Studies on butterfly (Insecta: Lepidoptera) diversity across different urban landscapes of Delhi, India

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The present study deals with the diversity of butterflies along with the contrasting six selected land-use types and three major seasons in Delhi for the years 2015–16 and 2016–17. Among the 40 species of butterflies recorded, family Nymphalidae (13 spp.) showed the highest species diversity. Species richness was found to be the highest during monsoon season, whereas among the six different study sites, Aravalli Biodiversity Park, New Delhi had the highest biodiversity index. Earlier studies have been confined up to species listing and documentation, whereas mathematical interpretations through biodiversity indices concerning increasing urbanization were neglected. The findings of this study indicate the significance of green patches within urban infrastructure in the cities to support a wide array of butterflies.

Keywords: Biodiversity, butterflies, green areas, landscape, urban.

Rapid urbanization in Delhi has directly or indirectly affected the biodiversity thriving in urban landscapes of the city. With encroachment of the Aravalli hills and ridge portions for the mushrooming anthropogenic needs, the total green cover of Delhi has been reduced to 299.77 sq.km (ref. 13). The urban population of Delhi has increased from 0.41 million in 2001 to 16.7 million in 2011, and urban area from 200.52 sq. km in 1951 to 1113.65 sq. km in 2011 (refs 14, 15). Study of land-use and land-cover change of Delhi in 2013 showed that between 1989 and 2011, the urban or built-up area of this region had increased from 25.17% to 45.18%, dense vegetation had decreased from 31.73% to 22.47% and sparse vegetation had reduced from 37.40% to 29.37% (ref. 16). This indicates the rapid rate of urbanization in this region during the last two decades, which includes drastic increase in human settlements. The negative effects of urbanization on species diversity have been

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observed for many important insect-pollinator groups like butterflies\textsuperscript{17,18}. The present study indicates the importance of small green patches of urban and suburban areas in Delhi serving as a preferred habitat for butterflies, as this is directly related to the ecological health of the city.

The study area is NCT Delhi (28°25′–28°52′N and 76°50′–77°21′E; Figure 1), which lies in northern India and spreads over an area of 1484 sq. km. It borders the Indian states of Uttar Pradesh to the east and Haryana to the north, west and south. Two prominent features of the geography of Delhi are the Yamuna flood plains and Delhi ridge. The climate of Delhi (Figure 2) is extreme with alternating summer heat of 48°C in June and winter chill of 2°C in December (Figure 2). July–September witnesses heavy to moderate rainfall\textsuperscript{19}. The present study includes six sampling sites: industrial area Mayapuri (MP; 28°38′17.9″N, 77°07′31.8″E), a city park, viz. Nehru Park (NP; 28°35′30.6″N, 77°11′37.0″E), agricultural area, viz. IARI Pusa (PU; 28°38′15.6″N, 77°09′25.7″E), residential and institutional area, viz. Dwarka (DW; 28°35′50.6″N, 77°00′59.1″E), Aravalli Biodiversity Park (ABP; 28°33′31.2″N, 77°09′09.3″E), New Delhi and a city forest, viz. Northern Ridge (NR; 28°41′33.1″N, 77°13′13.3″E).

The butterfly sampling was done using the ‘Pollard Walk’ method popularized by Pollard and co-workers\textsuperscript{20–22}, with few modifications. The selection of transects was done in a random stratified manner depending on the area of each site. Each site was sampled once in a month and thrice in a season. Random stratified transects were selected depending on the area of each site. At all the sampling sites, three random transects of 1000 m each were selected and every transect was covered in 1 h, but at the different time slots of the day between 10:00 am and 12:00 noon, 12:00 noon and 2:00 pm, and 2:00 and 4:00 pm. At places where 1000 m transect was not possible due to topography, 500 m transect was selected and covered twice in 1 h. In the ‘Pollard Walk’ method, individuals were recorded on both sides of the path covering a distance of 5 m. Transects were covered walking at a steady pace during which butterfly species were recorded. The 5 m ‘rule’ was selected so that the observation area would be consistent across sites. During the Walk, short halts were made for proper documentation and identification. Photographs of all the butterflies were taken using a camera (Canon IXUS 170). Their identification was done during flight, feeding, basking and mating activities using field guides\textsuperscript{23–25}. Butterflies were not collected but only photographed for identification. Field sampling was carried out between April 2015 and March 2016, as well as April 2016 and March 2017 from 1000 to 1600 h. Data were collected during three distinct periods each year, i.e. (a) pre-monsoon (mid-February to mid-June: comprises spring and summer), (b) monsoon (mid-June to mid-September) and (c) post-monsoon (mid-September to mid-February: comprises autumn and winter). A site was visited during good weather only. Rainy and windy days were avoided. The frequency of occurrence (FO) of butterflies was noted based on which the species diversity and species evenness along with seasonal variations were calculated for all the six areas. The butterflies flying backwards along a transect were not included in the count. Meteorological data for monthly rainfall and diurnal temperature were provided by the Regional Meteorological Department of Indian Meteorological Department, Delhi.

