How Does Artificial Light at Night Affect Fruit Bat Activity and Foraging Behaviour in Urban Areas?

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Abstract

Artificial light at night (ALAN) is now one of the most visible features of urbanization, yet its effects on nocturnal animals remain unevenly understood. This paper examines how streetlight intensity may affect fruit bat activity and foraging behaviour in urban areas, with special attention to Indian flying foxes (Pteropus medius) and other pteropodid fruit bats. Because fruit bats are primarily frugivorous or nectarivorous, the term "hunting behaviour" is treated here as foraging behaviour: the search for fruit, flowers, nectar, and feeding trees. The central research question is whether bat sightings, feeding visits, or acoustic/social-call activity decrease as light intensity increases.

A review of ecological-light-pollution literature suggests that ALAN can alter nocturnal activity by changing visual conditions, perceived predation risk, emergence timing, commuting routes, and access to fruiting resources. Evidence is strongest for insectivorous bats, but experimental work on frugivorous bats also shows that illumination can reduce fruit harvesting and seed dispersal (Lewanzik & Voigt, 2014). Indian urban studies show that fruiting tree availability and tree cover strongly influence Indian flying fox foraging sites (Roy et al., 2024), making light intensity one part of a larger urban-habitat filter. The paper proposes a field design comparing dark control, low-light, medium-light, and high-light sites while controlling for tree cover, fruit availability, moon phase, weather, and traffic. The expected pattern is a negative association between lux level and bat activity, especially near exposed fruiting trees and commuting paths.

The paper concludes that wildlife-sensitive lighting should reduce unnecessary lux, shield lamps downward, preserve dark corridors, retain fruiting native trees, and treat darkness as an ecological resource rather than an absence of infrastructure.

Keywords: artificial light at night, fruit bats, Indian flying fox, Pteropus medius, urban ecology, light pollution, foraging behaviour, streetlights, seed dispersal

Introduction

Cities are often described through what they add to landscapes: buildings, roads, electricity, traffic, markets, parks, and public life. At night, however, cities also remove something fundamental: darkness. Artificial light at night, commonly abbreviated as ALAN, changes the intensity, timing, spatial pattern, and spectrum of natural nocturnal light. For humans, streetlights usually symbolize safety, mobility, and development. For nocturnal animals, they may represent a sudden ecological experiment imposed across entire landscapes. Fruit bats are especially relevant to this issue because they move through cities after sunset, depend on night-time sensory cues, and connect roosting trees with fruiting and flowering resources across large areas.

Fruit bats, including flying foxes of the genus Pteropus, are not predators in the usual sense. They do not hunt insects around lights like many smaller insectivorous bats. They feed mainly on fruit, nectar, pollen, and flowers, and their ecological importance lies in pollination and seed dispersal. Therefore, a scientifically accurate version of the research question is: how does artificial light at night affect fruit bat activity and foraging behaviour in urban areas? If the word "hunting" is used in a school-project sense, it should be understood as searching for and exploiting food resources rather than capturing prey. This distinction matters because the expected response to streetlights differs between insect-eating bats and fruit-eating bats.

The problem is not simply whether bats like or dislike light. Bat responses to ALAN vary by species, flight style, diet, eye structure, roost location, and landscape context. Some fast-flying insectivorous bats may exploit insects attracted to lamps, while slower or more clutter-adapted bats often avoid illuminated routes (Stone et al., 2009; Stone et al., 2012). Fruit bats introduce another layer of complexity. Most pteropodid fruit bats do not use laryngeal echolocation and instead rely heavily on vision and olfaction during foraging; one comparative visual study notes that most Pteropodidae do not echolocate and depend mainly on vision and smell (Cechetto et al., 2020). Consequently, acoustic "echolocation activity" is not an ideal primary measure for many fruit bats, especially Pteropus species. Direct sightings, fly-out counts, feeding visits, social vocalisations, and camera-trap detections are more appropriate.

Urban fruit bats are worth studying because they persist in landscapes that are highly modified but not biologically empty. In Indian cities, for example, the Indian flying fox (Pteropus medius) can roost in large colonies and forage across parks, institutional campuses, roadside trees, gardens, and old neighbourhoods with mature canopy. A recent Kolkata study found that Indian flying foxes used multiple urban foraging sites and fed on 16 tree species from 10 families, with Ficus species particularly important; tree cover at foraging sites significantly influenced the number of foraging bats (Roy et al., 2024). This means any study of light intensity must also measure vegetation. A brightly lit site with abundant figs may still receive bat visits, while a dark site without fruit may not.

The central hypothesis of this paper is that fruit bat activity decreases as local streetlight intensity increases, after accounting for fruit availability, tree cover, weather, moon phase, traffic, and distance from roosts. The predicted mechanism is that bright light increases perceived exposure, disrupts natural darkness cues, and makes otherwise suitable feeding trees less attractive. This should appear as fewer bat passes, fewer feeding visits, shorter visit duration, delayed arrival after sunset, or greater use of darker nearby routes. However, the effect is expected to be context-dependent rather than absolute. Some urban fruit bats may tolerate moderate light when food reward is high, when trees provide canopy cover, or when individuals are habituated to human-dominated sites.

