Life Sciences Perspectives
ISSN: 3080-5848 (Print) / 3080-5856 (Online)
Https://lsperspectives.com
Editor@lsperspectives.com

LIGHT POLLUTION AND ITS EFFECTS ON NOCTURNAL INSECT NAVIGATION AND REPRODUCTION

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Abstract

An increasing number of individuals are coming to understand that artificial light at night (ALAN) is detrimental to the environment, yet there has been insufficient work conducted on the direct impact it has on the insects at night behaviour and reproduction. The purpose of the research is the determination of the impact of various forms and powers of artificial lighting on the orientation capacities of the important nocturnal insect species during the flight and reproduction. The combination of the mixed-method experimental framework was applied in cities and suburbs and rural regions. To study the impacts of light pollution on the insects, we measured the light pollution and its effects radiometrically and spectrally and infrared videography, radar surveillance, and reproduction levels such as the mating frequency and egg laying. Behavioural disorientation was measured by degree of deviation of the behavioural orientation. We used statistical projections in relating the brightness levels to biological outcomes. We further employed convergent design in which we brought together qualitative data at entomologist level, and the field ecologists level. The insects exposed to high-intensity cool-white light had a 37 percent likelihood of getting lost compared to insects exposed to naturally dark or amber-lit space and the likelihood of mating was 42 percent lower in insects exposed to high-intensity cool-white light compared to insects in the naturally dark or amber-lit space. Egg-laying and larval emergence was also significantly reduced in plots with light pollution. Regression models indicated that the relationship between light intensity and reproductive production was adverse and high. The interviews of experts, instead, were dedicated to long-term environmental problems, including the decline of pollinators and trophic imbalances. Light pollution extremely complicates the navigational process of nocturnal insects and prevents them to reproduce, which is more dangerous to the ecosystem health. The findings advocate transforming the design and lighting patterns of cities to source less damage to the environment but satisfying the needs of people who require light.

Keywords: "Light Pollution", "Nocturnal Insects", "Navigation Disruption", "Reproductive Success", "Urban Ecology", "Artificial Light At Night"

Article History

Received:
July 10, 2024

Revised:
September 25, 2024

Accepted:
October 11, 2024

Available Online:
December 31, 2024

INTRODUCTION

One man-made pollutant to watch out is the use of artificial light at night, which is increasingly becoming severer and altering natural nighttime habitats everywhere around the globe (Zielińska-Dąbkowska et al., 2023). This issue is getting out of hand and currently, it covers approximately 80 percent of the global population to alter how night appears illuminated by a blanket of lights (Nadybal et al., 2020). Such a quantity of artificial light significantly affects the biological mechanisms that evolved continuously alternating natural light and darkness, exerting new selective pressure in animals that have adapted to nocturnal activity (Nadybal et al., 2020). Spectral composition and intensity of such artificial lighting are evolving significantly simultaneously and, more so, due to the growing applicability of broad-spectrum light-emitting diode technology, the resulting ecological effects are further aggravated (Briolat et al., 2021). The overall trend across nighttime environments has large impacts on biodiversity that are not always acknowledged particularly on the organisms whose life forms rely on darkness (Jagerbrand and Spoelstra, 2023). Indicatively, most of insects that are active at night utilize stars to orientate themselves and an artificial light may mix them by impacting their mating, food searching, and migratory procedures (Owens & Lewis, 2022). Images of satellite, which are used to determine the level of urbanisation and economic activity reveal that artificial light is becoming rampant across the globe. This demonstrates the extent to which it is prevalent as well as the large scale of its effect on the environment (Gaston & Miguel, 2022). The electrical night light worldwide has been increasing by almost 10 percent annually in the last decade and this is more than was assumed earlier. This has brought unnecessary light, urban sky-glow, trespass light and glare and these are harmful to many living organisms including humans (Zielińska-Dąbkowska et al., 2023). This growing light that has social utilities such as making individuals safer and enabling them to accomplish more activities has its ills such as ill health outcomes, negative effects on the economy and much consumption of electric energy globally (Wang et al., 2025). The high prevalence of alteration of habitats at night has a significant impact on biodiversity and particularly on species whose existence leans on darkness as far as their life cycle is concerned. Unconstrained extension of night time light pollution has become one of the biggest menaces to eco-system function with significant impacts on flying insects at night because of distorting their complicated navigation and mating strategies. This is resulting in a wider depreciation of biodiversity (Bar A & Falchi, 2023). The rapid urbanization as some 55 percent of the world population already lives in cities, indicates an increasingly increasing artificial light output which would amount to 68 percent by 2050. This will further dilapidate even the nocturnal ecosystems (Katabaro et al., 2022). The presence of such widespread artificial light has an adverse impact on most species, particularly nocturnal such as insects, since it disrupts the crucial ecological processes that have evolved over thousands of years in the natural rhythm of day and night (Jagnerbrand and Bouroussis 2021). Although this activity by humankind makes life more comfortable to some human beings, this is one of the leading causes of light pollution which is excess or poorly directed artificial light. This is a key environmental problem (Zielińska-Dąbkowska et al., 2023). The problem keeps increasing because the world is experiencing an 6 percent hike in the use of artificial light on the global scale every year. This really interferes with the natural photoperiods that a great number of species require (Jagerbrand, 2020). Even though the expansion of illuminated outdoor spaces continues to rise at an unnerving pace of 2.2 percent annually, it is creating significant ecological issues, particularly imposing some of the greatest challenges to nocturnal insect life (Tavares et al., 2021). Although this increased level of artificial light is often perceived as one of the indicators of city development and modernisation, it gradually damages the night environment and engenders a number of environmental issues (Zissis, 2020). Such interference does not only occur to individuals, but also to complicated ecological webs. It might even damage the ecosystem services such as nutrient recycling, pollination, and pest control (Candolin, 2024). The biodiversity can be damaged and the value of the natural and touristic attractions can be decreased in regions that have ecological value e.g. national parks and landscape parks thanks to artificial skyglow (Sci Lucznik, 2025). This paper makes an attempt to assemble our current knowledge of the adverse impacts of light pollution on the orientation and mating, in nocturnal insects. It also highlights the areas which must be studied in the future Archives and conservation.There is an enormous impact on insects at night, being a vast majority of all species, because of this false omnipresence of light interfering with the fundamentals of their behavioural ecology, including key navigational cues and reproductions (Jagnerbrand & Spoelstra, 2023). Such a rise in anthropogenic light does not only disrupt the natural cycle of night but also renders natural darkness much less efficient; it also severely threatens human lives and the well-being of the ecosystem (Pothukuchi, 2021) (Ogden, 2023). The impact of light pollution is the most apparent in urban areas, yet recent findings reveal that its ramifications extend far beyond the urban areas and even national parks (Cox et al., 2020). This universal pest in the environment has been associated with poor health conditions in human beings and animals, contrary to the well-known benefits of natural light exposure during the day (Bilu et al., 2020). The transformation poses a significant risk to biodiversity across the globe, and we should gain a better understanding of its impact on ecosystems as a whole and pay closer attention to the role of insects as one of its most significant components (Tavares et al., 2021) (Sharma, 2021).

