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Moths of Bukit Timah Nature Reserve, Singapore

R. Karam & J.H. Chong

Saint Joseph's Institution, 38 Malcolm Road,
308274 Singapore
raykaram01@hotmail.com

ABSTRACT. The moth fauna of Bukit Timah Nature Reserve, Singapore, was studied using light trapping. Specimens and photographs were sorted into morphospecies including macro and micro moths. A total of 399 species has been found, of which nearly 200 have been identified to species level. Several are notably rare or otherwise of interest. The figures do not reach an asymptote, suggesting that the total moth fauna may be considerably greater. The nature reserve may be too small to yield statistically significant differences in the moth fauna between forest vegetation zones.

Keywords. Biodiversity, insects, Lepidoptera, survey techniques, tropical rain forest

Introduction

Although Alfred Russel Wallace investigated extensively the fauna and flora of the Malay Archipelago between 1854 and 1862, collecting at least 110,000 insects, including more than 3,000 Lepidoptera (Wallace, 1869), his emphasis was not upon moths. Some moths were mentioned and/or collected by him but not in significant numbers (Wallace, 1869). Except for several months after his first arrival, in 1854, when he was based near what is now Bukit Timah Nature Reserve (BTNR), his trips to Singapore seem to have been largely for practical reasons, such as replenishing supplies, rather than focussing on nature. This is understandable in the context that, relative to the richness of the surrounding islands, Singapore was likely to yield fewer and fewer new species for a given time or effort. It was when in Borneo that he remarked how, after a rainy day in the middle of the forest staying at a house with white washed walls, tens of moths were attracted to the light with up to 260 on the most productive night (Wallace, 1869).

Moths have continued to attract rather little attention in Singapore and have been an adjunct to broader studies by entomologists. Murphy (1973), an avid collector of many invertebrates, focussed primarily on the insect communities of mangroves and lowland forest, including but not highlighting moths. Similarly, professional and amateur entomologists in Singapore have found it more productive to work on moths of neighbouring areas, such as Fraser's Hill and other Malaysian highlands (Barlow, 1982; Leong et al., 2017).

However, Singapore is still rich in biodiversity and, to conserve what still exists, it is very important to maintain public interest, to track species and populations, and to perform ecological studies investigating the variety of fauna and flora in this

small and densely populated island nation. Moths are of particular interest as they are numerous, readily studied (Beck & Linsenmair, 2006), closely linked to the plant species and vegetation quality (Kitching et al., 2000), very sensitive to environmental disturbances (Holloway, 1985) and taxonomically diverse (Barlow & Wowoid, 1989). They can therefore be helpful indicators of environmental quality.

The comprehensive biodiversity survey of the 163 ha BTNR has been introduced by Chan & Davison (2019). A study of the moths was conducted as part of the survey, and is described here.

Materials and Methods

The study was carried out between 8 May 2015 and 15 September 2016. Throughout the study, sampling was undertaken between 19:00 – 22:00 hrs.

Light traps were positioned in different parts of the reserve, near Catchment Path, Jungle Fall Path, Lasia Track, Main (Summit) Road and South View Path, to cover primary, old secondary and maturing secondary forest zones. There were no lights within the reserve at night although Singapore experiences a very high degree of night-time illumination exceeding 3000 μcd/m^2 on all nights (Falchi et al., 2016). A generator was employed to supply the necessary electricity for the light traps. A 150 W UV light bulb was used. A long cable was used to keep the generator away from the trap. The trap itself consisted of the light bulb fixed about 1.5 m from the ground on a tripod placed about 0.5 m from a white sheet of material about 2×2 m hanging over an improvised frame.

The main challenge for this project was the transport of the generator (approx. 20 kg). The reserve is quite hilly and the sampling points inaccessible by car. The generator had to be carried by hand across rough terrain and up and down steps. This, combined with the ongoing structural works on the reserve, meant that it was not possible to set up the light trap for equal times at equal spacing across the reserve. For instance, it was a long stretch to carry the generator to the Lasia Track location whilst the Jungle Fall Path was not accessible until 2016. On the other hand, Main Road was the easiest to get to so was visited most frequently.

