Taxonomic Diversity of the Fruit-feeding Butterflies (Lepidoptera: Nymphalidae) in Kubah National Park, Sarawak, Southwest Borneo

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Abstract.– The diversity of nymphalid assemblages in primary, secondary and heath forests and forest edges in Kubah National Park, Kuching, was assessed by employing both conventional and taxonomic biodiversity indices. The lower variation in the taxonomic distinctness index (Λ^+) in the primary forest indicated a distantly related array of nymphalids at a low taxonomic level, which is likely to be sustained by the numerous microhabitats. However, despite that the primary forest contained 74% of the total nymphalid species sampled in this study, the forest edge had the highest Λ^+, specifying speciose genera that were abundantly sampled in this habitat. Closer values of Λ^+ between the secondary and heath forests and forest edges showed a resemblance in the taxonomic properties for these three assemblages, as having similar habitat requirements and ecological adaptations in their respective habitat. The utilization of taxonomic-based biodiversity indices inclusively leads to more meaningful findings and assists in diversity studies.

KEY WORDS: Taxonomic diversity, fruit-feeding butterflies, Nymphalidae, Kubah National Park

INTRODUCTION

Recording and understanding species abundance in natural communities and the processes that control their variation in space and time are fundamental to ecological studies of diversity and its application to environmental management, monitoring and conservation.

Although the highest biodiversity is known in the tropics, terrestrial tropical environments and especially rainforests are being destroyed at a rapid pace due to the expansion in the human global economies and population growth mediated changes in land use and resource exploitation patterns (Caughly and Gunn, 1996; Laurance and Peres, 2006; Nepstad et al., 2006). Therefore, studies of diversity patterns are urgently required.

Insects not only play a major role in many terrestrial ecosystem processes, including pollination, herbivory, decomposition and nutrient recycling, seed predation and predation / parasitism of other species (Janzen, 1987; Band, 1994), but form the major portion of the vast diversity of known (and estimated likely actual net) animal and plant species in tropical rainforests, and are greatly affected by the relentless habitat destruction (Lowman, 1997). Habitat complexity allows the diverse heterogeneous assemblages of insects, since two species of insects cannot coexist in the same habitat if their temporal and spatial niche requirements completely overlap (Speight et al., 2008; Wagner, 2001). The vast variety of flora in the tropical rainforests has created and served as a suitable and diverse range of habitats for the specific associations between insects and plants, which in terms of being a food source range

from specialist monophagy to generalist oligophagy (Kitching et al., 1997). Therefore, the considerable species richness observed for the insect communities is strongly associated with the diversity of plants in that particular area.

The tremendous diversity of insects, especially in tropical rainforests, is thus related to the habitat they are found in, as the species abundance of insects reflects the heterogeneity of niches including food plants in the particular habitat (Speight et al., 2008). Therefore, as species persistence or extinction is affected by the habitat status, it is vital to assess the overall species abundance so that proper documentation and suitable measures for conservation can be performed (Speight et al., 2008). Moreover, since species occur in characteristic limited ranges of habitats and tend to be more prevalent around their environmental optimum, which can be different for larval and adult insect forms, then their relative composition and sustainability changes along environmental gradients. Although predictions have been performed by extrapolation from known relationships between species diversity and habitat area (Watt et al., 1997), this technique is limited in that it neglects the ability of a species to survive in the new habitat.

Forest canopy alone is found to be dominated by Coleoptera, Hymenoptera, Lepidoptera and Araneae (Basset, 2001). Most of these entomofauna are considered as flagship taxa and so are commonly utilized as the subjects of research for biodiversity purposes. Lepidoptera, including butterflies, are known to be sensitive to changes in their habitat, including floral diversity, fruit diversity, habitat structure (including water supply, canopy light levels, rainfall and ground water, vegetative structure and climatic

