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Full Length Research Paper

Ecology and conservation needs of nymphalid butterflies in disturbed tropical forest of Eastern Himalayan biodiversity hotspot, Assam, India

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We examine the hypothesis, whether the diversity of Nymphalid butterflies in primary forest is related to vegetation structure and canopy openness and that this relationship differs between butterfly taxa in relation to phylogenetic differences in light and shade preferences. The study also examines whether the increasing diversity of butterflies in degraded tropical forest is associated with the loss of species with restricted geographical distribution. Present study has considered eight habitat parameters for habitat data collections and the t-test using equal variance, spearman rank correlation and multiple regressions were used for statistical analyses. Species diversity was analyzed using Margalef's D indices that indicate both the species richness and abundance. Bootstrap method was used to compare the diversity among samples. PCA was carried out to examine the relationship between vegetation structure and species diversity in primary and degraded forest. The relationship between vegetation factor scores and species diversity at each sampling station in primary and degraded forest was analyzed using stepwise multiple regression. Results indicates that the butterflies species sampled in closed canopy forest had more restricted geographical distribution than those being sampled in disturbed forest. The species with greater light preference had significantly wider geographical distribution, whereas, the species with greater shade preferences had significantly narrower geographical distributions. The stepwise analysis of multiple regressions between the diversity indices of shade groups of butterflies and vegetation density (PRIN1) of closed forest shows a significant positive relationship, but the relationship was negative when similar analysis was performed between species diversity indices of light preferred Nymphalid groups and vegetation density. Results indicate that the greater numbers of closed canopy forest butterflies are sensitive to changes in moisture availability and humidity. Thus, changes in canopy cover and light penetration, through microclimatic effects on adult and larval survival, does have an impact on butterfly distributions. While, the species richness and diversity are higher in forest gaps, the conservation value of close canopy forest lies more in the presence of species with restricted ranges. Owing to loss of heterogeneous vegetation in degraded forest, the dense canopy cover and transparent ground cover has been reduced and thus declination of forest butterflies species. Study has clearly indicated the strong and significant relationship between the species of narrow range of geographical distribution and species shade preference. The restricted ranges species are affected due to forest degradation. Thus, clearly bringing into light, that increasing diversity in degraded forest is associated with the loss of species with restricted geographical distribution. Out of seven gap preferred shade group of butterflies, two have wide geographical distribution and the other five have medium range distribution. Thus, there is a strong phylogenetic relationship between the genera of light preferred shade loving group of butterflies and the butterflies of light loving group and the genera of shade preferred light loving group of butterflies and the butterflies of shade loving group.

Key words: Ecology, closed canopy forests, conservation, degraded forests, endemic species, geographic distribution range, light and shade groups, nymphalid butterflies, phylogeny, tropical forests.

INTRODUCTION

The conservation of biological diversity in tropical forest ecosystem is under threat throughout Southeast Asia owing to various human related problems (Willott et al., 2000; Hill et al., 2001). The most widespread anthropogenic problems in tropical forest, viz., encroachment of forested land, illegal logging and shifting cultivation, caused forest disturbance, leading to open up canopy and forest fragmentations (Hill et al., 2001). These forest fragmentations and canopy openness of the forest habitat change the microclimatic condition of forest floor and impoverishes the soils, resulting in changes of butterfly community compositions and species structures. Again, the butterflies are very sensitive to modification of habitat, humidity and moisture conditions, and thus, most specialized and native butterflies have disappeared from artificially modified habitat of tropical forest (Hill et al., 2001). Moreover, the under-story of closed canopy tropical rainforest is characterized by the presence of highly specialized biota (Spitzer et al., 1997), and the ecology of such habitat with closed canopy is very constant in most features which form a 'core-space' of ecological stability within the formation of undisturbed rainforest (Whitmore, 1975; Jacobs, 1988; Brokow and Scheiner, 1998). Apart from that, the 'under-story' butterflies of tropical forest are highly habitat specific, steno-topic and relatively small geographical ranged species, often nearly endemic in particular bio-geographic forest environment (Leps and Spitzer, 1990; Spitzer et al., 1993).

In the recent habitat modification, the potential role of sunlight in determining plant species assemblages, structures and diversity have been given more importance for ecological studies (Denslow, 1987; Brokow and Busing, 2000). The Comparable studies on the relationships between habitat modification and insect species within undisturbed tropical forests have been made by Hamer et al. (2003). Hence, the examination of these relationships in primary forests will be an important prerequisite for understanding the process causing changes in distribution patterns and species composition of butterflies following anthropogenic disturbance (Kremen, 1992; Davis et al., 2001; Hamer et al., 2003). The present ecological study on the Nymphalid butterflies has emphasized the effects of anthropogenic problems on butterflies habitat, associated with various environmental factors such as light penetration into the forest floor and vegetation growth, canopy cover and canopy openness in different topographic situation within the Rani- Garbhanga Tropical Forest of Assam, as suggested by Huston (1994), Rosenzweig (1995) and Hill et al. (2001). One of the major environmental gradients in tropical forests ecosystem is the amount of sunlight below the canopy level, and this varies in relation to gap dynamics. Gaps are formed by tree falls, either naturally or artificially, and exist within the areas of regeneration and mature forest with dense canopy cover (Whitmore, 1992; Grieser-Johns, 1997).

The present study tests the hypothesis that, the diversity of butterflies in primary forest is related to vegetation structure and canopy openness, and that this relationship differs among butterfly taxa in relation to phylogenetic differences in light and shade preferences. It also tests the hypothesis that the increasing diversity of butterflies in degraded tropical forest is associated with the loss of species with restricted geographical distribution.

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MATERIALS AND METHODS

Study area

Study has been carried out in Rani-Garbhanga Tropical Forest (Coordinates: 25°45′00″-26°30′00″N longitudes and 91°0′00″ - 91°55′00″ E Longitudes; elevation, 40 - 744 m msl) with covering an area of 254.85 km^2 in Kamrup District, Assam India (Figure 1). It is chiefly located in the hilly terrain covering a small- extended plain in the down slopes of the hills. The hills are actually continuation in the form of spurs of Khasi Hill ranges of Eastern Himalayan biodiversity hotspot. In plains, the forests are located in alluvial terrain and these are cut up by numerous narrow, winding low-lying tracts. The study area has a unique geologic and physiographic make up and is composed of special habitat mosaic. The Meghalaya hill ranges are on the north, and the River Brahmaputra is on the west. The climate of study area is mesothermal humid, with heavy rainfall (300 - 450 cm) in addition to periodic wind, storm and thunders (Borthakur, 1986). On the basis of temperature, humidity and precipitation pattern, the climate of RGTF could be divided into four distinct season viz., Pre-monsoon, Monsoon, Re-treating monsoon and winter. The rainfall, fogs and temperature were found to change in relation to different seasons and in different physiographic areas within it. The Forest type of study areas are tropical wet evergreen, tropical semi-evergreen and tropical moist deciduous types with presence of occasional sub-tropical broad- leafed hill forest. With respect to the degree of gap dynamics and availability of sun light on the forest floor and under story, it could be distinguished in to two zones: Disturbed forest (DF) and relatively undisturbed closed canopy forest (CF).

Disturbed forest (DF)

Disturbed forests consist of logged forest of a variety of species, which might be seen along the vast extended parts of the forest habitat in RGTF. The overall configuration in canopy coverage of individual tree species in degraded forest could not satisfy the criteria of closed canopy forest that permits sufficient sunlight to enter into the forest floor. Yet again, on either side of the regular roads and trails of RGTF, very less tree densities have been found and thus the forest floors are occupied by diverse species of grasses, herbs and scrubs. These areas could be categorized as disturbed forest. The accessibility of various larval host plants exists in those areas and this in turn attracts the butterflies in disturbed forest habitat. This type of categorization of DF habitat in RGTF was primarily based on the anthropogenic forest disturbances and as well as natural tree fall gaps. Consequently, the comparison of butterfly diversity in disturbed forest and in closed canopy forest

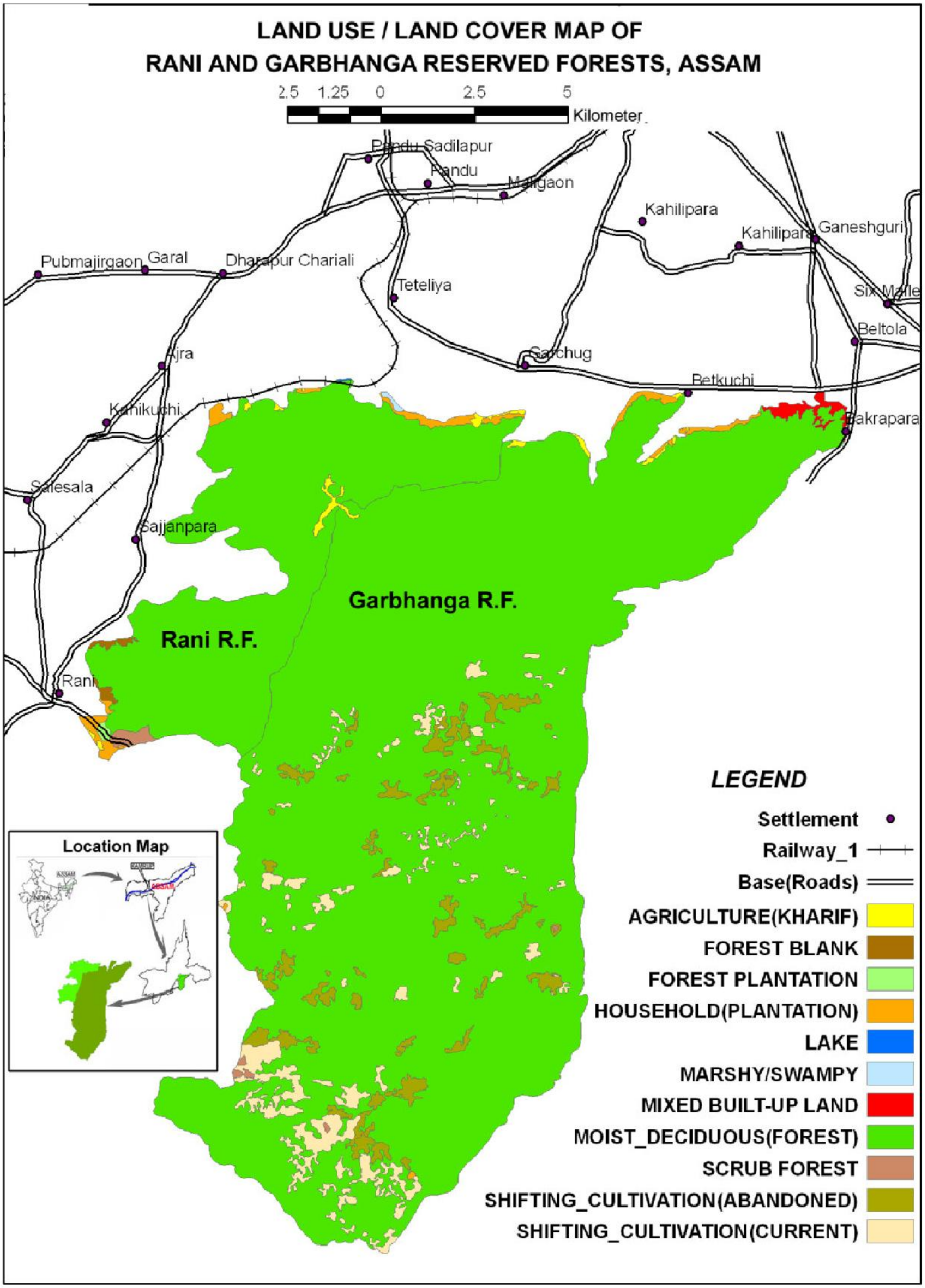


Figure 1. Land use and cover of Rani and Garbhanga Reserved Forests, Assam.