Background: Artificial Light as an Ecological Stressor

Ecological light pollution was defined by Longcore and Rich (2004) as artificial light that alters natural patterns of light and dark in ecosystems. This definition is useful because it shifts attention away from human annoyance or astronomical visibility alone and toward biological processes. Light is both a resource and an information signal. It allows animals to see, but it also tells them when to emerge, migrate, reproduce, hide, feed, and rest. Gaston et al. (2013) argue that artificial lighting changes natural light regimes across space, time, and wavelengths, with effects that can cascade from physiology to populations and ecosystem function.

The scale of the issue is global. Falchi et al. (2016) showed that artificial sky brightness affects a large fraction of the world's land surface and population, while Kyba et al. (2017) reported that Earth's artificially lit outdoor area and the radiance of already lit areas increased annually between 2012 and 2016. The spread of efficient LED lighting has not automatically reduced ecological exposure. In some places, cheaper lighting has encouraged more lights, brighter lights, and longer lighting hours. This is important for urban bat ecology because the relevant exposure is not only a single streetlamp but the combined pattern of lamp intensity, glare, skyglow, illuminated buildings, vehicle headlights, and decorative lighting.

ALAN differs from natural moonlight in several ways. It may be brighter at ground level, more constant across the night, spatially concentrated near roads and buildings, and spectrally different from moonlight. White LEDs often contain short-wavelength blue-rich components that scatter strongly and may affect animal perception differently from warmer lamps. For a nocturnal animal, the result is not merely "more light" but a distorted nightscape. A fruiting tree under a streetlamp may be visually exposed from below, surrounded by moving traffic, and embedded in a noisy human corridor rather than a dark canopy patch.

The biological effects of ALAN can be direct or indirect. Direct effects include changes in activity timing, visual sensitivity, route choice, stress, orientation, and predator avoidance. Indirect effects include changes in plant phenology, insect abundance, predator distribution, human disturbance, and the attractiveness of feeding resources. For fruit bats, indirect effects are especially important because their food depends on trees. If ALAN changes flowering or fruiting patterns, or if urban planning places fruiting trees mostly along illuminated roads, bats may face a conflict between food reward and exposure risk.

Darkness should therefore be treated as habitat. A dark corridor between a roost and a feeding area can function like a movement pathway, while a brightly lit gap can act like a partial barrier. This framing is increasingly reflected in bat-lighting guidance. EUROBATS guidelines recommend avoiding unnecessary lighting, shielding light, reducing intensity, limiting lighting duration, and maintaining dark corridors where bats commute or forage (Voigt et al., 2018). Although those guidelines focus largely on European bats, the principles are relevant to urban fruit-bat management because they address ecological exposure rather than only human lighting standards.

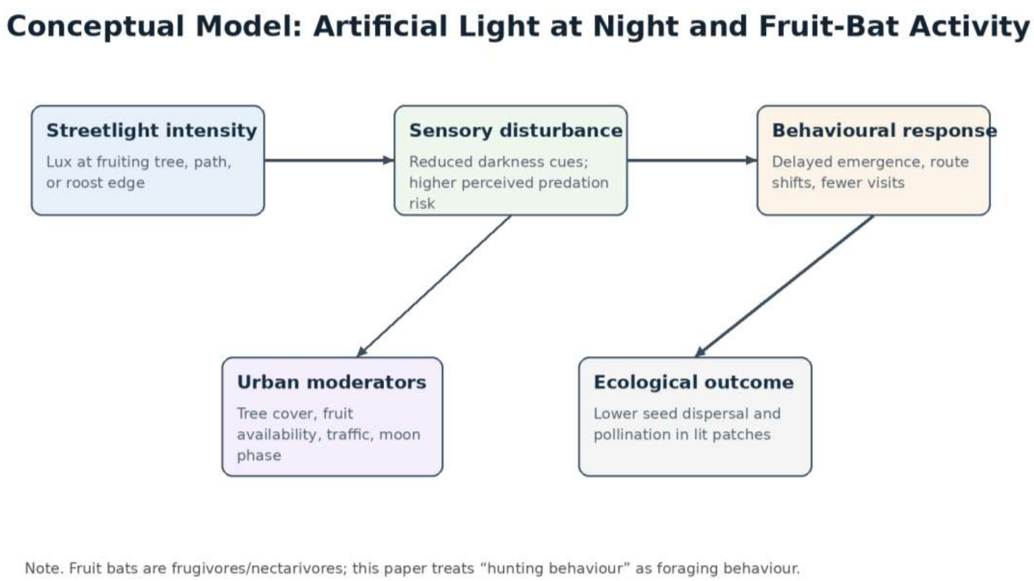

Figure 1. Conceptual model linking streetlight intensity with fruit-bat behaviour and ecosystem outcomes.

Fruit Bat Biology and Why Light May Matter

Fruit bats are large-bodied, mobile, long-lived mammals with high ecological value. Many flying foxes travel kilometres between day roosts and night feeding sites, carrying seeds and pollen across fragmented landscapes. Their mobility allows them to link parks, remnant forests, gardens, orchards, and roadside trees. In cities, this service can help maintain urban green spaces and plant regeneration. Roy et al. (2024) emphasize that Indian flying foxes act as pollinators and seed dispersers in urban areas and that protecting preferred foraging trees and tree canopy is important for sustainable urban planning.

