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Butterfly Diversity in Harding Park, Patna, Bihar, India: A Case Study of Urban Ecosystem

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Authors' contributions

This work was carried out in collaboration between both authors. This study was planned and designed by Author MB. Authors AK and MB contribute equally in data analysis and writing. Both authors read and approved the final manuscript.

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ABSTRACT

Butterflies serve as crucial bioindicators susceptible to habitat degradation, emphasising the need of green spaces in urban conservation efforts. Current study investigates butterfly diversity in Harding Park, Patna, within a very high density, heavily anthropogenically impacted urban area. This study documented 1,089 butterfly individuals of 45 species belonging to five families using the Pollard Walk Method (100m each) between April and July 2022. The Hesperiidae family was most abundant, comprising 36.2% of total butterfly abundance, with Rice Swift as highest recorded species followed by Pieridae (27.4%) Nymphalidae (27.6%) and Papilionidae (9%) that were notably prevalent. However, the reduced occurrence of Lycaenidae (8%) indicates a potential need for species specific habitats. Diversity indices (Shannon, Simpson, and Evenness) were mainly used to compare diversity across different months. Shannon diversity peaked in May (3.217), with

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highest species richness (37 species) and evenness (0.73, whereas the lowest diversity was recorded in July (2.382) and this was associated with an increase in dominance as a few species became predominant during July. In April, the lowest richness (24 species) and abundance (137 individuals) were reported, perhaps attributable to dry, less humid pre-monsoon conditions. Butterfly abundance increased consistently, reaching 540 individuals in July, presumably due to favourable monsoon conditions. The butterfly assemblages of May and June had a similarity of 68%, whereas the July assemblages, with a similarity of approximately 54%, as it distinctly separated from assemblages of other months. The current study highlights the significance of Harding Park in offering green environment and thus microclimatic conditions supporting butterfly populations and other biodiversity. The study further discusses the role of urban parks in conserving biodiversity, particularly in the context of increasing urbanisation.

Keywords: Butterfly; Harding park; Patna; species diversity; urban ecosystem.

1. INTRODUCTION

Deforestation and human interference have drastically altered butterfly habitats (Spaniol et al., 2020), causing significant disruptions in ecological balance. The extinction of a single butterfly species can trigger cascading effects (Fatemi Nasrollahi et al., 2023), potentially driving related species toward extinction and destabilizing entire ecosystems (Koh et al., 2004). Immediate conservation of butterfly populations is essential to maintaining ecological stability (Smallidge & Leopold, 1997). Developing effective conservation strategies requires comprehensive data on species diversity, population status, and the environmental factors influencing both population size and survival (Brown et al., 2015; McLaughlin et al., 2022)). Comparative analyses of butterfly diversity across regions provide crucial insights into their specific conservation needs (Thomas, 2005; Bonebrake et al., 2010; Bhardwaj et al., 2012). For instance, studies on habitat fragmentation and climate impacts reveal that species diversity and adaptation responses are highly variable, necessitating region-specific approaches (McFrederick & LeBuhn, 2006; Riva & Fahrig, 2022). Monitoring butterfly population trends and habitat conditions is therefore critical to inform targeted conservation interventions and preserve biodiversity within vulnerable ecosystems (Bhardwaj et al., 2012; Uniyal et al., 2013). Understanding these dynamics enables researchers to identify areas of concern and prioritize conservation efforts for species that are particularly sensitive to habitat changes (Asaad et al., 2017).

Butterflies are recognized as vital bioindicators, reflecting the health of ecosystems due to their sensitivity to environmental changes (Holloway et al., 1987; Forister et al., 2019). Moreover, they play a critical role in food chains, serving as prey for numerous species, and their diversity is an indicator of ecological stability and population persistence (Bhardwaj & Uniyal 2009; Bowler et al., 2010). The intricate relationships between butterflies and their habitats, particularly their dependence on larval host plants, nectar sources, and habitat structure, make them especially vulnerable to habitat degradation (Gilbert & Singer, 1975; Erhardt, 1985; Blair & Launer, 1997). This reliance on specific ecological niches throughout their life cycle emphasizes their role as ecological indicators for habitat quality and environmental changes (Potts et al., 2010).

