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RESEARCH

Assemblage and diversity analysis of butterfly species in relation to climatic conditions in some tropical habitats: optimization through artificial neural network model

Subha Shankar Mukherjee and Asif Hossain*

Department of Zoology, The University of Burdwan, Golapbag, Burdwan, West Bengal 713104, India

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***Corresponding author**
Asif Hossain
E-mail ahossain@zoo.buruniv.ac.in

Background: Biodiversity serves as the foundation for ecosystems and the functional roles of species that supply services to human well-being. The functional roles of species in a region can be assessed by estimating biological diversity. Due to their presence in both aquatic and terrestrial ecosystems, insects have been used as model organisms in several studies, and among insects, butterfly species are considered important model organisms for both ecology and conservation biology. Butterfly species are very sensitive to changes in climatic conditions and serve as important bioindicators for both habitat and climate. For this reason, estimation of butterfly diversity at the spatio-temporal scale is important. On a spatial scale, habitat heterogeneity is believed to be the important factor that plays an important role in maintaining butterfly species diversity, while the differences in diversity of butterfly species on a temporal scale can be linked with climatic conditions both at the regional and local scales.

Results: The present study aimed to determine the effects of habitat characteristics and climatic conditions on the diversity of butterfly species in Purulia, India. A total of 83 butterfly species were found during the present study. Out of 83 butterfly species, Nymphalidae dominate over other families (28 species; 33.73%). The highest species richness was observed in the Ajodhya Hill region (61 species), followed by Garh Panchakot (54 species) and Leprosy Mission (47 species). The relative abundance and butterfly species richness differed between sites with different habitat characteristics. Maximum temperature serves as the most sensitive variable for species richness and is negatively related.

Conclusions: From this study, it is evident that different habitats in Purulia can sustain a diverse variety of butterfly species, but significant conservation effort is required. So, considering Purulia as a model area, steps must be taken to maintain habitat heterogeneity and local climatic conditions for sustaining ecosystem services provided by butterfly species.

Keywords: butterfly, climatic conditions, habitat heterogeneity, maximum temperature

Introduction

The study of biodiversity takes into accounts both anthropocentric and intrinsic benefits connected with it. The biological elements' values are acknowledged in accordance with human perceptions of their significance, which are realized in terms of ecosystem services (Baumgärtner 2007; Daily 1997; Mukherjee et al. 2015). The foundation for maintaining ecosystems and the functional characteristics of the species that produce commodities and services necessary for human well-being is biological diversity. Estimating the potential functional roles of a species is made possible by assessing the species diversity in a given area. The benefits of biological diversity are examined from both an intrinsic and an anthropocentric perspective (Mukherjee et al. 2015). Due to their dominance in both terrestrial and aquatic environments and their ability to provide ecological services including pollination, pest control, nutrient decomposition, and species maintenance, insects have been the subject of several studies that have highlighted their diversity (Losey and Vaughan 2006).

Among different insects, butterfly species serve as important herbivores and pollinators (Kunte 2000; Tiple et al. 2006). In terrestrial ecosystems, butterfly species are considered good bioindicators of habitat and climate (Mukherjee et al. 2015; Parmesan 2003; Pe'er and Settele 2008; Watt and Boggs 2003). Therefore, butterfly species are treated as excellent model organisms for both ecology and conservation biology (Ehrlich and Hanski 2004; Parmesan et al. 1999; Watt and Boggs 2003). So, the conservation of butterfly species is necessary for various kinds of ecosystem services that are governed by this lepidopteran species (Mukherjee et al. 2015).

They were among the first taxa to show widespread phonological changes in response to climate, and it was discovered that these changes were congruent with those of other taxonomic groups (Comay et al. 2021; Parmesan et al. 1999). It was found that higher temperatures and earlier snowmelt in Greenland have an effect on butterfly flight season (Comay et al. 2021). Previous studies made by Ombugadu et al. (2024) demonstrating that variation in maximum temperature (Tmax) urban habitats in tropics may be the driving force behind the frugivorous butterfly species diversity and richness. Empirical studies also demonstrated that in urban landscape hotter microclimates are related with greater species richness for insect species (Adams et al. 2020; Uhler et al. 2021). But this trend is not followed by all insect taxa. In case of ant communities (Pelini et al. 2014) and phorid flies (McGlynn et al. 2019) richness has been found to be negatively related with increasing temperature. According to Comay et al. (2021) butterfly species occurrence was negatively related with temperature and this lepidopteran insect species also react to soil conditions (Oostermeijer and van Swaay 1998).

In case of spatial scale, variations in butterfly diversity can be explained by the landscape heterogeneity. In contrast, variations of butterfly diversity in temporal scales are due to changes in climatic conditions at both local and regional levels. Mukherjee et al. (2015) demonstrated that the areas with heterogeneous vegetation contain greater variety of butterfly species compared to the sites with homogenous vegetation. In was also demonstrated that differences in butterfly species richness reflect variations in host plant abundance and the landscape characteristics of the region (Mukherjee et al. 2015). In case of temporal scale it was observed that in response to rising temperatures in Europe, butterfly faunas changed more quickly than bird populations (Devictor et al. 2012). Additionally, it was also discovered that the abundance of butterflies in Iberia changed more quickly than that of birds (Herrando et al. 2016). An empirical study compared four taxonomic groups in Malaysia and discovered that butterflies were the most promising group as bioindicators (Syaripuddin et al. 2015). Previous studies have shown that the models that were trained to correlate weather and butterfly abundance in the 20th century were able to replicate patterns of variation in butterfly abundance all the way back to the 19th century (Roy et al. 2001).