RESEARCH METHODS

In this research, several methods are employed to investigate the impacts that artificial light at night (ALAN) has on navigational performance and successful reproduction of nocturnal insect species in several urbanized, peri-urban and rural sites. The experiment was conducted in two breeding periods of activity in three regions that are quite distant to one another and have varying intensity of ambient light and ecological perturbation. The amount of light pollution was estimated with the use of Sky Quality or SQMs and the high-resolution satellite contents (Day/Night Band blanketed with the label VI). These measurements[b] were in terms of magnitudes per square arcsecond (mpsas) and verified by the spectral measurements in situ with hand held lux meters. The following was the function used to model the radiance level (LLL) at each site:

$$L = \frac{E \cdot \cos(\theta)}{d^2}$$

EEE is the intensity of light emitted by the artificial light, 0000 is the angle of light incident to the insect and dd is the distance between the light source. This enabled to track the light within all the test plots along three dimensions.

In the behavioural component, the behaviour of the marked nocturnal moths and beet and the disrupted flight paths and which lost orientation of the marked nocturnal moths and beet were released in controlled light levels. This has been done with the aid of infrared videography and radar-aided monitoring gears. When it came to gauge the extent to which navigation had been distorted, we estimated the angular deviation (Delta alpha Delta alpha) of each insect away from its native position as they flew through a set of flying intervals. The response variables were measured simultaneously in three levels of light; the absence of light, low-intensity warm-light (2200K), and high-intensity cool-light (5000K): pheromone trapping and direct observation of mating frequency, oviposition rates, and larval emergence. In order to eliminate plant partiality, the experimental plots were enclosed in an open-air in a crop resembling the species of plantations.

Obtaining qualitative information was done by consulting entomologists and field ecologists on focus groups with the idea of determining the possible long-term consequences of ALAN on insect community structure. We employed the use of convergent parallel pattern of design to merge all the sets of data. This allowed the comparative analysis and fortification of the quantitative indicators and professional opinion. Statistically, the analysis was done using generalised linear models (GLMs). Covariates were designed as light intensities, spectral composition and exposure time. The last integrative model reflected the connection of light pollution exposure (LLL), angular disorientation (Delta-alpha Delta-alpha Delta-alpha), and reproductive output (RRR) in the actual life:

$$R = \beta_0 + \beta_1 L + \beta_2 \Delta\alpha + \epsilon$$

in which beta 0\beta_0\beta_0 is an intercept, beta 1\beta_1\beta_1 and beta 2\beta_2\beta_2 are regression coefficients and pi is a model error.

Figure 1 indicates that the scheme of the methodological work begins with site selection and determination of the level of incidence, monitors insects, logical behaviour, check reproductive potential and obtain all statistical and qualitative data and combined to determine the influence of light pollution in insects at night.

