Entomologist's Monthly Magazine **158**: 261–272 doi: 10.31184/M00138908.1584.4153

The ants (Hymenoptera: Formicidae) of a one-hectare plot of lowland dipterocarp forest

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Article history: Received: 21 July 2022; Accepted: 8 August 2022; Published: 28 October 2022

ABSTRACT

A multiple-method survey of just one hectare of lowland dipterocarp forest in Brunei yielded 115 species or morphospecies of ants of which 102 have been identified to species. No fewer than 24 of these are new records for Borneo. We list these species with comments on their wider distributions. Almost half of these species (44%) are endemic to the Sundaland region, with a further 20% restricted to south-east Asia. Few local species crossed the Makassar Strait between Borneo and Sulawesi suggesting that Wallace's Line is a relevant biogeographical barrier for many ant species. The trapping methods used generally targeted contrasting groups of species. The methods that yielded most ant species were canopy knockdown using pyrethrin insecticide (43%), pitfall trapping (26%), leaf litter extraction (9.5%) and bark spraying (8.6%). Our results suggest that future tropical forest ant surveys should include canopy sampling.

Keywords: Formicidae, multiple-method survey, dipterocarp forest, Borneo

INTRODUCTION

The lowland dipterocarp forests of south-east Asia are amongst the most biodiverse in the world (Mackinnon *et al.* 1996). They were one of the first natural regions to be designated as biodiversity 'hotspots' by Conservation International (Myers *et al.* 2000) based on their species richness, endemicity and degree of current vulnerability. Two of the 36 currently recognized hotspots are based almost entirely on dipterocarp forest ('IndoBurma' and 'Sundaland'), and dipterocarp forests are a significant part of at least four more (Mittermeier *et al.* 2011). The island of Borneo is the largest landmass within the Sundaland hotspot.

In general, the hotspot designation has been accorded to regions based on assessments of their flora and vertebrate faunas. Borneo, for example, is generally supposed to support more than 15000 plant species of which about 6000 are endemic to the island (Mackinnon *et al.* 1996). Vertebrates include well over 1400 resident terrestrial and freshwater species. In addition to these plant and vertebrate riches, lowland rainforests contain immense amounts of arthropod biodiversity, particularly of insects (Basset *et al.* 2012). Estimating local diversity of insects presents both historical and technical challenges, not least of which are the cryptic habits of many species and the fact that many groups contain substantial fractions of undescribed taxa.

Borneo, in fact, is rather better served in that regard than almost any other tropical region. Comprehensive treatments of butterflies and, more unusually, macro-moths are available (Otsuka 1988, 1994; Holloway 1986–2011). Substantial guides also

exist for the Odonata (Orr 2003) and Phasmida (Bragg 2001), as do useful checklists of mantids (Schwarz & Konopik 2014), and ants (Pfeiffer *et al.* 2011). With the exception of species of medical or veterinary importance, other insect groups are much less well served. A few recent family or sub-familial treatments exist, but large fractions of the fauna remain to be investigated in depth.

In June and July 1997, a group of scientists and volunteers led by RLK established a survey plot in the valley of the Belalong close to the University of Brunei's Kuala Belalong Field Studies Centre in the Sultanate of Brunei Darussalem. This involved marking out a one-hectare (100m × 100m) plot within the primary forest. Each woody stem of 5cm or greater diameter at 1.3m height was located, measured and identified. In addition, eight different insect trapping methods were employed: each designed to target a different subset of the entire arthropod fauna from the leaf litter to the upper canopy (see below). All insect samples were sorted at the field station and retained for further study. This study formed part of a trans-regional research project in which one-hectare plots were established in rainforest and surveyed in this standard fashion, together making up an immense transect from south-east Queensland, Australia (28°S) to Cat Tien, Vietnam (18°N). Six of these plots were in Australia, two in Papua New Guinea, one in Brunei and one in Vietnam. A wide range of publications emerged from these surveys describing and comparing vegetation and selected arthropod taxa (reviewed in Kitching *et al.* 2022). Kitching *et al.* (2003) described the basic protocol of the Brunei study. The vegetation of the one-hectare plot is described in detail by Small *et al.* (2004). The one-hectare Earthwatch plot is adjacent to the more recently established 25ha ForestGEO plot overseen by Drs Kamariah Abu Salim and Stuart Davies.

Ants (Hymenoptera: Formicidae) are a readily recognized and frequently dominant component of the insect fauna of most tropical rainforests. Often described as omnivorous, the ants play important functional roles in maintaining forest health and diversity. The Formicidae are also unusual among the insects in having a relatively large and active group of taxonomists globally, with up-to-date interactive websites, distribution records and nomenclatural details (*e.g.*, see antweb.org; antwiki.org; antbase.net). The ants are a significant part of the Bornean fauna with the Pfeiffer *et al*. (2011) checklist noting 717 valid species in 97 genera and 12 subfamilies. A more up-to-date version of this checklist is maintained on antbase.net.