An attempt was made at every site to position the light trap on paths so that the light could shine up and down the paths to maximise the range of attraction to moths, unobscured by trees and bushes.

Using a light bulb that gets very hot meant that we could not set up the trap when it was raining. The table shows some trapping days when rain had fallen yet this would have only occurred during daytime, not when the trap was operated.

Moths started to be attracted to the light almost half an hour after the set up. Most of the moths that were attracted to the light and settled down on the white sheet were photographed. It was clear at times that some moths passed by and seemed indifferent to the light. Some were attracted yet flew off immediately afterwards. Very few of the moths that failed to settle were caught without being photographed.

Medium and large moths were collected in vials and placed in a cooler box containing bottles filled with ice. This calmed down the moths without causing much damage to their wings. The vials were later placed in a freezer for a couple of hours and then stored in a refrigerator. After a few days the moths were set and then kept in plastic boxes containing dehumidifiers and sealed with tape to reduce damage to the moths.

A few moths were photographed yet escaped before they could be captured. Others, as mentioned above, did not settle long enough to be photographed and were caught to avoid losing them. Many micromoths were attracted to the light and were photographed yet not captured, as this study was not able to handle and set such small specimens. However, identifications of micromoths from photographs were included in the procedures and totals given below.

The set moths were given the camera/site reference numbers and attempts were made to identify as many of the species as possible using the various available books, especially those of Barlow (1982) and Holloway (1983–2010). Only colour and other external visible characteristics were used. No analyses of genitalia were attempted. Photographs from each location within BTNR were analysed and all duplicates were removed in order to count the number of morphospecies (recognisable taxonomic units). To err on the cautious side, any moths that showed only tiny differences were removed from the count. In 2018, photographs of the set specimens were sent to Henry Barlow who identified most of the samples that are listed in this study. The set specimens were later deposited with the Lee Kong Chian Natural History Museum (LKCNHM), National University of Singapore for DNA barcoding and retention, so that the balance of unidentified material can be identified in future.

Results

Table 1 shows the number of moth morphospecies counted per location and per session. Having compiled all the photographs and removed any duplicates across all trapping locations it was found that the 22 trapping sessions yielded 399 species of moths (including micro and macro moths). Of these, approaching 200 different species have been named to species level and more than 100 photographs are yet to be identified. The list of taxa identified to date (Table 2) is subject to continuing revision. A few of the species identified are considered rare and are of national or more than national interest (Fig. 1–2).

A comparison of trapping results in primary forest (Catchment Path, Jungle Fall Path, Main Road) versus old secondary (South View) and maturing secondary forest (Lasia Track) does not suggest any significant differences (Table 1). Bearing in mind that moths are mobile, the extent of the forest types and the distances between them are probably too small to show differences within a limited survey effort. Jungle Fall Path had the highest average number of species per session (65, but only three sessions). The Main Road had a rather low average, 35 species per session (average of eight sessions) but attracted in one visit 68 species and at another time only 19.

Table 1. Trapping statistics for moths at five locations within Bukit Timah Nature Reserve, Singapore. Data on moon and rainfall were supplied by the Meteorological Service Singapore.