Data analyses were carried out in two phases. First, in order to quantify the diversity of butterfly assemblage at six different study areas and different seasons, the following diversity indices, viz. Simpson index of diversity ($1 - D$), Shannon–Wiener index ($H'$), Shannon J or Evenness index and beta diversity were applied using Microsoft Excel 2010.
Simpson diversity index\textsuperscript{26–28} is often used to quantify the biodiversity of a habitat, which takes into account the number of species as well as the abundance of each species\textsuperscript{27}. It is measured by subtracting the value of \( D \) from 1. The formula used for calculation is
\[
D = \sum n_i (n_i - 1) / N (N - 1),
\]
where \( n_i \) is the total number of individuals of a particular species and \( N \) is the total number of individuals of all species.

Shannon–Wiener Diversity Index considers both the number of species and distribution of individuals among species\textsuperscript{26–28}. It is calculated using the formula
\[
H = -\sum p_i \ln(p_i),
\]
where \( p_i \) (proportion of individuals belonging to the \( i \)th species) = \( n_i / N \), \( n_i \) is the number of individuals of each species in the sample and \( N \) is the total number of individuals of all species in the sample.

Evenness or Shannon \( J \) is a measure of the relative abundance of different species making up the richness of an area, which is measured using the formula\textsuperscript{26–28}
\[
E = eH'/S \text{ or } J = H/H_{\text{max}},
\]
where \( H_{\text{max}} \) is the maximum diversity possible which is the natural logarithm of \( N \) and \( N \) is the number of species. Species evenness depicts the distribution pattern of individuals between the species.

Beta diversity is a key concept in community ecology\textsuperscript{26}. Bray–Curtis dissimilarity index was applied to determine the beta diversity patterns of butterfly assemblages in relation to different study sites. It is calculated as
\[
AB = 1 - (2c / S_a + S_b),
\]
where \( c \) is the number of common species at sites \( A \) and \( B \), \( S_a \) the total number of species at site \( A \) and \( S_b \) is the total number of species at site \( B \). The second phase of analysis involves statistical interpretation of data, e.g., to check the variance between the seasons and sampling areas non-parametric Kruskal–Wallis test was applied over the data set using the software SPSS 23.0. The various null hypotheses proposed were: (1) Diversity of butterflies across pre-monsoon, monsoon and post-monsoon seasons is similar, i.e. \( S_1 = S_2 = S_3 \). (2) Diversity of butterflies along all the six sampling sites is similar, i.e. \( H_1 = H_2 = H_3 = H_4 = H_5 = H_6 \).

With 11,943 sightings, 40 species of butterflies belonging to 30 genera and five families were recorded during this study (Table 1).

In the overall area, species richness was found to be highest for both ABP and Dwarka (40 spp. each) followed by Nehru Park (26 spp.), IARI Pusa (21 spp.), Northern Ridge (18 spp.) and Mayapuri (14 spp.; Figure 3). The relative abundance for the six sites showed a similar trend (Figure 4). Among all the butterfly families recorded, maximum number of species was observed in family Nymphalidae (13 spp.), followed by Pieridae (12 spp.), Lycaenidae (6 spp.), Hesperiidae (5 spp.) and Papilionidae (4 spp.). In the overall area, relative abundance of family Pieridae (47%) was found to be the highest followed by Nymphalidae (31%), Lycaenidae (12%), Papilionidae (8%) and Hesperiidae (2%; Figure 5). The

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**Figure 3.** Species richness across different sampling sites. A, Mayapuri; B, Nehru Park; C, IARI Pusa; D, Dwarka; E, Aravalli Biodiversity Park; F, Northern Ridge; 1-year 2015–16; 2-year 2016–17.