Table 1. Design of line and point transects established at RGTF with fixed width of 10 m for line transect and 30 m radius for point transect (total 34 points, both Rani and Garbhanga Tropical Forest after 200 m of interval).

Transact Number	Garbhanga Tropical Forest		Transact Numbers	Rani Tropical Forest	
	Length in degraded forest (m)	Length in closed forest (m)		Length in Degraded forest (m)	Length in Closed forest (m)
Line transact					
T_{1L}	2000	------	T_{5L}	1500	------
T_{2L}	-----	1800	T_{6L}	------	1200
T_{3L}	1000	-----	T_{7L}	600	------
T_{4L}	------	1000	T_{8L}	------	600
Point transact					
T_{1p}	1800 (9 points)	------	T_{4p}	600 (3 points)	
T_{2p}	------	1800 (9 points)	T_{5p}		1000 (5 points)
T_{3p}	1000 (5 points)	------	T_{6p}	600 (3 points)	--------

would be a good output of the anthropogenic forest disturbance in study site.

Undisturbed or closed canopy forest (CF)

The Closed canopy forest (CF) of RGTF has been characterized on the basis of the forest that has maintained an average of 75 - 85% canopy cover in the forest, where artificial or natural tree fall gaps are scarce. The habitat is distinguished by the existence of less dense under story, less herbs, shrubs and climbers. The area is very dense at canopy level and almost no canopy gap is persisted for sunlight to enter into the forest floor. The topsoil of the forest ground zone is characterized by high humus and leaf litter.

Methods of sampling

Transect design

Intensive regular samplings were carried out between April 2001 and June 2006 to collect the butterflies data using transect methods described by Pollard et al. (1975) and Pollard (1977), with some modification described in sampling design (Table 1). Overall eight randomly selected permanent line transact (T_{1L}-T_{8L}, for Line transact, also see Table-1) and six randomly selected point transacts (T_{1p}-T_{6p}, for point transact, also see Table 1) were established. Four line transacts were established in disturbed (DF) and four others in undisturbed closed canopy forest (CF) of Rani- Garbhanga Tropical Forest to collect the butterflies and habitat data. The 34 observation points (within 30 m radius) were used to collect the additional data on butterflies along with line transact data. In point transacts, altogether 23 points were selected at Garbhanga reserve forest and 11 points were selected (in a gap of 200 m between two points) at Rani reserve forest in the study (Table 1). All butterflies and habitats data were collected from within 30 m radius of each point. At each point, data were collected for at least 30 min time period and all possible data were gathered from the point. Before each data collection at point, at least 5 min time was spent in noise free conditions to reduce disturbance factor. The closed forest (CF) and disturbed forest (DF) data were recorded separately for different analyses. The data from traps were also used to determine the shade and light preference of each butterfly species independently.

Trap design

It is difficult to identify butterflies when they are in flight and therefore, the study focused on the guild of fruit feeding Nymphalid butterflies that could be caught in traps or baited with rotten fruits (Hill et al., 2001; Hamer et al., 2003). During this study, traps were used and baited with fresh and rotten Bananas and Jackfruits (De Vries, 1987; Daily and Ehrlich, 1995). Altogether 20 bait traps were hung (each above 2 meters from ground), 10 in forest shade and 10 in forest gaps for the butterfly data collections. The fresh bananas were placed in each trap on the day prior to the first sampling day and were left in the trap for the rest of the sampling period. A fresh piece of banana was then added to each trap, every second day. This ensured that, all traps contained a mixture of fresh as well as rotten baits. After identification and noted down of all the trapped butterflies at dusk, the species were released into the habitat by marking them on their abdomen and thorax with fluorescent marker pen. The confusing butterflies species were taken to the laboratory for verification.

Data collection

We walked together along each transect at the speed of approximately 10 m per 10 min and collected and recorded all butterflies that were seen using butterfly net in a belt of 10 m width. The butterflies and the habitat data were collected from eight line transacts and 34 aforesaid observation points (within a 30 m radius) along each transect T_{1p} - T_{6p} (Table 1), as per the methods used by Torquebiau (1986), Hill et al. (2001) and Hamer et al. (2003). After collection of butterfly data within a period of 30 min time, the habitat data were also collected from each point. The butterfly data from traps and transacts were used to determine the shade and light preference of each Nymphalid butterfly species. During each sampling period, traps were emptied daily and all trapped butterflies were identified and recorded.

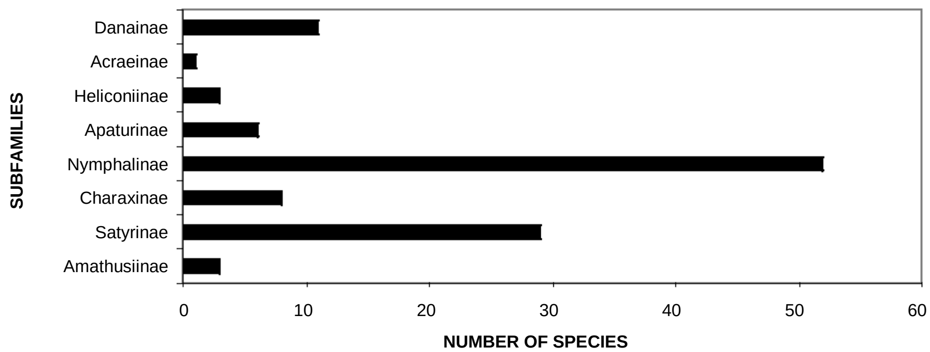


Figure 2. Total numbers of species sighted in each subfamilies of nymphalid butterflies at study sites of RGTF.

The parameters used for habitat data collections were (1) height of the trees, (2) circumference at breast height, (3) distance of 10 nearest trees from the station (circumference, 0.6 m) (Torquebiau, 1986), (4) Estimated vegetation cover (%), (i) at ground, (ii) low (2 m above ground), (iii) under story and (iv) canopy levels.

Identification and geographic distribution

The identification of butterflies and knowledge of their geographic ranges were based on the information of Antram (1924), Evans (1932), Wynter- Blyth (1957), Tsukada (1982), Otsuka (1988) and Haribal (1992). The geographic distribution ranges of Nyphalid butterflies were categorized on a scale of 1 - 5 (smaller to larger) to convert the distribution ranges into numerical scale for statistical analysis as per the methods used by Spitzer et al. (1997), with some minor modifications to fit with the study area viz., (1) Eastern Himalayas (Sikkim to Assam), (2) Northeastern India and northern Indochina (up to Northern Burma), (3) Indo- Malayan region (India, including Andaman Island, and Burma), (4) Indo-Australian region or Australasian tropics (all India, Burma and up to Sri Lanka etc.), (5) Paleotropic (up to Baluchistan). No species were recorded beyond Paleotropic.

Data analysis

The diversity of species was estimated in terms of species evenness, using Margalef’s D Index. Bootstrap method was used to calculate 95% confidence intervals (Hurlbert, 1971; Magurran, 1988). Evenness or Equitability refers to the pattern of distribution of the individuals between the species. In order to test the differences in diversity between habitats (CF and DF), pair-wise randomization tests were carried out, based on 10,000 re-samples of species abundance data following Solow (1993). Species richness was estimated using rarefaction (Heck et al., 1975). Percentage of cumulative abundance was plotted (K dominance) against log species rank (Lambshead et al., 1983) for comparing diversity between samples. The log normal distribution has been analyzed as per the method of May (1975) using Species Diversity and Richness Software, version 3.0 (Pisces conservation Ltd., UK).

For each Nymphalid species, the proportion of individuals recorded in closed forest or shade (CF) [using formulae for shade preference, (CF)/(CF+ DF), where CF + DF 3] indicates shade preference (value of ‘1’ for species only in ‘CF’, value of ‘0’ for species only in ‘DF’ or gap) and proportion of individuals in disturbed forest (DF) or gap [using formulae for light preference, (DF)/(DF + CF), where DF + CF 3] indicates the light preference (value of ‘1’ for species only in ‘DF’ or gap sites, value of ‘0’ for species only in ‘CF’ or shade sites) of the butterflies. To reduce sampling error, it included only those species for analysis, where the total number of individuals sampled was n 3, which was more appropriate than that of Davis et al. (2001) and Ribera et al. (2001), who considered that n 2 was sufficient for inclusion. Data were arcsine transformed for analysis and only selected data (CF + DF 3) were used. For statistical analysis of data, t-test using equal variance, Spearman Rank correlation and multiple regressions were used as per Hamer et al. (2003). All statistical analyses were done using SPSS, Statistical Software, Version 11.0.1. (as per Dytham, 1999). The species diversity was analyzed using Species Diversity and Richness Software as per Magurran (1988).

