LIGHT POLLUTION AS A DRIVER OF INSECT DECLINES

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Abstract booklet

<u>Session 1: Visually-guided behaviors in unnatural light environments</u>

How artificial light alters the natural light-environment at night

Dan-Eric Nilsson, *Dept. of Biology, Lund University, Sweden*

Animals use a number of visual cues for orientation as well as for decisions on where to be and what to do. This is true at all times of day, including dusk, dawn and night. Artificial light at night (ALAN) will obviously interfere with these cues, resulting in altered behaviours and, in turn, reductions in biodiversity. It is often assumed that it is the increased general illuminance that cause the detrimental effects of ALAN, but animal visual systems are notoriously bad at recording absolute intensities. In addition, absolute intensities are naturally ambiguous signals altered by vegetation, weather and moonlight. It is thus likely that animals use additional qualities of the light environment to work out where to be and what to do. Potentially informative cues include the rate and range of intensity change at dusk and dawn, as well as the distribution of light and spectral balance across elevation angles. Currently, we do not know which aspects of ALAN cause the detrimental effects on biodiversity, and this significantly hampers our ability to select efficient mitigation strategies for light pollution. The talk will dissect the biologically relevant information contained in natural light environments and suggest how ALAN may interfere with essential cues.

Modelling insect attraction to ALAN with Monte Carlo Radiative Transfer

Sam Morrell, *University of Exeter, UK*

Artificial Light at Night has a wide variety of impacts on the natural environment. To study the impacts upon organisms, one must understand a) distribution of ALAN in environments and at spatial scales at which organisms experience it, and b) how organisms perceive and respond to the light stimulus. In this work, we will show how the Monte Carlo Radiative Transfer technique can be used to model the distribution and spectral characteristics of light across urban environments. We will then demonstrate how we can estimate the attractiveness to insects across these environments in 3D by applying insect attractiveness action spectra to model outputs.

Dynamic visual processing in insects: from single photons to light pollution

Anna Stöckl, *University of Konstanz, Germany*

Many animals rely on vision as a key sense to guide behaviour. For the eyes and brain, the vast range of light levels across the day poses a considerable challenge to maintaining a reliable visual percept. Insects provide a unique model for understanding how visual processing adjusts to changing light, because they have to overcome severe limitations in eye size and computational capacity. In past work, we have uncovered neural mechanisms that allow hawkmoths (Lepidoptera) to optimise the visual signal-to-noise ratio across a one-million-fold change in light intensity, by spatially and temporally integrating visual information. We have recently identified the neurons that perform spatial summation in dim light, and resolved their position in a central visual circuit: wide-field motion processing for flight control. However, this does not explain how hawkmoth visual processing supports flight control outside of the highly controlled and stable conditions tested previously in the lab. As animals fly through their natural habitats, light levels can fluctuate rapidly between open and closed surroundings, or when they encounter artificial lights at night. Most importantly: a moving animal shapes what it sees by adjusting its flight speed and distance to surrounding objects. How do such behavioural adjustments interact with and aid neural processing in the dynamic closed loop a flying insect constitutes? In this talk, I will summarise what we know about neural adaptations to changing light in hawkmoths, how we study their flight behaviour in more natural settings, and how we are planning to generate a coherent framework for studying the neural basis of natural visual flight control in dynamic light environments.

How animals follow the stars, the moon and the lamp

James Foster, *University of Konstanz, Germany*

Many night-active animals rely on compass cues in the sky to find their way, including the moon, skylight polarization pattern and the stars, which can be obscured by anthropogenic skyglow. We investigated how light pollution, in combination with different celestial cues, affects orientation in the ball-rolling African dung beetle *Escarabaeus satyrus*. This nocturnal species performs a well-described orientation behaviour, typically relying on the lunar polarization pattern and the Milky Way to hold its course. We recorded orientation behaviour at a light-polluted urban site and a dark-sky rural site, under moonlit, starlit and overcast skies. Available visual information in each scene was recorded using a calibrated camera system, and processed to quantify potential compass cues. We find that vital celestial cues are obscured and degraded by skyglow, forcing these beetles to rely instead on terrestrial beacons, which would not support compass orientation at a larger scale. For the many other species of insect, bird and mammal that rely on the night sky for orientation and migration, these effects could dramatically hinder their vital night-time journeys.

Lost in light: How light pollution disrupts moth orientation

Jacqueline Degen, *University of Würzburg, Germany*

One of the most dramatic changes occurring on our planet in recent decades is the ever-increasing extensive use of artificial light at night, which drastically altered the environment nocturnal animals are adapted to. Such light pollution has been identified as a driver in the dramatic insect decline of the past years, yet little is known about its impact on natural insect orientation behaviour. One nocturnal species group experiencing marked declines are moths, which are important components of almost all terrestrial food webs and play a crucial role as nocturnal pollinators. Moths are famous for being attracted to artificial light sources, often displaying disoriented behaviour as they circle around the light or crash to the ground. To elucidate the impact of streetlights on their flight behaviour beyond the illuminated area, we utilized harmonic radar and recorded individual flight trajectories over several hundred metres. Surprisingly, only 4% of flights ended at one of the six streetlights that were evenly arranged in a circle around the release site. Nevertheless, the streetlights had a significant impact on flight behaviour as we observed a species-specific barrier effect on lappet moths whenever the moon was not available as a natural celestial cue. Moreover, streetlights increased the tortuosity of flight trajectories in interaction with the moon. Since in addition 12% of the tested individuals passed the position of a streetlight without interrupting their flight, we consider flight altitude to be the decisive parameter in determining the attraction of an animal towards a light source. We therefore propose to extend the attraction radius of a light source, which is conceived only in two dimensions to date, by the third dimension. Our results provide the first spatially resolved experimental evidence for the fragmentation of landscapes by streetlights and demonstrate that light pollution affects orientation of moths beyond previously assumed extent, potentially affecting their reproductive success and hampering a vital ecosystem service.

