

Butterflies as potential bioindicators of primary rainforest and oil palm plantation habitats on New Britain, Papua New Guinea

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Our research team worked with Nakanai land-holders in Papua New Guinea to perform the first survey of butterflies in the Lake Hargy caldera of West New Britain Province. Methods included modified Pollard transects quantifying sampling effort based on aerial netting and visual observations, as well as traps baited with fermenting fruit. Results were compared with surveys on the adjacent Hargy Oil Palm plantation. Our sampling yielded 312 specimens representing 73 species; of these, 50 were limited to primary rainforest, 12 to oil palm plantation and 11 species occurred at both sites. Four species are newly recorded for New Britain, including one potentially invasive species on *Citrus*. Singleton specimens made up the largest abundance class in the data set, representing 34% of records in primary rainforest. Sixty-two percent of the butterfly taxa recorded are regionally endemic to the Bismarck island chain or to New Britain in particular. Calculated levels of similarity between sites ranged from 0.151 to 0.262, suggesting the oil palm and rainforest habitats supported highly distinct species assemblages. Although rapid assessment data such as these are necessarily limited in scope, they can still aid in documenting the impact on biodiversity from conversion of primary tropical rainforest to oil palm monoculture.

Key words: butterfly, Papua New Guinea, New Britain, oil palm, biodiversity, similarity, conservation

INTRODUCTION

WITHIN the last decade, oil palm (*Elaeis guineensis*) has made rapid gains as a source of vegetable oil for human consumption, industrial production, cosmetics, and, increasingly, biofuels (Fitzherbert *et al.* 2008; Koh and Wilcove 2007). A native of West Africa, oil palm has recently supplanted soybean as the world's foremost vegetable oil crop (Turner *et al.* 2008). Malaysia, Indonesia, and Papua New Guinea have witnessed especially rapid expansion of oil palm cultivation (Buchanan *et al.* 2008; Fitzherbert *et al.* 2008). However, less than 1% of the research papers published on oil palm between 1970 and 2008 consider issues of biodiversity and species conservation (Turner *et al.* 2008). Unfortunately the biomes where oil palm plantings have burgeoned are those harbouring some of the world's most distinctive, and most vulnerable, biota: such regions have been termed biodiversity hotspots (Myers *et al.* 2000). For example, the East Melanesian Islands Hotspot comprising the Bismarck Archipelago in eastern Papua New Guinea is under great pressure from deforestation and unsustainable farming practices (Conservation International 2010). The island of New Britain, whose land area constitutes more than two-thirds of the Bismarck Archipelago, lost in excess of 12% of its forest cover between 1989 and 2000 (Buchanan *et al.* 2008).

Compared to primary rainforest, oil palm monocultures are characterized by low structural complexity comprising a low canopy and sparse

undergrowth. Vines and epiphytes may become established in the upper levels of plantation trees, but these do not necessarily boost species richness, at least with respect to birds (Aratrakorn *et al.* 2006) and butterflies (Koh 2008). Plantation trees are typically replaced every 25–30 years, resulting in even-aged stands. The uniform spacing of trees and lowered canopy cover drive greater microclimatic fluctuations than those seen in primary forest (Fitzherbert *et al.* 2008; Turner and Foster 2009).

Butterflies hold promise as bioindicators of terrestrial environments and habitat quality, hence their established role in biological monitoring and conservation (Koh 2007; McGeoch 1998; Stork *et al.* 2003). Other diverse invertebrate taxa used in biological assessment include beetles (Golet *et al.* 2008) and moths (Chey 2006), but butterflies have the advantage of being especially well characterized (Ehrlich 2003), and they are charismatic (New *et al.* 1995). Because of their often close association with specific larval host plants, as well as their pollinating activities, butterflies can be strong indicators of the presence of particular plant taxa (Sparrow *et al.* 1994). The Papua New Guinea (PNG) butterfly fauna owes its high conservation value to its diversity and endemism (Parsons 1998; Perlman and Adelson 1997). Many forest-dwelling butterflies in PNG are specialists on one or a few closely related host plants; consequently, species richness is correlated with high levels of plant diversity (Koh 2008; Southwood *et al.* 1979). Thus

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targeting butterflies for conservation planning is likely to benefit non-target biota substantially (Reyers *et al.* 2000). Here we present details from the first survey of butterflies in the Lake Hargy caldera region of West New Britain, an area remaining largely uninhabited and even unexplored, in part because of its rugged topography. The use of butterflies as potential bioindicators allows us to make inferences on anthropogenic alterations to habitat quality and impacts on biodiversity at a regional spatial scale.

MATERIALS AND METHODS

Study sites

New Britain, PNG (c. 5°30'S, 151°30'E, 35 000 km²) lies east of the main island of New Guinea and forms a major part of the Bismarck Archipelago, a chain characterized by active vulcanism.

