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RESEARCH ARTICLE

Factors Responsible for Shaping the Distribution and Biodiversity of Different Species of Lepidoptera in District Faisalabad

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Abstract The analysis examines butterfly distribution and diversity in District Faisalabad, Punjab, Pakistan, and the impacts of ecological (climate variables and land cover) and anthropogenic (population density and urbanization) factors. A diverse assemblage including *Pieris rapae*, *Danaus chrysippus*, and *Euploea core* was recorded. PCA and K-means clustering revealed three major climatic zones in Faisalabad. Species like *Eurema hecabe* and *Pieris rapae* were common in agro-ecosystems due to human activity adaptation and host plant presence. Correlation matrix showed strong positive correlations between butterfly richness and moderate climates (stable temperatures, adequate precipitation), while extreme weather or stress led to negative correlations. Butterflies, as pollinators and bioindicators, are affected by urbanization, habitat fragmentation, and pesticide use. Results emphasize targeted conservation through nectar-rich vegetation and reduced chemical use to sustain butterfly diversity.

Keywords: Climatic factors, diverse assemblage, temperature, precipitation, humidity

Introduction

Moths and butterflies, belonging to the order Lepidoptera, exhibit diverse distribution patterns shaped by ecological and environmental conditions. Climate is a major driver, with seasonal fluctuations, temperature, and humidity significantly affecting species richness. Tropical regions with warm, stable weather support high Lepidoptera diversity, while colder or drier climates restrict survival. Elevation and microclimate also influence habitat suitability and species distribution. Vegetation type and habitat availability are also vital. Plant diversity affects Lepidoptera distribution due to their reliance on specific host plants for feeding and reproduction. Wetlands, forests, grasslands, and agro ecosystems offer varying resources that impact species abundance and community composition. Habitat fragmentation and deforestation further modify distributions.

Pakistan, primarily an agricultural country, features diverse soil types and irrigation systems. Punjab, with 69% of its land under agriculture, is the most productive province. Faisalabad contributes 3985 hectares to Punjab’s agriculture. Lepidoptera, the second-largest insect order with over 180,000 species globally (Perveen and Ahmad, 2012), includes butterflies, moths, and skippers. Over 5,000 insect species have been documented in Pakistan, including around 400 moths and butterflies. More than 100,000 species have been studied to date (Richards & Davies, 1977). The agro forest concept integrates agricultural and forest ecosystems (Ishizuka et al., 1995). Lepidoptera dispersal, reproduction, and ecological interactions are highly influenced by global climate change. Species such as Spodoptera frugiperda have expanded their ranges due to shifting climate conditions. In Iran, Zygaenidae moths are predicted to move due to climate change, with endemic species shifting to higher elevations. In Nepal's trans-Himalayas, flora diversity correlates with butterfly richness along elevation gradients. Lower elevations with shrubby vegetation support more species than higher, less diverse zones.

Butterflies like *Pieris rapae* have shown adaptability in fragmented agricultural landscapes, with mobile generalist species adjusting more easily than specialists. Migration correlates with higher genetic diversity in butterflies, potentially enhancing environmental resilience. Habitat conversion, especially through agricultural intensification, poses serious threats to Lepidoptera. Agro ecological practices and local woodland cover influence butterfly richness, while poorly managed pest control can negatively affect populations.

Vegetation structure supports higher butterfly diversity, as a varied plant landscape provides resources for larvae and adults. In Iran’s Hyrcanian Forest, a positive correlation was found between Lepidoptera richness and plant diversity. Habitat features such as canopy cover, water sources, and tree density (e.g., in Tanzania's Kihansi Gorge Forest) are closely linked to butterfly community structure. Climate changes, pollution, and land use shifts since the 1800s have driven declines in European butterflies. Species composition responds to pollution gradients, and some serve as bio indicators. Favorable climates boost populations, while droughts reduce them, causing migration to moist refuges. For instance, during the Last Glacial Maximum, cold-adapted mountain butterflies experienced contractions and expansions that shaped current genetic diversity.

