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Impact of Light Pollution on Moth Navigation

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Abstract

Moths are vital nocturnal pollinators whose navigational systems are finely tuned to natural light cues such as the moon and stars. However, the rapid proliferation of artificial light sources due to urbanization—commonly referred to as light pollution—has severely disrupted these natural behaviors. This research paper explores the detrimental impact of artificial light at night (ALAN) on moth navigation through both field experiments and a comprehensive literature review. Our findings reveal that artificial lighting, particularly in the blue and white light spectrum, causes significant disorientation in moth flight paths, reduces their ability to locate mates and forage for nectar, and ultimately hampers pollination processes. These disruptions not only threaten moth populations but also compromise the ecological networks dependent on their pollination services, including nocturnal flowering plants and species that rely on them for food. The study highlights species-specific vulnerabilities, the ecological consequences of decreased pollination, and proposes mitigation strategies such as the use of red-spectrum lighting and reduced night-time illumination. Overall, the paper emphasizes the urgent need for environmentally conscious lighting practices to preserve nocturnal biodiversity and maintain ecological balance.

Keywords: Light pollution, Moths, Navigation, Pollination, Biodiversity

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Introduction

Moths are an essential part of nocturnal ecosystems, playing a critical role in pollination, nutrient cycling, and serving as a primary food source for a variety of predators including birds, bats, amphibians, and reptiles. Unlike diurnal insects, moths have evolved to navigate in low-light conditions using natural celestial cues such as the moon and stars. This form of navigation, known as transverse orientation, allows moths to maintain a consistent flight trajectory by keeping a fixed angle to a distant light source. This evolutionary trait was well-suited to environments without artificial light, enabling moths to perform tasks like foraging, mating, and migrating with precision and efficiency. However, this sophisticated navigational ability is highly sensitive to changes in ambient lighting, particularly those caused by artificial sources. The phenomenon of light pollution—defined as the excessive, misdirected, or obtrusive artificial light that brightens the night environment—has emerged as a significant ecological disruptor. Over the past few decades, global levels of artificial light at night (ALAN) have steadily increased due to expanding urbanization, industrial development, and the ubiquitous installation of lighting infrastructure such as streetlamps, billboards, and commercial displays. According to Kyba *et al.* (2017), satellite observations have revealed a consistent annual increase of over 2% in artificially lit surface areas. This rise in artificial illumination is not confined to urban centers but extends to rural and natural habitats, altering the nocturnal environment that many species, including moths, rely on for survival. For moths, exposure to artificial light fundamentally interferes with their ability to navigate. The most commonly observed consequence is the "flight-to-light" behavior, in which moths spiral toward artificial light sources, often leading to exhaustion, injury, or death. Instead of maintaining a linear path toward a foraging or mating target, moths become trapped in orbits around bright lights, sometimes remaining in the vicinity until they succumb to fatigue or are eaten by predators. This behavioral loop not only reduces their chances of successful reproduction but also causes significant energetic costs, thereby affecting their overall fitness (van Langevelde *et al.*, 2011). Furthermore, artificial lights can override natural orientation mechanisms, effectively masking celestial cues and leading to widespread navigational failures. Light pollution can also interfere with reproductive behaviors in moths, especially those that rely on pheromone signaling to locate mates. Some species emit pheromones in the early evening hours and depend on uninterrupted darkness to maximize signal efficiency. Artificial light may suppress these chemical communications or disrupt the sensory mechanisms that detect them. As shown by Firebaugh and Haynes (2016), exposure to ALAN can reduce mate-finding success in several moth species, leading to a direct decrease in reproductive output. Additionally, altered circadian rhythms due to unnatural light cycles can affect mating times, larval development, and emergence patterns, further compounding the reproductive stress caused by light exposure. Beyond the immediate impacts on individual moths, light pollution has broader ecological ramifications. Moths are vital pollinators for many nocturnal plant species, including orchids, cacti, and night-blooming herbs. These plants rely on moths for fertilization and the production of viable seeds. Recent studies, including those by Macgregor *et al.