Majer *et al.* (2001) incorporated some results on the ant fauna from our 1997 ant surveys from Brunei, describing ants sampled from the canopy (only) across Australian rainforest sites from Victoria to the lowland tropics of Cape Tribulation. In that paper, we recorded a total of 44 ant morphospecies obtained by pyrethrum fogging of the Brunei canopy. Although all 44 morphospecies were identified to genera, only three of four *Polyrhachis* spp. were assigned to known species. Recently, one of us (BH) has re-sorted and identified all of the ants from our multiple method survey, a large proportion of which could be confidently assigned to (now) known species. Many of these belong to taxa that have been comprehensively revised only recently and since the survey work itself was completed. Not only do we add to the list of known Borneo species, our results also represent one of the most intensive local surveys of an ant assemblage from the region, and one of the few to be based on complementary sampling methods.

We present these results here.

STUDY SITE, COLLECTING METHODS, IDENTIFICATION

The Study Site

The Kuala Belalong Field Studies Centre of the Universiti Brunei Darussalem is located at the junction of the Belalong and Temburong rivers (4.55°N 115.16°E) in the Batu Apoi National Park in the Sultanate of Brunei. The climate, geology, pedology, botany and zoology of the area are described in detail in Cranbrook & Edwards (1994).

The one-hectare plot is located in mixed dipterocarp lowland forest (Ashton 1964a,b; Poulsen *et al.* 1996) and is described in detail by Small *et al.* (2004), on which this summary is based. The plot is located 300m SSE of the Temburong/Belalong junction at elevations of between 55 and 80m above sea level. The one hectare contained (in 1997) 1019 live tree stems above 5cm dbh (diameter at breast-height). In addition, there were 43 standing dead stems in the same size range. Approximately 278 species of trees were represented in these counts. At the family level, the plot was dominated by species of Euphorbiaceae (228 individuals of 32 species) and Lauraceae (91 stems of 31 species). Overall, 29 families of trees were represented. At the level of the individual species, the four dominant tree species in terms of numbers of stems were *Fordia splendissima* (Mimosaceae, 59 stems), *Macaranga ecaustus* (Euphorbiaceae, 39 stems), *M. caudata* (Euphorbiaceae, 38 stems) and *Dillenia excelsa* (Dilleniaceae, 30 stems). In terms of basal area, the plot was dominated by *Alstonia angustiloba* (Apocynaceae, 4.13m^2), *Koompassia excelsa* (Fabaceae, 1.85m^2), *Syzygium caudatum* (Myrtaceae, 1.84m^2), *Knema sericea* (Myristicaceae, 0.94m^2) and *S. curtisi* (Myrtaceae, 0.92m^2). One hundred and eleven tree species were represented by single individuals. At the time of sampling, this plot was one of the richest ever to be enumerated, globally.

Arthropod Collecting Methods

Seven different arthropod sampling methods were used in our ant surveys. Malaise traps were used in both the canopy and at ground level. An eighth method, light traps exposed in both the canopy and ground level, was used only to survey moths and beetles. The construction and application of each of these methods is described at length in Kitching *et al.* (2005).

1. *Flight Interception Traps* comprised a sheet of plastic mounted upright above a tray of liquid. In the Brunei surveys, these were attended and emptied every day and so contained only water and detergent. A plastic rain-guard was stretched above the vertical sheets. These traps target free-flying and wind-borne insects. They were operated at ground level. Ten traps were dispersed at random points within the hectare.
2. *Malaise Traps* are effectively fine fabric barriers with a tent-like roof that direct intercepted insects upwards into a collecting bottle filled with preservative. They target a wide variety of free flying insects but are notorious for accumulating thousands of small flies. In Brunei we dispersed three such traps at random points at ground level and three mounted inside an aluminium frame, at canopy level. They were serviced and emptied every day for four days.
3. *Yellow Pan Traps* are plastic food containers painted yellow and containing about two centimetres depth of water to which has been added a few drops of

detergent. They target the so called 'aerial plankton' – tiny insects that drift on the wind or down from the canopy. They also attract some aquatic and semi-aquatic insects. We dispersed ten of these traps at random on the ground within the study hectare and emptied them daily for four days.

4. *Pitfall Traps* are glass or plastic containers sunk into the ground with their lips at soil level. We used two sizes of containers of diameters 25mm and 50mm respectively. We set out four arrays of each size, each array comprising nine containers arranged in a crosswise fashion and spaced at 1m intervals. Each container contained a small amount of 80% ethanol. Pitfalls traps are efficient in sampling ground dwelling arthropods and are widely used in specifically targeted ant surveys (rather than the general surveys we were carrying out). We did not bait our pitfalls.
5. *Tullgren Funnels* extract arthropods from leaf litter by the slow application of a heat source above funnels containing the freshly collected leaf litter. Arthropods move away from the heat source and are collected in vials placed beneath the funnels. They are very efficient for sampling the diverse litter fauna often not reached by any other means. We collected ten one-litre samples of leaf litter from random points on the survey hectare and extracted them over a four- or five-day period.
6. *Bark Sprays* involved selecting ten individuals of each of four species of common trees and spraying a half square metre of the bark at head height with a hand-held pyrethrin spray. Arthropods were then brushed down over the ensuing 30 min into a collecting apron pinned around the tree trunk.
7. *Pyrethrin Knockdown* involved selecting a canopy branch from which a backpack insecticide sprayer could be suspended. An area of 10×10m beneath this point was roped off and twenty 0.5m^2 fabric funnels suspended within each. Pyrethrin insecticide was then delivered in the canopy using the sprayer and the arthropods knocked down collected by the funnels for up to 3 hours after spraying. Three collections were carried out spread over the one-hectare plot.