Although, the vegetation measurement data were taken at 34 sampling stations in Rani-Garbhanga Tropical Forest (RGTF), only 28 sampling data were considered at the time of analysis (14 stations at DF and 14 stations at CF). To examine the relationship between vegetation structure and species diversity in both the habitats, the vegetation measurements were used to calculate 7 variables (Table 3) to analyze the Principal Component factors (PCA) (Hamer et al., 1997; Pearman, 2002). The PCA factors allowed ordination of differences among stations in vegetation structure, by generating a number of independent factors comprising sums of weighted variables. The relationship between vegetation factor scores and species diversity at each sampling station in close canopy forest and degraded forest was analyzed using stepwise multiple regression (using SPSS version 11.0.1, as per Dytham, 1999).

RESULTS

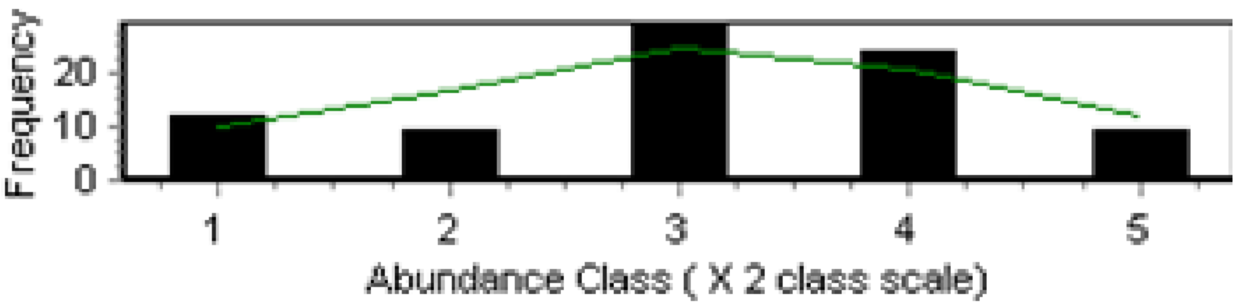
Diversity and abundance

A total of 2550 individuals referable to 113 Nymphalid butterfly species and eight subfamilies, counted in closed forest (CF) and degraded forest (DF) (Figure 2 and Table 2) of Rani-Garbhanga Tropical Forest formed the basis of calculations. The highest number of species have been sampled in DF (N = 107 species), compared to CF (N = 84 species). Comparison of significant difference of diversity between CF and DF showed that, the species richness was different among the habitats. The species richness (rarefaction) of CF habitat was 80.88 species, whereas, it was 101.03 species in DF habitat (Table 2). Margalef’s D Index of diversity was significantly different

Table 2. Species richness, abundance and diversity of butterfly fauna sampled in DF and CF of RGRF (Margalef's D means followed by the different letter are significantly different at the 5% level; Rarefaction estimate was done for species richness based on present absent data of each of the transact data of CF and DF; also see text).

Variables estimate	Habitat studied	
	CF	**DF**
Species (Total = 113)	84	107
Individuals (Total = 2550)	836	1714
Richness	80.88	101.3
(SE)	(±1.54)	(± 2.05)
Margalef's D	12. 48a	14. 18b
(SD)	(±0.54)	(±0.56)

[*Margalef's D; DF vs. CF: P< 0.01 at 5% level] *DF is more diverse than CF].



(a)CF

(b)DF

Figure 3. Truncated log normal distribution of relative abundance in CF and DF butterflies data of RGRF (CF**:** species behind the Veil line = 0.015; DF: species behind the Veil line = 2.68). (a = Closed forest; b = Degraded forest).

in 'DF' and 'CF' at 5% level (Table 2; DF vs. CF randomization test, = -1.69, P< 0.01 at 5% level; pair wise randomized test based on 10,000 random samples), where DF was more diverse than CF, which proved the proposed hypothesis. The sampled data of CF and DF fit the truncated log normal distribution (for DF: χ^2 = 2.1, df = 6, P = 0.9, with predicted species in the community was 109.68, species behind the veil line = 2.68, = 184.54; for CF: χ^2 = 5.92, df. = 4, P = 0.20, with predicted species in the community was 83.07, species behind the veil line = 0.07, = 228.21; Figure 3a and b). But the data sets of DF and CF habitat did not fit the log series model (for CF

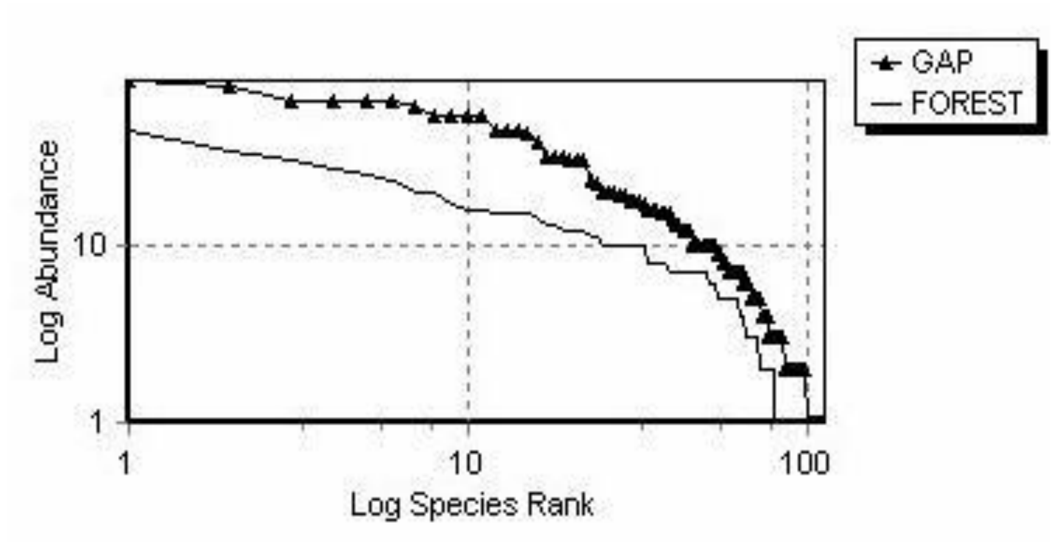


Figure 4. Log Ranked proportional abundance of butterfly species in CF and DF habitat of RGRF showed that, DF has higher butterflies abundance than CF habitat (Gap=DF; Forest = CF).

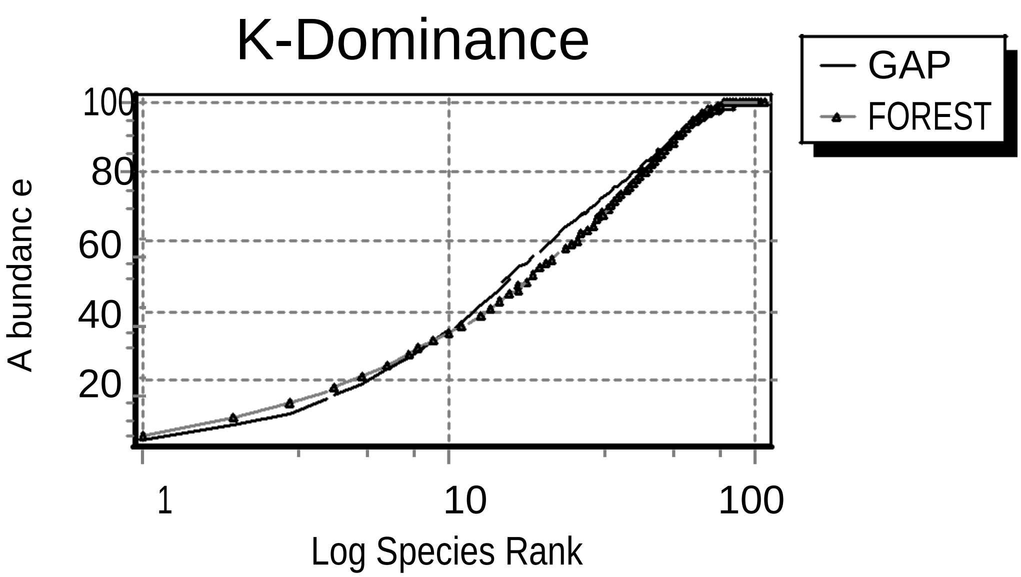


Figure 5. K dominance curve plotted for comparing the diversity among relatively undisturbed (Forest) and disturbed habitat (Gap) samples (see text).

(for CF: x = 0.97, $\propto$ = 23.59, χ^2 = 54.42, d.f. = 5, p = .001; for DF: x = 0.98, $\propto$ = 25.09, χ^2 = 12.73, d.f. = 6, p = 0.04, distributions are significantly different at 5% level). The log-ranked proportional abundance of the species in DF was also higher than CF (Figure 4) with most abundant species in each habitat category comprising around 10% of the total species scores. The percentage cumulative abundance plotted (K dominance, Figure 5) against log species rank for comparing diversity between samples (CF and DF) showed that, both graphs cross each other and showed difference of diversity (also see Lambshead et al., 1983).

Shade preferences of butterflies

We encountered 2550 individuals of Nymphalid butterflies belonging to 113 species at gaps or degraded forest (DF) and shade sites or closed canopy forest (CF) of Rani-Garbhanga Tropical Forest (RGTF). The survey revealed that, of all the total 113 species recorded in study area, the individual counts and proportional abundance of 60 species were found to be higher in degraded forest, whereas, in close canopy forest, the individual counts or proportional abundance were higher for 51 species. Again, out of 60 species, 29 were found only in forest gaps and out of 51 species, six were found only in CF (shade sites). Apart from that, one species from sub-family Amathusiinae and one from Charaxinae had equal abundance in both the habitats (Appendix I). The species *Mycalesis gotama charaka* Moore*, Apatura ambica ambica* Kollar*, Neptis ananta ochracea* Evans and *Pareba vesta* (Fabricius) belonging to the subfamilies Satyrinae, Apaturinae, Nymphalinae and Acraeinae respectively, sampled less than three individuals each. Thus, those four species were being excluded from the statistical analysis (see methods for data selection for analysis). On the basis of the proportional abundance of the butterfly species (where n 3) both in gaps (light sites) and shade sites, the species were differentiated in to two groups (shade and light groups). Analysis showed that, the mean proportion of butterflies in shade sites were higher in sub-families Amathusiinae, Satyrinae and Apaturinae (shade group) than that in the sub-families of Nymphalinae, Charaxinae, Heliconiinae and Danainae (for shade group mean = 0.81, n = 36 species, SD = 0.42; for light group mean = 0.33, n = 73, SD = 0.39; t-test using equal variance estimate with arcsine transformed data; t_{106} = 4.974, P < 0.001; Figure 6; also see Table 3). On the contrary, the proportion of individuals of each species of butterflies occurring at gap sites or degraded forest were significantly higher in Nymphalinae, Charaxinae, Heliconiinae and Danainae subfamilies (light group) (mean = 0.96, n = 73 species, SD = 0.55; t-test using equal variance estimate with arcsine transformed data; t_{106} = -5.02, P < 0.001) than that in Amathusiinae, Satyrinae and Apaturinae (mean = 0.38, n = 36, SD = 1.5; Figure 7), indicating the phylogenic relationship of shade and light preferences of Nymphalid butterflies.