change), and so, combined with their general ease of monitoring and identification (as adults), from important bioindicators for monitoring the environment (Pearson, 1994; Parmesan et al., 1999; Hill et al., 2001; Brehm et al., 2003). Specifically, butterflies are among the most well studied lepidopteran group, and are typically documented to be host-plant specific and thus a good bioindicator (Corbet and Pendlebury, 1992; Fermon et al., 2000; Cleary and Gennert, 2004). Fruit-feeding butterflies are defined as those species that are attracted to fruit to feed, rather than plant nectar, but note that this may not be their sole food source as for example they may also utilize honey dew, tree sap and rotting plant materials. Regardless, this specialist feeding guild of butterflies is characterized distinctly from the other butterflies by their reduced foreleg size in the imago (adult) stage (Corbet and Pendlebury, 1992). Their colorful appearance and relatively large size makes them conspicuous and easy to identify and so are one of the popular groups of insects used to classify the tropical insect diversity (DeVries et al., 1997; DeVries and Walla, 2001). The potential ease of sampling of these butterfly taxa (when allowing for their temporal and spatial zonation) also assists in predicting the patterns of diversity in any particular habitat (DeVries et al., 1997). Furthermore, they are also known to be very sensitive to any changes in the environment, as mentioned above, as well as in physical factors of the habitat, such as gaps and edge (Ramos, 2000; Haber, 2006).

In the present study, a survey on the frugivorous butterflies in four contrasting forest habitats was conducted with the aim of evaluating the influence of different vegetation types to the properties of the nymphalid assemblages. Taxonomic
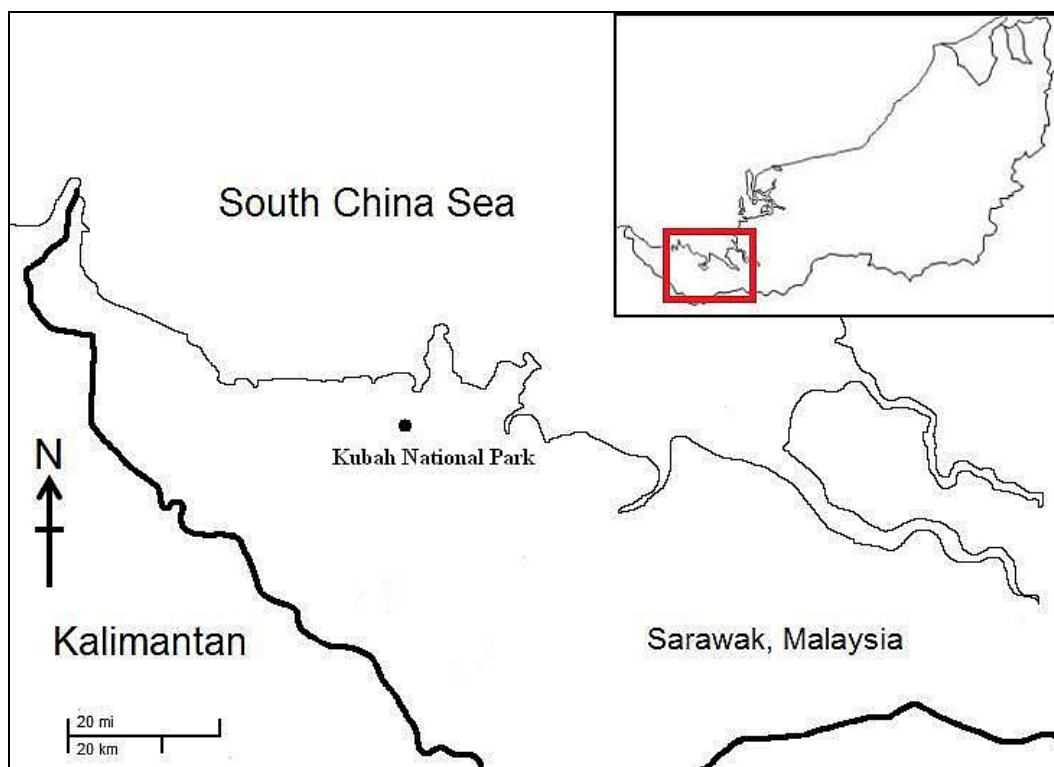
FIGURE 1. Study area, located in the Kubah National Park, Kuching, Sarawak, in the southern part of Malaysian Borneo (Source: Modified after Google Map 2011).

relatedness-based diversity indices were utilized as the main approach in this study, since they are relatively insensitive to sampling effort and produce more intuitive information than other techniques (Anu and Sabu, 2006). Different interpretations between the standard diversity and taxonomic diversity indices were also evaluated.