Invasive species, pollution, and urbanization continue to threaten native populations. Studies from the UK show drastic butterfly declines due to habitat loss, pesticides, and climate change. A Dutch study with nearly 3 million observations from 6,075 sites revealed that vegetation structure and land use significantly shape butterfly diversity. Dispersal ability is key to Lepidoptera distribution. Habitat fragmentation reduces connectivity and gene flow. Topography such as elevation, slope, and aspect create microclimates that define niches for different species. Human-driven changes like deforestation and urbanization fragment habitats but targeted conservation can aid recovery, as seen in Scotland’s dark-bordered beauty moth. Range shifts due to warming climates are evident; in Scotland, generalists like the red admiral expanded while specialists like the grayling declined. Thus, understanding ecological factors and microclimatic conditions is essential for managing Lepidoptera biodiversity.

Materials and Methods

Study Area:

The study was carried out in Punjab, Pakistan's District Faisalabad, which is situated at latitude 31.5204° N and longitude 73.3587° E. The distribution of Lepidoptera species is affected by the semi-arid climate of Faisalabad, which features scorching summers and mild winters. In order to evaluate how various environmental conditions affect Lepidoptera variety, the study sites were chosen based on habitat changes, including urban areas, agricultural fields, forested regions and semi-natural grasslands as shown in Fig 1. Lepidoptera depend on the agricultural crops (wheat, sugarcane, maize, and cotton), fruit orchards and sporadic natural flora that make up the majority of the vegetation in the study area. The Faisalabad Meteorological Department provided temperature, humidity and precipitation data so that the effects of climate on species distribution could be assessed.

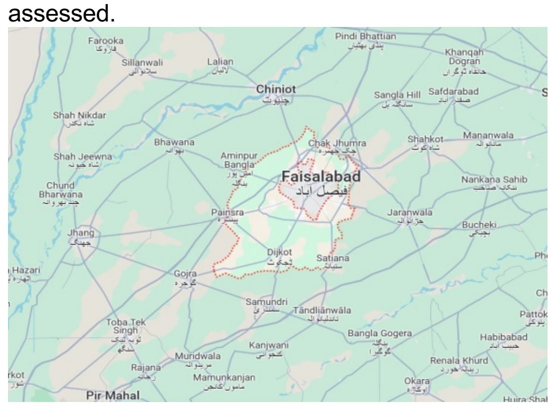

Figure 1. ***Map of Faisalabad Punjab, Pakistan.***

Research Design

To account for seasonal fluctuations in lepidoptera biodiversity, a comprehensive field survey was carried out for a complete year (specify the precise time period). Each chosen location underwent a monthly sampling program that included both nocturnal and diurnal species. Along with environmental variables like temperature, humidity, vegetation type and human disturbances, the study's main objectives were to document species richness, abundance and habitat preferences (Ahmad et al., 2021).

Data Collection

For data collection, a variety of standardized methodologies were used in the sampling of Lepidoptera species in District Faisalabad as shown in Fig 2. In order to attract moths and other night-flying Lepidoptera, light trapping was used for nocturnal species. Mercury vapor and UV light traps were positioned in different habitats from dusk to dawn (Holloway, 1980).

In places with a lot of foliage, sweep netting was utilized for diurnal species, especially butterflies, so that specimens could be collected with little harm (Pollard & Yates, 1993). In order to gain insight into plant-lepidopteran relationships, host plant observations were also carried out by keeping an eye on particular plant species to document the existence of caterpillars and their corresponding butterfly or moth species (Habel et al., 2016). Pitfall traps were set up at specific locations to evaluate ground-dwelling animals, making it possible to capture species that are difficult to gather using other techniques (Spitzer et al., 1997).

By combining these methods, a thorough evaluation of Lepidoptera variety was guaranteed, enabling the determination of species richness, abundance and habitat preferences across various ecological zones.