Geographic distribution of butterflies

Study revealed that, the butterflies species sampled in relatively undisturbed closed canopy forest had more restricted geographical distribution than those sampled in disturbed forest (Appendix I). The analysis of variance between species ranked range of geographic distribution and species shade and light preferences showed that, the species with greater light preference or species sampled in degraded forest had significantly wider geographical distribution (ANOVA performed: Dependant variables: Proportion to DF; Independent variable: Species Ranked Range; $F_{4,\ 109}$ = 23.32, P< 0.001). Again, the species sampled in degraded forest or forest gap sites had significant positive relation with wide range of geographical distribution (Spearman Rank Correlation, where $n \geq 3$; r^s = 0.70, P<0.01; Median range = 3.00 ± 1.01 SD), whereas, the species with greater shade preferences had significantly narrower geographical distributions (ANOVA performed; where $n \geq 3$; Dependant variable: Proportion to CF; Independent variable: Species Ranked Range; $F_{4,\ 109}$ = 31.90, P< 0.001) . Again, the species sampled in closed canopy forest or shade sites had significant negative relation with wide range of geographical distribution (Spearman Rank Correlation, where $n \geq 3$; r^s = - 0.73, P<0.01; Median range = 2.47± 0.86 SD). Figure 8 also distinctly shows that, in closed canopy forest, the value of proportional abundance of butterflies' increases in case of narrow geographical distribution range species and the value reduce when distribution range of the species increases. Opposite results could be observed in the Figure 9, where, in degraded forest, the values of proportional abundance of butterflies were lowest in the case of narrow or restricted range species and it was observed that the value gradually increased in the case of wide range species. Thus, the result supports the proposed hypothesis that, the increasing diversity of butterflies in degraded tropical forest is associated with loss of species with restricted geographical distributions.

Impact of forest destruction on individual species

The result shows that, majority of narrow range species belong to Amathusiinae, Satyrinae, and Apaturinae*,* whereas*,* the majority of wide range species belong to Nymphalinae, Charaxinae, Heliconiinae and Danainae. In Amathusiinae, Satyrinae, and Apaturinae, there was a significant and strong negative relationship between shade preference and impact of forest destruction (Spearman correlation; r^s = -0.84, n = 36 species, p < 0.001), which means that, the shade preferred species are most adversely affected by forest destruction. However, there is a positive relationship between light preference and impact of forest destruction witnessed in Nymphalinae, Heliconiinae and Danainae (Spearman correlation r^s = 0.83, n = 73 species, P < 0.001).

Vegetation structure and butterfly diversity in CF and DF habitat

The Principal component analysis (PCA) of vegetation data such as tree height, tree density and vegetation covers of the study area (to correlate with butterflies data of Rani-Garbhanga Tropical Forest), extracted essential results. PCA extracted two components of variations in undisturbed closed canopy forests i.e. PRIN1 and PRIN2, which explains 54 and 23% variability in the vegetation data, respectively. The first factor (PRIN1) increases with increase of vegetation cover in canopy and under-storey and with increase of density of trees and mean height and

Appendix 1. Comprehensive checklist and Ranked distribution range of Nymphalid butterflies in Rani-Garbhanga Tropical Forest in Degraded Forest (DF) and Closed Canopy Forests (CF) (*Distribution ranges of each Nymphalid butterflies have been categorized 1-5 rank as per their geographical distribution area; also see methods).

S/ No.	Species/Sub families	DF	CF	Ranked distribution ranges*
	Amathusiinae			
1	Jungle Glory-*Thaumantis diores diores* (Doubleday), 1845	2	12	3
2	Common Duffer-*Discophora sondiaca zal* Westwood, 1851	4	20	3
3	Great Duffer-*Discophora timora timora* (Westwood)	3	10	3
	Satyrinae			
4	Common Evening Brown-*Melanitis leda ismene* (Cramer), 1775	85	4	4
5	Dark Evening Brown-*Melanitis phedima bela* Moore, 1875	2	34	2
6	Great Evening Brown-*Melanitis zitenius zitenius* (Herbst), 1796	5	12	3
7	Common Palmfly-*Elymnias hypermnestra undularis* (Drury), 1773	15	65	2
8	Spotted Palmfly-*Elymnias malelas malelas* (Hewitson), 1863	3	10	2
9	Blue-striped Palmfly-*Elymnias patna patna* (Westwood), 1851	10	16	2
10	Peal's Palmfly-*Elymnias pealii* Wood Mason	0	5	1
11	Bamboo Treebrown-*Lethe europa niladana* Fruhstorfer, 1911	5	11	3
12	Common Tree brown-*Lethe rhoria rhoria* (Fabricius), 1707	5	15	3
13	Common Red Forester-*Lethe mekara zuchara* (Fruhstorfer), 1857	1	10	2
14	Angled Red Forester-*Lethe chandica flanona* (Fruhstorfer), 1857	1	14	2
15	Blue Forester-*Lethe scand* Moore, 1857	0	8	1
16	Banded Treebrown-*Neope confusa gambara* (Fruhstorfer), 1898	2	16	2
17	Dusky Diadem-*Ethope himachala* (Moore), 1865	2	45	2
18	Yellow Owl- *Neorina hilda* Westwood, 1850	1	7	1
19	Whitebar Bushbrown-*Mycalesis anaxias oemate* Fruhstorfer, 1911	2	7	3
20	Common Bushbrown-*Mycalesis perseus blasius* (Fabricius), 1798	20	13	3
21	Darkbrand Bushbrown-*Mycalesis mineus mineus* (Linnaeus), 1765	15	15	3
22	Brighteye Bushbrown- *Mycalesis nicotia* Westwood, 1850	9	10	3
23	Long-brand Bushbrown-*Mycalesis visala visala* Moore, 1857	6	7	3
24	Lilacine Bushbrown-*Mycalesis franscica santana* Moore, 1857	3	5	3
25	Chinese-bushbrown- *Mycalesis gotoma charaka* Moore	0	2	2
26	Whiteline Bushbrown-*Mycalesis malsara* Moore, 1857	1	10	1
27	Nigger-*Orsotrioena medus medus* (Fabricius), 1775	10	25	3
28	Common Fivering-*Ypthima baldus baldus* (Fabricius) 1775	15	8	3
29	Himalayan Fivering- *Ypthima sakra austeni* Moore	2	8	2
30	Common Fourring-*Ypthima hubenri hubenri* Kirby, 1871	18	7	3
31	Common Threering-*Ypthima asterope maharatta* Moore, 1884	6	0	5
32	Large Threering-*Ypthima nareda newara* Moore	0	8	1
	Charaxinae			
33	Tawny Rajah-*Charaxes polyxena hierax* Felder, 1867	45	0	3
34	Yellow Rajah-*Charaxes marmax* Westwood, 1848	13	0	3
35	Tawny Raja-*Charaxes pleistoanax* Felder	12	4	2
36	Scarce Tawny Rajah- *Charaxes aristogiton* Felder, 1867	12	0	3
37	Common Nawab-*Polyura athamas athamas* (Drury), 1770	30	2	3
38	Pallid Nawab-*Polyura arja* (Felder and Felder), 1867	16	0	3
39	Great Nawab-*Polyura eudamippus eudamippus* (Doubleday) 1843	3	3	3
40	Jeweled Nawab-*Polyura delphis delphis* (Doubleday), 1843	43	0	3
41	Sergeant Emperor-*Apatura chevana* (Moore), 1865	3	10	2

Appendix 1. Contd.

S/ No.	Species/Sub families	DF	CF	Ranked distribution ranges*
	Apaturinae			
42	Indian Purple Emperor- *Apatura ambica ambica* Kollar	2	0	3
43	Eastern Courtier-*Sephisa chandra* (Moore), 1857	2	4	2
44	Courtesan-*Euripus halitherses* Doubleday and Hewitson, 1848	18	2	3
45	Constable- *Dichorragia nesimachus* (Boisduval), 1836	2	12	3
46	Popinjay-*Stibochiona nicea nicea* (Gray), 1833	1	7	2
	Nymphalinae			
47	Angled Castor-*Ariadne ariadne pallidior* (Fruhstorfer)	8	3	3
48	Common Castor-*Ariadne merione assama* (Evans)	16	7	2
49	Common Leopard-*Phalanta phalantha* (Drury), 1770	65	0	5
50	Large Yeoman-*Cirrochroa aoris aoris* Doubleday, 1847	7	23	1
51	Common Yeoman-*Cirrochroa tyche mithila* Moore, 1872	19	3	3
52	Vagrant-*Issoria sinha sinha* (Kollar), 1844	23	0	3
53	Indian Fritillary-*Argyreus hyperbius hyperbius* (Johanseen), 1764	60	0	5
54	Yellow Pansy-*Junonia hierta magna* (Evans), 1923	65	0	3
55	Lemon Pansy- *Junonia lemonias lemonias* (Linnaeus), 1758	78	0	3
56	Peacock Pansy- *Junonia almana almana* (Linnaeus), 1758	54	0	4
57	Grey Pansy- *Junonia atlites atlites* (Johanssen), 1764	54	0	4
58	Chocolate Pansy-*Precis iphita iphita* (Cramer), 1779	54	5	3
59	Blue Admiral-*Kaniska canace canace* (Linnaeus), 1767	2	8	2
60	Common Jester-*Symbrenthia lilaea khasiana* Moore, 1874	32	7	3
61	Wizard- *Rhinopalpa polynice birmana* Fruhstorfer	12	5	3
62	Great Eggfly-*Hypolimnas bolina* (Linnaeus), 1758	54	0	5
63	Danaid Eggfly-*Hypolimnas misippus* (Linnaeus), 1764	4	0	5
64	Orange Oakleaf-*Kallima inachus inachus* (Boisduval), 1836	3	15	1
65	Autumn Leaf- *Doleschallia bisaltide indica* Moore, 1881	4	5	3
66	Common Map-*Cyrestis thyodamas thyodamas* Boisduval, 1836	10	6	3
67	Common Maplet-*Chersonesia risa risa* (Doubleday & Hewtson), 1850	1	5	3
68	Common Sailer-*Neptis hylas varmona* Moore, 1872	44	2	4
69	Common Sailer-*Neptis hylas adara* Moore	10	27	2
70	Himalayan Sailer-*Neptis mahendra* Moore, 1872	10	20	2
71	Yerburi's Sailer-*Neptis yerburyi sikkima* Evans	2	15	1
72	Broad-banded Sailer-*Neptis sankara quilta* Moore	7	5	3
73	Clear Sailer-*Neptis clinia susruta* Moore, 1872	15	7	3
74	Sullied Sailer-*Neptis soma soma* Moore, 1858	10	2	3
75	Short Banded Sailer-*Phaedyma columella ophiana* (Moore), 1872	17	1	3
76	Yellow Sailer- *Neptis ananta charcoal* Evans, 1924	0	1	2
77	Yellow Jack Sailer- *Lassipa viraja viraja* Moore, 1872	20	0	3
78	Common Lascar-*Pantoporia hordonia hordonia* (Stoll), 1791	32	3	3
79	Orange Staff Sergeant-*Parathyma cama* (Moore), 1857	14	5	3
80	Colour Sergeant-*Parathyma nefte inara* (Doubleday and Hewtson), 1850	65	2	3
81	Common Sergeant- *Parathyma perius* (Linnaeus), 1758	7	0	3
82	Studded Sergeant-*Parathyma asura asura* (Moore), 1857	8	0	3
83	Blackvein Sergeant- *Parathyma ranga ranga* (Moore), 1857	6	11	3
84	Commander- *Moduza procris procris* (Cramer), 1877	8	4	3
85	Commodore- *Limenitis danava* (Moore), 1857	5	0	3
86	Knight- *Lebadea martha ismene* Doubleday & Hewitson	5	30	1