Butterflies require specific environmental conditions to survive, making them particularly sensitive to ecological disturbances and other changes. Their typical habitats include grasslands, forest canopies, semi-wild areas, and riverbanks, which are essential for both reproduction and survival (Karmakar et al., 2022). The ongoing destruction of these habitats increases the risk of population declines and local extinctions (Habel et al., 2024). To ensure the long-term survival of butterflies, conservation efforts must focus on both the protection and restoration of these critical habitats and the reduction of harmful agricultural practices such as pesticide use (Seymoure, 2018).

Recent studies emphasize the need for urgent action to mitigate the impacts of habitat destruction and climate change on butterfly populations (van Swaay et al., 2016). Conservation efforts must prioritize the protection of remaining natural habitats along with active ecosystem restoration and the promotion of sustainable land-use practices (Uniyal et al., 2013). These actions are crucial to ensuring long term survival of butterflies (van Swaay et al., 2008) and other pollinators.

India is renowned for its biodiversity, hosting approximately 1,504 butterfly species (Gunathilagaraj, 1998; Kunte, 2000a). Between 2001 and 2018, India lost approximately 1.6 million hectares of tree cover, representing 19.1% of its total forest area (Mongabay India, 2018). This habitat loss, compounded by climate change, has led to severe declines in butterfly populations. Globally, the Food and Agriculture Organization (FAO) has reported that 35% of pollinators, including butterflies, are at risk of extinction (FAO, 2022). Butterfly populations have faced significant threats due to pesticide use, deforestation, and climate change (Braak et al., 2018). Unfortunately, there is a notable lack of data on butterflies for the Magadh division in Bihar. In Bihar 64 species have been recorded from Rajgir region (Sharma & Kumar, 2017).

In this paper, butterfly diversity of Harding Park is studied in a highly urban landscape of Patna city in Bihar, India. Butterfly diversity is compared across months during the sampling period. This study also discussed community structure and sampling adequacy of butterflies in the Harding Park.

2. MATERIALS AND METHODS

2.1 Study Area

Harding Park, now known as Shaheed Veer Kunwar Singh Azadi Park, was constructed in 1916 during the British Raj in Patna (Fig. 1). It was originally named after Viceroy Charles Harding, who played a pivotal role in the establishment of Bihar as a separate province. As Patna's first public park, it is located centrally between Patna Junction and the Bihar Secretariat (Fig. 1).

Following India's independence, the park was renamed to honor Shaheed Veer Kunwar Singh, a prominent figure in the Indian freedom struggle. In 2016, the park celebrated its centennial, marking 100 years since its creation.

The park’s geographical features and biodiversity are influenced by several factors, including human activities, conflict over land use and the scarcity of host plants during the butterfly breeding season, often caused by deforestation or plant removal. Additional pressures, such as pollution, further impact the ecological

