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Correspondence of butterfly and host plant diversity: foundation for habitat restoration and conservation

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ABSTRACT

At a spatial scale, the diversity of butterflies varies with numerous factors including the availability of the host plant species. In parity with this proposition, the correspondence of diversity of butterfly and plant in the background of the urban–rural gradient was evaluated using Kolkata, India, as a model study area. The results reveal significant positive correlation between the diversity of butterflies and the plants, with the different values for the suburban, rural, and urban areas. Identification of the butterfly loads for the plants in the respective areas can be useful in enhancing the conservation of the butterflies through enhanced plantation of the concerned plant species. Alternatively, the disclosure of the generalist and specialist pattern of the plant species preference by the butterflies may be useful in enhancing the population of the respective species in the concerned areas. The conservation strategy for butterfly species may be refined through the use of both or any one of the quantitative assessment of the butterfly–plant links in the urban–rural gradient in Kolkata, India, and similar places in the world.

KEYWORDS

butterfly, plant, diversity, mutualistic relationship, urbanization gradient

INTRODUCTION

Butterflies are considered as indicator species (Bonebrake et al. 2010) with multiple functional roles that sustain ecosystems and the services derived thereof. Butterflies and plants are extremely interlinked (Feltwell 1986). Besides pollination, the butterflies are involved in various other interactions that facilitate the maintenance of the integrity of the ecosystems (Bonebrake et al. 2010). In almost all terrestrial ecosystems across the globe, the species assemblages of butterfly differ considerably depending on the vegetation and land use pattern (Blair & Launer 1997; Bergerot et al. 2011; Sagwe et al. 2015). And therefore, butterfly is used as an important bioindicator for environmental assessment in studies of conservation biology (Sakuratani & Fujiyama 1991; Bonebrake et al. 2010). The dependency of the larval stage on a specific host plant and adult stage on flowering plants connects butterflies strongly to the diversity and health of their habitats (Sparks et al. 1996). The correspondence of the plant and butterfly abundances is crucial to understand the health and quality of the ecosystem as well as planning conservation strategies (Maccherini et al. 2009; Ferrer-Paris et al. 2013). In the recent time, human interference is generally associated with ecologically unsustainable ecosystems, including local extinction of plant and animal species diversity and reduction of resource quality (Grimm et al. 2008; Pickett et al. 2011). Studies of biodiversity assessment are often used for recognizing the level of anthropogenic disturbance (Myers et al. 2000) and these studies may be useful for conservation biologist for taking decision by identifying dominant or more common species or by observing interactions among species in a specific region or time period (Wilson et al. 2009). Monitoring of butterfly and corresponding plants in cities (Koh & Sodhi 2004; Tiple et al. 2011; Lee et al. 2015; Barranco-León et al. 2016), forests (Liivamägi et al. 2014), agricultural fields (Loos et al. 2014), and human-made river levees (Moroń et al. 2017) facilitate the assessment of the diversity status and development of necessary conservation

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steps. Empirical studies indicate that butterflies can thrive in numerous smaller green patches in the urban ecosystems (Croxton et al. 2005), making the urban spaces as valued sites for butterfly conservation (Lee & Kwon 2012; Lee et al. 2015). In the green spaces of urban and suburban regions, the relative density and abundance of butterflies vary corresponding to the richness and abundance of the host plant species (Smalidge & Leopold 1997; Lee et al. 2015). Before promoting the urban green spaces for conservation of butterflies, an appraisal of the diversity relationship between the butterfly and vegetation is essential, as evident from studies across the different continents (Smalidge & Leopold 1997; Kitahara et al. 2008; Lee et al. 2015). Dependence of the butterflies on the plant species in a community can be considered through an alternative viewpoint. A butterfly species can be linked to a single, few, or multiple number of plant species and can be classified accordingly in the continuum of specialist to generalist consumer (Tudor et al. 2004). The availability of the butterfly species will then depend on the heterogeneity of the landscape with the available vegetation. Thus correspondence of the plants and the butterflies needs to be highlighted in terms of the richness and abundance aspects of diversity.

Assuming that the trophic nature of the butterflies is important feature in determining the pattern of diversity, the assessment of correspondence between the richness of the butterflies and the plant species in unit area becomes critical in deciding the nature of conservation strategy (van Halder et al. 2008; Farhat et al. 2014). While majority of the studies on butterflies of urban landscapes have addressed the diversity aspects with homogeneous or heterogeneous vegetation patterns (Ramírez-Restrepo & MacGregor-Fors 2017), in the present study, the aspects of richness and abundance of the butterflies and the plant species were assessed to supplement the required information to standardize the conservation aspects. Both the abundance and richness of plants were used to predict the prospective abundance and richness of the butterflies in the study sites with the urban, suburban, and rural areas in and around Kolkata, India, being the three different types of landscapes. This urbanization gradient approach is expected to be utilizable for recognizing the distribution pattern of butterflies and their food plants in and around Kolkata. The results are expected to be useful for choosing most appropriate plants that serve for butterfly conservation along with an urban greening program of Kolkata, India, and similar regions around the world. The results are expected to supplement information to the urban development authority for habitat restoration in terms of both ecosystem services and the conservation of butterfly and plant community.

1. MATERIAL AND METHODS

1.1. Sampling sites

The present study was conducted in and around Kolkata megacity, India. On the basis of physical features, three study areas, namely, urban, suburban, and rural areas, were selected. Each area consisted of two study sites comprising of spatially distinct places. The selection of these sites was made following on-site visits, Google Earth Image, and land use planning map before the initiation of the sampling study. To demarcate three different study areas, the space image or Google Earth Image of the each site was classified into vegetation, open land, water body, settlement, and agricultural land and the percentage of these parameters was calculated by MicroImages, Inc. © 2015 . The percentage of the physical parameters of each site (about 7km^2) was calculated (See Table S1). The geographic coordinates of the central points of urban area (South Sinthee (Site 1) 22°37′24.19″ N, 88°23′25.73″E; and Central Kolkata (Site 2) 22°34′14.23″N, 88°21′28.03″E), suburban area (Narendrapur (Site 3) 22°25′43.70″N, 88°24′6.35″E; and Gourangapur (Site 4) 22°49′16.29″N, 88°19′13.02″E), and rural area (Kuliagarhat (Site 5) 22°52′52.51″N, 88°27′33.86″E; and Haringhata (Site 6) 22°57′10.12″N, 88°31′21.53″E) were recorded by Global Positioning System (GPS) (GPSMAP® 76Cx, Garmin, Kansas, USA).

1.2. Sampling period and time

For a period of 1 year, butterflies and plants were observed in the sampling sites from January 2014 to December 2014 and each study site was visited once in a month and transects were observed from early morning (07:00 hours) to afternoon (17:00 hours) during good weather periods (without rain and strong wind) following the standard protocol (Pollard 1977; Pollard & Yates 1993), as described in earlier publications (Mukherjee et al. 2015a, b).

1.3. Sampling techniques

In each sampling site, the butterflies were recorded following "Pollard Walk" method (Pollard 1977; Pollard & Yates 1993) with required modifications. Five "transect paths" of 1 km each with a gap of 500 m were selected in each site within each area (i.e., 5 transects × 12 months × 2 sites =120 samples in each area (urban/suburban/rural)) and butterflies were counted on either side of the path (at a distance of 2.5 m) following Mukherjee et al. (2015a). The method of Clark et al. (2007) was used for recording the plant species that were used by butterflies for either sucking nectar or laying eggs (Mukherjee et al. 2016). The plant species encountered within 2.5 m to either side of a particular point in the transect were also recorded. But it was not possible to count all the herbaceous plant individuals located within 2.5 m to either side of a particular point in the transect. Within 2.5 m to side of each transects, five quadrats (with a dimension of 5 m × 5 m) were established using poles and ropes at 200-m intervals (Mukherjee et al. 2015b) for the sampling of herbaceous plants. Some flowering plant specimens were collected and preserved as herbaria for further confirmation of identification using appropriate keys (Kehimkar 2000; Paria 2005, 2010; Mandal & Jana 2012). The selection of the study sites and the areas covered were in compliance with the norms of general observational studies, without procurement of any butterfly. Although the plant parts were plucked in minimum for identification, no plants were uprooted for identification. Similarly, no butterfly individuals were killed intentionally or otherwise in this study, although photographs were taken for supportive evidence of identification (Mukherjee et al. 2015a, b, 2016).