Appendix Contd.

S/No.	Species/Sub families	DF	CF	Ranked distribution ranges*
	Nymphalinae			
87	Great Archduke-*Adolias cyanipardus* Butler	1	13	2
88	Dark Archduke- *Adolias khasiana khasiana* Swinhoe	0	10	1
89	Red Spot Duke- *Euthalia evelina derma* Kollar	7	5	3
90	Grey Count- *Tanaecia lepidea lepidea* (Butler), 1868	10	17	2
91	Grey Count- *Tanaecia lepidea miyana* Fruhstorfer	7	12	3
92	Plain Earl- *Tanaecia jahnu jahnu* (Moore), 1857	2	6	2
93	Common Earl- *Tanaecia julii adima* Moore	1	7	1
94	Common Baron- *Euthalia garuda garuda* Moore	30	0	3
95	White-edged Blue Baron- *Euthalia phemius* (Doubleday & Hewitson) 1848	2	3	3
96	Streaked Baron- *Euthalia jama jamida* (Felder) 1866	7	10	1
97	Gaudy Baron- *Euthalia lubentina indica* Fabricius	2	7	3
98	Blue Baron- *Euthalia telchinia* (Menetries) 1857	3	1	3
	Heliconiinae			
99	Leopard Lacewing- *Cethosia cyane* Drury, 1770	20	0	3
100	Cruiser-*Vindula erota erota* (Fabricius) 1793	16	0	4
101	Red Lacewing- *Cethosia biblis tisamena* Fabricius, 1770	18	2	3
	Acraeinae			
102	Yellow Coster- *Pareba vesta* (Fabricius) 1787	2	0	1
	Danainae			
103	Glassy Tiger- *Parantica aglea melanoides* (Moore) 1883	19	2	3
104	Chocolate Tiger- *Parantica melaneus platiniston* (Fruhstorfer) 1910	10	7	3
105	Blue Tiger-*Tirumala limniace leopardus* (Butler) 1866	32	0	5
106	Dark Blue Tiger-*Tirumala septentrionis* (Butler) 1874	3	1	3
107	Common Tiger- *Danaus (Salathura) genutia* (Cramer) 1779	22	0	5
108	Plain Tiger-*Danaus (Anosia) chrysippus* (Linnaeus) 1758	30	0	5
109	Striped Blue Crow- *Euploea mulciber mulciber* Cramer, 1777	9	0	3
110	Long Branded Blue Crow- *Euploea aglea deione* Fruhstorfer, 1910	13	6	3
111	Magpie Crow-*Euploea diocletiana ramsayi* Moore	1	7	1
112	Blue King-crow- *Euploea klugii klugii* Moore, 1858	44	0	3
113	Common Crow-*Euploea core core* Cramer, 1790	38	10	3

and girth and with the decrease of vegetation cover at ground zone and low cover (Table 4). A high PRIN1 (PCA Factor 1) score thus represents dense forest with closely spaced trees with broad canopy diameter of individual trees, and a relatively poor field layer. The PRIN2 (PCA Factor 2) score increases with increasing height and girth of the trees. Thus, PRIN1 primarily reflects density of forest, whereas PRIN2 primarily represents sizes and architecture of trees in undisturbed closed canopy forest of study site.

Again, PCA extracted 2 components of variation in degraded forests (PRIN1 and PRIN2) that accounted for 34 and 20% of the variability in the vegetation data, respectively. The first factor increases with increasing of vegetation cover at ground, low and under -storey and with the decreasing of canopy cover, mean height and girth of trees. A high PRIN1 score thus represents vegetation structure with widely spaced trees with canopy openness, and relatively high field layer. The decreasing girth of the trees in degraded forest accounted for the selective logging of big trees (Table 4). The PRIN2 score increased with increasing girth and height of the trees. Thus, PRIN1 primarily does not reflect the overall dense forest covers, whereas, PRIN2 primarily represented sizes and architecture of trees.

The stepwise analysis of multiple regressions between

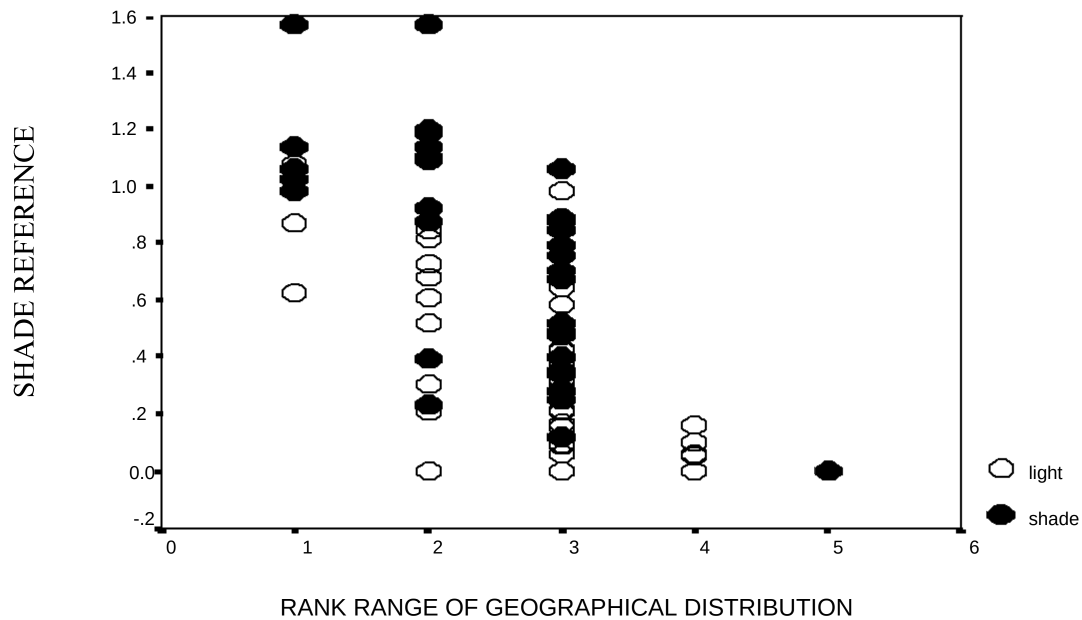


Figure 6. Shade preference of butterflies sampled in DF and CF habitat (Black solid circles: Amathusiinae, Satyrinae and Apaturinae; Open circles: Nymphalinae, Charaxinae, Heliconiinae and Danainae subfamilies).

Table 3. Proportional abundance of butterfly species (Arcsine transformed data) in closed canopy forest and degraded forest in RGTF. (Mean value in bold are significantly higher in each habitat).

Subfamily	Proportion to closed forest (CF)		Proportion to degraded forest or forest gap (DF)		N
	Mean	± SD	Mean	± SD	
Amathusiinae	0. 96	0.07	0.18	0.04	3
Satyrinae	0. 81	0.44	0.39	0.41	28
Nymphalinae	0.41	0.42	0. 84	0.54	51
Charaxinae	0.10	0.19	1. 30	0.41	8
Apaturinae	0. 68	0.43	0.47	0.43	5
Heliconiinae	0.03	0.05	1. 42	0.26	3
Danainae	0.21	0.32	1. 11	0.49	11

the diversity (Margalef's D index) of Amathusiinae, Satyrinae and Apaturinae butterflies and vegetation density (PRIN1) of closed forest showed the significant positive relationship ($F_{2,\ 28}$ = 7.3, p < 0.02; r^2 = 0.58; Figure 10), but the relationship was found to be negative, when the similar types of analysis was performed between the diversity of Nymphalinae, Heliconiinae, Charaxinae and Danainae butterflies with vegetation density (Figure 11; $F_{2,\ 28}$ = 7.3, p < 0.03, r^2 = -0.47).

