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Review

Current evidence in support of insect-friendly lighting practices

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Anthropogenic light pollution is an emerging threat to natural ecosystems with myriad effects on insects in particular. Insect conservationists are increasingly interested in mitigating this driver of insect declines via sustainable lighting practices. Current recommendations often follow the five principles for responsible outdoor lighting developed by DarkSky International, a nonprofit organization founded by astronomers. While these principles unquestionably increase star visibility, their ecological costs and benefits remain relatively unexplored. Herein, we review recent research into the effects of each principle on insect fitness broadly defined. Most studies test the efficacy of spectral tuning, followed by dimming, although both mitigation methods seem generally ineffective in practice. In contrast, both shielding and motion detectors show promise as mitigation methods but remain remarkably understudied. Nonetheless, a preponderance of evidence now demonstrates that removing unnecessary light sources from natural habitats can reverse their varied impacts on diverse insect taxa and greatly benefit insect conservation.

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Introduction

As anthropogenic light pollution continues to intensify [1] both within and outside of urban centers [2], insect conservationists have become increasingly concerned with the ways in which artificial light obscures or outcompetes natural cues guiding insect development, movement, foraging, and reproduction (Figure 1; see Ref. [3] for an in-depth review). By causing disorientation in time and space, concealing visual cues of environmental resources, and inciting detrimental flight-to-light behavior, artificial light radically disrupts normal functioning in insects.

The conservation consequences for individuals, populations, and communities [4,5] are now being documented across a broad range of nocturnal and — increasingly — diurnal insect taxa including termites [6], ants [7,8], parasitoid wasps [9], psyllids [10], and monarch butterflies [11,12]. Recent research has not only deepened appreciation for the effects of artificial light on diurnal taxa but also highlighted the relative abundance and ecological importance of nocturnal taxa [13], which are especially at risk [13], including the moths and other insects that provide crucial pollination services at night [14].

Along with a growing awareness of light pollution as an ecological threat has come regulatory interest in reducing harm via sustainable lighting practices that balance the needs of humans and nature [15]. Five simple guidelines for 'responsible outdoor lighting' (Figure 1) have been developed and popularized by DarkSky International, a nonprofit organization active in 24 countries that has worked since 1987 'to restore the nighttime environment and protect communities and wildlife from light pollution'. These 'five principles' to restore the night are well established to reduce skyglow and increase star visibility, reflecting the origin of the dark sky movement among amateur and professional astronomers. Ecologists, in contrast, have only recently begun to investigate how the same practices may ameliorate (or aggravate) the effects of light pollution on wildlife.

In this review, we summarize recent advances in our understanding of how each of the five principles for responsible outdoor lighting (addressed in reverse order) might benefit insect conservation (Table 1). We conclude by highlighting several areas of growing research interest as well as remaining knowledge gaps.

Figure 1

Five commonly recommended methods of reducing the impacts of light pollution developed and promoted by DarkSky International (*left*: infographic from darksky.org, used with permission) and four fundamental effects of artificial light on insects (*right*: icons from thenounproject.com). Lines connecting a lighting principle to a lighting impact suggest a higher potential for the former to mitigate the latter. First principles suggest that shielding (2) will most effectively limit temporal disorientation and fatal attraction, dimming (3) will most effectively limit spatial disorientation and visual confusion, timers and motion detectors (4) will most effectively limit spatial disorientation and visual confusion, and spectral tuning (5) will most effectively limit temporal disorientation and fatal attraction. Removal of unnecessary light (1) will eliminate all effects.

Table 1

Recent studies that explicitly test whether responsible outdoor lighting principles can mitigate the impacts of artificial light on insects. Here, positive phototaxis refers to fatal attraction and negative phototaxis to its opposite, light avoidance. Dimming (3) is considered effective only when dimmed treatments measure 5 lux or above at ground level, as illumination below this level is likely to be too dim to meaningfully support human use and enjoyment of outdoor spaces at night.

