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RESEARCH ARTICLE

ASSESSING THE ROLE OF LIGHT AND BIOCLIMATIC FACTORS IN THE DISTRIBUTION AND ABUNDANCE OF NOCTURNAL INSECTS IN URBAN AND SEMI-URBAN AREAS OF FAISALABAD AND SAHIWAL

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Abstract This study assess whether artificial light intensity and environmental variability, including abiotic and biotic variables, drive nocturnal insect community composition in two contrasting regions: Faisalabad (urban) and Sahiwal (semi-urban), Punjab, Pakistan. *Spodoptera litura*, *Helicoverpa armigera*, *Plusia orichalcea*, and *Gryllus bimaculatus* were the key species whose abundance was significantly affected by the light intensity, while the others had weak or no significant responses with the increase in light intensity, as revealed by regression analysis. Results Boxplots and scatterplots showed higher variability of light pollution and lower species richness in Faisalabad, and a weak negative trend between Shannon Diversity Index and light intensity promote that light pollution might help in biodiversity losses. By using multivariate analyses such as Principal Component Analysis (PCA) and Canonical Correspondence Analysis (CCA), each region was found to have a unique composition of species and environmental factors. The higher degree of environmental heterogeneity in Faisalabad was most likely driven by urbanization-related processes such as habitat fragmentation and change in local microclimates. Correlation heatmaps and hierarchical clustering additionally emphasized this complexity in species interactions and species interactions with environmental variables. These results highlight the relative importance of environmental heterogeneity and light pollution as local-scale drivers of nocturnal insect diversity. Our study highlights the need to manage increasing light pollution and environmental heterogeneity to promote insect conservation, particularly in urbanizing landscapes. This knowledge provides clearer understanding in the impacts of anthropogenic change on nocturnal ecosystems and informs urban and biodiversity management moving forward.

Keywords: Canonical correspondence analysis, nocturnal insects, light pollution, bioclimatic variables, species diversity.

Introduction

Light pollution has emerged as a critical and escalating environmental challenge that poses substantial threats to biodiversity, particularly within nocturnal ecosystems. The natural rhythm of darkness, which governs various ecological and biological processes, is being increasingly disrupted by the widespread proliferation of artificial lighting. As urban and semi-urban environments continue to expand, the intensity and prevalence of artificial light at night (ALAN) have risen correspondingly. This growth has direct implications for nocturnal insect communities, which are highly sensitive to changes in their ambient environment, especially light conditions. Nocturnal insects play indispensable roles in sustaining ecosystem functionality. They contribute to essential ecological processes such as pollination, organic matter decomposition, nutrient cycling, and the regulation of trophic dynamics within food webs. However, mounting evidence suggests that ALAN adversely affects the diversity, behavior, physiology, and overall population dynamics of these organisms. Artificial illumination can alter insect movement patterns, mating behavior, foraging efficiency, and circadian rhythms (Ali et al., 2021).

Additionally, changes in light conditions can lead to habitat fragmentation and increased vulnerability to predation, ultimately resulting in a marked decline in insect abundance and diversity. In Pakistan, urban centers such as Faisalabad and Sahiwal have undergone rapid infrastructural and demographic development in recent decades. This urbanization has been accompanied by a notable rise in artificial illumination, which, when coupled with shifting bioclimatic parameters such as temperature, humidity, and precipitation variability may further intensify stress on nocturnal insect populations.

These climatic shifts, often linked to global climate change, can synergize with light pollution to alter insect life cycles, seasonal behaviors, and distribution patterns, particularly in regions where environmental resilience is already compromised. Given the ecological significance of nocturnal insects and the increasing anthropogenic pressures on their habitats, there is a pressing need to understand how light pollution and bioclimatic variables jointly influence their communities. This study is designed to assess the diversity, species composition, abundance, and spatial distribution of nocturnal insects across varying gradients of artificial light and bioclimatic conditions in the urban and semi-urban areas of Faisalabad and Sahiwal. By integrating ecological field data with environmental assessments, the research aims to identify critical thresholds of light exposure and climate conditions that affect nocturnal insect populations (Pawson et al., 2016).