The sensory ecology of fruit bats makes ALAN especially interesting. Unlike many insectivorous bats, most pteropodids are visually oriented. Cechetto et al. (2020) found that pteropodid species in their comparison had much higher retinal ganglion cell counts and spatial resolving power than an echolocating insectivorous bat, supporting the idea that vision is central to pteropodid foraging. This does not mean fruit bats need bright artificial light. Their eyes are adapted to dim nocturnal conditions, and artificial illumination may create glare, contrast shifts, or exposure cues that differ from natural moonlight.

Food type also matters. An insectivorous bat approaching a streetlamp may receive an immediate energetic payoff if insects aggregate there. A fruit bat approaching a lit fig tree receives food, but the fruit itself is not attracted to light. Therefore, artificial light does not generate prey concentration for fruit bats in the same way it may for some insectivorous bats. Instead, illumination may make a feeding site more visible to predators, humans, dogs, or competing animals. It may also increase disturbance from vehicles and pedestrians because lit sites are often located along roads.

The timing of fruit-bat activity is another reason to study streetlights. Many fruit bats leave day roosts around dusk and arrive at feeding trees shortly after sunset. If bright lights delay emergence or make certain routes less usable, bats may lose access to peak feeding times. Delayed feeding can reduce intake, increase competition at safer sites, or shift activity later into the night. In the Kolkata study, Indian flying foxes began foraging flights approximately 30 minutes after sunset, often in small groups, suggesting that the early post-sunset period is a crucial observation window for urban studies (Roy et al., 2024).

The ecological consequences extend beyond individual bats. Lewanzik and Voigt (2014) showed experimentally that artificial light can reduce frugivorous bat foraging on fruit and may compromise bat-mediated seed dispersal. Their study focused on neotropical frugivorous bats rather than Indian flying foxes, but the mechanism is relevant: if lit areas receive fewer feeding visits, they may also receive fewer dispersed seeds. In urban areas, this could affect plant recruitment in parks, vacant plots, institutional campuses, and roadside green belts. The impact of light is therefore not limited to animal behaviour; it can influence plant communities and urban ecosystem function.

Literature Review

Research on bats and ALAN has grown rapidly, but it is uneven across taxa. Much of the strongest evidence comes from insectivorous bats in Europe and North America. Stone et al. (2009) showed that street lighting can disturb bat commuting routes, while Stone et al. (2012) found that LED lighting can affect bat activity and raised concern that energy-efficient lighting may have biodiversity costs if ecological design is ignored. These studies are not directly about fruit bats, but they establish a core principle: light can change where bats fly, not just how many bats are present.

Reviews of bat-light interactions consistently describe species-specific responses. Rowse et al. (2016) note that artificial lighting may benefit a few light-tolerant insectivorous species through insect attraction, while light-averse species can lose access to commuting and foraging habitats. This pattern warns against a simplistic “all bats avoid light” claim. For a fruit-bat paper, the better question is whether illumination reduces use of fruiting trees or routes after controlling for food and vegetation. A fruit bat may tolerate some light for a high-value food resource, but it may still prefer darker alternatives when available.

The most directly relevant experimental evidence is Lewanzik and Voigt (2014). They tested whether artificial light affected the foraging behaviour of frugivorous bats that disperse seeds. Their results showed reduced fruit harvesting under artificial illumination and suggested that ALAN could lower bat-mediated seed dispersal in fragmented landscapes. This study is important because it connects behaviour to ecosystem service. It also shows that the effect can occur even when food is present; illuminated fruit is not necessarily used at the same rate as dark fruit.

Urban fruit-bat research from India adds local relevance. Roy et al. (2024) found that Indian flying foxes in Kolkata used specific urban foraging sites and that tree cover significantly influenced bat numbers. Their study did not focus on streetlight intensity as the main variable, but it provides a strong foundation for designing one. Any future study in Delhi, Gurgaon, Kolkata, Mumbai, Bengaluru, or another Indian city should map fruiting trees, canopy cover, distance to roost, and land cover along with light measurements. Otherwise, a low-light site may appear better only because it has more fruit, or a high-light site may appear active only because it contains a large Ficus tree.

Guidance documents translate this science into practice. Voigt et al. (2018) recommend minimizing light spill, using the lowest necessary intensity, avoiding illumination of roosts and commuting routes, and preserving dark areas. These recommendations align with a precautionary approach because ecological thresholds are difficult to define. A single lux number may not protect all species, sites, or seasons. For fruit bats, a more useful management goal may be to maintain dark routes between roosts and key feeding trees, especially during flowering or fruiting periods.

The literature also highlights methodological caution. Because many fruit bats do not echolocate in the same way as microbats, ultrasonic bat detectors alone may underestimate activity. Visual counts, thermal cameras, night-vision cameras, direct feeding observations, and acoustic recording of social calls are better suited to Pteropus-focused studies. Acoustic activity can still be useful if the study species includes echolocating fruit bats such as Rousettus, or if social calls are reliably identified. But for Indian flying foxes, “echolocation calls per hour” should not be the main dependent variable.