MATERIALS AND METHODS

Study site.– The study was conducted in a mixed-dipterocarp forest in Kubah National Park, Kuching, Sarawak (N 1°36'48.43", E 110°11'51.59"), approximately 22 km west of Kuching city (Fig. 1). The 22 km² conservation area is comprised of mixed-dipterocarp, alluvial, submontane, heath and secondary forests (Hazebroek and Abang Morshidi, 2000). Butterfly trapping was conducted along four different trails, (Waterfall, Rayu, Belian and Summit), which each represent contrasting habitats of primary, heath and secondary forests plus forest edges, respectively) (Table 1). Small jungle streams were found at the Waterfall and Belian Trail, while damp areas were observed along the Summit Trail. The secondary forest in this park results from the gradual succession from agricultural land over 30 years following the establishment of this park (Hazebroek and Abang Morshidi, 2000).

TABLE 1. Habitat descriptions for the study area in Kubah National Park, Sarawak, based on Hazebroek and Abang Morshidi (2000) and personal observations.

Forest Trail	Forest Habitat	Elevation (m amsl)	Plant Community
Waterfall	Primary forest	305	*Pandanus* spp., Strangling fig tree, *Alocasia robusta* (Giant Aroid)
			Large tree crowns which permits only a low level of light penetration and less dense woody undergrowth (seedlings and sapling trees, shrubs and climbers)
Belian	Secondary forest	120	Succession (30 years) from farmland with replanting of mostly 'Engkabang', and also local fruits such as *Artocarpus* spp., *Durio* spp. and *Musa* spp.
Summit	Forest edge	120 – 270	Along the road to the summit of Mt. Serapi, at the ridge of a transition from primary to heath forests
Rayu	Heath forest	274	Bintangor, *Dryobalanops becarii* (Kapur Bukit), *Shorea inappendiculata* (Tekam)
			Dense herbaceous undergrowth, scarce buttresses and climbers, and single-dominant communities of trees

Rainfall during the study period at the four trails is not known, but data from the nearby Meteorological Department in Kuching, based in Kuching International Airport (N 1°29', E 110°20' in South Sarawak, 21.7 m amsl), some 37 km away, gave a range from an average 133 mm per month in September 2009 to 625 mm per month in October 2009, with the driest period in July 2009 (78.5% monthly mean relative humidity).

Butterfly sampling.– Sampling was performed for 14 continuous days per month, for six months from 17th May 2009 to 17th November 2009 inclusive (Table 2). From the total of 84 days of sampling, five replicates of sampling unit were selected in each forest habitat, with each sampling unit being comprised of one ground level baited trap hung 1 – 1.5 m above the ground, and a canopy baited trap hung at between 21 – 27 m above the ground (per sampling unit). Thus, for the four forest habitats, a total of 20 traps were established at the ground level, and another 20 traps at the canopy level (Fig.2). Baited traps were installed by utilizing the single-rope technique, and suspended from thin nylon ropes run over the branches which are adjusted to the desired height. All traps were baited with pineapples, and replenished with new fermenting fruit on each subsequent trapping day. In order to minimize sampling bias, only fermenting pineapples were used as bait in this study, as the main approach is not the bait preference among the nymphalids. Missing baits, for example due to removal by squirrels or dislodging by strong wind were also replaced the next day. After 14 days of sampling, all traps were then collected and re-installed in the next

TABLE 2. Summary of the six sampling periods performed during May to November 2009, in Kubah National Park, Sarawak.

Sampling Occasion	Date
First	$17^{th} - 30^{th}$ May 2009
Second	$16^{th} - 29^{th}$ June 2009
Third	22th July $- 4^{th}$ August 2009
Fourth	25th August $- 7^{th}$ Sept 2009
Fifth	29th Sept $- 12^{th}$ Oct 2009
Sixth	$4^{th} - 17^{th}$ Nov 2009

sampling occasion. Butterfly specimens were preserved properly and identified to species level, following Otsuka (1988) and Tsukada (1991). All specimens were deposited at the UNIMAS FRST Museum, Kota Samarahan.