Lake Hargy Caldera (LHC)

The Lake Hargy caldera spans 11 km and lies 14 km east of Biella, West New Britain Province. In August 2007, July 2009 and June 2010 we established our base camp on the north shore of Lake Hargy, near its outlet, the Lobu River (5°20.64'S, 151°08.01'E, 340 m a.s.l.) (see map, Figure 1). Primary tropical rain forest still surrounds Lake Hargy, but much of the adjacent low-lying coastal areas have undergone conversion to oil palm plantations. The LHC supports lowland dipterocarp rain forest, with a dense canopy reaching 30–40 m high and a complex structure comprising forest understorey, lower forest, subcanopy and canopy. The canopy holds few directly observable butterflies, but a spectacular example is the birdwing swallowtail *Ornithoptera priamus*. Natural forms of disturbance such as wind storms have toppled trees, resulting in productive forest light gaps. Forest clearings from slash-and-burn activities yield gardens which, once abandoned, provide a rich source of young host plants suitable for oviposition by butterflies (Parsons 1998). The deep understorey is relatively depauperate in butterflies, although understorey specialists such as *Tellervo* spp. may abound.

Hargy Oil Palm plantation (HOP)

Hargy Oil Palms Ltd., Biella, West New Britain Province (HOPL) comprises approximately 10 000 planned or planted hectares on the coastal plain, as well as 14 000 additional hectares on independent estates held by customary landowners, many of whom represent the Nakanai tribal group (Figure 1). HOPL purchases palm fruit from about 3650 smallholders for processing, and at the time of this

writing had been approved for certification by the Roundtable on Sustainable Palm Oil (RSPO web-site 2010). The HOP survey area was centered at the Hargy Oil Palm Guest House, atop a hill (5°18.52'S, 151° 03.08'E, 100 m a.s.l.). This site encompassed oil palm plantation but included cultivated gardens and roadsides lined with weedy vegetation. We classified oil palm plantations, weedy roadsides and village gardens as disturbed habitats. At both LHC and Hargy Oil Palm plantation, average annual rainfall exceeds 4000 mm; distinct dry and wet seasons are lacking. The local climate of LHC is comparable to that at Hargy Oil Palm plantation.

Methods

We sampled butterflies using transects and bait traps. Transects were completed following a modified Pollard Technique (Caldas and Robbins 2003; Pollard 1977; Pollard *et al.* 1975) in which butterflies are counted while walking along trails or within habitat patches at a movement rate of approximately 1 km per hour. Because our primary objective was surveying the previously unexplored Lake Hargy caldera, we concentrated our efforts there, beginning at base camp. Surveys at HOP were centered around the HOP guest house. Sampling time and distances were recorded as estimates of sampling effort. Sampling transects were carried out as weather permitted, generally between 900 h and 1300 h; typically, afternoon thunderstorms terminated collecting activities. We made an effort to classify the principal habitats in which each species was found, including forest light gaps, forest edges, stream beds, grassy swales, forest canopy, forest understorey and disturbed areas. In 2007 we sampled for a total of 47 person-hours (equivalent to about 47 km covered) at LHC and 5 hr at HOP; in 2009, 43 person-hours at LHC and 5 at HOP. Total estimated areas covered were 7 ha at LHC and 6 ha at HOP, hence the spatial scales at both sites may be classified as “large,” according to the criteria provided in Koh (2007). Sampling large areas efficiently at HOP was facilitated by the relatively great openness of disturbed habitats; viz., butterflies were far more visible at HOP than at LHC. In 2010, we sampled rain forest plants, but no butterfly surveys were carried out.

As an alternative sampling technique, we used three cylindrical van Someren-Rydon bait traps (Rydon 1964) in preliminary trials on the 2009 expedition. Because the distribution of fruit-feeding rainforest butterflies tends to be stratified vertically (DeVries *et al.* 1997; Tangah *et al.* 2004), we set up traps at different levels at the LHC site: one in the lower reaches of closed forest canopy at base camp, 21 m above the ground; one 4 m above the shore of Lake