1.4. Data analysis

Pooling data from the five transects were taken for the calculation for each site as data sets were too small to calculate diversity parameters per transect following Stout & Casey (2014) with necessary modifications. Biodiversity Pro Software (McAleece et al. 1997) was used to calculate diversity index. Ranked species abundance curve (Heip et al. 1998) was used to rank species from 1, those that are most abundant, to S, those that are least abundant, and the log (n) transformed data of butterflies and plants species abundances were used to form rank of species of all six sites. The data on the plant richness and abundance and butterfly richness and abundance were subjected to mixed model generalized linear model (GLM) to justify the effects of the months and the areas (U, urban; SU.U, suburban; and RU, rural) followed by post hoc multiple comparisons (Fisher's least square difference) (Legendre & Legendre 1998; Zar 1999). The purpose was to highlight the significant variations in the month and area as reflected on the diversity of plants and butterfly. The statistical analyses (Legendre & Legendre 1998) were performed using XLSTAT software (Addinsoft 2010).

In order to understand the relative importance of individual plant species in the butterfly association, an index was estimated representing the butterfly load of the plant. Using the data on the number of butterfly species recorded from the plants and the relative abundance of the plant in the concerned sampling unit, the data on the butterfly load were estimated (Mukherjee et al. 2015b) by applying the following formula: butterfly load in each plant species = P_b/P_i (where P_b is the proportion of the total butterfly species and P_i is the proportion of the i^{th} plant species). Similarly, the choice of the butterfly for the plants was assessed to highlight the extent of the plant species linked with the butterfly species (Mukherjee et al. 2015b). For the butterfly species, relative preference for the plant species was calculated by proportion presence in the plants. Link to the plant species = B_i/P_i (where B_i is the proportion of the

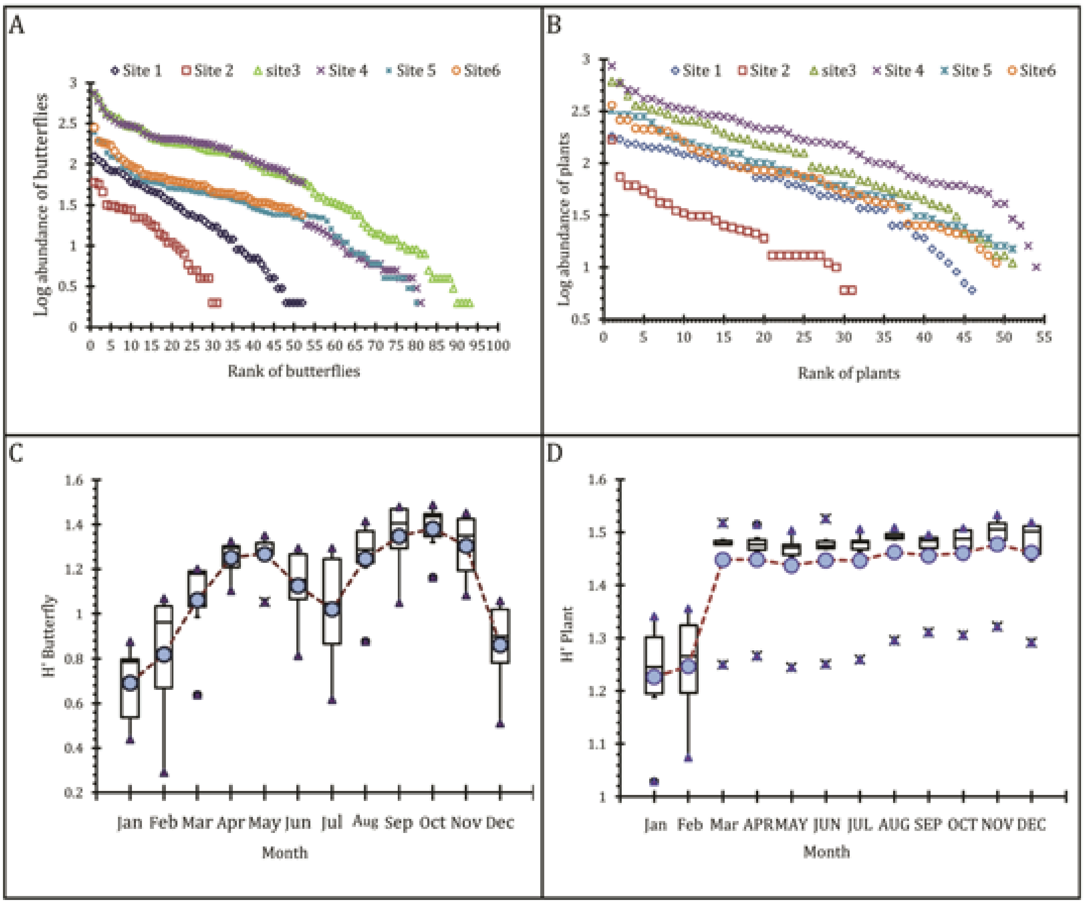

Figure 1. *The log (n + 1)-transformed data of butterflies species (A) and plants species (B) abundance were used to show the rank of butterflies and plants along each study site in Kolkata, India, and box-plot representation of month-wise diversity index (Shannon H' log base 10) of butterflies (C) and plants (D) during study period irrespective of sites. The filled circles represents the mean H' values for all the areas (n = 30 transects for each site under the three areas). The upper quartile and lower quartile values are separated by the median value in each box. The extreme values and outliers are also shown.*

Table 1. The results of mixed model GLM and post hoc multiple comparisons to explain the variations in the plant and butterfly abundance and diversity as a function of the three levels (U, urban; SU.U, suburban; RU, rural) of areas (A) and months (M).
(A) The results of the mixed models using sites and months as explanatory variables (numerical, N; denominator, D)

Subject	Source of variation	df (N)	df (D)	F-ratio	Level of significance (P)
Plant abundance (PA)	Month(M)	1	354	77.447	<0.0001
	Areas (A)	2	354	262.933	<0.0001
	M*A	2	354	12.551	<0.0001
Plant richness (PR)	Month(M)	1	354	92.161	<0.0001
	Areas (A)	2	354	126.313	<0.0001
	M*A	2	354	3.963	0.020
Butterfly abundance (BA)	Month(M)	1	337	28.284	<0.0001
	Areas (A)	2	337	84.356	<0.0001
	M*A	2	337	10.057	<0.0001
Butterfly richness (BR)	Month(M)	1	337	70.964	<0.0001
	Areas (A)	2	337	77.399	<0.0001
	M*A	2	337	9.027	<0.0001

(B) Fisher's least square differences among the three areas representing urban (U), suburban (SU.U), and rural (R) regions with the target factors being abundance and richness of plant and butterfly.

Area comparison	PA	PR	BA	BR
U vs SU.U	−117.600	−14.025	−172.584	−22.634
U vs RU	−44.183	−8.250	−39.625	−12.789
RU vs SU.U	−73.417	−5.775	−132.958	−9.845

i^{th} butterfly species in the plant and P_i is the proportion of the i^{th} plant species). A two tailed t-test (Zar 1999) was applied for each species to assess whether the values of the indices differ significantly from the mean value observed in the samples for all the areas concerned. A difference from the expected mean value will enable judging the rank of the butterfly as being specialist or generalist in nature with respect to the association of the plant species. The statistical analyses (Legendre & Legendre 1998) were performed using the SPSS ver.10 (Kinnear & Gray 2000) and XLSTAT software (Addinsoft 2010).