Their short life cycles probably allow them to respond to changes in the environment quickly, but their varying degrees of reliance on certain host plants allow them to respond to local environmental conditions quite strongly (Comay et al. 2021). Significantly fewer studies have looked at the effects of local conditions, despite the fact that several studies have been made on biogeographical patterns in butterfly faunas on regional scales (Dapporto et al. 2017; Hawkins 2010; Stefanescu et al. 2004).

Local biodiversity assessment in terms of the lepidopteran fauna is well studied in almost throughout the globe and this tropical heterogenous habitat around Purulia is not explicit of that (Das 2018; Mukherjee et al. 2023; Samanta et al. 2017). The aim of the present study is to fill the knowledge gap by linking the relationship between habitat heterogeneity and local climatic conditions with butterfly diversity in tropical heterogeneous habitats taking Purulia as the study area.

Materials and Methods

Study area

We selected three study sites, namely Leprosy Mission (23.32939N, 86.33786E), Ajodhya Hill Region (23.17107N, 86.10458E), and Garh Panchakot Hill Region (23.61677N, 86.76673E), to conduct the present study over a one-year period between July 2020 and June 2021. We selected the study sites based on their habitat types and accessibility for observing butterfly species. Various herbs and shrubs, including *Lantana camara*, *Catharanthus roseus*, *Tridax procumbens*, and *Chromolaena odorata*, dominate the plains in the Leprosy Mission area. The Ajodhya Hill region, part of the Chhotanagpur Plateau, features deciduous forest and a flowing stream, while the Garh Panchakot Hill region boasts hilly terrain and dense forest.

Sampling techniques

Direct observation and documentation of the butterflies was done in the field using the “Pollard Walk” method (Pollard 1977; Pollard and Yates 1993), with the required modifications. Three 1,000-m transects were available for each location. Butterfly species were counted at a 5-m distance on either side of the transects. Under essential circumstances, they were captured using an insect net (Tiple 2012), identified with appropriate keys (Evans 1932; Kehimkar 2008; Wynter-Blyth 1957), and released with the least amount of disturbance possible in the same habitat.

Climatic variables

GeoTiff files for Tmax, minimum temperature (Tmin), and precipitation with 2.5-minute resolution were collected from the historical monthly weather database of WorldClim (2020–2021) (http://www.worldclim.org). The data were extracted using the “Point Sampling Tool” plugin of QGIS 3.28.

Diversity indices and statistical analysis

Different diversity indices, viz., the Shannon–Wiener index (Shannon 1948), Pielou's index (Pielou 1969), and Simpson's index (Simpson 1964), were computed. A one-way permutational multivariate analysis of variance (PERMANOVA) followed by a pairwise test was performed for the community composition of butterflies to check whether significant differences between sites were present or not in the presence-absence and species abundance data. Jaccard and Bray–Curtis indexes were applied to perform PERMANOVA for presence-absence and species abundance data, respectively. To perform this analysis we selected 83 butterfly species as variables and three study sites as groups. In case of presence-absence data, presence of a species was denoted as 1 and absence as 0. Principal coordinate analysis (PCoA) was also performed for the aforementioned dataset.

To check the most sensitive climatic variables that affect butterfly species richness an artificial neural network (ANN) model was constructed. For the construction of the ANN model, climatic variables were used as inputs, or covariates, while species richness was included as an output, or dependent variable. For the purpose of data smoothing, variables were scaled so that the highest value of each variable was considered 1. Using the aforementioned factors, a multi-layered perceptron neural network was constructed (Mukherjee et al. 2024). The identity function was used for output layer activation and the hyperbolic tangent function for hidden layer activation in the development of this model. Using the IBM SPSS Statistics 23 software (trial version; IBM Co., Armonk, NY, USA), this model was created. The following equation was used to create the ANN model:

$$Cv \times w = \sum_{n=0}^{i} Cv_n \times w_n$$

where; Cv denoted as the climatic variables ($Cv_n = Cv_0 \ldots, Cv_i$), w defined as synaptic weight for each Cv ($w_n = w_0 \ldots, w_i$)

$$sp\_richness = \phi(Cv \times w)$$

where; $sp\_richness$ = number of butterfly species, ϕ = coefficient of activation function.

During performance, the model randomly assigned 72.2% of the data for training purposes and 27.8% of the data for testing. A total of 26 runs were performed to find the best model. The accuracy of the ANN model was evaluated using the R^2 value of model's observed and predicted values. After the best model selection, scaled values transformed into real values.

A generalized log linear model (GLM) with a quasipoisson function and log link is used to check how the climatic variables affect the butterfly species richness. For GLM analysis climatic variables and species richness were used as independent and dependent variables respectively. All the analyses were performed using PAST 4.07 and R version 4.2.2.