Locality	Latitude/ Longitude	Forest Vegetation Type	Dates Surveyed	Moon Illumination/ Moon Rise/ Daily Rainfall*	No. of species noted	Average no. of species
Catchment Path	1º21'13"N 103º46'42"E	Primary next to Secondary	8 May 2015	85.8%, 22:50 hrs No rainfall	66	
Collected 112 specimens			30 June 2015	97.3%, 17:38 hrs No rainfall	48	
			28 Aug 2015	95%, 17:49 hrs No rainfall	56	
			19 Nov 2015	52.4%, 13:02 hrs No records	26	
			1 April 2016	46.6%, 01:20 hrs No rainfall	31	**45**
Jungle Fall Path	1º21'19"N 103º46'28"E	Primary	29 Jan 2016	79.1%, 23:18 hrs 3.2mm	52	
Collected 126 specimens			11 Feb 2016	9.9%, 09:24 hrs No rainfall	71	
			29 April 2016	62.8%, 00:06 hrs 6.8mm	73	**65**
Lasia	1º21'02"N 103º46'52"E	Maturing Secondary	3 July 2015	99.3%, 18:33 hrs No rainfall	38	
Collected 33 specimens			14 Aug 2015	0.3%. 06:33 hrs No rainfall	15	**27**
Main Road	1º21'11"N 103º47'05"E	Primary	17 Apr 2015	3.9%, 05:25 hrs 4mm	43	
Collected 149 specimens			10 July 2015	37.2%, 01:45 hrs 17.4mm	53	
			2 Sep 2015	86.7%, 22:26 hrs No rainfall	19	
			23 Nov 2015	92.4%, 16:33 hrs No records	25	
			25 Mar 2016	98.6%, 20:37 hrs No rainfall	68	
			13 May 2016	47.6%, 12:52 hrs 6.4mm	25	
			3 Aug 2016	0.2%, 07:11 hrs 14.6mm	21	
			15 Sep 2016	95%, 17:50 hrs No rainfall	26	**35**

Table 1. Continuation.

Locality	Latitude Longitude	Forest Vegetation Type	Dates Surveyed	Moon Illumination/ Moon Rise/ Daily Rainfall*	No. of species noted	Average no. of species
South View Path	1°20'50"N 103°46'50"E	Old Secondary	8 Apr 2015	89.7%, 22:15 hrs No rainfall	38	
Collected 67 specimens			15 May 2015	12.5%, 04:08 hrs 40.2mm	45	
			4 Mar 2016	29.8%,02:38 hrs 0.2mm	51	
			8 Apr 2016	1.0%, 07:38 hrs No rainfall	32	**42**

Over the two years of research in 2015 to 2016, seven sessions in the period August to November yielded an average of 27 species per session while 15 sessions in the period January to July yielded an average of 54 species per session. Along the Main Road, in September 2015, there were only 19 species and in September 2016 there were 26 species. However, in August 2015, 56 species were noted in the Catchment Path and only 21 in August 2016 in the Main Road location. There is evidently a great deal of stochastic variation. A more extensive study would need to be conducted in one location over several years to establish if a seasonal variation does exist.

No obvious correlation was found between moon rise, the moon phases and rainfall versus the number of moths that were attracted. In regard to moonlight and moon rise, there are many examples of high counts with an almost full moon (e.g. Catchment Path, 56 species in August 2015) but low counts as well (e.g. Main Road, 19 species in September 2015). Besides, Singapore is often cloudy so this is another area that would require further investigation.

The light traps attracted not only moths but other creatures as well. At times, some specific insects were very abundant as if they were synchronised. Mosquitoes seemed to avoid the UV light so once the light is on, they were nowhere to be seen. On the other hand, wasps were the most worrying and had to be placed in the cool box and released at the end of the trapping sessions.

Discussion

It is encouraging to find that at least 399 species have been recorded in this study and nearly 200 identified, including some rare species. It is uncertain what proportion of Singapore's moth fauna or even the proportion of the Bukit Timah moth fauna this

Table 2. Provisional identification of moth taxa recorded from Bukit Timah Nature Reserve, Singapore, in 2015–2016.

Family: Subfamily	**Species**
Bombycidae	*Ocinara albicollis*
	Trilocha friedelin
Cossidae	*Bergaris lutescens griseola*
Erebidae: Aganainae	*Asota caricae*
	Asota egens
	Asota producta
	Mecodina lanceola
	Neochera inops
Erebidae: Anominae	*Plecoptera recta*
	Rema costimaculata
Erebidae: Arctiinae	*Cyana malayensis*
	Cyana selangorica
Erebidae: Boletobiinae	*Saroba maculicosta*
	Sarobides inconclusa
	Trichoblemma badia
	Tamba lahera
	Tamba lala
	Tropidotamba lepraota
Erebidae: Calpinae	*Eudocima homaena*
Erebidae: Erebinae	*Armana nigraericta*
	Avatha rufiscripta
	Bastilla absentimacula
	?*Buzara feneratrix*
	Ercheia cyllaria
	Ercheia pulchrivenula
	?*Ercheia* sp.
	Erygia spissa
	Hypopyra pallidigera
	Ischyja ferrifracta
	?*Lygniodes schoenbergi*
	Ommatophora luminosa

Table 2. Continuation.