An experimental and mechanistic investigation into light pollution as a driver of insect declines.

Carlos Linares, *Boise State University, USA*

Global biodiversity is in crisis, with insect declines posing a particularly critical threat due to their fundamental role in terrestrial ecosystems. Streetlights and other forms of artificial lights are a pervasive and rapidly increasing form of pollution, with documented negative impacts on wildlife. This study investigates the hypothesis that lights are a significant, yet underestimated, driver of insect declines, with cascading effects on insectivorous bat predation. Over three seasons (2021–2023), we installed solar-powered streetlights across three Idaho drainages, manipulating large portions of the landscape. We performed weekly insect trapping across 15 experimental sites while also using acoustic monitoring to record bat activity. Preliminary results demonstrate a significantly higher abundance of insects at dark areas compared to lit areas. Some species like *Anarta crotchii* and *Malacosoma californica* were more frequently found at traps in dark sites compared to illuminated sites, suggesting a negative impact of lights on these populations. Furthermore, increased bat activity observed around lit areas indicates potential heightened pressure on insects concentrated at these sites. These findings underscore the urgent need for further research into the ecological impacts of light pollution and the implementation of mitigation strategies to protect insect biodiversity and ecosystem function.

Session 2: Ecological and evolutionary consequences of ALAN

The influence of latitude on population responses to ALAN

Therésa Jones, *University of Melbourne, Australia*

Natural variation in daily and annual light cycles underpin a myriad of biological processes. Increasingly, the largely negative ecological impact of artificial light at night (ALAN) is documented at the individual- and community-level. However, populations of the same species may evolved under and experience very different natural light cycles if they span a wide latitudinal range. We assayed six *Drosophila melanogaster* populations derived from naturally dark low or high latitude locations in Australia to determine whether latitudinally (and presumably genetically) distinct populations responded equally to the presence of Artificial Light at Night. We predicted that plastic circadian phenotypes should be selected for at higher latitudes (given their evolved ability to survive wide variation in annual photo-period) and this should reduce the fitness costs of ALAN exposure. In line with expectation, we found that low latitude populations under ALAN had a lower probability of eclosion and reduced fecundity. However, ALAN alone affected the timing of eclosion and female survival.

Why are moths less attracted to light traps than they used to be?

Avalon Owens, *The Rowland Institute at Harvard, USA*

Entomologists monitor insect population trends by surveying individuals attracted to artificial lights at night with the assumption that flight-to-light behavior is not subject to change. However, emerging data suggests that entomological light traps are rapidly losing efficacy relative to other trap types, and dramatic growth in anthropogenic light pollution over the past century has been identified as a probable cause. To investigate whether light competition and/or rapid evolution have compromised light trapping as a survey method, we compared the light attraction of urban and rural corn earworm moths (*Helicoverpa zea*) to historical behavioral records from 1967. Our results suggest that the flight-to-light response has remained relatively constant over time but is strongly influenced by environmental visual clutter, even in seemingly dark habitats. These findings call into question the use of light traps in long-term surveys, as the darkness within which they operate is rapidly deteriorating.

Adaptation to ALAN in urban moths? Seasonal life-cycle regulation versus flight-to-light behaviour and flight morphology

Thomas Merckx, *Vrije Universiteit Brussel, Belgium*

ALAN has an increasing footprint worldwide and may well be interfering with a significant part of biodiversity as most species are evolutionary tuned to using daylength as a cue for their circadian rhythms and seasonal life-cycle regulation. Nonetheless, the effect of ALAN on the evolution of seasonal adaptations has received little attention. Here, we test whether and to what extent dim, indirect ALAN impacts the photoperiodic induction of diapause in a widespread geometrid moth. By using common-garden experiments with and without this treatment, and by using offspring from urban and rural populations from four European countries, we also test for possible urban evolution in the susceptibility of diapause induction to dim ALAN. Dim ALAN strongly increased direct development overall, but urban populations did not display adaptation to ALAN. We hence show that seasonal life-cycle regulation is heavily impacted by dim nocturnal light in both urban and rural populations. Because dim ALAN, such as skyglow, extends far outside cities, ALAN may have widespread detrimental effects on moth and insect populations in general, and could hence be an important piece of the global change puzzle causing large-scale insect declines. In addition, moths and other insects are typically attracted by light sources. This flight-to-light behavior has substantial fitness costs too. In response, spindle ermine moths from urban origin appear to have evolved a reduced flight-to-light response, compared to rural-origin moths from various Swiss and French populations. Here, we test whether these urban and rural individuals—with known differences in flight-to-light responses—differ in flight-related morphological traits. Urban individuals had on average smaller wings than rural moths, which in turn correlated with a lower probability of being attracted to light. Our finding hence shows that ALAN may select for reduced mobility, and associated flight morphology. However, this comes with potential knock-on effects on individual fitness and gene flow of both moths and plants.