Results

A total of 83 butterfly species belonging to six families, viz., Nymphalidae, Papilionidae, Pieridae, Hesperiidae, Lycaenidae, and Riodinidae, were recorded during the present study (Table 1). *Ypthima huebneri*, with a relative abundance of 6.90 ± 0.41, dominates the Leprosy Mission area (Table 1). Whereas the most abundant species, Ajodhya and Garh Panchakot, were *Eurema hecabe* (6.31 ± 0.42) and *Amblypodia anita* (9.49 ± 0.88), respectively (Table 1). The value of the Shannon–Wiener index was highest for Ajodhya (3.77 ± 0.09), followed by Garh Panchakot (3.72 ± 0.07) and Leprosy Mission (3.54 ± 0.04). In the case of Pielou's index for evenness, it was also highest for Ajodhya (0.99 ± 0.002). Pielou's index was also high for both Garh Panchakot (0.98 ± 0.002) and Leprosy Mission (0.93 ± 0.01). All three sites, viz., Leprosy Mission (0.031 ± 0.001), Ajodhya (0.025 ± 0.002), and Garh Panchakot (0.027 ± 0.002), were observed to have a low Simpson's dominance index. The high value of Shannon–Wiener index, Pielou's index for evenness and low value of Simpson's dominance index demonstrate that the all three study sites are quite even and having high species richness.

The results of PERMANOVA for community composition showed that both in the case of species abundance (permutation = 9,999, F = 14.83, p = 0.0001) and presence-absence data (permutation = 9,999, F = 20.75, p = 0.0001), significant differences between sites were present. The pairwise tests also revealed all three sites were significantly different from each other (Tables 2, 3). Results of PCoA revealed that the two sites, viz., Ajodhya and Leprosy Mission, were slightly overlapped for both species abundance and presence-absence data, whereas Garh Panchakot was separated from those two sites (Figs. 1 and 2). It was observed that in term of community composition all the three sites are different from each other.

Climatic variables, viz., precipitation, Tmax, and Tmin, were selected as covariates and butterfly species richness as a dependent variable for ANN model building. The ANN structure consists of one hidden layer and four hidden nodes (Fig. 3). The sum square errors are 2.068 and 0.385 for training and testing, respectively. The observed and predicted values of species richness show a linear R^2 value of 0.859. The ANN result demonstrated that Tmax serves as the most sensitive variable for species richness (Fig. 4).

Then the Tmax was subjected to GLM to check whether it is positively or negatively related to species richness, and the result demonstrated that the Tmax maintains a negative relationship with species richness ($p < 0.05$).

