

Artificial Light at Night as an Overlooked Driver of Urban Insect Decline and Ecological Disruption

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Abstract - Artificial light at night (ALAN) has become the defining feature of the urban environment, transforming natural nocturnal landscapes by streetlights, commercial lighting, illuminated buildings and other artificial sources. While artificial lighting is essential for human activity (both safety and economic), it is not well-integrated in urban biodiversity management. This paper critically considers the role of artificial illumination as an underestimated factor in the decline of urban insects and its ecological impact through a review of existing literature and presents evidence on insect attraction and disorientation, circadian disturbances, impaired reproduction, feeding behaviour, and interactions between different species. This paper particularly focuses on ecological implications of these impacts for nocturnal pollination, trophic relationships, and urban ecosystems. There are existing studies that show that artificial lighting may affect nocturnal pollinator behaviour, community composition, and the abundance of insects beyond the immediate vicinity of light sources. Yet the scope and effects of artificial lighting are different in terms of insect habitats and species in terms of light intensity, spectral composition, habitat characteristics, and exposure duration. Artificial light is no longer a nuisance and should not be treated as just a nuisance to humans but rather as a potentially critical environmental threat that is also part and parcel of habitat loss and chemical pollution in relation to climate change. This report also highlights the need for biodiversity-sensitive lighting policies based on darkness if ecologically relevant, reduce unnecessary light, and incorporate nocturnal biodiversity in urban planning. By linking individual behaviour to more macro-economic and environmental impact, artificial light at night is a key but not well-understood aspect of urban environmental change.

Keywords- artificial light at night; urban insect decline; light pollution; nocturnal biodiversity; pollination; ecological disruption; urban sustainability

I. INTRODUCTION

Urbanization is now regarded as one of the most important drivers of environmental change, transforming natural habitats through the development of infrastructure, land-use change, habitat fragmentation and increased resource consumption. In addition to these visible changes, artificial lighting has fundamentally altered the natural light-dark cycles that govern ecological processes. Streetlights, illuminated buildings, commercial advertisements, transport infrastructure and residential lighting now extend human activity into the night and there is a new habitat where organisms' behaviour and survival evolved under natural daylight and darkness periods. While artificial lighting is well known as a driver of urban development, public safety and economic activity, the ecological impact of artificial lighting has received little, if any, attention compared with other forms of environmental pollution.

Insects are particularly important for this concern as they have a wide range of ecological functions (pollination,

decomposition, nutrient cycling, herbivory and energy transfer through food webs). They have an ecological significance in both terrestrial and freshwater environments where they are a key part of ecosystem life and support a wide range of other organisms. However, insect populations are under multiple anthropogenic pressures such as habitat destruction, pesticide distribution, climate change, invasive species and urban environmental change and while these pressures have been recognized and studied in the scientific and public community, artificial light pollution is still not a focus of conservation of insects. Owens and Lewis (2018) have commented that artificial light can have a negative impact on nocturnal insects, for example, attraction or disorientation, altered behavior and visual communication. These responses imply that the ecological effects of urban lighting could be more than just the presence of insects around illuminated structures.

The relationship between artificial lighting and the decline of insects is more complex than the common picture of insects gathered near lamps. Artificial light can influence

how insects are distributed, how they move, how they orient themselves in space and how they do what they need to do to survive. Nocturnal and crepuscular insects depend on the environment, and the environment's light to locate food, find a habitat for themselves, avoid predators and find and mate with others. Artificial lighting could interfere with this process by creating patches of light, in otherwise dark areas, or by altering the environmental cues from nature's day-night cycle. The phenomenon of an increased number of insects around a light source does not necessarily mean that the population is more abundant than in the surrounding area, it just means that the individuals are spread out. Therefore, the ecological impact of artificial light on insects is not just to be evaluated from the observation of insects near a light source.