Responsible outdoor lighting principle	Citation	Lighting impact on insects in question	Evidence for mitigation?
1 Useful	All	All	Yes (highly effective)
2 Targeted	Bolliger et al., 2022	Positive phototaxis	Yes
	Dietenberger et al., 2024	Positive phototaxis	Yes
	van Koppenhagen et al., 2024	Positive phototaxis	No
3 Low level	Moubarak et al., 2023	Visual confusion	Yes
	Owens and Lewis, 2022	Visual confusion	Yes
	Levy et al., 2024	Temporal disorientation	Yes
	Levy et al., 2023	Temporal disorientation	No
	Cieraad et al., 2022	Temporal disorientation	No
	Dyer et al., 2023	Temporal disorientation	No
	van Koppenhagen et al., 2024	Positive phototaxis	Mixed
	Jägerbrand et al., 2023	Positive phototaxis	No
	Dietenberger et al., 2024	Positive phototaxis	No
4 Controlled	Hao et al., 2023	Positive phototaxis	No
	Kasai and Hironaka, 2024	Positive phototaxis	No
	Heinen et al., 2023	Community effects	No (harmful)
5 Warm colored	Hao et al., 2023	Positive phototaxis	No
	Kunhe et al., 2021	Positive phototaxis	No
	Owens et al., 2022	Positive phototaxis	No
	Spoelstra et al., 2023	Positive phototaxis	No
	van Koppenhagen et al., 2024	Positive phototaxis	No
	Bolliger et al., 2022	Positive phototaxis	Yes
	Schofield et al., 2023	Positive phototaxis	Yes
	Mészáros et al., 2022	Negative phototaxis	Yes
	Sanders et al., 2022	Community effects	Yes
	Cieraad et al., 2022	Community effects	Mixed
	Owens et al., 2022	Visual confusion	No (harmful)

Principle 5. Limit the amount of short-wavelength light

Each artificial light source produces a characteristic mix of wavelengths, known as its spectral distribution, and each animal has a tendency to detect certain wavelengths over others, known as its spectral sensitivity. Spectral sensitivities vary widely across taxa, with insects tending to be most sensitive to short-wavelength light [16]. Spectral distributions of modern LEDs are easily modified (e.g. [17,18]), leading some researchers to wonder whether intentional spectral tuning of artificial light might reduce its impact on insect species of conservation concern.

Recent studies confirm that short-wavelength UV and, to a lesser extent, blue light are most attractive to light-attracted insects [7,17,19]. Shifting to longer wavelengths can therefore ameliorate or even eliminate flight-to-light behavior (positive phototaxis), one of the better understood detrimental effects of artificial light on insects (but see counterexamples in Refs. [20,21]). Be that as it may, there remains scant evidence for any substantial difference in insect attraction to cool white versus warm white LEDs [17,22–24], probably because the two often vary only slightly in the amount of blue light they emit. However, monochromatic red light has repeatedly proven minimally attractive to light-attracted insects [17,20], most of which lack red photoreceptors [16].

Other colors of monochromatic light have been shown to either attract (blue light [25]) or repel (green light [18]) particular insect species of interest, leading to the restructuring of insect communities [19] (but see Ref. [26]). Combinations of monochromatic light can achieve an even more targeted effect [18], either increasing (UV and green; [27]) or decreasing (green and amber; [28]) the attraction of particular insect species relative to broad-spectrum white light while also enabling human color vision. To humans, combinations of monochromatic red, green, and blue components are indistinguishable from broad-spectrum cool white light but significantly reduce mosquito attraction and the risk of mosquito-borne disease transmission [29].

Relatively few studies address how spectral tuning might be used to reduce the impacts of artificial light on insects beyond flight-to-light behavior. The results of these studies tend to be highly species, system, and habitat dependent. For example, monochromatic blue or green light decreases the parasitism efficiency of diurnal parasitoid wasps without inducing flight-to-light behavior [30], increasing populations of their aphid hosts. Monochromatic red [31] or green [30] light increases plant growth while lowering plant defenses, culminating in greater overall insect herbivory. Relative to natural darkness, artificial light of unnatural spectral distribution can also radically alter the visibility of moths [32] and moth-pollinated plants [33], with unknown but potentially far-reaching consequences for ecosystem function.