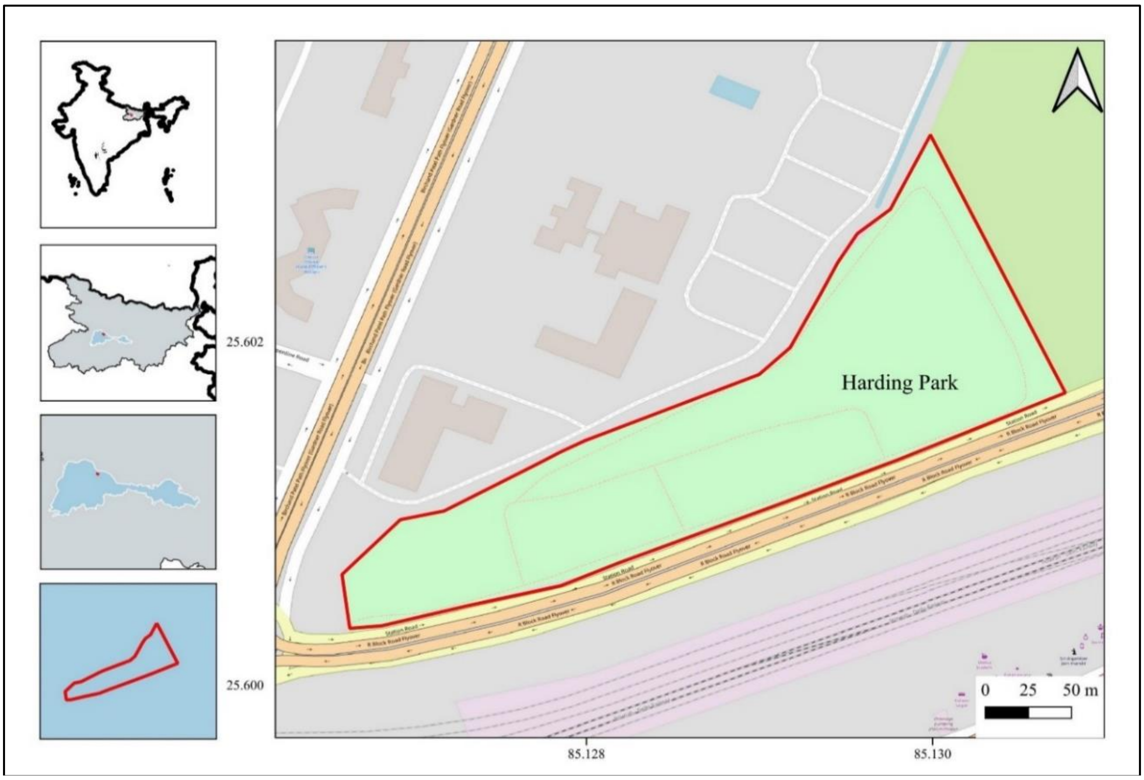

Fig. 1. Map of Harding Park in Patna, Bihar, India

balance within the park. Despite these challenges, Harding Park remains an important green space within the urban landscape of Patna.

2.2 Butterfly Sampling

Butterflies were sampled over a period of four months from April to July 2022 in Harding Park using the Pollard Walk Method (100m each) (Pollard & Yates, 1993), which is a well-established technique for monitoring butterfly populations. Transects measuring 100 meters were walked during each sampling session, which lasted between 20 to 30 minutes. These walks were carried out during the morning hours, from 8:00 AM to 11:00 AM, a time when butterflies are most active due to favorable light and temperature conditions.

The butterflies were recorded within a 5-meter range on both sides of the transects, ensuring comprehensive coverage while minimizing disturbance to the species. Transect walks were conducted only when cloud cover was less than 30%, as butterflies tend to be less active on cloudy days, which could lead to lower observation rates.

When butterflies could not be immediately identified in the field, they were photographed for later identification, allowing for a more detailed analysis of their wing patterns and other distinguishing features. This approach ensured accurate and reliable documentation of butterfly species during the sampling period.

2.3 Identification of Butterflies

The identification of butterflies in this study was based on external morphological traits such as body color, wing patterns, and wing shape. These features, unique to each species, were carefully observed in the field. To ensure accurate species identification, authoritative field guides and taxonomic references were used. Identification for butterflies was followed using Kehimkar (2008) and Wynter-Blyth (1957).

By using these expert references, the identification process was cross-verified with images and descriptions of butterfly species, ensuring that each observation was accurately recorded. Additionally, where necessary, butterflies were photographed for later confirmation of their species, particularly in cases where immediate identification in the field was difficult. This careful approach allowed for reliable documentation of the butterfly species present in Harding Park, contributing to the first systematic recording of butterfly diversity in this urban area.

2.4 Data Analysis

Ecological indices e.g., Shannon, Simpson, Fisher's alpha, Chao1, Evenness and Dominance (Magurran, 1988) were calculated to understand and compare butterfly diversity across months. Rarefaction curve was calculated for diversity comparison and sampling efficiency during each month. Cluster analysis (Bray-Curtis) was used to observe composition similarity across month during sampling season. All the indices, rarefaction and cluster analysis and figures used in article were calculated and generated using program Past 5.0 (Hammer et al., 2001). Rank abundance curve was generated to see the relative composition distribution of butterfly community using program Mathematics (version 9.0.1). The map was created using the free and open source QGIS 3.32.1-Lima software.

3. RESULTS AND DISCUSSION

3.1 Butterfly Species Richness, Abundance and Diversity

The butterfly survey conducted in Harding Park, Patna, recorded a total of 1,089 individuals of 45 species belonging to five families in an urban ecosystem of Patna, Bihar, India. Species richness was highest in May (37) and lowest in April (24) (Table 1). Abundance steadily increased from April (137 individuals) to a peak in July (540 individuals) with total abundance of 1,089 individuals over the complete sampling period (Table 1).

Shannon Index: The Shannon index (Shannon & Weaver,1949) accounts for both abundance and evenness, with higher values indicating greater diversity. Diversity was highest in May (3.217) and lowest in July (2.382). The overall Shannon index was 2.858, showing moderate diversity.