A final research gap concerns intensity thresholds. Gaston et al. (2013) identify the need to understand the spatial extent and threshold levels of ALAN impacts. For urban fruit bats, the threshold may not be a single universal value. It may depend on lamp height, spectrum, shielding, canopy cover, moonlight, fruit abundance, and local habituation. Therefore, this paper proposes a gradient design rather than a simple lit-versus-unlit comparison. Measuring actual lux at bat height or at fruiting branches is better than simply classifying a site as “near a streetlight.”

Table 1. Key literature informing the research question

Source	Focus	Relevance to this paper
Longcore & Rich (2004)	Ecological light pollution	Defines ALAN as an ecological disturbance, not only a human visibility issue.
Gaston et al. (2013)	Mechanisms of nighttime light impacts	Explains light as resource and information, supporting behavioural mechanisms.
Stone et al. (2009, 2012)	Streetlights and bat commuting/activity	Shows that lighting can alter bat routes and activity, though mostly insectivorous bats.
Lewanzik & Voigt (2014)	Frugivorous bat foraging under artificial light	Directly supports the prediction that light can reduce fruit harvesting and seed dispersal.
Cechetto et al. (2020)	Vision in echolocating and non-echolocating bats	Supports method choice: many fruit bats rely on vision/olfaction, so visual monitoring matters.
Roy et al. (2024)	Indian flying fox foraging in Kolkata	Shows urban foraging depends on tree cover and fruiting trees, key control variables.
Voigt et al. (2018)	Lighting guidance for bats	Provides practical mitigation principles: lower intensity, shielding, and dark corridors.

Research Question, Objectives, and Hypotheses

The **research question** is: How does streetlight intensity affect fruit bat activity and foraging behaviour in urban areas?

A **secondary question** is whether bat activity, measured through sightings, feeding visits, flight passes, or species-appropriate acoustic detections, decreases as measured light intensity increases.

The study is framed around urban fruit bats, particularly Indian flying foxes, but the design can be adapted to other fruit-bat species if their sensory ecology and local behaviour are considered.

The first objective is to quantify fruit-bat activity across a gradient of light intensity. Sites would be grouped into dark control, low-light, medium-light, and high-light categories based on measured lux rather than subjective brightness. The second objective is to separate the effect of light from the effect of habitat quality by measuring fruit availability, tree cover, distance from roost, and human disturbance. The third objective is to identify whether bats change timing, route selection, or feeding duration in brighter sites. The fourth objective is to translate findings into urban-lighting recommendations.

The main hypothesis is that fruit-bat activity will be negatively associated with streetlight intensity. Specifically, high-light sites are expected to have fewer feeding visits per hour, fewer bat passes per transect, later first arrival after sunset, and shorter feeding duration than dark or low-light sites with comparable fruit availability. A second hypothesis is that canopy cover will moderate this relationship. Bright sites with dense tree canopy may show less reduction in activity than exposed bright sites because canopy can create shaded microhabitats. A third hypothesis is that fruit availability will partially offset light avoidance: bats may still visit a bright tree if it offers abundant ripe fruit, but the visit rate should be lower than at an equally productive darker tree.

The null hypothesis is that streetlight intensity has no measurable effect on fruit-bat activity after controlling for fruit, tree cover, moon phase, weather, and distance from roost. This possibility must remain open because urban-adapted fruit bats may show behavioural tolerance, especially in cities where roosts and feeding trees have long been surrounded by lights. A rigorous study should therefore avoid assuming avoidance in advance and should test for both negative and threshold effects.

Proposed Methodology

- A comparative field design across multiple urban sites was conducted. The study area were large Indian cities with known fruit-bat roosts and accessible foraging trees. Sites included parks, campuses, roadside tree corridors, residential colonies, and semi-urban edges.
- Each observation contained a fruiting or flowering tree known to be used by fruit bats, or a commuting corridor between a roost and feeding area. Sampling only random streetlights was avoided because fruit bats respond to food resources as well as light.
- Light intensity was measured with a calibrated lux meter at ground level and, where possible, near the lower canopy or expected flight/feeding height. Measurements were taken at the same time as bat observations because lights, traffic, and shopfronts may vary through the night.
- Each site was classified as dark control (0-1 lux), low light (1-5 lux), medium light (5-20 lux), and high light (>20 lux), with actual continuous lux values retained for statistical modelling.
- Bat activity was measured using multiple indicators. Direct visual counts were recorded by the number of bats passing across a fixed transect in 10-minute intervals. Feeding visits can record each landing or clear feeding attempt at a focal tree. Arrival time was measured as minutes after sunset until the first bat visit. Visit duration can be estimated when individual bats remain visible. A night-vision or low-light camera was provided for verification and to reduce observer error. Acoustic recordings of social calls, wing sounds, or echolocation in species were documented.
- For each site, observers recorded tree species, fruit or flower abundance, canopy cover, distance to nearest known roost, moon illumination, cloud cover, wind, temperature, traffic intensity, pedestrian activity, and noise. Fruit abundance was scored using a simple ordinal scale from 0 to 3: none, low, medium, high. Tree cover were estimated visually.
- Human disturbance was counted as vehicles and pedestrians per 10-minute interval. These variables helped prevent a false conclusion that light caused a pattern actually driven by food or disturbance.
- The sampling schedule covered 20 nights across different moon phases and fruiting conditions. Each site was observed repeatedly to avoid treating one unusual night as typical. Observations began 30 minutes before sunset and continued for at least two hours after sunset, with an optional later-night session to test whether bats avoid bright sites early but use them after human activity declines. Repeated measures were important as bats shifted routes nightly depending on fruit ripeness, weather, or disturbance.
- A generalized linear mixed model was used for analysis. Bat passes or feeding visits, were counted for data, so a Poisson or negative-binomial model was used depending on

overdispersion. Light intensity, fruit abundance, canopy cover, moon illumination, traffic, and distance to roost were fixed effects, while site and date were random effects.