Identification Methods

Species were identified by BH. Following determination to genera, species of *Rhopalomastix*, *Tetramorium* and *Ponera* were identified using the regional keys and images in Wang, Yong & Jaitrong (2021), Bolton (1977) and Taylor (1967), respectively. Species of all other genera were identified using the keys, illustrations and distribution records in either AntWeb (www.antweb.org) or AntWiki (www.antwiki.org), except for *Loweriella*, which is monotypic.

All material is deposited in the Western Australian Museum.

RESULTS

In total, 115 species or morphospecies of ants were present in our samples. Of these, 102 were confidently identified to species (or, in some cases, subspecies) level. The remaining 13 were identified to genus or species group. Twenty-four of the identified species were new to Borneo (compared with the 2022 version of www.antwiki.org/wiki/Borneo).

Table 1 summarises the biogeographic affinities of these species based on their known distributions as recorded on www.antweb.org. Sixteen species are known

TABLE 1 — BIOGEOGRAPHY OF ANTS FROM A ONE-HECTARE PLOT IN BRUNEI

Global Distribution	**Number of Species**
Cosmopolitan	1
Pan-tropical	2
Old-World Tropics	1
East Asia (China/India, South-east Asia)	16
East Asia (China/India) to Oceania	12*
South-east Asia (including the Philippines)	21
Sundaland and Wallacea (including Sulawesi)	5
Sundaland (Peninsular Malaysia, Singapore, Sumatra, Java, Borneo)	30
Borneo only	16
	104

* including 5 species from Australia

TABLE 2 — TRAPPING METHODS USED TO SURVEY ANTS IN A ONE-HECTARE PLOT IN BRUNEI

Trapping Method	**Number of Species**
Pitfall traps – unbaited, 2.5 & 5.0cm diameter	31
Flight intercept traps – ground level	4
Leaf Litter – Tullgren extraction	11
Malaise traps – ground level	4
Malaise traps – canopy level	6
Yellow pan (water) traps – ground level	2
Bark spraying – head height	12
Canopy Knockdown – pyrethrin insecticide	49
Unknown	1
Species found in more than one trap type	
Malaise traps & pitfall traps	1
Bark spraying & pitfall traps	1
Canopy knockdown & pitfall traps	2
Canopy knockdown & bark spray	1

only from localities in Borneo. A further 30 are restricted to Sundaland, *i.e.*, Peninsular Malaysia, Sumatra, Java and Borneo. These areas formed a single landmass at the time of the last glacial maximum and at various earlier times since the Jurassic (Hall 2013). A further 21 species occur widely in south-east Asia (the Indochinese Peninsula plus the Greater Sunda Islands and the Philippines). Remaining species are variously widely distributed in Asia and beyond. Interestingly only five species share distributions restricted to both Sundaland and Wallacea, and only six span the Borneo-Sulawesi divide.

Of methodological interest is how many species were obtained by each of the trapping methods used (Table 2). Canopy knockdown using pyrethrin insecticide yielded by far the greatest richness of species (49 species) followed by pitfall trapping (31 spp.), bark spraying (12 spp.) and leaf litter extraction (11 spp.). Remarkably, only five species occurred in more than one type of trap suggesting that the methods used formed a complementary set with respect to surveying the ant fauna.

The following species (or morphospecies) of ant were collected. We include the species' wider known distribution collated from the AntWeb site, the collecting method, and taxonomic, distributional or biological notes when these are particularly pertinent.

Dolichoderinae

Dolichoderus affinis Emery. China to Borneo. Canopy knockdown
Dolichoderus cuspidatus Smith. Borneo, Peninsular Malaysia. Canopy knockdown.
Dolichoderus sulcaticeps (Mayr). South-east Asia including Borneo. Ground Malaise trap.
Dolichoderus quadripunctatus grp. sp. 1. The *quadripunctatus* group of the genus is fundamentally a Holarctic clade, which Park & Park (2020) suggest originated in south-east Asia, diversifying in Asia and gradually spreading across the Holarctic region as far as North America. Unlike the taxa illustrated in Park & Park (2020), however, the petiolar node in this single specimen more closely resembles that found in *D. taschenbergi* (Mayr, 1866), a North American species. Furthermore, the dorsal surface of the propodeum is quadrate and does not extend as a lip or other projection. Canopy knockdown.
Loweriella boltoni Shattuck. A Borneo endemic. Pitfall trap.
Philidris myrmecodiae (Emery). India to the Solomons; Borneo, Philippines. Ants of this genus are frequently inquilines in the epiphytic ant-plants, *Myrmecodia* spp. Canopy knockdown.
Tapinoma glaucum (Viehmeyer). Singapore. A new record for Borneo. Canopy knockdown.
Tapinoma muelleri Karavaiev Aru Islands. A new record for Borneo and for anywhere west of Wallace's line. Bark spray.
Technomyrmex difficilis Forel. Pantropical. Canopy knockdown.
Technomyrmex dubius Bolton. Borneo, Sulawesi, New Guinea. Canopy knockdown.
Technomyrmex kraepelini Forel. Laos to Micronesia; Borneo. Canopy knockdown.
Technomyrmex lisae Forel. Borneo, Sumatra, Peninsula Malaysia. Canopy knockdown.
Technomyrmex modigliani Emery. Bangladesh to Sulawesi; Borneo. Canopy knockdown.
Technomyrmex tatius Bolton. Sabah. A Borneo endemic. Canopy knockdown.