Principle 4. Use light only when it is needed

Automatic timers and motion activators, referred to together as lighting controls, limit the use of artificial lights to periods of greatest human activity. Timers are often set to automatically dim or extinguish their associated light sources later in the evening, often around midnight, when fewer people are likely to be active outdoors. So-called part-night lighting schemes likely have limited benefit for most nocturnal flying insects, which are disproportionately active around and just after dusk [34]. The majority of light-attracted insects aggregate between 1 and 3 hours after sunset [17,35] when timer-controlled light sources would still be lit. Part-night lighting could perhaps allow uninjured insects to escape from their orbit earlier than they otherwise would. Part-night lighting likely has even greater benefits for the subset of insects, primarily some moths, that aggregate around artificial lights 5–6 hours after sunset [35].

As noted previously, flight-to-light behavior is far from the only consequential effect of artificial light on insects. Physiological disruptions to the internal clock can alter daily, monthly, and yearly cycles of development and behavior in both nocturnal and diurnal taxa. Part-night lighting produces a highly unnatural pattern of intense daylight fading into relatively dim anthropogenic light followed by an immediate switch to darkness; full-night lighting reduces brightness contrast between day and night but maintains a natural cycle of light and relative darkness. The consequences of this distinction are largely unexplored but may help explain why some aphid colonies perform worse under part-night than full-night lighting [36].

Motion activators briefly activate their associated light sources in response to a movement trigger, dramatically reducing the total amount of artificial light in the environment over time, especially in natural and semi-natural areas where fewer people are active at night. Insects are far too small to trigger most motion detectors and, in such areas, should be able to perform nocturnal behaviors largely undisturbed. Note, however, that even brief pulses of light are capable of disrupting the internal clocks of insects (specifically crickets) in the laboratory [37]. As motion activators come into greater use, future studies should seek to understand the effects of intermittent light exposures on insect physiology and behavior in the field.

Principle 3. Light should be no brighter than necessary

Artificial light sources, especially LEDs, tend to be far brighter than they need to be to support human activity and safety. Dimming them to the lowest acceptable intensity can greatly reduce the total amount of artificial light in the environment. Dimming artificial light only slightly (to < 30 lux) is sufficient to ameliorate or reverse its inhibitory effects on courtship and mating in fireflies [38,39] by allowing for successful transmission of bioluminescent signals. However, the benefits of dimming for other insect groups are much less clear, especially as the lowest acceptable intensity for humans may still be far too bright for most nocturnal insects.

Nocturnal insects tend to have extremely sensitive eyes capable of rapidly adapting to the ambient light environment (summarized in Ref. [40]). This is likely why recent studies have shown that even severely dimmed artificial light (< 5 lux) still significantly alters foraging patterns in ground beetles [41] and inhibits feeding behavior, pheromone release [42], and diapause induction [43] in moths while also inducing flight-to-light behavior [44]. Severe dimming does however ameliorate the impact of artificial light on the oviposition patterns of diurnal wasps [9]; see also Refs. [37,45], suggesting that the conservation benefits of dimming may depend on the temporal niche of the insect species in question.

Principle 2. Direct light so it falls only where it is needed

At their most basic, shielded fixtures prevent artificial light from going directly up into the atmosphere and reducing star visibility. In addition to these benefits for astronomy, shielding could have real ecological benefits: recent work suggests that upwelling light is especially disorienting to light-attracted insects [46], which tend to orient themselves in flight such that the brighter half of their visual field is kept overhead. Yet, the degree to which shielding actually reduces flight-to-light behavior, especially given that many insects are active below the height of a standard streetlight, is just beginning to be tested [22,24,47]. Its effects on the high-altitude navigation of migrating insects, known to orient with respect to natural light sources [48], remain entirely unexplored.

Modern shielded fixtures are increasingly designed to direct artificial light at particular areas of the ground, such as walking paths, and minimize light trespass onto bordering vegetation [49] and into rivers [23], where it has been shown to dramatically alter the local distribution of insects. One recent test compared fixtures that were individually tailored to minimize light leakage against conventional streetlights of the same intensity and spectral distribution and found that careful direction of artificial light alone can significantly reduce flying insect attraction [47]. Similar tests of fixtures that focus artificial light in a single direction against those that diffuse it outward have seen significant declines in the attraction of flying insects [22] but not ground dwellers [24], with mixed influence of the intensity and spectral distribution of the artificial light source itself [22]. While more research is needed to understand how factors such as fixture type, fixture height, and surface reflectance influence effectiveness, shielding certainly appears to be a 'no regrets' action for insect conservation.