Statistical analyses.– The taxonomic-based biodiversity indices included two general measures, which are parametric and non-parametric. The parametric measure is comprised of the two different indices of the average taxonomic diversity (Δ) and the average taxonomic distinctness based on abundance data (Δ^*), whereas the non-parametric measure is based on the presence-absence of species data to acquire the average taxonomic distinctiveness (Δ^+) and the variation in taxonomic distinctiveness (Λ^+) indices (Clarke and Warwick, 2001). In the present study, four taxonomic levels were considered for the analysis, which were species, genus, subfamily and family. On the other hand, the conventional alpha-biodiversity indices of species richness (S), Shannon's richness and evenness diversity (H'), Simpson's diversity (1-D) and Simpson's index of evenness (1-λ') were generated with Past v.1.96.

The calculated Λ^+ index for a local community can be tested based on a master taxonomy list of a region, and simulated subsets are used to produce a probability funnel plot from the calculated Λ^+ against which the measured local Λ^+ can be compared. Each regional list was compiled from the data in the present study and the Bornean butterflies (Otsuka, 1988). This overall analysis was tested against the null hypothesis that suggests that species present at any one place or time would behave like a random selection from the regional species selection pool (Clarke and Warwick, 1998).

A dendogram of the Bray-Curtis similarity coefficient based on hierarchical agglomerative clustering was also generated with a Multivariate Statistical Package (MVSP) to compare between forest types. Lastly, by deriving appropriate variance formula, a 'confidence funnel' was derived against which the distinctiveness values for any specific approaches, such as habitat types, could be checked (Clarke and Warwick, 1998). The taxonomic relatedness-based diversity indices and variances of qualitative taxonomic diversity indices value Δ^+ (with respect to the master list values as estimated by drawing 95% confidence funnels) were generated using the Vegan package (Oksanen et al., 2009) developed for R program (R Development Core Team, 2008).

TABLE 3. Recorded species and numbers of individuals collected with baited traps at two different heights above ground level, in Kubah National Park, Sarawak.

Species	Number of Individuals at Different Trap Heights		Total
	Ground	**Canopy**	
Charaxes			
Charaxes bernadus repititus Butler 1869	3	3	6
Charaxes durnfordi everetti Rothschild 1893	1	0	1
Polyura athamas uraeus Rothschild & Jordan 1890	0	1	1
Prothoe franckii borneensis Fruh 1913	24	1	25
Morphinae			
Amathusia perakana perakana Honrath 1888	1	2	3
Amathusia phidippus phidippus Linnaeus 1763	4	0	4
Amathuxidia amythaon ottomana Butler 1869	46	3	49
Discophora necho cheops C & R Felder 1867	2	0	2
Faunis stomphax stomphax Westwood 1858	1	0	1
Zeuxidia amethystus wallacei C & R Felder 1867	42	3	45
Zeuxidia aurelius euthycrite Fruh 1911	24	1	25
Zeuxidia doubledayi horsefieldii C & R Felder 1867	27	4	31
Nymphalinae			
Amnosia decora buluana Fruh 1913	6	0	6
Bassarona dunya monara Fruh 1913	93	0	93
Bassarona teuta bellata Distant 1886	46	26	72
Chersonesia intermedia Martin 1895	1	1	2
Cirrochroa emalea emalea Guenin Meneville 1843	2	0	2
Dichorragia nesimachus derdas Fruh 1903	3	0	3
Dophla evelina magama Fruh 1913	1	0	1
Euthalia iapis ambalika Moore 1858	2	0	2
Euthalia monina bipunctata Vollenhoeven 1862	0	3	3
Kallima limborgi boxtoni Moore 1879	3	0	3
Lexias canescens canescens Butler 1868	2	0	2

RESULTS

In total 665 individuals (84 from the canopy and 581 from the understory) representing 49 species of Nymphalidae (5 unique to the canopy, 20 unique to the understory and 24 shared species) (Table 3) were sampled in this study. These represented a total of 4 subfamilies with

TABLE 3. Continue.