Simpson's Diversity Index: Simpson index (Simpson, 1949) measures the probability that two randomly selected individuals belong to different species. Higher values indicate higher diversity. The index value was high in May (0.9469), indicating greater diversity, and lowest in July (0.788), where there was a decrease in diversity, likely due to dominance by a few species.

Table 1. List of butterfly species recorded in Harding Park during April 2022 – July 2022

S.no.	Common name	Species name	Abundance
Family: Papilionidae			
1	**Lime Butterfly**	*Papilio demoleus* Linnaeus, 1758	38
2	**Common Mormon**	*Papilio polytes* Linnaeus, 1758	42
3	**Common Jay**	*Graphium doson* C. & R. Felder, 1864	10
4	**Common Mime**	*Papilio clytia* Linnaeus, 1758	9
5	**Common Rose**	*Pachliopta aristolochiae* (Fabricius, 1775)	9
Family: Pieridae			
6	**Common Emigrant**	*Catopsilia pomona* (Fabricius, 1775)	98
7	**Mottled Emigrant**	*Catopsilia pyranthe* (Linnaeus, 1758)	69
8	**Indian Cabbage White**	*Pieris canidia* (Sparrman, 1768)	4
9	**Common Jezebel**	*Delias eucharis* (Drury, 1773)	6
10	**Common Grass Yellow**	*Eurema hecabe* (Linnaeus, 1758)	38
11	**Spotless Grass Yellow**	*Eurema laeta* Boisduval, 1836	2
12	**Common Gull**	*Cepora nerissa* Fabricius, 1775	2
13	**Pioneer**	*Belenois aurota* (Fabricius, 1793)	17
14	**Psyche**	*Leptosia nina* (Fabricius, 1793)	58
15	**Common Wanderer**	*Pareronia valeria* (Cramer, [1776])	6
Family: Lycaenidae			
16	**Pea Blue**	*Lampides boeticus* (Linnaeus, 1767)	11
17	**Common Pierrot**	*Castalius rosimon* (Fabricius, 1775)	7
18	**Rounded Pierrot**	*Tarucus extricates* Butler, 1886	1
19	**Common Silverline**	*Cigaritis vulcanus* (Fabricius, 1775)	3
20	**Zebra Blue**	*Leptotes plinius* (Fabricius, 1793)	1
21	**Indian Gram Blue**	*Euchrysops cnejus* (Fabricius, 1798)	5
22	**Grass Jewel**	*Freyeria trochylus* (Freyer, 1845)	2
23	**Dark Cerulean**	*Jamides bochus* Stoll, 1782	8
24	**Dark Grass Blue**	*Zizeeria karsandra* (Moore, 1865)	2
25	**Forget Me Not**	*Catochrysops strabo* Fabricius, 1793	2
26	**Lime Blue**	*Chilades lajus* (Stoll, [1780])	44
27	**Plains Cupid**	*Luthrodes pandava* (Horsfield, 1829)	1
Family: Nymphalidae			
28	**Peacock Pansy**	*Junonia almana* (Linnaeus, 1758)	2
29	**Lemon Pansy**	*Junonia lemonias* (Linnaeus, 1758)	5
30	**Blue Pansy**	*Junonia orithya* (Linnaeus, 1758)	5
31	**Grey Pansy**	*Junonia atlites* (Linnaeus, 1763)	8
32	**Common Baron**	*Euthalia aconthea* (Cramer, [1777])	34
33	**Plain Tiger**	*Danaus chrysippus* (Linnaeus, 1758)	6
34	**Blue Tiger**	*Tirumala limniace* (Cramer, [1775])	6
35	**Striped Tiger**	*Danaus genutia* (Cramer, [1779])	49
36	**Common Leopard**	*Phalanta phalantha* (Drury, [1773])	5
37	**Common Evening Brown**	*Melanitis leda* (Linnaeus, 1758)	57
38	**Common Crow**	*Euploea core* (Cramer, 1780)	2
39	**Common Castor**	*Ariadne merione* (Cramer, 1777)	10
40	**Tawny Coster**	*Acraea terpsichore* (Linnaeus, 1758)	1
41	**Painted Lady**	*Vanessa cardui (*Linnaeus, 1758)	10
Family: Hesperiidae			
42	**Indian Palm Bob**	*Suastus gremius* (Fabricius, 1798)	13
43	**Rice Swift**	*Borbo cinnara* (Wallace, 1866)	297
44	**Small Branded Swift**	*Pelopidas mathias* (Fabricius, 1798)	81
45	**Asian Grizzled Skipper**	*Spialia galba* (Fabricius, 1793)	3

Fisher's Alpha: This index is used to estimate species diversity, accounting for species richness and abundance. Fisher's Alpha peaked in May (13.71), indicating the highest diversity and lowest in July (7.146).