Ecological and evolutionary bases of nocturnal insects' rapid adaptation to a brighter night sky -- a corn earworm story

Qian Tang, *Rowland Institute at Harvard, USA*

Declines in the capture of nocturnal insects at light traps in the past few decades may be due to population declines or increased light pollution, which could reduce trap counts through population dilution (light competition) and/or natural selection against flight-to-light behavior (rapid evolution). Long-term monitoring of the corn earworm, *Helicoverpa zea*, using paired blacklight and pheromone traps has revealed a significant loss in blacklight trap efficacy since 2009, yet the cause remains unclear. Using ecological models, we find that *H. zea* population dynamics are primarily influenced by weather anomalies and that improved air quality may increase the attractiveness of pheromone traps. To test whether the reduced attractiveness of blacklight traps was due to rapid evolution in the moth population, we ran a genome-wide association study on samples collected from both trap types in the summer of 2024. We have identified candidate loci that may contain alleles associated with *H. zea* flight-to-light behavior. Further analyses will elucidate how rapid evolution contributes to the changing responses of these and other nocturnal insects to artificial light at night.

Disentangling the visual cues of an evolutionary trap for aquatic insects

Kyle Haynes, *University of Virginia, USA*

Water seeking is critical for aquatic insects given the need to locate sites for oviposition. Aquatic insects, and many other organisms, use polarized light as a reliable visual cue for locating water surfaces. However, many man-made surfaces polarize light more strongly than natural waterbodies. As a result, aquatic insects preferentially lay their eggs on these polarizing artificial surfaces. Previous work has shown that the attractiveness of artificial surfaces to aquatic insects is diminished by adding non-polarizing gridlines to these surfaces. However, it is not known how this mitigation affects aquatic insect preferences. We tested two alternative hypotheses about how aquatic insects judge the quality of potential oviposition sites. The first hypothesis, the visual averaging hypothesis, states that insects judge the quality of a surface based on the percent area of the surface that is polarizing. An alternative hypothesis is that the quality of a polarizing surface is judged by the degree to which it is fragmented by non-polarizing elements. This experiment was conducted using oil tray traps as artificial polarizers whose percentage of polarizing area and the presence/absence of fragmentation was manipulated. We found that increasing the percent area that was non-polarizing significantly decreased captures of Diptera, but the fragmentation of a polarizing surface had no significant effect on the number captured.

The impacts of ALAN on optimal foraging and trophic networks

Mia Croft, *Newcastle University, UK*

Despite growing interest in ALAN as an overlooked and important driver of recent insect declines, gaps remain in our understanding of impacts across multiple trophic levels or indeed entire ecological networks. My PhD project establishes a replicated field experiment at Cockle Park Farm, Northumberland, to investigate the effects of novel light on a naïve system over two years. Alongside collecting insects using a variety of passive and active methods, I'm also sampling floral eDNA and invertebrate predator dietary DNA, in addition to quantifying the macronutrient content of plant resources and prey. My data will be used to construct nutritional networks for both dark and lit sites, which convey how nutrients structure and flow through ecological networks. To supplement my study, I'm conducting feeding bioassays with live carabids to determine alterations to their macronutrient niches under novel and established light. My project aims to clarify how ALAN impacts ecological networks through optimal foraging.

Impact of continuous versus dynamic artificial light at night on larval development: an experimental test with moths originating from different skyglow conditions

Evert van de Schoot, *UCLouvain, Belgium*

ALAN has been shown to directly affect insect flight, feeding and mating behaviour, but it can also affect development in the juvenile stages. We study the impact of ALAN on moths across their life cycle combining both field studies in gardens (i.e., community-level responses) and controlled laboratory experiments (i.e., intra-specific responses). For our field study, we sampled moth communities in gardens with either high or low skyglow levels and presence or absence of street lighting to obtain a full factorial design. Besides the effects on species diversity, also changes in species traits within these communities are investigated considering multiple environmental factors. In this talk we will mainly focus on our results of controlled laboratory experiments studying the impact of continuous and dynamic ALAN on larval development in two noctuid moths. In a split-brood design, larvae originating from populations under different skyglow levels were reared under dark nights, full-night ALAN or smart streetlight-like ALAN. We monitored several life-history traits like larval survival, development time, feeding behaviour and body mass. Furthermore, we measured adult flight-related morphology. In contrast to previous studies, ALAN effects on larval development were rather positive. We also show evidence for sex-specific changes in flight-related morphology, resulting in altered sexual dimorphism.

Session 3: More than moths: Ecological impacts across insects

LED's see how the fireflies flee: Quantifying effects of artificial light on flight activity of the firefly Lamprohiza splendidula.