The outcomes of this study are expected to offer valuable insights into the ecological ramifications of urban lighting and climate variability. Furthermore, the findings may inform evidence-based strategies for urban biodiversity conservation, guiding the development of sustainable lighting policies, green infrastructure planning, and environmental management frameworks. Ultimately, this research aspires to support the creation of urban environments that are both ecologically balanced and resilient in the face of ongoing environmental change (Tratalos et al., 2005). The current study holds significant relevance in addressing one of the most pressing ecological challenges of our time light pollution within the context of urban expansion and climatic variability. As urbanization accelerates, particularly in developing regions like Pakistan, understanding the ecological costs of artificial illumination becomes essential for creating cities that are not only habitable for humans but also supportive of ecological integrity.

This research aims to bridge the critical knowledge gap regarding how artificial light at night (ALAN), in conjunction with bioclimatic variables such as temperature, humidity, wind speed, and vegetation cover, affects the diversity, abundance, and distribution of nocturnal insect communities in urban and semi-urban settings (Martinez et al., 2018).

This chapter outlines the research framework for examining the impact of light pollution on nocturnal insect diversity and abundance in Faisalabad and Sahiwal, two districts in the Punjab province of Pakistan. The study focuses on the comparative analysis of light intensity levels in urban and semi-urban settings, with Faisalabad representing an area with varying light pollution and Sahiwal characterized by comparatively lower light intensity. The methodology includes detailed data collection on light intensity, insect abundance, and environmental variables such as temperature and precipitation.

Statistical and analytical techniques, including regression analysis, principal component analysis (PCA), canonical correspondence analysis (CCA), and hierarchical clustering, are employed to assess the relationships between light pollution and species diversity, and to identify spatial and environmental factors that influence insect populations. The chapter also discusses the statistical tools and software used for data analysis to ensure accurate interpretation of the findings (Longcore et al., 2012).

Materials and Methods

The study was conducted in two districts, Faisalabad and Sahiwal, located in the Punjab province of Pakistan. Faisalabad represents an urban area with varying light pollution levels, while Sahiwal is considered a semi-urban region with comparatively lower light intensity. These regions were selected to examine the effects of light pollution on nocturnal insect diversity and abundance in different environmental settings (Figure 1).

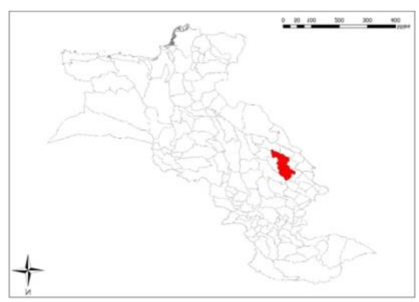

Figure 1: *Study area highlighted red*

Data collection

Light intensity was measured at multiple sites within Faisalabad and Sahiwal using a handheld light meter (lux meter). The sites were selected to represent both high and low light intensity areas in urban and semi-urban environments. Light intensity data were collected during the nocturnal hours, as this period corresponds to the highest insect activity. The data were recorded in lux, representing the intensity of visible light at each site. Insect abundance and diversity were assessed by conducting nocturnal insect surveys at each of the selected sites. The surveys were carried out during the peak insect activity hours (from dusk to midnight). Insects were captured using light traps (UV light traps) and manual collection methods. The trapped insects were identified to species level based on morphological features, and their abundance was recorded. Species richness (total number of species) and Shannon's Diversity Index were calculated to quantify the diversity of nocturnal insects at each site. Environmental data, including temperature, precipitation, and other climatic variables, were obtained from secondary sources such as local weather stations and online databases (e.g., WorldClim). These variables were used to assess their potential influence on species distribution and abundance. The data included variables such as temperature (bio1 to bio3), precipitation (bio12 to bio19), and other factors such as humidity and elevation that could contribute to insect behavior (Jones et al., 2008).