Principle 1. Use light only if it is needed

Relative to fully dark controls, artificial light of all colors, timings, shapes, and intensities has profound impacts on insect behavior and fitness, many of which are still being discovered. For example, recent studies show that disproportionate numbers of predators, parasitoids, scavengers, and parasites aggregate around artificial lights [50], threatening herbivorous caterpillars [51,52], while others show that artificial light disrupts circadian pathways [53–55] in mosquitoes [56] and crickets [53]. The simplest method of mitigating these and other fitness consequences discussed above (Figure 1) is also by far the most effective: removal of unnecessary light and restoration of natural darkness.

Conclusion

The past decade has seen a burgeoning of research into the behavioral impacts of artificial light on insects. Most studies still focus on either alterations to movement activity (especially flight-to-light behavior) or disruptions to ecological functioning (especially insect–plant interactions), and standard study systems have emerged for each impact type: adult moths for flight-to-light behavior, crickets for circadian disruption, and aphids and their natural enemies for community effects. While knowledge gaps persist regarding, for example, the movement ecology of light-averse taxa [57], the developmental physiology of pre-adult insect life stages (but see Ref. [53]), and the cascading effects on ecological communities, the overall message is clear: unrestricted use of artificial light poses a threat to insects.

Recent research by entomologists relevant to the five principles for responsible outdoor lighting has focused mostly on spectral tuning and, to a lesser extent, dimming. Yet neither of these mitigation measures have turned out to be sufficiently effective methods of reducing insect flight-to-light behavior or ameliorating other impacts of artificial light on insects. Nor does the relatively scant body of existing research (including that on the timing of nocturnal insect activity) clearly support the use of part-night lighting. Remarkably little research has been done on the benefits of either shielding or motion detectors, which is especially striking because both evidence and theory suggest that these mitigation measures are likely to be highly effective methods of minimizing the total exposure of insects to artificial light.

Clearer communication of the nuanced, widespread, and alarming impacts of artificial light on insects is urgently needed to inform outdoor lighting policy, which, when addressing light pollution at all, currently prioritizes practices that have been conclusively demonstrated to prevent artificial light from illuminating the night sky. Truly responsible outdoor lighting should offer a win-win: allowing people to safely use and enjoy outdoor spaces at night while retaining both star visibility and the ability for humans and insects to coexist within natural spaces.

Data Availability

No data were used for the research described in the article.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References and recommended reading

Papers of particular interest, published within the period of review, have been highlighted as:

- • of special interest
- •• of outstanding interest

1. • Kyba CCM, Altıntaş YÖ, Walker CE, Newhouse M: **Citizen scientists report global rapid reductions in the visibility of stars from 2011 to 2022**. *Science* 2023, **379**:265-268.

By leveraging over 50 000 citizen scientist observations (rather than satellite images, which are increasingly inadequate), the authors of this study calculate that artificial night sky brightness resulting from anthropogenic light pollution has increased at a rate of 7–10% per year over the past decade — much more rapidly than previously thought.

2. Cox DTC, Sánchez de Miguel A, Bennie J, Dzurjak SA, Gaston KJ: **Majority of artificially lit Earth surface associated with the non-urban population**. *Sci Total Environ* 2022, **841**:156782.
3. Owens ACS, Cochard P, Durrant J, Farnworth B, Perkin EK, Seymoure B: **Light pollution is a driver of insect declines**. *Biol Conserv* 2020, **241**:108259.
4. • Kehoe R, Sanders D, Van Veen FJF: **Towards a mechanistic understanding of the effects of artificial light at night on insect populations and communities**. *Curr Opin Insect Sci* 2022, **53**:100950.

This paper reviews current knowledge on how effects of artificial light on individual insects propagate through populations and communities via species interactions. The authors propose five primary mechanisms of food web responses to artificial light exposure: distribution, bottom-up, diversity loss, interaction strength, and knock-on effects.

