Reduced flight-to-light behaviour of moth populations exposed to long-term urban light pollution

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The globally increasing light pollution is a well-recognized threat to ecosystems, with negative effects on human, animal and plant wellbeing. The most well-known and widely documented consequence of light pollution is the generally fatal attraction of nocturnal insects to artificial light sources. However, the evolutionary consequences are unknown. Here we report that moth populations from urban areas with high, globally relevant levels of light pollution over several decades show a significantly reduced flight-to-light behaviour compared with populations of the same species from pristine dark-sky habitats. Using a common garden setting, we reared moths from 10 different populations from early-instar larvae and experimentally compared their flight-to-light behaviour under standardized conditions. Moths from urban populations had a significant reduction in the flight-to-light behaviour compared with pristine populations. The reduced attraction to light sources of ‘city moths’ may directly increase these individuals’ survival and reproduction. We anticipate that it comes with a reduced mobility, which negatively affects foraging as well as colonization ability. As nocturnal insects are of eminent significance as pollinators and the primary food source of many vertebrates, an evolutionary change of the flight-to-light behaviour thereby potentially cascades across species interaction networks.

1. Background

Anthropogenic light pollution is recognized as a global environmental change negatively affecting humans [1], animals [2,3] and microbes [4]. The negative effects are well-known and even captured in the Shakespearean saying ‘Thus hath the candle singed the moth’, referring to someone tempted by something that eventually will lead to his downfall. As a global phenomenon [5,6], light pollution is a by-product of urbanization [6] and interferes with the natural day–night cycle, resulting in changed phenologies of organisms in the polluted habitat [7]. An even more direct effect of light pollution is the widely observed attraction of organisms ranging from migrating birds to insects to the light sources, which can result in increased mortality through direct burning or increased exposure to predators [8,9]. Furthermore, attraction to light may lure organisms out of their native habitat and interfere with normal feeding behaviour, mating and reproduction [3]. The negative effects of light pollution on community composition [4,10], population dynamics and organisms’ Darwinian fitness [11] have been globally documented, and mortality at artificial light sources can be 40- to 100-fold higher than in dark-sky populations [3,8].

Surprisingly, however, little is known about the potential evolutionary consequences. Existing data show that there is a high variability among species and
sexes to be attracted by light [12,13], and anecdotal evidence from naturalists even indicates within-species variation [14]. Given the detrimental effect of the flight-to-light behaviour in polluted areas it has been postulated that natural selection should favour individuals with a lower propensity of being attracted by light [7,12].

Organisms’ phenotypic and genetic responses to anthropogenic environmental changes are well-known, such as the classic example of industrial melanism of the peppered moth. However, possible selective responses to light pollution have not yet been documented, even though artificial night lighting has strongly increased over the last decades [3], has a pronounced geographical variation [6], and is having increasingly negative effects on many species [3], creating the necessary conditions for directional selection and adaptation to a novel anthropogenic stressor. Here, we report an experimental quantification of a reduced flight-to-light behaviour of small ermine moths from populations occurring in areas with high light pollution compared with populations with low pollution.

2. Methods

(a) Study organism and study sites

We used the small ermine moth (Yponomeuta cagnagella), which is widely distributed across Europe. Its larvae feed strictly on European spindle (Euonymus europaeus) [15]. Larvae live in loose silk-webs, forming gregarious full-sib groups on their host plants. In order to test for the effect of multi-generational exposure to artificial light pollution on flight-to-light behaviour, we collected larvae of the small ermine moths in areas with low-to-medium levels of light pollution (less than 3 × 10^-9 W cm^-2 sr^-1); subsequently called dark-sky populations; table 1) and in areas which have been exposed to strong light pollution for several decades (current light pollution 20 to more than 40 × 10^-9 W cm^-2 sr^-1; subsequently called light-polluted populations, data from http://www.lightpollutionmap.info) [6]. The latter populations were always sampled in the immediate vicinity of streetlights in urban parks or along streets (maximum distance to light source 20–50 m).