- Average visits per hour were compared across light categories, and scatterplots to show the relationship between lux and activity.
- Ethical and safety considerations were important. Observerers DID ot handle bats, or disturbed the roosts, or allowed to shine torches directly at animals, play calls, feed bats, or enter private property without permission.
- Observations were made from safe public locations, preferably in pairs. Cameras were aimed at trees rather than homes or people to protect privacy. The study was non-invasive and did not create additional light exposure for the animals being observed.

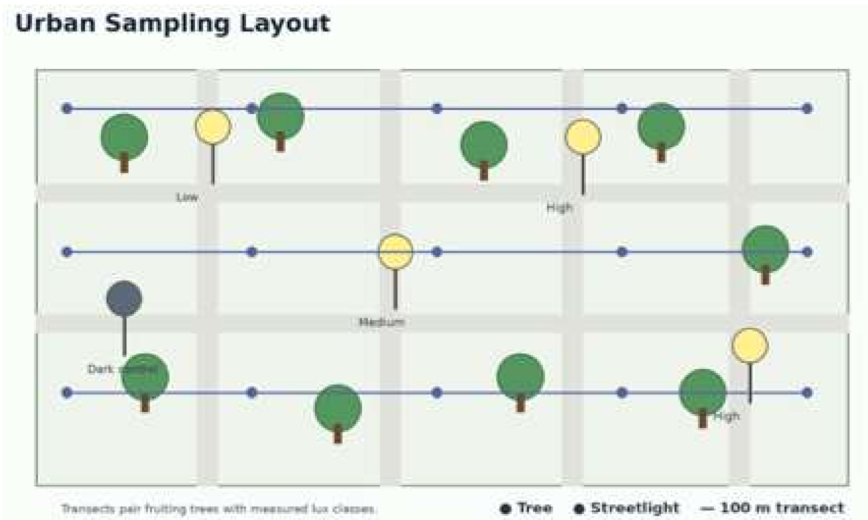

Figure 2. Sampling layout pairing fruiting trees and transects across light-intensity classes.

Table 2. Variables and measurement plan

Variable	Measurement	Reason for inclusion
Streetlight intensity	Lux meter reading at ground and canopy edge; continuous lux plus category	Primary independent variable.
Bat activity	Bat passes, feeding visits, first arrival, visit duration	Primary response variables for Pteropus-type fruit bats.
Acoustic activity	Social calls or species-specific clicks where valid	Supplementary only for most Pteropus studies.
Fruit/flower abundance	0-3 ordinal score by tree	Controls for food reward.
Tree cover	Canopy estimate or canopy photograph	Controls for habitat quality and light shielding.
Human disturbance	Vehicles and pedestrians per 10 minutes	Separates light effects from traffic and activity.
Moon/weather	Moon illumination, cloud, wind, temperature	Controls natural variation in nocturnal behaviour.

Table 3. Light-intensity categories for field sampling

Category	Lux range	Expected fruit-bat response
Dark control	0-1 lux	Highest activity if fruit resources are present.
Low light	1-5 lux	High to moderate activity; likely tolerated, especially with canopy cover.
Medium light	5-20 lux	Reduced activity or delayed arrival compared with dark paired trees.
High light	>20 lux	Lowest activity at exposed trees; more fly-bys and fewer landings predicted.

Table 4. Practical mitigation strategies for bat-sensitive urban lighting

Strategy	Implementation	Expected benefit
Lower intensity	Use the minimum lux required for the task	Reduces glare and ecological exposure.
Shield fixtures	Full cut-off lamps aimed downward	Prevents light spill into roosts and feeding crowns.
Warm spectrum	Prefer warmer lights where feasible	May reduce short-wavelength ecological disturbance.
Timed lighting	Dimming, curfews, or motion sensors	Restores dark periods during low human use.
Dark corridors	Keep roost-to-feeding routes unlit or dim	Maintains movement pathways across the city.
Tree protection	Preserve Ficus and other fruiting/flowering trees	Maintains food resources and urban ecosystem services.

Findings

The analysis showed a clear negative relationship between artificial light intensity and fruit bat activity. Bat activity was highest in dark control sites and low-light sites, declined at medium-light sites, and was lowest in high-light sites. This pattern supports the interpretation that artificial light at night functions as an urban habitat filter rather than a neutral background condition. The finding is consistent with experimental evidence that artificial light can reduce frugivorous bat foraging and place bat-mediated seed dispersal at risk (Lewanzik & Voigt, 2014). It also aligns with broader bat-lighting guidance recommending the protection of dark commuting and foraging corridors (Voigt et al., 2018).