Studies on behaviour changes in insects show that these behavioural disturbances are not only affecting the populations but also that they affect the populations of insects themselves as well in the wild. Boyes et al. (2021) have shown that street lighting can negatively affect the populations of insects in a neighbourhood, as in the case of moth caterpillars at low abundance and changes in the development and feeding behaviour of larvae in the early stages of development. Their findings are of particular interest because they show that artificial light can affect not only the adults attracted to light but also the larvae. Effects of light on the recruitment of insects in the field of insects and the local communities in the long term, habitat suitability and the survival of the population can be the subject of this study. But the relationship between artificial lighting and insect decline in all species is not uniform. Different species have different sensory abilities, behaviour patterns and ecological requirements, so how they react is dependent on the lighting intensity, spectral composition, exposure time and habitat.

Besides the impact of lighting on insects, artificial light at night may also disrupt ecological relationships that depend on insect activity. Nocturnal insects are involved in pollination networks and they are part of the diets of many predators and the relationship between plants, herbivores and decomposers. If illumination changes their behavior or distribution, the effects on organisms which don't have the same lighting may be more serious for them. Knop et al. (2017) showed that artificial light could reduce nocturnal pollinator visits and plant reproductive efficiency in experimental plant-pollinator communities. This case shows how an environmental disturbance in insect behaviour can affect the behaviour of other organisms more than the insects that are exposed to it. In the same way, the lack or availability of insects may affect the feeders of insects in feeders such as birds, bats, spiders and other predators. The magnitude of these indirect effects varies among different environments but they are of the order of

magnitude and help to justify artificial lighting in the context of ecosystem disruption.

Urban environments provide a particularly relevant context to understand these relationships since artificial light is often ubiquitous and persistent and associated with fragmented habitats. Roads, residential developments, commercial districts, industrial areas, and recreational areas can also bring artificial light to parks, gardens, wetlands and other green spaces that may otherwise have been home for insects. Illumination may also be on the edges of the built infrastructure, affecting ecological processes in adjacent areas. And artificial lighting is not independent of other urban pressures. Insects may experience less habitat connectivity, altered vegetation, chemical contamination, warmer temperatures and resource availability. Artificial light might then contribute to cumulative ecological stress, but the extent and nature of its interaction with other pressures should be closely investigated instead of assumed. Another critical consideration is the technological and spatial aspects of artificial lighting. Lighting systems are quite different in range of intensity, spectral composition, direction and duration and these differences can affect their ecological effects. LEDs are widely used and energy efficiency is improved and more flexible lighting is possible. Still, energy efficiency is not sufficient to ensure ecological compatibility. Electrical lighting installations have biological effects that depend on the environment, wavelength of light emitted and how long we can continue lighting at times without an energy need for human activity. Thus, a comprehensive approach to urban lighting must take into account both human benefit and environmental impact of artificial lighting.

Despite the awareness of light pollution as an ecological problem, there are still questions about its impact on insect decline, how individual behaviour of a species connects to population-level outcomes, and its impact on the functioning of the urban ecosystem. There are already a variety of studies on the negative impact of light pollution on a variety of species and ecological settings, but these findings need to be compared with the study design, exposure, geographical coverage and taxonomic representation of light pollution and the literature as a whole to separate the findings of well-known from the little-studied ecological effects. Such a synthesis will serve to make sense of how artificial illumination can be used in biodiversity conservation and urban environmental management. Based on this background, this paper reviews artificial light at night as an overlooked cause of urban insect decline and ecological damage in a critical review of the scientific literature. It investigates how artificial illumination affects insect behaviour, development, and ecological interactions; evaluates the implications for pollination, food webs, and urban biodiversity; and considers the potential impact of light pollution on other

factors. It also details the limitations of current knowledge and research in biodiversity-based lighting policy and future research areas. Rather than consider light as a single, or universal, cause of urban insects' decline, this review views light pollution as a potentially significant and manageable component of broader urban environmental change. Connecting the individual-level biological responses to population and ecosystem processes to better connect nocturnal biodiversity to sustainable urban planning aims to make the scientific basis of such a study more robust.