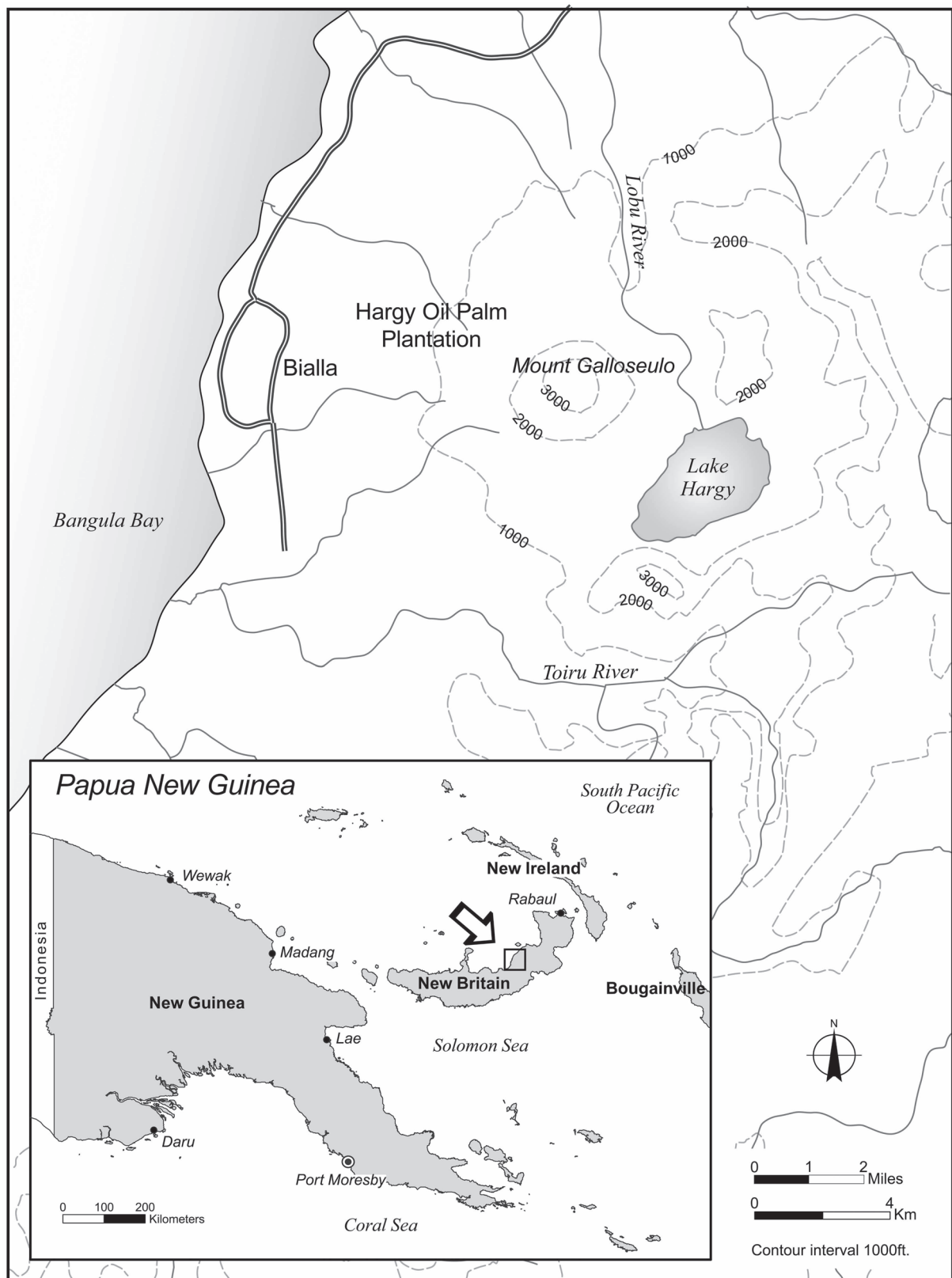


Fig. 1. Project location: Papua New Guinea and New Britain; Lake Hargy caldera region (inset). Lake Hargy caldera coordinates approx. $5^{\circ} 21'S$, $151^{\circ} 08'E$.

Hargy; the third 2 m above the Lobu River near base camp. Each trap was baited with fermenting bananas and checked twice daily over a period of 90 consecutive hours. Using both traps and transects offers the advantage of obtaining complementary data sets (Kremen 1994; Sparrow *et al.* 1994; Stork *et al.* 2003).

To a large extent, local Nakanai land-holders were employed in aerial collecting and preparing the bait traps. None was experienced in using a net, hence the smaller lycaenid and hesperiid butterflies were likely under-represented in the samples, a common bias when local collectors are used (Stork *et al.* 2003). All sampling at HOP was done by DGM.

Efforts were made to identify all butterflies encountered; however, only a portion of the diverse and abundant butterfly fauna was actually recorded. Consequently, abundance levels are rough estimates, but our methods may be regarded as reliable, assuming the number of specimens collected is highly correlated with the number of specimens observed (Caldas and Robbins 2003). Because of the difficulties identifying some butterflies in the field, most specimens were identified only following collection and careful examination, with three exceptions: *Ornithoptera priamus* (collection requiring special permit), *Papilio ulysses* and *Catopsilia pomona* (fast-flying, but recognized readily on the wing). One-half the voucher

specimens are housed at the CSU, Chico Entomology Collection; the remainder has been deposited at the Papua New Guinea National Agricultural Research Institute and the Dami Oil Palm Research Station collection. Species-level determinations of butterflies were done by DGM, consulting Parsons (1998) and Tennent (2006); subspecies determinations were carried out whenever these were taxonomically well-characterized. In the data analysis, subspecies-level determinations were treated as equivalent to species identifications. No more than one subspecies is listed for each species recorded on New Britain (Parsons 1998; Tennent 2006). Expert identifications of difficult specimens and confirmation of their geographic distribution were done by John Tennent, Chris Muller and Scott Miller.

The level of endemism for each butterfly taxon was assessed by consulting authoritative treatments of New Britain butterflies (Parsons 1998; Tennent 2006; Tite 1969). Thus, we classified biota according to three levels of endemism: island endemics, or those taxa restricted to New Britain; regional endemics, butterflies limited to the Bismarck Archipelago; and wide-ranging species, those occurring throughout PNG or with more cosmopolitan distributions (Table 1). Although we did not rear caterpillars from known host plants, as has been done elsewhere (e.g., Novotný and Basset 2000), we consulted Parsons (1998) to formulate a list

Table 1. Butterfly taxa, endemism, abundance, locality, habitats and principal host plants. Subspecies-level determinations provided where possible. Taxa are considered wide-ranging, including distributions outside Papua New Guinea (PNG), unless endemic to the Bismarck Archipelago (BA) or New Britain (NB). Range extensions listed indicate new records for New Britain. All individuals recorded by capture with net or bait trap, except *Ornithoptera priamus*, *Papilio ulysses* and *Catopsilia pomona*, which were recorded by observations only. Study localities consisted of primary forest at Lake Hargy caldera (LHC) and disturbed habitats on the Hargy Oil Palm Plantation (HOP). Records for principal host plants are provided for PNG unless indicated otherwise (source: Parsons, 1998). Host plant taxa flagged by asterisks (at first mention) were identified at the LHC site.