Species	Number of Individuals at Different Trap Heights		Total
	Ground	**Canopy**	
Lexias cyanipardus sandakanus Fruh 1896	3	0	3
Lexias dirtea chalcenoides Fruh 1913	19	1	20
Lexias pardalis borneensis Tsukada 1991	4	0	4
Lexias pardalis dirteana Corbet 1941	26	1	27
Phalanta alcippe alcippoides Moore 1900	1	0	1
Rhinopalpa polynice helionice Fruh 1912	0	1	1
Tanaecia aruna aparasa Vollenhoeven 1862	11	1	12
Tanaecia clathrata coerulescens Vollenhoeven 1862	23	3	26
Tanaecia munda munda Fruh 1899	2	1	3
Tanaecia pelea djataca Fruh 1913	0	1	1
Satyrinae			
Coelites euptychioides euptychioides C & R Felder 1867	2	1	3
Erites elegans elegans Butler 1868	2	0	2
Melanitis leda leda Linnaeus 1758	14	8	22
Melanitis zitenius rufinus Fruh 1908	10	4	14
Mycalesis amoena Druce 1873	1	0	1
Mycalesis anapita fucentia Fruh 1911	4	0	4
Mycalesis fusca adustata Fruh 1906	9	1	10
Mycalesis horsefieldi hermana Fruh 1908	0	1	1
Mycalesis kina Staudinger 1892	17	3	20
Mycalesis maianeas kadasan Aoki & Uemura 1982	9	1	10
Mycalesis mineus macromalayana Fruh 1911	1	0	1
Mycalesis mnasicles mnasicles Hewitson 1864	18	3	21
Mycalesis orseis borneensis Fruh 1906	13	3	16
Mycalesis patiana patiana Eliot 1969	1	0	1
Neorina lowii lowii Doubleday 1849	20	1	21
Ragadia makuta umbrata Fruh 1911	37	1	38
TOTAL (49 species)	**581**	**84**	**665**

differences in their abundance at the species and subfamily level in abundance between each habitat (Table 4). The conventional diversity indices revealed somewhat

TABLE 4. Conventional and taxonomic diversity indices of the fruit-feeding butterflies (Lepidoptera: Nymphalidae) in four different forest habitats in Kubah National Park, Sarawak. (Values in parentheses show the range for 95% confidence interval, derived from PAST v.1.96).

| Alpha diversity Index	Forest Types			
	Primary	Secondary	Edge	Heath
Parametric Diversity Index				
Total species richness (S)	26 (26 – 36)	32 (25 – 34)	36 (28 – 38)	29 (28 – 38)
Shannon's diversity index (H')	2.80 (2.85 – 3.18)	3.03 (2.82 – 3.17)	2.99 (2.89 – 3.18)	2.89 (2.89 – 3.18)
Simpson's diversity index (1-D)	0.92 (0.92 – 0.95)	0.93 (0.92 – 0.95)	0.92 (0.92 – 0.95)	0.93 (0.92 – 0.94)
Simpson's evenness index (1-λ')	0.63 (0.59 – 0.74)	0.65 (0.59 – 0.75)	0.55 (0.57 – 0.71)	0.62 (0.57 – 0.71)
Average taxonomic diversity (Δ)	83.48	83.24	84.91	83.29
Average taxonomic distinctness (Δ*)	90.09	88.51	91.53	89.14
Non-Parametric Diversity Index				
Average taxonomic distinctness (Δ^+)	88.44	85.39	84.39	86.82
Variation in taxonomic distinctness (Λ^+)	397.1	464.1	440.0	457.3

contrasting results compared to the parametric taxonomic diversity (Table 4). Significantly, for both the average taxonomic diversity (Δ) and average taxonomic distinctness (Δ*), the highest diversity was found at the forest edge whilst the lowest diversity was found in the secondary forest (Table 4). In contrast, Shannon's diversity index (H') recorded the highest diversity in the secondary forest and the lowest diversity in the primary forest, whilst Simpson's evenness index (1-λ) gave essentially the same values for all four habitats (Table 4).

The non-parametric taxonomic diversity indices Δ^+ and Λ^+ showed a different and contrasting result for the four fruit-feeding butterfly assemblages. The average taxonomic distinctness (Δ^+) was highest in the primary forest and lowest in the forest edge, whereas the most varied taxonomic distinctness (Λ^+) was formed in the secondary forest and the lowest in the primary forest (Table 4).