Table 1 Relative abundance of butterfly species in three sites in Purulia, India

Common name	Scientific name	Family	Leprosy Mission	Ajodhya	Garh Panchakot
Plain Tiger	*Danaus chrysippus* (Linnaeus 1758)	Nymphalidae	5.35 ± 0.62	4.88 ± 0.64	3.96 ± 0.76
Striped Tiger	*Danaus genutia* (Cramer 1779)	Nymphalidae	3.29 ± 0.49	2.77 ± 0.29	0
Blue Tiger	*Tirumala limniace* (Cramer 1775)	Nymphalidae	3.06 ± 0.65	2.08 ± 0.35	0
Lemon Pansy	*Junonia lemonias* (Linnaeus 1758)	Nymphalidae	4.70 ± 0.35	1.69 ± 0.38	0
Grey Pansy	*Junonia atlites* (Linnaeus 1763)	Nymphalidae	1.64 ± 0.28	2.61 ± 0.20	2.93 ± 0.27
Peacock Pansy	*Junonia almanac* (Linnaeus 1758)	Nymphalidae	3.78 ± 0.30	2.15 ± 0.37	2.85 ± 0.21
Blue Pansy	*Junonia orithya* (Linnaeus 1758)	Nymphalidae	0	0.75 ± 0.22	0
Chocolate Pansy	*Junonia iphita* (Cramer 1779)	Nymphalidae	3.11 ± 0.37	2.15 ± 0.23	2.96 ± 0.29
Palmfly	*Elymnias hypermnestra* (Linnaeus 1763)	Nymphalidae	0.98 ± 0.28	0.65 ± 0.15	0
Common Crow	*Euploea core* (Cramer 1780)	Nymphalidae	4.06 ± 0.38	3.69 ± 0.33	4.05 ± 0.38
Brown King Crow	*Euploea klugii* (Moore 1858)	Nymphalidae	0.24 ± 0.11	0	0
Common Four Ring	*Ypthima huebneri* (Kirby 1871)	Nymphalidae	6.90 ± 0.41	2.06 ± 0.23	0
Tawny Coaster	*Acraea terpsicore* (Fabricius 1793)	Nymphalidae	1.88 ± 0.24	0.81 ± 0.17	2.08 ± 0.22
Common Leopard	*Phalanta phalantha* (Drury 1773)	Nymphalidae	2.68 ± 0.33	0.91 ± 0.24	1.51 ± 0.35
Common Lascar	*Pantoporia hordonia* (Stoll 1790)	Nymphalidae	0	1.16 ± 0.29	0
Common Bushbrown	*Mycalesis perseus* (Fabricius 1775)	Nymphalidae	2.84 ± 0.58	1.67 ± 0.34	1.44 ± 0.25
Common Evening brown	*Melanitis leda* (Linnaeus 1758)	Nymphalidae	1.42 ± 0.45	2.43 ± 0.28	2.09 ± 0.35
Angled Castor	*Ariadne ariadne* (Linnaeus 1763)	Nymphalidae	0.65 ± 0.15	0	0.83 ± 0.22
Great Eggfly	*Hypolimnas bolina* (Linnaeus 1758)	Nymphalidae	4.41 ± 0.52	3.94 ± 0.46	3.31 ± 0.31
Common Sailer	*Neptis hylas* (Linnaeus 1758)	Nymphalidae	2.36 ± 0.24	3.60 ± 0.90	1.97 ± 0.30
Bamboo Treebrown	*Lethe europa* (Fabricius 1775)	Nymphalidae	0	0	0.98 ± 0.23
Double Branded Crow	*Euploea sylvester* (Fabricius 1793)	Nymphalidae	0	0	0.56 ± 0.19
Plain Tawny Rajah	*Charaxes psaphon* (Westwood 1847)	Nymphalidae	0	1.05 ± 0.20	0.77 ± 0.17
Variable Tawny Rajah	*Charaxes bernardus* (C. & R. Felder 1867)	Nymphalidae	0	0	0.18 ± 0.07
Indian Nawab	*Charaxes bharata* (C. & R. Felder 1867)	Nymphalidae	0	1.25 ± 0.25	0.84 ± 0.26
Commander	*Moduza procris* (Cramer 1777)	Nymphalidae	0	1.43 ± 0.30	0.73 ± 0.20
Baronet	*Symphaedra nais* (Forster 1771)	Nymphalidae	0	0.29 ± 0.10	2.95 ± 0.37
Chestnut Streaked Sailer	*Neptis jumbah* (Moore 1858)	Nymphalidae	0	0	0.30 ± 0.09
Common Emigrant	*Catopsilia pomona* (Fabricius 1775)	Pieridae	4.83 ± 0.43	4.40 ± 0.78	3.21 ± 0.30
Mottled Emigrant	*Catopsilia pyranthe* (Linnaeus 1758)	Pieridae	2.88 ± 0.25	2.95 ± 0.55	2.86 ± 0.65
Pioneer	*Belenois aurota* (Fabricius 1793)	Pieridae	0.70 ± 0.20	0	0
Common Gull	*Cepora nerissa* (Fabricius 1775)	Pieridae	1.49 ± 0.38	2.89 ± 0.26	2.55 ± 0.27
Common Grass Yellow	*Eurema hecabe* (Linnaeus 1758)	Pieridae	2.89 ± 0.34	6.31 ± 0.42	2.26 ± 0.20
Indian Wanderer	*Pareronia hippia* (Fabricius 1787)	Pieridae	1.23 ± 0.23	1.00 ± 0.24	0
Psyche	*Leptosia nina* (Fabricius 1793)	Pieridae	2.43 ± 0.30	1.73 ± 0.20	1.64 ± 0.26
Yellow Orange Tip	*Ixias pyrene* (Linnaeus 1764)	Pieridae	0	0	4.30 ± 0.27
White Orange Tip	*Ixias marianne* (Cramer 1779)	Pieridae	0	0	2.68 ± 0.30
One Spot Grass Yellow	*Eurema andersonii* (Moore 1886)	Pieridae	0	3.60 ± 0.61	0
Three Spot Grass Yellow	*Eurema blanda* (Boisduval 1836)	Pieridae	0	0	0.14 ± 0.07
Small Grass Yellow	*Eurema brigitta* (Stoll 1780)	Pieridae	0.17 ± 0.09	0.22 ± 0.07	0
Common Jezebel	*Delias eucharis* (Drury 1773)	Pieridae	0	1.82 ± 0.36	2.55 ± 0.26
Common Mormon	*Papilio polytes* (Linnaeus 1758)	Papilionidae	2.77 ± 0.29	3.17 ± 0.27	2.41 ± 0.22
Lime Butterfly	*Papilio demoleus* (Linnaeus 1758)	Papilionidae	3.12 ± 0.20	2.28 ± 0.23	1.08 ± 0.16
Common Jay	*Graphium doson* (C. & R. Felder 1864)	Papilionidae	0.59 ± 0.14	1.75 ± 0.24	0
Tailed Jay	*Graphium agamemnon* (Linnaeus 1758)	Papilionidae	0.90 ± 0.29	0	0
Common Rose	*Pachliopta aristolochiae* (Fabricius 1775)	Papilionidae	1.63 ± 0.24	0	0
Blue Mormon	*Papilio polymnestor* (Cramer 1775)	Papilionidae	0	0.65 ± 0.15	0.96 ± 0.20
Common Mime	*Papilio clytia* (Linnaeus 1758)	Papilionidae	0	1.02 ± 0.15	0
Five Bar Sowrdtail	*Graphium antiphates* (Cramer 1775)	Papilionidae	0	0.27 ± 0.10	0
Plains Cupid	*Chilades pandava* (Horsfield 1829)	Lycaenidae	1.73 ± 0.30	1.06 ± 0.11	0.83 ± 0.25
Indian Cupid	*Everes lacturnus* (Godart 1824)	Lycaenidae	0.37 ± 0.14	0.64 ± 0.18	0
Lesser Grass Blue	*Zizina otis* (Fabricius 1787)	Lycaenidae	2.84 ± 0.37	1.98 ± 0.14	1.87 ± 0.12
Pale Grass Blue	*Pseudozizeeria maha* (Kollar 1844)	Lycaenidae	1.83 ± 0.37	1.48 ± 0.24	1.60 ± 0.23
Tiny Grass Blue	*Zizula hylax* (Fabricius 1775)	Lycaenidae	0.73 ± 0.25	0.57 ± 0.14	0.80 ± 0.18
Common Hedge Blue	*Acytolepis puspa* (Horsfield 1828)	Lycaenidae	0.29 ± 0.10	0	0
Lime Blue	*Chilades lajus* (Stoll 1780)	Lycaenidae	2.16 ± 0.27	1.26 ± 0.16	1.52 ± 0.28
Gram Blue	*Euchrysops cnejus* (Fabricius 1798)	Lycaenidae	0.37 ± 0.12	0.65 ± 0.19	0
Pea Blue	*Lampides boeticus* (Linnaeus 1767)	Lycaenidae	0	0.42 ± 0.11	0
Common Pierrot	*Castalius rosimon* (Fabricius 1775)	Lycaenidae	4.41 ± 0.66	3.73 ± 0.36	3.17 ± 0.35