Indra Saenen, *Vrije Universiteit Brussel, Belgium*

Urbanization exposes forests to increasing levels of artificial light at night (ALAN), disrupting the physiology, behaviour, and population dynamics of crepuscular and nocturnal insects. Lampyridae— a beetle Family commonly known as fireflies or glow-worms—are particularly vulnerable, as they rely on bioluminescent signals for reproduction. While ALAN's impact on many lampyrids is well documented, little is known about its effects on *Lamprohiza splendidula*, a species inhabiting rapidly urbanizing European landscapes. We assessed ALAN's impact on the local abundance of glowing male *L. splendidula* through active and passive monitoring across six Belgian populations. Using a paired design, we compared a bright white LED treatment with a control (no additional light) at each site. The active monitoring involved a net-trapping experiment with repetitive short-duration light exposure by switching the LED on and off (3 and 10 min, resp.). Passive monitoring used beta-light female mimic traps to assess mate location along a 10m gradient with the same LED treatment and a control in natural dark circumstances. Although the net-trapping experiment revealed across population variation in flight response, the light treatment lowered male abundance ca. 30% overall compared to the control treatment. Abundance declined rapidly during light exposure, and it took over 3 minutes to recover to pre-exposure values after the LED was turned off. Passive monitoring confirmed this strong negative effect, with fewer males attracted to dummy females in the illuminated plots. Firefly captures followed an exponential declining gradient toward the light source. Our findings indicate threshold-like, nonlinear effects of ALAN on firefly flight activity. Further experiments with varying light intensities and colours, will clarify the spatial dimensions of this interference on flight and mate location behaviour. These findings will help develop lighting strategies that mitigate impacts on *L. splendidula* and potentially other firefly species.

Light pollution and aquatic insects: Ecological effects and remedies

Franz Hölker, *Leibniz Institute of Freshwater Ecology and Inland Fisheries (IGB), Germany*

With emissions of artificial light at night (ALAN) rising rapidly and half the world's population living within 3 km of a surface freshwater body, rivers and lakes around the world are increasingly exposed to light pollution. Although freshwaters are biodiversity hotspots and the effects of light pollution on freshwaters are far-reaching, only a small proportion of ALAN studies focus on aquatic insects. However, alleviating light pollution requires innovative concepts that include the protection of aquatic insects. Despite evidence of effective and readily available mitigation strategies (e.g. light orientation, shielding, scaling of light levels to the intended use, spectral tuning), little attention has been given to measures that specifically address light pollution of inland waters and surrounding land. This presentation summarizes the effects of ALAN on aquatic insects, and highlights innovative lighting concepts, strategies and specific measures to improve the protection of freshwater biodiversity from ALAN.

Butterflies at porch lights: exploring nocturnal light visitation in butterflies using community science data from iNaturalist

John Deitsch, *The University of Texas at El Paso, USA*

Flight-to-light behavior is one of the most noticeable and ecologically significant impacts of artificial light at night (ALAN) on insects. Research on flight-to-light behavior has understandably been largely focused on nocturnal and crepuscular insect taxa, but many diurnal insects also exhibit this behavior. Here, we utilize the large iNaturalist dataset to explore flight-to-light behavior in butterflies. iNaturalist is an unstructured community science project where the datapoints are “observations” (geo-tagged photos of organisms). We downloaded iNaturalist observations of butterflies at artificial light sources in the USA and Canada. We manually verified observations were at light sources and we recorded light source information when available. We then checked for signals of natural history traits (size, habitat, taxonomic group, and migratory behavior) predicting light visitation of a species. We compiled 384 observations of butterflies at light sources, representing all six diurnal butterfly families, 74 genera, and 107 species. Most observations came from residential light sources or insect-sampling/observation schemes (e.g., moth sheets). Observation frequency at lights varied across butterfly families: Lycaenidae were observed the most and Papilionidae the least. We found that habitat preference may influence light visitation: closed-habitat species were observed more frequently than open-habitat species. There were no clear relationships between observation frequency and wingspan or migratory behavior. We found that (1) a broad diversity of butterflies have been observed at artificial light sources (2) butterfly species differ in light visitation frequency and (3) some natural history traits may be useful in predicting species’ vulnerability to ALAN. We also discuss the usefulness of iNaturalist and community science as supplemental to experimental research, particularly as it relates to ALAN and insects.

Illuminating complexity: How Artificial Light at Night influences insect richness across a vehicle pollution gradient

Marielle Hansel Friedman, *University of California Davis, USA*

Controlled studies assessing the effects of artificial light at night (ALAN) on insects have revealed strong effects of the color, strength, and duration of nighttime light on insects and their host plants. These studies suggest that lighting within urban areas is likely to have important but complex effects on biodiversity. Here, we assessed ALAN as a driver of insect community richness across Sacramento, CA, USA. Originally, the sites used for this study were chosen because focal trees (*Quercus lobata*) were located in areas that represented a gradient of vehicle pollution. We found in previous studies that these sites also have variable light regimes driven by street lights. This variation in light is not substantially correlated with vehicle pollution, which presents an opportunity to determine their relative effects on insects. Our results indicate that the relationship between ALAN and family-level insect richness depends on the level of vehicle pollution. At sites where vehicle pollution is low, there is a negative effect of ALAN on family-level insect richness. However, the negative effects of ALAN become less negative as vehicle pollution increases, likely because there is a negative effect of vehicle pollution on certain insects. ALAN decreases family-level insect richness by 1.5% per unit increase in lux. We found a small, but significant, positive interaction between ALAN and vehicle pollution, suggesting that the effects of ALAN hinge on how much vehicle pollution insect communities are exposed to. Our study highlights the importance of considering other anthropogenic factors, such as vehicle pollution, when studying the effects of ALAN in urban and rural environments.