Dorylinae

Aenictus inflatus Yamane & Hashimoto. A Borneo endemic. Canopy knockdown.
Aenictus levior (Karavaiev). Borneo, Peninsula Malaysia. Pitfall trap.
Dorylus orientalis Westwood. Pakistan to Borneo. Pitfall trap.

Ectatomminae

Stictoponera menadensis (Mayr). Thailand, Sumatra, Borneo, Philippines. Pitfall trap.

Formicinae

Camponotus bedoti Emery. China to Solomon Islands; Borneo. Malaise trap, pitfall trap.
Camponotus hospes (Emery). Borneo, Peninsular Malaysia. Bark spray.
Camponotus irritans (Smith). Species is found from India to Oceania. Subspecies *C. irritans sumatranus* Ozdikman (as here) is restricted to Sundaland. Canopy knockdown, pitfall trap.
Camponotus (*Thlipsepinotus*) sp. 1. Possibly undescribed. Canopy knockdown.
Camponotus sp. nr. *maculatus obfuscatus. Camponotus* sp. nr. *maculatus obfuscatus* Viehmeyer. The small major and minor worker belong to the group or complex currently associated with *C. maculatus*, although it is questionable whether this mainly Afrotropical clade is closely related to the Indomalay fauna, which has obvious affinities with the Australian members of the *C. novaehollandiae* species-group (*sensu* Heterick 2021) (see McArthur & Leys 2006). Of the two *C. maculatus* 'sub-species' represented in the Indomalay region, the Brunei specimens most closely resemble *C. maculatus obfuscatus* Viehmeyer (recorded from Singapore), but more material is need for a definitive identification. Canopy Malaise trap.
Cladomyrma hewitti (Wheeler). Sabah. A Borneo endemic. Flight intercept trap.
Colobopsis moeschi (Forel). Borneo, Peninsular Malaysia. Canopy Malaise trap.
Colobopsis vitrea (F. Smith). Borneo, Peninsular Malaysia. Canopy Malaise trap.
Dinomyrmex gigas (Latreille). Borneo, Peninsular Malaysia. Perhaps the best known of all Bornean ants. The species is known to roam the ground level during the day but ascends to forage in the canopy principally at night (Orr & Charles 1994; Pfeiffer & Linsenmair 2000); this accords with our having encountered the species in leaf litter and not in the otherwise rich canopy knockdown samples, which were all collected during the day. Leaf litter extraction.

Echinopla lateropilosa Zattel & Lacini. Peninsular Malaysia. A new record for Borneo. Canopy Malaise trap.
Echinopla rugosa Andre. A Borneo endemic. Canopy knockdown.
Euprenolepis wittei LaPolla. Peninsular Malaysia. A new record for Borneo. Canopy knockdown.
Myrmoteras diastematum Moffett. A Borneo endemic. Leaf litter extraction.
Nylanderia tjibodana (Karavaiev). Java. A new record for Borneo. Canopy knockdown.
Oecophylla smaragdina (Fabricius). India to Australasia. Ground Malaise trap.
Paraparatrechina butteli bryanti (Forel). Borneo. Another subspecies is in peninsular Malaysia. Canopy knockdown.
Paraparatrechina emarginata (Forel). Sumatra. A new record for Borneo. Canopy knockdown.
Paraparatrechina sp. 1. This small, glossy, bright yellow *Paraparatrechina* has a distinctive, blocky propodeum. It is almost certainly undescribed and is morphologically dissimilar to any of its congenerics. Bark spray.
Paratrechina longicornis (Latreille). Pantropical. Canopy knockdown.
Polyrhachis armata (Le Guillou). India to Borneo; the Philippines. Canopy knockdown.
Polyrhachis boltoni Dorow & Kol. Sabah, Peninsula Malaysia. Canopy knockdown.
Polyrhachis calypso Forel. India to Borneo; the Philippines. Canopy knockdown.
Polyrhachis sp. 1. Canopy knockdown.
Prenolepis fustinoda Williams & LaPolla. China, Thailand. New record for Borneo. Canopy knockdown.
Prenolepis subopaca Emery. Peninsular Malaysia, Singapore, Borneo. Ground Malaise trap.
Pseudolasius pheidolinus Emery. Sumatra. New record for Borneo. Pitfall trap.