Table 1 Continued

Common name	Scientific name	Family	Leprosy Mission	Ajodhya	Garh Panchakot
Striped Pierrot	*Tarucus nara* (Kollar 1848)	Lycaenidae	0.64 ± 0.14	0.58 ± 0.20	0
Common Cerulean	*Jamides celeno* (Cramer 1775)	Lycaenidae	0.88 ± 0.16	1.13 ± 0.19	2.34 ± 0.24
Common Ciliate Blue	*Anthene emolus* (Godart 1824)	Lycaenidae	0.49 ± 0.19	1.58 ± 0.18	1.66 ± 0.21
Purple Leaf Blue	*Amblypodia anita* (Hewitson 1862)	Lycaenidae	0	1.33 ± 0.24	9.48 ± 0.88
Common Silverline	*Spindasis vulcanus* (Fabricius 1775)	Lycaenidae	0	0	0.94 ± 0.16
Monkey Puzzle	*Rathinda amor* (Fabricius 1775)	Lycaenidae	0	0	0.38 ± 0.13
Yamfly	*Loxura atymnus* (Stoll 1780)	Lycaenidae	0	0.97 ± 0.22	0
Common line Blue	*Prosotas nora* (C. Felder 1860)	Lycaenidae	0	0	1.67 ± 0.21
Tailless Line Blue	*Prosotas dubiosa* (Semper 1879)	Lycaenidae	0	0	1.76 ± 0.18
Angled Sunbeam	*Curetis acuta* (Moore 1877)	Lycaenidae	0	0	1.22 ± 0.23
Fluffy Tit	*Zeltus amasa* (Hewitson 1865)	Lycaenidae	0	0.31 ± 0.11	0
Malayan	*Megisba malaya* (Horsfield 1828)	Lycaenidae	0	0.044 ± 0.042	0
Continental Swift	*Parnara ganga* (Evans1937)	Hesperiidae	0.8 ± 0.30	0	1.10 ± 0.26
Ceylon Swift	*Parnara bada* (Moore 1878)	Hesperiidae	0.76 ± 0.24	0.57 ± 0.17	0.91 ± 0.20
Small-Branded Swift	*Pelopidas mathias* (Fabricius 1798)	Hesperiidae	0.80 ± 0.30	0.39 ± 0.14	0.98 ± 0.21
Obscure Branded Swift	*Pelopidas agna* (Moore 1866)	Hesperiidae	0.11 ± 0.07	0.54 ± 0.26	0.53 ± 0.15
Rice swift	*Borbo cinara* (Wallace 1866)	Hesperiidae	0.50 ± 0.29	0.86 ± 0.14	0.14 ± 0.09
Common Red Eye	*Matapa aria* (Moore 1866)	Hesperiidae	0.09 ± 0.06	0.42 ± 0.16	0
Palm Bob	*Suastus gremius* (Fabricius 1798)	Hesperiidae	0.82 ± 0.26	0.48 ± 0.15	0.64 ± 0.19
Smaller Dartlet	*Oriens goloides* (Moore 1881)	Hesperiidae	0	0.18 ± 0.09	0
Golden Angle	*Caprona ransonnettii* (Felder 1868)	Hesperiidae	0	0.48 ± 0.14	0
Common Grass Dart	*Taractrocera maevius* (Fabricius 1793)	Hesperiidae	0.039 ± 0.037	0	0
Paintbrush Swift	*Baoris ferri* (Moore 1878)	Hesperiidae	0	0	1.79 ± 0.31
Double Banded Judy	*Abisara bifasciata* (Moore 1877)	Riodinidae	0	0	0.42 ± 0.15

Values are presented as mean ± standard error.

Table 2 Results of pairwise test of one-way PERMANOVA for species abundance data

Sites	F-value	*p*-value
Leprosy Mission (Ajodhya)	8.142	0.0001
Leprosy Mission (Garh Panchakot)	21.01	0.0001
Garh Panchakot (Ajodhya)	15.83	0.0001

PERMANOVA: permutational multivariate analysis of variance.