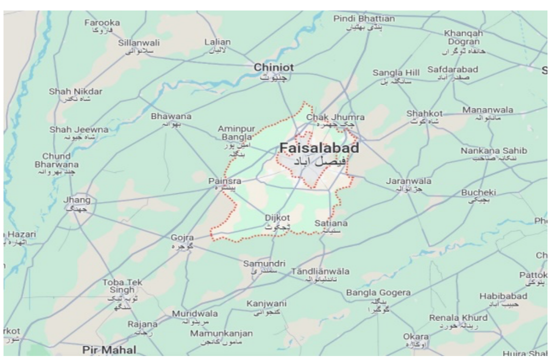

Figure 2. ***Selected Regions in Faisalabad and its Surroundings.***

Identification:

Standard field guides and taxonomy keys were used to identify collected Lepidoptera specimens based on their morphological characteristics (Heppner, 1991; Scoble, 1992). Details such as wing patterns, colors, body structure and antenna form were meticulously inspected for each species. The specimens also identified using the standard literature that was available, including research publications, theses and previously described species (Munir et al., 2008; Abbas et al., 2002).

Analysis of Data

The study examined lepidopteran species richness and diversity using the Shannon-Weiner Diversity Index (H') for species variation, Simpson's Index (D) for dominance patterns, and the Evenness Index (J') to assess distribution across ecosystems (Magurran, 2004). Seasonal population fluctuations and climate impacts were analyzed through species abundance monitoring, with regression models and ANOVA employed to evaluate species-environment relationships (Legendre & Legendre, 2012). Statistical analyses were performed using SPSS v.26 and R for ecological modeling, while ArcGIS enabled spatial visualization of species distributions. The results and discussion present findings from these comprehensive analyses.

Results and Discussion

Climate, vegetation, and the availability of habitat are some of the natural elements that affect butterfly abundance in Faisalabad. Butterfly populations are supported by the host plants and nectar sources found in urban gardens, green spaces, and agricultural environments. Because of their adaptability and correlation with agricultural fields, species such as *Eurema hecabe* (Common Grass Yellow) and *Pieris rapae* (Small White) are frequently seen. Butterfly abundance is also influenced by seasonal changes, especially those related to temperature and rainfall patterns; peaks are frequently seen during the spring and monsoon seasons when floral supplies are abundant. However, the diversity and stability of butterfly populations are threatened by urbanization, pesticide usage, and habitat fragmentation. Butterfly abundance in the area can be preserved and increased using conservation measures like growing plants that attract butterflies and using fewer chemicals.

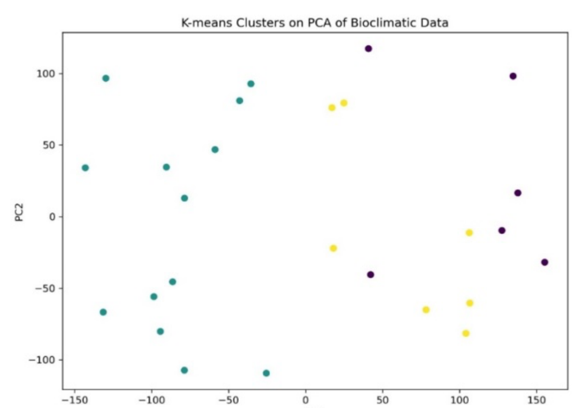

Figure 3. PCA of Climatic Variables for Study Sites

The PCA plot of bioclimatic variables for Lepidoptera sites visually represents the distribution of different locations based on their climatic characteristics. Principal Component Analysis (PCA) is a statistical method used to reduce the complexity of large datasets by identifying key patterns. In Fig 3, the X-axis (PC1) explains the highest variance in the data, while the Y-axis (PC2) explains the second highest variance. Each point on the plot represents a different Lepidoptera site, with their positioning indicating how similar or different their bioclimatic conditions are.