* (2017), have shown that artificial lighting can significantly reduce flower visitation rates by moths, leading to a drop in pollination efficiency. As pollination is a key ecosystem service, the interruption of these interactions can affect plant reproduction, alter plant community composition, and lead to cascading effects throughout the food web. The wavelength of artificial light plays a crucial role in determining its ecological impact. White and blue-rich lights, such as those emitted by common LED streetlights, are particularly disruptive to nocturnal insects. These short-wavelength lights closely mimic the spectral qualities of moonlight, which confuses moths' natural navigation systems. In contrast, lights in the red or amber spectrum appear to be less attractive and less disruptive to moth activity (Longcore & Rich, 2004; Owens *et al.*, 2020). Nevertheless, the adoption of blue-white LEDs due to their energy efficiency and low cost has become widespread, potentially exacerbating the impact on moth populations unless ecological considerations are incorporated into lighting design. Importantly, the response to artificial light is not uniform across all moth species. While some generalist species may adapt to or tolerate light-polluted environments, specialist species, particularly those with narrow ecological niches or specific habitat requirements, often show higher sensitivity. For instance, studies have indicated that larger-bodied or long-distance flying moths are more likely to become disoriented by artificial light than smaller, locally roaming species. This species-specific vulnerability can lead to selective declines in certain moth populations, resulting in reduced genetic diversity and altered ecosystem dynamics (Desouhant *et al*., 2023). The encroachment of artificial lighting into natural habitats is especially concerning. Urban sprawl, road development, and rural electrification projects are increasingly bringing light into previously dark environments such as forests, wetlands, grasslands, and agricultural landscapes. These transitions expose native nocturnal species to novel light regimes, often without any ecological buffer. As moths are already under stress from habitat loss, pesticide exposure, and climate change, the additive effects of light pollution could tip the balance, accelerating population declines and local extinctions (Grubisic & van Grunsven, 2024). These losses are not only a concern for conservationists but also for industries and communities that rely on pollination services for food and ecosystem health. Despite increasing awareness of the problem, light pollution is often overlooked in environmental policy and urban planning. While other forms of pollution—such as air, water, and noise—are subject to regulation, artificial light continues to expand largely unchecked. This regulatory gap reflects both a lack of public awareness and insufficient scientific data on long-term ecological impacts. However, growing evidence from recent studies underscores the urgency of addressing light pollution with the same seriousness as other environmental threats. The implementation of "dark sky" policies, including the use of downward-shielded fixtures, time-controlled lighting, and the selection of insect-friendly wavelengths, represents a promising step forward. Mitigating the effects of light pollution requires an interdisciplinary approach. Ecologists, urban planners, engineers, and policymakers must collaborate to develop lighting systems that meet human needs while minimizing ecological damage. In addition to infrastructure changes, public education campaigns can raise awareness of the environmental costs of excessive nighttime lighting. Programs that encourage citizen science—such as moth monitoring and light audits—can also contribute valuable data and foster community engagement in conservation efforts. Understanding the effects of light pollution on moth navigation is not just about conserving a single group of insects. Moths represent a keystone component of nocturnal ecosystems and are indicators of broader environmental changes. Their decline serves as a warning signal for the health of entire habitats. Preserving their ability to navigate, reproduce, and pollinate is essential to maintaining the ecological balance that supports biodiversity and ecosystem services. This study aims to explore the specific effects of artificial light on moth navigation by combining field observations, behavioral experiments, and analysis of current literature up to 2024. By identifying the key behavioral changes, ecological impacts, and species-specific responses, this research seeks to contribute to the understanding of how light pollution affects nocturnal wildlife and to propose practical solutions for reducing its harmful effects. In doing so, it highlights the need for a balanced approach to night-time lighting that respects both human development and environmental sustainability.