Family: Subfamily	Species
	Ophiusa trapezium
	Parallelia arcuate
	Pindara illibata
	Platyja umminia
	Sympis rufibasis
	Sypna ?albilinea
	Ugia signifera
	Ugia sundana
	?*Ugia* sp.
Erebidae: Herminiinae	*Adrpsa ?ereboides*
	Bocula microscala
	Bocula xanthostola
	Bocula ?divergens
	Erebus ephesperis ephesperis
	Hadennia mysalis
	Hypena similata
	Schistorhynx argentistriga
	Simplicia brevicosta
	Simplicia discosticta
	Simplicia cf. *discosticta*
	Simplicia griseolimbalis
	Simplicia rufa
	Simplicia schaldusalis
	Simplicia sp.
Erebidae: Hypocalinae	*Hypocala andamana*
Erebidae: Lymantriinae	*Artornis obtuse*
	Arctornis plumbacea
	Arctornis ungula
	Arctornis sp.
	Locharna limbata
	Olene mendosa
	Orvasca subnotata
	Scarpona ennomoides

Table 2. Continuation.

Family: Subfamily	Species
Erebidae: Pangraptinae	*Cultripalpa lunulifera*
	Masca abactalis
	Throana klossi
Erebidae: Scoliopteryginae	*Cosmophila scitipennis*
	Falana sordida
Erebidae: Tinoliinae	*Poeta denotalis*
Erebidae: Miscellaneous genera	*Arthisma amissa*
	Oxyodes scrobiculata
	Tamsia hieroglyphica
	Xanthonomis xanthine
Erebidae: incertae sedis	*Asta* sp.
	Brontypena ochrocuprea
	Flammona quadrifasciata
	Hyperlopha discontenta
	Marapana flavicosta
Geometridae: Desmobathrinae	*Alex palparia*
	Eumelea florinata
	Eumelea ludovicata
Geometridae: Ennominae	*?Hypulia* sp. or *Nadagara sp.*
	Borbacha altipardaria
	Celenna festivaria
	Fascellina castanea
	Fascellina viridicosta
	Hypomecis ?sommereri
	Hypomecis sp.
	Ophthalmitis rufilauta
	Petelia medardaria
	Petelia paroobathra
	Plutodes malaysiana
	Probithia exclusa
	Probithia sp.
	Racotis inconclusa

Table 2. Continuation.

Family: Subfamily	Species
	Racotis sp.
	Tasta micaceata
	Zamarada balata
	Zamarada sp.
	Zeheba aureatoides
Geometridae: Geometrinae	*Agathia laetata*
	Agathia succedanea
	Dysphania malayanus
	Herochroma sp.
	Ornithospila bipunctata
	Ornithospila sp.
	Spaniocentra megaspilaria
Geometridae: Sterrhinae	*Scopula (Antitrygodes) divisaria*
Geometridae	*Thalassodes* sp.
Lasiocampidae	*Cyclophragma basidiscata*
	Euthrix laeta
	Kunugia basidiscata
	Kunugia gynandra
	Paralebeda lucifuga
	Trabana ?krishna
	Trabada viridana
Limacodidae	*Cania bandura*
	Cania minuta
	Griseothosea cruda
	Idonauton apicalis
	Setora nitens
	Thosea medialis
	Thosea vetusta
Noctuidae: Aventiinae	*Cruxoruza geometrica*
Noctuidae: Noctuinae	*Athetis* sp. or *Spodoptera* sp.