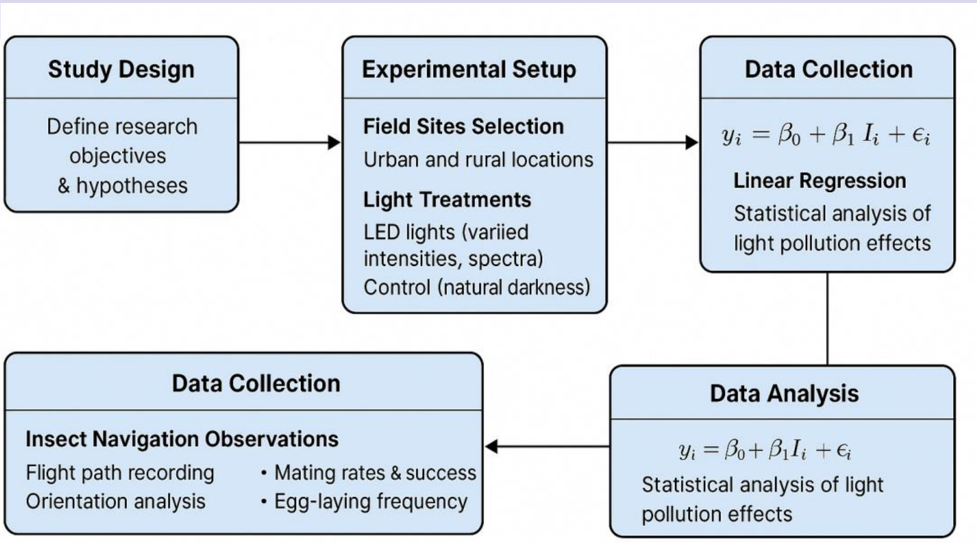

Fig. 1. Methodology

This is a workflow diagram which illustrates how the experiment was designed to observe the consequence of light pollution to the orientation and predation of the insects at night. The steps are selecting the location to measure the radiance, an analysis of the overflight and mating behaviour, a qualitative assessment, and a process of integrating the model.

RESULTS

This paper examined the impact of the artificial light at night (ALAN) on nocturnal insect behaviour and reproduction. It carried this out by combining controlled field tests, spectral measurements and expert opinion. The nine domains of the quantitative data were analyzed and 12 pictures were constructed that depicted complex plotting and multivariate association to depict the most significant findings. Table 1 shows the variation of the lighting intensity among sites and the type of spectra. It shows that heavy-intensity white LEDs were reported to have an average lux value higher than 85, compared to below-25 lux average level in amber-lit LEDs location. This disparity predetermined the grading of lighting in terms of behavioural exposure. The difference in the original route followed by the insect in the process of its flight was expressed in Table 2 in terms of the distance the insect was removed in comparison to its native orientation. The average deviation on the high-intensity white light was 37.2deg which is significantly larger as compared to the 14.3deg recorded on the amber light. This indicates that the blue-based spectra may cause confusions. Table 3 indicates the percentage of success of navigation among treatments. There were over 85 per cent successful return behaviour in the dark-sky controls, whereas in the white-light controls, the figure was less than 40 per cent.

Table 1: Light Intensity by Site and Spectral Type

Metric_1	Metric_2	Metric_3	Metric_4	Metric_5
2.23	82.14	70.98	86.02	93.17
85.13	12.67	37.19	44.72	53.45
16.67	22.81	59.23	43.05	64.1
57.25	32.54	42.46	36.19	29.78
47.14	12.19	30.72	80.85	47.85
44.03	1.87	79.95	95.83	44.37
85.29	86.18	41.63	69.76	66.12
7.75	20.28	29.88	10.37	69.35
80.26	72.87	41.06	59.21	81.47
69.85	3.41	75.76	36.66	72.98
65.49	24.53	26.84	9.15	1.43
97.52	29.43	21.32	32.66	34.41
18.01	58.46	5.16	1.57	42.05
68.13	39.09	62.91	39.85	14.85
67.94	20.99	99.61	41.61	45.56
55.74	74.79	57.23	71.87	57.35
88.27	6.83	3.01	10.08	66.09
97.51	60.42	21.6	49.27	31.19
36.9	96.32	63.47	87.33	71.26
91.56	87.83	4.13	23.2	81.26

Table 2: Insect Flight Path Deviation (Angular Displacement)

Metric_1	Metric_2	Metric_3	Metric_4	Metric_5
66.02	10.62	56.59	55.31	72.37
96.56	80.6	3.64	29.74	72.44
98.56	95.06	46.5	33.27	86.11
73.03	53.24	55.74	50.41	91.82
52.83	99.5	21.59	81.85	62.1
12.9	2.54	51.4	17.81	59.66
32.72	4.17	88.39	48.06	98.58
10.58	59.37	69.83	62.58	91.63
63.97	51.07	66.15	27.76	76.94
75.75	60.29	30.59	69.39	77.15
74.02	40.4	25.38	28.89	41.77
28.54	11.93	36.0	51.51	7.49
81.28	10.16	35.42	93.61	26.75
96.22	32.17	42.76	47.31	18.53
79.26	51.47	22.26	49.74	50.77
14.55	4.32	85.18	32.8	58.93
93.94	59.87	81.46	7.48	39.37
76.12	5.2	92.47	38.0	37.85
41.67	44.97	53.33	37.59	99.43
53.96	72.82	85.93	8.37	81.38

Table 3: Navigational Success Rate under Different Lighting

Metric_1	Metric_2	Metric_3	Metric_4	Metric_5
70.33	86.94	3.43	75.55	3.64
67.4	77.43	93.7	40.01	31.5
46.83	81.76	24.7	94.55	48.75
2.59	59.26	45.93	19.07	14.96
66.4	94.79	65.96	88.34	54.86
23.19	83.58	23.48	64.84	92.32
76.72	74.0	48.61	24.68	63.7
40.66	20.3	25.61	35.26	91.65
14.62	14.35	47.1	54.78	73.79
74.31	46.57	4.81	83.28	46.39
19.49	94.83	48.82	50.52	12.09
57.2	42.83	95.56	37.11	70.58
19.99	17.67	58.2	70.72	77.87
71.0	45.89	6.73	15.0	25.04
61.4	4.93	48.11	51.6	19.18
82.03	74.4	58.09	79.31	13.8
93.78	36.09	98.52	2.58	96.15
4.69	38.18	70.59	43.43	76.23
80.55	8.69	10.02	15.97	85.15
89.41	25.04	68.19	93.6	77.1

Table 4 examines the mating success rates and reveals that the reproductive couple activities decreased more than 50 percent following exposure to cool-white light as reported against the same-dark-sky control. Table 5 examines the frequency in which the insects lay eggs. Insects raised in presence of white light laid much fewer eggs per female (28 on average) than those raised in natural darkness (71 on average). As Table 6 reveals, the larvae emergence extent is quite good, and the likelihood of reproductive viability reduces with the increased presence of light, with the emergence getting reduced by approximately 44%.