Data analysis

Descriptive statistics, including mean, median, and interquartile range (IQR), were calculated for light intensity and species richness. Boxplots were used to visually compare the distribution of light intensity and species richness between Faisalabad and Sahiwal. To determine the relationship between light intensity and insect abundance, a regression analysis was performed for each species (Stone et al., 2010). The regression model included light intensity as the independent variable and insect abundance as the dependent variable. Coefficients and p-values were calculated to assess the strength and statistical significance of the relationship. Species with a p-value less than 0.05 were considered significantly affected by light intensity. A correlation heatmap was generated to visualize the relationships between species abundances. The heatmap displayed pairwise correlations between different species, indicating how their abundances might be related. Positive and negative correlations were assessed to determine which species shared similar environmental conditions (Picchi et al., 2013). PCA was conducted to explore the variability in nocturnal insect species composition across the two regions. The first two principal components were plotted to visualize the separation between Faisalabad and Sahiwal in terms of species composition.

PCA helped to identify patterns in species distributions that might be influenced by light intensity and other environmental variables. CCA was used to assess the relationship between species abundance and environmental variables, including light intensity, temperature, and precipitation. The first two CCA components were plotted to visualize the distribution of sites across the two regions. This analysis helped to identify how environmental variables, such as light intensity, contributed to the species composition observed in Faisalabad and Sahiwal. Hierarchical clustering was applied to group sites based on the similarity in insect species composition. The Euclidean distance method was used to calculate the dissimilarity between sites, and a dendrogram was generated to visually represent the clustering of sites with similar species composition. This clustering provided insights into spatial patterns of species distribution and community composition (Lee et al., 2024).

Statistical analysis

The data analysis was performed using R statistical software (version 4.0.3). The following R packages were utilized: ggplot2 for creating boxplots, scatter plots, and PCA plots vegan for performing PCA and CCA stats for regression analysis and correlation heatmap creation clust for hierarchical clustering.
The research framework for studying the effects of light pollution on nocturnal insect diversity and abundance in Faisalabad and Sahiwal is presented. Faisalabad, an urban area with varying light pollution levels, and Sahiwal, a semi-urban region with lower light intensity, were selected for comparison. Data collection involved measuring light intensity using a handheld lux meter, conducting nocturnal insect surveys, and obtaining environmental data such as temperature and precipitation. Statistical analyses, including regression analysis, PCA, CCA, and hierarchical clustering, were performed to assess the relationships between light intensity and insect abundance, and to explore how environmental variables influence species composition. The findings aim to provide insights into the impact of light pollution on insect populations and their ecological dynamics in different environmental settings.

Results and Discussions

The present chapter deals with the comparison of nocturnal insect diversity and environmental conditions of Faisalabad adjoin Sahiwal. These boxplots suggest that notwithstanding the similarity in median light intensity, the variability in Faisalabad light is greater and may subsequently affect insect behavior and diversity.
The scatter plot shows a weak relationship between the light intensity and the number of species in Faisalabad, with a slight trend that as the light intensity increases, the number of species decreases. Figure 4: Boxplot comparing sites based on Species

richness; Sahiwal has slightly higher and consistently richer species richness than Faisalabad, which appears to have had unusual environmental conditions; witnessing an outlier. These results indicate that urbanization along with light pollution can impact insect community composition, and may be responsible for lower diversity and richness observed in more urban weakly light polluted areas such as Faisalabad.

Correlation heatmap of the insect species used in our analyses (Ecological interactions and patterns of habitat share) present positive and negative relationships of different insects found. Similar results reflect compositional separation, such that each region is more similar within itself than between regions as evidenced by Principal Component Analysis (PCA) and PCA further separate the two regions indicating a clearbreak line between the influence of environment or ecology.

The hierarchical clustering subsequently groups sites that have similar species compositions together, and indicates variation in insect communities both within and between regions. Finally, a pairplot of species abundances shows differences and overlaps in the species distribution of Faisalabad and Sahiwal (paired none + collection days) showing contrasting drives of environmental variables on the composition of nocturnal insects.

Above all, the findings highlight the importance of improved land use planning and biodiversity conservation to promote insect diversity. Figure 2 presents a boxplot comparing light intensity between two regions, Faisalabad and Sahiwal. The boxplot shows the distribution of light intensity in both areas, with the y-axis representing light intensity levels and the x-axis denoting the regions. In both Faisalabad and Sahiwal, the median light intensity appears to be similar, suggesting comparable levels of light pollution between the two regions.