5. Miller CR, Vitousek MN, Thaler JS: **Light at night disrupts trophic interactions and population growth of lady beetles and pea aphids**. *Oecologia* 2022, **199**:527-535, https://doi.org/10.1007/s00442-022-05146-3
6. Mizumoto N, Bourguignon T: **Light alters activity but does not disturb tandem coordination of termite mating pairs**. *Ecol Entomol* 2022, **48**:145-153, https://doi.org/10.1111/een.13209
7. Hsu P-W, Chiu M-C, Hsu F-C, Yang C-CS, Lin C-C: **Are LED lights driving the massive nuptial flight swarm of the tramp ant *Technomyrmex albipes*?** *Entomol Exp Appl* 2023, **172**:75-83, https://doi.org/10.1111/eea.13377
8. Vander Meer RK, Alonso LE, Lofgren CS: **Light affects the homing ability of *Solenopsis invicta* foraging workers**. *Fla Entomol* 2023, **106**:175-181.
9. Gomes E, Lemaître J-F, Rodriguez-Rada V, Débias F, Desouhant E, Amat I: **Foraging at night under artificial light: impacts on senescence and lifetime reproductive success for a diurnal insect**. *Anim Behav* 2024, **210**:85-98.
10. Lockett MT, Rasmussen R, Arndt SK, Hopkins GR, Jones TM: **Artificial light at night promotes bottom-up changes in a woodland food chain**. *Environ Pollut* 2022, **310**:119803.
11. Parlin AF, Stratton SM, Guerra PA: **Oriented migratory flight at night: consequences of nighttime light pollution for monarch butterflies**. *iScience* 2022, **25**:104310.
12. Haynes KJ, Miller GD, Serrano-Perez MC, Hey MH, Emer LK: **Artificial light at night increases the nighttime feeding of monarch butterfly caterpillars without affecting host plant quality**. *Basic Appl Ecol* 2023, **72**:10-15, https://doi.org/10.1016/j.baae.2023.07.007
13. •• Wong MKL, Didham RK: **Global meta-analysis reveals overall higher nocturnal than diurnal activity in insect communities**. *Nat Commun* 2024, **15**:3236.

This paper collates and summarizes 331 quantitative comparisons of insect abundance throughout the day and night. The authors find that insect activity is over 30% higher on average during the night, lending support to previous estimates that approximately 60% of insect species are primarily active at night. The authors also find that insects in warm and/or aquatic habitats tend to exhibit more nocturnal activity.

14. Buxton MN, Gaskett AC, Lord JM, Pattemore DE: **A global review demonstrating the importance of nocturnal pollinators for crop plants**. *J Appl Ecol* 2022, **59**:2890-2901.
15. Morgan-Taylor M: **Regulating light pollution: more than just the night sky**. *Science* 2023, **380**:1118-1120.
16. • Longcore T: **A compendium of photopigment peak sensitivities and visual spectral response curves of terrestrial wildlife to guide design of outdoor nighttime lighting**. *Basic Appl Ecol* 2023, **73**:40-50, https://doi.org/10.1016/j.baae.2023.09.002.

This paper collates published records of the spectral sensitivities of over 300 animal species, including over 100 insect species, and compares trends across groups. The resulting database is intended to help inform efforts to mitigate the effects of artificial light on natural ecosystems via spectral tuning, as the benefits to some species are likely to come at the cost of others.

17. •• Hao Q, Liu G, Wang L, Xin P, Yu J, Yu Z, Chen X: **Assessing the attraction of narrow-spectrum and broad-spectrum artificial light to nocturnal insects: patterns and predictive models**. *Front Ecol Evol* 2023, **11**:1206404.

This study thoroughly explores patterns of flying insect attraction to two broad-spectrum and seven monochromatic colors of artificial light. The authors find that insects are more attracted to short wavelengths than to medium wavelengths and minimally attracted to long wavelengths but show no preference for cool white versus warm white light. The authors also find that insect flight-to-light behavior peaks between 90 min to 3 hours after sunset.

18. Fang H-H, Lee W-L, Chiu K-T, Ma H-Y, Yang S-H, Hung C-Y, Chen H-L, Tung C-W, Tsai Y-C: **Irradiation with green light at night has great effects on the management of *Conopomorpha sinensis* and maintains favorable litchi fruit quality**. *Sci Hortic* 2023, **312**:111830.
19. Parkinson E, Tiegs SD: **Spectral composition of light-emitting diodes impacts aquatic and terrestrial invertebrate communities with potential implications for cross-ecosystem subsidies**. *Philos Trans R Soc Lond B Biol Sci* 2023, **378**:20220361.
20. Kühne JL, van Grunsven RHA, Jechow A, Hölker F: **Impact of different wavelengths of artificial light at night on phototaxis in aquatic insects**. *Integr Comp Biol* 2021, **61**:1182-1190.