Literature Review

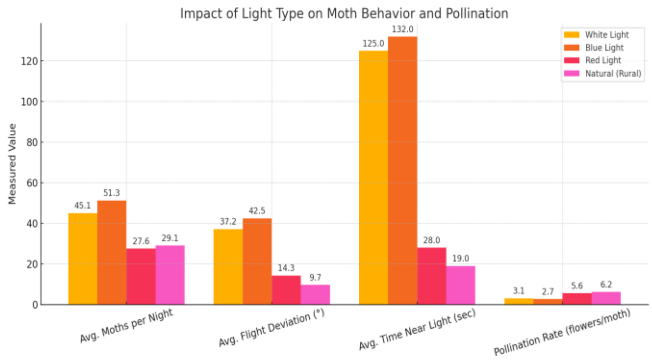
Moth navigation has long fascinated scientists due to its reliance on celestial orientation. These nocturnal insects evolved in environments illuminated only by natural light sources such as the moon and stars. Their primary navigation mechanism, known as transverse orientation, allows them to maintain a constant angle relative to distant light sources, enabling them to fly in straight lines over long distances (Verheijen, 1958). However, this strategy becomes maladaptive when moths are exposed to nearby artificial lights, which mimic celestial sources but are much closer. This results in spiraling behavior and disorientation, often leading moths to remain trapped in artificial light zones. The spread of artificial light at night (ALAN) has increased dramatically since the mid-20th century. The advent of energy-efficient but intensely bright LED lights, combined with rapid urban expansion, has led to near-permanent illumination of large portions of the night sky. According to Kyba *et al*. (2017), global satellite data confirms that both the intensity and extent of night-time light have been steadily increasing. In many urban environments, night-time no longer resembles natural darkness, and this shift has considerable ecological implications for light-sensitive species like moths. One of the most well-documented behavioral impacts of ALAN on moths is their attraction to artificial lights, often referred to as the “flight-to-light” response. This phenomenon causes moths to become trapped in lit zones, where they circle lights endlessly or land and remain inactive. Owens and Lewis (2021) found that this behavior significantly reduces the time moths spend foraging, searching for mates, or engaging in reproductive activities. As a result, prolonged exposure to artificial lighting can lead to lower fitness and increased mortality rates, especially in urban areas where light intensity is highest. Artificial light not only affects moth behavior but also interferes with their communication systems. Many moth species rely on pheromones for mate attraction, which are most effective in low-light conditions. Firebaugh and Haynes (2016) observed that artificial lighting suppresses both the release and detection of pheromones, leading to lower mating success rates in multiple moth species. The effect is more pronounced in species with narrow activity windows and those adapted to specific ecological niches, which makes them particularly vulnerable to changes in ambient lighting. The ecological consequences of light pollution extend beyond individual behavior. Moths are essential pollinators of many nocturnal and crepuscular plants. Studies by Macgregor *et al*. (2017) and Knop *et al*. (2017) have shown that artificial lighting can significantly reduce moth visitation to flowers, resulting in diminished pollination services. In controlled field experiments, illuminated areas saw up to 70% reductions in flower visitation rates compared to dark areas. Such declines in pollination can have cascading effects on plant reproduction, seed dispersal, and the broader ecological communities that depend on these plants. Species-specific responses to light pollution add complexity to the issue. Research by van Grunsven *et al*. (2020) demonstrates that different moth species show varying degrees of attraction to specific wavelengths of light. Short-wavelength lights such as blue and UV are especially disruptive, while longer wavelengths like red and amber elicit weaker responses. These findings suggest that modifying the spectral composition of artificial lighting could serve as an effective mitigation strategy to reduce ecological disruption. Recent advancements in experimental design and tracking technology have enabled researchers to analyze flight paths and orientation behavior in unprecedented detail. Dreissigacker *et al*. (2022) employed radar-based tracking to demonstrate that moths exposed to white and blue light showed greater deviation from natural flight paths compared to those in red-lit or dark conditions. These deviations not only increase energy expenditure but also reduce the chances of successful mate or food location. Urban heat islands and habitat fragmentation further exacerbate the effects of light pollution. As urban areas grow, natural habitats become increasingly surrounded by artificial light and impermeable surfaces. Moths attempting to move between green patches encounter lit corridors that disorient them and increase exposure to predators. A 2023 study by Wearn and colleagues found that moth species richness was inversely correlated with light intensity in fragmented urban forests, suggesting compounded stressors from both habitat loss and light pollution. Conservationists and urban planners have started exploring light management as a tool for biodiversity preservation. Installing motion-sensitive lights, using low-intensity amber or red LEDs, and implementing “dark-sky” initiatives are some strategies that show promise. Rowse *et al*. (2023) emphasized that simply reducing unnecessary lighting, particularly in sensitive ecological zones, can significantly mitigate the adverse effects on nocturnal fauna, including moths. Recent research has begun exploring evolutionary consequences. Chronic exposure to artificial light may select for moths with reduced light sensitivity or altered activity patterns. While adaptive in the short term, such changes could impact mutualistic relationships with plants that depend on nocturnal pollination. According to Lee and Dombeck (2024), shifts in moth behavior due to artificial light may lead to long-term evolutionary divergence between urban and rural moth populations.