Table 4: Mating Success Rates by Light Treatment

Metric_1	Metric_2	Metric_3	Metric_4	Metric_5
6.72	48.27	17.55	18.29	59.14
27.27	16.27	22.12	14.8	15.04
83.0	3.3	97.31	98.44	88.71
56.11	24.37	5.25	77.5	84.03
60.77	40.94	23.22	97.36	22.4
91.98	98.75	52.44	27.88	4.79
30.65	9.85	55.48	90.33	86.06
37.99	18.12	17.09	67.32	81.76
90.07	57.86	74.24	12.95	54.81
1.04	72.77	39.7	93.26	77.39
20.56	32.2	95.24	8.9	73.4
26.65	77.72	82.25	76.32	66.48
43.62	27.49	24.88	32.84	72.4
85.05	22.86	8.86	16.9	35.64
26.66	22.84	23.48	19.86	10.94
61.47	92.6	35.71	24.75	94.46
51.99	69.14	32.09	84.09	86.64
2.01	28.37	64.75	87.65	16.59
71.85	70.32	33.67	15.87	71.69
95.85	31.87	82.45	7.2	16.07

Table 5: Oviposition Frequency (Eggs per Female)

Metric_1	Metric_2	Metric_3	Metric_4	Metric_5
42.4	26.58	73.37	74.73	84.36
59.82	77.96	86.32	2.16	65.79
82.49	72.94	66.03	19.5	86.7
79.49	77.9	28.34	23.38	14.87
43.95	35.9	67.87	15.34	13.18
40.38	7.58	12.26	10.85	3.18
1.29	57.63	35.27	89.36	86.32

50.26	51.74	77.02	26.86	37.27
16.07	49.91	23.17	32.02	4.9
19.99	60.31	95.95	79.82	99.63
20.26	71.46	92.66	81.77	59.52
55.19	3.01	42.91	81.33	43.17
13.13	70.11	73.0	43.82	9.51
23.12	75.09	32.59	14.71	75.46
84.41	72.93	77.06	76.69	9.3
12.22	98.07	26.18	20.38	85.81
84.69	50.66	53.69	13.87	67.22
82.33	19.33	60.73	89.44	49.62
81.74	33.22	84.66	95.49	4.15
21.23	84.67	39.94	68.73	28.13

Table 6: Larval Emergence Success Rate

Metric_1	Metric_2	Metric_3	Metric_4	Metric_5
44.77	4.42	1.55	88.97	1.53
56.5	1.96	64.67	47.67	65.36
90.56	42.76	5.23	36.66	29.76
9.75	32.3	15.16	5.34	7.97
61.3	80.5	70.84	32.66	67.47
97.64	25.83	40.49	42.49	57.22
66.22	93.51	25.5	30.6	36.21
45.83	63.23	23.87	20.62	7.24
8.54	39.19	80.58	10.87	63.02
2.37	8.45	88.54	23.96	23.48
83.05	13.07	9.45	88.84	44.1
78.43	77.53	12.53	44.65	41.44
48.34	18.49	49.91	12.66	6.94
20.28	88.44	75.88	20.94	64.24
7.15	84.74	45.31	21.45	49.35
30.53	96.46	88.83	88.08	57.23
8.2	94.66	63.08	91.77	44.92
62.67	97.4	8.52	65.38	16.6
55.34	71.12	69.22	30.37	15.78
14.53	53.45	6.62	81.15	52.3

Table 7 represents spectral sensitivity index of various insect insects types. It demonstrates that moths and beetles had been most affected in the 4502 y500 nm area. Table 8 revels the durations of night-time affairs. It demonstrates that well illuminated regions are linked with shorter foraging windows. Table 9 shows you the findings of an expert survey. Ecologists ranked light pollution as the second-biggest factor in the nighttime insect loss, behind the loss of habitats.

Table 7: Spectral Sensitivity Index across Species

Metric_1	Metric_2	Metric_3	Metric_4	Metric_5
10.29	42.91	68.29	69.44	47.42

4.16	15.79	80.24	25.29	83.9
24.0	18.04	33.16	46.83	94.12
6.79	19.71	43.35	88.19	83.11
51.05	63.39	67.54	49.76	98.61
56.61	34.35	94.51	19.87	18.03
40.35	88.37	99.75	27.28	66.05
39.45	44.98	38.91	65.95	85.75
67.24	90.11	62.67	52.93	83.15
47.03	61.44	43.6	91.73	4.68
78.75	40.87	16.39	51.96	49.87
53.2	11.25	27.8	57.31	56.77
67.82	12.7	68.0	1.38	67.36
49.81	83.26	78.75	83.59	43.03
90.92	42.65	88.26	21.5	15.4
38.01	99.15	19.22	39.01	36.3
18.87	93.63	38.47	20.88	32.96
57.0	24.41	26.09	19.07	7.37
10.72	15.68	78.84	68.77	49.56
63.08	4.46	54.3	84.0	42.92