DISCUSSION

Diversity of Nymphalid butterflies

We observed that, the species diversity is higher in the disturbed forest (DF) or canopy gap area (Margalef's D index = 14.18; n = 107 species) than that in the undisturbed or closed canopy forest (CF) (Margalef's D index = 12.48; n = 84 species) of Rani-Garbhanga Tropical Forest (RGTF). This finding is in conformity with the other studies, comparing disturbed and undisturbed habitats, which shows that the increased light is associated with increased butterfly diversity (Pinheiro and Ortiz, 1992; Sparrow et al., 1994; Willott et al., 2000). The disturbed forest of Rani-Garbhanga Reserve Forest was logged 12-13 prior to the undertaking of the present study. Thereafter, the earlier closed canopy forest was replaced by secondary vegetation as well as weed species like *Melastoma malabathricum, Lantana camera, Eupatorium odoratum, Mikania scandens,* etc. These secondary vegetations and weed species attracted the 'light-loving' and generalized species of butterflies, owing to availability of flower nectars almost throughout the year. In disturbed habitat of RGTF, large numbers of previously available short range or native butterfly species

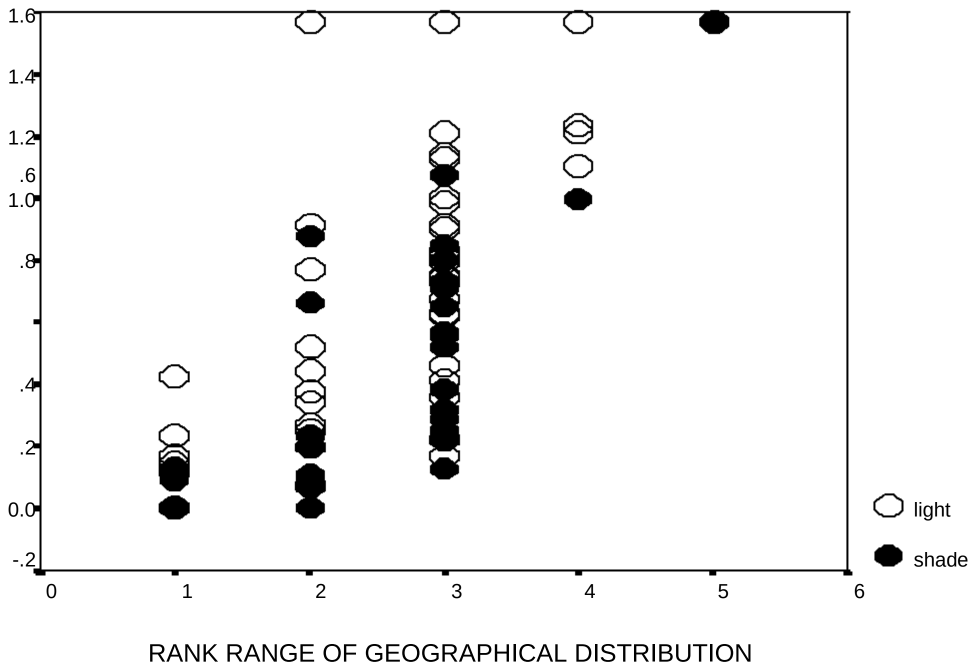


Figure 7. Light preference of butterflies sampled in DF and CF habitat (Black solid circles: Amathusiinae, Satyrinae and Apaturinae subfamilies; Open circles: Nymphalinae, Charaxinae, Heliconiinae and Danainae subfamilies).

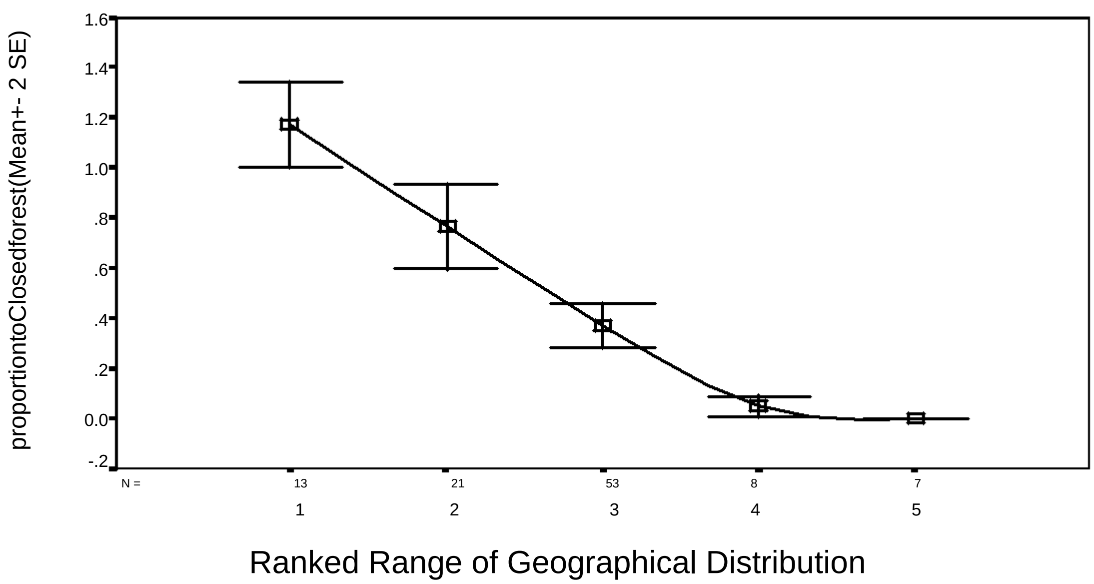


Figure 8. Arcsine proportions of individuals in butterflies species at closed forest areas and species ranked range of geographical distribution in RGRF (ANOVA results; $F_{4,109} = 31.90$; $P < 0.001$).

species vanished from this modified habitat. They were being replaced by wide-range or generalized butterfly species. Ghazoul (2002) suggested that, the increase in species richness is often due to invasion of disturbed areas by generalized and widespread species and the resulting homogenization of the world's biological

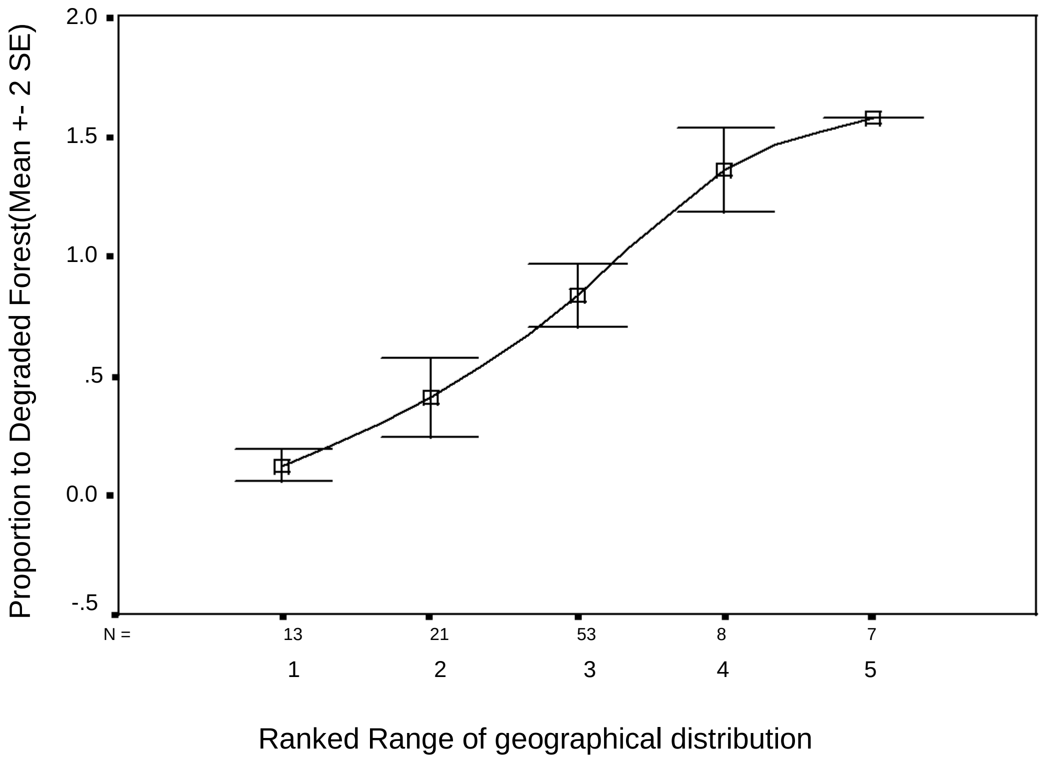


Figure 9. Arcsine proportion of individuals in butterfly species at degraded forest or canopy gap areas and species ranked range of geographical distribution in RGRF (ANOVA results; $F_{4,109} = 23.32$ $P < 0.001$).

Table 4. Contribution of different variables to two principal components (PRIN1 and PRIN2) of variation in vegetation structures. Variables making main contributions to each principal component are in bold.

Variables	**Weighing**			
	PRIN1		**PRIN2**	
	Primary Forest	**Degraded forest**	**Primary Forest**	**Degraded forest**
Trees				
Mean Height	0.74	0.39	0.84	0.53
Mean girth	0.73	0.24	0.79	0.70
Density	0.53	0.86	-0.51	-0.28
Percentage cover				
Ground cover	-0.41	0.77	-0.55	0.06
Low cover	-0.43	0.80	-0.36	0.31
Under story	0.88	0.63	-0.67	0.61
Canopy cover	0.95	-0.10	-0.36	0.67

communities is an important threat to the global biodiversity conservation. The present study shows that, the abundance and diversity is higher in disturbed forest than in undisturbed forest habitat. This point has been proved from the various analyses such as log-ranked proportional abundance and K-dominance curve (K dominance curve of Closed canopy forest (CF) and Degraded forest (DF) crosses each other, indicating differences of diversity; Lambshead et al., 1983). The Margalef's D Index of diversity is also significantly higher in disturbed forest than in closed canopy or undisturbed forest (P < 0.01 at 5% level). These findings support the hypothesis that, disturbed habitat or forest gaps have higher butterfly diversity than that in closed canopy or dense forests. Spitzer et al. (1993), Hill et al. (1995), Hamer et al. (1997) and Wood and Gillman (1998), using similar census methods recorded higher butterfly diversity and abundance in disturbed sites than in closed-canopy