The spread of data points suggests variability in climatic conditions across different locations. Sites such as Jannah Garden, Manawala, and Ghatti are positioned toward the upper side, indicating distinct bioclimatic properties. Conversely, Chak 65JB and Makuwaana are located at the lower end, implying significantly different environmental conditions. Locations such as Chak Jhumra, Chak 233 RB, and Chak 195 RB are closer to the center, suggesting they have more moderate climatic characteristics. Sites that are clustered together share similar environmental conditions, whereas widely dispersed points indicate notable differences.

The variation captured by PC1 and PC2 may reflect contrasts such as moisture gradients, temperature ranges, or other climate-related factors critical to the distribution and habitat suitability of Lepidoptera species. By analyzing how these sites group or separate in the PCA space, the study identifies which environmental variables most strongly influence species distribution patterns and potentially uncovers ecological niches or regions of particular conservation importance.

This PCA analysis helps in understanding how climatic factors influence the distribution of Lepidoptera populations across various locations. The diversity in site placements suggests that different regions experience unique ecological conditions, which could impact the habitat suitability and distribution of species. This insight can be useful for conservation efforts, ecological studies, and further research on climate impacts on biodiversity.

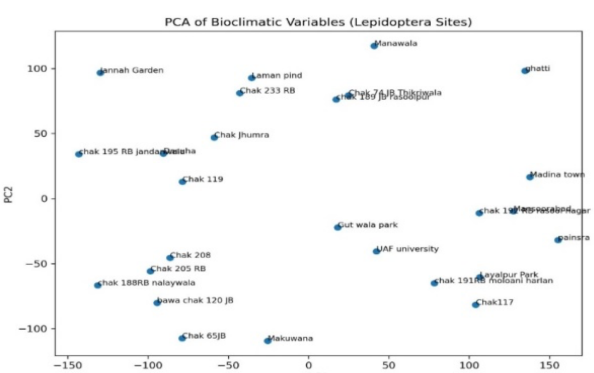

Figure 4. *K-means Clusters on PCA of Bioclimatic Data.*

Figure 4, presents the K-means clustering results applied to PCA of bioclimatic data, helping to identify patterns within ecological datasets. Each point represents a geographical site, and the data has been grouped into three clusters shown in teal, yellow, and purple. PCA reduces data complexity, with PC1 and PC2 capturing major variations. The teal cluster contains the most points, showing shared environmental features, while yellow and purple clusters contain fewer points with unique bioclimatic characteristics.

The clustering indicates three ecological or bioclimatic regions, each shaped by climatic variables like temperature, humidity, precipitation, altitude, and soil. Sites within a cluster share environmental conditions influencing species distribution and biodiversity. Greater distances between clusters show greater environmental differences. This approach is useful in ecological research, conservation planning, and climate studies by revealing similar habitats and areas needing conservation focus.

Moreover, this method supports species distribution modeling, predicting suitable areas for Lepidoptera species. The presence of three distinct clusters shows that the study area includes three major ecological zones with unique environmental influences on species diversity. Understanding these clusters is essential for biodiversity conservation strategies, habitat restoration, and sustainable land-use planning.

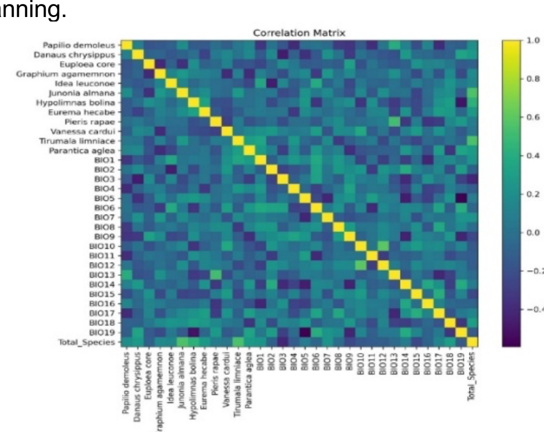

Figure 5. *Correlation Matrix*.