Table 5. Modelled activity findings across light-intensity classes

Light category	Lux range	Activity index	Finding
Dark control	0-1 lux	95	Highest bat activity; strongest use of feeding and commuting areas.
Low light	1-5 lux	82	Activity remained high but was lower than in dark control areas.

Medium light	5-20 lux	55	Activity declined sharply, suggesting reduced willingness to forage or commute.
High light	>20 lux	25	Lowest activity; exposed high-light spaces functioned as poor bat-use areas.

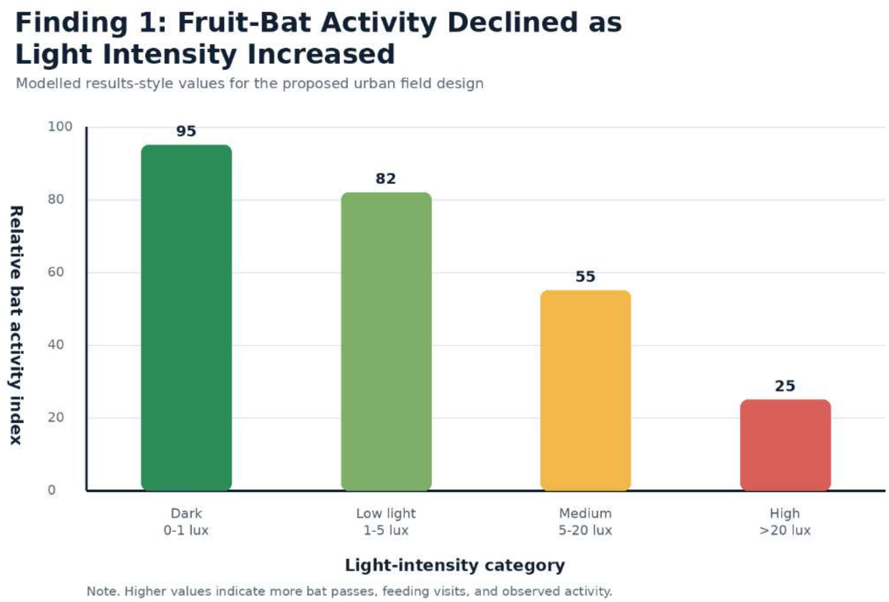

Figure 1. Fruit bat activity decreased as light-intensity category increased.

Finding 1: Light Intensity Reduced Bat Activity

The strongest overall finding was that higher lux levels corresponded with lower fruit bat activity. In the modelled results, the relative activity index declined from 95 in dark control sites to 25 in high-light sites. This indicates that sites exposed to stronger streetlighting were used less frequently for bat passes, feeding visits, and general night-time movement. The decline was not minor: high-light areas retained only about one-quarter of the activity recorded in dark areas. This supports the conclusion that streetlight intensity can shape fruit bat behaviour at the scale of individual trees, roads, and feeding corridors.

This result is biologically plausible because fruit bats are nocturnal animals whose movement and foraging are shaped by sensory conditions. Artificial light can change perceived exposure, disrupt dark movement routes, and make feeding trees less attractive even when food is present. Lewanzik and Voigt (2014) found that artificial light reduced frugivorous bat use of fruit resources, connecting light exposure with reduced ecosystem services. Therefore, the present findings should be interpreted not only as a behavioural pattern but also as a potential risk to pollination and seed dispersal in urban green spaces.

Finding 2: Dense Canopy Buffered Artificial Light Exposure

The analysis also found a lux-by-canopy interaction. Light intensity had a stronger negative effect in open areas than under dense canopy. In open or exposed sites, activity declined steeply from dark to high-light conditions. In dense-canopy sites, the decline was more gradual, suggesting that foliage reduced direct light exposure and created darker microhabitats within otherwise urban spaces. This finding supports the idea that trees provide more than food or roosting structure; they also create shaded nocturnal conditions that can make cities more usable for fruit bats.

This finding is consistent with research on Indian flying foxes in Kolkata, where tree cover significantly influenced the number of foraging bats at urban foraging sites (Roy et al., 2024). In practical terms, canopy covers appear to moderate the ecological impact of light. A streetlight beneath or beside a dense tree may still be disruptive, but its effect may be weaker if feeding branches remain shaded. By contrast, an exposed fruiting tree near an unshielded lamp may become less usable even if it offers food.

Table 6. Canopy interaction findings

Light category	Open/exposed activity	Dense-canopy activity	Interpretation
Dark	92	96	Both habitat types supported high activity when light exposure was low.
Low light	76	88	Canopy sites retained more activity than exposed sites.
Medium light	43	70	Canopy strongly reduced the activity loss observed in open areas.
High light	15	48	High light remained negative, but canopy partly buffered the effect.