II. REVIEW APPROACH AND CONCEPTUAL FRAMEWORK

The study uses narrative literature review as a methodology to explore artificial light at night (ALAN) as a possible cause of urban insect decline and ecological damage. The literature-based approach is appropriate because we aim to synthesize existing scientific knowledge, compare findings from different ecological contexts and find connections between them and explore general trends without taking into account new data or conducting new statistical analyses. We use literature reviews from experimental works, field studies and observational studies to explore light pollution, insect behaviour, nocturnal biodiversity, pollination and ecosystem functioning. Research that connects artificial illumination with real biological responses and ecological consequences is more important than light pollution just for humans.

We define the literature through three interlinked dimensions: direct biological effects, population and community-level responses, and ecosystem consequences. Direct biological results include changes in the orientation of insects, movement, feeding, circadian rhythms, and reproduction. Population and community-level consequences include abundance, distribution, development, species composition, and whether or not a particular environment is right for them. Ecosystem-level effects include changes in plant-pollinator interactions, predator-prey relationships, food web structure and ecological processes of insects. These dimensions provide a generalised framework for investigating how a disturbance in an environment produced by an individual organism may be spread across biological scales. They also help to distinguish between evidence of immediate behavioural responses from evidence of longer-term population changes or indirect ecological effects.

We consider the nature and effects of artificial light in a review. The light intensity, spectral composition, direction, duration, and spatial arrangement of illuminated areas are among the characteristics to be considered. As insects are sensory, they have different activities to do and they have

different habitat requirements for light and behaviour to respond to light. Therefore, the experimental findings cannot generalize to all insect species and landscapes. For example, the effects of light on the environment can be different for urban areas in which the illumination is interacting with vegetation, temperature, habitat fragmentation and other environmental conditions in complex urban areas. So, the authors take the literature in a different light and consider the ecological and environmental context and limitations. The concept of artificial light at night is that artificial light at night is an environmental pressure that may affect the activity of the insects in a direct and indirect manner. Direct pathways are disorientation, changed behaviour, disrupted biological timing and effects on feeding and reproduction. Indirect pathways are when insects behave or are more or less abundant and so in the presence of plants, predators and other animals. For example, less pollinators at night may have an effect on plant reproduction and so does how much insects move around and their location in the ecosystem and, in turn, the predators might feed on them. These are not entirely independent pathways, so changes in behaviour affect survival and reproduction and species' interactions may affect the ecosystem on which insects are dependent. But the existence of a plausible pathway does not mean that its effects will be true for every habitat or that it will lead to a specific decline in each species. One important difference in our review is that artificial light is a contributing factor to insect decline but artificial light is not the sole driver for beetle population decline. Insect abundance and diversity are driven by a variety of environmental factors including habitat destruction, pesticide use, climate change, invasive species and resource availability. Artificial illumination should therefore be considered within the wider context of urban ecological change. Where there are direct effects reported by published studies, they should be differentiated from more general implications that are not well understood yet and need more investigation.

The paper is not based on original fieldwork, surveys, lab experiments, primary data collection, or statistical analysis. It does not claim to be a systematic review or meta-analysis. It is instead a critical narrative synthesis that draws on existing evidence, considers the relevance of published evidence and identifies gaps in current knowledge. It is important to connect research on insect response to artificial light with urban biodiversity conservation and ecosystem functioning questions. Based on this framework, the review aims to provide a clearer conceptual understanding of artificial light at night as a potentially significant and manageable element of urban environmental pressure at least in the context of urban life. By connecting the individual biological responses to a population's behaviour and ecosystem processes, it is a base for assessing the ecological value of artificial illumination and for

considering how this might be applied in practice to biodiversity-sensitive city lighting.

III. MECHANISMS LINKING ARTIFICIAL LIGHT TO INSECT DECLINE

Artificial light at night affects insects in many different biological and ecological processes that are interrelated. These effects go beyond the attraction of insects to illuminated structures and may influence their orientation, movement, feeding, reproduction, development, and survival. The ecological consequences depend on the interaction of artificial light and the sensory and behavioural characteristics of various insect species. Artificial light should thus be treated as an environmental pressure that can affect individual behaviour and the ecological conditions that drive a population's persistence (Owens & Lewis, 2018).

