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A Systematic Review on Artificial-Light-at-Night (ALAN): Foraging Activity and Behavioral Patterns Involving the Chiroptera

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Abstract: Artificial Light at Night (ALAN) exposure on nocturnal animals is a growing environmental threat to wildlife, particularly to the species of bats. Understanding the negative impact of this anthropogenic event on wildlife can reduce the disruption in the behavioral pattern, which ameliorates the survival strategies, to acclimate successfully to the environment—adaptation. However, some of the related studies regarding the effect of ALAN on behavioral patterns of bats are limited. The main objective of this systematic review was to expound the sample size and to determine the correlation between the light exposure and the bat's adaptation, focusing on the behavioral approach. To synthesize, the relevant studies such as the registered and databases were analyzed through a proper identification of the eligible sources and removal of the duplicates. Lack of access to literature and irrelevant studies were automatically excluded in the screening process. The synthesis revealed that bats experienced significant avoidance behavior in blue-rich LED lighting with a high intensity of (≥50 lux), while other species exhibited attraction to low-intensity due to the insect abundance. On the other hand, urban-adapted species demonstrated a high tolerance on light exposure, whereas forest-dwelling and edge species showed heightened sensitivity. The findings suggest species-specific light tolerances and its long-term behavioral impacts. By integrating these findings in urban planning and conservation efforts, the adverse effect of ALAN on bat's behavior can be minimized, in addition to ensure the preservation of their essential ecosystem services.

Keywords: *Adaptation, Bats, LED, Light Condition, Light Intensity, Light Pollution.*

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I. INTRODUCTION

Light pollution in wildlife is the overabundance of brightness by means of extensive use of artificial light sources that inflicts disruption in the behavioral pattern and physiological aspects such as the Circadian Rhythm (Kyba, 2025). Nocturnal animals are mostly affected by this type of harmful presence because they are highly active during night, thus the presence of Artificial Light at Night (ALAN) adversely affects their adaptation in the environment. This anthropogenic phenomenon of using artificial lights near in nocturnal habitat discomforts an order such as C*hiroptera* or bats, which is commonly known for its heightened senses in hearing and vision. *Chiroptera* requires echolocation to perceive the location of their prey and avoidance in predation, therefore the significance of non-polluted in artificial lights play a vital role in the survival and behavioral pattern (Stone, E. L et. al., 2020)

Previous studies have conducted various methods of determining the effects of ALAN in bat activities, all the findings highlighted a significant change regarding their foraging, roosting and communication. The parameters differ in light intensity, spectral composition of light, insect abundance and diversity in lighted areas. Using materials such as acoustic monitoring, light measurement, tracking

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technology, and insect population assessments, it provides the systematic interpretation of bat activities through a behavioral approach. These reviewed studies contributed valuable data on determining the effect of ALAN in bat activities. It provides significant results, however, some findings lacked large sample sizes which made the results hard to generalize.

The study aims to fill gaps regarding the behavioral patterns in bats, and how the light pollution affects them synchronously in their daily lives. The foraging patterns and how it affects their behavior, being a nocturnal animal. Different methodological processes were done in supporting literature that has varying results and interpretations. Through this systematic review, the researchers can synthesize and interpret the following related literature that can give insights and claims regarding how the behavior of the bats are affected due to their exposure to artificial light.

The study will assess the risks involving bats and their interaction within their environment, the changes in their behavior after exposure to artificial lights at night. This paper can also be used to contribute to the further studies of the ALAN and its effect on bats. This can be utilized to further know the foraging behaviors of the bats, understand the interaction with its surroundings, and identify the behavioral patterns it has.

II. METHODOLOGY

The systematic review aims to synthesize various related literature regarding the behavioral patterns of the bats. In this section, the selection of the related studies that will be employed in the paper is screened through these processes.

A. Design Approach

The researchers utilized the Preferred Reporting Items for Systematic Reviews and Meta-analysis or PRISMA. It consists of a series of steps, such as searching for the related studies, skimming the abstract, screening the full paper, and finalizing the papers that will be used in the review. This approach will also be used in the framework of the paper.

B. Instrumentation Approach

Search engines of Google Scholar and Google were used, that lead to the sites of the ResearchGate, Pubmed or National Library of Medicine, MDPI Open Access Journals, International Journal of Innovative Science and Research Technology or IJRST, ScienceDirect, Springer Nature, and other accessible journal public sites or government sites that has factual claims. Several bat websites also have articles regarding the risks and effects of its exposure to artificial light at night. With the use of right filtering of the timeline in years, from the year 2015 - 2025, and determining which study discusses the goal of the paper. The first set of keywords used are “bats and light pollution”, “bats and artificial light”, or “bats in the urban setting”. The second set keywords used are the “behavioral patterns of bats in light”, “bat movements in response to artificial light”, or “chiroptera activity in light at night”. The last set of keywords include “intensity of light in bats” and “foraging behavior of bats in response to light”.

All of the collected related studies in the preliminary searching were based both on the publication title and the skimming of the abstract provided. To exclude the duplicates in the gathered literature, screening the whole paper is adhered.