2. RESULTS

The species composition with the relative proportion of butterflies and plants recorded through the study periods in each area was measured (presented in Table S2 and Table S3). Of 54 food plant species belonging to 29 families, 21 species were shrubs and 31 spices were herbs. Although tree was exempted from the study, only two species of tree were recorded because of those short heights. Relative abundance (mean ± SE) of butterflies (A) and plants (B) was highest in suburban area followed by rural and urban areas (presented in Table S4). Including the occurrence of the species in each site as a parameter for comparison, the rank abundance curves of diversity of butterflies (A) and diversity of plants (B) were presented in Figure 1. The rank abundance curve indicated greater diversity of butterflies and plants in site 3 and site 4 (suburban areas) in comparison to site 5 and site 6 (rural areas) and site 1 and site 2 (urban areas). The value of diversity index (Shannon H' Log Base 10) of butterflies (C) and plants (D) in 12 months irrespective of sites was presented through box-plot (Fig. 1). The values of diversity index of butterflies and plants were changed in a rhythm. The values of butterflies increased from March to May and from September to November, whereas they decreased from December to February and from June to August. It is to be noted that the abundance of butterflies was changed with the species richness of plants irrespective of study areas (Fig. 2A). The abundance of plants and abundance of butterflies irrespective of study areas was correlated (Fig. 2B). Beside abundance, the species richness of butterflies was also changed with the species richness of plants irrespective of areas (Fig. 2C), and as shown in Figure 2D, the mean number of individuals per species of butterflies was found to be a power function with the mean number of individuals per species of the plants, irrespective of the study areas. An extension of this general relationship is shown in the regression equations in Figure 3, where the butterfly species richness and the abundance are being portrayed as a function of the species richness and the abundance of the plants separately for the urban, suburban, and rural areas of Kolkata. In comparison to the urban areas, the regression equations (Fig. 3) exhibited higher values of coefficient of determination (R^2) for the suburban and rural areas. The results of mixed model GLM and post hoc multiple comparisons explained the variations in the plant and butterfly abundance and richness as a function of the areas

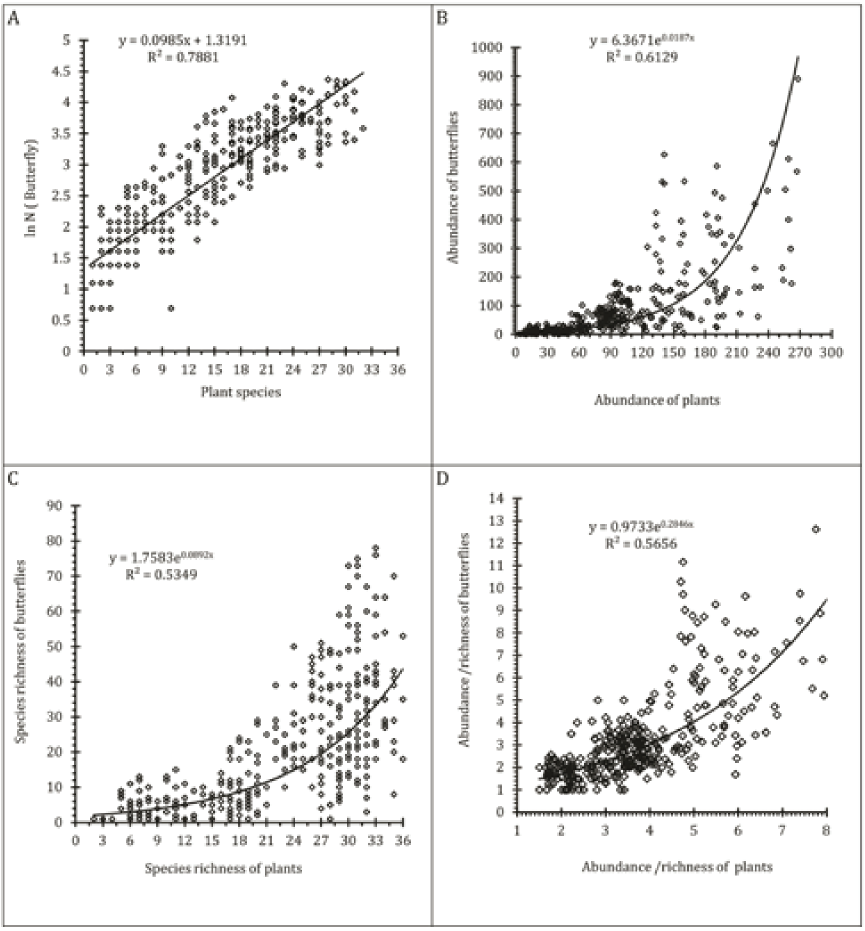

Figure 2. *The relation between abundance of butterflies (ln transformed) against the species richness of plants (A), abundance of plants in each transect as an explanatory variable for the observed abundance of butterflies (B), plant and butterfly species richness encountered in each transect (C), and the plant and butterfly in terms of the individuals per species (ln transformed) (D) during the study period irrespective of the habitat concerned (n= 360 transects).*

and months (Table 1). In all instances, the areas, months, and interactions remained significant contributor for the observed variations in the butterfly and plant richness and abundance. The urban, suburban, and rural areas were significantly different in terms of the plant and the butterfly species richness and abundance (Table 1). When considered in terms of the relative load of butterfly for each species of plant encountered in the three areas, differences were prominent both within and between the plant assemblages of the areas concerned. *Lantana camara* in the urban area; *Ageratum conyzoides, L. camara*, and *Ziziphus mauritiana* in suburban area; and *L. camara*, *Glycosmis pentaphylla,* and *A. conyzoides* in rural area exhibited high load for the butterflies; however, the plants did not show highest level of abundance in the respective areas. In terms of relative abundance, the plant *Ixora coccinea* was the highest for urban area, *Cassia sophera* for suburban area, and *Alternanthera sessilis* for rural area (Fig. 4). When considered for the range of plant species used by the butterflies, *Junonia atlites* was the highest for urban area, *Delias eucharis* for suburban area, and *Pareronia valeria* for the rural area. The highest level of relative abundance was exhibited by *Catopsilia pomona* in urban area, *Catopsilia pyranthe* in suburban area, and *Papilio polytes* in rural area (Fig. 5). For both plants and butterflies, a vast number of species exhibited local-scale dominance in one of the three areas, urban, suburban, and rural areas, and were absent in the other areas. Similarly, few species of butterflies such as *Graphium agamemnon, Papilio demoleus, Eurema hecabe, Danaus chrysippus,* and *Junonia almana* showed comparable presence in all the three areas, providing impression about the generalist nature in distribution within the geographical region concerned.

3. DISCUSSION

During the present course of study, 54 species of plants were recorded as food plants of butterflies. Among these plant species, 21 species were shrubs and 31 spices were herbs, indicating that butterflies visited more frequently to herbs rather than to shrubs. Similar observations were recorded earlier from different geographical area (Ouin & Burel 2002; Kamimura 2004; Tiple et al. 2006; Kitahara et al. 2008). The diversity of butterflies and plants, however, varied with the time scale (months)