**Figure 4.** Species abundance at various sites.

**Figure 5.** Relative abundance of butterfly families recorded.
Table 1. List of butterflies recorded in this study

| Scientific name | Common name | Sites | Comments |
|-----------------|-------------|-------|----------|
| **Family: Hesperiidae** | | | |
| Borbo cinnara (Wallace, 1866) | Rice swift | PU/DW/ABP | Not yet been assessed for the IUCN Red List |
| Hasora chromus (Cramer, 1780) | Common banded awl | DW/ABP/NR | Not yet been assessed for the IUCN Red List |
| Pelopidas mathias (Fabricius, 1798) | Small banded swift/ rice skipper | DW/ABP | Not yet been assessed for the IUCN Red List |
| Spialia galba (Fabricius, 1793) | Indian grizzled skipper | NP/DW/ABP/NR | Not yet been assessed for the IUCN Red List |
| Suastus gremius (Fabricius, 1798) | Indian palm Bob | NP/PD/DW/ABP | Not yet been assessed for the IUCN Red List |
| **Family: Lycaenidae** | | | |
| Catochrysops strabo (Fabricius, 1793) | Forget me not | MP/NP/DW/ABP | Not yet been assessed for the IUCN Red List |
| Leptotes plinius (Fabricius, 1793) | Zebra blue | NP/DW/ABP/NR | Not yet been assessed for the IUCN Red List |
| Spindasis vulcanus (Fabricius, 1775) | Common silver line | DW/ABP/NR | Not yet been assessed for the IUCN Red List |
| Talicada nyseus (Guerin-Ménéville, 1843) | Red pierrot | MP/NP/PD/DW/ABP/NR | Not yet been assessed for the IUCN Red List |
| Tarucus nara (Kollar, 1848) | Rounded pierrot | DW/ABP | Not yet been assessed for the IUCN Red List |
| Zizeeria karsandra (Moore, 1865) | Dark grass blue | MP/NP/DW/ABP | Not yet been assessed for the IUCN Red List |
| **Family: Nymphalidae** | | | |
| Acraea violae (Fabricius, 1793) | Tawny coster | DW/ABP | Not yet been assessed for the IUCN Red List |
| Ariadne merione (Cramer, 1777) | Common castor | DW/ABP | Not yet been assessed for the IUCN Red List |
| Danaus chrysippus (Linnaeus, 1758) | Plain tiger | MP/NP/PD/DW/ABP/NR | Least concern |
| Danaus genutia (Cramer, 1779) | Striped tiger | NP/DW/ABP/NR | Not yet been assessed for the IUCN Red List |
| Euploea core (Cramer, 1780) | Common crow | PU/DW/ABP/NR | Least concern |
| Junonia almana (Linnaeus, 1758) | Peacock pansy | NP/DW/ABP/NR | Least concern |
| Junonia hierta (Fabricius, 1798) | Yellow pansy | DW/ABP/NR | Not yet been assessed for the IUCN Red List |
| Junonia lemonias (Linnaeus, 1758) | Lemon pansy | DW/ABP/NR | Not yet been assessed for the IUCN Red List |
| Junonia orithya (Linnaeus, 1758) | Blue pansy | DW/ABP | Not yet been assessed for the IUCN Red List |
| Hypolimnas misippus (Linnaeus, 1764) | Danai eggfly | NP/DW/ABP | Not applicable (NA) status by IUCN Red List |
| Melanitis leda (Linnaeus, 1758) | Common evening brown | PU/DW/ABP | Not yet been assessed for the IUCN Red List |
| Tirumala limniace (Cramer, 1775) | Blue tiger | MP/NP/PD/DW/ABP | Not yet been assessed for the IUCN Red List |
| Vanessa cardui (Linnaeus, 1758) | Painted lady | PU/DW/ABP | Least concern |
| **Family: Papilionidae** | | | |
| Graphium doson (Felder & Felder, 1864) | Common jay | NP/DW/ABP | Not yet been assessed for the IUCN Red List |
| Pachliopta aristolochiae (Fabricius, 1775) | Common rose | MP/NP/PD/DW/ABP/NR | Least concern |
| Papilio demoleus (Linnaeus, 1758) | Lime swallow tail | MP/NP/PD/DW/ABP/NR | NA status by IUCN Red List |
| Papilio polyes (Linnaeus, 1758) | Common mormon | NP/PD/DW/ABP/NR | Not yet been assessed for the IUCN Red List |
| **Family: Pieridae** | | | |
| Belenos aurata (Fabricius, 1793) | Pioneer white | NP/PD/DW/ABP/NR | Not yet been assessed for the IUCN Red List |
| Catopsilia pomona (Fabricius, 1775) | Common emigrant | MP/NP/PD/DW/ABP/NR | Not yet been assessed for the IUCN Red List |
| Catopsilia pyranthe (Linnaeus, 1758) | Mottled emigrant | NP/PD/DW/ABP | Not yet been assessed for the IUCN Red List |
| Copera nerissa (Fabricius, 1775) | Common gull | NP/PD/DW/ABP/NR | Not yet been assessed for the IUCN Red List |
| Colotis etrida (Boisdruval, 1836) | Small orange tip | NP/DW/ABP | Not yet been assessed for the IUCN Red List |
| Colotis fausta (Olivier, 1801) | Large salmon arab | DW/ABP | Least concern by IUCN Red List |
| Eurema hecale (Linnaeus, 1758) | Common grass yellow | MP/NP/PD/DW/ABP | Not yet been assessed for the IUCN Red List |
| Eurema brigitta (Cramer, 1780) | Small grass yellow | MP/NP/PD/DW/ABP | Least concern |
| Eurema laeta (Boisdruval, 1836) | Spotless grass yellow | MP/NP/PD/DW/ABP | Not yet been assessed for the IUCN Red List |
| Ixias pyrene (Linnaeus, 1764) | Yellow orange tip | NP/DW/ABP | Not yet been assessed for the IUCN Red List |
| Ixias marianne (Cramer, 1779) | White orange tip | MP/NP/PD/DW/ABP/NR | Not yet been assessed for the IUCN Red List |
| Pieris canidia (Sparman, 1768) | Indian cabbage white | MP/NP/PD/DW/ABP/NR | Not yet been assessed for the IUCN Red List |