C. Inclusion and Exclusion Criteria

All relevant studies accumulated are classified in respect to: (1) the behavioral patterns of the Chiroptera family in relation the artificial night at light; (2) bat activity in response to the exposure of artificial light at night; (3) research studies conducted and published within the timeline of 2015 - 2025; (4) peer-reviewed journals and other articles related to the literature and (5) studies published in English or provide accurate English translation.

Studies that belong to the area of exclusion are due to: (1) duplicates, that has the same title but in different sites; (2) papers that lack the relevance to the goal of the paper and (3) related literature that are not peer-reviewed and at the same time published before the required timeline.

D. Search Results

From the gathered related literature, a total of 29 studies are searched from the engines of the Google Scholar and Google, specifically from the sites of PubMed, ResearchGate, MDPI, IJRST, ScienceDirect, Springer Nature, and other government-funded sites. From the pool of 29 papers, only 19 studies were chosen based on the inclusion criteria set. The 19 papers handpicked are due to its relevance to the objectives and screened in accordance with the criteria set in inclusion. 10 out 19 related literatures can be used for quantitative analysis and 9 papers from the pool of 19 related literatures will be used in the review which can be interpreted for qualitative analysis. See Figure 1 which summarizes the process of PRISMA in the paper.

E. Data Extraction

The 29 related studies are assessed to identify the behavioral patterns involving the bats in relation to artificial light exposure at night. Still, the information relevant regarding the study was utilized to the extent. The chosen 19 related literature from the 29 preliminary studies supplied insights and claims regarding the effect of ALAN on bats. Furthermore, supplementary factors are also provided, examining the various patterns involving bats that were seen while on the review process. These related literatures collected are screened to obtain information regarding the study.

F. Statistical Analysis

The 19 related literature are grouped whether it has the basis for the qualitative analysis or in the quantitative analysis. Both existing data from the collected studies are identified and tabulated.

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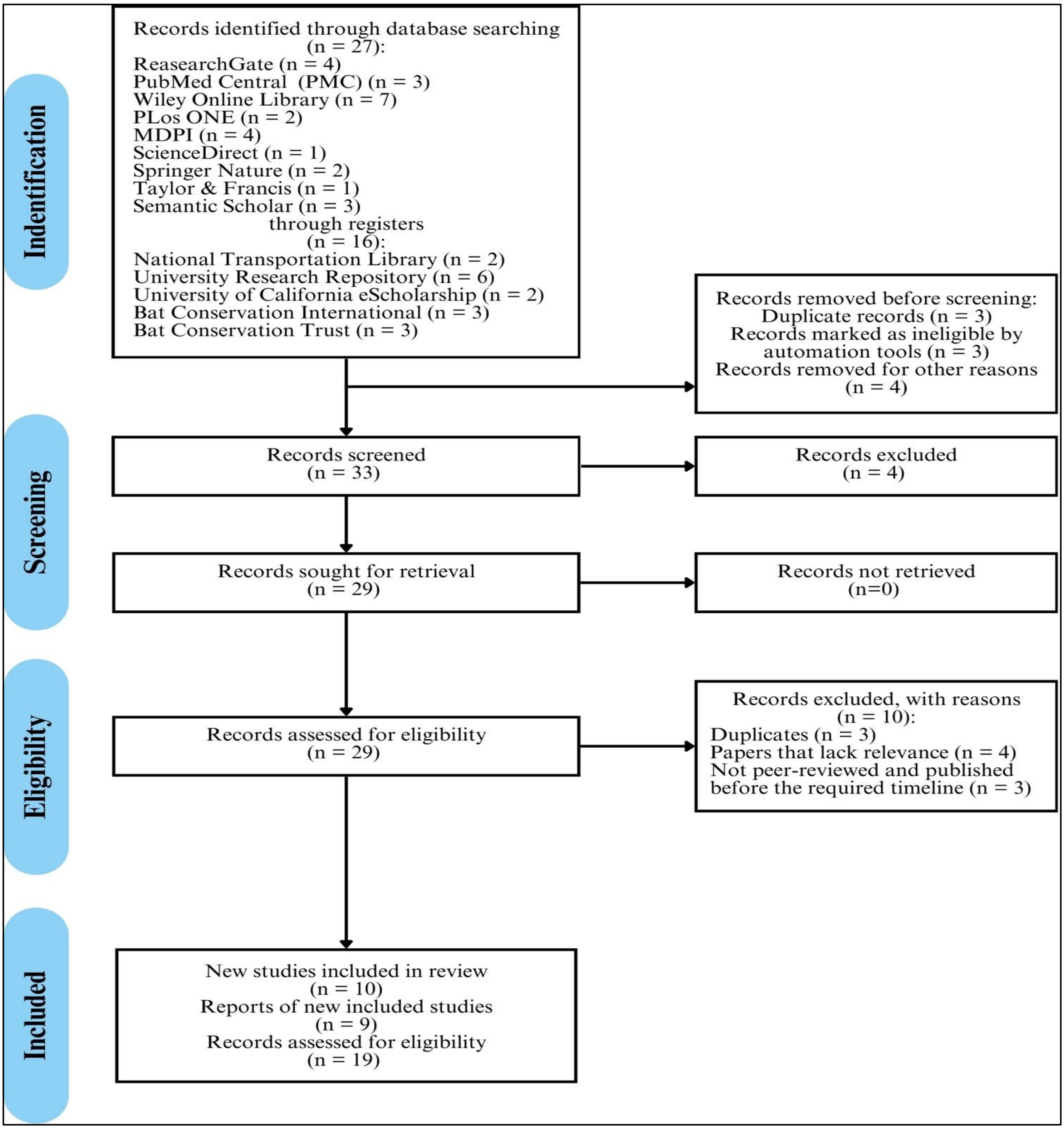