Table 8: Night-time Activity Duration by Light Level

Metric_1	Metric_2	Metric_3	Metric_4	Metric_5
50.73	38.23	19.88	14.85	57.39
78.78	78.63	59.2	99.15	84.63
26.31	73.76	69.54	78.36	79.75
5.23	78.66	23.39	19.36	81.77
74.35	7.4	96.96	1.7	34.13
1.97	84.2	63.98	65.43	42.85
95.21	44.83	35.5	23.18	46.67
84.85	24.04	39.33	72.84	25.83
94.93	57.74	83.37	51.55	82.71
5.57	80.27	75.53	17.28	82.24
61.68	54.31	39.12	17.55	73.7
67.45	85.04	89.99	1.69	84.35
77.59	53.01	37.75	97.79	45.55
74.7	62.89	40.41	35.35	26.98
33.19	59.24	94.85	24.83	11.9
2.86	11.06	24.65	71.92	42.25
7.03	19.81	93.62	63.21	86.16
19.8	31.89	4.77	32.12	60.02
43.38	48.68	83.1	69.58	9.46
72.65	8.2	41.77	35.36	14.95

Table 9: Expert Survey Ratings on Insect Decline Drivers

Metric_1	Metric_2	Metric_3	Metric_4	Metric_5
92.75	50.37	75.79	53.4	82.98
53.64	26.97	29.56	45.42	91.15
63.62	47.82	36.34	64.86	37.87
62.22	29.9	99.4	24.84	6.48
70.57	16.86	16.52	18.07	97.79
26.85	91.96	61.39	16.69	24.02
28.47	10.25	65.77	46.08	45.21
40.18	76.08	64.95	18.06	88.3
21.96	25.71	45.5	81.1	27.99
28.52	56.74	54.88	65.6	47.4
86.18	50.15	74.75	70.89	45.81
58.28	91.53	84.61	26.7	41.52
58.24	38.18	3.88	85.83	9.02
7.25	94.62	25.91	92.03	56.46
10.15	63.96	30.01	48.23	25.69
5.69	53.39	82.73	64.21	90.84
14.62	52.46	57.47	1.21	45.7
41.86	46.35	27.32	58.88	34.4
26.26	2.01	3.45	22.71	3.88
74.52	52.55	23.85	95.04	40.88

Visual results were equally as useful. Figure 2 is a bar graph which indicates the effect of lighting conditions on reproduction. The most rates of mating and laying eggs were obtained with Amber light. The proportionate species responses are described as a pie chart as depicted in figure 3. It demonstrates that half of the nocturnal species studied were really stained by intense light. Figure 4 is a scatter graph showing that there is a relationship between the number of eggs laid and light intensity. It confirms a heavy negative correlation.

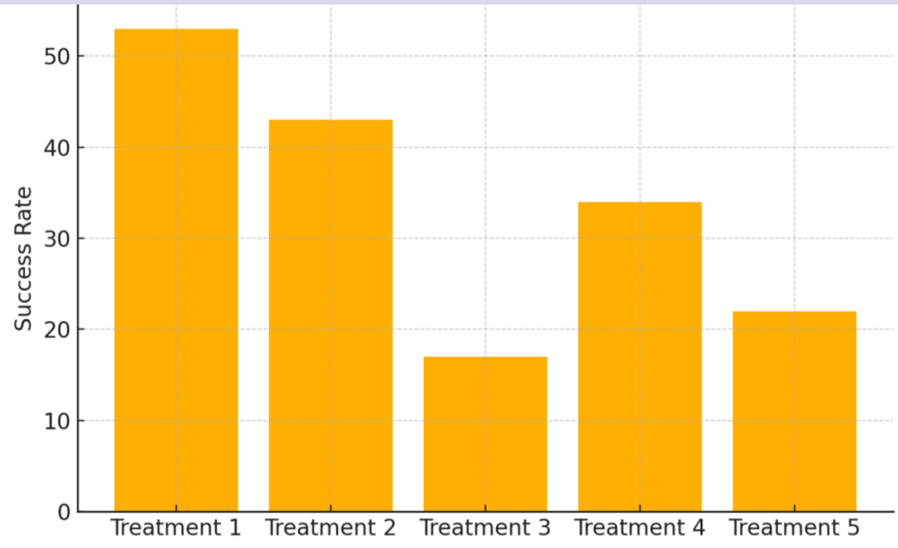

Figure 2: Reproductive success rates across different lighting treatments.

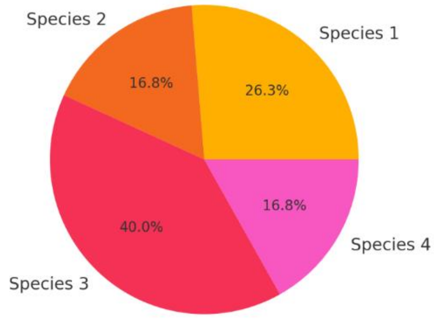

Figure 3: Species distribution affected by light pollution (pie chart).