Table 3 Results of pairwise test of one-way PERMANOVA for species presence-absence data

Sites	F-value	*p*-value
Leprosy Mission (Ajodhya)	12	0.0001
Leprosy Mission (Garh Panchakot)	31.64	0.0001
Garh Panchakot (Ajodhya)	20.34	0.0001

PERMANOVA: permutational multivariate analysis of variance.

Discussion

Empirical studies demonstrated that butterflies are very sensitive to environmental conditions and are considered indicators of ecosystem health (Mukherjee and Mondal 2020), and that is one of the main reasons for observing the diversity of butterfly species on a spatio-temporal scale (Stefanescu et al. 2004). The estimation of butterfly diversity provides valuable information about species abundance and richness variations that were shaped by the landscape's vegetation (Harrington and Stork 1995; Öckinger et al. 2009; Öckinger and Smith 2006) and species interactions (Mukherjee et al. 2015). In the case of the spatial scale, habitat heterogeneity is the major factor that governs differences in butterfly diversity, while variations in the temporal scale can be linked with climatic conditions both at the regional and local scales. The present study deals with the assumption that differences in butterfly diversity occur at three sites due to habitat heterogeneity and changes in climatic conditions. The Leprosy Mission area is mainly dominated by various herb and shrub species: *L. camara*, *C. roseus*, *T. procumbens*, and *C. odorata*. By contrast, Ajodhya and Garh Panchakot are characterized by diverse vegetation patterns with a greater diversity of butterfly species than the Leprosy Mission. Out of 83 butterfly species, the Ajodhya Hill region contains 61, followed by Garh Panchakot (54 species) and Leprosy Mission (47 species). The variations in three sites in terms of butterfly diversity provide an idea about the abundance of host plants and the characteristics of habitat. Empirical studies demonstrated that, due to habitat heterogeneity, the diversity of butterfly species increases in agricultural landscapes rather than suburban and urban regions. The present study also demonstrated that Ajodhya and Garh Panchakot, which are characterized by diverse vegetation, contain greater butterfly diversity than the Leprosy Mission. In the case of temporal scale, machine learning demonstrated that Tmax was the most sensitive factor for butterfly species richness, and the

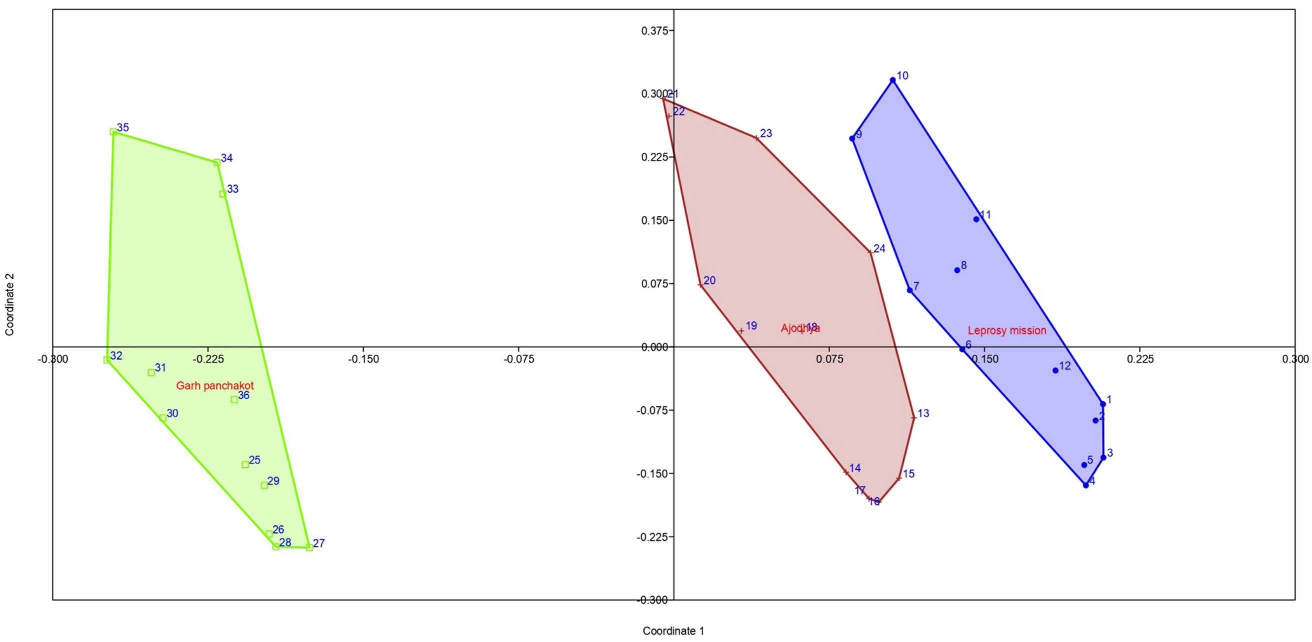

Fig. 1 Principal coordinate analysis of three sites for species abundance data by using Bray–Curtis index.