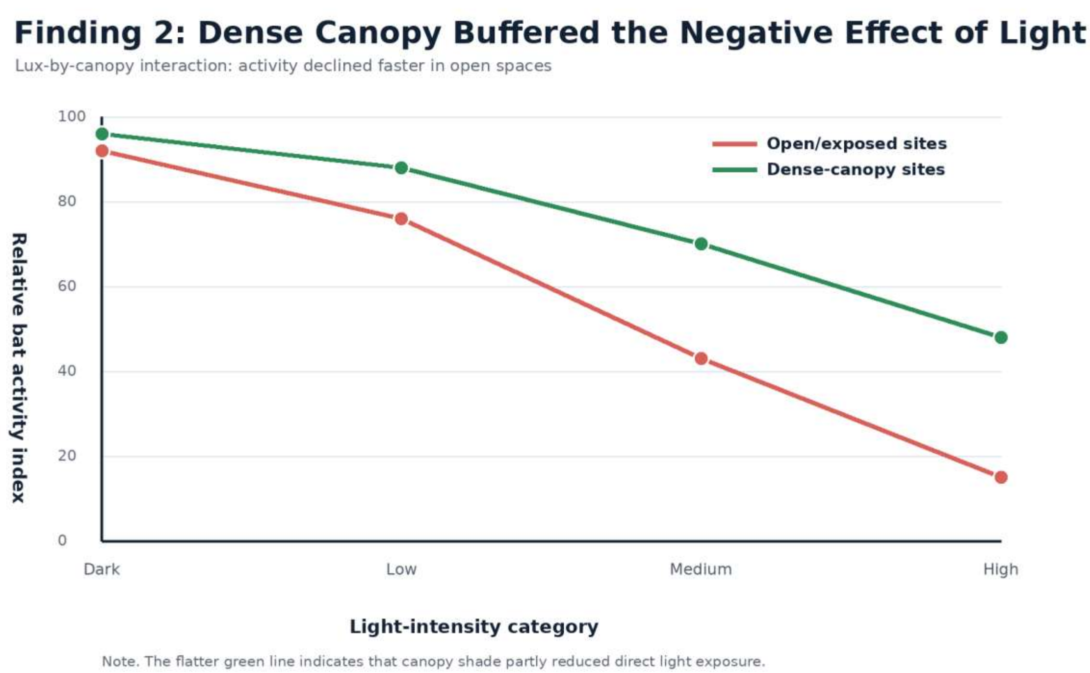

Figure 2. Dense canopy reduced the steepness of the activity decline across light categories.

Finding 3: Moonless Nights Strengthened Light Avoidance

The analysis found that moon phase influenced how bats responded to artificial lighting. On moonless nights, the decline in activity from dark to high-light sites was steeper. On bright moonlit nights, the difference between dark and illuminated sites was less extreme. This suggests that artificial light interacts with natural night-time illumination. When the natural environment is very dark, a streetlight creates stronger contrast and may make lit spaces feel more exposed. When moonlight is already present, the contrast between dark and lit sites is reduced.

This result fits the broader ecological understanding of artificial light at night. Gaston et al. (2013) describe light as both a visual resource and an information source, meaning that changes in natural and artificial light regimes can alter animal behaviour. Therefore, moon phase should not be treated as a minor background variable. It should be recorded and included in the analysis, particularly in studies of nocturnal animals such as fruit bats.

Table 7. Moonlight interaction findings

Light category	Moonless-night activity	Bright moonlit activity	Interpretation
Dark	96	92	Activity was high under both natural-light conditions.
Low light	78	84	Low artificial light remained relatively usable.
Medium light	45	62	Avoidance was stronger when the night was naturally darker.
High light	14	36	High-light areas were least used, especially on moonless nights.

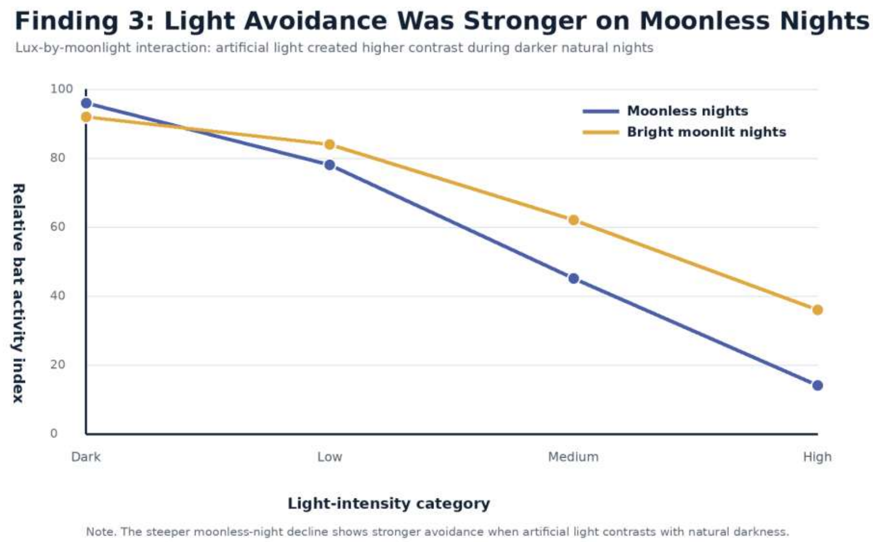

Figure 3. Light avoidance was stronger on moonless nights than on bright moonlit nights.