Evenness: Evenness indicates how evenly individuals are distributed across species, with values closer to 1 suggesting more equal distribution. Evenness decreased over time, with April having the highest evenness (0.7362) and July the lowest (0.349), indicating an increasingly uneven distribution as time progressed.

Dominance: Dominance measures how one or a few species dominate the community. Higher values suggest that a few species dominate. Dominance was lowest in May (0.0531), suggesting a more evenly distributed community in that month, while it was highest in July (0.212), indicating that a few species were particularly dominant.

Chao1: Chao1 is an estimator of species richness that considers the likelihood of undetected species. Estimated species richness was highest in May (42.97) and lowest in April (25.65), with an overall estimate of 45.75 for the study period.

Highest diversity and evenness were observed during May reflecting a more balanced and diverse community, while community of July month showed increased dominance and decreased evenness, suggesting that a few species became particularly abundant. Over the entire period, there was a general trend of increasing abundance but decreasing evenness and diversity, possibly due to seasonal changes or species-specific growth patterns from April to July as conditions changes from very dry pre monsoon summer to high humid monsoon (Koh et al., 2004; Sanyal et al., 2012; Bhardwaj et al., 2012). These findings are significant as they provide a comprehensive overview of the butterfly diversity within the park, which had not been previously documented. This study documented a relatively healthy butterfly population (1,089 individuals over 4 months) despite the park being located in a highly urban environment (Table 1). These findings are significant as they provide a comprehensive overview of the butterfly diversity within the park, which had not been previously documented. This study documented a relatively healthy butterfly population (1,089 individuals over 4 months) despite the park being located in a highly urban environment (Table 1).

3.2 Rank Abundance Curve

Rank abundance curve of the butterfly community (Fig. 2) represents species richness (number of species) and evenness (distribution of individuals among species) in Harding Park. This rank abundance curve (Fig. 2) provides a clear, comparative visualization of species diversity and the structure of the butterfly community in Harding Park, reflecting both dominant and less common butterfly species (Fig. 2 and Table 2).