	Endemism ¹	Individuals recorded	Locality ²	Habitats	Principal host plants ³
Hesperiidae					
<i>Tagiades nestus presbyter</i>	BA	1	LHC	forest light gaps	<i>Dioscorea</i> sp. (Dioscoreaceae)
<i>Allora doleschallii albertisi</i>	W	2	LHC	forest edges	<i>Rhyssoterys timorensis</i> (Malpighiaceae)
<i>Hasora hurama hurama</i>	W	1	LHC	stream beds	<i>Derris trifoliata</i> (Fabaceae*) (AU) ⁴
<i>Notocrypta waigensis waigensis</i>	W	3	LHC	forest edges	<i>Alpinia caerulea</i> (Zingiberaceae) (AU)
					<i>Hornstedtia scottiana</i> (Zingiberaceae) (AU)
<i>Notocrypta renardi</i>	W	2	LHC	forest edges	<i>Alpinia caerulea</i> (Zingiberaceae)
					<i>Tapenochilus</i> sp. (Costaceae)
<i>Telicota colon vega</i>	W	3	LHC	grassy swales	Poaceae
<i>Telicota kezia lenna</i>	BA	1	LHC	grassy swales	Poaceae
<i>Parnara amalia</i>	RE	1	LHC	grassy swales	<i>Oryza sativa</i> (Poaceae)
<i>Pelopidas agna agnata</i>	W	1	HOP	disturbed areas	<i>Paspalum</i> sp. (Poaceae)
<i>Suniana sunias isabella</i>	W	3	LHC, HOP	disturbed areas, grassy swales	<i>Panicum maximum</i> (Poaceae) (AU)
					<i>Leersia hexandra</i> (Poaceae) (AU)
Papilionidae					
<i>Ornithoptera priamus bornemanni</i>	NB	6	LHC, HOP	forest canopy, disturbed areas	<i>Aristolochia tagala</i> (Aristolochiaceae)
<i>Papilio aegaeus websteri</i>	NB	1	LHC	forest edges	Rutaceae*
<i>Papilio phestus parkinsoni</i>	NB	3	LHC	stream beds	Rutaceae
<i>Papilio fuscus lamponius</i>	NB	3	LHC	forest edges	Rutaceae

Table 1. — continued.

	Endemism ¹	Individuals recorded	Locality ²	Habitats	Principal host plants ³
<i>Papilio ulysses ambiguus</i>	BA	2	LHC, HOP	forest canopy, disturbed areas	<i>Euodia</i> spp.* (Rutaceae)
<i>Papilio euchenor depilis</i>	NB	2	LHC	stream beds	Rutaceae
<i>Papilio demoleus novoguineensis</i>	RE	1	HOP	disturbed areas	<i>Psoralea</i> spp. (Fabaceae), <i>Citrus</i> spp. (Rutaceae)
Pieridae					
<i>Catopsilia pomona</i>	W	12	HOP	disturbed areas	<i>Cassia</i> spp. (Fabaceae)
<i>Eurema hecabe kerawara</i>	BA	7	LHC, HOP	forest clearings,	<i>Cassia</i> spp., <i>Mimosa</i> spp. (Fabaceae)
<i>Eurema blanda saraha</i>	W	2	LHC	forest clearings	<i>Caesalpinia bonduc</i> , <i>Albizia falcataria</i> (Fabaceae)
<i>Eurema candida xanthomelaena</i>	BA	4	LHC	forest light gaps	unknown
<i>Elodina primularis citrinaris</i>	NB	3	LHC	forest light gaps	probably <i>Capparis</i> (Capparaceae)
<i>Delias lytaea lytaea</i>	BA	1	LHC	stream beds	probably Loranthaceae
Lycaenidae					
<i>Philiris tombara</i>	BA	2	LHC	stream beds	unknown
<i>Philiris intensa regina</i>	BA	1	LHC	forest light gaps	<i>Pipturus argenteus</i> (Urticaceae)
<i>Hypolycaena danis milo</i>	BA	1	HOP	disturbed areas	Orchidaceae
<i>Deudorix woodfordi</i>	BA	1	LHC	stream beds	unknown
<i>neopommerana</i>					
<i>Nacaduba lucana</i>	BA	1	LHC	forest edges	unknown
<i>Nacaduba berenice apira</i>	BA	1	LHC	forest edges	probably Sapindaceae*, Proteaceae*
<i>Erysichton lineata uluensis</i>	BA	1	LHC	forest edges	Sapindaceae, Proteaceae, Boraginaceae* (AU)
<i>Erysichton palmyra clara</i>	BA	1	LHC	forest edges	Loranthaceae (AU)
<i>Psychonotis brownii</i>	BA	26	LHC	forest edges, stream beds	unknown
<i>Ionolyce helicon caracalla</i>	W	1	LHC	forest edges,	unknown
<i>Jamides soemias soemias</i>	W	4	LHC, HOP	forest edges, disturbed areas	<i>Crotalaria retusa</i> (Fabaceae)
<i>Jamides celeno sundara</i>	W	5	LHC, HOP	forest edges	<i>Canavaria maratima</i> (Fabaceae)
<i>Jamides aetherialis caerulea</i>	W	13	LHC	disturbed areas	unknown
<i>Jamides nemophila paralectus</i>	BA	22	LHC	forest edges, stream beds	<i>Strongylodon</i> sp. (Fabaceae)
<i>Epimastidia arienis bornemanni</i>	BA	2	LHC	forest light gaps	unknown
<i>Catochrysops panormus papuana</i>	W	3	LHC, HOP	forest edges, disturbed areas	<i>Cajanus cajan</i> (Fabaceae)
<i>Zizina labradus lampra</i>	W	8	HOP	disturbed areas	<i>Desmodium scorpiurus</i> (Fabaceae)
<i>Zizula hylax dampierensis</i>	W	2	HOP	disturbed areas	<i>Desmodium scorpiurus</i> (Fabaceae)
<i>Udara rona rona</i>	W	1	LHC	forest edges	unknown
<i>Udara cardia cardia</i>	RE	4	LHC	forest light gaps, forest edges	unknown
<i>Luthrodes cleotas cleotas</i>	BA	3	HOP	disturbed areas	<i>Cycas circinalis</i> (Cycadaceae)
Nymphalidae					
<i>Tellervo nedusia talasea</i>	BA	3	LHC	forest understorey	probably Apocynaceae*
<i>Tellervo zoilus aequicinctus</i>	BA	15	LHC	forest understorey	<i>Delpyodon oliganthus</i> (Apocynaceae)
<i>Ideopsis juvenis sobrinoides</i>	W	12	LHC	forest edges	<i>Cynanchum ovalifolium</i> (Apocynaceae)
					<i>Heterostemma papuana</i> (Apocynaceae)
<i>Euploea leucostictos perdita</i>	BA	1	LHC	forest light gaps, forest edges	<i>Ficus wassa</i> (Moraceae*)
<i>Euploea charox illudens</i>	BA	2	LHC	forest light gaps, forest edges	probably Apocynaceae
<i>Euploea treitschkei coerulea</i>	NB	11	LHC	forest edges	Apocynaceae
<i>Euploea modesta cerberus</i>	BA	4	LHC, HOP	forest edges, disturbed areas	Apocynaceae
<i>Euploea doretta</i>	BA	1	LHC	forest light gaps, forest edges	unknown
<i>Taenaris phorcas phorcas</i>	W	5	LHC, HOP	forest understorey	<i>Cordyline terminalis</i> (Liliaceae)
<i>Mycalesis phidon xanthias</i>	BA	8	LHC	forest edges, stream beds	Poaceae
<i>Mycalesis shiva maura</i>	BA	6	LHC	forest edges, grassy swales	probably Poaceae
<i>Mycalesis terminus matho</i>	BA	1	HOP	disturbed areas	Poaceae
<i>Orsotriaena medus licium</i>	W	6	HOP	disturbed areas	<i>Saccharum officinarum</i> (Poaceae) <i>Oryza sativa</i> (Poaceae)