Fig 1: PRISMA Diagram in Relation to Choosing the Related Literatures

III. RESULTS AND DISCUSSION

A. Quantitative Results

The systematic review synthesized data from ten key studies to elucidate the effects of Artificial-Light-at-Night (ALAN) on the foraging activity and behavioral mechanisms of bats. Overall, the findings indicate that ALAN exerts multifaceted and species-specific influences on bat behavior, with both the spectral composition, light intensity, and condition playing critical roles.

➢ *Effects of Light Intensity*

The quantitative data from the reviewed studies consistently indicate that light intensity is a critical factor influencing bat foraging behavior. High-intensity lighting (e.g., ≥50 lux) has been shown to elicit strong avoidance responses in several species. For instance, *Rhinolophus hipposideros* exhibited significant avoidance of white LED lighting at 450 nm under high-intensity conditions, with foraging activity decreasing markedly ($P < 0.001$) (Straka et al. 2020; Spoelstra et al. 2017). Similarly, certain Pipistrellus species displayed significant alterations in their behavior,

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with statistical analyses (e.g., $\beta = 1.95 \pm 0.21$ SE, $P < 0.001$ for *Pipistrellus nathusii*) indicating that higher light intensities disrupt their natural activity patterns (Straka et al. 2020). Straka et al., 2020 inferred that bats have increasing tolerance to lights with longer wavelengths i.e. red light. Though there are few studies on bats' perception of different light colors, these findings suggest that bats can perceive three common light spectra as varied in brightness and that there is a threshold beyond which increased brightness significantly disrupts sensory processing, possibly by interfering with echolocation and vision.

➢ *Effects of Light Type (Spectral Composition)*

The spectral quality of artificial light also plays a pivotal role in modulating bat behavior. Studies revealed that shorter wavelengths, such as those emitted by white LEDs (450 nm), are more disruptive than longer wavelengths, such as red LEDs (700 nm). To illustrate, *Myotis capaccinii* and *Miniopterus schreibersii* showed less avoidance under red LED exposure, suggesting that the reduced short-wavelength component minimizes sensory disruption (Rowse, 2019; Kerbiriou et al., 2020). Quantitative metrics such as beta coefficients (e.g., $\beta = 0.074 \pm 0.037$ SE, $P = 0.046$ in *Pipistrellus kuhlii*) underscore that even small spectral shifts can yield statistically significant differences in behavior. This finding implies that spectral composition is not merely a cosmetic difference but a functional determinant that can modulate foraging efficiency and risk assessment.

➢ *Effects of Environmental Conditions*

Environmental context and light conditions further modulate the impact of ALAN on bats. Urban environments, characterized by constant and high-intensity light pollution, tend to produce different behavioral outcomes compared to areas with natural, low-light conditions. For instance, urban-adapted species such as *Eptesicus fuscus* displayed an attraction to light under specific conditions, likely due to increased insect abundance, while species in less disturbed, dark habitats (e.g., *Myotis lucifugus* in Connecticut, USA) exhibited significant reductions in activity under artificial illumination (Rowse, 2019; Stone et al., 2015). This variability suggests that long-term exposure to urban lighting may induce habituation or adaptive shifts in behavior, although the ecological costs, such as disrupted predator–prey dynamics, remain a concern. Another study by Li and Wilkins, 2022 explored the effects of spatial complexity coupled with increasing ALAN luminance. Foraging activities of bat species such as *Eptesicus fuscus* and *Lasiurus cinereus* were positively influenced in open sites, unlike *Lasiurus borealis* and *Lasionycteris noctivagans*, which boded well in cluttered sites, possibly indicating that effects of ALAN varied when linked with spatial complexity, particularly in urban areas.

➢ *Integrated Quantitative Analysis and Implications*

The integration of data across these studies reveals a complex, multifactorial impact of ALAN on bat behavior. The pragmatic statistical analyses—from significant avoidance responses in high-intensity, short-wavelength lighting (Straka et al. 2020; Spoelstra et al., 2017) to the nuanced differences in responses under varying spectral compositions (Rowse, 2019; Kerbiriou et al., 2020)—indicate that ALAN can drastically alter foraging efficiency and spatial use. Quantitative differences, as reflected by varying beta coefficients and p-values, exhibit that even subtle modifications in light intensity or spectral composition can have expansive behavioral repercussions. Such disruptions in foraging behavior may cascade into broader ecological consequences, including imbalances in insect populations and altered ecosystem services like pollination and seed dispersal (Gili et al., 2024).