The Bray-Curtis similarity coefficient showed a higher similarity between the Master-list and the assemblage in the forest edge, compared with the other forest habitats. On the other hand, the nymphalid assemblages in the primary forest showed the closest resemblance with the heath forest, and were the least related to the master list (the list of all species recorded in the area) (Fig. 3). Thus, the forest edge has sustained the highest number of representative species in common with the Master-list, whereas the least was observed in both heath and primary forest. The average taxonomic distinctness (Δ^+) values for the fruit-feeding butterflies from all four forest habitats fell within the 95% funnel confidence for the appropriate numbers of species randomly drawn from the regional species pool (Fig.4).
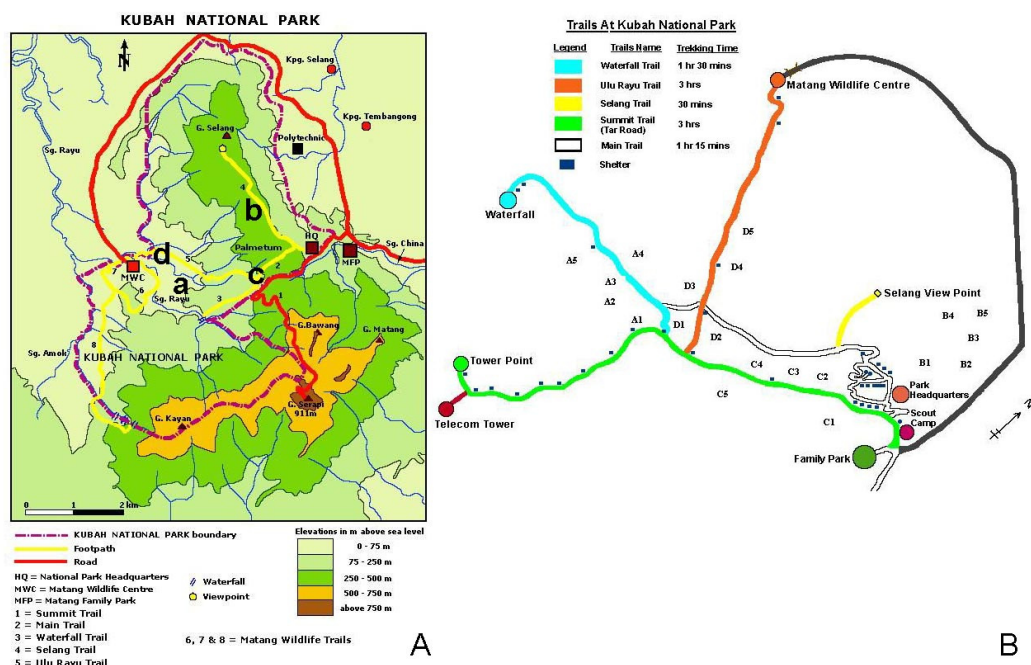
FIGURE 2. A. Study site in Kubah National Park, Sarawak with four sampling areas; a. Primary forest, b. Secondary forest, c. Forest edge, d. Heath forest. **B.** Numbers designate individual replicate sampling units which represents one canopy and one ground level trap (Note: Map is not up to scale) (Source: Hazebroek and Abang (2000)).

DISCUSSION

Acquiring the taxonomic diversity and distinctness indices is an alternative approach in assessing the overall diversity in a particular habitat. Overall, there are four taxonomic indices, related to the abundance and presence-absence data, which can be used as a guide to evaluate the biodiversity sustained in the area. Taxonomic diversity is measured as the average taxonomic 'distance' between two individuals which are chosen at random (Clarke and Warwick, 1998). On the other hand, taxonomic distinctness is the average path length between two different species (Clarke and Warwick, 1998; Simaika and Samways, 2009).

In order to investigate the taxonomic evenness properties of the nymphalids in the present study, data representing assemblages from all forest habitats were analyzed and the non-parametric diversity index was highlighted. Due to the incapability of detecting variations in taxonomic evenness (Anu and Sabu, 2006), the reliance on the average taxonomic distinctness index (Δ^+) was shifted to the variation in taxonomic distinctness index (Λ^+), which then revealed that the primary forest was associated with high taxonomically even nymphalids assemblages. In other words, nymphalids sustained in this habitat were distantly related at a low taxonomic level and thus the phylogenetic diversification was high.