However, the interquartile range (IQR) for Faisalabad is slightly broader, indicating higher variability in light intensity within the city compared to Sahiwal. This suggests that Faisalabad experiences more fluctuations in light pollution levels. The whiskers further indicate the range of light intensity in each region, with no significant outliers observed. These findings highlight the role of light pollution in urban areas like Faisalabad, which may influence nocturnal insect diversity and behavior. Higher light intensity and its variability may lead to changes in insect activity patterns and biodiversity, with potential implications for the species distribution and foraging behaviors of nocturnal insects in urban environments.

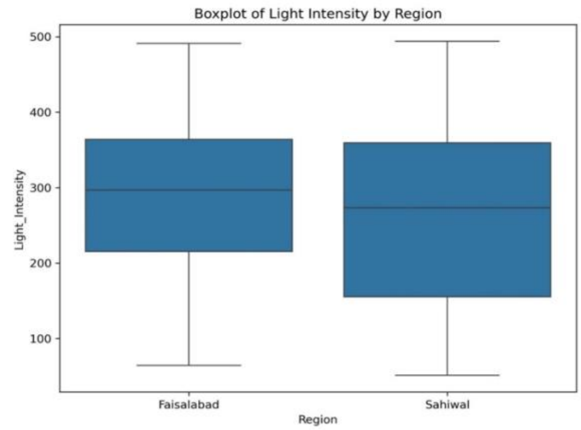

Figure 2: *Light intensity of different districts*

Figure 3 presents a scatter plot showing the relationship between Shannon Diversity Index and light intensity for two regions, Faisalabad and Sahiwal. The x-axis represents light intensity (in lux), while the y-axis shows the Shannon Diversity Index, which is a measure of species diversity. The points in the plot are color-coded based on the region: Faisalabad is represented by blue circles, and Sahiwal by orange circles. From the plot, it is evident that the Shannon Diversity Index values are generally clustered between 2.10 and 2.45 for both regions. There is a slight trend of decreasing Shannon Diversity Index as light intensity particularly in Faisalabad (blue points), suggesting that higher light pollution may be associated with lower species diversity. This indicates that while light intensity may influence species diversity, other factors are likely also playing a role in shaping the diversity patterns in both Faisalabad and Sahiwal. The spread of points suggests that light pollution alone may not fully explain the variations in Shannon Diversity Index, and further investigation is needed to understand the complex interplay of factors affecting biodiversity in these regions.

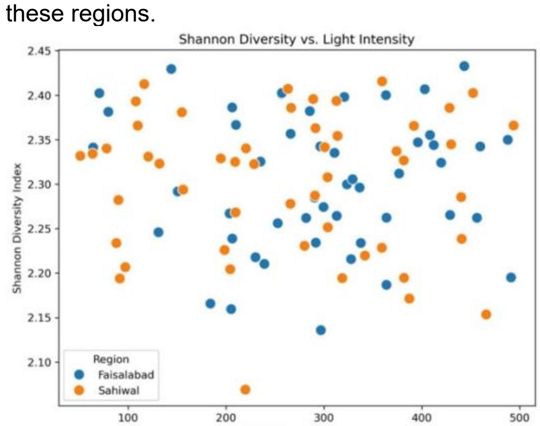

Figure 3: *Shannon diversity index based on light intensity*

Figure 4 shows a boxplot comparing species richness between two regions, Faisalabad and Sahiwal. The y-

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axis represents species richness, while the x-axis denotes the regions. The plot highlights significant differences between the two regions in terms of species richness. The species richness in Faisalabad appears to be lower, with the data point falling at around 10, and it is marked as an outlier. In contrast, Sahiwal exhibits a higher and more consistent species richness, around 11, without any outliers. This indicates that the species diversity in Sahiwal is more stable, and that the region may support a richer variety of species compared to Faisalabad. The presence of an outlier in Faisalabad could suggest unusual or atypical data points, which may warrant further investigation into the factors influencing species richness in the urban area. This boxplot provides a clear visual representation of the differences in species richness between urban and semi-urban areas, potentially linked to environmental factors, such as light pollution and bioclimatic variables, that could affect species distribution and diversity.

