and short-wavelength light which are known to affect flight-to-light of moths. During our three-year field study approximately 20% of all known moth species in Slovenia were recorded. The blue and yellow illumination type attracted up to six times less specimens and up to four times less species compared to the original illumination type. This was true for all detected moths as well as within separate moth groups. This gives our study a high conservation value: usage of alternative, environmentally more acceptable illumination can greatly reduce the number of moths attracted to artificially illuminated objects.

1. Introduction

A large part of our planet is being artificially illuminated in hours of darkness, and the proportion of illuminated territory continues to increase (Cinzano, Falchi, & Elvidge, 2001; Hölker et al., 2010). Excessive artificial lighting has several negative effects on ecosystems, and has commonly been referred to as "ecological light pollution" (Longcore & Rich, 2004). Moths, predominantly nocturnal insects, are among the most severely affected animal groups (Frank, 1988), whose declines in diversity (i.e., species richness) and abundance have already been detected in parts of northern Europe (Conrad et al., 2006; Mattila et al., 2006; Groenendijk & Ellis, 2010; Fox, 2013). As moths present a major food source for numerous other animals and act as important pollinators, such declines represent a major threat to local ecosystems (see Macgregor et al., 2014). Moreover, as moths are one of the most species rich animal groups, this threat transcends to the global scale and urges immediate and serious conservation actions (van Langevelde et al., 2011; Fox, 2013).

Considering the importance of its consequences, this phenomenon has so far received insufficient attention (see Gaston, Visser, & Holker, 2015 for review). It is well known that moths are strongly attracted to lights emitting wavelengths that correspond with peak sensitivities of their visual systems (Cowan & Gries, 2009) and that the degree of attraction differs between species and families (van Langevelde et al., 2011; Truxa & Fiedler, 2012; Somers-Yeates et al., 2013). It is also known that lamps emitting light at shorter wavelengths, especially ultra-violet light, attract more and larger individuals as well as more species compared to lamps emitting light at longer wavelengths (Rydell, 1992; Eisenbeis, 2006; van Langevelde et al., 2011; Barghini, Augusto, & Medeiros, 2012). The explicit causes of moth declines due to excessive artificial lighting are however still not properly understood, although it has been demonstrated that artificial lights increase mortality through direct interaction between moths and lamps (Frank, 1988), influence life history traits (van Geffen et al., 2014) and disrupt natural behaviour, particularly dispersal, foraging and breeding (Altermatt, Baumeyer, & Ebert, 2009; Frank, 2006; van Geffen et al., 2015a,b). On the other hand, a recent study by Spoelstra et al. (2015) did not show any negative effects of artificial lighting on moth populations. Unfortunately, field studies testing practical solutions to reduce impact of artificial lighting on moths are completely lacking.

According to Luginbuchl et al. (2009), the major sources of artificial lighting are sport fields, commercial and industrial buildings and street lights. These are mostly concentrated in urban areas,

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where moth diversity is already expected to be low due to absence of suitable habitats and diversity of habitats. On the other hand, the majority of cultural heritage buildings that are illuminated at night are, particularly churches, often located at exposed positions (e.g., on top of small hills) in relatively dark rural areas where they are often the only source of light. This is the case in Slovenia (and some other European countries), where almost 3000 churches are illuminated during the whole night. Therefore, illumination of cultural heritage buildings could represent an important source of light pollution and a threat to local moth populations.

We conducted a field study, in which a practical solution for moth conservation was tested for the first time. Our aim was to determine if we can decrease the abundance and diversity of moths attracted to illuminated cultural heritage buildings by changing the type of illumination. Thus, we selected fifteen churches and recorded moth abundance and diversity under three different types of illumination. In addition to illumination type changes, custom blinds preventing the scattering of light away from the object were also used. We predicted that changing the existing light type to a longer wavelength type will result in decreased abundance and diversity of moths around churches. As these two measures are also dependent on habitat quality and suitability, we additionally measured the percentage of woodland around churches as an approximation for suitable moth habitat. We predicted that the abundance and diversity of moths will be positively correlated with habitat quality in the close surroundings of the churches.

2. Materials and methods

2.1. Design of the field study

For the purpose of our study, fifteen illuminated churches across three biogeographic regions in Slovenia were selected as representative illuminated cultural heritage buildings (Fig. 1A, Table A1). More precisely, we selected five geographically distant groups of three adjacent churches (hereafter referred to as "church triplets"). Churches in each group were chosen close to each other to offset the effect of geographic position on sampling. All churches considered were located in relatively dark rural areas and outside larger settlements to avoid interference with other artificial sources of light (e.g., street lights and light from residential buildings).