The high taxonomic evenness in the primary forest likely reflects (and so potentially revealed) the availability of a
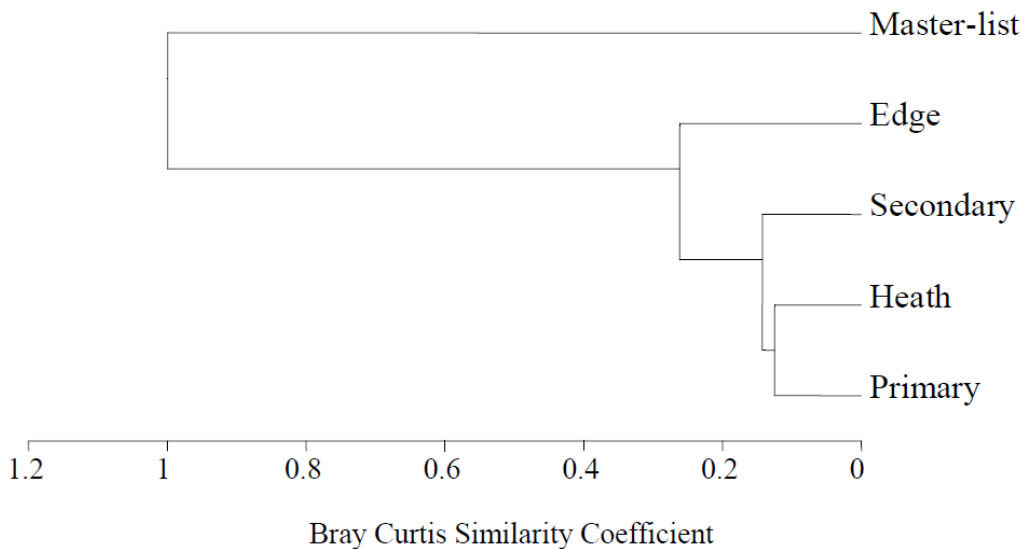
FIGURE 3. Dendogram based on hierarchical agglomerative clustering (group-average linking) of fruit-feeding butterflies (Lepidoptera: Nymphalidae) in four different forest habitats with the Master-list (Bornean nymphalids) in Kubah National Park, Sarawak.

wide range of habitats for nymphalid species. For instance, the presence of gaps in this habitat would attract nymphalids that are known to exploit forest gaps, such as Nymphalinae and Charaxinae (Hamer et al., 2003). Alterations in the canopy cover, which would influence the light penetrability, will disrupt the microclimatic conditions of the particular habitat, and consequently affect the adult and larval survival, as well as the host-plant quality (Hamer et al., 2003).

The numerous microhabitats offered by the diversity in the primary forest have generally formed the most suitable habitat for insects (Richards, 1996). Peculiarities, such as the occurrence of numerous sympatric tree species of the same genus; *Shorea* and *Eugenia*, provide a better and long-term habitat for the entomofauna, compared with the pioneer tree species in secondary forests (Richards, 1996). Forest butterflies are known to be very specific in

choosing their larval host-plants (Schulze et al., 2001), and so the availability of particular larval host plant densities and quality influences their distribution, as well as parasitoids or other predators, and for adults, the presence of suitable food, courtship areas, light, etc.