One of the most well-known responses to artificial lighting is the attraction of flying insects to light sources. Many insects rely on natural light and celestial signals to guide them, and artificial light can interfere with these mechanisms. In some situations, insects get stuck in repeated flight patterns around lamps and expend too much energy or locate themselves in places not suitable for feeding and reproduction, where predators and other dangers can be more imminent. But the response is not uniform among all species, and attraction to artificial light is not the same for all insects and should not be thought of as a universal behaviour. Some species are attracted to a particular lighting environment, while others may avoid the light or show only weak responses. Therefore, many insects around a lamp might indicate that there is an aggregation rather than a true growth in population.

The effects of artificial illumination may also affect the distribution of insect communities. When insects move towards illuminated sites, they may also spread across the surrounding landscape and may be less available in darker areas. Light-sensitive species may avoid illuminated sites and, therefore, cannot access otherwise suitable feeding, breeding, or resting sites. These contrasting responses can produce different forms of insect communities and also shift the balance of species in the ecosystem for different ecological needs. Lockett et al. (2021) investigated the different responses of airborne and ground-dwelling invertebrate communities to urban street lights and the importance of distinguishing between ecological groups when assessing the effects of light pollution. These results indicate that the consequences of light pollution cannot be adequately captured through a single measure of total insect abundance.

Another mechanism involves the disruption of biological rhythms and the environmental cues associated with natural darkness. Insects depend on daily and seasonal changes in light to regulate activities such as movement, feeding, mating, and other behaviours. Artificial light can modify these cues, potentially changing the timing of essential behaviours or creating mismatches between insect activity and environmental conditions. For example, changes in activity periods may reduce opportunities for insects to encounter food resources or reproductive partners. The extent of these effects depends on the species concerned, the intensity and duration of illumination, and the relationship between natural light cycles and the insect's biological rhythms. Although not every alteration in activity leads to a decline in population, persistent disruption may affect the ecological performance of sensitive species.

Artificial lighting can also interfere with reproductive activity, especially in species that rely on visual signals for communication. Fireflies are a prime example because their courtship systems rely on bioluminescent signals that facilitate mate recognition. Additional illumination can reduce the visibility or effectiveness of these signals, potentially interfering with successful mating. Other insects may experience reproductive disruption indirectly when artificial lighting changes movement patterns, separates individuals from suitable habitats, or alters the timing of reproductive activity. These mechanisms are ecologically significant because population persistence depends not only on the survival of individual insects but also on their ability to reproduce successfully and maintain subsequent generations. Nevertheless, the strength of the evidence varies across taxa, and the reproductive consequences observed in particular species should not be generalized without further support (Owens & Lewis, 2018).

The effects of artificial light on feeding behaviour and development are also important. Insects may experience changes in foraging efficiency, feeding duration, or access to food when illumination modifies their activity patterns. In herbivorous species, such changes may affect interactions with host plants, while in predatory insects, they may alter opportunities to locate and capture prey. Artificial light can also influence the development of immature life stages, which may be less visible than adult insects but are essential for population recruitment. Boyes et al. (2021) reported lower moth caterpillar abundance under street lighting and identified changes in larval development and feeding behaviour. These findings indicate that the ecological consequences of artificial illumination may extend beyond immediate behavioural attraction and affect processes relevant to insect population maintenance. However, the precise pathways linking these responses to long-term population trends remain dependent on species characteristics and environmental conditions.

The characteristics of the light source play a critical role in determining the severity and direction of these effects. Light intensity influences the extent of illumination, while spectral composition determines the wavelengths to which organisms are exposed. Different insect species possess different visual sensitivities, meaning that lighting systems with similar human-perceived brightness may produce different biological responses. The direction of light, its duration, and the degree to which it spreads into surrounding vegetation or other habitats can further influence ecological exposure. Light-emitting diodes offer opportunities to reduce energy consumption and control illumination more precisely, but their ecological suitability cannot be assessed through energy efficiency alone. Lighting systems must also be evaluated in terms of their effects on wildlife and the surrounding environment.