Considering these findings, there is an urgent need for conservation strategies that incorporate adjustments in light intensity, spectral composition, and urban planning to mitigate ALAN's detrimental effects. The evidence suggests that carefully tailored lighting technologies and urban design modifications can help preserve critical nocturnal behaviors in bats while maintaining essential ecological functions (Schamhart et al., 2023; Stone et al., 2015).

Table 1: Effects of ALAN on Foraging Activity and Behavioral Mechanisms of Chiroptera Species

Chiroptera Order (family or specie)	**Location**	**Factors affecting Light**				**Foraging Activity**	**Behavioral Mechanism**	**Statistical Results**	**Reference**
		Control Group	Type of Light	Light Intensity	Light Condition				
Rhinolophus hipposideros	Siemers Bat Research Station	Dark	White LED	450 nm	Intermittent	Negatively influenced	Avoidance in all the LEDs	*P<0.001*	Straka et. al., 2020
			Amber LED	590 nm	Intermittent				
			Red LED	700 nm	Intermittent				
Myotis capaccinii		Dark	White LED	450 nm	Intermittent	NS	Least avoidance in Red LED	*P=0.11*	
			Amber LED	590 nm	Intermittent				
			Red LED	700 nm	Intermittent				
		Dark	White LED	450 nm	Intermittent	NS			

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Miniopterus schreibersii			Amber LED	590 nm	Intermittent		Least avoidance in Red LED	*$P<0.001$*		
			Red LED	700 nm	Intermittent					
Barbastella barbastellus	NS	Dark	White LED	121 lumens per watt	NS	Negative influenced	Not concluded due to small number	$\beta=-7.21\pm81.06$ SE	*$P=1.00$*	Lacoeuilhe et. al., 2015
			Sodium Vapor Lamp	110 lumens per watt					*$P=0.76$*	
Eptesicus serotinus	NS	Dark	White LED	121 lumens per watt	NS	No significant difference	Attracted to light	$\beta=6.67\pm1.17$ SE	*$P=0.52$*	
			Sodium Vapor Lamp	110 lumens per watt					*$P<0.001$*	
Pipistrellus pipistrellus	NS	Dark	White LED	121 lumens per watt	NS	Positively influenced	Attracted to light	$\beta=0.15\pm0.087$ SE	*$P = 0.076$*	
			Sodium Vapor Lamp	110 lumens per watt						
Pipistrellus pygmaeus	NS	Dark	White LED	121 lumens per watt	NS	No significant difference	Attracted to light	$\beta=0.092\pm0.066$ SE	*$P=0.16$*	
			Sodium Vapor Lamp	110 lumens per watt						
Pipistrellus kuhlii	NS	Dark	White LED	121 lumens per watt	NS	Positively influenced	Attracted to light	$\beta=0.074\pm0.037$ SE	*$P=0.046$*	
			Sodium Vapor Lamp	110 lumens per watt						
Pipistrellus nathusii	NS	Dark	White LED	121 lumens per watt	NS	No significant difference	No attraction nor avoidance in light detected	$\beta=1.95\pm0.21$ SE	*$P<0.001$*	
			Sodium Vapor Lamp	110 lumens per watt						
Nyctalus leisleri	NS	Dark	White LED	121 lumens per watt	NS	Negatively influenced	Avoidance to light	$\beta=-6.77\pm2.61$ SE	*$P=0.56$*	
			Sodium Vapor Lamp	110 lumens					*$P=0.51$*	

				per watt						
Nyctalus noctula	NS	Dark	White LED	121 lumens per watt	NS	Negatively influenced	Avoidance to light	β=0.50±0.07 SE	*P*=0.05	
			Sodium Vapor Lamp	110 lumens per watt					*P*=0.25	
Plecotus spp.	NS	Dark	White LED	121 lumens per watt	NS	Negatively influenced	Avoidance to light	β=−12.62± 2.04 SE	*P*=0.99	
			Sodium Vapor Lamp	110 lumens per watt					*P*=0.54	
Myotis lucifugus	Connecticut, USA	No Light Infrastructure	White LED	450 nm - 590 nm	Random	Less activity on light	NS	$Z = -4.952$, $p < .001$	Seewagen and Adams, 2021	
			Dark	None						
Eptesicus fuscus	Connecticut, USA	No Light Infrastructure	White LED	450 nm - 590 nm	Random	Less activity on light	NS	$Z = 2.347$, $p = .049$		
			Dark	None						
Lasiurus borealis	Connecticut, USA	No Light Infrastructure	White LED	450 nm - 590 nm	Random	No significant difference	NS	$F_2 = 0.138$, $p = .872$		
			Dark	None						
Lasiurus cinereus	Connecticut, USA	No Light Infrastructure	White LED	450 nm - 590 nm	Random	Declined with date; more active on control	NS	$Z = 2.591$, $p = .026$		
			Dark	None						
Lasionycteris noctivagans	Connecticut, USA	No Light Infrastructure	White LED	450 nm - 590 nm	Random	Less active on light	NS	$Z = -2.082$, $p = .004$		
			Dark	None						
Chalinolobus tuberculatus	Peri-urban area of Tamahere, New Zealand	NS	Lit Street Lamp	4000 K	Intermittent	Negatively influenced	Avoidance to light	$t = 3.2$, $P < .01$	Schamhart et. al., 2023	
			Unlit Streetlamp	4000 K						
Mystacina tuberculata		NS	Lit Street Lamp	4000 K	Intermittent	No significant difference	NS	$t = 1.5$, $P > .05$		
			Unlit Streetlamp	4000 K						
Pipistrellus kuhlii	Upper Susa Valley, Northwestern Italy	NS	Brightly lit area within construction site	146.58 ± 75.23 lux	NS	Highest within the construction site	NS	n = 66,241, 45.8 %	Gili et al., 2024	
			High-lit urban area	66.94 ± 48.95 lux	NS		NS			