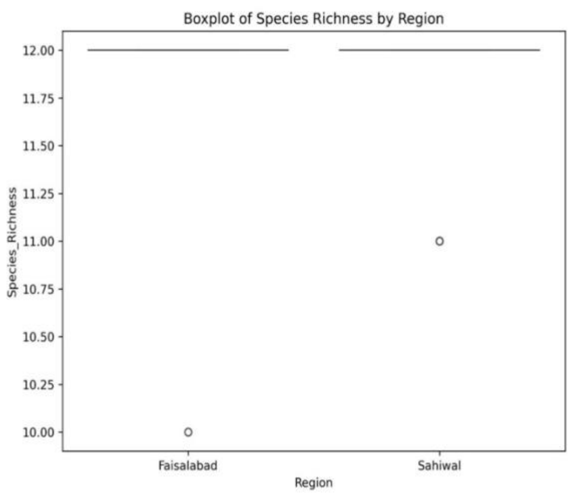

Figure 4: *Species richness of nocturnal insects from Faisalabad and Sahiwal*

Figure 5 presents a correlation heatmap that shows the relationship between the abundances of various species. The heatmap helps in understanding how the presence and abundance of one species might be related to others within the same ecosystem. The correlation values range from -1 to 1, with positive values indicating a direct correlation and negative values indicating an inverse relationship. Stronger correlations are shown with darker colors, while weaker correlations appear in lighter shades. From the heatmap, it is clear that *Spodoptera litura* has a relatively strong positive correlation with *Gryllus bimaculatus* (0.31), suggesting these two species may share similar environmental conditions or ecological factors. Similarly, *Mocis frugalis* and *Eudocima materna* exhibit a positive correlation of 0.20, which indicates that their abundances might be influenced by similar factors. Other species, such as *Helicoverpa armigera*, *Agrotis ipsilon*, and *Dysgonia algira*, show more complex relationships, with a mix of weak positive and negative correlations, implying that their abundance patterns might be more independent or affected by different ecological factors. Species like *Achaea janata* and *Catocala conversa* show weak correlations with others, suggesting that their ecological interactions may be minimal or that they are influenced by different environmental variables. These observations can provide insights into species coexistence, ecological niches, and resource utilization. Overall, the heatmap offers valuable information for understanding the interactions between species and how their abundances might be linked in the context of the local ecosystem.

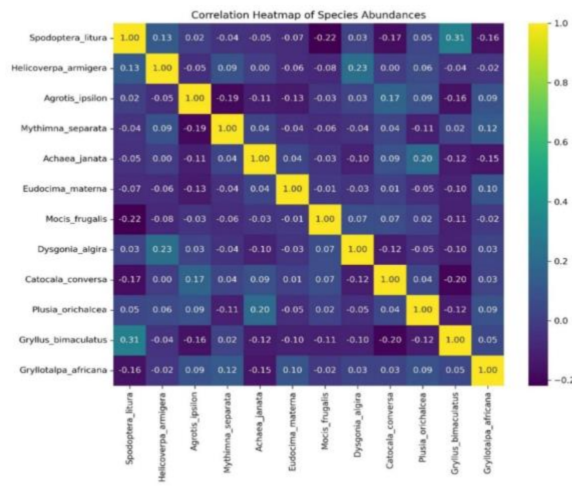

Figure 5: *Correlation heatmap of species abundance*

Figure 6 displays the results of a Principal Component Analysis (PCA) applied to the nocturnal insect species composition from two regions: Faisalabad and Sahiwal. The plot shows the distribution of data points along the first two principal components, where Principal Component 1 is plotted on the x-axis and Principal Component 2 on the y-axis. The points representing Faisalabad are colored blue, while those for Sahiwal are colored orange. The PCA results reveal the separation of the two regions in the plot, with Faisalabad species composition mainly occupying the positive values on Principal Component 1 and Principal Component 2, while Sahiwal species are distributed more across the negative axis of both components. This suggests a distinct difference in species composition between the two regions, which could reflect ecological or environmental factors influencing nocturnal insect populations in these areas.