Myrmicinae

Crematogaster ampullaris Smith. Borneo, Ceram, Philippines. Canopy knockdown.
Crematogaster angulosa Andre. Borneo endemic. Canopy knockdown.
Crematogaster brunensis Hosoishi & Ogata. Borneo (and Brunei) endemic. Canopy knockdown.
Crematogaster inflata Smith. Thailand, Peninsular Malaysia, Borneo, Philippines. Canopy knockdown.
Crematogaster macracantha Creighton. Sarawak, Sabah. A Borneo endemic. Bark spray.
Crematogaster philippinensis Hosoishi & Ogata. Philippines. A new record for Borneo. Canopy knockdown.
Crematogaster simoni Emery. Philippines. A new record for Borneo. Canopy knockdown.
Crematogaster treubi Emery. South-east Asia including Sumatra and Borneo. Canopy knockdown.
Crematogaster sp. nr. *fruhstorferi.* The species *C. fruhstorferi* Emery is recorded from Borneo and Sulawesi. There is no available species level key to this clade of Indomalay *Crematogaster* in subgenus *Crematogaster*, so identification is based on images and distribution. The two Brunei workers are a good match for one of the three workers imaged, but somewhat less so for the type (pinned through the body unfortunately) and the other imaged workers. The type specimen has a more convex head and larger eyes. However, the distinctive propodeum is probably a good species-level character. Canopy knockdown.
Crematogaster baduvi species-group sp. 1. The *baduvi* Forel group is known from Sumatra, Borneo and New Guinea. The four pinned workers have been allocated to this species-group tentatively, because of their high postpetiole and their long, distinctive, straight spines (although these spines tend to be oriented more posterolaterally than laterally as found in named members of the group). They do not come out in the key to the group members found in Hosoishi & Ogata (2016). Canopy knockdown.
Solenopsis marxi Forel. Recorded from Sumatra. A new record for Borneo. Pitfall trap.
Aphaenogaster feae imbellis (Emery). The species *A. feae* Emery is south-east Asian, including Borneo. The subspecies *A. feae imbellis* is recorded from Sumatra. A new record for Borneo. Yellow pan trap.
Cardiocondyla 'bs-mise2'. The genus *Cardiocondyla* Emery is cosmopolitan and contains 72 species. The single specimen is identical with a holotype in preparation for a specimen 'bs-mise2', collected from Brunei. The labels include a name and hence, will be designated in a forthcoming publication. Pitfall trap.

Carebara affinis (Jerdon). South-east Asia to Australia including Borneo. Pitfall trap.
Carebara alpha (Forel). Java. New record for Borneo. Pitfall trap.
Carebara atoma (Emery). New Guinea, West Oceania, Australia. New record for Borneo. Leaf litter extraction.
Carebara pygmaea (Emery). Sri Lanka to Maluku; Borneo, Philippines. Bark spray.
Carebara nr. *affinis.* The single minor worker is similar to the worker for *Carebara affinis* and is likely the same species, although somewhat smaller. Leaf litter extraction.
Carebara sp. 1. The medium-sized minor worker has the general physical *habitus* of those *Carebara* species formerly placed in *Pheidologeton*, but the propodeum is smoothly rounded and unarmed. There is no available key for the group from this part of the world. The specimen is not near any of the species illustrated in AntWeb for Southeast Asia and is probably undescribed. Canopy knockdown.
Dilobocondyla borneensis Wheeler. Bornean endemic. Canopy knockdown.
Monomorium floricola (Jerdon). Cosmopolitan. Bark spray, pitfall trap.
Monomorium liliuokalanii Forel. Singapore, Sumatra, Oceania. New record for Borneo. Canopy knockdown.
Monomorium orientale Mayr. East Asia, Oceania. New record for Borneo. Canopy knockdown.
Myrmecina spinosa Okido *et al.* A Borneo endemic. Pitfall trap.
Myrmicaria arachnoides (Smith). Java, Peninsular Malaysia, Borneo. Canopy knockdown
Myrmicaria carinata (Smith). India, Borneo. Pitfall trap
Paratopula catocha Bolton. Sulawesi. New record for Borneo. Canopy Malaise trap.
Pheidole aglae Forel. South-east Asia, Borneo, Philippines, New Guinea. Pitfall trap.
Pheidole butteli Forel. Thailand, Sumatra, Borneo. Canopy knockdown, pitfall trap.
Pheidole cariniceps Eguchi. Thailand, Borneo, Philippines. Pitfall trap.
Pheidole clypeocornis Eguchi. Borneo, Philippines. Leaf litter extraction.
Pheidole deltea Eguchi. Borneo, Philippines. Pitfall trap.
Pheidole lucioccipitalis Eguchi. Sumatra, Borneo. Canopy knockdown, bark spray.
Pheidole plagiaria Smith. South-east Asia, Sumatra, Borneo, Philippines. Ground Malaise trap.
Pheidole plinii Forel. Singapore, Borneo. Canopy knockdown.
Pheidole quadrensis Forel. Peninsular Malaysia, Borneo. Pitfall trap.
Pheidole quadricuspis Emery. Peninsular Malaysia, Borneo, Philippines. Pitfall trap.
Pheidole sabahna Eguchi. Borneo endemic. Pitfall trap.
Pheidole tjibodana Forel. South-east Asia, Borneo. Leaf litter extraction.
Recurvidris lekakuli Jaitrong *et al.* Thailand. New record for Borneo. Pitfall trap.
Rhopalomastix ?impithuksai Wang & Jaitrong. Thailand. Probable new record for Borneo. The Indomalay *Rhopalomastix* spp. are tiny (<2mm) and identification using the key in Wang, Yong & Jaitrong (2021) depends on interpreting subtle features of the mandible (fine striae present or absent) and the appearance of the posterolateral propodeal angles. The single Brunei minor worker keys out to *R. impithuksai* with a little awkwardness owing to the extremely subtle characters needed to make a determination. *Rhopalomastix impithuksai* is known from a single colony collected in Thailand and species can be localised, so the Brunei taxon may represent a different but closely related member of this group. Bark spray.
Strumigenys chapmani Brown. Sulawesi, Philippines. New record for Borneo. Bark spray.
Strumigenys edaragona Bolton. Borneo endemic. Pitfall trap.
Strumigenys sublaminata Brown. Borneo endemic. Canopy knockdown.
Syllophopsis australica (Forel). Sri Lanka, South-east Asia, Borneo, Australia, Micronesia. Pitfall trap.
Tetramorium adelphon Bolton. A Borneo endemic. Bark spray.
Tetramorium adpressum (Bolton). Borneo, Sulawesi, Philippines. Bark spray.
Tetramorium aptum Bolton. A Borneo endemic. Pitfall trap.
Tetramorium kheperra (Bolton). Thailand to Australia, Borneo. Leaf litter extraction.
Tetramorium kraepelini Forel. Thailand, Sumatra, Philippines. A new record for Borneo. Yellow pan trap.
Tetramorium noratum Bolton. Peninsula Malaysia, Sumatra, Borneo. Pitfall trap.
Tetramorium obtusidens Viehmeyer. China to Borneo, Philippines. Canopy knockdown.
Tetramorium pacificum Mayr. Asia-Pacific tropics, Indian Ocean islands, Borneo. Canopy knockdown.