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			Low-lit urban area	20.26 ± 13.31 lux	NS		NS		
			Dark area	0.48 ± 0.86 lux	NS		NS		
Nyctalus leisleri		NS	Brightly lit area within construction site	146.58 ± 75.23 lux	NS	Significant selection for the construction site	NS	n = 22,311, 15.4 %	
			High-lit urban area	66.94 ± 48.95 lux	NS		NS		
			Low-lit urban area	20.26 ± 13.31 lux	NS		NS		
			Dark area	0.48 ± 0.86 lux	NS		NS		
Hypsugo savii		NS	Brightly lit area within construction site	146.58 ± 75.23 lux	NS	Active in predominantly selected urban environments	NS	n = 10,959, 7.6%	
			High-lit urban area	66.94 ± 48.95 lux	NS		NS		
			Low-lit urban area	20.26 ± 13.31 lux	NS		NS		
			Dark area	0.48 ± 0.86 lux	NS		NS		
Pipistrellus pipistrellus		NS	Brightly lit area within construction site	146.58 ± 75.23 lux	NS	Clear selection for dark and poorly-lit areas	NS	n = 26,489, 18.3 %	
			High-lit urban area	66.94 ± 48.95 lux	NS		NS		
			Low-lit urban area	20.26 ± 13.31 lux	NS		NS		
			Dark area	0.48 ± 0.86 lux	NS		NS		
Pipistrellus pipistrellus	NS	NS	LDS street lamps	NS	NS	Positively influenced	Increase in buzz ratio	p=0.005	Kerbiriou et. al., 2020
			LED street lamps	17.7 ± 8.5 lux					
Pipistrellus pygmaeus		NS	LDS street lamps	NS	NS	Negatively influenced	Decrease in buzz ratio	p=0.730	
			LED street lamps	17.7 ± 8.5 lux					
Nyctalus spp.		NS	LDS street lamps	NS	NS	Positively influenced	NS	p=0.158	
			LED street lamps	17.7 ± 8.5 lux					

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Myotis sp.	Netherlands	Dark	White light	1800 lumens	NS	NS	Few passes	NS	Spoelstra et al., 2017
			Red Light			NS	More passes	NS	
			Green Light			NS	Few passes	NS	
Plecotus sp.		Dark	White light	1800 lumens	NS	NS	Few passes	NS	
			Red Light			NS	More passes	NS	
			Green Light			NS	Few passes	NS	
Pipistrellus sp.		Dark	White light	1800 lumens	NS	NS	More passes	NS	
			Red Light			NS	No different to control	NS	
			Green Light			NS	More pasess	NS	
Pipistrellus pipistrellus	Cornwall, England	Unchanged LPS Light (32.8 lux)	White Metal Halide Light	56.2 lux	Intermittent	More passes	No significant difference in buzz ratio across treatment and control	*s.e. = 0.007, p =0.863; s.e. = 3.046, p = 0.97*	Stone et al., 2015
			LPS Light	32.8 lux	Intermittent	Fewer passes			
Pipistrellus pygmaeus		Unchanged LPS Light (32.8 lux)	White Metal Halide Light	56.2 lux	Intermittent	More passes	NS	*s.e. = 0.47, p ≤ 0.01*	
			LPS Light	32.8 lux	Intermittent	Fewer passes			
Nyctalus/Eptesicus spp.		Unchanged LPS Light (32.8 lux)	White Metal Halide Light	56.2 lux	Intermittent	More passes	NS	*s.e. = 0.21, p ≤ 0.05*	
			LPS Light	32.8 lux	Intermittent	Fewer passes			
Pipistrellus pipistrellus	Southern England	Unchanged LPS Light	LED Light	Not possible to obtain accurate lux reading	Intermittent	No significant difference	No significant difference in buzz ratio	*p = 0.84, p = 0.58*	Rowse, 2019
			LPS Light	Not possible to obtain accurate lux reading	Intermittent				