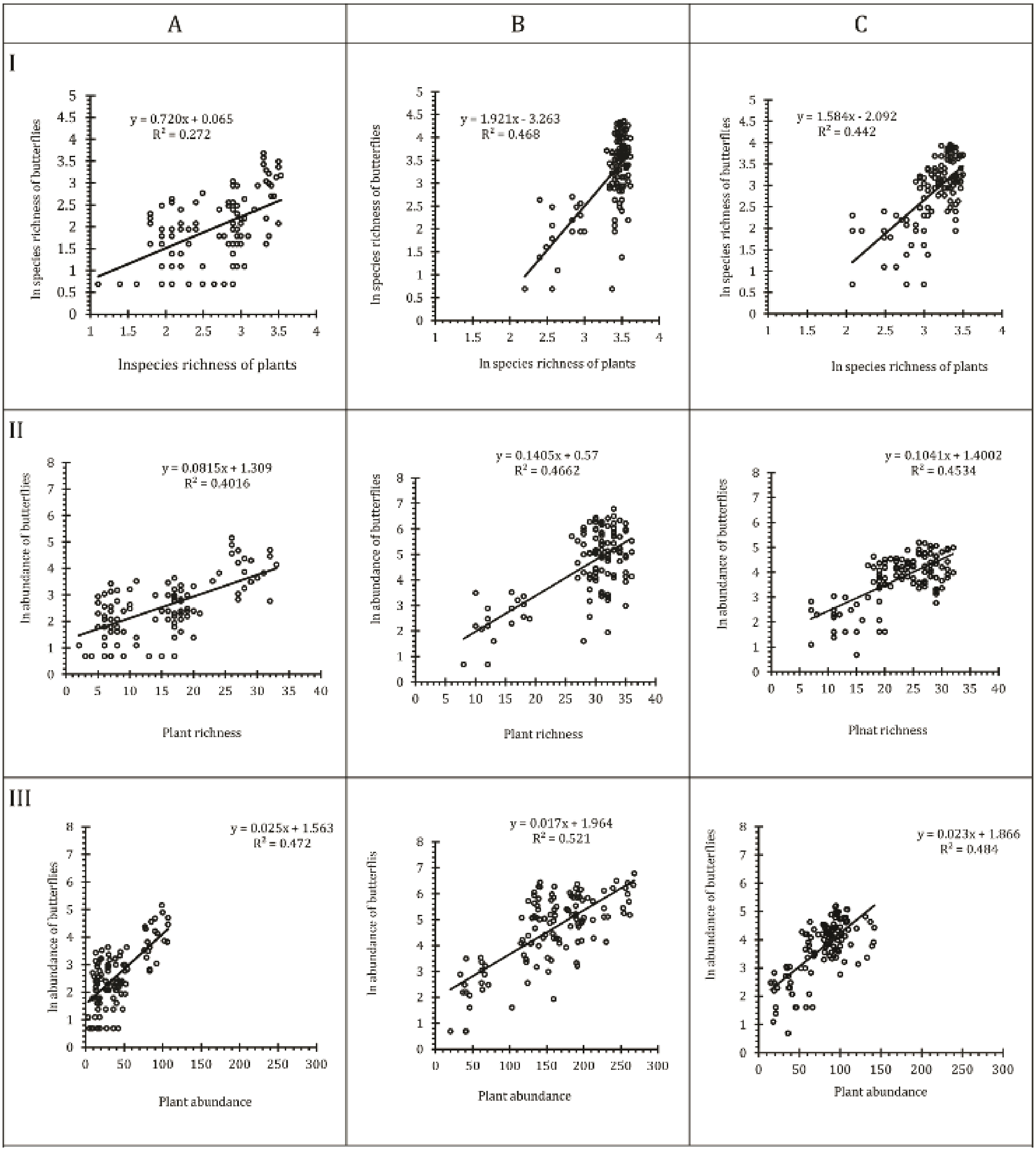

Figure 3. *Correlation between butterflies and plants in urban (A), suburban (B), and rural areas (C) of Kolkata. Species richness (ln transformed) of butterflies varied against the species richness of plants (ln transformed) (I), abundance of butterflies (ln transformed) varied with the species richness of plants (II), and abundance of butterflies (ln transformed) varied with the abundance of plants (III). In each graph, data of all the sites were taken for each of the areas concerned (n = 5 × 12 × 2 =120 samples)*

as well as with the urban–rural gradient (Fig. 1 C,D and Tables 1, S5, and S6) in a similar way as observed earlier from the same geographical area (Mukherjee et al. 2015a, 2016) and other parts of the world such as Palo Alto, California, USA (Blair & Launer 1997), Mt. Fuji, central Japan (Kitahara and Sei 2001), Ontario, Canada (Hogsden & Hutchinson 2004), and Île-de-France, France (Bergerot et al. 2011).

The results of this study show that, of the three areas studied, the suburban area had the greatest food plant diversity and supported a greater diversity and abundance of butterflies. The present result indicates that the abundance and richness of butterflies was changed with the abundance and richness of plants species irrespective of study areas (Fig. 2A-2D). The similar association between diversity of plants and diversity of

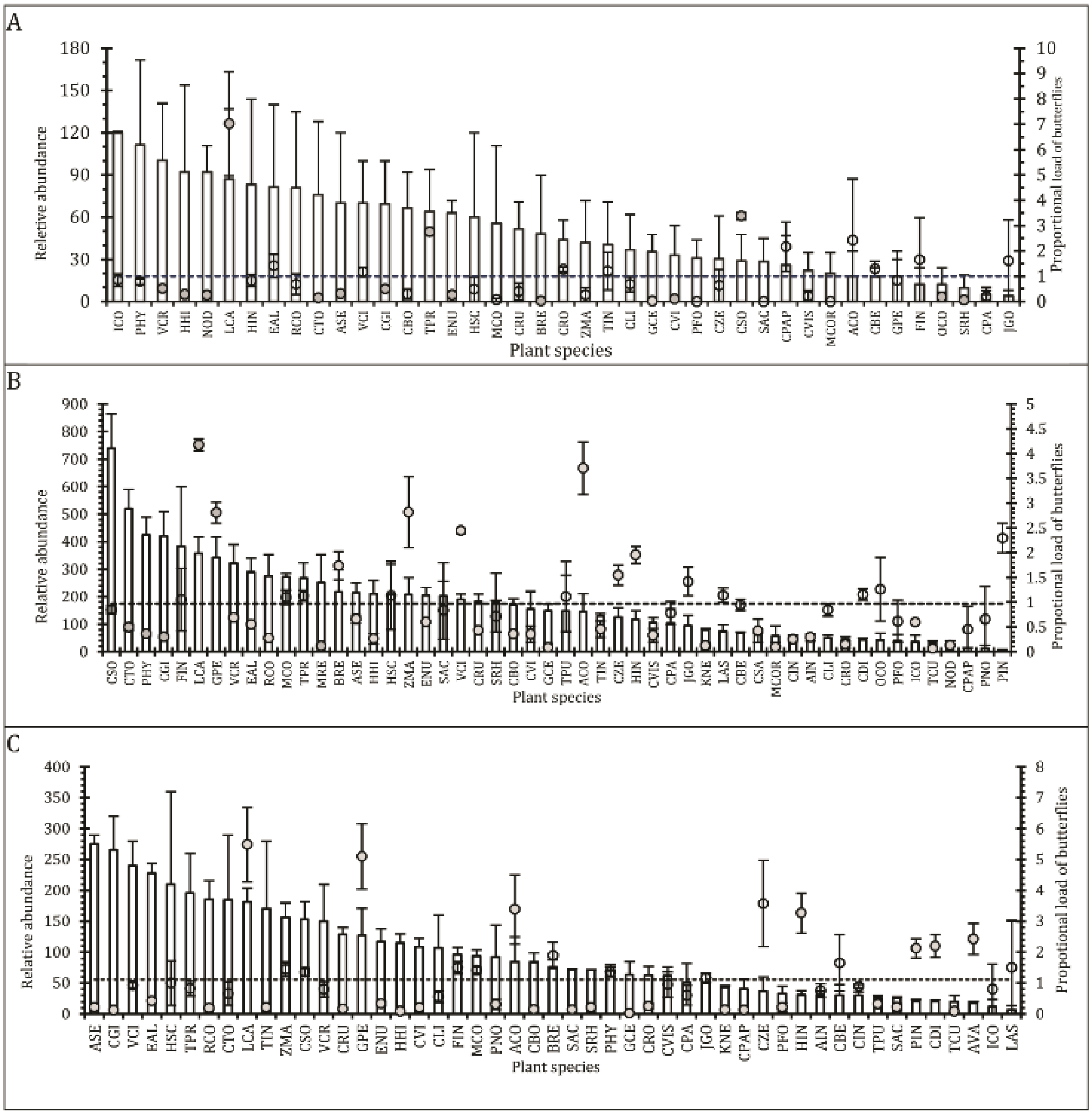

Figure 4. *The relative abundance of (mean ± SE, filled columns) the plant species (three-letter codes of plant species were described in Appendix) along with the proportional load of butterfly species (mean ± SE, filled circles) of the respective plant species in urban (A), suburban (B), and rural areas (C) of Kolkata. For the plant species, area-specific differences can be observed for the abundances and load as well as the mean load (dashed lines) in the three graphs. In the urban, suburban, and rural areas, the number of plant species encountered was 37, 52, and 49, respectively, from a sample size of n = 120 (5 transects × 12 months × 2 sites = 120) from each area. The shaded circles represent significant deviation from a mean value, as observed through two-tailed t-test with df 23 in each area.*