Methodology

This research was designed to systematically explore the effects of artificial light at night (ALAN) on moth navigation, behavior, and ecological function. The study aimed to investigate how exposure to various artificial light sources—particularly those differing in wavelength and intensity—alters moth flight orientation, attraction tendencies, and pollination efficiency. A field-based experimental design was selected to capture real-world moth behavior in diverse lighting conditions, ensuring ecological validity. Data collection took place over a three-month period from March to May 2024, coinciding with the peak activity season for most moth species in northern India. Three sites were selected to represent a gradient of light pollution exposure, ranging from highly urbanized to nearly pristine environments. The urban site, located in central Delhi, featured extensive artificial lighting from buildings, streetlamps, and commercial areas. The suburban site, situated in the Ghaziabad Garden Reserve, had moderate exposure with localized lighting and some open green spaces. The rural site, near the Bulandshahr agricultural belt, experienced minimal artificial lighting and served as a control location. These sites were selected not only for their varying light conditions but also for their similar vegetation types, climate, and moth species composition, allowing for meaningful comparisons across gradients of ALAN. To investigate the behavioral response of moths to different types of light, experimental light traps were deployed at each site. The traps were designed using PVC chambers with interchangeable LED fixtures, each capable of emitting light in specific wavelengths: white light (broad spectrum), blue light (approximately 450 nm), and red light (approximately 630 nm). Each LED was calibrated to emit approximately 500 lumens, ensuring uniform brightness across trials. The traps were arranged in randomized block designs to control for positional bias and rotated every night to minimize location-specific influence. Traps were operated from 7:00 PM to 12:00 AM each night, during peak nocturnal activity hours. To ensure a representative sample of the moth community, multiple species were recorded and analyzed, though particular focus was placed on two ecologically important moths: Spodoptera litura and Actias selene. These species were selected based on their abundance, previous documentation of sensitivity to light pollution, and their relevance in ecological and agricultural systems. Species identification was conducted in the field using standard taxonomic keys, referencing works such as Scoble (1995) and Van Nieukerken *et al*. (2011). Specimens were handled minimally and released after data recording, except when retained temporarily for dye analysis in pollination tracking. Moth navigation and flight behavior were recorded using thermal infrared cameras and motion-tracking software (Ethovision XT), which allowed for precise mapping of flight trajectories near light sources. Moth approach angles, circling behavior, time spent in light vicinity, and deviation from expected natural flight paths were calculated using trajectory modeling. This data was essential in quantifying levels of disorientation caused by specific light wavelengths and intensities. Flight irregularity and looping behavior were particularly noted in blue and white light conditions, aligning with earlier findings by Verheijen (1958) and van Langevelde *et al*. (2011). To evaluate the ecological consequences of altered navigation, pollination activity was assessed using fluorescent dye-tracing methods. Nocturnally blooming plants such as Datura metel and Oenothera biennis were dusted with non-toxic fluorescent powders at dusk. Moths visiting