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.

URBAN expansion is threatening biodiversity globally by destroying the natural and seminatural habitats and increasing the levels of anthropogenic disturbance[1]. Urbanization in cities has generated many fragmented and concrete lands at a rapid pace, while very few places have been recreated as green areas for the conservation of biodiversity of local flora and fauna. Butterflies being poikilotherms respond to such environmental changes sharply with a decline in their population diversity and hence are considered as an important section of biodiversity because they have considerable resonance with both the general public and decision-makers[2]. While greenery in urban areas may reduce the impact of urbanization on biodiversity, it is often over-managed and ends up in small, fragmented patches which may be isolated. Effective management strategies for different urban landscapes require proper understanding of the ecology and habitat requirements of all relevant taxa. Yet, little is known of how invertebrates and, in particular, lepidopteran assemblages utilize urban landscapes despite their common occurrence. They provide the best rapid indicators of habit quality being sensitive indicators of climatic change[3]. Longstaff and Müller[4] recorded 14 species of butterflies, which was a pioneering work on the Delhi butterflies. Later Jandu[5]; Donahue[6] and Ashton[7] contributed to the lepidopteran list. Sevastopulo[8] critically reviewed the earlier works of Delhi butterflies briefly. In 1997, an annotated list of 90 species of butterflies was recorded[9], whereas in 2004, 86 species of butterflies from all over Delhi were listed[10]. In recent years, 24 butterflies[11] from Guru Gobind Singh Indraprastha University campus, Dwarka, Delhi have been reported[11], whereas 2017 witnessed a total of 115 butterflies from all over Delhi region[12], which is a positive sign for the ecological health of the city.

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

Figure 1. Location map of Delhi, India.

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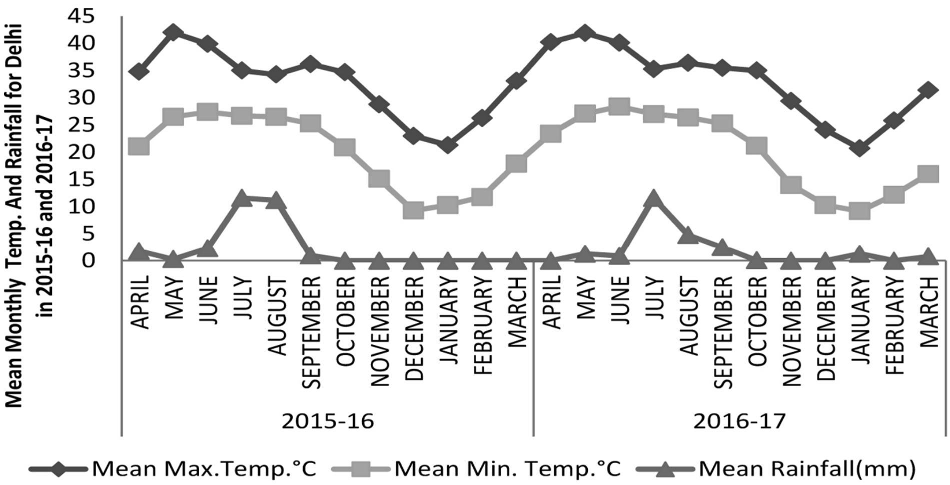


Figure 2. Monthly average temperature and rainfall in Delhi during 2015–16 and 2016–17 (source: India Meteorological Department, New Delhi).

observed for many important insect-pollinator groups like butterflies[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[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[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[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[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[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[26–28]. It is calculated using the formula

$$H = -\sum_{i=1}^{S} p_i \times \ln(p_i),$$

where p_i (proportion of individuals belonging to the ith 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[26–28]

$$E = eH'/S \text{ or } J = H/H_{\max},$$

where $H_{\max}$ 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[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

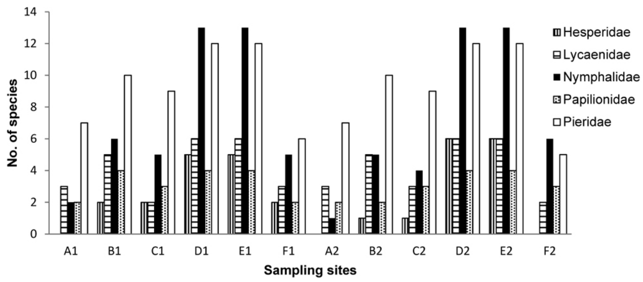


Figure 3. Species richness across different sampling sites. A, Mayapuri; B, Nehru Park; C, IARI Pusa; D, Dwarka; E, Aravalli Biodiversity Park; F, Northern Ridge; 1-year 2015–16; 2-year 2016–17.