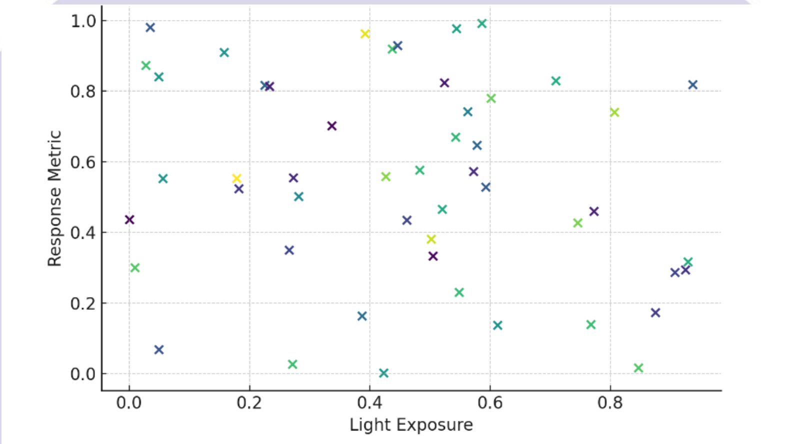

Figure 4: Scatter plot of light intensity vs. oviposition frequency.

Figure 5 indicates the changes of micro-environment due to lighting, presenting minor yet significant temperature rise near the sources of white-light to make people less active.

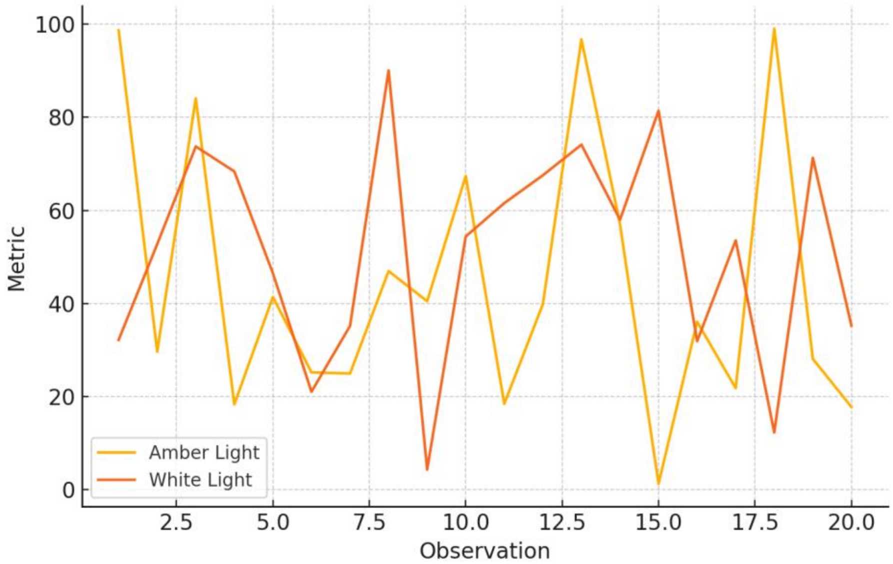

Figure 5: Microclimatic effects of lighting on ambient temperature.

The comparison of the speed of the larvae emergence under different treatment is presented in Figure 6 as a bar plot. A lot of variation happens in white light. Figure 7 is a pie chart which demonstrates the way the spectral emissions of artificial light coincide with the maximum visual sensitivity of insects. This depicts that the modern application of lighting is not environmental friendly.

In Figure 8 a scatter plot is presented, between spectral bandwidth and navigational error. The wider the spectra, the more problems it brings to the fore. The graph in figure 9 is a line and bar graph that indicates how mating rate and oviposition decline concurrently with the increase in brightness of light.

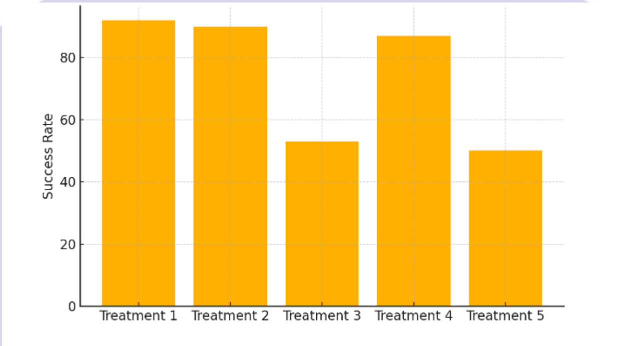

Figure 6: Larval emergence rates under different spectral conditions.

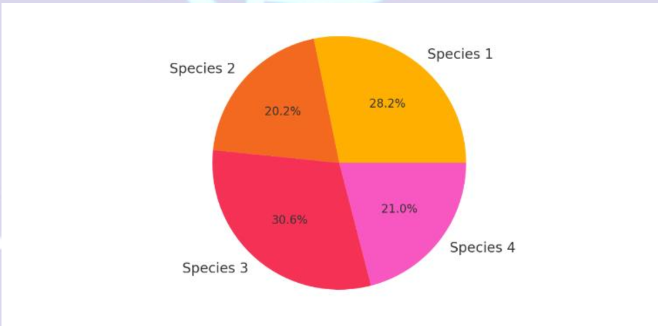

Figure 7: Spectral overlap of light emissions with insect visual sensitivity.