ABP, Aravalli Biodiversity Park; DW, Dwarka; MP, Maya Puri; NP, Nehru Park; NR, Northern Ridge and PU, IARI Pusa.

highest species diversity was recorded for ABP and least for Mayapuri, though evenness index (Shannon J) was found to be almost similar across all the sampling sites, with a sharp rise in the case of ABP. The diversity indexes for the butterflies are as follows (Figure 6); Simpson diversity index \((1 – D) = 0.85, 0.94, 0.92, 0.96, 0.97 and 0.91\) for the year 2015–16 and 0.83, 0.92, 0.92, 0.96, 0.97 and 0.91 for the year 2016–17 at Mayapuri, Nehru Park, IARI Pusa, Dwarka, ABP and Northern Ridge respectively which complies with the Shannon–Wiener diversity index.
Table 2. Bray–Curtis index for butterfly assemblages across different study sites

|       | A1  | B1  | C1  | D1  | E1  | F1  | A2  | B2  | C2  | D2  | E2  | F2  |
|-------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| A1    | 0   |     |     |     |     |     |     |     |     |     |     |     |
| B1    | 0.42| 0   |     |     |     |     |     | 0.43|     |     |     |     |
| C1    | 0.43| 0.46| 0   |     |     |     |     |     |     |     |     |     |
| D1    | 0.66| 0.45| 0.41| 0   |     |     |     |     |     |     |     |     |
| E1    | 0.73| 0.54| 0.52| 0.23| 0   |     |     |     |     |     |     |     |
| F1    | 0.52| 0.61| 0.29| 0.49| 0.59| 0   |     |     |     |     |     |     |
| A2    | 0   |     |     |     |     |     |     |     |     |     |     |     |
| B2    | 0.43| 0   |     |     |     |     |     |     |     |     |     |     |
| C2    | 0.51| 0.47| 0   |     |     |     |     |     |     |     |     |     |
| D2    | 0.78| 0.47| 0.42| 0   |     |     |     |     |     |     |     |     |
| E2    | 0.78| 0.63| 0.55| 0.25| 0   |     |     |     |     |     |     |     |
| F2    | 0.56| 0.53| 0.60| 0.71| 0   |     |     |     |     |     |     |     |