butterflies was found in the earlier findings in different countries such as Britain (Quinn et al. 1998), Mount Fuji, central Japan (Kitahara et al. 2008), Tuscany, central Italy (Maccherini et al. 2009), Nairobi, Kenya (Humpden & Nathan 2010), Tokyo, central Japan (Soga & Koike 2012), Denmark (Ferrer-Paris et al. 2013), as well as similar areas in India such as Maharashtra (Nimbalkar et al. 2011), Tripura (Majumder et al. 2012), and Gujarat (Patel & Pandya 2014). Empirical studies also supported this suburban peak in plant biodiversity (McKinney 2002, 2008; Von der Lippe & Kowarik 2008). When compared between the richness of the butterflies and the plants, a positive correlation was observed in all the sampling sites—urban, rural, and suburban areas (Figure 2A). At the proximate level, both the abundance and richness components of butterfly and plant diversity exhibited correspondence of high degree, although the values remained more consistent for the suburban area in comparison to either rural or urban areas. A power regression equation is a best fit to explain the richness of the butterflies as a function of the abundance of the plants in the sampling sites. Possibly, the diversity of the plants in the urban and rural areas is comparatively lower than that in suburban area, which is reflected through the fit of the regression equations in the three sites. In

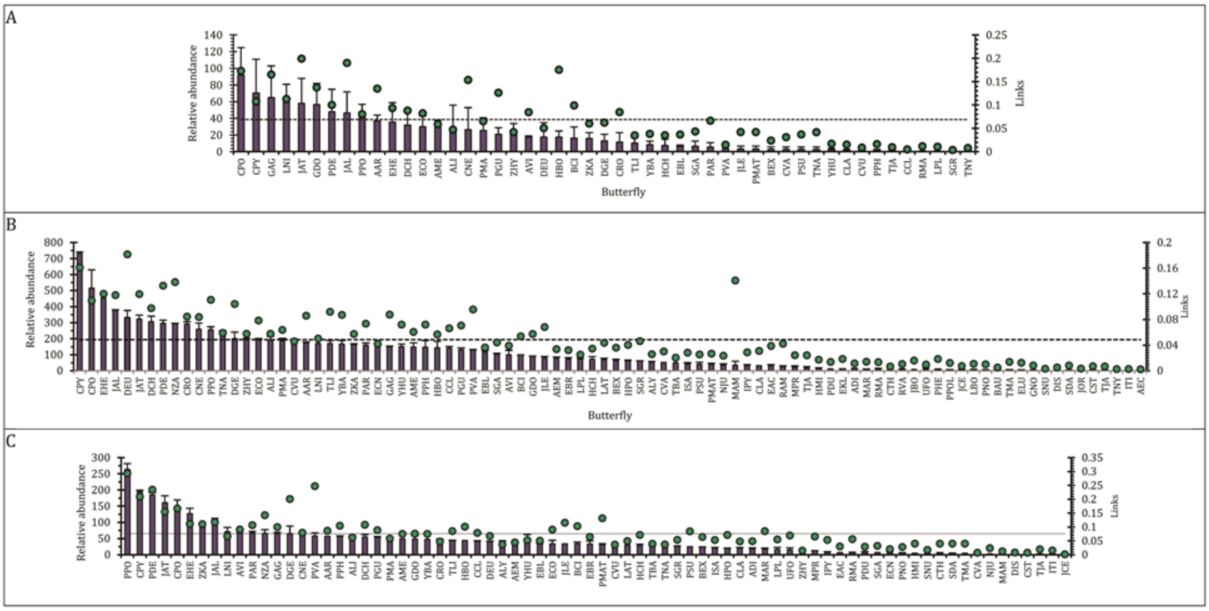

Figure 5. *The relative abundance (mean ± SE, filled columns) of the butterfly species (three-letter code of butterfly species were described in Appendix) along with the proportional links to the plant species (mean ± SE, filled circles) of the respective butterfly species in species in urban (A), suburban (B), and rural areas (C) of Kolkata. For the butterflies, area-specific differences can be observed for the abundances and link as well as the mean link (dashed lines) in the three graphs.*

rural areas, the agricultural landscapes dominate, which may cause low richness of the plant species (Luoto et al. 2003; José-María et al. 2010; Bassa et al. 2012), whereas in urban areas, the low plant richness may be attributed to shortage of suitable space. This assumption is collated with the findings on the diversity of the butterflies in agricultural (Loos et al. 2014) and urban landscapes in Japan (Kitahara & Sei 2001) and Mexico (Ramírez-Restrepo & Halffter 2013). The richness and abundance of the butterflies did not show any consistent reflection of positive correlations when urban areas of different geographical locations are considered (Kocher & Williams 2000; Kitahara & Sei 2001; Ramírez-Restrepo & Halffter 2013, 2017). In Mexico (Ramírez-Restrepo & Halffter, 2013), the correlation was observed to be negative in few instances and positive in other instances such as in Japan (Yamamoto et al. 2007). However, in both cases, the vegetation remained a crucial factor for the association of the butterflies in the urban context (Rundlöf et al. 2008; Jonason et al. 2011; Pe'er et al. 2011; Soga et al. 2015; Tam & Bonebrake 2016).

At the individual species level, the contribution to the abundance remained different for both the butterfly and plant groups. Keeping apart the unique species in the respective areas, the common species in the urban, suburban, and rural areas exhibited disparity in the numerical abundance (Fig. 4). Similarly, the relative load of the butterfly species in the plants or the number of plants used by the butterfly, remained unequal for the three different areas (Fig. 5). Assuming the load of butterfly in a plant to be an indicator of the relative importance of the plant in conservation, it was apparent that the value differed with the sampling area concerned. Thus, even though the plants remained common in the three areas surveyed, their relative importance varied with reference to the load of butterfly. In the recent study, such disparity in the relative importance of the plants in the conservation of the butterflies has been observed in Central Florida (Josephitis 2014), Central Mexico (Barranco-León et al. 2016), and Canada (Leston & Koper, 2017), based on the urbanization gradient. Although adult butterflies exploit a wider variety of flowering plants (Courtney 1986; Shreeve 1992) than their larval stage (Hardy et al. 2007), butterflies visit flowering plants according to their preference (Tudor et al. 2004; Hardy et al. 2007; Tiple et al. 2009), and, therefore, the dependency of butterflies on different plants is varied. A decline in the occurrence of their preferred food resource may decrease their foraging and reproductive success by increasing the cost of searching for food (Benadi 2015) and ovipositor site. Beside this, in urban green space where grasses or small herbs are removed regularly, the herb- or grass-dependent small butterflies are absent (Konvicka & Kadlec 2011). Empirical studies show that, beside overall vegetation, herbaceous diversity is greatly affected in urban areas during the construction of concrete structures or use of herbicide or urban beautification (Kristoffersen et al. 2008; Huang et al. 2013; Cameron et al. 2015). To increase the value of urban green space for conservation of both arboreal and grassland species, it is necessary to improve the habitat and vegetation management. The present study is a pioneer effort to conserve butterflies by providing their preferred food plants and decreasing their dispersal cost and interspecific competition. However, the conservation efforts of butterfly require the availability of the plant species in abundance in the conservation sites (Schultz & Dlugosch 1999; Tudor et al. 2004). Increased richness of plant species will enable sustenance of both the specialist and the generalist butterflies in terms of their choice of the plant species that will serve for urban greening and help human to keep in touch with nature. Irrespective of the land use pattern and the human habitats, the conservation effort would succeed with the presence of a broad range of species and abundant forms to ensure the inclusion of large numbers of butterfly species. Further studies are necessary to confirm the hypothesis extending to the specific land use pattern in the urban as well as rural areas.