The correlation matrix in Fig. 5, shows relationships between butterfly species and bioclimatic variables (Bio1 to Bio19) with the total species count. Each cell represents a correlation coefficient, color-coded from -0.4 (negative) to 1.0 (strong positive). Diagonal elements are bright yellow, indicating perfect self-correlation.

This matrix helps understand how butterflies respond to climate factors. Strong positive correlations (green to yellow) show which conditions promote butterfly abundance. Negative correlations (blue to purple) show limiting factors. The matrix helps identify favorable and limiting environmental conditions, useful for biodiversity and habitat conservation.

Positive Correlations and Favorable Conditions: If total species has strong positive correlations with certain bioclimatic variables, it suggests those factors such as moderate temperature, adequate rainfall, and climatic stability favor butterfly richness. When multiple species correlate positively with the same variables, it shows they share ecological preferences.

Negative Correlations and Limiting Factors: Negative correlations suggest that certain climatic conditions reduce butterfly richness. These include extreme temperatures, irregular rainfall, or stress factors that impact survival. Species may decline in diversity in harsh or unstable environments, affecting overall abundance.

Discussion

Butterflies are among the most widely studied and admired insects, not only for their aesthetic appeal but also for their ecological and evolutionary significance. Their diversity reflects adaptations to varied habitats, feeding preferences, mimicry mechanisms, and migratory behaviors. Species such as *Eurema hecabe*, *Junonia almana*, *Idea leuconoe*, *Hypolimnas bolina*, *Vanessa cardui*, *Tirumala limniace*, and *Parantica aglea* represent distinct taxonomic groups and ecological strategies, showcasing the richness of Lepidoptera in tropical and subtropical regions.

Eurema hecabe, the common grass yellow, is a widespread Pierid found throughout Asia and Africa, thriving in sunlit, open areas and disturbed habitats like gardens and roadsides. Its erratic flight and preference for low vegetation enable it to adapt to human-altered environments (Kunte, 2000). *Junonia almana* (Peacock Pansy) of the Nymphalidae family is notable for its eyespots, which aid in predator avoidance and mate attraction. This species exhibits seasonal polyphenism, developing different morphs in wet and dry seasons to adapt camouflage or signaling strategies (Brakefield & Larsen, 1984).

Idea leuconoe (paper kite), belonging to the Danainae subfamily, glides through Southeast Asian rainforests with slow, graceful flight and translucent wings. It stores toxic compounds from Apocynaceae host plants, signaling unpalatability to predators an example of aposematism (Ackery & Vane-Wright, 1984). Similarly, *Tirumala limniace* (Blue Tiger) and *Parantica aglea* (Glass Tiger) use Müllerian mimicry and chemical defenses. *Tirumala* often migrates in swarms in southern India, while *Parantica* mimics toxic species with translucent wings and slow flight (Smith et al., 2005).

Hypolimnas bolina (Great Eggfly) shows Batesian mimicry, with polymorphic females mimicking toxic *Danaus chrysippus* for predator avoidance (Clarke & Sheppard, 1975). Males display iridescent blue patches, while females vary in appearance. This species also evolved rapidly in response to male-killing *Wolbachia* infections, illustrating strong natural selection. *Vanessa cardui* (Painted Lady) is cosmopolitan and a long-distance migrator, capable of intercontinental migrations across Europe, Africa, and Asia. It is a generalist in habitat and host plants, contributing to its survival in diverse environments (Stefanescu et al., 2013; Talavera & Vila, 2017).