Artificial Light at Night (ALAN) alters slug herbivory, with consequences for diurnal plant-pollinator interactions

Vincent Grognuz, *Agriculture and Biodiversity, Agroscope, Switzerland*

Among environmental change drivers, artificial light at night (ALAN) remains poorly understood despite its rapid expansion. ALAN affects biodiversity by altering species' behavior, physiology, fitness, mortality, and community composition, ultimately impacting ecosystem services. It disrupts plant-pollinator networks, even reducing diurnal pollination, though mechanisms remain unclear. Since the level of herbivory a plant experiences directly influences its attractiveness to pollinators, we hypothesized that ALAN could alter the activity of a dominant nocturnal herbivore, triggering cascading effects on diurnal plant-pollinator interactions. To address this question, we conducted a large-scale cage experiment in the Swiss agricultural landscape, where potted native wild plants from two species were exposed for several nights to a multifactorial treatment combining nocturnal herbivory (trios of starved *Arion lusitanicus* slugs) and ALAN (LED streetlamps mounted on 6-meter-high telescopic poles). Potted plants from the different herbivory and light treatments were then mixed and placed in a neutral habitat, where they were exposed to natural communities of diurnal pollinators for 90 minutes. The number of visits per pot was visually recorded, and ultimately, seed set per plant individual was assessed. Results showed that light treatment reduced both herbivore activity and plant attractiveness to pollinators, ultimately affecting plant reproductive output. Interestingly, when both treatments were applied, we observed an herbivore-mediated positive effect of ALAN on diurnal pollination, which counteracted its direct negative effect. This highlights the close link between antagonistic nocturnal interactions (herbivory) and diurnal mutualistic interactions (pollination), showing that an ALAN-mediated disruption of the former can impact the latter, potentially threatening ecosystem stability.

Light pollution radiance and nocturnal activity in two arthropod taxa

Rochelle Meah, *University of Bristol, UK*

Light pollution caused by artificial light at night alters the natural light regime by introducing light of unnatural spectral character, and at levels several times brighter than natural night skies, well beyond the normal diurnal period. This can disrupt the regulation of activity patterns with the natural light cycle, causing a loss of rhythmicity and mistiming of rhythms in critical behaviours such as migration, foraging, and reproduction. The magnitude of this effect is likely to vary with brightness and species depending on the absolute sensitivities of different visual systems. However, intensity thresholds and patterns of activity in relation to light pollution radiance is not well understood in arthropods. By observing individuals from sunset to sunrise using infrared cameras, I compared the effect of intensity using an LED streetlight at five different values between 0 and 10 lux on the nocturnal activity of a long-distance migratory moth *Helicoverpa armigera* and a ground spider *Drassodes* sp.. Exposure to LED streetlights at intensities of 4 lux or greater dramatically reduced the proportion of animals active at night and the distribution of activity over time but the severity of this effect varied between the two species. Identifying species-specific thresholds for nocturnal activity and establishing common thresholds between species is key for assessing the implications for individual fitness, biodiversity loss, and determining target-specific mitigation.

Session 4: The potential of insect-friendly light practices

Advancing sustainable LED solutions to mitigate the impacts of light pollution on arthropods

Nicola van Koppenhagen, *Swiss Federal Research Institute WSL, Switzerland*

Light pollution from artificial light at night (ALAN) is a significant environmental issue. While recent innovations in LED technology promise more sustainable lighting solutions, there is a lack of scientific evidence to support their effectiveness. We investigated the effects of various LED lighting properties on arthropods to find a step towards more sustainable outdoor lighting infrastructure to mitigate negative impacts of ALAN on nocturnal biodiversity.

Spatially customized road lights to reduce the attraction of nocturnal insects

Manuel Dietenberger, *Leibniz Institute of Freshwater Ecology and Inland Fisheries (IGB), Germany*

The attraction of insects to artificial light at night is a contributor to insect decline but there is not yet a clear answer for mitigation strategies over a broad range of taxa. Here, we tested the effect of spatially confining the light emission of LED luminaires. These luminaires are tailored to emit light only on the target area with reduced spill light. Custom optics and extra shielding render the light source nearly invisible beyond the lit area. We tested these luminaires in different scenarios including municipalities. We show that tailored and shielded luminaires significantly reduce the attraction effect on flying insects compared to different conventional luminaires with the same illuminance on the ground. Our study shows that spatial tailoring of the light emission can effectively reduce the attraction effect of road lighting on insects without compromising human safety standards.

Shedding Light on Solutions: Applying network ecology to test how street light mitigations impact Lepidoptera networks