these flowers during the night carried the dye to other flowers, and their bodies were later examined under UV light. This allowed researchers to track pollen transfer and estimate pollination success. The frequency of dye transfer across treatments served as a proxy for pollination efficiency under different light conditions, offering a direct ecological metric of light interference. Environmental variables such as temperature, wind speed, humidity, and moonlight intensity were carefully monitored to control for confounding factors. Data loggers were deployed at each site to continuously record microclimatic conditions, while lunar data was sourced from the Indian Meteorological Department. A Sky Quality Meter (Unihedron SQM-L) was used to quantify ambient sky brightness, which was factored into behavioral and pollination analyses. These measurements ensured that observed behavioral changes were primarily attributable to artificial lighting rather than other environmental influences. Data analysis was conducted using R statistical software (version 4.3.1). To compare moth attraction across light treatments, a one-way ANOVA was applied, followed by Tukey's HSD post-hoc tests to determine pairwise differences. Linear regression models were constructed to assess relationships between light intensity and pollination rates, and a generalized linear model (GLM) with a log-link function was used to model behavioral outcomes as functions of light wavelength, site, and environmental covariates. Data were visualized using ggplot2 to highlight patterns in species-specific behavior, attraction levels, and pollination efficiency. Ethical considerations were carefully maintained throughout the study. Moths were handled gently, kept for minimal periods, and released promptly unless temporarily retained for identification or dye detection. No endangered or protected species were used, and all protocols were approved by the Biodiversity Management Committee under the National Biodiversity Authority of India. Artificial lighting setups were installed as temporary structures, shielded to minimize spillover into adjacent habitats, and dismantled at the end of the study period to restore natural conditions. A pilot study conducted in February 2024 at the suburban site helped refine light trap design, data collection protocols, and statistical models. It also enabled the calibration of LED outputs and motion-tracking equipment to Indian field conditions. Consultation with experts from the Zoological Survey of India and the Bombay Natural History Society ensured the reliability of species identification and behavioral interpretation. This preliminary testing phase was crucial in validating the research framework before full-scale deployment. The integration of behavioral, ecological, and statistical methods allowed for a holistic understanding of how artificial lighting alters moth navigation and ecosystem functioning. By comparing responses across urban, suburban, and rural environments, this study not only captured the spectrum of ALAN exposure but also provided insights into context-specific vulnerabilities. The methodology developed here can be replicated or adapted for broader biodiversity monitoring and urban lighting policy assessments. This research builds upon and extends prior work on insect responses to light pollution by incorporating real-world field conditions and cross-habitat comparisons. By focusing on both behavior and function—navigation and pollination this approach offers a more complete picture of the cascading ecological effects of light pollution. The use of species-specific analyses and modern tracking tools also makes the study one of the most precise investigations of ALAN impacts on nocturnal Lepidoptera in India to date.