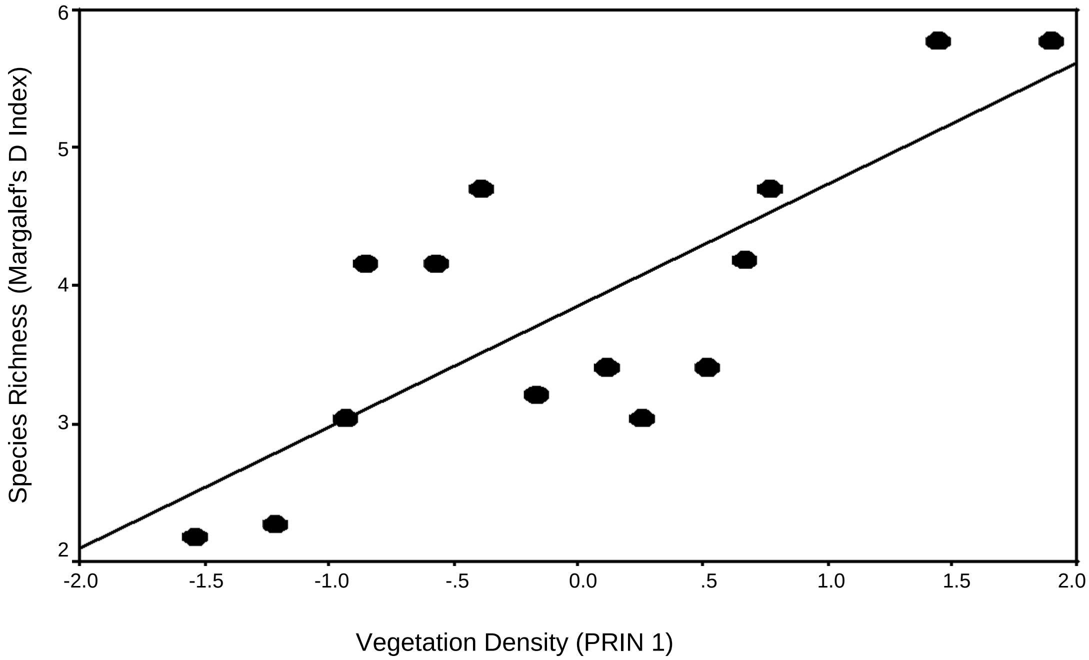


Figure 10. Figure shows the diversity of Amathusiinae, Satyrinae and Apaturinae in relation to vegetation density and canopy closeness.

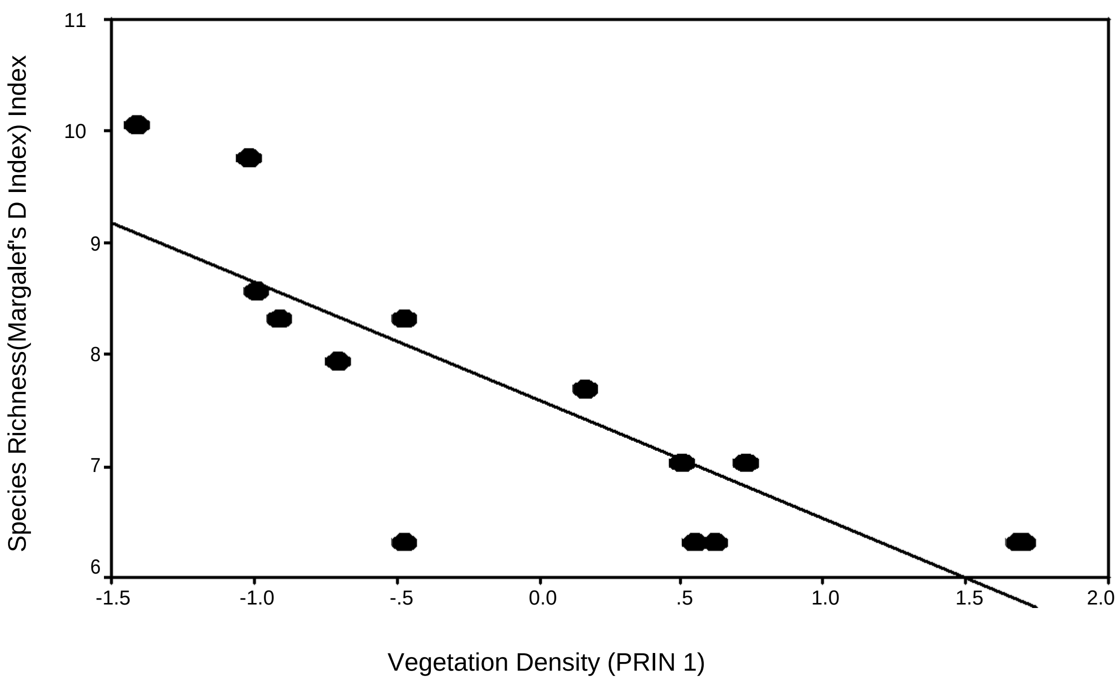


Figure 11. Diversity of Nymphalinae, Charaxinae, Heliconiinae and Danainae in relation to vegetation density and canopy openness.

undisturbed sites. Even though, the diversity increases in disturbed habitat, it results in the reduction of the native butterfly faunas, or endemic species, which are specialized in habitat use. The native or endemic species generally prefer low or moderate sunlight compared to wide range species. Again, these species are low and week fliers and hide under dense shades during various stress situations. The primary forest or undisturbed forests are inhabited by greater number of specialized butterflies and lesser number of generalized species and hence harbours less butterfly diversity in contrast to that in disturbed habitat. In fact, the butterfly diversity is reduced in modified habitat, immediately after logging in the tropical countries. But, with the increased growth of weed species and secondary vegetation along with the reduction of human interference, the diversity increases in a progressive way.

In the present study, the species abundance data for butterflies, fitted along with log normal distributions in both undisturbed and disturbed habitat and the log series model does not fit in both habitats. Thus, it indicates that, although the habitat has been modified due to logging, the habitat heterogeneity might not be changed so much. May (1975), Putman (1994), Hill and Hamer (1998) and Ghazoul (2002) suggested that, lognormal and log series models do not necessarily reflect biological conditions, log series model imply a structurally simplified habitat. Hill et al. (1995) have also opined that, species abundance and distribution of butterflies might be used as indicators of forest disturbance. But, in case of Rani-Garbhanga Tropical Forest, the significant differences of diversity and abundance were observed across the sites; yet log normal distributions fitted well in both the sites and log series model did not fit in both the habitats. Ghazoul (2002) remarked that, lognormals and log series models alone are not sufficiently sensitive to be used as disturbance indicators. This remark of Ghazoul has been re-established by our present study.

It could be concluded that, the butterflies are thus appropriate subjects for the study of logging impacts on biotic communities and have been widely used to assess patterns of tropical insect diversity in forest conservation studies (Brown, 1991; DeVries et al., 1997; Ghazoul, 2002). The change of butterfly species composition and community structure in tropical forest ecosystem is an important threat for the future biodiversity conservation. So, the ultimate solution lies in the conservation of butterfly species as well as the protection, preservation and restoration of close canopy forest and the plant species, especially the native or indigenous ones.

Rani-Garbhanga Tropical Forest is extremely rich in butterfly diversity, especially Nymphalidae family. The existence of 113 butterfly species, belonging to a particular family in a definite area of 254.85 km² indicates the habitat heterogeneity of Rani-Garbhanga Tropical Forest. Most of the forest degradation has occurred at the peripheral region, whereas the core area of the habitat has still sustained dense close canopy forest. The higher density of the vegetation (Table 4) at ground level, under storey and low canopy cover in degraded part of the forest took place owing to destruction of primary forest. This destruction occurred 12 - 13 years before the present study. Most of the bulky tall trees had been selectively felled and subsequently, the gap areas were occupied by different invasive plant species like *Lantana camera, Eupatorium odoratum, Mymosa sp., Adatoda sp., Mikania* sp. etc. In addition, the forest department also planted monoculture plantation of exotic species viz., *Tectona grandis*. Thus, the habitat of study site forms a mixture of both pioneer and climax vegetation. The availability of high butterfly diversity in degraded forest of Rani-Garbhanga Tropical Forest also indicates that the habitat is mostly suitable for butterfly species assemblages and diversity. The study findings also supported the earlier results of Horn (1975), Connell (1978) and Basset et al. (2001), who suggested that, the highest diversity occurs in situations of intermediate disturbance when both climax and pioneer species co-exist.

Out of eight subfamilies of Nymphalidae, the greatest numbers of species belonging to five subfamilies have been found to occur in degraded forest or forest gaps, whereas, the rest three subfamilies are being found in closed canopy forest. Nymphalinae, Charaxinae, Acraeinae, Heliconiinae and Danainae are those five subfamilies that prefers light or open areas rather than shade sites. The butterflies of Charaxinae and Nymphalinae have strong flying activity. They mostly prefer open areas rather than close canopy forest. According to Hill et al. (2001), the species of Charaxinae and Nymphalinae subfamilies have broad thorax and small abdomen and thus, they are frequently flying from ground zone to top canopy level. Consequently, they prefer to stay in open area or forest gaps rather than canopy closed forest areas. In contrary, the Satyrinae, Amathusiinae and Apaturinae are the three subfamilies that prefer shade sites. Spitzer et al. (1993,1997), Hamer et al. (1997), Hill and Hamer (1998) and Wood and Gillman (1998) also suggested that, most of the Satyrinae are restricted to undisturbed under storey habitats and are sensitive to canopy opening. The statistical analysis have also found highly significant results of the relationship between species phylogeny (subfamily level) and butterfly shade and light preference (Figures 6 and 7). These significant results show that the diversity of butterfly is related to vegetation structure and canopy openness and that this relationship differs in different butterfly taxa.

Again, there is a strong positive relationship that exists between species shade preference and narrow geographical distribution and also between species with light preference and wide range of geographical distributions. This relationship indicates that, gaps or degraded forests are mostly used by opportunistic and cosmopolitan species and on the other hand, shades or closed canopy forests are harboured by habitat specialist butterflies or endemic species. This finding is in conformity with the opinion of Thomas (1991), Spitzer et al. (1997), Hill et al. (2001) and Hamer et al. (2003). The endemic or habitat specialist species are mostly confined in close canopy forest. The present study recorded altogether 14 species are endemic (all ranked 1 species specified in Appendix I) and 19 species are nearly endemic (Spitzer et al., 1997) to this region (all ranked 2 species specified in Appendix I).

But the result is contradicted in case of one endemic and one nearly endemic species viz., *Charaxes pleistonax* Felder and *Pareba vesta* (Fabricius), both are found in forest gaps. However, this may be accidental occurrences, since; only two individuals of *Pareba vesta* (Fabricius) were recorded in a single spot of gap area during survey time. To give an ultimate conclusion of the habitat use of these two particular species, more samples should be collected from the study site.