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Pipistrellus pygmaeus		Unchanged LPS Light	LED Light	Not possible to obtain accurate lux reading	Intermittent	No significant difference	No significant difference in buzz ratio	*p = 0.48, p = 0.27*	
			LPS Light	Not possible to obtain accurate lux reading	Intermittent				
Nyctalus spp.		Unchanged LPS Light	LED Light	Not possible to obtain accurate lux reading	Intermittent	No significant difference	No significant difference in buzz ratio	*p = 0.78, p = 0.27*	
			LPS Light	Not possible to obtain accurate lux reading	Intermittent				
Myotis spp.		Unchanged LPS Light	LED Light	Not possible to obtain accurate lux reading	Intermittent	No significant difference	No significant difference in buzz ratio	*p = 0.48, p = 0.27*	
			LPS Light	Not possible to obtain accurate lux reading	Intermittent				
Tadarida brasiliensis	Texas, USA	NS	Low Illumination	<25 lux	Intermittent	Foraging ratio significantly high in high ALAN sites	No significant difference	*p < 0.05, p > 0.05*	Li and Wilkins, 2022
			Medium Illumination	90 lux	Intermittent				
			High Illumination	>250 lux	Intermittent				
Lasiurus borealis		NS	Low Illumination	<25 lux	Intermittent	Foraging ratio significantly high in high ALAN sites	NS	*p < 0.05*	
			Medium Illumination	90 lux	Intermittent				
			High Illumination	>250 lux	Intermittent				
Nycticeius humeralis		NS	Low Illumination	<25 lux	Intermittent	NS	No significant	*p > 0.05*	
			Medium Illumination	90 lux	Intermittent				

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			High Illumination	>250 lux	Intermittent		differen ce		
Eptesicus fuscus		NS	Low Illumination	<25 lux	Intermittent	Foraging ratio significantl y high in high ALAN sites	NS	$p < 0.05$	
			Medium Illumination	90 lux	Intermittent				
			High Illumination	>250 lux	Intermittent				
Lasiurus cinereus		NS	Low Illumination	<25 lux	Intermittent	Foraging ratio significantl y high in high ALAN sites	No significa nt differen ce	$p < 0.05$ $p > 0.05$	
			Medium Illumination	90 lux	Intermittent				
			High Illumination	>250 lux	Intermittent				
Lasionycteri s noctivagans		NS	Low Illumination	<25 lux	Intermittent	Foraging ratio increased with ALAN level	Signific antly higher in high ALAN sites	$p = 0.047$	
			Medium Illumination	90 lux	Intermittent				
			High Illumination	>250 lux	Intermittent				

B. Qualitative Results

Supporting literatures included the foraging behavior of the bats in response to the light intensity and condition can be further analyzed through thematic analysis. Codes and themes are implicated to represent each of the behavior of the bats to be generalized. Initial codes are based on the general factors affecting the bats. Themes are identified through the initial codes to summarize the major causes of behavioral patterns of bats in relation to ALAN.

➢ *Foraging Behavior of the Bats*

In the foraging behavior of the bats, several species from the other studies have observed that the *Nyctalus noctula* reacted negatively upon the presence of white light. For the *Pipistrellus pipistrellus* and *Pipistrellus kuhlii,* both exhibited attraction to the white and orange light (Lacoeuilhe et. al., 2015). According to the study of Pope dated in 2024, *Myotis* species that are categorized as slow fliers are observed to have a reduced activity when in the presence of light. *Pipistrellus pipistrellus* and *Pipistrellus pygmaeus* both inhabit within a dim area but can be seen positively influenced still upon the presence of a light source (Rowse, 2019). Lastly, *Nyctalus* and *Eptesicus species* showed no difference in their usual foraging activity based on Spoelstra et. al., 2017.

Two (2) studies validated the foraging behavior of the *Pipistrellus pipistrellus,* and in general the genus of *Pipistrellus* to be active under the influence of light. Species also from the *Nyctalus* genus are observed to have no significant difference in its foraging activity. However, another study showed that *Nyctalus* reacted negatively that caused a decline in their foraging activity.

➢ *Effects of ALAN on the Bats*

The behavior of bats under the presence of artificial lights at night has a corresponding influence on them, may it be a positive attraction, avoidance on the light sources, or resulting in a neutral reaction. Factors causing these are light intensity, light condition, and type of light. These variables are manipulated to know how it can affect bats. *Pipistrellus pipistrellus*, *Pipistrellus pygmaeus*, *Pipistrellus kuhlii*, *Eptesicus serotinus* and *Nyctalus noctula* are noticed to be attracted to lights, while *Nyctalus leisleri, Myotis spp.* and *Plecotus spp.* are not attracted. *Pipistrellus pipistrellus* and *Pipistrellus kuhlii* are both attracted to the white light and orange light. This is based on the study of Lacoeuilhe et. al., 2015, where researchers tested the different types of light on bats. From the similar study conducted (Hope, 2024), the *Myotis lucifugus* and *Eptesicus fuscus* reacted differently in response to the light condition exposed to. In contrast to the first study, *Eptesicus* species are reported as attracted to light. Although, the study conducted by Hope stated how the specific species of *Eptesicus fuscus* is negatively affected by light. The *Myotis spp.* both the studies observed have the same behavior, where it is not attracted to any light.