Table 1. — continued.

	Endemism ¹	Individuals recorded	Locality ²	Habitats	Principal host plants ³
<i>Melanitis leda bouruana</i>	W	2	LHC	forest understorey	<i>Imperata</i> spp. (Poaceae)
<i>Prothoe australis schulzi</i>	NB	1	LHC	forest understorey	possibly Rutaceae
<i>Dichorragia ninus distinctus</i>	RE	1	LHC	forest edges	probably Anacardiaceae*
<i>Cyrestis acilia fratercula</i>	BA	6	LHC	forest light gaps, forest edges	<i>Ficus</i> spp.* (Moraceae)
<i>Parthenos sylvia couppei</i>	BA	16	LHC, HOP	forest light gaps, forest edges	probably <i>Tinospora dissitiflora</i> , <i>T. glabra</i> (Menispermaceae)
<i>Neptis praslini praslini</i>	BA	2	LHC	stream beds	<i>Sterculia schumanniana</i> (Sterculiaceae)
<i>Mynes katharina</i>	BA	1	LHC	stream beds	Urticaceae*
<i>Hypolimnastis pithoea unicolor</i>	BA	1	LHC	forest edges	probably Malvaceae
<i>Hypolimnastis bolina nerina</i>	W	3	HOP	disturbed areas	<i>Ruellia repens</i> (Acanthaceae), <i>Sida rhombifolia</i> (Malvaceae), <i>Ipomoea batatas</i> (Convolvulaceae)
<i>Yoma algina kokopona</i>	BA	1	LHC	stream beds	probably Acanthaceae
<i>Junonia villida villida</i>	W	2	HOP	disturbed areas	<i>Thunbergia alata</i> (Acanthaceae), <i>Portulaca oleracea</i> (Portulacaceae), Convolvulaceae
<i>Junonia hedonia zelima</i>	W	5	HOP	disturbed areas	<i>Ruellia repens</i> (Acanthaceae), <i>Sida rhombifolia</i> (Malvaceae)
<i>Cethosia obscura antippe</i>	NB	2	LHC	forest edges	<i>Adenia heterophylla</i> (Passifloraceae)
<i>Vindula arsinoe insularis</i>	NB	3	LHC	stream beds	<i>Passiflora foetida</i> (Passifloraceae)
<i>Phalanta alcippe denosa</i>	BA	3	LHC, HOP	forest clearings, disturbed areas	probably Violaceae
<i>Cupha prosopis alexis</i>	BA	6	LHC	forest edges	Flacourtiaceae*

¹Level of endemism: BA, taxon restricted to Bismarck Archipelago; NB, taxon restricted to New Britain; W, taxon widespread globally or in Papua New Guinea. Range extensions (RE) indicate new records for New Britain.