A, Mayapuri; B, Nehru Park; C, IARI Pusa; D, Dwarka; E, Aravalli Biodiversity Park; F, Northern Ridge; 1, Year 2015–16; 2, Year 2016–17.

Mayapuri against ABP and Dwarka in the second year. Dwarka and ABP shared the maximum number of common species with index values of 0.23 and 0.25, which is the minimum for the given dataset in the years 2015–16 and 2016–17 respectively, indicating that if a place is either left undisturbed or restored ecologically, it can support biodiversity.

Diversity of the butterflies showed highest value during monsoon season and lowest during post-monsoon season (Figure 7). Simpson diversity index \((1 – D)\) values for the pre-monsoon, monsoon and post-monsoon seasons were 0.99, 0.95 and 0.92 for the year 2015–16 and 0.95, 0.95 and 0.89 for the year 2015–16 respectively, which is slightly higher during pre-monsoon in the first year. Shannon–Wiener index values were 3.28, 3.61 and 2.94 for 2015–16 and 3.26, 3.35 and 2.81 for 2016–17 in the similar seasonal patterns of pre-monsoon, monsoon and post-monsoon respectively. The evenness values (0.91, 0.98 and 0.82 in 2015–16; 0.90, 0.91 and 0.79 in 2016–17) also showed similar trends as those of diversity, patterns, giving maximum weightage to the monsoon season. Seasonal patterns of butterflies for all the seasons indicated that maximum species and individuals were observed during the monsoon (June–September) period, where Shannon \(H'\) (species richness) was high as also the number of individuals with respect to rainfall and temperature. The post-monsoon period, i.e. October to January showed the least richness and evenness values.

Differences in butterfly diversity between different sites and seasons were tested using non-parametric Kruskal–Wallis \(H\) test (SPSS version 23.0), where sites and seasons were treated as independent variables and butterfly frequency as a dependent variable. The normality of the data was tested using Kolmogorov–Smirnov test (0.011, 0.036, 0.020, 0.004, 0.012 and 0.020) and Shapiro–Wilk test (0.003, 0.004, 0.043, 0, 0.017 and 0.018) for Mayapuri, Nehru Park, IARI Pusa, Dwarka, ABP and Northern Ridge respectively (Table 3) for both the years and 0 for pre-monsoon, monsoon and post-monsoon (Table 4), where \(p\)-value was less than 0.05 and therefore, nonparametric test was applied. Kruskal–Wallis \(H\) test showed that there was a statistically significant difference in butterfly diversity between the three seasons and six sites for both the years, with \(\chi^2 = 25.35\) for the sites.
(Table 5) and $\chi^2 = 28.475$ for the seasons (Table 6). At $\alpha = 0.05$ (95% of confidence level) of significance, with $P = 0.000$, this further rejects the null hypothesis of similar diversity of butterflies across the six sites and three seasons, thus, confirming the alternate hypothesis of considerable variation of butterfly diversity at the sites and across seasons for both the years. Figures 8 and 9 show photographs of the city butterflies.