Pipistrellus kuhlii/Pipistrellus nathusii and *Hypsugo savii* exhibited neutral reactions upon the presence of light (Gili et. al., 2023). Additionally, the *Myotis* and *Plecotus species,* as well as *B. barbastellus, Pipistrellus pygmaeus* and *Rhinolophus ferrumequinum* reacted in avoidance to light. In relation to the study conducted (Lacoeuilhe et. al., 2015), the *Pipistrellus spp.* are attracted to light where it showed different results in the study of Gili et. al. The *Myotis* and *Plecotus species* consistently behave negatively when close to a light source. According to Rowse in 2019, *Pipistrellus pipistrellus* is attracted to both white light and green light. This is congruent to the previous findings where they exhibited positive reaction in a white light. Another study of Rowse in 2016 stated *Eptesicus nilssonii* has a neutral reaction or can be positively influenced by white light. Related literatures synthesized have different interpretations on the *Eptesicus spp.* as some are attracted to light and some findings of the study reported the negative reaction of the genus (Hope, 2024). *Pipistrellus pipistrellus, Pipistrellus*

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pygmaeus and Nyctalus/Eptesicus spp. are attracted to the white light (Stone et. al., 2015). Nevertheless, some species of *Nyctalus spp.* are reported to have a different reaction on some light (Lacoeuilhe et. al., 2015).

Chalinolobus tuberculatus exhibited differently in the presence of the street lights (Schamhart et. al., 2023). In contrast to the study conducted by Stone et. al., in 2015, long-tailed bats reacted negatively even in the slightest light it is exposed to. Based on the Spoelstra et. al., dated in 2017, Slow-flying *Plecotus* and *Myotis species* avoided the light in the color of green and white. It is different in the red spectra, and showed a neutral reaction. The *Myotis spp.* also produced no reaction similar to other studies where in all types of light it behaved neutrally (Gili et. al., 2023).

➤ *Adaptation of Bats in Relation to ALAN*

Bats also undergo adaptation in correspondence to the habitat they are in. The study conducted by Lacoeuilhe et. al., 2015, *Myotis spp.* increases its activity when then moths are present close to the light. In contrary to other findings that *Myotis spp.* is negatively affected in light (Hope, 2024), their activity can be influenced by the presence of prey. In connection to the study of *Pipistrellus kuhlii, Pipistrellus nathusii* and *Hypsugo savii,* even though these bats showed no significant difference when it comes to their activity, the presence of habitat and prey still increases their activity (Gili et. al., 2023). *Carollia sowelli* was found to have a decline in terms of hunting and both in its activity at night (Rowse, 2019). Another study of Rowse et. al., dated back in 2016 showed that ALAN also has an impact on their feeding time. *Leptonyctyris yerbabuenae* has reportedly a decline in terms of eating fruits and plants due to increasing light intensity. *Eptesicus fuscus, Lasiurus borealis, Lasiurus cinereus, Lasionycteris noctivagans, Myotis velifer, Nycticeius humeralis, Perimyotis subflavus,* and *Tadarida brasiliensis* adapted long ago in the increasing light intensity on their habitat. These bats reportedly showed neutral reactions, characterized as urban bats (Li and Wilkins, 2022).

The ALAN has an impact on bats whether it may be on their hunting or predation, habitat, or in their daily lives. The series of findings can be concluded to bats utilizing the ALAN as one of the tools in catching insects. They also adapted to the varying light conditions, as many species of bats can be found in the urban areas showing neutral reactions or they can be positively influenced in any type of light. Some bats also find this disturbing in their home and predation time.

Table 2: Thematic Analysis regarding Behavioral Patterns in Bats

Themes	Findings	References
Foraging Behavior	*N. noctula* was negatively influenced by white light. Both the white and orange light has a positive influence on *P. pipistrellus* and *P. kuhlii.*	Lacoeuilhe et. al., 2015
	Myotis species are slow fliers that can decrease more with a presence of light.	Pope, 2024
	P. pipistrellus and *P. pygmaeus* have their habitat in a dim area, but increase activity in light.	Rowse, 2019
	Nyctalus and *Eptesicus species* showed no difference in their activity even in the presence of light.	Spoelstra et. al., 2017
Artificial Light at Night (ALAN) Effects	*P. pipistrellus*, *P. pygmaeus*, *P. kuhlii*, *E. serotinus* and *N. noctula* are attracted to light while *N. leisleri, Myotis spp.* and *Plecotus spp.* are not attracted. *P. pipistrellus* and *P. kuhlii* are both attracted to the white light and orange light.	Lacoeuilhe et. al., 2015
	Myotis lucifugus and *Eptesicus fuscus* are the most affected by the light source.	Pope, 2024
	P. kuhlii/P. nathusii and *H. savii* showed no significant difference in the presence of light.	Gili et. al., 2023
	Myotis and *Plecotus species,* as well as *B. barbastellus, P. pygmaeus* and *R. ferrumequinum* avoided light at all.	
	P. pipistrellus are attracted between the presence of green light and white light.	Rowse, 2019
	E. nilssonii is positively influenced or it has no significant effect in the presence of light.	Rowse et. al., 2016
	P. pipistrellus, P. pygmaeus and Nyctalus/Eptesicus spp. are attracted to the white light.	Stone et. al., 2015
	Chalinolobus tuberculatus showed avoidance to the streetlights.	Schamhart et. al., 2023
	Slow-flying Plecotus and *Myotis species* reacted negatively in the presence of white and green light but showed no difference in red light.	Spoelstra et. al., 2017
Adaptation due to ALAN	*Myotis spp.* increases its activity in the presence of moths near the lights.	Lacoeuilhe et. al., 2015
	The increase in activity involving both *P. nathusii* and *H. savii* can be due to the emerging forest or habitat in relation to increasing light sources.	Gili et. al., 2023
	C. sowelli decreases its activity both in lit areas and when hunting for insects close to a light source.	Rowse, 2019