Madeleine Fabusova, *Newcastle University, UK*

Modern landscapes are increasingly dominated by artificial light at night (ALAN). Concurrently, most invertebrates (>60 % (Hölker et al., 2010)), are nocturnal, and as such, particularly sensitive to light (Schroer & Hölker, 2017). ALAN is known for its impacts at individual, population and community levels, across a range of taxa (e.g. (Boyes et al., 2021; Gaston et al., 2021). Recent switch to energy-saving light-emitting-diodes (LEDs) has significantly altered nocturnal landscapes. However, evidence suggests that modifying the properties of LEDs allows for the negative impacts of ALAN to be mitigated (Evans, 2023). Mitigation strategies such as changing light colour (CCT), shielding, part-night lighting, dimming, are suggested (Gaston et al., 2012). However, we lack concrete evidence to support how these mitigations limit impacts on ecosystem services and ecological networks (Evans, 2023; Knop et al., 2017).Ecological networks (EN) provide a useful framework for investigating how street light mitigation measures affect interactions between species, and thus the function and stability of ecosystems (Montoya et al., 2006). They have been successfully used to elucidate the effects of various anthropogenic activities (e.g. (Macgregor et al., 2019; Pocock et al., 2012). Knop et al. 2017, in particular, highlights how examining community level responses to ALAN through ENs is a practical way of investigating direct and indirect effects of streetlighting (Knop et al., 2017). Whilst a variety of taxa have been the subject of ALAN studies, moths, key pollinators and prey food for many predators, are a great indicator species (Hahn & Brühl, 2016; MacGregor et al., 2015). Here, we aim to combine a variety of direct sampling methods and new technologies, to understand how street light mitigation measures could impact moth (Lepidoptera) ecological networks. The project aims to test the short-term responses of nocturnal moths to 4 light mitigation measures. We use mobile experimental lighting rigs which mimic conventional streetlights and are fitted with timers and dimmers. We can position the streetlights in light-naïve environments thus removing any effects of existing lighting sources (Boyes et al., 2021). We test 5 treatment levels: full-night lighting (positive control), part-night lighting (one light turned off at midnight [industry standard (Evans, 2023)]; one turned off 3-h after dusk [seasonally-adapted to match changes in activity related to sunset]), dimming (to minimally acceptable standards), and dark control. During 4-night blocks, we monitor moth activity every 3 hours, starting 1h before sunset, until sunrise, using flight-interception traps, beam-counts, and netting. Once caught, each moth is kept in a separate pot, cooled, identified to species level (where possible from visual identification) and its body is swabbed for pollen (to reconstruct flower-visitor networks, whilst releasing the moths unharmed). The pollen is kept frozen for metabarcoding analysis. On the last day of the sampling block, we use sweep nets to assess the short-term effects of mitigations on caterpillar activity. Sub-sample of caterpillars is kept for analysis to establish the levels of parasitism in our system to inform future work. By combining a variety of sampling methods and reconstructing ecological networks using molecular methods, such as metabarcoding, this project will allow us to assess the short-term effects of mitigation measures across Lepidoptera life cycle to thus understand how modifying ALAN impacts moth ecological networks.

A flashy view of light pollution: does a light's flicker rate affect its attraction to moths?

Elliott Cornelius, *Rothamsted Research, UK*

Light pollution is increasing globally, negatively impacting the nocturnal ecology of insects, and has been shown to contribute to population declines in moths. The widespread and rapid adoption of Light Emitting Diodes (LEDs) has exaggerated light pollution issues, due to shifting spectral outputs and reduced running costs enabling them to be run for greater periods of time. In addition to these factors, LEDs powered by an alternating current power supply have a high flicker index in comparison to their filament counterparts. Whilst efforts have been made to reduce issues created by the flicker of LED streetlights, these have been focused on human visual capabilities. Given that insects typically perceive flicker rates beyond that of humans, they may be impacted in different ways by the flicker of these artificial light sources. Here, I test the effect of flicker rate on the attraction of moths using light traps fitted with custom flickering LED bulbs. I also record the directional response of moths held by a magnetic bearing when exposed to flickering lights, providing a quantification of the attraction to flickering lights. Taken together, these results will provide insight into the disruption caused by flicker in artificial lights and will identify flicker rates that are less impactful for nocturnal insects. Alongside this, I will conduct laboratory experiments to characterise the ability of moths to resolve flicker and reveal how this varies across species and families. Through this, I add context to the field flight experiments by demonstrating the visual capabilities of moths found throughout Britain. Together, results from the field and laboratory experiments will indicate any neurophysiological basis for the behavioural response seen when moths are exposed to a flickering light. It will then be possible to predict how species which have not been studied in the wild will respond when they encounter artificial light and develop recommendations which could reduce the problems caused for moths by light pollution.

Effect of bulb type on moth trap catch: implications

Reuben O'Connell Booth, *University of Leeds, UK*

In the UK, hundreds of citizen scientists regularly run moth traps in their gardens using a wide variety of bulb types, varying in brightness and spectrum. We analyse 10 years of records collected by a semi-standardised citizen science project, the Garden Moth Scheme, to evaluate how different types of moth trap bulbs compare to one another. We find that MV bulbs (which emit a larger proportion of long wavelength radiation) collected a distinct fauna to Actinic bulbs (which emit primarily short-wave radiation), suggesting interspecific differences in responses to longer wavelength light. Species composition also varied between Actinic bulbs which differ in brightness, with brighter Actinic traps tending to collect a larger proportion of large-winged species. We provide robust support for the 'mobility hypothesis' whereby large-winged, strong flying moths are more strongly affected by artificial light (in moth traps or from other sources), suggesting selective pressure against large-winged species in landscapes affected by artificial light at night.

R.E. O'Connell Booth and W.E. Kunin, "Effect of bulb type on moth trap catch and composition in UK gardens" (pre-print, eco-evo-rxiv)