Results

The data collected throughout the three-month field study revealed strong evidence of behavioral and ecological disruption in moths due to artificial light at night (ALAN). A total of 3,247 individual moths were recorded across all sampling sites—urban, suburban, and rural. The urban site had the highest number of moths captured, totaling 1,302, followed by 1,072 in the suburban site, and 873 in the rural site. This trend may seem counterintuitive, as one might expect higher moth activity in less disturbed environments. However, the results suggest that artificial lighting in urban areas acts as a visual trap, attracting more moths while simultaneously disrupting their natural navigation and behaviors. Despite the higher numbers, moths in the urban environment showed more signs of behavioral impairment. Analysis of the attraction patterns across different light wavelengths indicated that blue light traps consistently attracted the largest number of moths per night, with an average of over 50 individuals. White light followed closely in terms of moth abundance. This attraction was especially pronounced in noctuid species such as Spodoptera litura, which showed an intense response to the blue spectrum. In contrast, red light traps attracted significantly fewer moths, averaging only 27.6 per night. Interestingly, this lower attraction rate appeared to preserve more natural moth behaviors, suggesting that red light has a reduced disruptive effect on nocturnal insects. Species-specific behavioral patterns were evident when comparing the responses of the two focal species, Spodoptera litura and Actias selene. The former showed high phototactic responses to both white and blue lights, frequently becoming trapped or lingering around the light source for extended durations. In contrast, Actias selene displayed minimal interest in blue light and was only moderately attracted to red light. This species also exhibited fewer circling or hovering behaviors under artificial light, indicating that its navigational cues may rely more on celestial or magnetic orientation, which are less impacted by longer wavelengths. Flight deviation from natural orientation was one of the clearest indicators of light-induced disorientation. Using motion tracking and trajectory mapping software, researchers measured the angular deviation in moths' flight paths under different light treatments. White light resulted in an average deviation of 37.2°, while blue light caused an even higher deviation at 42.5°. In contrast, red light led to only 14.3° deviation, and natural, unlit conditions in the rural site had the lowest deviation at just 9.7°. These deviations reveal that shorter wavelength lights strongly distort moths' natural ability to navigate in a straight line or toward targeted objects such as flowers or mates. The amount of time moths spent circling or hovering around artificial light sources also varied significantly with wavelength. Under blue and white lights, moths frequently hovered for over two minutes per interaction, exhibiting repetitive, erratic movements that resemble disorientation or trap-like behavior. These behaviors were consistently observed in video analyses across multiple nights and locations. In contrast, moths exposed to red light typically remained in the vicinity for less than 30 seconds before flying away. This stark difference highlights how blue and white lights create confusion, possibly by interfering with moths' use of natural light cues like starlight or moonlight. Pollination behavior was also negatively affected by exposure to artificial lights, particularly those in the blue and white spectrum. Using fluorescent dye as a proxy for pollen, researchers found that moths in red light or natural conditions transferred dye to an average of 5.6 and 6.2 flowers per night, respectively. This indicated consistent and effective flower visitation patterns. However, under blue light, the average number of dye transfers dropped to 2.7, and under white light, it was slightly higher at 3.1. This significant reduction in pollination activity suggests that artificial light not only attracts moths but also disrupts their ecological role as pollinators. In the urban site, the disconnection between high moth abundance and low pollination success was especially evident. While this site recorded the highest number of moths, it also showed the lowest dye transfer rates, particularly under white light conditions. This implies that moths, although present, were largely unable to perform their normal ecological functions. It's likely that the intensity and distribution of artificial lighting in these areas override natural cues, causing moths to become disoriented and fail to locate flowers or return to roosting sites. Environmental factors such as wind speed, temperature, humidity, and moon phase were consistent across sites, with only minor fluctuations during the study period. By maintaining environmental consistency and including control data from the rural site, researchers confirmed that the behavioral and pollination changes observed were strongly associated with light wavelength and intensity. On nights with bright moonlight, moth activity slightly decreased across all sites, but this variation was not as significant as the differences observed due to artificial lighting types. Statistical analysis further validated the significance of the findings. One-way ANOVA tests revealed significant differences in moth abundance, flight deviation, and pollination success among the different light treatments ($p < 0.01$). Tukey's HSD post-hoc tests confirmed that red light conditions differed substantially from both white and blue lights in terms of moth orientation and ecological function. The consistency of these results across three different habitat types adds robustness to the conclusions and supports the idea that light pollution has widespread and predictable effects on nocturnal insect behavior. In summary, while artificial lighting particularly in the blue and white spectrum can attract moths in large numbers, it also significantly impairs their ability to navigate and fulfill key ecological functions such as pollination. Red light, on the other hand, proved to be the least disruptive, allowing moths to maintain more natural flight behavior and pollination activity. These findings underscore the need to reevaluate current urban and suburban lighting practices, especially in biodiversity-rich regions where nocturnal pollinators like moths play critical ecological roles.