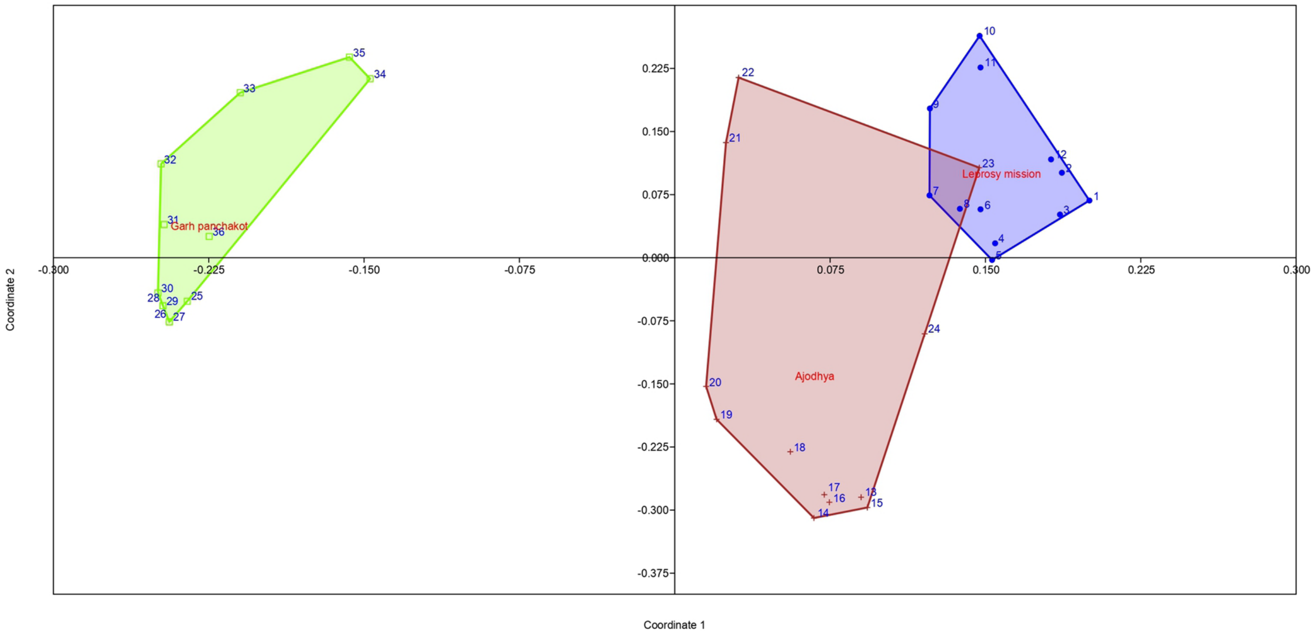

Fig. 2 Principal coordinate analysis of three sites for species presence-absence data by using Jaccard index.

results of GLM described that Tmax was negatively related to species richness.

The decline in species richness observed with Tmax contradicts the global trend of increasing butterfly species richness at lower latitudes (Hawkins 2010). However, a closer look at global and European patterns shows that butterfly species richness is higher in mountainous regions (Hawkins 2010). It was also observed that in southern Europe species richness is greater in mountainous regions (cooler areas) (Comay et al. 2021). Comay et al. (2021) demonstrated that some species of butterflies will disappear due to global warming and a large number of butterfly species will become rarer in increasingly arid environment. Previous studies demonstrated that higher temperatures affect flight season (Høye et al. 2014) and immune function (Karl et al. 2011). Karl et al. (2011) suggested that global warming will not only decrease performance due to the direct impact of thermal stress but also through secondary impacts on adult immune function of butterfly species. Butterflies are regarded as significant indicators of biodiversity and essential ecosystem functions. However, to effectively use them as bioindicators, we need a clearer understanding of how their observed responses are connected to environmental factors. Additionally, understanding how

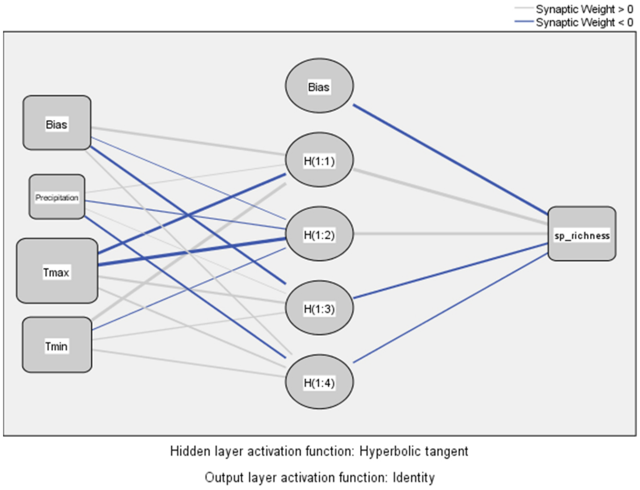

Fig. 3 Structure of artificial neural network containing one hidden layer and four hidden nodes. Tmax: maximum temperature; Tmin: minimum temperature.