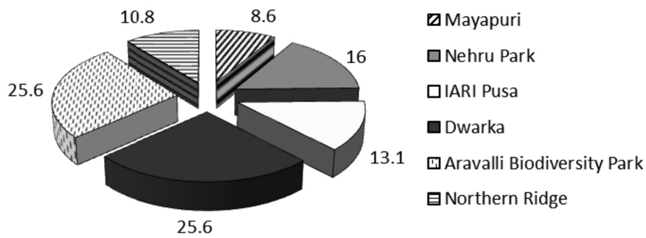


Figure 4. Species abundance at various sites.

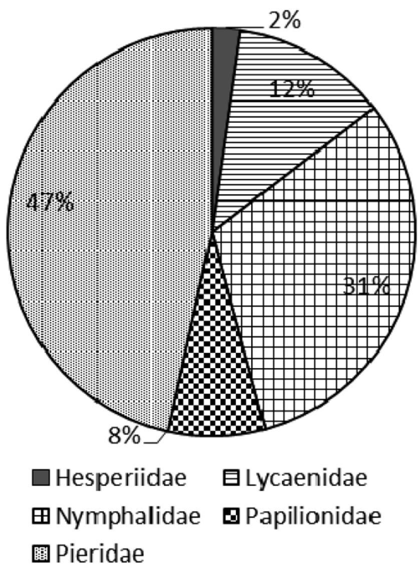


Figure 5. Relative abundance of butterfly families recorded.

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/PU/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/PU/DW/ABP/NR	Not yet been assessed for the IUCN Red List
Spindasis vulcanus (Fabricius, 1775)	Common silver line	NP/DW/ABP/NR	Not yet been assessed for the IUCN Red List
Talicada nyseus (Guerin-Méneville, 1843)	Red pierrot	MP/NP/PU/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/PU/DW/ABP/NR	Least concern
Danaus genutia (Cramer, 1779)	Striped tiger	NP/PU/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	Least concern
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)	Danaid 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/PU/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/PU/DW/ABP/NR	Least concern
Papilio demoleus (Linnaeus, 1758)	Lime swallow tail	MP/NP/PU/DW/ABP/NR	NA status by IUCN Red List
Papilio polytes (Linnaeus, 1758)	Common mormon	NP/PU/DW/ABP	Not yet been assessed for the IUCN Red List
Family: Pieridae			
Belenois aurota (Fabricius, 1793)	Pioneer white	NP/PU/DW/ABP/NR	Not yet been assessed for the IUCN Red List
Catopsilia pomona (Fabricius, 1775)	Common emigrant	MP/NP/PU/DW/ABP/NR	Not yet been assessed for the IUCN Red List
Catopsilia pyranthe (Linnaeus, 1758)	Mottled emigrant	NP/PU/DW/ABP	Not yet been assessed for the IUCN Red List
Cepora nerissa (Fabricius, 1775)	Common gull	MP/NP/PU/DW/ABP/NR	Not yet been assessed for the IUCN Red List
Colotis etrida (Boisduval, 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 hecabe (Linnaeus, 1758)	Common grass yellow	MP/NP/PU/DW/ABP	Not yet been assessed for the IUCN Red List
Eurema brigitta (Cramer, 1780)	Small grass yellow	MP/NP/PU/DW/ABP	Least concern
Eurema laeta (Boisduval, 1836)	Spotless grass yellow	MP/NP/PU/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/PU/DW/ABP/NR	Not yet been assessed for the IUCN Red List
Pieris canidia (Sparrman, 1768)	Indian cabbage white	MP/NP/PU/DW/ABP/NR	Not yet been assessed for the IUCN Red List

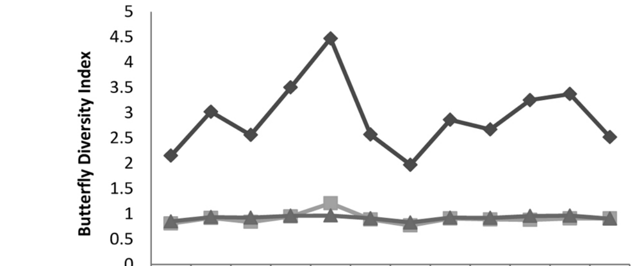
ABP, Aravalli Biodiversity Park; DW, Dwarka; MP, Maya Puri; NP, Nehru Park; NR, Northern Ridge and PU, IARI Pusa.