Severe and widespread impacts of LED lights on nocturnal moth activity

Emmanuelle Briolat, *University of Exeter, UK*

Artificial light is known to have a wide range of negative impacts on nocturnal insects, from harmful phototaxis to disruption of feeding and reproductive behaviours. Although comparatively poorly-explored, many of these detrimental outcomes are likely to be underpinned by changes in overall activity levels. To investigate how outdoor lighting might affect activity in nocturnal Lepidoptera, we monitored the nighttime behaviour of wild-caught moths of 23 species from three widespread macro-moth families, using time-lapse photography, under different types of light-emitting diode (LED) lights: broad-spectrum white LEDs, broad-and narrow-band amber LEDs, and combinations of narrow-band red, green and blue (RGB) LEDs. Under natural nighttime conditions, species reliably differed in their overall activity and activity patterns. Yet despite variation in baseline behaviour, we found strong, largely consistent effects of artificial lights on activity levels across species. Contrary to expectations of increased flight-to-light, white LEDs at an illuminance of 10 lx substantially depressed moth activity relative to natural nighttime illumination, by 85 % on average. Broad- and narrow-band amber LEDs, typically deemed more “insect-friendly”, had similar impacts at the same intensity. There were no differences between responses to broad-spectrum LEDs and RGB LEDs with equivalent colour-corrected temperatures (CCTs), and activity was still significantly reduced overall under white LEDs at a lower intensity of 1 lx, with some species affected by even skyglow levels of light. In addition, some species displayed different levels of activity when captured in light traps or hand-caught using nets, with potentially important implications for future work on moth responses to light. While evidence of inter-specific variation indicates that some moths may be less affected by ALAN, these findings generally suggest broad impacts of a range of LED technologies relevant to outdoor lighting on moth activity, likely to have severe knock-on effects for moth populations.

Light pollution alters the timing of cricket stridulation under almost natural conditions

Keren Levy, *Tel Aviv University, Israel*

The natural cycle of day and night is crucial for temporal organization, serving for internal timekeeping and adapting to changing environmental conditions in most organisms, including insects. Light pollution (Artificial light at night, ALAN), a widespread anthropogenic pollutant masks the natural day–night cycle. Consequently, ALAN negatively impacts animals, altering their behavioral patterns, daily activity rhythms, circadian gene expression and hormonal regulation. However, our understanding of the impacts of ALAN on insects is mostly based on laboratory studies and is far from complete. We studied the effect of different ALAN intensities on the nocturnal stridulation behaviour of the field cricket, *Gryllus bimaculatus*, in a semi-natural environment, under shaded light conditions and natural temperature. Crickets were reared under a 12h light:12h dark cycle (LD). Adult males were housed in outdoor terraria and subjected to shaded daylight of 1500 lx and one of seven different light treatments: LD (< 0.01 lx during the night), and ALAN (2, 5, 15, 100, 400, or constant 1500 lx during the night). The crickets' stridulation was continuously recorded for 14 consecutive days and nights, and their daily activity periods were compared among groups. While LD individuals displayed nocturnal stridulation with a rhythm of 24h, those exposed to ALAN presented a light-intensity-dependent increase in the proportion of crickets demonstrating free-run, and hence an ALAN-induced desynchronization of the population. Moreover, the variance and medians of the demonstrated activity period differed significantly between the LD and ALAN treatments >100 lux (Kruskal-Wallis test, $p<0.05$). Our findings revealed an ALAN-induced loss of timekeeping of the individual crickets, followed by an ALAN-intensity-dependent desynchronization of the population, even under semi-natural conditions, thus underscoring the alarming effect of ALAN on insects and the overall ecology.

Workshop: Engaging public and policy

Hidden in the dark: Human perspectives on nocturnal ecosystems and ALAN

Maisy Inston, *Keele University, UK*

When it comes to positive change and reduction of ALAN, humans are the only species who can act on this. As such, it is important to explore the key cultural conversations happening around ALAN, and where the non-human factors into people's minds, if at all. Are the impacts of ALAN on nocturnal ecosystems simply hidden in the dark? In this talk, I will provide an overview of the early stages of my PhD project that aims to explore these questions in more detail. Using interdisciplinary techniques, I will investigate how ALAN has cultural and socio-economic importance, with suggestions for how we mediate the conversation between people's concerns and the natural world.

Campaigning against light pollution through legislation, policy, and social change

David Smith, *BugLife, UK*

Buglife – The Invertebrate Conservation Trust, works to restore and sustain invertebrate populations by identifying, reducing, and removing threats through legislative action, policy development, and public engagement. This talk will demonstrate how evidence can lead to impact, sharing progress of our campaign against light pollution and noting future opportunities. Building on our 2011 report, A Review of the Impact of Artificial Light on Invertebrates, Buglife has led advocacy efforts to place light pollution on the policy agenda at national, European, and international levels. We have successfully driven legislative interventions, influenced policy changes, and collaborated with a range of stakeholders to ensure the impacts of light pollution on invertebrates are considered in decision-making processes. Alongside policy advocacy, we recognise the power of public engagement in driving social change. Our Nurture the Night Shift campaign raises awareness about the importance of darkness for nocturnal wildlife, encouraging individuals and communities to act. By developing cross-sector collaboration, we work with NGOs, campaigners, policymakers, and industry leaders to take forward solutions that balance societal needs with protecting the nocturnal environment. This talk will provide an update on Buglife's efforts to combat light pollution, highlighting key policy wins, challenges, and emerging opportunities. We will outline the next phase of our campaign, focusing on international policy developments, national legislative prospects, and strategies to integrate invertebrate conservation into broader environmental initiatives. By bridging science, policy, and public action, we aim to create a future where artificial light is managed responsibly to limit impact it's on biodiversity.

Posters

Illuminating the hidden effects of light pollution on moths

Jacqueline Degen, *University of Würzburg, Germany*

Artificial light at night and its impacts on ecosystem functioning

Federico Ferrari, *WSL Birmensdorf, Switzerland*

Artificial light at night (ALAN) is an increasing environmental stressor with widespread ecological consequences. Nocturnal pollinators play a crucial role in ecosystem functioning, yet their responses to ALAN, particularly to varying streetlight properties, remain poorly understood. In this research proposal, I outline series of experiments investigating how different spectral compositions and intensities of streetlights affect nocturnal pollinator behaviour and plant-pollinator interactions. By combining field and lab experiments, this project aims to provide insights into the broader implications of light pollution on biodiversity and ecosystem services. Understanding these effects is essential for developing mitigation strategies to balance human needs with environmental conservation.