In addition, there is a strong positive relationship between canopy openness of habitat and the butterflies of Nymphalinae, Charaxinae, Heliconiinae and Danainae (gap preferred group) subfamilies that includes majority of wide geographical distribution range species. However, these subfamilies also include a number of narrow range species confined only in close canopy forest. Among gap preferred group, 19 species belong to Nymphalinae and one species belonging to Danainae subfamily, shows strong affinity to shade sites, (see Appendix I). Among the aforesaid gap preferred group , the species *Cirrochroa aoris aoris* Doubleday, *Kaniska canace canace* (Linnaeus), *Kallima inachus inachus* (Boisduval), *Neptis hylas adara* Moore, *Neptis mahendra* Moore, *Neptis yerburi sikkima* Evans, *Lebadea martha ismene* Doubleday and Hewtson, *Adolias cyanipardus* Butler, *Adolias khasiana* Swinhoe, *Tanacea lepidea lepidea* (Butler), *Tanaecia julii adima* Moore, *Tanaecia jahnu jahnu* (Moore), *Euthalia jama jamaida* (Felder), and *Euploea diocletiana ramsayi* Moore are narrow geographic distribution range species. This finding clearly indicates that, there is a strong and significant positive relationship between the species of narrow geographical distribution range and shade preference of the species. This present finding is similar to the finding of Hamer et al. (2003) that had been observed in Tropical Rain Forest of Northern Borneo. Thus, it is clear that most of the restricted distribution range species are affected owing to forest degradation. According to Evans (1932), habitat of Eastern Himalaya houses 96 endemic butterfly species, of which 45 species have been reported from Assam. There were altogether 13 endemic species recorded in close canopy forest of Rani-Garbhanga Tropical Forest and only one endemic species was in degraded forest during present study. But, the butterfly diversity was found to be low in closed canopy forest than in degraded forest (Kakati, 2006). These findings have clearly brought into light that the increasing diversity in degraded forest is associated with the loss of species with restricted geographical distribution.

Yet again, amongst shade-preferred butterfly sub-families group (Amathusiinae, Satyrinae and Apaturinae), five species of Satyrinae and two species of Apaturinae have higher population abundance in gap sites than in closed canopy forests. These are *Melanitis leda ismene* (Cramer), *Mycalesis perseus blasius* (Fabricius), *Ypthima baldus baldus* (Fabricius), *Ypthima hubneri hubneri* Kirby and *Ypthima asterope maharatta* Moore from Satyrinae and *Euripus halitherses* Doubleday and Hewitson and *Apatura ambica ambica* Kollar from Apaturinae sub-families. Hamer et al. (2003) reported that the Satyrinae include some cosmopolitan species (e.g., *Melanitis leda, Mycalesis horsfield, Mycalesis orseis*) which prefer gap area within the forest. Willott et al. (2000) also reported the same findings with an increase in the abundance of several Satyrinae species in Bornean logged forest. Out of these seven gap preferred species, two have wide geographical distribution and other five are medium range species. The present study revealed that, there may be some possibilities of phylogenetic relationship between the genera of light preferred shade loving group of butterflies and the butterflies of light loving group and also between shades preferred light loving group of butterflies and the butterflies of shade loving group. As the phylogenetic study of Southeast Asian butterflies have not been done beyond subfamilies level (Corbert and Pendlebury 1992; Parsons 1999), it would be very early to give ultimate conclusions about those species exhibiting opposite behaviour regarding habitat use. Thus, detailed study is necessary in future to establish the relationship among various butterfly groups.

However, the study carried out across the globe emphasizes the importance of environmental heterogeneity for generating and maintaining species diversity in tropical logged forest (Huston, 1994; Rosenzweig, 1995). Ganzhorn et al. (1990) and Hill et al. (1995) reported that the degraded forest vegetation is more homogeneous than primary forest. The present study also revealed gre-ater heterogeneity in forest structure within undisturbed forest than in degraded forests of Rani-Garbhanga Tropical Forest (RGTF). Dense shade or closed canopy forest of Rani-Garbhanga Tropical Forest is formed by large patches of bamboo growths and assemblages of huge *Ficus* ssp., *Michelia* sp., *Shorea* ssp., *Artocarpus chapasha*, *Lagerstroemia parviflora, Gmelina arborea, Phyllanthus aficinalis, Bauhinia variegata, Terminalia belarica*, *Phoebe goalparaensis*, *Amoora wallichii, Cassia fistula* species etc. The studies of DeVries (1987) and Beccaloni (1997) emphasizes that butterfly distributions are expected to depend on the heavy growth and abundance of their host plants even at smaller area within forest stands and changes in stratification and type of forest vegetation may reflect differences in the com-position of butterfly community. The forest disturbances, that had caused increased canopy openness and light penetration leads to the increase in the abundance of herbaceous growth and vines and favours the species normally frequenting tree fall gaps and streams (Ghazoul, 2002). He also emphasizes that, in Amathusiinae, Satyrinae and Apaturinae subfamilies, those species with higher shade preference with narrower geographical distribution, were most adversely affected by forest de-gradation, whereas, cosmopolitan species with low shade preference benefited from forest degradation. The study in Rani-

Garbhanga Reserve Forest also revealed that, there is a significant difference in the faunal composition of butterfly assemblages in undisturbed and disturbed forest, which are strongly associated light and shade preference and geographical distribution of the species. Due to loss of heterogeneous vegetation in degraded forest of Rani-Garbhanga Tropical Forest, the dense canopy cover and transparent ground cover has been reduced, ultimately leading to the declination of the forest butterfly species. PCA analysis also shows that in case of undisturbed forest, the Principle Component factor 1 (PRIN1) increased with the increasing value of canopy cover, under story and tree density and the decreasing value of ground cover and low cover which represented the dense forest with closely spaced trees, whereas, the Principle Component factor1 (PRIN 1) of degraded forest is increasing with the increase of ground cover, low cover, underscore and tree density and decreasing canopy cover, which represented the widely spaced trees with canopy openness. The Principle Component factor 2 (PRIN 2) represented the overall size and architecture of the forest, which has no major variation in both the primary and degraded forest due to the presence of monoculture plantations and medium sized trees in degraded forest (Table 4). The comparison between vegetation structure and the diversity of Nymphalinae, Charaxinae, Heliconiinae and Danainae in undisturbed forest shows the significant negative correlation between vegetation density (PRIN1) and butterfly diversity, in which the diversity of butterfly is decreasing with increasing (PRIN1 factor) canopy cover or shade sites (Figure 11). On the contrary, diversity of Amathusiinae, Satyrinae and Apaturinae are shows significant positive correlation with increased canopy cover (Figure 10).

The creation of gaps by local tree fellers at Rani-Garbhanga Tropical Forest changes the natural disturbance regime and causes a threat to biota confined to the closed canopy forest. According to Blau (1980), Schulze and Fielder (1998), Hill (1999) and Hamer et al. (2003), the majority of close canopy forest butterflies, especially Amathusiinae, Satyrinae and Apaturinae are sensitive to changes in moisture availability and humidity; hence the changes in canopy cover and light penetration have impact on butterfly distributions through micro-climatic effects on adult and larval survival, as well as indirectly through effects on host plant quality. This has also been observed in the present study of butterflies at Rani-Garbhanga Tropical Forest. While, the species richness and diversity are higher in gaps or degraded forest, the conservation value of close canopy forest lies in the presence of species with restricted ranges. Thus, the conservation value of a biological community is determine not only by its richness and diversity, but also by the rarity and endemicity of its constituent species and the ability of species to maintain viable population in the face of disturbance pressure, which has also been suggested by the Ghazoul (2002).

Conclusion

In summary altogether eight subfamilies of Nymphalidae butterflies have been observed in study area of which majority of five subfamilies have been found to occur in degraded forest and rest have been found in closed canopy forest. Mean proportions of butterflies in shade sites were higher for Amathusiinae, Satyrinae and Apaturinae than that of Nymphalinae, Charaxinae and Heliconiinae subfamilies. While the proportion of individuals of each species of butterflies occurring at gap sites or degraded forest were significantly higher in Nymphalinae, Charaxinae, Heliconiinae and Danainae subfamilies than the others, indicating the phylogenic relationship of shade and light preferences of Nymphalid butterflies. The butterfly species sampled in closed canopy forest had more restricted geographical distribution than those that were being sampled in degraded forest. The species sampled in degraded forest had significant positive relation with wide geographical range, whereas, the species sampled in closed forest had significant but negative relation with wide range species. Thus, the result supports the proposed hypothesis that, the increasing diversity of butterflies in degraded tropical forest is associated with loss of species with restricted geographical distributions. Again, most of narrow range species belong to Amathusiinae, Satyrinae, and Apaturinae, whereas, Nymphalinae, Charaxinae, Heliconiinae and Danainae were generally wide range species. In Amathusiinae, Satyrinae, and Apaturinae, there was a significant and strong negative relationship between shade preference and impact of forest destruction, which means that, the shade preferred species were most adversely affected by forest destruction. However, there was a positive relationship between light preference and impact of forest destruction on Nymphalinae, Heliconiinae and Danainae. The creation of gaps by local tree fellers at Rani-Garbhanga Reserve Forest changes the natural disturbance regime and causes a threat to biota confined to the closed canopy forest. The majority of close canopy forest butterflies, especially Amathusiinae, Satyrinae and Apaturinae are sensitive to changes in moisture availability and humidity; hence the changes in canopy cover and light penetration do have an impact on butterfly distributions through microclimatic effects on adult and larval survival, as well as indirectly through effects on host plant quality. While, the species richness and diversity are higher in gaps or degraded forest, the conservation value of close canopy forest lies more in the presence of species with restricted ranges. Thus, the conservation value of a biological community is determined not only by its richness and diversity, but also by the rarity and endemicity of its constituent species and the ability of species to maintain viable population in the face of disturbance pressure. These finding clearly indicates that, there is a strong and significant relationship between the species of narrow range of geographical distribution and the shade preference of the species. It is also clear that most of the restricted distribution range species are affected due to forest degradation. These findings have clearly brought into light that increasing diversity in degraded forest is associated with the loss of species with restricted geographical distribution. There might be some potentiality of phylogenetic relationship between the genera of light preferred shade loving group of butterflies and the butterflies of light loving group. In the present study, there is a significant difference in the faunal composition of butterfly assemblages in undisturbed and disturbed forest, which is being strongly associated with species light and shade preference and geographical distribution. Due to loss of heterogeneous vegetation in degraded forest of Rani-Garbhanga Tropical Forest, the dense canopy cover and transparent ground cover has been reduced, which in turn leads to the reduction in numbers of forest butterfly species.

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