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Supplementary File Table S1, Table S2, Table S3, Table S4, Table S5, Table S6

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SUPPLEMENTARY MATERIAL

Table S1 *Characteristic feature of the sites surveyed during the study period. The site features are based on the classification of images of each site. The values are in percentage as obtained from satellite imagery. Owing to the presence of broad streets and roads, the percentage of open space was highest in urban area*

Area	Site	Vegetation	Open Land	Waterbody	Settlement	Agricultural Land
Urban	1	1.6	2.3	1.2	2.5	0
	2	1.4	2.6	0.45	2.8	0
Suburban	3	1.5	0	1.2	2.1	2.8
	4	4.5	0.5	0.3	1.3	1.1
Rural	5	2.2	0	0.43	0.62	4.5
	6	3.3	0	0.49	0.75	3.2

Table S2.*The list of butterfly species encountered in Kolkata, India, in 2014, with the relative proportion found in each sample in each area. The proportion of the each butterfly species in the samples as a function of total number of species of the three areas was used to calculate the occurrence of butterflies and plants in urban, suburban, and rural areas.*

No	Scientific name	Code	Urban	Suburban	Rural
	Family: Papilionidae				
1	*Graphium doson* (Felder & Felder, 1864)	GDO	0.052	0.008	0.013
2	*Graphium agamemnon* (Linnaeus, 1758)	GAG	0.054	0.013	0.018
3	*Papilio polytes* Linnaeus, 1758	PPO	0.041	0.023	0.074
4	*Papilio demoleus* Linnaeus, 1758	PDE	0.041	0.026	0.052
5	*Chilasa clytia* (Linnaeus, 1758)	CCL	0.001	0.013	0.012
6	*Papilio polymnestor* Cramer, [1775]	PPOL	0	0.001	0
7	*Pachliopta aristolochiae* (Fabricius, 1775)	PAR	0.003	0.014	0.019
8	*Pachliopta hector* (Linnaeus, 1758)	PHE	0	0.001	0
9	*Graphium nomius* (Esper, 1798)	GNO	0	0.001	0
	Family: Pieridae				
10	*Eurema brigitta* (Stoll, 1780)	EBR	0	0.006	0.009
11	*Eurema blanda* (Boisduval, 1836)	EBL	0.009	0.01	0.01
12	*Eurema hecabe* (Linnaeus, 1758)	EHE	0.028	0.04	0.037
13	*Catopsilia pomona* (Fabricius, 1775)	CPO	0.089	0.047	0.041
14	*Catopsilia pyranthe* (Linnaeus, 1758)	CPY	0.059	0.066	0.055
15	*Ixias pyrene* (Linnaeus, 1764)	IPY	0	0.003	0.002
16	*Pareronia valeria* (Cramer, [1776])	PVA	0.002	0.012	0.016
17	*Appias libythea* (Fabricius, 1775)	ALI	0.017	0.018	0.015
18	*Cepora nerissa* (Fabricius, 1775)	CNE	0.016	0.024	0.017
19	*Delias eucharis* (Drury, 1773)	DEU	0.01	0.029	0.012
20	*Leptosia nina* (Fabricius, 1793)	LNI	0.064	0.015	0.019
21	*Belenois aurota* (Fabricius, 1793)	BAU	0	0.0004	0
	Family: Nymphalidae				
22	*Tirumala limniace* (Cramer, 1775)	TLI	0.009	0.015	0.012
23	*Danaus genutia* Cramer, 1779	DGE	0.011	0.019	0.018

Table S2 continued. *The list of butterfly species encountered in Kolkata, India, in 2014, with the relative proportion found in each sample in each area. The proportion of the each butterfly species in the samples as a function of total number of species of the three areas was used to calculate the occurrence of butterflies and plants in urban, suburban, and rural areas.*

No	Scientific name	Code	Urban	Suburban	Rural
	Family: Nymphalidae				
24	*Danaus chrysippus* (Linnaeus,1758)	DCH	0.031	0.028	0.015
25	*Euploea klugii* (Moore & Horsfield, 1857)	EKL	0	0.001	0
26	*Euploea core* (Cramer, 1780)	ECO	0.028	0.018	0.009
27	*Melanitis leda* (Linnaeus, 1758)	MLE	0.073	0.048	0.033
28	*Lethe europa* (Fabricius, 1775)	LEU	0	0.001	0.004
29	*Elymnias hypermnestra* (Linnaeus, 1763)	EHY	0.006	0.014	0.027
30	*Mycalesis perseus* (Fabricius, 1775)	MPE	0.029	0.017	0.014
31	*Mycalesis mineus* (Linnaeus, 1858)	MMI	0	0.018	0.007
32	*Ypthima asterope* (Klug, 1832)	YAS	0.0003	0	0
33	*Ypthima baldus* (Fabricius, 1775)	YBA	0.007	0.015	0.013
34	*Ypthima huebneri* (Kirby, 1871)	YHU	0.004	0.014	0.01
35	*Acraea violae* (Fabricius, 1775)	AVI	0.02	0.009	0.02
	Family: Nymphalidae				
36	*Phalanta phalantha* (Drury, 1773)	PPH	0.001	0.014	0.016
37	*Moduza procris* (Cramer, 1777)	MPR	0	0.002	0.004
38	*Neptis jumbah* (Moore, 1857)	NJU	0	0.003	0.001
39	*Euthalia aconthea* (Cramer, 1779)	EAC	0	0.003	0.002
40	*Euthalia lubentina* (Cramer, 1779)	ELU	0	0.0004	0
41	*Ariadne ariadne* (Linnaeus, 1763)	AAR	0.039	0.016	0.016
42	*Ariadne merione* (Cramer, 1779)	AME	0.03	0.013	0.014
43	*Junonia almana* (Linnaeus, 1758)	JAL	0.039	0.034	0.025
44	*Junonia atlites* (Linnaeus, 1763)	JAT	0.051	0.03	0.045
45	*Junonia lemonias* (Linnaeus, 1758)	JLE	0.003	0.008	0.01
46	*Junonia orithya* (Linnaeus, 1764)	JOR	0	0.0002	0
47	*Hypolimnas bolina* (Linnaeus, 1758)	HBO	0.016	0.014	0.012
48	*Hypolimnas misippus* (Linnaeus, 1764)	HMI	0	0.002	0.001
	Family: Lycaenidae				
49	*Spalgis nubilus* Moore, 1883	SNU	0	0.0003	0.001
50	*Curetis thetis* (Drury, 1773)	CTH	0	0.001	0.001
51	*Mahathala ameria* (Hewitson, 1862)	MAM	0	0.003	0.001
52	*Iraota timoleon* (Stoll, 1790)	ITI	0	0.0002	0.001
53	*Loxura atymnus* (Cramer, 1780)	LAT	0	0.006	0.008
54	*Rathinda amor* (Fabricius, 1775)	RAM	0	0.002	0
55	*Virachola isocrates* (Fabricius, 1793)	VIS	0	0.0004	0.001
56	*Rapala manea* (Hewitson, 1863)	RMA	0.001	0.001	0.002
57	*Rapala varuna* (Horsfield, 1829)	RVA	0	0.001	0
58	*Spindasis vulcanus* (Fabricius, 1775)	SVU	0.001	0.017	0.009
59	*Anthene emolus* (Godart, 1824)	AEM	0	0.007	0.011
60	*Anthene lycaenina* (Felder, 1868)	ALY	0	0.005	0.011
61	*Castalius rosimon* (Fabricius, 1775)	CRO	0.007	0.026	0.013

Table S2 continued. *The list of butterfly species encountered in Kolkata, India, in 2014, with the relative proportion found in each sample in each area. The proportion of the each butterfly species in the samples as a function of total number of species of the three areas was used to calculate the occurrence of butterflies and plants in urban, suburban, and rural areas.*