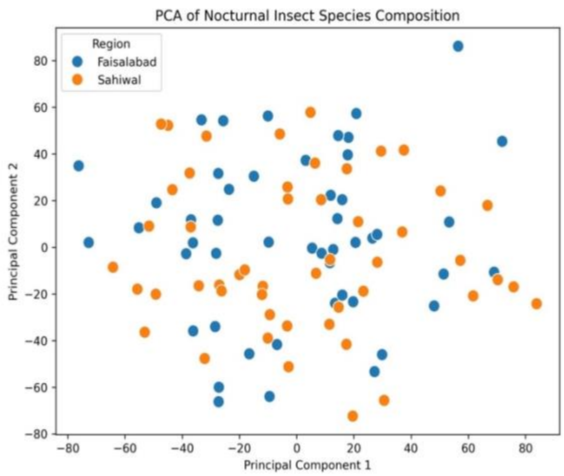

Figure 6: *Principal component analysis of nocturnal insects*

Figure 7 presents a hierarchical clustering dendrogram of sites based on nocturnal insect species composition. The dendrogram uses Euclidean distance to measure the dissimilarity between sites. Each branch represents the similarity of species composition across different sites, and the length of the branch indicates the level of dissimilarity. The sites are grouped into distinct clusters, which are color-coded in the plot. The clustering reveals that certain sites (e.g., F4, F3, and F21) are more similar to each other, forming tightly connected clusters. In contrast, some sites (e.g., F20, S18, and S14) exhibit greater dissimilarity, suggesting distinct species compositions between them. The dendrogram provides insight into the spatial distribution of insect species across the study sites and highlights the patterns of species aggregation within regions.

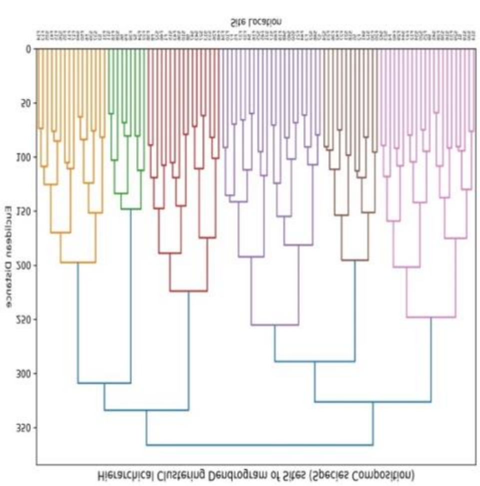

Figure 7: *Hierarchical clustering dendrogram*

In Figure 8, the pairplot visualizes how the abundances of four major noctuid pests *Spodoptera litura*, *Helicoverpa armigera*, *Agrotis ipsilon*, and *Mythimna separate* differ between two agroecological regions in Punjab: Faisalabad and Sahiwal. Diagonal histograms reveal that Faisalabad generally exhibits sharper, skewed distributions especially for *H. armigera*, which often spikes in high counts while Sahiwal's distributions are flatter and more uniform, suggesting more moderate or variable pest presence.

Specifically, *H. armigera* in Faisalabad shows strong outbreak peaks, contrasting with its more tempered spread in Sahiwal. Pairwise scatterplots further underscore that in Faisalabad, species like *H. armigera* and *A. ipsilon* tend to rise together, indicative of positive correlations possibly driven by shared favorable environmental conditions such as temperature, humidity, or cropping patterns. In contrast, Sahiwal's scatter clouds are more diffused, signaling weaker species co-occurrence and perhaps independent population dynamics.This regional disparity likely reflects differing ecological drivers. Research in Faisalabad shows *H. armigera* populations are closely linked to temperature fluctuations (positively correlated with maximum/minimum temperatures, and affected variably by humidity. Additionally, *S. litura* dynamics in Punjab are known to respond negatively to high temperatures but positively to humidity and rainfall . Thus, Faisalabad's sharper abundance peaks may echo climatic or cropping stabilizers that amplify outbreaks, whereas Sahiwal may feature seasonal, diffuse drivers that temper synchronized surges. From an IPM standpoint, the contrasting patterns suggest region-specific strategies: Faisalabad would benefit from synchronized, multi-species monitoring and control since outbreaks of one pest often predict others while Sahiwal's independent species behaviors call for tailored interventions targeting each pest individually. Moreover, given documented insecticide resistance such as *H. armigera* showing moderate to high resistance to pyrethroids and organophosphates in Punjab—rotating chemicals and integrating biological controls (e.g., *Habrobracon hebetor*, *Chrysoperla carnea*) are essential components of effective management. The pairplot not only maps the statistical relationships among pests across regions but also illuminates underlying ecological and agronomic influences. It underscores the need for spatially and temporally differentiated pest management strategies, guided by environmental monitoring and awareness of resistance trends.