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

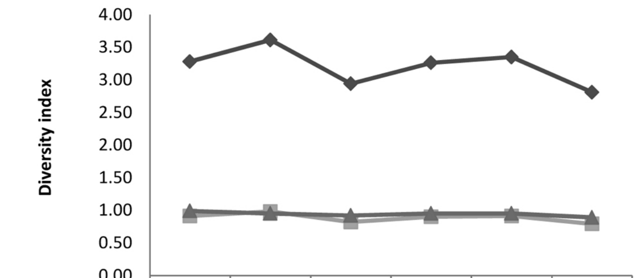
	A1	B1	C1	D1	E1	F1		A2	B2	C2	D2	E2	F2
A1	0						A2	0					
B1	0.42	0					B2	0.43	0				
C1	0.43	0.46	0				C2	0.51	0.47	0			
D1	0.66	0.45	0.41	0			D2	0.78	0.47	0.42	0		
E1	0.73	0.54	0.52	0.23	0		E2	0.78	0.63	0.55	0.25	0	
F1	0.52	0.61	0.29	0.49	0.59	0	F2	0.56	0.53	0.40	0.60	0.71	0

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.



	A1	B1	C1	D1	E1	F1	A2	B2	C2	D2	E2	F2
ShannonH'	2.15	3.02	2.56	3.5	4.47	2.57	1.97	2.86	2.67	3.25	3.37	2.52
Shannon J	0.81	0.92	0.84	0.95	1.21	0.89	0.77	0.91	0.89	0.88	0.91	0.91
Simpson 1-D	0.85	0.94	0.92	0.96	0.97	0.91	0.83	0.92	0.92	0.96	0.97	0.91

Figure 6. Diversity of butterflies recorded across different study sites.



	PrM1	M1	PoM1	PrM2	M2	PoM2
ShannonH'	3.28	3.61	2.94	3.26	3.35	2.81
Shannon J	0.91	0.98	0.82	0.90	0.91	0.79
Simpson 1-D	0.99	0.95	0.92	0.95	0.95	0.89

Figure 7. Diversity of butterflies recorded across different seasons. PrM, Pre-monsoon; M, Monsoon and PoM, Post-monsoon.

too with values 2.15, 3.02, 2.56, 3.5, 4.47 and 2.57 in 2015–16 and 1.97, 2.86, 2.67, 3.25, 3.37 and 2.52 in 2016–17 respectively, following the similar order of study sites.

Bray–Curtis dissimilarity index was applied to determine beta diversity patterns of butterfly assemblages in relation to different study sites (Table 2). Higher the index values, lower was the number of common shared species between the two sites. Mayapuri and ABP share the least number of species with the index value of 0.73 in the first year whereas the index value is 0.78 for 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 furthers 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 landfill has been converted to a rich butterfly conservatory. Many diverse ecosystems (forests, grassland, shrub land, wetlands and so on) have been established in ABP. In these varied ecosystems with a mosaic of habitats, varieties of foraging niches (guilds) have been carved which attract many species of butterflies. In these areas, reconstruction of ecosystem with the help of assemblage of species and utilizing some of the principles of ecological restoration enabled historical niches to get established.

Dwarka is a suburban area that had similar species richness as ABP, but species evenness is slightly lower than that of ABP. This area is comparatively less congested compared to other parts of the city. Unmanaged areas, often with a high diversity and quality of (often native) early-successional plants, provide suitable foraging habitat for butterflies[33,34]. The suburban areas (DW and ABP) had a greater variety of butterfly species, possibly as a consequence of larger areas with diverse vegetation patterns.

The urban areas (NP, PU, NR and MP) were less diverse in terms of vegetation and the space available for plant growth, though several gardens and green patches do exist in the city of Delhi. The species richness value in Nehru Park was slightly low compared to ABP and DW, which indicates that the use of herbicides and other chemicals in the manicured parks can decimate faunal diversity. The low availability of nectar and larval food plants in the parks can be the other elements as well. Moreover, a traffic intersection will always harm the local biodiversity. The city parks should focus on lush green growth of grasses, as grasslands are particularly important for supporting the highest densities of butterflies[35] and should stop irresponsible human encroachment of green patches leading to habitat fragmentation. IARI Pusa recorded moderate species richness and evenness. The cause of decline might be the non-availability of nectar and larval host plants, or agricultural intensification which destroys grasslands that are important for completion of the life cycle of a butterfly[35]. Intensively managed sites, such as those frequently mowed, are reported to sustain low populations and abundance of butterflies due to the destruction of potential host plants and foraging

Table 3. Normality tests for butterfly abundance across different study sites. As p value is less than 0.05, the alternate hypothesis is accepted, i.e. data are not normal