²Locality: LHC, Lake Hargy Caldera; HOP, Hargy Oil Palm plantation.

³All records from Parsons (1998).

*Host plant record for Australia, where none given for Papua New Guinea. Reference: Parsons, 1998.

of known larval host plants for the butterfly taxa recorded (Table 1), reasoning that these plants were likely supporting resident butterfly populations. Hence our butterfly data set adds value to complementarity analyses, in which butterflies may serve as surrogates for biodiversity in general (Faith *et al.* 2001a; but see Prendergast and Eversham 1997). In 2009 and 2010 we sampled vegetation randomly at the LHC site,

in part to confirm the presence of known larval host plants given in Table 1.

Data analysis

A cumulative species curve, in which species richness was plotted against sampling effort (days of sampling), was constructed: this reveals the rate at which additional species were recorded, as well as a rough estimate of the

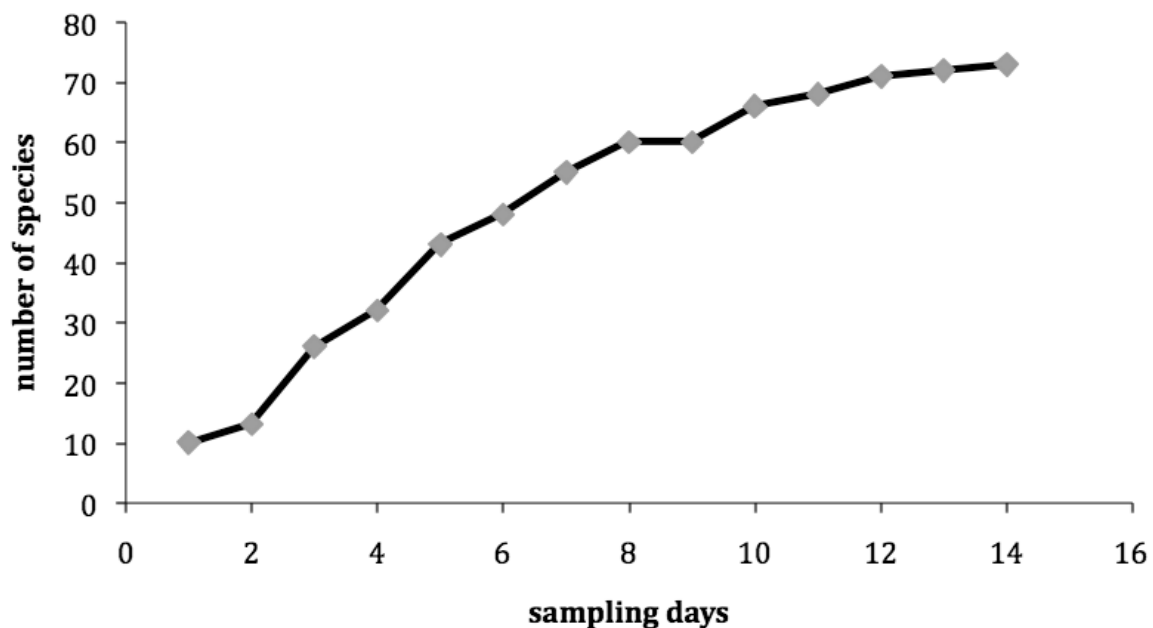


Fig. 2. Cumulative species curve for Hargy Oil Palm plantation and Lake Hargy caldera sites combined.

Table 2. Diversity and similarity index statistics for butterfly samples from the Lake Hargy caldera and Hargy Oil Palm sites. Computed values generated using EstimateS 7.5 (Colwell, 2005).

Metric	Lake Hargy Caldera	Hargy Oil Palm	Similarity Value
Total species richness	61	23	
Singletons	21	4	
Jackknife 1 richness estimator	104.0	38.2	
Bootstrap richness estimator	88.5	38.5	
Coleman rarefaction estimate (+/- SD)		55.4 (3.2)	
Jaccard Classic similarity index			0.151
Chao's Jaccard abundance-based			0.121
Sørensen Classic incidence-based			0.262
Chao's Sørensen abundance-based			0.216

overall sampling completeness (Beccaloni and Gaston 1995). Because sampling effort was skewed heavily towards the undisturbed site (LHC), all data were pooled to generate the cumulative species curve, representing diversity from the regional species pool. Coleman rarefaction, based on the entire set of species recorded, was applied to estimate the true richness of the smaller sample (HOP). Standard deviation estimates for rarefaction were generated analytically for the HOP data, with EstimateS Version 7.5 software (Colwell 2005).

We used the raw data to generate species richness values, which were then compared to those derived theoretically from Jackknife 1 and Bootstrap estimators, to obtain estimates of sampling completeness. We calculated similarity coefficients including Jaccard, Sørensen incidence-based, and Chao's modifications of the Jaccard and Sørensen indices, which include corrections for unseen shared species (Chao *et al.* 2005; Magurran 2004). Because of limitations in obtaining estimates of relative abundance in the rainforest environment, we avoided estimators highly sensitive to abundance (such as the Morisita-Horn index). EstimateS (Colwell 2005) was used in calculations of Coleman rarefaction values, diversity estimators and species composition similarity between the LHC and HOP sampling sites.