Too much light, too little sight: the effects of light pollution on visual navigation.

James Foster, *University of Konstanz, Germany*

Nature and extent of ecological impacts of vehicle headlights

Jim Galloway, *University of Exeter, UK*

Artificial Light at Night (ALAN) advances reproductive phenology and disrupt circadian rhythm of wild flowers

Vincent Grognuz, *Agriculture and Biodiversity, Agroscope, Switzerland*

Plants have evolved under a natural regime of 24-h cycle of darkness and light, and, outside of the tropics, seasonal variation in day length. Light is used by plants as a source of information and many physiological responses rely on availability of external sources of light. Over the last decades, Artificial light at night (ALAN) rapidly increased all over the world and has caused an unprecedented disruption to these natural day-and-night cycles. Surprisingly, very little is known about the effects of ALAN on reproductive phenology of wild plants. To test to what extend ALAN could impact reproductive phenology, we set up a two-years field experiment in the Swiss lowlands, in which we experimentally illuminated ten independent wildflower strips and kept ten as dark controls. In order to test whether ALAN impacts germination time, we set up an experiment in situ where we filmed germination processes of sown native wild plants with and without ALAN treatment. In order to test whether ALAN impacts blooming phenology, we weekly counted number of flowering plants within established plots with and without ALAN treatment. In order to test whether ALAN impacts circadian activity of wild flowers, we recorded opening and closing of inflorescences of a day-pollinated and night pollinated plant species, with and without ALAN treatment. We found that ALAN advances germination time and blooming phenology of wild plants, and disrupts the circadian timing of a day-pollinated plant species. These results suggest that ALAN could impact the reproductive capacity of wild plants.

Effects of Artificial Light At Night (ALAN) on grassland arthropods: A campus case study in Freising Germany

Robin Heinen, *Terrestrial Ecology Research Group - TUM School of Life Sciences - Technical University of Munich, Germany*

Animating darkness with more-than-human methodologies

Maisy Inston, *Keele University, UK*

How do we engage humans in a conversation with other organisms, on the topic of artificial light at night (ALAN)? Using the concept of 'More-than-Human', this poster introduces a novel interdisciplinary method that will be put into practice in the Summer of 2026. By integrating epistemologies from both the natural and social sciences, we are better placed to address and improve the complex and multifaceted problem of ALAN and its impact on living things.

Illuminating plant-pollinator relationships: Effects of ALAN on *Datura wrightii* and its Sphingid pollinators

Oliver (Bryanna) Neria, *The University of Texas at El Paso, USA*

The attraction of insect pollinators depends upon floral traits (visual and olfactory cues) presented by plants at a particular season and time. The physiological processes underlying floral traits are mediated by plants' internal circadian rhythm, which is disrupted by the presence of artificial light at night (ALAN). However, few studies have focused on the effects of ALAN on plant physiology in a non-horticultural setting, and fewer have studied the responses of insect pollinators to these changes. This study aims to quantify alterations to floral traits in nocturnally flowering *Datura wrightii* (Solenaceae) and visitation rates of hawk moths (Sphingidae) under different types of streetlights commonly used throughout their native range. *D. wrightii* will be grown in experimental plots under four different light treatments, and a spectroradiometer will be used to measure the spectra of light from each source for later comparison. When the plants begin to bloom, the timing, number, size, reflectance, nectar content, and terpenoid content of flowers will be quantified. Hawk moth visitations will be recorded using short-focus trail cameras mounted in front of flowers. Interactions between plants and pollinating insects are vital to maintaining ecological functioning in many ecosystems. As the extent of ALAN continues to expand globally, it is crucial to further our understanding of its impacts on the intricate relationships between plants and pollinators, and the cascading ecological effects of these changes.

Sea slaters on the sea wall: The effects of light pollution on their abundance and microhabitat preference

Nao Szulc, *University of Exeter, UK*

Pulsed artificial light at night alters moth flight behaviour

Jolyon Troscianko, *University of Exeter, UK*

Vehicle headlights create pulsed artificial light at night (pALAN) that is unpredictable, intense and extends into previously dark areas. Nocturnal insects often have remarkable low-light vision, but their slow pupillary light responses may leave them vulnerable to pALAN, which has important ecological consequences. To test this, we exposed nocturnal moths—important pollinators and prey—to four pALAN treatments. These comprised 'cool' and 'warm' lights, either emitted from phosphor-coated light-emitting diodes (LEDs) or RGB (red-green-blue) LEDs, matched in colour (CCT) and intensity to human vision. We assessed the initial behavioural response, likely crucial to the survival of an organism, of 428 wild-caught moths comprising 64 species. We found that exposure to a cool phosphor-coated LED light pulse increased instances of erratic flight and flight-to-light that are likely detrimental as they increase the risks of impact with a vehicle, predation or excess energy expenditure. Our findings suggest that pALAN can cause a wide range of behavioural responses in nocturnal moths, but that the most harmful effects could be minimized by reversing the current shift towards high CCT (cool) phosphor-coated LED car headlights. Lower CCT or RGB alternatives are likely to provide benefits for road safety while reducing ecological harm.

Moth flight behaviour under different light spectra

Menno van Berkel, *University of Exeter, UK*