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	Leptonyctyris yerbabuenae has decreased activity in eating fruits and plants due to increasing light intensity.	Rowse et. al., 2016
	Eptesicus fuscus, Lasiurus borealis, Lasiurus cinereus, Lasionycteris noctivagans, Myotis velifer, Nycticeius humeralis, Perimyotis subflavus, and *Tadarida brasiliensis* adapted to ALAN due to their long exposure in urban habitats.	Li and Wilkins, 2022

IV. CONCLUSION

In reviewing the relevant studies regarding the effect of ALAN exposure on bats, the available evidence provided comprehensive data using a parameter of light intensity and light condition correlated to the changes of behavioral pattern such as roosting, foraging, and communication through echolocation. Through various methods of light manipulation such as intensity, condition and type of light, it resulted that the behavior changes on bats relied on the interplay of different artificial light sources. Species such as *Pipistrellus Pipistrellus*, *p. kuhlii*, and *p. pygmaeus* (a *Vespertilionidae family*) demonstrated an active behavior and high tolerance in white and orange spectrum, at variance with *Myotis* and *Plecotus* species which exhibited strong avoidance manner. Thus, *Myotis* and *Plecotus* genera are more vulnerable to artificial light than the *Vespertilionidae* (the evening bats or vesper bats). Additionally, some species, such as *Myotis lucifugus* and *Eptesicus fuscus*, experience notable disruptions due to ALAN, while others, like *Chalinolobus tuberculatus*, actively avoid artificial light sources. However, certain bat populations, particularly those inhabiting urban environments (*Eptesicus fuscus, Lasiurus borealis, Lasiurus cinereus*, and others), appear to have adapted to prolonged exposure to ALAN, suggesting potential behavioral plasticity.

Despite the variations of sample size and methods, the overall trends showed that studies demonstrate that habitat structure and spatial complexity influence ALAN's effects. *Eptesicus fuscus* and l*asiurus cinereus* increased foraging activity in open environments with ALAN exposure, whereas *Lasiurus borealis* and *Lasionycteris noctivagans* were more active in cluttered habitats with lower light levels. While P*ipistrellus pipistrellus* exhibited an increased buzz ratio (a measure of foraging efficiency) under streetlights with an intensity of 17.7 ± 8.5 lux ($p = 0.005$), while P*ipistrellus pygmaeu*s showed a decrease ($p = 0.730$). Taken together, these findings indicate that ALAN can significantly disrupt foraging efficiency, sensory perception, and spatial behavior in bats, leading to broader ecological consequences such as imbalances in insect populations and altered ecosystem services like pollination and seed dispersal.

In terms of methodological rigor, the strength of this systematic review went through a keen process of assessment of relevant studies and removal of ineligible sources. However, certain scope such as the large sample size and limited variability to the adaptation of bats should be acknowledged. Therefore, the findings suggest that while the review provides valuable insights into the effects of Artificial Light at Night (ALAN) on bat behavior, further research is necessary to address existing gaps. Specifically, future studies should incorporate broader sample sizes, account for greater species diversity, and examine long-term adaptation mechanisms to ALAN across different ecological contexts. Additionally, variations in experimental design, such as differences in light intensity, spectral composition, and habitat conditions, highlight the need for standardized methodologies to enhance comparability across studies.

Future research should prioritize investigating the long-term impacts of Artificial Light at Night (ALAN) on bat populations, particularly in relation to species-specific adaptation mechanisms and ecological consequences. Expanding studies to encompass a wider range of bat species, diverse geographic locations, and varying habitat conditions will provide a more comprehensive understanding of ALAN's effects. Additionally, standardized methodologies—such as uniform light intensity thresholds, spectral compositions, and experimental conditions—are crucial for improving cross-study comparability.

Finally, applied research on mitigation strategies, including the effectiveness of wildlife-friendly lighting (e.g., red-spectrum LEDs, dimmable or motion-activated lights), should be prioritized to inform conservation policies. Collaborative efforts between ecologists, urban planners, and policymakers will be vital in developing sustainable lighting solutions that balance human needs with biodiversity conservation.

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