RESULTS

A total of 312 specimens representing 73 species was identified from all combined sampling methods (Table 1). Bait traps contributed only a minor portion of the total, yielding three specimens representing two butterfly species amidst a host of moths, bees and flies. The only bait trap successful for butterflies was stationed at the Lobu River, near ground level. However, one lycaenid butterfly collected in the trap, *Udara cardia cardia*, represents a range extension for New Britain; additionally, the skipper butterfly *Allora doleschalii albertisi* was recorded exclusively from this trap. Forest edges, light gaps and disturbed areas proved the richest habitats for butterflies; forest understorey the poorest. Records for principal

host plants reflect what is known for Papua New Guinea butterflies generally, rather than New Britain in particular. In some cases records for the better-studied fauna of Australia are given in lieu of those for PNG. For many species, knowledge of host plants is unknown or limited to family only: this is consistent with the general dearth of life-history information on New Britain butterflies.

The species accumulation curve for the pooled data set appears to be approaching an asymptote, though the estimated total lies well beyond our limited sampling effort (Figure 2). Sampling completeness ranged from 59% to 69% of the estimated totals (Table 2). Even after accounting for unequal levels of sampling effort, there were substantial differences in species assemblages between the sites, with that at LHC much greater than HOP. Overall, we accounted for 73 of the 229 species (32%) recorded from the regional species pool (New Britain). The number of unique species was 50 at LHC and 12 at HOP, and 11 species (15%) were shared. There were 21 (34%) singletons (species represented by a single specimen) at LHC and 4 (17%) at HOP.

DISCUSSION

This report, the first survey of the butterfly fauna of the Lake Hargy caldera, documents a diverse species assemblage in which endemic taxa are well represented. Notwithstanding the limitations of our study, the fauna of the adjacent oil palm plantation appears depauperate and lacks the distinctiveness found in primary rainforest. Our species richness estimates represent point diversity, as our sampling efforts were restricted to single sites and embodied single, combined samples (Magurran 2004; Rosenzweig 1995). The low level of sampling completeness, as compared to Benedick *et al.* (2006), DeVries *et al.* (1997) and Koh (2008), suggests only a fraction of the true butterfly richness has yet been recorded. Within the limited time frame, the combined cumulative species curve fails to level off, further substantiating that our samples underestimate true point diversity (Figure 2). For example, our daily

sampling periods may have missed crepuscular species, such as some satyrine butterflies (Tangah *et al.* 2004). Further, it is important to note that rapid assessments such as ours may overlook species with even minor seasonal preferences, i.e., Satyrinae and Morphinae (DeVries *et al.* 1997; Hamer *et al.* 2005). This effect can be especially pronounced in butterfly fauna likely to be sampled solely by bait traps, rather than transect surveys (Hamer *et al.* 2005). Indeed, species restricted to the canopy may well have gone undetected, as our trap positioned in the canopy yielded no butterflies. More generally, because undescribed species endemic to New Britain likely occur in the poorly-sampled interior of the island (Parsons 1998), the total documented regional diversity is bound to rise.

Of the 73 taxa recorded across both sites, 45 (62%) are regionally endemic to the Bismarck Archipelago generally or to New Britain in particular. This reflects the high level of endemism (52%) of butterfly taxa represented in the regional pool of 229 species, including the 4 range extensions reported here (Parsons 1998; Tennent 2006). The distinctiveness of the New Britain butterfly fauna parallels that of the island's avifauna, recognized as part of a high priority Endemic Bird Area (Buchanan *et al.* 2008). Predictably, the levels of butterfly regional endemism in species limited to the undisturbed LHC (72%) exceeded those recorded only at HOP plantation (25%). Most endemism occurs at the regional (rather than the island) level, reflecting New Britain's strong affinity with the Bismarck Archipelago as a whole and as a "centre of butterfly endemism" (Parsons 1998).

The preponderance of singleton specimens imparts an impression of rarity for many of the butterflies occurring at the study sites. Indeed, singletons composed the largest abundance class of butterflies, especially at LHC (34%). Species represented by single specimens are prevalent in insect assemblages, especially in the tropics (Hamer *et al.* 2005; Hebert 1980; Orsak *et al.* 2001). Our estimates are comparable to those for other diverse tropical biota, e.g., the 41%-60% singletons reported in geometrid moths among sites in an Andean rainforest (Brehm *et al.* 2003), 45% singletons reported in an extensive study of phytophagous insects in New Guinea (Novotný and Basset 2000) and 49% singletons in trees in Amazonian Ecuador (Valencia *et al.* 1994). Rather than indicating genuine rarity, the high proportion of singletons reported here may be an artifact of low sampling intensity, or represent transients from nearby, unsampled habitats such as the forest canopy (Erwin 1988; Novotný and Basset 2000).