Taken together, these mechanisms suggest that artificial light at night can affect insects through several pathways that may operate simultaneously. Attraction and disorientation can modify movement and exposure to hazards; disruption of biological rhythms can alter the timing of essential activities; interference with communication can affect reproduction; and changes in feeding and development may influence survival and population recruitment. These effects are not uniform, and their ecological significance depends on the characteristics of individual species and their environments. Nevertheless, the convergence of evidence across behavioural, developmental, and ecological dimensions provides a strong basis for considering artificial illumination as a potentially important contributor to urban insect decline. Understanding these mechanisms is essential for evaluating the broader consequences of light pollution for pollination, food-web relationships, and urban ecosystem functioning.

IV. ECOLOGICAL CONSEQUENCES AND URBAN ECOSYSTEM DISRUPTION

At night artificial light is not only of ecological importance to individual insects, but also to the ecosystem at large. Since insects are part of interconnected ecological networks, changes in their behaviour, abundance, distribution and reproduction may affect the behaviour, abundance and survival of other organisms and the processes that make up urban life. Artificial light can have effects on a number of different aspects of ecology such as changes in their behaviour, pollination of food webs, food web relationships and community structure. Although these impacts are different in nature at different ecological levels the effects of artificial light are not uniform over the environment, and it is argued that nocturnal light pollution should be taken into account as a generalised analysis of urban biodiversity and ecosystem functioning.

One of the most important consequences will concern plant-pollinator interaction. Nocturnal insects pollinate flowering plants and their work is important especially for plants with a high level of pollination during darkness. Artificial light might disrupt the timing and frequency of the insect visit in plants producing pollen and thus the plant reproduction process. Knop et al. (2017) found that artificial light at night in an experimental plant-pollinator community disrupted nocturnal pollination. They found that illuminated plots had fewer nocturnal pollinator visits and less fruit production in the focal plant, and clearly indicated that artificial lighting has an impact on an ecological process that goes beyond just the insects that are directly exposed to it. These findings are relevant to the ecology of urban green spaces, in gardens and other habitats, where artificial illumination may overlap with flowering vegetation.

The consequences of plant reproduction are not limited to nocturnal behaviour. Plant and pollinator networks are connected, and disturbances to one group of pollinators can affect the overall structure of ecological relationships. Giavi et al. (2021) investigated the effects of artificial light at night on plant and pollinator interactions in the day in which plants and pollinators might take place and the situation is very different. Pollinator behaviour change, plant-pollinator association, or floral resources availability may alter the interaction in these networks. However, the extent to which nocturnal pollination losses translate in a long-term way into plant populations is dependent on plant reliance on particular pollinators, availability of other pollination pathways, and local environmental conditions. Artificial illumination should therefore be seen as an element of disruption to pollination networks but not as a factor that will result in a reduction of reproduction of all plant species. Artificial light also may influence urban food webs because it changes the abundance, distribution, and timing of insect activity. Insects provide food for bats, birds, spiders, amphibians and predatory insects. When artificial light attracts or concentrates insects around lamps, certain predators take advantage of these temporary concentrations. But in general this kind of aggregation does not mean much additional food. It may also redistribute insects away from the surrounding habitats and change the timing and accessibility of prey. At the same time, light-sensitive insect species may avoid illuminated areas and this may reduce the prey available to predators that forage in those areas. The ecological outcome depends on the responses of insects and their predators, and the arrangement of illuminated and unilluminated habitats.

The consequences of such changes may be broader for ecological interaction. A decrease in a particular group of insects could put predators on the defensive and the relative abundance of herbivorous and predatory insects in the ecosystem could change the relationship between plants and

consumers. Insects are also involved in decomposition and nutrient cycling, and so any fluctuations in their communities might affect the ecosystem beyond predation and pollination. But these effects should be taken very carefully. A change in the behaviour or abundance of an insect group when artificial illumination is applied does not mean an ecosystem that is functioning poorly. Demonstrating the wider ecosystem impact would require evidence connecting changes in insect populations to changes in ecological processes or interactions.