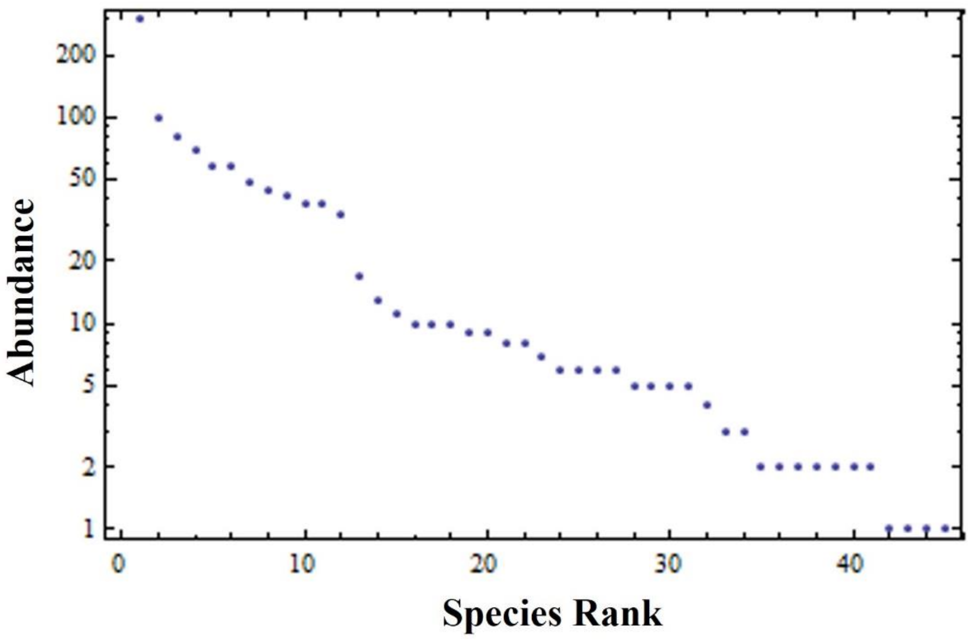

Fig. 2. Rank abundance curve of the butterfly community in Harding Park

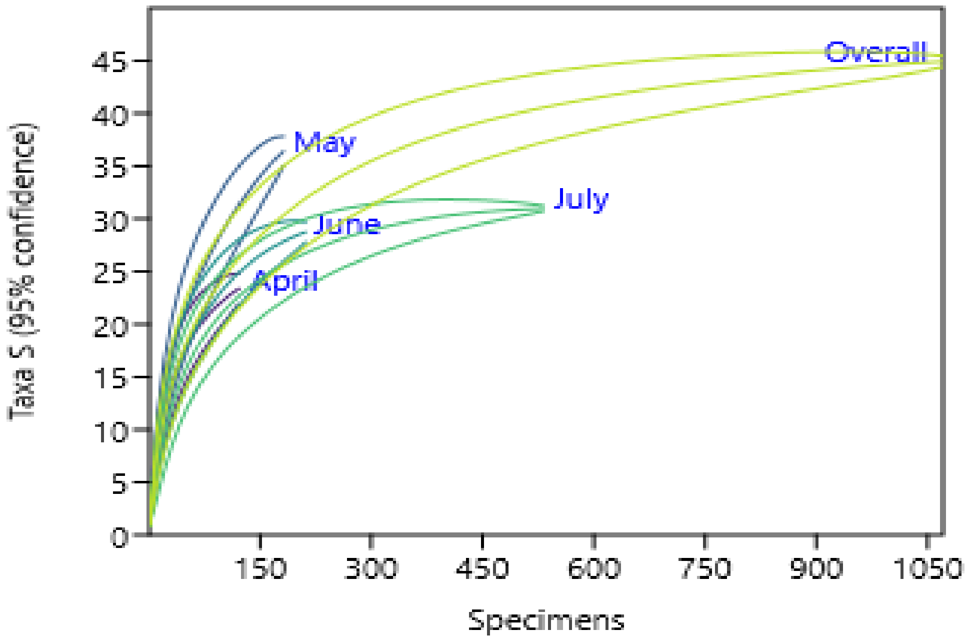

Fig. 3. Rarefaction curves showing the status of butterfly community in Harding Park

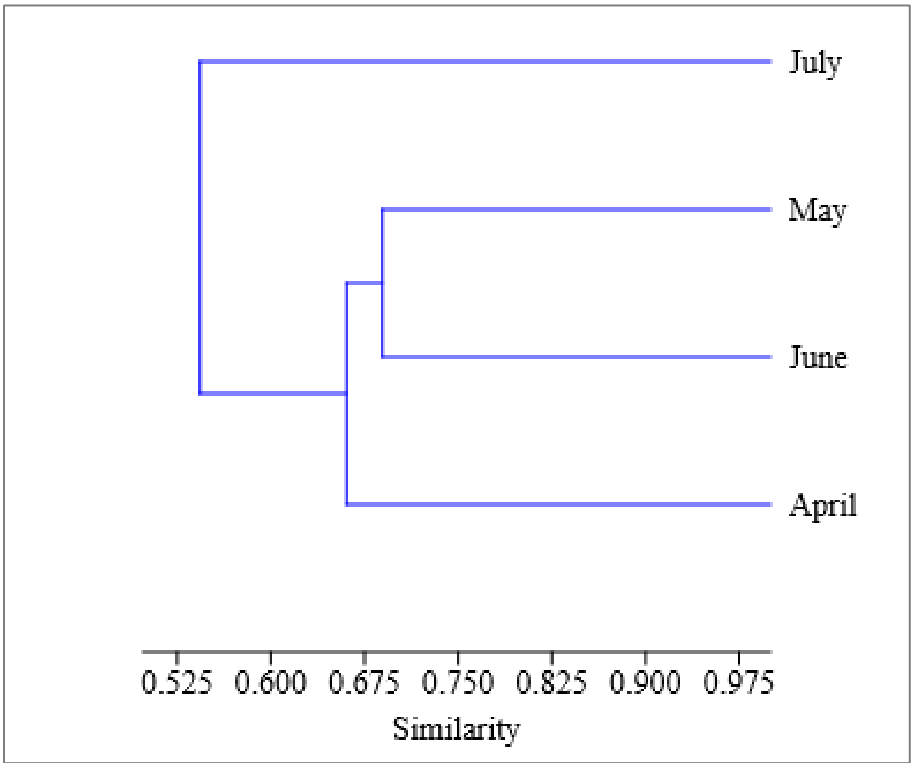

Fig. 4. Cluster analysis (Bray-Curtis: Single link) showing similarity between butterfly communities across sampling months in Harding Park

Species Richness: The length of the curve along the x-axis (species rank) indicates species richness. A longer curve signifies more species, while a shorter curve reflects fewer species in the community. This curve helps confirm the diversity of butterfly families observed, such as Pieridae, Nymphalidae and Lycaenidae.