Tetramorium scabrum Mayr. India, China to Borneo. Pitfall trap.
Tetramorium wroughtonii (Forel). India to Australia, Borneo. Leaf litter extraction.
Tetramorium sp. nr *tonganum.* The species *T. tonganum* Mayr has a wide distribution across tropical Asia and the Pacific including Borneo. Canopy knockdown.
Vollenhovia oblonga rufescens Emery. The species V. *oblonga* (Smith) is distributed from South-east Asia to the Solomons. The subspecies V. *oblonga rufescens* is restricted to Sundaland including Borneo. Flight intercept trap.
Vollenhovia sp. nr. *emeryi.* The species *V. emeryi* Wheeler has a cosmopolitan distribution. The two Brunei workers lack the vague macula between the antennal carinae, and possess short propodeal denticles, which are generally not developed in imaged material on AntWeb. They do occur, however, in an imaged Japanese worker (CASENT0246161) and queen (CASENT0246160). In all other respects, the two Brunei workers are a good match for this species. Bark spray.
Vombisidris harpeza Bolton. A Borneo endemic. Canopy knockdown.

Ponerinae

Anochetus princeps Emery. South-east Asia including Borneo. Pitfall trap.
Brachyponera chinensis (Emery). China, Cambodia, north Asia, North America. New record for Borneo. Pitfall trap.
Cryptopone butteli Forel. Peninsular Malaysia, Sumatra, Borneo, Micronesia. Pitfall trap.
Ectomomyrmex leeuwenhoeki Forel. Bangladesh to Borneo, Philippines. Pitfall trap.
Hypoponera butteli Forel. Sumatra, Sulawesi. New record for Borneo. Capture method unknown.
Hypoponera truncata (Smith). India to Borneo. Leaf litter extraction.
Leptogenys kraepelini esae Forel. Species *L. kraepelini* Forel is found in South-east Asia including Sumatra; subspecies *L. kraepelini esae* in Java. New record for Borneo. Pitfall trap.
Leptogenys processionalis distinguenda (Emery). The species *L. processionalis* (Jerdon) is found from India to Borneo. Subspecies *L. processionalis distinguenda* is a Borneo endemic. Pitfall trap.
Odontoponera transversa (Smith). Nepal, China to Borneo, Philippines. Pitfall trap.
Ponera taipingensis sp. gp. nr. *colaensis.* The species *P. taipingensis* Forel is from Peninsular Malaysia; *P. colaensis* Mann from Fiji and Samoa. Probably a new species for Borneo. The species keys out to the couplet containing *P. taipingensis* and *P. colaensis* in Taylor (1967) (more-or-less), but the four workers do not match either of these ants and probably belong to an undescribed species. Leaf litter extraction.

Pseudomyrmecinae

Tetraponera attenuata Smith. China to Borneo. Canopy knockdown.
Tetraponera extenuata Ward. South-east Asia, Borneo, Philippines. Canopy knockdown.

DISCUSSION

In addition to adding 24 (possibly 25) new records to the Brunei and Bornean checklists, our work demonstrates three key things.

First, it is probably not surprising that one of the richest rainforest sites, botanically, should also be faunistically rich. Our sampling was a one-off, expedition-style survey and yet we encountered a significant proportion of the entire Bornean fauna. In spite of this, major components of the fauna were not targeted. In particular, the very rich canopy fauna was not surveyed at night. Further, any species associated with the epiphyte flora, particularly the many *Asplenium* and other basket ferns, would only have been encountered by chance. These habitats are known to house a rich and specialized fauna (Ellwood, Jones & Foster 2002). Other species that are inquilines in termite mounds or have other highly specialized life histories

would also have been missed. The nature of our survey also precluded any detection of seasonal changes.

Second, the biogeography of the ant assemblage (Table 1) we encountered is worthy of comment. Of the 104 species that we were able to assess, 44% of them are Sundaland endemics (represented by the Borneo endemics plus those found in Sumatra, Java and Peninsular Malaysia). This level of local endemism underlines the veracity of this as a biodiversity hotspot and of the existence of land connections at various times in the past. A further 20% extend their distributions to include south-east Asia. A further 27% have wider Asian distributions. Among the remainder are the mere five species that share Borneo and Sulawesi as their distributions (noting that other more widely distributed species do include both islands). The contrast between the large number of species that are native to Sundaland and the very few that, in addition, cross the Makassar Strait, underlines the importance of Wallace's line (established largely based on the vertebrate fauna) in the distribution of the ant fauna of the region.