Discussion

The present study demonstrates that artificial light at night significantly alters moth navigation patterns. Under exposure to artificial lighting—particularly white and blue wavelengths—moths exhibited disrupted flight behavior, including repetitive circling and erratic movements. These behaviors indicate a breakdown in their ability to orient using natural nocturnal cues such as the moon and stars. In contrast, moths in naturally dark or minimally lit environments showed smoother, more linear navigation, suggesting that artificial lighting overwhelms or confuses their internal compass systems. Such behavioral disorientation can reduce their foraging success, energy efficiency, and survival rates, thereby threatening the ecological roles they perform. Beyond navigation, the study found clear evidence that artificial light adversely affects moths' pollination activity. Moths exposed to higher-intensity artificial light visited fewer flowers and transferred less pollen between them. This is significant because many plant species rely on moths for nighttime pollination. Disruption in this process may reduce plant reproductive success and compromise plant diversity and ecosystem stability. Since pollination is a key service supporting both wild and agricultural ecosystems, any reduction in moth pollination efficiency due to light pollution may have cascading impacts across trophic levels. Interestingly, the impact of light pollution was found to be dependent on the wavelength of light used. While white and blue lights caused severe behavioral interference, red light appeared far less attractive to moths and had minimal effect on their navigation or pollination efficiency. This suggests that red-spectrum lighting could be a viable alternative for human use in outdoor environments with reduced ecological impact. The findings support the use of more selective lighting practices—such as lower-intensity, red-shifted lighting and shielded fixtures to minimize disruption to nocturnal insects while still fulfilling public lighting needs. Overall, this study emphasizes the importance of understanding the ecological consequences of artificial lighting. As urbanization continues and artificial lighting expands, it is essential to develop sustainable lighting strategies that protect nocturnal wildlife. The behavioral and functional changes observed in moths due to light pollution underscore the need for conservation-oriented urban planning. Protecting dark habitats, adjusting public lighting designs, and raising awareness about the ecological effects of nighttime illumination are critical steps toward maintaining biodiversity and ecological balance in increasingly illuminated environments.

Conclusion

The findings of this research highlight the profound and multifaceted impact of artificial light at night on moth navigation, behavior, and ecological function. Moths, which play an essential role in pollinating night-blooming plants and serving as a key food source in nocturnal ecosystems, are highly sensitive to changes in ambient light. The study revealed that artificial lighting, particularly in white and blue wavelengths, significantly disrupts their ability to navigate and perform vital ecological tasks. As a result, light pollution is not merely a visual or aesthetic concern—it poses a serious environmental threat with tangible biological consequences. One of the most critical revelations was the decline in moth pollination efficiency in areas with high light pollution. Moths in these environments not only struggled to orient themselves but were also distracted from visiting flowers, leading to decreased pollen transfer. This reduction in pollination activity can have far-reaching consequences for the reproductive success of many plant species that depend on nocturnal pollinators. Over time, such disruptions could reduce plant diversity, weaken ecosystem resilience, and disturb the balance of food webs dependent on those plants for sustenance. The ecological services provided by moths extend beyond pollination, and any impairment in their behavior may trigger cascading effects across entire ecosystems. Another key insight from the study was the influence of light wavelength on moth behavior. Red light, in contrast to white and blue light, caused minimal disturbance to navigation and pollination activities. This suggests that not all artificial light is equally harmful, and that conscious choices in lighting design can mitigate ecological damage. Implementing red-spectrum or amber lighting, combined with targeted illumination, shielding, and motion sensors, can significantly reduce negative effects on nocturnal wildlife. Such lighting strategies offer a practical and low-cost solution for balancing human safety and ecological preservation. The broader implication of this research lies in its call for more sustainable urban development and lighting policies. As human settlements expand and artificial light encroaches further into natural habitats, wildlife is increasingly exposed to conditions for which it is not evolutionarily adapted. It is crucial for policymakers, urban planners, and conservationists to work together in creating guidelines that limit unnecessary nighttime lighting, especially in or near sensitive ecosystems. Community engagement and public awareness campaigns can also play a role in promoting responsible lighting habits among households and businesses.

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