Another important aspect of urban insects is the organisation and ecology of the communities. Some species are attracted to light, others are indifferent to light and all are dependent on dark habitats. Artificial lighting may be favourable for some but not others and the community composition may change even if there is no overall decline in the number of insects. For example, a species that is strongly attracted to a particular light source may be more concentrated in the illuminated area but a species that is also not attracted to the light source may be excluded from the environment which is not suitable for them. The effects of street lighting on airborne and ground-dwelling invertebrate communities reported by Lockett et al. (2021) underscore the importance of considering different ecological groups rather than assuming that all invertebrates respond the same way to light.

Artificial lighting may also be contributing to the fragmentation of city landscapes. Roadways, buildings and other infrastructure already divide habitats into smaller or less connected areas. Artificial lighting may add to this fragmentation by altering the suitability of illuminated spaces for light-sensitive organisms. Even where vegetation remains physically intact, whether insects use that habitat for movement, feeding, or reproduction when the light is nocturnal, will not be well enough for all. This may be more true for urban parks, roadside habitat, gardens, wetlands and vegetated corridors that provide habitat in heavily developed landscapes. Therefore keeping dark areas and linking them may be a complementary approach to habitat conservation.

Artificial illumination in the context of other environmental stressors also makes it ecological. Urban insects can also experience habitat loss and pesticide exposure, vegetation changes, and temperature changes, and other factors of urban expansion. All these factors can affect the resources available to insects and their tolerance to disturbance. Artificial lighting may have increased ecological stress in some situations, but the combined effects need to be taken into account as additive but not additive. So it is a matter of species-specific response, habitat and exposure to the environment, and interactions of these factors. A critical

ecological assessment should then distinguish the existence of known effects of artificial illumination from potential interactions that are currently poorly understood. The bottom line is that ecological implications of artificial light at night can't be evaluated in isolation by studying illuminated insects. In this respect, changing insect behaviour and distribution may affect pollination, prey availability, community composition, and habitat use, and thus urban ecosystems at the same time can be affected to a wide extent. The variety of responses shows the importance of context and long-term ecological effects. When integrated into urban environmental assessment, we would better understand how artificial illumination impacts biodiversity and it would be more in line with science to protect ecological processes in increasingly illuminated landscapes.

V. RESEARCH GAPS AND FUTURE DIRECTIONS

Although artificial light at night is being recognized as an ecological pressure, there are still gaps in terms of how it is affecting urban insect populations. The development of artificial light at night has already found the mechanisms of how it affects the behaviour and ecology of the insects but the extent and duration of the effect of artificial light on them is still not well understood. It is important to address them in order to distinguish short-term behaviour patterns from long-term changes and develop conservation strategies based on evidence and research.

One of the main limitations of the literature is the relatively poor representation of insect taxa and geographical regions. Most research is focused on moths, flying insects or nocturnal pollinators, while many other ecologically important groups are underrepresented. In addition, the results of individual experimental sites or urban environments may not be representative of the whole range of ecological conditions observed in various climatic conditions, vegetation types and urban development patterns. We suggest that future research must focus on more general insect groups and habitats, such as tropical and subtropical urban landscapes where different environmental conditions and insect communities are very different from temperate ones. A second research challenge is to distinguish between immediate behavioural disturbance and long-term population decline. Attraction to artificial light, change of direction and avoidance of the illuminated areas are all common but this alone is not the only indication that population size declines. Long-term studies are required to better understand how long-term exposure affects survival, reproductive success, development and population recruitment. It would help to better understand the extent to which artificial light in insects is unrelated to

decreases in population size and when it is becoming demographically significant.

One other major gap concerns lighting characteristics. Artificial light can be bright or dark, with different spectral composition and direction, operating duration and distribution. These characteristics can affect insect responses in different ways, and comparisons are hard between different studies when exposure and measurement techniques are not well defined. More standardized descriptions of ecological light exposure and the difference of individual lighting characteristics can be made in future studies. This should be especially important in the light-sensitive species in particular, given the ecological implications of modern LED installations.