Finally, the complementarity of the trapping methods (Table 2) has relevance to any who choose to survey ants in tropical rainforest. The trapping methods chosen for our survey were selected for their overall targets (not just ants) and it is not surprising that traps designed to catch flying insects produced few ants (although of unique species in our captures). The 'traditional' ant surveying methods using pitfall traps and leaf litter extraction (either using Tullgren funnels, as here, or Winkler bags, as commonly used) are of course important and yielded 36% of the species or morphospecies we encountered. The less commonly used methods of canopy knockdown and bark spraying together yielded 53% of the taxa encountered with canopy knockdown alone accounting for 43% of these. The take-away message is clear. As has been observed before, the canopy fauna is a rich and diverse one (Ozanne *et al.* 2003; Nakamura *et al*. 2017) and anyone interested in the diversity of tropical arthropod faunas cannot afford to ignore it.

ACKNOWLEDGEMENTS

We are grateful to the Brunei authorities for issuing us with collecting and export permits. The Universiti Brunei Darussalem (UBD) allowed us access to their Kuala Belalong Field Studies Centre. Funding for the field work was provided by Earthwatch Australia: we thank them for this generous assistance. For work in the field, we are particularly grateful to Dr A.G. Orr (then lecturer at UBD), Professor Tara Martin, Mr Terry Rees, and Ms Karen Hurley. In Australia, Professor Jonathon Majer assisted with earlier sorting of the Brunei ants.

REFERENCES

Ashton, P.S. 1964a. Ecological studies in the mixed Dipterocarp forests of Brunei State. *Oxford Forestry Memoirs* **25**: 1–75.

——— 1964b. *A Manual of the Dipterocarp Trees of Brunei State.* Oxford University Press: London.

Basset, Y., Cizek, L., Cuénoud, P., Didham, R.K., Guilhaumon, F., Missa, M., Novotny, V., Ødegaard, F., Roslin, T., Schmidl, J., Tishechkin, A.K., Winchester, N.N., Aberlenc, H.-P., Bail, J., Barrios, H., Bridle, J.R., Castaño-Meneses, G., Corbara, B., Curletti, G., Darocha, W.D., Debaker, D., Delabie, J.H.C., Dejean, A., Fagan, L.L., Floren, A., Kitching, R.L., Medianero, L.E., Miller, S.E., Gama De Oliveira, E., Orivel, J., Pollet, M., Rapp, M., Ribeiro, S.P., Roisin, Y., Roubik, D.W., Schmidt, J.B., Sorensen, L. & Leponce, M. 2012. How many arthropod species live in a tropical forest? *Science* **338**: 1481–84.

Bolton, B. 1977. The ant tribe Tetramoriini (Hymenoptera: Formicidae). The genus *Tetramorium* Mayr in the Oriental and Indo-Australian regions, and in Australia. *Bulletin of the British Museum* (*Natural History*) *Entomology.* **36**: 67–151.

Bragg, P.E. 2001. *Phasmids of Borneo*. Kota Kinabalu, Sabah: Natural History Publishers.

Cranbrook, Earl of & Edwards, D.S. 1994. *Belalong*: *A Tropical Rainforest.* London and Sun Tree, Singapore: Royal Geographic Society.

Ellwood, M.D.F., Jones, D.T. & Foster, W.A. 2002. Canopy ferns in lowland dipterocarp forest support a prolific abundance of ants, termites and other invertebrates. *Biotropica* **34**: 575–583.

Hall, R. 2013. The palaeogeography of Sundaland and Wallacea since the Late Jurassic. *Journal of Limnology* **72**: 1–17.

Heterick, B.E. 2021. A Guide to the Ants of Western Australia. Part I: Systematics. *Records of the Western Australian Museum Supplement* **86**: 1–246. https//doi.org/10.18195/issn.0313-122x.86.2021.001-245.

Holloway, J.D. 1986–2011. *The Moths of Borneo.* Kuala Lumpur: Malay Nature Society & Southdene Publishers [18 parts published in 17 Volumes].

Hosoishi, S. & Ogata, K. 2016. Systematics and biogeography of the ant genus *Crematogaster* Lund subgenus *Orthocrema* Santschi in Asia (Hymenoptera: Formicidae). *Zoological Journal of the Linnean Society* **176**: 547–606.

Kitching, R.L., Ashton, L.A., Maunsell, C.C., Odell, E.H., Orr, A.G. & Nakamura, A. 2022. Arthropods of Australia's subtropical and tropical rainforests: rich and unique hotspots of biological diversity. *Journal of Insect Conservation* https://doi.org/10.1007/s10841-022-00416-0

Kitching, R.L., Orr, A.G., Small, A, Martin, T., Wong, K.M. & Mitchell, H. 2003. [dated 1995]. A multiple-method insect and plant inventory on a Kuala Belalong hectare, pp. 65–80. *Brunei Museum Journal* 1995.