No	Scientific name	Code	Urban	Suburban	Rural
62	*Talicada nyseus* (Guérin-Ménéville, 1843)	TNY	0.0003	0.0001	0
63	*Tarucus nara* Kollar, 1848	TNA	0.002	0.021	0.007
64	*Tarucus plinius* (Fabricius, 1793)	TPL	0.0003	0.006	0.004
65	*Prosotas nora* (Felder, 1860)	PNO	0	0.001	0.002
66	*Prosotas dubiosa* (Semper, 1879)	PDU	0	0.001	0.002
67	*Jamides bochus* (Stoll, 1782)	JBO	0	0.001	0
68	*Jamides celeno* (Cramer, 1775)	JCE	0	0.001	0
69	*Catochrysops strabo* (Fabricius, 1793)	CST	0	0.0002	0.001
70	*Lampides boeticus* (Linnaeus, 1767)	LBO	0	0.001	0
71	*Zizula hylax* (Fabricius, 1775)	ZHY	0.016	0.017	0.004
72	*Pseudozizeeria maha* (Kollar, 1844)	PSE	0.022	0.017	0.014
73	*Zizeeria karsandra* (Moore, 1865)	ZKA	0.015	0.015	0.026
	Family: Lycaenidae				
74	*Neopithecops zalmora* (Butler, 1870)	NZA	0	0.026	0.019
75	*Euchrysops cnejus* (Fabricius, 1798)	ECN	0	0.014	0.002
76	*Chilades lajus* (Stoll, 1780)	CLA	0.003	0.003	0.006
77	*Catochrysops vapanda* (Semper, 1890)	CVA	0.002	0.005	0.001
78	*Abisara echerius* (Moore, 1901)	AEC	0	0.00004	0
	Family: Hesperiidae				
79	*Badamia exclamationis* (Fabricius, 1775)	BEX	0.002	0.006	0.007
80	*Hasora chromus* (Cramer, 1780)	HCH	0.005	0.006	0.008
81	*Spialia galba* (Fabricius, 1793)	SGA	0.004	0.009	0.002
82	*Tagiades japetus* (Stoll, 1782)	TJA	0	0.0002	0
83	*Sarangesa dasahara* (Moore, 1865)	SDA	0	0.0002	0.001
84	*Taractrocera maevius* (Fabricius, 1793)	TMA	0	0.0004	0.001
85	*Oriens goloides* (Moore, 1881)	OGO	0.001	0.002	0.001
86	*Telicota ancilla bambusae* (Moore, 1878)	TAN	0	0.004	0.008
87	*Parnara guttatus* (Bremer & Gray, 1853)	PGU	0.02	0.012	0.015
88	*Borbo cinnara* (Wallace, 1866)	BCI	0.012	0.009	0.009
89	*Pelopidas mathias* (Fabricius,1798)	PMA	0.002	0.004	0.009
90	*Pelopidas subochracea* (Moore, 1878)	PSU	0.002	0.004	0.007
91	*Halpe porus* (Mabille, 1876)	HPO	0	0.006	0.006
92	*Suastus gremius* (Fabricius, 1798)	SGR	0.0003	0.005	0.007
93	*Iambrix salsala* (Moore, 1865)	ISA	0	0.004	0.006
94	*Matapa aria* (Moore, 1865)	MAR	0	0.001	0.005
95	*Ampittia dioscorides* (Fabricius, 1793)	ADI	0	0.001	0.005
96	*Udaspes folus* (Cramer, 1775)	UFO	0	0.002	0.004
93	*Iambrix salsala* (Moore, 1865)	ISA	0	0.004	0.006
94	*Matapa aria* (Moore, 1865)	MAR	0	0.001	0.005
95	*Ampittia dioscorides* (Fabricius, 1793)	ADI	0	0.001	0.005
96	*Udaspes folus* (Cramer, 1775)	UFO	0	0.002	0.004

Table S3. *List of plants with their relative proportion observed during the study period irrespective of study sites. Type : S = Shrub, H = Herb, T =Tree. The proportion of the each plant species in the samples as a function of total number of species of the three areas was used to calculate the occurrence of butterflies and plants in urban, suburban and rural areas*

No.	Scientific name	Code	Type	Urban	Suburban	Rural
	Family Acanthaceae					
1	*Adhatoda vasica* Nees	AVA	S	0	0.001	0.004
2	*Hygrophila schulli* (Buch.-Ham.) M.R. Almeida & S.M. Almeida	HSC	H	0.018	0.025	0.045
3	*Hemigraphis hirta* (Vahl) T. Anders.	HHI	H	0.038	0.024	0.024
	Family Amaranthaceae					
4	*Alternanthera sessilis* (L.) R.Br. ex DC.	ASE	H	0.028	0.023	0.057
5	*Gomphrena celosioides* Mart.	GCE	H	0.019	0.016	0.013
	Family Apocynaceae					
6	*Catharanthus roseus* (L.) G. Don	CRO	S	0.024	0.005	0.013
7	*Nerium odorum* Aiton	NOD	S	0.054	0.003	0.007
	Family Asclepiadaceae					
8	*Calotropis gigantea* (L.) W. T. Aiton	CGI	S	0.041	0.045	0.055
	Family Asteraceae					
9	*Pluchea indica* (L.) Less.	PIN	S	0.002	0	0.004
10	*Ageratum conyzoides* L.	ACO	H	0.005	0.015	0.017
11	*Eclipta alba* (L.) Hassk.	EAL	H	0.036	0.031	0.047
12	*Mikania cordata* (Burm.f.)Roxb.	MCO	H	0.017	0.03	0.019
13	*Spilanthes acmella* (L.) Murray	SAC	H	0.013	0.008	0.005
14	*Tridax procumbens* L.	TPR	H	0.032	0.029	0.042
15	*Vernonia cinerea* (L.) Less	VCI	H	0.036	0.021	0.05
16	*Parthenium hysterophorus L*	PHY	H	0.058	0.046	0.015
	Family Boraginaceae					
17	*Heliotropium indicum* L.	HIN	H	0.033	0.013	0.006
	Family Caesalpiniaceae					
18	*Cassia sophera* (L.)Roxb.	CSO	S	0.013	0.08	0.032
19	*Cassia tora* L.	CTO	S	0.032	0.057	0.037
	Family Capparaceae					
20	*Capparis zeylanica* L.	CZE	S	0.009	0.013	0.007
	Family Caricaceae					
21	*Carica papaya L*	CPAP	T	0.01	0.001	0.009
	Family Cleomaceae					
22	*Cleome rutidosperma* DC	CRU	H	0.027	0.02	0.027
23	*Cleome viscosa* L.	CVI	H	0.014	0.016	0.022
	Family Commelinaceae					
24	*Commelina benghalensis* L.	CBE	H	0.01	0.007	0.006
25	*Commelina salicifolia* Roxb.	CCL	H	0	0.007	0
	Family Convolvulaceae					
26	*Evolvulus nummularius* (L.) L.	ENU	H	0.039	0.022	0.025
	Family Cucurbitaceae					
27	*Trichosanthes cucumerina* L.	TCU	H	0.001	0.004	0.004
	Family Cyperaceae					

Table S3 continued. *List of plants with their relative proportion observed during the study period irrespective of study sites. Type : S = Shrub, H = Herb, T =Tree. The proportion of the each plant species in the samples as a function of total number of species of the three areas was used to calculate the occurrence of butterflies and plants in urban, suburban and rural areas*