(b) Laboratory conditions

We collected second-instar larvae, such that organisms were independently sampled with respect to the subsequent experimental test method, in 10 independent populations from locations in northwestern Switzerland and in eastern France in spring 2007 (table 1). These populations were not connected by suitable habitat and represented independent units. At each location, larvae from multiple full-sib family clutches were collected. Some of these populations had been used in a previous analysis on sex-specific flight-to-light behaviour [12]. Larvae were reared in the laboratory under standardized, common garden conditions in 500 ml plastic boxes at 80% relative humidity and a daily light–dark cycle of L16 : D8 h, including 1 h dusk and dawn phases. The temperature were 23°C during the light phase, and 19°C during the dark phase. Food was provided ad libitum.

(c) Flight-to-light experiment

We experimentally tested the flight-to-light behaviour of small ermine moths in an indoor flight cage, measuring 5.7 × 2.5 m at the bottom, 5.7 × 1.8 m at the top and of 3 m height (see electronic supplementary material, figure S1). In this cage, moths can be attracted from every position, as the effective range of the light traps used is about 3–5 m [13]. Temperature and humidity in the flight cage were held constant at 20–22°C and 60–80% relative humidity, respectively.

A standard Heath trap equipped with a fluorescent tube (Philips, Eindhoven, The Netherlands, TL 6 W/05; see electronic supplementary material, figure S2) was placed at the long-end side of the flight cage. Previous to the experiment, adult moths were individually marked and kept at L16 : D8 cycle such that they adapted physiologically to the day-to-night change. For the flight-to-light experiment, we used individuals 2–3 days post-eclosion before they were sexually mature. We thereby pooled individuals from different families and populations of origin. Moths were released at the opposite end to the lamp, and the tests started at the onset of dusk. The species flies generally at night and is not only crepuscular. We recorded the number and identity of all moths captured by the light trap and all moths not attracted after 8 h.

(d) Analysis

We used a generalized linear mixed effect model to test for a difference in flight-to-light behaviour of moths originating from light-polluted areas versus dark-sky areas. As response variable, we used the odds ratio of individuals attracted versus individuals not attracted, and a model with a binomial error distribution. Light pollution, sex and their interaction were included as fixed effects in the model, whereas populations and family nested
Flight-to-light behaviour of small ermine moths from dark-sky and light-polluted populations did not deviate from 1:1 (mean term was removed from the model). The sex ratio within sex on the flight-to-light behaviour, and the interaction no significant interaction between population of origin and sex on the flight-to-light behaviour, and the interaction between sex and population of origin affecting adult behaviour or other selective effects of light pollution on natural populations may not necessarily vanish immediately when the lights are turned off, and that light pollution has already resulted in systematic changes in organisms’ behaviour. This advocates for preventing light pollution, event at low levels, from spreading to rural and urban populations may bias biodiversity surveys based on commonly used light traps [13], in particular if populations of different species respond differently to changes in light condition.

Consistent with many other species, males are the more mobile sex in small ermine moths, and are thus also more often attracted to light [12]. Of note, males from light-polluted habitats exhibited an almost identical flight-to-light behaviour to females from dark-sky habitats (figure 1a). The reduced flight-to-light propensity, however, may come with a cost. Explanations for the reduced flight behaviour of moths originating from light-polluted populations include that these moths have a behaviourally or physiologically reduced perception or reaction to the light [14]. For example, size of the eyes, light receptors in the eyes or information processing of perceived light might be altered. Alternatively, the reduced flight-to-light response may be caused by a decrease in overall mobility. Such a change could have far-reaching consequences, as a reduced mobility is known to negatively interact with habitat fragmentation and dispersal, to reduce flower visiting rates and pollination or take the moths out of the sky, and thus reduce prey availability for the nocturnal insectivores, such as bats or spiders.

Given the recent recognition of the pollution effects acting on individuals to ecosystems, there have been calls to reduce light pollution and street light intensity [3]. While this is commendable, our demonstration of a presumably adaptive change in flight-to-light behaviour in populations having been exposed to long-term light pollution suggests that the effects of light pollution on natural populations may not necessarily vanish immediately when the lights are turned off, and that light pollution has already resulted in systematic changes in organisms’ behaviour. This advocates for preventing light pollution, event at low levels, from spreading to areas that are so far unaffected, in order both to reduce the direct negative effects of light pollution as well as to prevent long-term evolutionary changes.


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Competing interests. We declare we have no competing interests.

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