Our low calculated similarity coefficients between HOP plantation and LHC primary

forest suggest substantial differences in habitat quality, which may result from differential plant species composition and architecture. The literature on quantifying similarities in butterfly communities between intact and disturbed tropical forests is limited, but we may cautiously place our findings into this context. For example, Humpden and Nathan (2010), in a study of the effects of forest structure on butterfly diversity in Kenya, reported Sørensen similarity indices ranging from 0.18, between undisturbed and disturbed forests, to 0.776, for comparable intact forests. In the current study, all four values presented in Table 2 are at the low end of Humpden and Nathan's range. Likewise, all similarity coefficients reported by Ramesh *et al.* (2010) for Indian butterflies inhabiting scrub jungle versus highly disturbed plantation monocultures exceed those in Table 2. Even after standardizing for sampling efforts, richness estimators still point to higher levels of diversity at the LHC site. Moreover, similarity values are probably overestimates, since a number of species recorded at the disturbed site (HOP plantation) were likely transients from nearby forests and not residents on the plantation. The low level of species common to both habitats (15.1%) is remarkably consistent with previous work that has indicated a mean of 15% of species shared between oil palm and primary forest (Fitzherbert *et al.* 2008).

In terms of complementarity, our data set is valuable; viz., areas rich in indicator species, such as butterflies, will also be rich in species generally (McGeoch 1998). In the face of limitations of time, funding, and the lack of detailed knowledge of most tropical rainforest biota, complementarity may serve as a practical, essential approach to conservation planning (Faith *et al.* 2001b). Certainly, insect diversity can be highly correlated with plant community diversity (Koh 2007; Rosenzweig 1995; Southwood *et al.* 1979), but such relationships are far from universally straightforward: for example, Orsak *et al.* (2001) found no close correspondence between species richness values for moths and plants sampled in southern New Ireland, immediately east of New Britain.

Our records of *Parnara amalia* (Hesperiidae), *Udara cardia* (Lycaenidae) and *Dichorragia ninus* (Nymphalidae) all constitute range extensions for New Britain. These species are likely residents on New Britain, but had simply been overlooked by earlier collectors (Tennent, pers. comm.). All three records were from the LHC site and extend the known ranges of these species from the New Guinea mainland or other, better-collected portions of the Bismarck Archipelago such as New Ireland. The single male *Papilio demoleus* (Papilionidae) collected at HOP was apparently searching for females on

ornamental *Citrus* sp. (Rutaceae), a suspected host plant. Parsons (1998) lists the host plant of the PNG race of *P. demoleus* as *Psoralea* spp. (Fabaceae), but indicates the typical food plant of *demoleus* outside of PNG and Australia is *Citrus* (Table 1). Recently, *demoleus* has undergone a range extension in PNG, including the Bismarck Archipelago: Chris Muller found it numerous on New Ireland in 2005 (Tennent 2006). Since much of the global distribution of *demoleus* appears to be the result of accidental human-assisted introductions on *Citrus* (Parsons 1998), the presence of *demoleus* on New Britain may, too, reflect an anthropogenic range extension.

Beyond supporting fewer species, habitat modifications such as commercial logging tend to favour generalist species and to disfavour specialists, e.g., myrmecophilous butterflies (Orsak *et al.* 2001; Thomas 2005). The lower species richness values at HOP imply lowered environmental quality, suggesting oil palm habitats have only a limited ability to support a diverse arthropod community (Magurran 2004; Turner and Foster 2009). Moreover, many of the wide-ranging species thriving in disturbed areas, e.g., *Eurema hecabe* and *Junonia villida*, benefit from conversion of primary rainforest to habitats supporting ruderal, “weedy” vegetation in which preferred larval host plants are abundant and broadly distributed (Raguso and Llorente-Bousquets 1991). These synanthropic butterflies are expected to proliferate with continued expansion of oil palm, along with invasive species such as crazy ants (*Anoplolepis gracilipes*), Polynesian rats (*Rattus exulans*), and blood pythons (*Python brongersmai*), which have the potential to affect trophic relationships among native fauna, thus causing extinction (Fitzherbert *et al.* 2008; Sax and Gaines 2008). Interestingly, the C.I.T.E.S.-listed *Ornithoptera priamus bornemannii* may actually benefit from the increased presence of its aristolochiaceae host plants in plantation habitats (Bob Prior, pers. comm.), suggesting this iconic species is not a reliable indicator of environmental quality, at least on New Britain. A firm understanding of the utility of butterflies as bioindicators on New Britain will depend on more extensive surveying and monitoring activities than this preliminary survey; however, our results suggest butterflies are sensitive to the effects of conversion from primary rainforest to oil palm plantation.

Conclusions

This study represents the first survey of the butterfly fauna of the Lake Hargy caldera region of West New Britain province. A striking contrast in species richness and composition is demonstrated between the intact rainforest of the caldera, and the adjacent oil palm planta-

tion habitat. Although preliminary, these data have implications for the effects on biodiversity from the conversion of primary forest to commercial plantation. As most of the earth's species are found in tropical rainforest canopy (Hamilton *et al.* 2010; Peck 2010), the most critical step towards long-term preservation of biodiversity will be preserving large blocks of old-growth rainforest (Fitzherbert *et al.* 2008; Koh and Wilcove 2007; New *et al.* 1995). Because of the complementary nature of unrelated biota sharing the rainforest, conservation areas managed for butterflies may also benefit non-target taxa such as host plants (Faith *et al.* 2001a; Reyers *et al.* 2000). New Britain, with its distinctive and diverse flora, fauna and indigenous cultures, is especially deserving of measures designed to achieve the best possible balance of sustainable commerce and biodiversity planning (Bamford 2007; Buchanan *et al.* 2008; Faith *et al.* 2001b).

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