No.	Scientific name	Code	Type	Urban	Suburban	Rural
28	*Kyllinga nemoralis* (J.R. Forst. & G. Forst.) Dandy ex Hutch. & Dalziel	KNE	H	0.003	0.009	0.009
	Family Euphorbiaceae					
29	*Jatropha gossypifolia* L.	JGO	S	0.001	0.01	0.01
30	*Ricinus communis* L.	RCO	S	0.034	0.029	0.039
31	*Mallotus repandus* (Rottler) Müll.Arg.	MRE	S	0	0.03	0.002
32	*Croton bonplandianum* Baill	CBO	H	0.035	0.019	0.017
33	*Tragia involucrata* L.	TIN	H	0.016	0.015	0.034
	Family Fabaceae					
34	*Crotalaria pallida* Ait.	CPA	H	0.001	0.011	0.011
35	*Tephrosia purpurea* Pers.	TPU	H	0	0.014	0.006
	Family Flacourtiaceae					
36	*Flacourtia indica* (Burm. f.) Merr.	FIN	S	0.004	0.046	0.02
	Family Lamiaceae					
37	*Leucas aspera* (Willd.) Link	LAS	H	0	0.008	0.001
	Family Linderniaceae					
38	*Vandellia crustacea.* (L.) Benth.	VCR	H	0.052	0.035	0.031
	Family Malvaceae					
39	*Abutilon indicum* G.Don	AIN	S	0.002	0.006	0.006
40	*Sida acuta* Burm. f.	SAC	S	0.001	0.02	0.015
41	*Sida rhombifolia* L.	SRH	S	0.003	0.018	0.015
	Family Nyctaginaceae					
42	*Boerhaavia repens* L. var. diffusa Hook. f.	BRE	H	0.02	0.023	0.016
	Family Oxalidaceae					
43	*Oxalis corniculata* L.	OCO	H	0.004	0.004	0
	Family Passifloraceae					
44	*Passiflora foetida* L	PFO	H	0.016	0.004	0.007
	Family Rhamnaceae					
45	*Ziziphus mauritiana* var. *fruticosa* (Haines) Seb. and Balak	ZMA	S	0.017	0.022	0.033
	Family Rubiaceae					
46	*Ixora coccinea* L	ICO	S	0.112	0.004	0.002
	Family Rutaceae					
47	*Citrus limon* (L.) Burm. f.	CLI	T	0.015	0.005	0.023
48	*Glycosmis pentaphylla* (Retz.) Correa	GPE	S	0.005	0.037	0.026
	Family Solanaceae					
49	*Cestrum diurnum* L.	CDI	S	0	0.005	0.004
	Family Sterculiaceae					
50	*Melochia corchorifolia* L.	MCOR	H	0.008	0.006	0.001
	Family Verbenaceae					
51	*Clerodendrum viscosum* vent	CVIS	S	0.01	0.012	0.013
52	*Lantana camara* L.	LCA	S	0.034	0.039	0.038
53	*Clerodendrum indicum* (Linn.) O. Kuntze	CLI	S	0	0.006	0.006
54	*Phyla nodiflora* (L.) Greeene	PNO	H	0	0.001	0.019

Table S4. *Relative abundance (mean ± SE) of butterflies (A) and plants (B) recorded during the study period.*

A.

Month	Urban	Suburban	Rural
Jan	0.18 ± 0.05	0.72 ± 0.25	0.61 ± 0.25
Feb	0.19 ± 0.08	1.82 ± 0.49	1.43 ± 0.43
Mar	0.9 ± 0.33	12.63 ± 3.14	5.43 ± 1.31
Apr	2.89 ± 0.69	25.88 ± 5.18	7.35 ± 1.49
May	2.9 ± 0.66	30.14 ± 5.91	7.6 ± 1.44
Jun	1.42 ± 0.40	12.31 ± 2.16	3.75 ± 0.81
Jul	1.19 ± 0.42	11.73 ± 0.42	3.95 ± 0.86
Aug	2.35 ± 0.51	17.10 ± 2.34	5.81 ±0 .86
Sep	3.44 ± 0.63	34.11 ± 4.15	10.56 ± 1.35
Oct	5.083 ± 0.87	49.86 ± 6.48	13.18 ± 1.60
Nov	2.38 ± 0.54	35.34 ± 4.77	12.31 ± 1.83
Dec	0.54 ± 0.22	4.35 ± 1.16	2.46 ± 0.11

B.

Month	**Urban**	**Suburban**	**Rural**
Jan	3.22 ± 0.65	9.31± 2.24	6.00 ± 1.31
Feb	3.41 ± 0.66	8.57 ± 2.01	5.35 ± 1.09
Mar	6.67 ± 0.99	30.89 ± 4.16	15.69 ± 2.10
Apr	6.72 ± 0.97	30.26 ± 4.15	15.3 ± 2.10
May	6.81 ± 1.06	31.17 ± 4.24	15.82 ± 2.18
Jun	7.11 ± 1.06	32.73 ± 4.28	16.46 ± 2.21
Jul	7.00 ± 1.06	33 ± 4.42	16.96 ± 2.21
Aug	7.44 ± 1.04	33.19 ± 40	17.09 ± 2.19
Sep	8.15 ± 1.16	34.24 ± 4.69	17.67 ± 2.26
Oct	8.13 ± 1.17	34.72 ± 4.65	17.72 ± 2.23
Nov	8.28 ±1.15	34.87 ± 4.51	17.81 ±2.19
Dec	6.93 ± 0.99	28.28 ± 4.15	16.19 ± 2.03

Table S5 *To observe the variation with respect to area and month, data on butterfly abundance were subjected to three-way factorial analysis of variance (ANOVA) (Legendre & Legendre, 1998; Zar, 1999) using SPSS ver 10 (Kinnear & Gray, 2000) considering sampling area, month, and butterfly family as variables. This was followed by post hoc Tukey to observe disparity between and among butterfly family and areas.*
The results of three-way factorial ANOVA on the abundance of butterflies considering sampling area (A), month (M), and family (F) as explanatory variables (A). The results of post hoc Tukey test between the family (B) and area (C). Values formatted in bold are significant at P < 0.05.
The results of the three-way factorial ANOVA showed significant differences for area, months, and the family of butterfly as explanatory variables. The significant interactions among the months, sites, and the families reflected the variability in the abundance pattern of the butterflies in the seasons and the sampled areas. The post hoc Tukey test revealed significant differences among the areas and the families of butterfly.

Source	Sum of Squares	df	Mean Square	F	Partial η^2
Family (F)	694,599.63	4	173,649.91	**402.63**	0.90
Month (M)	1,516,721.90	11	137,883.81	**319.70**	0.95
Area (A)	1,928,330.44	2	964,165.22	**2,235.53**	0.96
F * M	452,583.84	44	10,286.00	**23.85**	0.85
F * A	602,074.34	8	75,259.29	**174.50**	0.89
M * A	1184,065.56	22	53,821.16	**124.79**	0.94
F * M * A	447,500.99	88	5,085.24	**11.79**	0.85
Error	77,632.50	180	431.29		
Total	9,790,243.00	360			

B] df = 180, 4; SE = 3.46

(I) Family	(J) Family	(I – J)
Papilionidae	Pieridae	**−60.31**
Papilionidae	Nymphalidae	**−102.15**
Papilionidae	Lycaenidae	**−23.1**
Papilionidae	Hesperiidae	**21.15**
Pieridae	Nymphalidae	**−41.85**
Pieridae	Lycaenidae	**37.21**
Pieridae	Hesperiidae	**81.46**
Nymphalidae	Lycaenidae	**79.06**
Nymphalidae	Hesperiidae	**123.31**
Lycaenidae	Hesperiidae	**44.25**

C] df =180, 2; SE= 2.68

(I) Area	(J) Area	(I – J)
Urban	Suburban	**−171.58**
Urban	Rural	**−40.81**
Sub urban	Rural	**130.77**

Table S6. *The results of three-way factorial ANOVA on the abundance of plants considering sampling area (A), month (M), and plant types (PT) (herb/shrub/tree) as explanatory variables (A). The results of post hoc Tukey test between the plant types (B) and area (C). Values formatted in bold are significant at P < 0.05. The variation of plant species abundance was subjected to three-way factorial analysis of variance (ANOVA) considering sampling area, month, and plant types as variables and post hoc Tukey test was made to observe disparity between and among plant type and areas.*
The results of the three-way factorial ANOVA showed significant differences for area, months, and the type (herbs/shrubs/tree) as explanatory variables. The post hoc Tukey test revealed significant differences among the type of plants and areas.

A

Source	Sum of Squares	df	Mean Square	F	Partial η^2
Plant Types (PT)	2,433,552.84	2	1,216,776.42	**350.57**	0.87
Month (M)	416,280.94	11	37,843.72	**10.90**	0.53
Area (A)	1,411,462.26	2	705,731.13	**203.33**	0.79
PT * M	284,383.16	22	12,926.51	**3.72**	0.43
PT * A	756,672.88	4	189,168.22	**54.50**	0.67
M * A	163,413.07	22	7,427.87	**2.14**	0.30
PT * M * A	108,168.12	44	2,458.37	0.71	0.22
Error	374,849.50	108	3,470.83		
Total	10,794,693.00	216			

B] df =108, 2; SE= 9.81

(I) Type	(J) Type	(I-J)
Herb	Shrub	−171.54
Herb	Tree	−254.97
Shrub	Tree	−83.43

C] df =108, 2; SE= 9.81

(I) Area	(J) Area	(I-J)
Urban	Suburban	−196.00
Urban	Rural	−73.64
Sub urban	Rural	122.36