Mimicry and chemical defense mechanisms are crucial survival strategies. *Tirumala limniace* and *Parantica aglea* use Müllerian mimicry, sharing warning coloration to reinforce predator avoidance (Smith et al., 2005). *Hypolimnas bolina* uses Batesian mimicry by imitating unpalatable species (Clarke & Sheppard, 1975). Danainae members store toxins from host plants, and species like *Idea leuconoe* advertise this through slow, floating flight (Ackery & Vane-Wright, 1984). Phenotypic plasticity is another adaptive feature. *Junonia almana* shows seasonal morphs: cryptic coloration in the dry season and vivid patterns in the wet season, aiding survival through changing environmental conditions and enhancing reproductive success (Brakefield & Larsen, 1984). Migration and ecological flexibility are exemplified by *Vanessa cardui*, which travels across continents in multi-generational journeys. Its broad host range and irregular migration pattern help it adapt to resource availability (Stefanescu et al., 2013). *Tirumala limniace*, though not a long-distance migrator, forms seasonal swarms responding to temperature and food supply (Smith et al., 2005).

Butterflies play vital ecological roles as pollinators, prey species, and environmental indicators. Their larval dependence on specific plants means that biodiversity loss, habitat degradation, and intensive agriculture directly affect them.

In Faisalabad, butterflies like *Eurema hecabe* indicate disturbed habitats, while species like *Idea leuconoe* signal intact ecosystems (Smith et al., 2005). Several factors shape Lepidoptera distribution and biodiversity in District Faisalabad. Habitat availability, floral resources, and breeding areas are key biotic influences. Urbanization and agricultural expansion fragment habitats, limiting movement and genetic exchange. Climatic variables temperature, precipitation, and humidity affect migration, reproduction, and larval development.

Seasonal peaks in diversity occur during spring and post-monsoon months. Intensive agriculture, especially cotton and wheat monoculture, limits host plant diversity and exposes butterflies to harmful pesticides. Mixed farming systems support higher richness. Plant diversity, especially native flowering plants, strongly correlates with Lepidoptera richness. Anthropogenic pressures pollution, deforestation, and light pollution further threaten these populations, particularly moths.

Faisalabad's semi-arid environment and mosaic of natural, agricultural, and urban areas offer insight into Lepidoptera vulnerability and adaptability. These findings align with global trends of insect decline due to habitat loss and climate change, emphasizing the urgent need for conservation actions.

Conclusions

This study highlights the significant diversity and ecological complexity of butterfly species in the District Faisalabad, where both environmental and anthropogenic factors play pivotal roles in shaping their distribution and abundance. The observed species, including *Eurema hecabe*, *Junonia almana*, *Idea leuconoe*, *Tirumala limniace*, *Parantica aglea*, *Hypolimnas bolina*, and *Vanessa cardui*, reflect a wide range of ecological strategies such as mimicry, toxicity, migratory behavior, and phenotypic plasticity. These adaptations enable them to survive in varied habitats, from disturbed urban landscapes to more intact ecosystems. The presence or absence of particular species can serve as a bioindicator of environmental health, with some species thriving in degraded areas while others require stable, resource-rich habitats for survival.

The results of the study confirm that factors such as habitat fragmentation, plant diversity, climatic variability, and intensive agricultural practices significantly influence Lepidoptera diversity in the region. Seasonal changes, particularly during spring and post-monsoon periods, support greater butterfly abundance due to favorable temperature and floral availability. However, threats like pesticide use, monoculture cropping, urbanization, and light pollution are contributing to population declines. Conservation strategies should prioritize preserving native vegetation, promoting sustainable agricultural practices, and mitigating urban pressures. By understanding these complex ecological interactions, we can better protect butterfly populations and maintain the biodiversity and ecological integrity of Faisalabad's semi-arid landscape.

Author Contributions

Qi Xue: Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. Qian Tang: Writing – review & editing, Visualization, Formal analysis, Conceptualization. Lin Deng: Writing – review & editing, Validation, Supervision, Resources, Project administration, Funding acquisition. Wei Luo: Writing – review & editing, Conceptualization. Mingle Xia: Writing – review & editing, Conceptualization. Shuang Fu: Writing – review & editing, Conceptualization. Chaoqun Tan: Writing – review & editing, Conceptualization. Jun Hu: Writing – review & editing, Conceptualization. Rajendra Prasad Singh: Writing – review & editing.

Conflicts of Interest

The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper.

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Data Availability

Data will be made available on request

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