	Kolmogorov–Smirnov	Shapiro–Wilk
Sampling sites	Significance (p value at $\alpha = 0.05$)	Significance (p value at $\alpha = 0.05$)
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

Table 4. Normality tests for butterfly abundance across different seasons

	Kolmogorov–Smirnov	Shapiro–Wilk
Seasons	Significance (p value at $\alpha = 0.05$)	Significance (p value at $\alpha = 0.05$)
PrM	0.000	0.000
M	0.000	0.000
PoM	0.001	0.000

PrM, Pre-monsoon; M, Monsoon and PoM, Postmonsoon. As p value is less than 0.05, the alternate hypothesis is accepted, i.e. data are normal.

Table 5. Kruskal–Wallis H test for butterfly abundance across study sites. p value is less than 0.05, hence, proving the alternate hypothesis of dissimilar diversity across sites

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

Table 6. Kruskal–Wallis H test for butterfly abundance across seasons. p value is less than 0.05, hence proving the alternate hypothesis of dissimilar diversity across seasons

Chi-square value	28.475
Degrees of freedom	2
Significance (p value; $\alpha = 0.05$)	0.000

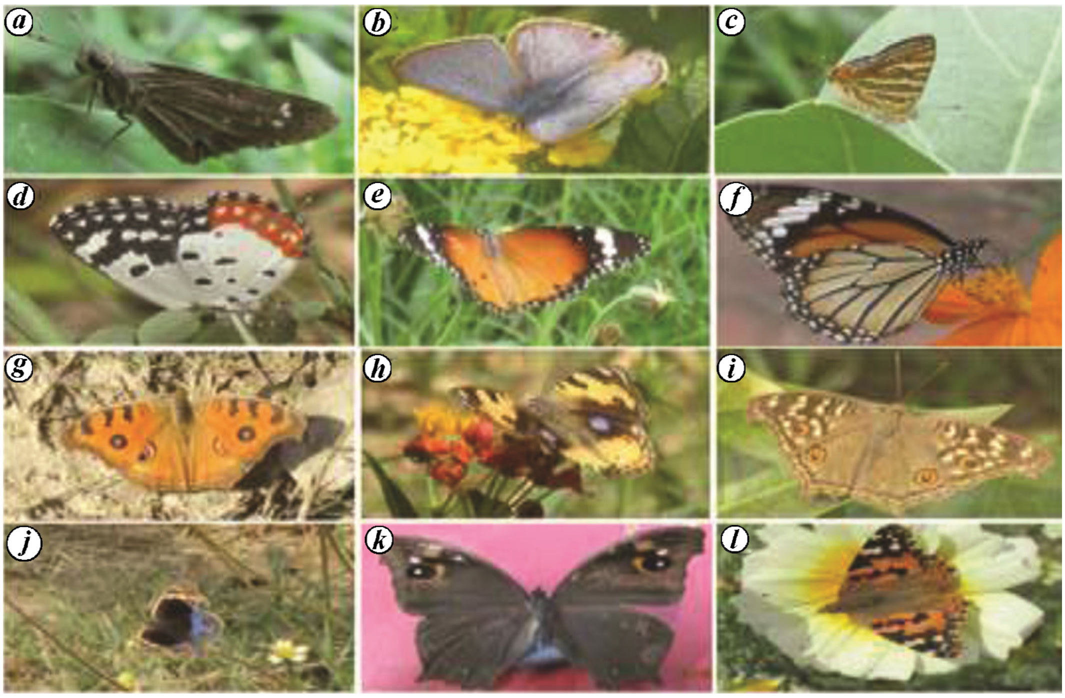


Figure 8. Butterflies of Delhi. ***a***, Hesperiidae: *Pelopidas mathias*. ***b–d***, Lycaenidae: *Catochrysops strabo* (***b***), *Spindasis vulcanus* (***c***) and *Talicada nyseus* (***d***). ***e–l***, Nymphalidae: *Danaus chrysippus* (***e***), *Danaus genutia* (***f***), *Junonia almana* (***g***), *Junonia hierta* (***h***), *Junonia lemonias* (***i***), *Junonia orithya* (***j***), *Melanitis leda* (***k***) and *Vanessa cardui* (***l***).