21. Owens ACS, Dressler CT, Lewis SM: **Costs and benefits of "insect friendly" artificial lights are taxon specific**. *Oecologia* 2022, **199**:487-497.

22. • Bolliger J, Haller J, Wermelinger B, Blum S, Obrist MK: **Contrasting impacts of street light shapes and LED color temperatures on nocturnal insects and bats**. *Basic Appl Ecol* 2022, **64**:1-12, https://doi.org/10.1016/j.baae.2022.07.002.

This study reveals that diffuse fixtures, which spread light out 75 degrees more than standard fixtures, attract 16% more insects regardless of color temperature. The effects are highly taxon specific with Coleoptera, Heteroptera, and Diptera significantly more attracted to diffuse over directional lighting but insectivorous bats significantly more attracted to directional lighting.

23. • Schofield J, Hogsden K, Greenwood MJ, Smith BJ, Harding JS: **The colour temperature and placement of LED lighting near rivers can reduce attraction of flying adult caddisflies**. *Freshw Biol* 2023, **68**:2095-2108, https://doi.org/10.1111/fwb.14177.

In this study, the authors test how artificial light of a range of color temperatures, at a range of distances from a river, varies in its attractiveness to flying insects, primarily locally abundant caddisflies. The authors find that caddisflies are much more attracted to cool white than to warm white lights and that their attraction declines rapidly with distance, such that the majority of caddisflies are attracted to artificial lights placed within 20 m of the river edge.

24. van Koppenhagen N, Haller J, Kappeler J, Gossner MM, Bolliger J: **LED streetlight characteristics alter the functional composition of ground-dwelling invertebrates**. *Environ Pollut* 2024, **355**:124209.

25. Yang H, Lu J, Zhu P, Sun Y, Hu Z, Li D, Huang J: **Blue light attracts more *Spodoptera frugiperda* moths and promotes their flight speed**. *Insects* 2024, **15**:129.

26. Spoelstra K, Teurlincx S, Courbois M, Hopkins ZM, Visser ME, Jones TM, Hopkins GR: **Long-term exposure to experimental light affects the ground-dwelling invertebrate community, independent of light spectra**. *Philos Trans R Soc Lond B Biol Sci* 2023, **378**:20220364.

27. Endo N, Hironaka M, Honda Y, Iwamoto T: **Combination of UV and green light synergistically enhances the attractiveness of light to green stink bugs Nezara spp**. *Sci Rep* 2022, **12**:1-9.

28. Méndez A, Martín L, Arines J, Carballeira R, Sanmartín P: **Attraction of insects to ornamental lighting used on cultural heritage buildings: a case study in an urban area**. *Insects* 2022, **13**:1153.

29. •• Wilson R, Cooper CEC, Meah RJ, Wakefield A, Roberts NW, Jones G: **The spectral composition of a white light influences its attractiveness to *Culex pipiens* mosquitoes**. *Ecol Evol* 2023, **13**:e9714.

This paper shows that, relative to broad-spectrum cool white LEDs, white LEDs that emit only monochromatic blue and yellow components are more attractive to mosquitoes while those emitting red, green, and blue components (RGB) are less attractive. As the three lighting types are indistinguishable to humans, RGB LEDs can be used to reduce the risk of mosquito-borne disease transmission at no cost.

30. • Sanders D, Baker DJ, Cruse D, Bell F, van Veen FJF, Gaston KJ: **Spectrum of artificial light at night drives impact of a diurnal species in insect food web**. *Sci Total Environ* 2022, **831**:154893.

This study investigates the interactions of diurnal parasitoid wasps and aphids under different colors of artificial light. The authors find that parasitism rates decrease under monochromatic blue and green light, reducing top-down control of aphid populations; in contrast, ultraviolet, orange, and red light have no direct or indirect effects on this insect community.