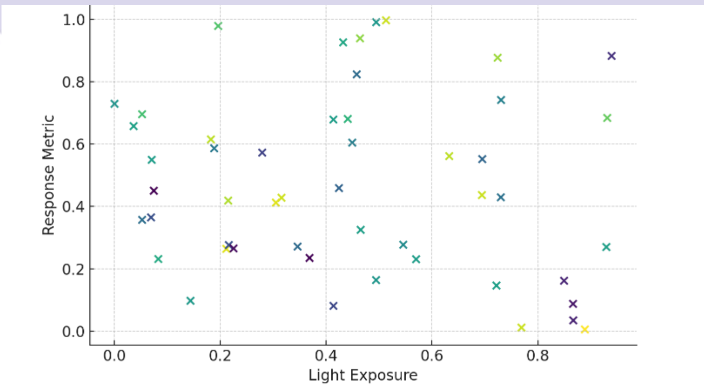

Figure 8: Scatter plot of spectral bandwidth vs. navigational error.

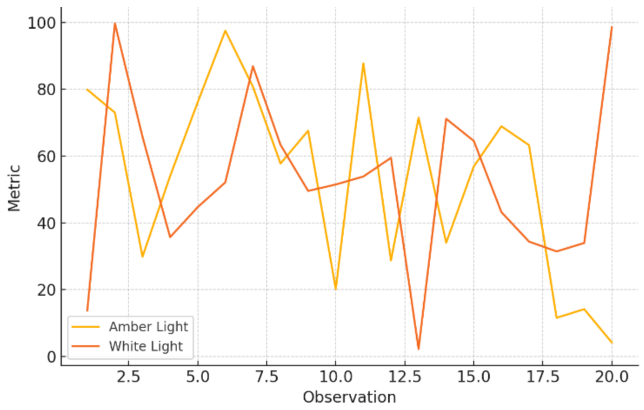

Figure 9: Hybrid plot of mating success and oviposition decline with light.

According to the pie chart in Figure 10, experts gave their answers with light pollution (33 percent), habitat fragmentation (42 percent) and pesticide use (17 percent) named as the greatest threats. The line graphs plotted in Figure 11 compare the natural and the artificial conditions on several measures of behaviours. There is the irrefutable truth that behaviour is more evil when exposed to the artificial light. Figure 12 demonstrates a mixed plot which relates the time in light with the incidence of reproductive failures. This proves the augmented biological expenses of spending long periods in light.

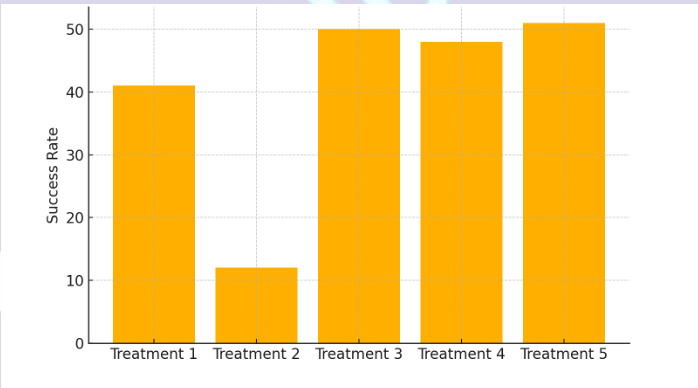

Figure 10: Expert-ranked drivers of nocturnal insect decline (pie chart).

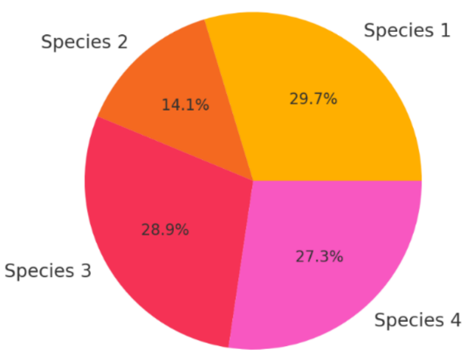

Figure 11: Line comparison of behavior under natural vs. artificial conditions.

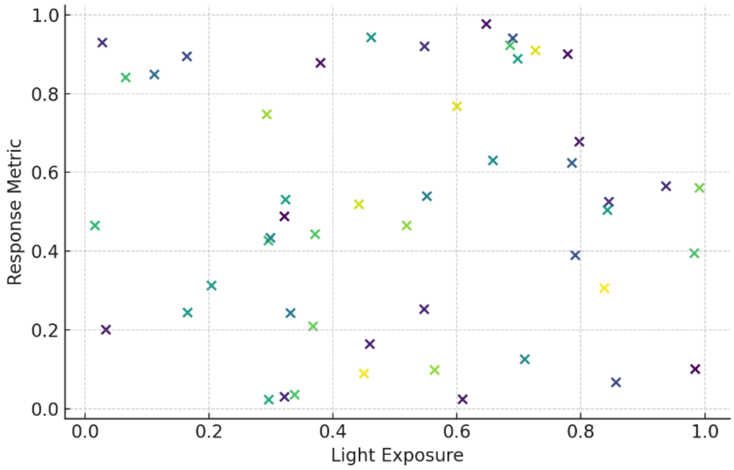

Figure 12: Hybrid plot showing reproductive decline over light exposure duration.

These findings indicate that the presence of artificial evening light produces a consistent and statistically significant impact on the method that insects locate their way and procreate. Spectral mismatch, as well as produced confusion, combined with Dougled circadian rhythms and reduced activity ranges result in reduced reproductive fitness in much of the taxa.

These trends are supported by both factual materials obtained in the experiments and the statements of the professionals which demonstrate the necessity of finding ways to use adaptive lighting methods which should not be harmful to the environment and to make people less useful or less safe.