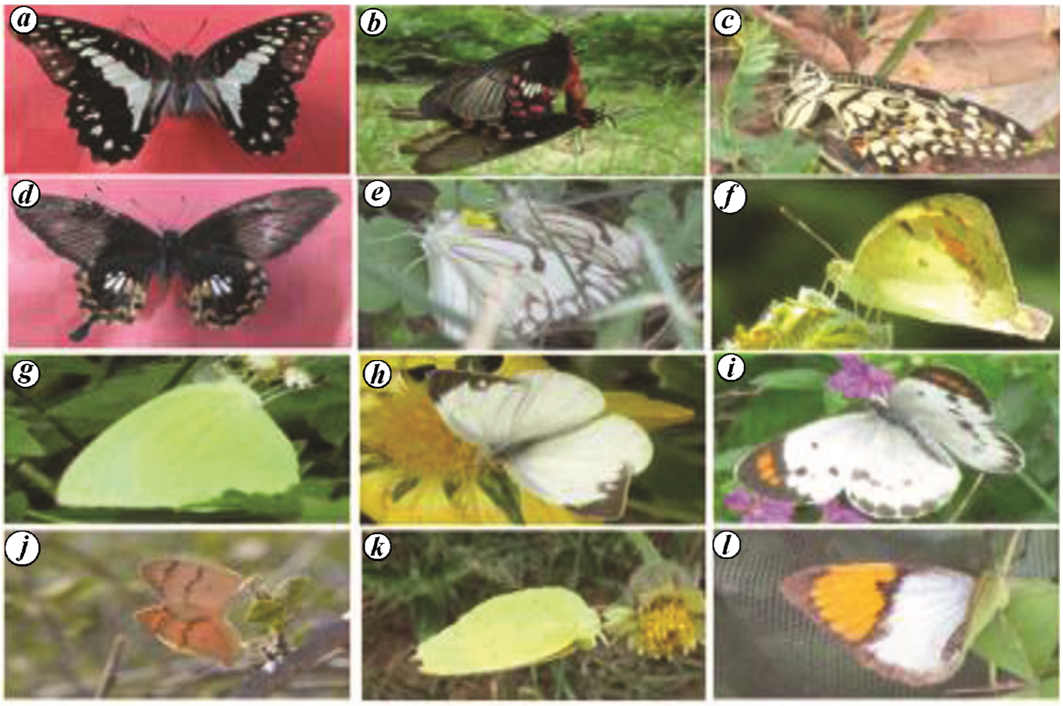


Figure 9. ***a–d***, Papilionidae: *Graphium doson* (***a***), *Pachliopta aristolochiae* (***b***), *Papilio demoleus* (***c***), *Papilio polytes* (***d***). ***e–l***, Pieridae: *Belenois aurota* (***e***), *Catopsilia pomona* (***f***), *Catopsilia pyranthe* (***g***), *Cepora nerissa* (***h***), *Colotis etrida* (***i***), *Colotis fausta* (***j***), *Eurema hecabe* (***k***) and *Ixias marianne* (***l***).

patches[36,37]. 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[26]. 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[38]. 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[39].

The climate of Delhi varies with extreme temperature ranges[19]. 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 prefer diapause[40]. In the pre-monsoon months, spring arrives in February and March in Delhi; hence flower bloom acts as an attractant for the nectar-loving insects. Hence, a slight rise in the peak of diversity could be seen for both the years. In the latter pre-monsoon months (April–mid June) when the summer heat was high, they tend to go into hiding inside the bushes or their larval host plants during their activity periods when the recordings had been done, therefore, leading to the fewer sightings. Overall, seasonal trend exhibits that there is a dual peak (rise) in the butterfly diversity throughout the year. The first rise is seen during the early pre-monsoon months (February and March) and a second peak is observed during early monsoon to the end of the rainy season. The reason being for such a trend is that during these seasons there are the factors which influence the growth of nectar plants which have a direct impact on the butterfly population across all six sampling sites[41]. The butterfly abundance increased twice corresponding to early summer and monsoon, while it decreased during winter, 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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ACKNOWLEDGEMENTS. We thank Guru Gobind Singh Indraprastha University for financial assistance and Indian Agricultural Research Institute, Pusa, New Delhi for giving the permission to conduct the research in their agricultural fields. We also thank Dr M. Shah Hussain (Aravalli Biodiversity Park, New Delhi) for help; and Mr Manish Joshi, Ms Mandeep Kaur and Ms Shubhi Malik (Guru Gobind Singh Indraprastha University, Dwarka, New Delhi) for useful suggestions that helped improve the manuscript.

Received 1 February 2019; revised accepted 30 October 2019

doi: 10.18520/cs/v118/i5/819-827

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 anthocorid bugs, namely *Blaptostethus pallescens* Poppius, *Cardiastethus affinis* Poppius and *Montandoniola indica* Yamada (Heteroptera: Anthocoridae) 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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