Table 2. Continuation.

Family: Subfamily	Species
Noctuidae: Pantheinae	*Cyclodes omma*
	Donda striatovirens
Noctuidae: Stctopteryginae	*Lophoptera squammigera*
	Stictoptera columba
	Stictoptera semialba
Nolidae: Chloephorinae	*Blenina donans*
	Diehlea tumida
	Diehlea sp.
	Xenochroa costiplaga
	Xenochroa xanthia
Notodontidae	*Ambadra suriga*
	Cerasana anceps
	Chadrisa bipars
	Brykia horsfieldi
	Saliocleta nonagrioides
Pyralidae: Epipaschinae	Sp. indet.
Pyralidae: Pyralinae	*Herculia marthalis*
Pyralidae: Pyraustinae	*Arthroschista tricolora*
	?*Bradina* sp.
	Conogethes clioalis
	Conogethes sp.
	Crypsiptya coclesalis
	Glyphodes bivitralis
	Glyphodes canthusalis
	Gluphodes stolalis
	Glyphodes sp.
	?*Glyphodes* sp.
	Nacoleia charesalis
	Nevrina procopia
	Nosophora sp.
	Parotis ?*brocata*
	Parotis hilaris

Table 2. Continuation.

Family: Subfamily	Species
	Parotis laceritalis
	Parotis marginata
	Parotis cf. *marginata*
	Parotis squamopedalis
	Parotis sp.
	Piletocera sp.
	Pitama hermesalis
	Pleuroptya sp.
	Rhimphalea trogusalis
	Tyspanodes venosa
Pyralidae	*Gadessa nilusalis*
	Syllepte fabiusalis
	Syllepte iophanes
Sphingidae	*Daphnusa ocellaris*
	Eupanacra regularis
Thyrididae	*Banisia flavidiscalis*
	Banisia myrtaea
	Opula lepida
	shoppe
	Telechines vialis
Uranidae: Epipleminae	*Dysaethria quadricaudata*
	Dysaethria ?oriocharis
Uranidae	*Lyssa zampa*
	Micronia (Urapteroides) astheniata
Zygaenidae: Chalcosiinae	*Eucormopsis lampra*

Fig. 1. *Cruxoruza geometrica* (Noctuidae: Aventiinae) is considered very rare in Southeast Asia. (Photo: R.Karam)

Fig. 2. The very rare *Eumelea ludovicata* (Geometridae: Desmobathrinae) will settle in the forest understorey. (Photo: R. Karam)

represents. Not all moths are attracted to light traps, and bright ambient illumination throughout Singapore by night might interfere even with moths that are typically attracted to UV light traps. We attracted only two hawk moths although we found that elsewhere, such as in Bukit Brown cemetery, we attracted many more. We attracted one swallowtail moth *Lyssa zampa* although these are often very common in Singapore. Atlas moths are well known and very popular in this part of the world; we did not manage to attract even one atlas moth. The above observations are indicators that our trapping window did not record all of Singapore's species yet it did shed light on the potential number of moth species that Singapore may have.

Only one other systematic trapping study has been conducted in BTNR, by Koh (2007). She found 222 morphospecies in 12 sessions, which was nearly 40% more species than the next most diverse site at Nee Soon in the Central Catchment Nature Reserve. Her BTNR sample showed a larger total of individuals (47% more than the next most populous site) and a higher Shannon diversity index than other sites in Singapore, but was outperformed on some other non-parametric measures of diversity (Koh, 2007). However, that study used different trapping equipment (black-light, automated trapping) and protocols, so the results are not directly comparable to ours. Our tally of 399 species over 22 sessions exceeds the anticipated total if Koh (2007) had continued trapping for a similar duration (based on visual comparison with her rarified species accumulation curve), but unlike her study we included micro moths in our totals.

The present study is the only one to provide a substantial body of species identifications for moths from BTNR. Together with trapping locations and information on vegetation zones, a baseline has been set for comparison with future studies that will be able to track performance and sustainability of the moth fauna in BTNR.

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