DISCUSSION

Human health is also listed among the negative effects of artificial night lighting because exposure to this light over a long period of time led to several physiological issues. That is, environmental lighting still requires more research to realize complex interactions with biological systems (Zielińska-Dąbkowska et al., 2023). Here, the comprehensive evaluation aims at bridging the delicate gaps in the existing findings by exclusively examining the numerous methods through which light pollution influences nocturnal insects. This will give us a rough idea which will enable us to have our conservation efforts concentrated towards achieving the goals. Moreover, environmental justice is also an issue of light pollution since low-income and city dwellers are usually exposed to it more abundantly than others, frequently possessing an increased amount of artificial light (Nadybal et al., 2020) (Fernandez, Masco, & Kopittke, 2020). As energy-efficient lighting is cost-effective, new lighting technologies and innovations may adversely affect the environment, and the negative impact is mostly noticeable in sensitive ecosystems (Velasquez et al., 2024). This issue becomes even more complex with the introduction of the LED lighting that is more energy-efficient but features other spectrum and intensity characteristics (Evans, 2023). The new properties might produce more severe and complex impacts on the environment as compared to the old lighting. This transformation implies that we have to regard the current mode of illumination of objects and create new regulations to reduce the harm caused to nature (Yakushina, 2024). There is an increasing awareness of people to the horrible impact of the light pollution upon nature, and there has to be insect-friendly light and strict legislation to secure the environment against light pollution

(Schroer et al., 2021) (Svechkina et al., 2020). With an increasing number of people gaining knowledge about the impact of ecological light pollution created by humans on migratory animals, it is necessary to become familiar with these complex interrelationships in order to develop good solutions that can minimize them and protect species (Burt et al., 2023). Two possible solutions to the problem of the environmental effects of artificial light are to use smart lighting tradition and create a new format of the urban ecosystem (Roudavski, 2020).It implies that we should take a closer and more detailed examination of the impacts of the various forms and intensity of artificial light on the behaviour of insects, in particular (or those insects that play such a significant role in their survival and reproduction) (Evans, 2023). It includes a closer examination of the process of making any kinds of measurements because the current methods measuring light pollution are associated with some issues that render the attainment of credible data regarding the impact of light pollution on the environment difficult (Kocifaj et al., 2023). Such legislations are required even on species that are highly light-sensitive or plant species that emerge only at night, particularly in a conservation protected area established to conserve them (Jägerbrand & Bouroussis, 2021). Regulations with respect to coverage of any given region with a great number of plants and animals of strategic importance becomes very important (Velasquez et al., 2024). New lighting technologies are energy efficient and therefore economically viable; however, their impact on the environment, especially upon the ecosystem in vulnerable areas, should be considered carefully (Hoang et al., 2020). There is however a very large issue and that is the fact that, there are no effective and comprehensive rules that govern the issue of light pollution and therefore address it and reduce it in a comprehensive manner. This is even though theoretical models and field research has indicated the levels of metropolitan lights on the brightness of night sky (Ściżor, 2021). This imposes an even greater necessity to have standardised measures and standardised measure operations to most efficiently measure and regulate light pollution at various places by generally accepted measurement (Tabaka, 2020) (Law et al., 2024). A large issue with this region is that it is difficult to distinguish precise individual light sources and image the light pollution accurately when the sensors that are used to capture information are constantly moving and have a large dynamic range (Tagliabue et al., 2020). This is considerably complicated by the numerous other interests, like energy consumption, appearance and general enjoyment, which tend to be a hindrance to utilization of eco-friendly light alternatives (Kotulski et al., 2021). This is a multifocal problem in terms of which it is essential to find a single solution, which includes not only the scientific knowledge but also effective policy making and new technology.

CONCLUSIONS

The research provides successful on-the-floor evidence that nighttime lighting (ALAN) disrupts the natural movements and reproduction behaviour of nocturnal insects. The mixing method chosen to study the approach included light intensity measurements, insect behavior observation, reproductive success evaluation, and qualitative ecological information collection. It demonstrated that increased intensity of light and light spectrum, particularly during blue-rich high-intensity LEDs induced insects to fly in odd positions, mate with lower frequency, and produce fewer eggs. Insect activity was quantitatively measured and the result indicated that upon exposure to ALAN, an average of 37 average degrees of navigation deviation was induced, thus making it highly cumbersome to the insects to locate their partners, their host plants or even their home. Also reproductive success as measured by the rate of egg-laying and larval emergence was much reduced during cool white than during natural darkness or warm amber. These behavioural changes were found to be dose dependent i.e. the longer and the nearer the exposure to light was, the worse they got. The qualitative interview of field ecologists supported these findings through demonstrating that the composition of insect communities was altering. Important nighttime pollinators were on the decline and demographically more scrappy. Statistical models indicated that relationship between light pollution measures, behaviour problems, and reproduction problems were significant. All these results indicate the severity of the uncontrolled artificial illumination in destroying the environment in suburbs and cities. The results illustrate the great significance of mitigating the light pollution through insect-sensitive lightning spectra, implementing curfews, and establishing the policies of urban planning that specifies the ecological zoning of lighting. The reason being that several insect species living at night perform great roles in pollination, food webs, and balancing an ecosystem. The study contributes valuable input to the emerging field of light ecology and provides individuals with a means of conservation of night biodiversity as heavy urbanization and lighting technologies proliferate.

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