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Experimental light at night has a negative long-term impact on macro-moth populations

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The current decline in insect numbers and biomass is likely due to several factors [1] and one of the lesser studied factors is the increased artificial light at night (ALAN). Several negative impacts of ALAN on insects have been described [2] but evidence that it ultimately results in population declines has been circumstantial due to a lack of emperical data [3,4]. Here, we experimentally exposed natural habitats to three colours of artificial light, and a dark control, and studied the impact on moth population numbers during five consecutive years. With this experimental, multi-year study, we can isolate the effects of artificial light from other anthropogenic factors that are often confounded in correlative studies. Furthermore, we can study long-term effects that only become apparent after several years. In the first two years, the number of moths in the illuminated and dark treatments did not differ, but after the second year, the number of moths in the illuminated treatments was lower than in the dark control (Figure 1). This first implies a causal relationship between ALAN and local population declines and thus a contribution of ALAN to insect declines.

When testing the impact of a long-term presence of ALAN on local moth populations, it is essential to exclude confounding disturbance by other anthropogenic activities often co-occurring with ALAN. We used unique replicated setups in which natural habitat is experimentally illuminated with lampposts emitting white, green and red light at night, in addition to a dark control in seven locations in the Netherlands [5]. We monitored the local population of all macro-moth species present over five consecutive years using moth traps (see Supplemental Information for details). Based on the difference in the impact on behaviour and attraction of moths between spectra, we predicted a strong reduction in moth presence when the habitat is illuminated by green and white light, and little to no decline when illuminated by red lampposts, compared with the dark control [6]. Initial effects may be different from long-term effects. The aggregation of moths underneath the lamp posts, the so-called 'vacuum cleaner effect' [7], can result in higher numbers being observed near the light source. This aggregation may, however, be a sink, resulting in a gradual depletion of the surrounding area. This depletion may only become apparent after several years. Therefore, we tested for an effect of light treatment underneath light posts in an initial and second phase separately. This is a suitable approach for detecting subtle effects under natural conditions where other factors, such as weather and natural population fluctuations, cannot be excluded.

When we analysed all years (2012–2016) together, there was no difference in the total yearly number of macro-moths captured at the different treatments, nor was there an interaction between treatment and year. For a model with an initial and second phase, we split the data series such that separate models without the factor year for each of the two phases yielded the least mean squares of all residuals of both phases. There was a significant interaction between phase and illumination, indicating that the effect of illumination differs between the two phases as hypothesised. In the initial phase (2012–2013), the treatment did not affect the total number of macro-moths. In the second phase (2014–2016), there was a clear and significant negative effect of illumination on the total number of moths (-14%, se = 6%, $p = 0.02$), which did not differ for the three spectra (Figure 1).

In this study, we experimentally demonstrated that moth populations are negatively affected by the presence of light at night, but that possible effects can be very latent, and hence may only be visible after multiple years. While short-term effects of artificial light on moths have often been reported, the potential impact of the long-term effects on populations has thus far been

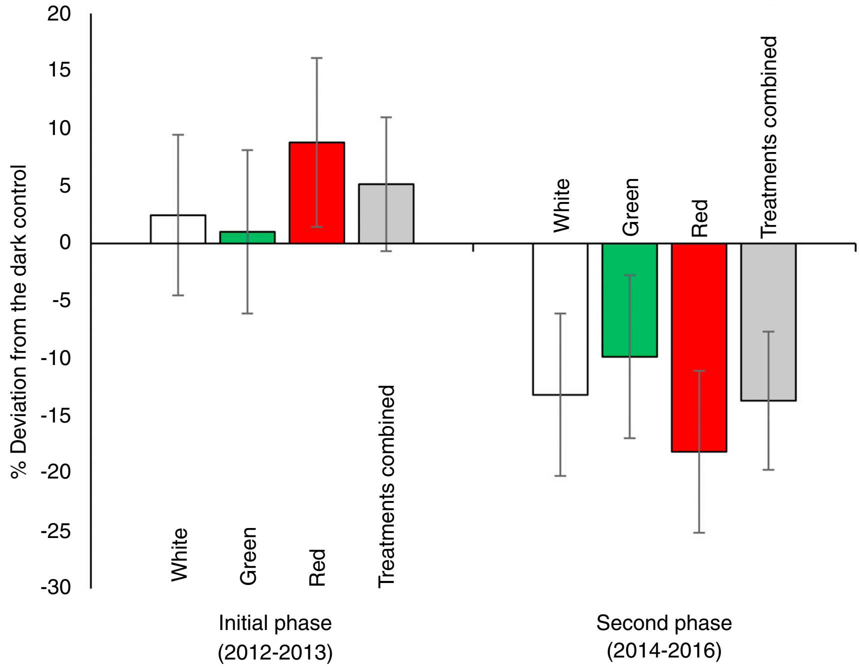

Figure 1. Effect of artificial illumination on moth numbers.
Deviation from the dark control (% ± SE) in the number of moths caught per transect per night for each light treatment separate and all illuminated treatments combined in the initial phase (2012–2013) and second phase (2014–2016).

primarily inferred from direct effects on individuals or correlative studies [4]. Here, we show that the impact of ALAN in our experimental setup only becomes apparent after the initial phase of two years. This underlines the importance of long-term experiments, as small incremental effects over the years might otherwise go undetected. Interestingly, we did not see differences between the three spectra, which does not support the hypothesis that effects on insects can be reduced by adjusting spectra [6], leaving as a potential mitigation measure only to reduce light at night altogether.

Our setup may contrast with more extensive illuminated areas in (peri-)urban surroundings. The presence of light at our research sites is limited to five lamp posts per colour, and surrounded by relatively large areas of dark natural habitat, a situation similar to illuminated roads and bicycle paths outside urban areas. This, combined with the limited distance from which moths are attracted [8], results in very local effects on moth populations. Moths disappearing from underneath the lampposts may be partly replenished from the dark surrounding. In (peri-)urban surroundings stronger effects are to be expected as illumination is more extensive and moth populations are likely smaller than in our setups in natural areas.

Our results confirm that artificial illumination plays a critical role in the current decline of moths. As ALAN is widespread and increasing [9] and affects many other insects [2], it is likely that the impact of ALAN on insect populations is substantial. These results support the notion that reduction of light pollution is an essential component of the roadmap for insect recovery [10].

SUPPLEMENTAL INFORMATION

Supplemental Information includes one figure, one table, experimental procedures and supplemental references and can be found with this article online at https://doi.org/10.1016/j.cub.2020.04.083.

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DECLARATION OF INTERESTS

The authors declare no competing interests.

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