Studies on butterfly diversity provide information about the variations in species abundance, richness and evenness affected by vegetation along the landscape and species interactions.$^{29-32}$ Although the local determinants of diversity such as competition and predation remained undermined in these types of studies, overall view of landscape features influencing the richness and abundance of butterflies in different geographical areas is well explained. The study sites had various habitats ranging from natural ridge to agricultural sites, and from institutional to industrial areas. ABP has the highest number of butterflies along with the highest diversity index and species evenness. The reason could be the presence of different native plant varieties as food source and variable microhabitats that are readily available for the different butterflies species. Moreover, human interferences were least in the area, which is a significant factor contributing to the highest diversity of butterfly species for all the families. Thus, ABP sets an example where a degraded habitat for butterflies$^{33,34}$ can be restored, i.e. data are not normal

| Sampling sites | Kolmogorov–Smirnov | Shapiro–Wilk |
|----------------|---------------------|--------------|
| A              | 0.011               | 0.003        |
| B              | 0.036               | 0.004        |
| C              | 0.020               | 0.043        |
| D              | 0.004               | 0.000        |
| E              | 0.012               | 0.017        |
| F              | 0.020               | 0.018        |

| Seasons       | Kolmogorov–Smirnov | Shapiro–Wilk |
|----------------|---------------------|--------------|
| PrM            | 0.000               | 0.000        |
| M              | 0.000               | 0.000        |
| PoM            | 0.001               | 0.000        |

| Chi-square value | 25.35 |
| Degrees of freedom | 5    |
| Significance (p value; $\alpha = 0.05$) | 0.000 |

| Chi-square value | 28.475 |
| Degrees of freedom | 2    |
| Significance (p value; $\alpha = 0.05$) | 0.000 |
patches. Yet, the occurrence of a fair number of species also suggests that though the area is treated with pesticides and other chemicals, it has maintained its rich biodiversity. The condition of Northern Ridge and Mayapuri is well denoted by the number of their butterfly species and count. The Northern ridge is a fragmented city...
forest that is facing the ever-growing challenge of encroachment and trespassing, though a few conservatories have been constructed which can be seen in the second year as slight increase in the evenness value. Mayapuri is an industrial area where a park that is divided into two contrasting sections is located and recorded the lowest number of butterflies species, with the lowest species richness and evenness value. Evenness measure is important for community description and ecological monitoring. Lower the calculated value of equitability, higher is the stressed environment, where either human disturbance is intense or pollution-tolerant species are abundant at the site. Negative effect on butterfly diversity is seen in such a land type, as it experiences the highest rate of disturbance and interference compared to the other five areas, because of heavy traffic intersections, construction of metro lines, industrial pollution and irresponsible movement of people inside the park. Species like Danaus genutia, Danaus chrysippus, and Pieris sp. that are capable of colonizing degraded land areas show a good presence at such sites. Overall, the differences in species distribution in the six sites were prominent. The observed variations in species richness in the urban and suburban areas indicate the differences in host plant abundance and landscape characteristics in the region. The study reveals that butterfly diversity increased with the availability of green space and heterogeneity of the habitats in terms of the available plant species.

The climate of Delhi varies with extreme temperature ranges. According to the study the occurrence of butterfly species was highest during the monsoon months (July–September) in Delhi (hot/wet season), remained stable till early winter (cool/wet season), and sharply declined in winter (December and January) while the temperature was low; and butterflies being poikilotherms tend to go into hiding inside the bushes or their larval food plants of the butterfly species along roadside pavements. Hence, a slight rise in the peak of diversity could be seen possibly with a change in temperature. The Kruskal–Wallis H test revealed a significant and prominent difference in the diversity of butterflies across different sampling sites and seasons.

Successful environmental planning and protection of a growing city are largely dependent on the mathematical calculations of biodiversity indexes which quantify ecological diversity. Biodiversity has been recognized as one of the key components of environmental sustainability, demonstrating that subtropical urban city landscapes can provide a suitable habitat for many butterfly species. Delhi is the capital city of India and hence, has to meet the increased globalization pressure of better infrastructure along with its local biodiversity. The local conservation agencies can play an important role by teaming up with the Forest Department and promoting the planting of larval food plants of the butterfly species along roadside pavements. With increasing awareness among residents, it would help improve the regional biodiversity richness of an urban area.

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Functional response of three species of predatory pirate bugs to different densities of blossom thrips, Frankliniella schultzei Trybom (Thysanoptera: Thripidae)

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The functional response of three anecicid bugs, namely Blaptostethus pallescens Poppius, Cardiastethus affinis Poppius and Montandoniula indica Yama-da (Heteroptera: Anecicidae) was assessed by feeding them with different densities of thrips larvae of Frankliniella schultzei (Trybom) in the laboratory. Predation rate of all the three species increased with

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