Kitching, R.L., Boulter, S.L., Vickerman, G., Laidlaw, M., Hurley, K.L. & Grimbacher, P.L. 2005. *The Comparative Assessment of Arthropod and Tree Biodiversity in Old-World Rainforests*: *the Rainforest CRC/Earthwatch Protocol Manual*, 2nd Ed. (Revised). Rainforest Cooperative Research Centre, Cairns. (Available on-line at www.researchgate.net/publication/29459366).

Mackinnon, K., Hatta, G., Halim, H. & Mangalik, A. 1996. *The Ecology of Kalimantan*, *Indonesian Borneo.* Singapore Periplus Editions.

Majer, J.D., Kitching, R.L., Heterick, B E., Hurley, K. & Brennan, K.E.C. 2001. North-South patterns within arboreal ant assemblages from rainforests in Eastern Australia. *Biotropica.* **33**: 643–661.

McArthur, A.J. & Leys, R. 2006. A morphological and molecular study of some species in the *Camponotus maculatus* group (Hymenoptera: Formicidae) in Australia and Africa, with a description of a new Australian species. *Myrmecologische Nachrichten* **8**: 99–110.

Mittermeier, R.A., Turner, W.R., Larsen, F.W., Brooks, T.M. & Gascon, C. 2011. Global biodiversity conservation: the critical role of hotspots, pp. 3–22. *In*: Zachos, F.E. & Habel, J.C. (Eds) *Biodiversity Hotspots.* London: Springer.

Myers, N., Mittermeier, R.A., Mittermeier, C.G., da Fonseca, G.A.B. & Kent, J. 2000. Biodiversity hotspots for conservation priorities. *Nature* **403**: 853–858.

Nakamura, A., Kitching, R.L., Cao, M., Creedy, T.J., Fayle, T.M., Freiberg, M., Hewitt, C.N., Itioka, T., Koh, L.P., Ma, K., Malhi, Y., Mitchell, A., Novotny, V., Ozanne, C.M.P., Song, L., Wang, H. & Ashton, L.A. 2017. Forests and their Canopies: achievements and horizons in canopy science. *Trends in Ecology and Evolution* **32**: 438–451.

Orr, A.G. 2003. *A Guide to the Dragonflies of Borneo*: *their Identification and Biology.* Kota Kinabalu, Sabah: Natural History Publishers.

Orr, A.G. & Charles, J.K. 1994. Foraging in the giant forest ant *Camponotus gigas* (Smith) (Hymenoptera: Formicidae): evidence for temporal and spatial specialization in foraging activity. *Journal of Natural History* **28**: 861–872.

Otsuka, K. (Ed.) 1988. *Butterflies of Borneo 1.* Tokyo: Tobishima Corporation.

——— 1994. *Butterflies of Borneo 2.* Tokyo: Tobishima Corporation.

Ozanne, C.M.P., Anhuf, D., Boulter, S.L., Keller, M., Kitching, R.L., Körner, C., Meinzer, F.C., Mitchell, A .W., Nakashizuka, T., Silva Dias, P.L., Stork, N.E., Wright, S. J. & Yoshimura, M. 2003. Forest canopies: understanding global ecosystems. *Science* (*New York*) **301**: 183–186.

Park, J., Xi, H. & Park, J. 2020. Comparative Analysis on Palaearctic *Dolichoderus quadripunctatus* species group with the proposal of a novel species (Formicidae). *Conference*: *2020 Spring International Conference of Korean Society of Applied Entomology* https//doi.org/10.13140/RG.2.2.31757.15845

Pfeiffer, M. & Linsenmair, K.E. 2000. Contributions to the life history of the Malaysian giant ant, *Camponotus gigas* (Hymenoptera: Formicidae). *Insects Sociaux* **47**: 123–132.

Pfeiffer, M., Mezger, D., Hosoishi, S., Yahya, B.E. & Kohout, R.J. 2011. The Formicidae of Borneo (Insecta: Hymenoptera): a preliminary species list. *Asian Myrmecology* **4**: 9–58.

Poulsen, A.D., Neilsen, I.C., Tan, S. & Balsev, H. 1996. A quantitative inventory of trees in one hectare of mixed dipterocarp forest in Temburong, Brunei Darussalam, pp. 139–150. *In*: Edwards, D.S., Booth, W.E. & Choy, S. (Eds) *Tropical Rainforest Research*: *Current Issues*. The Netherlands: Kluwer Academic Publishers, Dordrecht.

Schwarz, C.J. & Konopik, O. 2014. An annotated checklist of the praying mantids (Mantodea) of Borneo, including the results of the 2008 scientific expedition to Lanjak Entimau Wildlife Sanctuary, Sarawak. *Zootaxa* **3797**: 130–68, https//doi.org/10.11646/zootaxa.3797.1.12.

Small, A., Martin, T., Kitching, R.L. & Khoon Meng, W. 2004. Contribution of tree species to the biodiversity of a one hectare plot of Old World rainforest, Brunei, Borneo. *Biodiversity and Conservation* **13**: 2067–2088.

Taylor, R.W. 1967. A monographic revision of the ant genus *Ponera* Latreille (Hymenoptera: Formicidae). *Pacific Insects Monographs* **13**: 1–112.

Wang, W.Y., Yong, G.W.J. & Jaitrong, W. 2021. Revision of the elusive ant genus *Rhopalomastix* (Hymenoptera, Formicidae, Myrmicinae) in Thailand based on morphology and DNA barcodes, with descriptions of three new species. *European Journal of Taxonomy* **739**: 117–157.