Table 2. Butterfly species richness, abundance and diversity across April-July 2022 in Harding Park, Patna

	April	May	June	July	Overall
Species richness	24	37	29	31	45
Abundance	137	190	222	540	1089
Dominance	0.0726	0.0531	0.0857	0.212	0.1066
Simpson	0.9274	0.9469	0.9144	0.788	0.8934
Shannon	2.872	3.217	2.846	2.382	2.858
Evenness	0.7362	0.6741	0.594	0.349	0.3871
Fisher_alpha	8.426	13.71	8.91	7.146	9.466
Chao-1	25.65	42.97	30.42	31.08	45.75

Species Evenness: A steeper slope is observed initially due to the dominance of Hesperiidae, particularly the Rice Swift, followed by decreasing flatter curve contributed by other species like Mottled Emigrant, Small Branded Swift, Common Emigrant, Psyche, Common Evening Brown, Striped Tiger, Lime Blue, Common Mormon, Lime Butterfly, Common Grass Yellow and Common Baron etc (Table 1). These species are known for their adaptability to a wide range of habitats and their resilience to human-disturbed environments (Kehimkar, 2008). Their dominance suggests that Harding Park offers a favorable habitat, even in a highly urban habitat. It supports various butterfly species from various families that depends upon various host plants and thus it provides a heterogeneous habitat with protection.

Dominant and Rare Species: The rank positions also highlight dominant and rare species. Highly ranked (leftmost) species are more abundant, while lower-ranked (rightmost) species represent rare or less abundant butterflies, like certain Lycaenidae species including Common Silverline, Plains Cupid, Dark Grass Blue, Forget Me Not, Rounded Pierrot, Pea Blue, Zebra Blue.

The rarity of these species might be attributed to the specific ecological requirements they have, such as specialized host plants or high human presence (Koh et al., 2004; Lien, 2015; Peiris et al., 2020). Their lower numbers may also reflect the impact of urban pressures such as habitat fragmentation, pollution, or relatively more homogeneous plant diversity (Gilbert & Singer, 1975).

3.3 Rarefaction Curve

This rarefaction curve illustrates butterfly species richness (number of taxa) as a function of the number of specimens sampled each month (April, May, June, July) and for the overall study period in Harding Park (Fig. 3). This rarefaction analysis shows that May had the highest observed species richness, while April had the lowest (Fig. 3). During May it reaches the highest taxa richness comparing with the curve approaching nearly 40 species to other months. April has the lowest species richness, indicating fewer species were observed compared to other months, likely due to less favorable conditions in the pre-monsoon period. June and July show intermediate richness, with July exhibiting a more gradual rise. This could imply that although more individuals were sampled in July, they included fewer new species, possibly due to dominance by a few species. The overall curve for the entire sampling period continues to rise before plateauing near 45 species, indicating a comprehensive sampling effort where most species present in the area were likely observed (Fig. 3).

3.4 Sampling Adequacy

The rarefaction curve shapes suggest that while during May month sampling captured much of the diversity, there may still be some unobserved species overall. The plateau in the Overall curve suggests that additional sampling would yield few new species, indicating that the sampling effort was nearly adequate (Fig. 3). However, few more species may be added if the sampling was further continued. It is also ensured from the estimates of Chao-1 that estimates the diversity based on number of singleton taxa found during sampling. The study's overall sampling effort was likely sufficient, as the overall curve plateaus, capturing most of the butterfly diversity in Harding Park and considered as comprehensive sampling in taking policy decisions for conservation (Cardoso, 2009).