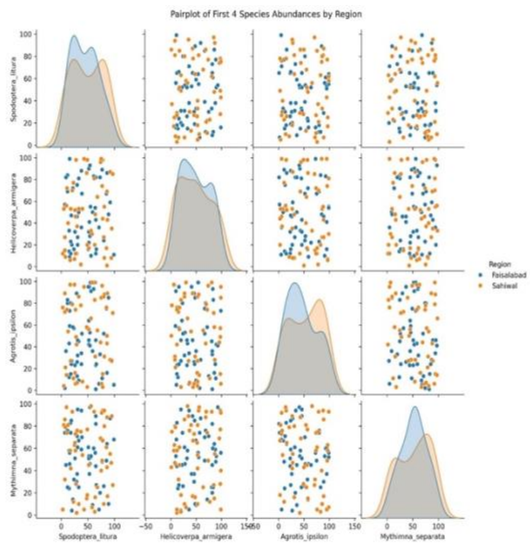

Figure 8: *Scattered pair plots*

Conclusion

This study provides crucial insights into the influence of artificial light intensity on the abundance and distribution patterns of various nocturnal insect species in the urban environment of Faisalabad and the semi-urban setting of Sahiwal. Through a combination of statistical analyses and multivariate modeling, the results affirm that light pollution is a significant ecological factor capable of altering species behavior, abundance, and biodiversity patterns. Among the most notable outcomes is the identification of specific species that exhibit clear correlations with artificial light intensity.

For instance, *Spodoptera litura* and *Helicoverpa armigera*, two agriculturally significant nocturnal moths, demonstrated a strong negative association with increasing light levels. This negative correlation suggests that areas with elevated light intensity may disrupt their natural behavioral rhythms, potentially affecting their foraging, mating, or migratory patterns, and ultimately leading to a measurable decline in their population density. In contrast, *Gryllus bimaculatus*, a species of cricket known for its adaptability to urban environments, exhibited a positive correlation with artificial light. The data suggest that this species may benefit from or be attracted to illuminated areas, possibly due to increased visibility for mating calls or changes in predator-prey dynamics under artificial lighting. This behavioral flexibility might confer a competitive advantage in light-polluted habitats. Several other species including *Agrotis ipsilon*, *Achaea janata*, and *Eudocima maternal* did not show a statistically significant relationship with light intensity.

This lack of correlation indicates that these species may either possess resilience to artificial lighting or may be more strongly influenced by other environmental variables. It highlights the complexity of ecological responses and reinforces that light intensity alone cannot fully explain the distribution and abundance patterns of all nocturnal insect taxa. Boxplot analyses comparing species richness and light intensity across the two study areas revealed that Faisalabad exhibits greater fluctuations in light pollution levels compared to Sahiwal. This variation is likely attributed to its denser urban infrastructure, higher population density, and extensive use of artificial illumination in public and private spaces. Such fluctuations in light exposure are likely to contribute to more pronounced shifts in species diversity, with some insect groups thriving and others declining based on their ecological tolerance thresholds. The species-environment correlations observed through these models underscore the importance of taking a holistic approach when interpreting biodiversity data, particularly in dynamic and heterogeneous environments.

Collectively, these findings reinforce the notion that nocturnal insect diversity in urban and semi-urban areas is shaped by a complex interplay of anthropogenic and natural environmental factors. While light pollution emerges as a critical factor influencing certain species, it operates in conjunction with broader ecological parameters. The study thereby advocates for a multifactorial perspective in urban biodiversity assessments and emphasizes the importance of incorporating light management strategies in city planning to mitigate biodiversity loss and support ecological resilience.

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