In contrast, despite 74% of the total nymphalid species listed in the present study being found in the forest edge, it recorded the lowest average taxonomic distinctness index (Δ^+) which indicated the least number of genus and subfamilies of the nymphalids being sampled. Speciose genera, such as *Bassarona*, have negated the value of the taxonomic index for this habitat, as being abundantly dominated by these nymphalids. Apparently, regardless of the availability of greater variations in terms of species composition in this type of habitat (Ramos, 2000), the taxonomic evenness among the nymphalid species were low.
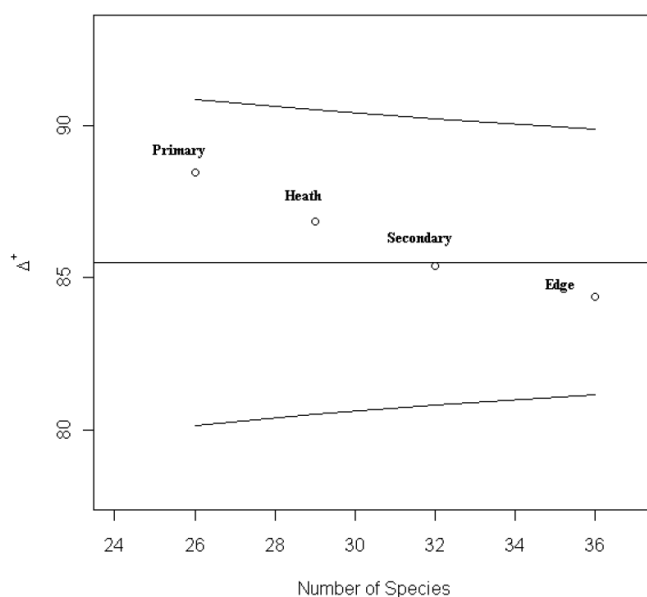
FIGURE 4. Measured values of Δ+ of the fruit-feeding butterfly assemblages in four different forest habitat types (sites) in Kubah National Park, Sarawak, plotted against the number of species as points on the simulated 95% confidence funnel and theoretical 95% confidence funnel.

Closer values of Λ^+ between the secondary, heath and forest edge indicate the similarity of taxonomic properties for those three assemblages of nymphalids. The high rise in Λ^+ values means that species are more closely related at low taxonomic levels and are considered to have a lower phylogenetic diversification (Clarke and Warwick, 2001; Moreno et al., 2009). Apart from that, it also shows the unevenness in the taxonomic tree as there might be some groups of species which are under- or over-represented (Clarke and Warwick, 2001). This was observed for the nymphalids in these three habitats, and indicated similar habitat requirements as well as ecological adaptations in their respective forest habitats (Anu & and Sabu, 2006). Moreover, the high Λ^+ and lower taxonomic spread are characteristics of degraded environments (Anu and Sabu, 2006).

Low species richness in small forest fragments, particularly for butterflies, was observed by Didham (1997), who concluded that habitat availability and suitability are essential for the maintenance of invertebrate populations. The impacts of forest clearance as well as geographical fragmentation, for example, have threatened the insect diversity and thus became a major determinant of these insect species assemblages (Dennis, 1997; Stork et al., 1997). Nonetheless, these habitats should actually receive equal conservation attention, as the nymphalids associated here have adapted very well in order to survive in these less favorable habitats (Anu and Sabu, 2006). The presence of two species that are endemic to Borneo (*M. amoena* and *M. kina*) in the secondary and heath forest, respectively, raises the conservational value of the disturbed area (Otsuka, 1988; Hamer et al., 2003).

Taxonomic-based indices may prove to be the most ecologically relevant measure of biodiversity for the purpose of habitat disturbance assessment. Apart from being independent of sampling effort and size, it is also useful in indicating the habitat status for environmental assessments (Clarke and Warwick, 1998, 2001). Traditional biodiversity indices are somehow unsuccessful in reflecting the phylogenetic diversity, as species richness does not possess monotonic responses to environmental degradation (Simaika and Samways, 2009). In contrast, taxonomic diversity and distinctness have the ability to relate to the habitat quality and so the evaluation priorities for habitat conservation (Anu and Sabu, 2006).

CONCLUSION

The utilization of the taxonomic relatedness-based diversity indices revealed the interesting phylogenetic diversification in this particular array of fruit feeding nymphalids. Despite sustaining a poor number of species, the primary forest is associated with these distantly related frugivorous butterflies in different habitat types. On the other hand, speciose genera of nymphalids were recorded at the forest edge and thus the taxonomic evenness among nymphalid species were low. A closer resemblance of taxonomic properties was also observed between the secondary and heath forests and the forest edge, which indicated similar habitat requirements and ecological adaptations of these nymphalids in the respective forest habitats. The practical utility of taxonomic relatedness-based diversity indices was highlighted in this present study in comparison with the conventional indices.

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