3.5 Butterfly Families and Species Composition

Hesperiidae (Skippers) was most abundant family with only four species but 36.2% (n=394) of total individuals (n=1089) of all species during the sampling period. Rice Swift was most abundant species with 297 individuals (Table 1). This seems a population outbreak of the species with open spaces, grasses and humid environment providing ideal conditions. Family Pieridae was second most abundant accounting 10 species, with 27.5% (n=300) of total individuals. Family Nymphalidae (Brush-footed) was represented by 14 species accounting 26.4% (n=287) of total recorded individuals (Table 1), reflecting a presence of flowering plants and shrubs for feeding, shade and reproduction. Papilionidae (Swallowtails) was only represented by five species with 9.9% (n=108) of total individuals (Table 1), with abundance of Common Lime (n=42) and Common Mormon (n=38) butterfly, likely due to presence of required host plants of family Rutaceae supporting both adults and larval stages. Lycaenidae (Blues) was least abundant family with 12 species accounting 8% (n=87) of total abundance, may be indicating sensitivity to habitat conditions, possibly affected by presence of food plants and urban surroundings.

The observed distribution highlights Harding Park's effectiveness as a supportive environment for butterfly diversity. The parks combination of open spaces, diverse nectar sources, and specific host plants enables it to accommodate various butterfly families, particularly those like Hesperiidae and Pieridae, which thrive in open, grassy areas with presence of host plants. However, the relative less abundance of Lycaenidae suggests a need for host plants and providing suitable habitat that would favour specific habitat requirements with regular monitoring. This short study reveals Harding Park suitability for supporting butterfly diversity, especially for families favoring open, grassy areas with a variety of nectar and host plants (Pillai & Kumar, 2020; Malek et al., 2024).

3.6 Butterfly Composition Similarity Across Months

Butterfly composition during April and June show higher similarity compared to May and July, clustering together at around 0.68 similarity (Fig. 4). May and July are slightly different from April and June but are still closely related, as all months have some degree of overlap in butterfly species. July shows a unique community, clustering separately, which could be due to the increased dominance of a few species and high butterfly diversity, species richness and abundance during the monsoon season (Fig. 4). The dendrogram suggests that while there are similarities in butterfly communities across the months, July stands out as the month with the most distinct species composition, possibly due to seasonal conditions that support different or more abundant species.

The study recorded the highest butterfly diversity and richness in July 2022, coinciding with the monsoon season (Fig. 4). This is a critical time for butterfly populations, as the increased availability of water and blooming plants provides ample nectar sources and host plants for laying eggs (Helen et al., 2024). The favorable climate during the monsoon season, with moderate temperatures and sufficient humidity, supports the life cycles of many butterfly species, leading to increased activity and population growth during this time (Vu et al., 2015; Gezon et al., 2018). Conversely, the lowest butterfly diversity was recorded in April 2022, which might be attributed to the dry and hot conditions typical of the pre-monsoon season in Patna (Fig. 4). During this period, plant resources are scarcer, and the harsh climate can reduce the availability of nectar and suitable habitats for butterflies (Sharma & Sharma, 2021). This seasonal variation is consistent with the ecology of butterflies, which are highly sensitive to environmental conditions such as temperature, humidity, and plant availability (Kunte, 1997; Vu & Yuan, 2003; Vu, 2008; Peiris et al, 2020).

4. CONCLUSION

This study signifies Harding Park significance as an urban refuge for butterfly diversity in Patna, documenting 1,089 individuals across 45 species and five families (Malek et al., 2024). Temporal variations revealed May as the peak of diversity and evenness, while July recorded highest abundance but reduced diversity and evenness, dominated by a few species during the monsoon onset (Smith & Johnson, 2018). The presence of Lycaenidae highlights the park's ability to support sensitive species, though targeted efforts are needed to enhance habitat quality for species with specific ecological requirements. Urban parks like Harding Park play a vital role in conserving biodiversity by providing suitable habitats for source populations of various biodiversity groups amidst a space of vast urbanization (Tiple et al., 2006; Swamy et al., 2019; Kumar et al., 2023; Habel et al., 2024). Further, conservation strategies must focus on habitat restoration, diverse vegetation (heterogeneous habitats), and mitigating anthropogenic activities to ensure the long-term sustainability of biodiversity (van Swaay et al., 2008). Extending future studies to other seasons and assessing the effects of pollution, land-use changes, and climate change may provide actionable insights, aiding effective conservation planning for urban ecosystems (Bufford et al., 2024; Habel et al., 2024) in rapidly growing cities.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declares that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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COMPETING INTERESTS

Authors declare that no competing interests exist.

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