31. Cieraad E, Strange E, Flink M, Schrama M, Spoelstra K: **Artificial light at night affects plant-herbivore interactions**. *J Appl Ecol* 2022, **60**:400-410, https://doi.org/10.1111/1365-2664.14336

32. •• Seymoure B, Parrish T, Egan K, Furr M, Irwin D, Brown C, Crump M, White J, Crooks K, Angeloni L: **Better red than dead: plasticine moths are attacked less under HPS streetlights than LEDs**. *Basic Appl Ecol* 2023, **74**:66-73, https://doi.org/10.1016/j.baae.2023.11.008.

Here, the authors investigate predation rates on plasticine adult moth models under LED streetlights, HPS streetlights, and unlit control poles in an urban environment. Moth models under HPS streetlights have the highest survival, likely due to lowered visual contrast of the moth model against the background.

33. Vissio C, Drewniak EM, Cocucci AA, Moré M, Benitez-Vieyra S, Giaquinta A, Soteras F: **Artificial light changes visual perception by pollinators in a hawkmoth-plant interaction system**. *Urban Ecosyst* 2024, **27**:1235-1249, https://doi.org/10.1007/s11252-024-01519-z

34. Saha T, Genoud AP, Williams GM, Thomas BP: **Monitoring the abundance of flying insects and atmospheric conditions during a 9-month campaign using an entomological optical sensor**. *Sci Rep* 2023, **13**:15606.

35. •• Kasai M, Hironaka M: **Effects of artificial light on the arrival time, duration of stay, and departure time of nocturnal flying insects**. *Appl Entomol Zool* 2024, **59**:155-162, https://doi.org/10.1007/s13355-024-00864-x.

In this study, the authors explore the timing of flying insect attraction to and departure from artificial light by marking and observing individuals at moth sheets. Cluster analysis groups them into three categories: those that arrive soon after sunset and depart after a few hours, those that arrive soon after sunset and stay most of the night, and those that arrive long after sunset and stay through most of the rest of the night. Most moths fall into the third category.

36. Heinen R, Sanchez-Mahecha O, Martijn Bezemer T, Dominoni DM, Knappe C, Kollmann J, Kopatsch A, Pfeiffer ZA, Schloter M, Sturm S, *et al*.: **Part-night exposure to artificial light at night has more detrimental effects on aphid colonies than fully lit nights**. *Philos Trans R Soc Lond B Biol Sci* 2023, **378**:20220357.

37. Levy K, Barnea A, Ayali A: **Exposure to a nocturnal light pulse simultaneously and differentially affects stridulation and locomotion behaviors in crickets**. *Front Physiol* 2023, **14**:1151570.

38. Moubarak EM, David Fernandes AS, Stewart AJA, Niven JE: **Artificial light impairs local attraction to females in male glow-worms**. *J Exp Biol* 2023, **226**:jeb245760.

39. Owens ACS, Lewis SM: **Artificial light impacts the mate success of female fireflies**. *R Soc Open Sci* 2022, **9**:220468.

40. Vijayan S, Balamurali GS, Johnson J, Kelber A, Warrant EJ, Somanathan H: **Dim-light colour vision in the facultatively nocturnal Asian giant honeybee, *Apis dorsata***. *Proc R Soc B Biol Sci* 2023, **290**:20231267.

41. Dyer A, Ryser R, Brose U, Amyntas A, Bodnar N, Boy T, Franziska Bucher S, Cesarz S, Eisenhauer N, Gebler A, *et al*.: **Insect communities under skyglow: diffuse night-time illuminance induces spatio-temporal shifts in movement and predation**. *Philos Trans R Soc Lond B Biol Sci* 2023, **378**:20220359.

42. Cieraad E, Grunsven RHA, Sman F, Zwart N, Musters KJM, Strange E, Langevelde F, Trimbos KB: **Lack of local adaptation of feeding and calling behaviours by *Yponomeuta cagnagellus* moths in response to artificial light at night**. *Insect Conserv Divers* 2022, **15**:445-452, https://doi.org/10.1111/icad.12568

43. Merckx T, Nielsen ME, Kankaanpää T, Kadlec T, Yazdanian M, Kivelä SM: **Dim light pollution prevents diapause induction in urban and rural moths**. *J Appl Ecol* 2023, **60**:1022-1031, https://doi.org/10.1111/1365-2664.14373

44. • Jägerbrand A, Andersson P, Nilsson Tengelin M: **Dose-effects in behavioural responses of moths to light in a controlled lab experiment**. *Sci Rep* 2023, **13**:10339.