The field study was carried out in three consecutive years (2011–2013). In the first year each church in a church triplet was illuminated with one of the three illumination types in such a way, that all three types were present concurrently at a church triplet. In the next two years illumination types were rotated among the churches in the triplet, so that by the end of the study, each church was illuminated with all three illumination types (Fig. 1B). Characteristics and details about illumination types are thoroughly described below.

Each year six surveys (for survey protocol see below) were carried out at every church during the period of adult moths main activity i.e., (from mid-May until mid-September). Surveys at churches from the same church triplet were done on the same night, always in the same order. Over the three years this summed up to 18 surveys per church altogether.

2.2. Illumination types

Three illumination types were studied:

(1) Original—existing illumination type on the church before we started the study. This illumination was very variable in terms of lamp type (including metal halide and high pressure sodium vapour lamps), power, and the amount of UV and short-wavelength light (see Fig. 2; see Fig. A1 for examples of spectrograms).

(2) Blue—metal halide lamps (PHILIPS Master Color CDM-T 70–150 W/830), 70 W or 150 W, with a custom-made filter cutting off wavelengths shorter than 400 nm and with a custom blind unique for each church preventing the scattering of light away from the building (see Fig. A1 for examples of spectrograms).

(3) Yellow—metal halide lamps (PHILIPS Master Color CDM-T 70–150 W/942), 70 W or 150 W, with a custom-made filter cutting off wavelengths shorter than 470 nm and with a custom blind unique for each church preventing the scattering of light away from the building (see Fig. A1 for examples of spectrograms).

2.3. Sampling plot

A 10 m wide and 3 m high sampling plot was determined on the facade of each church. Surveys (for survey protocol see below) were confined to this area. The average luminance of sampling plots was obtained by photographing them with Canon EOS 5D + 16 mm lens, F8, ISO 800 (night images in RAW format) and subsequent image analyses with EcoCandela software developed for the purpose of LIFE at Night project (Mohar Andrej, pers. comm.). Spectral composition of light emitted from sampling plots was

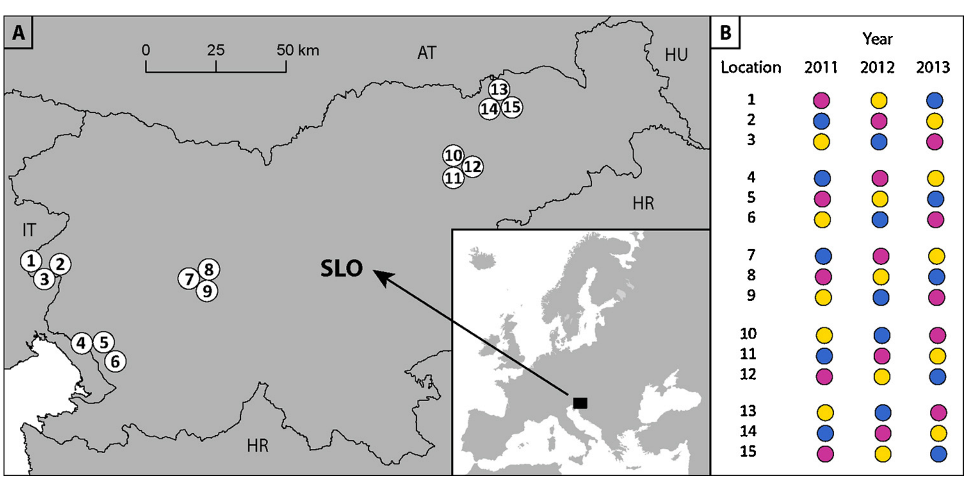

Fig. 1. (A) A map of sampling localities. In five distant geographic regions three adjacent churches (a "church triplet") were chosen for the purpose of the study. Locality numbers match with numbers on the right and with locality IDs in Table A1. (B) An illumination scheme shows illumination types at each church in three consecutive years of the study. At each church triplet all three illumination types were present in each year. Every church was illuminated with all three illumination types during the study. Purple, blue and yellow colored circles represent the original, blue and yellow illumination type. (Country abbreviation codes: SLO = Slovenia, IT = Italy, AT = Austria, HR = Croatia, HU = Hungary). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)