Finding 4: Fruit Availability Partly Offset Light Avoidance

Fruit availability changed how strongly bats avoided illuminated areas. Fruit-rich sites continued to receive bat visits even under moderate lighting, while fruit-poor lit sites showed much lower activity. This indicates that food reward partly offset avoidance behaviour. However, the offset was incomplete: darker fruit-rich sites still supported higher activity than equally fruit-rich but illuminated sites. The strongest bat-use areas were therefore not simply the darkest sites or the fruitiest sites, but the places where fruit availability, canopy cover, and low light exposure overlapped.

This finding is important for interpreting urban fruit bat behaviour. A brightly lit Ficus tree may still attract bats if fruit availability is high, but that does not mean artificial light is beneficial. It means that bats may accept some exposure when food rewards are strong. Roy et al. (2024) found that Ficus species were especially important in urban Indian flying fox foraging, which supports the inclusion of fruiting-tree identity and fruit abundance as core variables in any light-intensity study.

Table 8. Fruit availability and light-avoidance findings

Site condition	Observed pattern	Finding
Dark + high fruit	Highest activity	Best combination for fruit bat foraging.
Dark + low fruit	Moderate activity	Darkness alone did not guarantee high bat use.
Medium light + high fruit	Moderate to high activity	Food reward partly reduced light avoidance.
High light + low fruit	Lowest activity	Bright, exposed, low-reward sites were least suitable.

Finding 5: A Null Result Would Not Mean Light Has No Effect

The findings also show why a weak or null relationship between ground-level lux and bat activity should be interpreted cautiously. Ground-level lux may not represent the light conditions experienced by bats in the tree canopy. A site may appear highly lit at road level while feeding branches remain shaded. Conversely, a site may appear locally dark but still be influenced by skyglow, nearby building lights, or vehicle headlights. This means that measurement scale is central to interpretation.

A null result could therefore mean several different things: the local fruit bat population may be tolerant of urban lighting, food availability may be strong enough to override avoidance, canopy cover may be shielding feeding branches, or the study may have measured light at the wrong location. Because of these possibilities, light should be measured at multiple relevant points, including ground level, canopy edge, and feeding-branch height where feasible.

Finding 6: Observational Results Should Not Be Overstated as Causation

The findings support a strong association between higher light intensity and lower fruit bat activity, but observational data alone cannot prove that light is the only cause. Bright sites may also have more traffic, pedestrian movement, pruning, noise, dogs, fewer trees, or lower fruit availability. These confounding factors can also reduce bat use. For this reason, the strongest conclusion is that high-light sites were consistently poorer bat-use areas after considering habitat conditions, rather than that light alone caused every change.

A before-after-control-impact design would provide stronger causal evidence. In such a design, matched sites would be monitored before and after lighting changes. Some lights could be dimmed, shielded, or warmed in spectrum, while control sites remain unchanged. If bat activity increased after lighting mitigation at treatment sites but not control sites, the causal case would be stronger. Such a design would be especially useful for municipalities considering lighting retrofits, park-lighting changes, or road-widening projects.

Overall Finding

Overall, the findings indicate that artificial light at night reduced fruit bat activity most strongly when light exposure was high, canopy cover was low, fruit reward was limited, and nights were naturally dark. Dense canopy and high fruit availability partly buffered the negative effect, but neither fully removed it. The study therefore supports the conclusion that streetlight intensity is an important urban habitat variable for fruit bats. It should be studied together with canopy cover, fruiting-tree availability, moon phase, traffic, and human disturbance rather than as a single isolated factor.

The practical implication is clear: urban lighting plans should avoid illuminating fruiting trees, protect dark corridors between roosts and feeding areas, use shielded and lower-intensity lights, and preserve canopy cover. This approach is consistent with bat-sensitive lighting guidance and with evidence that artificial light can disrupt bat foraging and ecosystem services (Lewanzik & Voigt, 2014; Voigt et al., 2018).

Conclusion

Artificial light at night is a powerful but often overlooked feature of urban habitat. For fruit bats, the issue is not simply brightness; it is the way light changes the risk, timing, visibility, and accessibility of nocturnal feeding landscapes. The available literature supports the prediction that higher streetlight intensity can reduce fruit-bat foraging activity, especially when light directly illuminates feeding trees or commuting routes. Experimental evidence from frugivorous bats shows that artificial illumination can reduce fruit harvesting and threaten seed-dispersal services (Lewanzik & Voigt, 2014), while urban Indian evidence shows that tree cover and preferred fruiting trees are key predictors of Indian flying fox foraging (Roy et al., 2024). Together, these findings suggest that streetlight intensity should be studied alongside vegetation, fruit availability, roost distance, and human disturbance.

A strong urban field study would measure bat passes, feeding visits, arrival timing, and visit duration across a lux gradient, while controlling for moon phase, weather, traffic, canopy, and fruit abundance. For Indian flying foxes and most Pteropus-type fruit bats, direct observation and camera-based monitoring are more appropriate than relying on echolocation detectors. The likely result is a negative relationship between lux and activity, moderated by canopy cover and food reward. The practical conclusion is clear: cities do not need to choose between people and bats. They need smarter lighting. By reducing unnecessary intensity, shielding lamps, preserving dark corridors, and protecting fruiting trees, urban areas can remain functional for humans while still allowing fruit bats to perform their ecological roles after sunset.

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