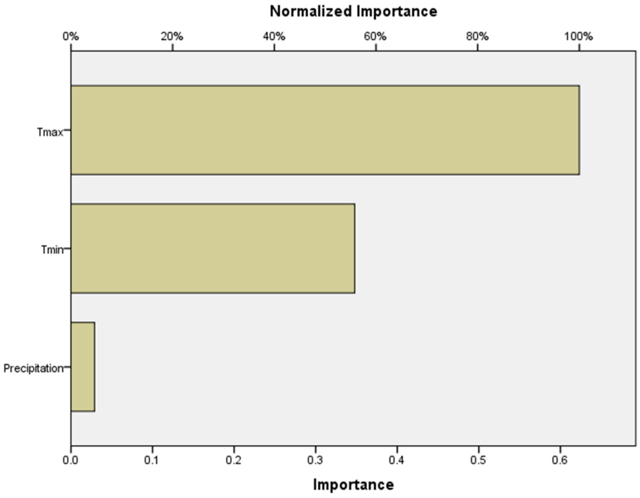

Fig. 4 Normalized importance of climatic variables demonstrating Tmax as most sensitive variable for species richness. Tmax: maximum temperature; Tmin: minimum temperature.

butterfly populations vary with climate and land cover can help estimate the potential impacts of different drivers, such as climate change, botanical succession, grazing, and afforestation. Identifying which butterfly species are sensitive to specific environmental drivers is particularly important (Comay et al. 2021).

The 83 butterfly species that were observed during the present survey belong to six families. Out of 83 butterfly species, Nymphalidae contains 28 species (33.73%), followed by Lycaenidae (22 species; 26.50%), Pieridae (13 species; 15.66%), Hesperiidae (11 species; 13.25%), Papilionidae (8 species; 9.63%), and Riodinidae (1 species; 1.20%). *Euploea klugii*, *Acytolepis puspa*, and *Taractrocera maevius* were only found in the Leprosy Mission area. *Junonia orithya*, *Pantoporia hordonia*, *Eurema andersonii*, *Papilio clytia*, *Graphium antiphates*, *Loxura atymnus*, *Zeltus amasa*, *Megisba malaya*, *Lampides boeticus*, and *Caprona ransonnettii* were observed only in the Ajodhya Hill region. Thirteen butterfly species, viz., *Lethe europa*, *Euploea sylvester*, *Charaxes bernardus*, *Ixias pyrene*, *Ixias marianne*, *Eurema blanda*, *Cigaritis vulcanus*, *Rathinda amor*, *Prosotas nora*, *Prosotas dubiosa*, *Curetis acuta*, *Baoris ferri*, and *Abisara bifasciata*, were observed only in Garh Panchakot.

The butterfly species *Cepora nerissa*, *L. boeticus*, and *Euchrysops cnejus* are placed under Schedule II Part II of the Indian Wildlife (protection) Act, 1972. The butterfly species *C. nerissa* was found in higher abundance in contrast to other butterfly species that were protected under the Indian Wildlife (protection) Act, 1972. The butterfly species *Everes lacturnus* (Mukherjee and Hossain 2022), *M. malaya* (Samanta et al. 2022), *E. sylvester* (Mukherjee and Hossain 2023), and *C. bernardus* (Mukherjee et al. 2022) were observed for the first time in Purulia, India.

The difference in butterfly diversity is not a useful predictor of the selection and prioritization of locations for butterfly conservation; the current findings are compatible with records and perceptions of butterfly species in various parts of the world (Koh and Sodhi 2004; Sodhi et al. 2010; Wilson et al. 2004). The dominance of the families Nymphalidae and Lycaenidae is similar to previous observations in different parts of the world. By observing butterfly diversity in Purulia, India, we can assume that butterfly species fulfill a variety of functional roles in different habitats. The difference in species composition at three different sites is due to different vegetation characteristics and changes in climatic conditions.

Observing butterfly diversity in Purulia suggests that the selection of conservation strategies is necessary for the sustenance of various ecosystem services that are governed by butterfly species. In the current context, the butterfly diversity in Purulia suggests it can sustain a variety of butterfly species, but conservation effort is necessary. The outcomes of the present study are anticipated to supplement important knowledge on conservation management and increase the ecological services that are governed by butterfly species in Purulia, India.

Conclusions

Eighty-three butterfly species were observed in three sites in Purulia with different relative abundances. Out of 83 butterfly species, Nymphalidae consists of 28 species, followed by Lycaenidae (22 species), Pieridae (13 species), Hesperiidae (11 species), Papilionidae (8 species), and Riodinidae (1 species). The maximum number of butterfly species (61 species) was observed in the Ajodhya Hill region. One of the limitation in our study is to reliance on one-year (2020–2021) data rather than summary of the several years. Habitat heterogeneity and changes in climatic conditions are considered the major factors for differences in butterfly diversity. Tmax emerged as the most sensitive factor for differences in species richness, and it was negatively related to species richness. One of the limitation in our study is to reliance on one-year (2020–2021) data rather than summary of the several years. Future research must be done with multiple years' data. The present study gives information about those different habitats in Purulia can sustain a wide variety of butterfly species, but proper conservation management is necessary.

Abbreviations

PERMANOVA: Permutational multivariate analysis of variance
PCoA: Principal coordinate analysis
ANN: Artificial neural network
GLM: Generalized log linear model
Tmax: Maximum temperature
Tmin: Minimum temperature

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Authors' contributions

SSM conceived the ideas, conducted the data collection and analysis, and wrote the original draft of the manuscript. AH conceived the ideas, checked the database, and reviewed the manuscript. All authors read and approved the final manuscript.

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Availability of data and materials

Datasets of the present study available from the corresponding author upon reasonable request.

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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