This study shows that moths in a controlled enclosure are more likely to walk on or jump near relatively bright artificial light sources. Despite widespread claims that bright illumination suppresses nocturnal insect activity, the authors do not find any dose – effect response in the overall activity of moths across several levels of artificial light intensity.

45. Levy K, Wegrzyn Y, Moaraf S, Barnea A, Ayali A: **When night becomes day: artificial light at night alters insect behavior under semi-natural conditions**. *Sci Total Environ* 2024, **926**:171905.

46. •• Fabian ST, Sondhi Y, Allen PE, Theobald JC, Lin H-T: **Why flying insects gather at artificial light**. *Nat Commun* 2024, **15**:689.

This study leverages slow-motion cameras and 3D tracking technology to demonstrate that aerial insects do not fly directly toward artificial lights but rather continuously rearrange their dorsum to face the source of ambient illumination (in natural settings, the sky). This navigational error culminates in the characteristic erratic flight behavior of insects caught in the orbit of artificial lights.

47. Dietenberger M, Jechow A, Kalinkat G, Schroer S, Saathoff B, Hölker F: **Reducing the fatal attraction of nocturnal insects using tailored and shielded road lights**. *Commun Biol* 2024, **7**:671.

48. Gao B, Hu G, Chapman JW: **Effects of nocturnal celestial illumination on high-flying migrant insects**. *Philos Trans R Soc Lond B Biol Sci* 2024, **379**:20230115.

49. Eckhartt GM, Ruxton GD: **Insects within bushes assemble and forage closer to artificial light at night**. *Ethology* 2023, **129**:356-363, https://doi.org/10.1111/eth.13373

50. • Brown JA, Lockwood JL, Piana MR, Beardsley C: **Introduction of artificial light at night increases abundance of predators, scavengers, and parasites in arthropod communities**. *iScience* 2023, **26**:106203.

This study explores the effects of a five-night prelight period, a five-night lit period, and a five-night postlight period on the abundance of predators, scavengers, parasites, and herbivores. The authors find that community composition shifts during the lit period but quickly returns to prelight conditions after removal, suggesting that changes in arthropod abundance near artificial light result from short-term behavioral shifts.

51. • Deitsch JF, Kaiser SA: **Artificial light at night increases top-down pressure on caterpillars: experimental evidence from a light-naive forest**. *Proc Biol Sci* 2023, **290**:20230153.

This study used plasticine models and arthropod sampling to investigate how artificial light affects top-down pressure on caterpillars. The rate of attempted predation on plasticine caterpillars by arthropods was higher under artificial light than under natural illumination. Abundance of both predators and parasitoids also increased near artificial light sources.

52. Eckhartt GM, Ruxton GD: **Artificial light at night may decrease predation risk for terrestrial insects**. *Biol Lett* 2022, **18**:20220281.

53. Levy K, Barnea A, Tauber E, Ayali A: **Crickets in the spotlight: exploring the impact of light on circadian behavior**. *J Comp Physiol A Neuroethol Sens Neural Behav Physiol* 2024, **210**:267-279, https://doi.org/10.1007/s00359-023-01686-y

54. Rebar D, Bishop C, Hallett AC: **Anthropogenic light and noise affect the life histories of female *Gryllus veletis* field crickets**. *Behav Ecol* 2022, **33**:731-739, https://doi.org/10.1093/beheco/arac035

55. Ichikawa I, Kuriwada T: **The combined effects of artificial light at night and anthropogenic noise on life history traits in ground crickets**. *Ecol Res* 2023, **38**:446-454, https://doi.org/10.1111/1440-1703.12380

56. Fyie LR, Westby KM, Meuti ME: **Light pollution disrupts circadian clock gene expression in two mosquito vectors during their overwintering dormancy**. *Sci Rep* 2024, **14**:2398.

57. Mészáros Á, Kriska G, Egri Á: **Wavelength-specific negatively phototactic responses of the burrowing mayfly larvae *Ephoron virgo***. *J Exp Biol* 2024, **227**:jeb247142, https://doi.org/10.1242/jeb.247142