The interaction between artificial light and other environmental stresses can be examined in more detail. Urban insects are frequently subject to habitat fragmentation, pesticide exposure, vegetation change, high temperatures, and food availability problems. These pressures may affect the extent to which insects respond to artificial lighting, but the effects of each of them are not expected to be determined from the combined effects of the different pressures. Future research should explore these effects to see if artificial light is more damaging to other forms of ecology, has different impacts in certain environments or has relatively little impact in other habitats. The research has to also look at ecosystem effects beyond just individual organisms. If artificial illumination changes insect activity or abundance, it does not imply that pollination services, food web stability, decomposition, or plant reproduction changes. Studies that link insect behaviour to measurable ecological processes are extremely valuable. Studies on plant-pollinator networks, insectivorous predators and habitat connectivity could also help in understanding when local changes in insect behaviour translate into larger ecological consequences. It would also help to answer such questions as whether some species or ecological functions can compensate for disturbances to other parts of the community.

Finally, how effective are the mitigation measures in practice? Shielding, dimming, reducing operating hours, adaptive lighting control and protecting dark corridors are all possible means to minimize ecological exposure. However, it is important to note that they can vary in habitat type, lighting configuration and biological needs for the species in question. In comparative studies, it is important to see which interventions have the best environmental benefits while providing the necessary human visibility and safety. The findings provided could guide municipal lighting policy, urban development policy and biodiversity conservation programs.

These research priorities show artificial light at night to be an important area for interdisciplinary research in ecology, entomology, urban planning, environmental management and lighting engineering. Although there is significant uncertainty, we have sufficient data to make the case that artificial illumination is not ecologically neutral. A precautionary approach that minimizes unnecessary lighting, protects dark habitats and encourages scientific inquiry would allow cities to manage environmental pressure and make sure that there is more evidence available for future conservation decisions.

VI. CONCLUSION

Artificial light at night is an important yet relatively under-discussed aspect of urban ecology and its impact on the population, ecological functioning and ecosystem. AI light is relevant to insects in several different ways and we have discussed the effects and how it affects them - disorientation in the body, movement changes, biological rhythms, reproduction and feeding and development. These effects show that the ecological implications of artificial lighting are much more than just the appearance of insects around lamps but also the biological processes of survival and reproduction that are required for the formation of a population. But the magnitude of the effect is more than simple visual and the species and environmental conditions, and artificial lighting should be seen as a pressure rather than as the cause of insect decline. The wider ecological implications are particularly important as insects are involved in pollination, decomposition, nutrient cycling and food-web functioning. The study of lower nocturnal pollinator activity when artificial lighting is used shows how the effects of artificial lighting on insects impact plant reproduction and ecology (Knop et al., 2017). The effects of artificial lighting on the population of insects are also shown to be harmful (Boyes et al., 2021). However, how these effects will continue to influence ecosystem health, community structure and population persistence will need to be examined across a wide range of species and regions in the future. One of the main conclusions of this review is that artificial light at night should be integrated into urban biodiversity conservation and environmental planning more holistically. Healthy urban development is often based on habitat protection, green infrastructure and pollution reduction, but this is sometimes not enough if the nature of the environment at night remains very different. Reducing unnecessary illumination, shielding light sources, adjusting brightness and operating schedules, and protecting darker habitat connections are ways to reduce avoidable ecological damage. These interventions must be tailored with local conditions in mind along with legitimate public safety, accessibility and energy use concerns. Future research needs to focus on long-term population responses, the differences

between lighting technologies, interactions with other urban stressors and measurable impacts on ecosystem processes. Stronger interactions between findings and ecological outcomes would help explain when artificial illumination has long-term impacts on biodiversity. At the same time, uncertainty about the extent of particular effects should not prevent the implementation of appropriate measures to minimize unnecessary exposure. The ecological use of darkness should be more widely recognized in urban planning and management. Artificial light is an economic and environmental hazard and can be addressed by informed planning and responsible lighting. Recognizing artificial light at night as one of the reasons for insect decline would also broaden the scope of urban conservation to ecology and urban development: ecology and the environment of a city to support its inhabitants. Such considerations are necessary to sustain biodiversity in insects, to enable life of whole ecosystems to persist and to promote sustainability.

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