Journal of Tropical Biology and Conservation 16: 229–251, 2019 ISSN 1823-3902
E-ISSN 2550-1909

Research Article

Diversity of Frogs in Tawau Hills Park, Sabah, Malaysia

Yong Huaimei[1], Anna Wong[2*], Muhammad Afif Bin Zakaria[2]

[1]Wetlands International, 3A31, Block A, Kelana Centre Point, Jalan SS7/19, 47301, Petaling Jaya, Selangor, Malaysia.
[2]Institute for Tropical Biology and Conservation, Universiti Malaysia Sabah, Jalan UMS, 88400 Kota Kinabalu, Sabah, Malaysia.

*Corresponding author: anna888@ums.edu.my

Abstract

A study on the diversity of anurans was carried out via Visual Encounter Survey (VES) method in Tawau Hills Park (THP), from June 2009 to September 2010. Twenty-eight line transects were established and surveyed, resulting in 925 individuals from 51 species, representing six families. Eighteen species were new locality records for THP, bringing the total number of identified frogs to 68 species. These frogs occupy elevations from lowland area (200 m a.s.l.) at the headquarters of THP, Balong substation and Merotai substation to submontane area (>900 m a.s.l.) at Mount Maria, Mount Lucia and Mount Magdalena. All 68 species recorded represent 62% of the total frog species found in Sabah, with 15% of them endemic to Borneo. Frog species in THP were dominated by Ranidae (39.4%) and Dicroglossidae (24.4%). *Limnonectes leporinus* was the most abundant species (10.2%), followed by *Meristogenys orphnocnemis* (10.1%). The high species diversity and richness in THP could be due to the rich topography of this park, which provides ample feeding, breeding and shelter for frogs.

Keywords: Anurans, Lowlands, Submontane, Visual Encountered Survey, Endemic, Borneo

Introduction

Borneo is one of the most important biodiversity hotspots for amphibians where inventory studies have been systematically carried out in Sabah and Sarawak since the late 1850s (Inger & Stuebing, 2005; Matsui 2006, Das and Haas, 2010). There were only 138 frog species recorded in Borneo in 1996, but the figure increased to 150 species in 2005 (Malkmus et al., 2002; Inger and Stuebing, 2005), and 167 species in 2012 (Inger & Tan, 2010; Frost, 2012).

Received 26 April 2019
Reviewed 21 Jun 2019
Accepted 03 July 2019
Published 15 October 2019

According to Frost (2012), there are seven families comprising 46 genera and 234 species of frogs recorded in Malaysia (Peninsula Malaysia, Sabah and Sarawak). In Borneo, frogs consist of seven families of 37 genera and 160 species. There are 108 species of frogs from over seven families and 30 genera in Sabah. Approximately 57% or 96 species of frogs recorded are endemic to Borneo (Malkmus et al., 2002; Inger & Stuebing, 2005; Inger & Tan, 2010, Frost, 2012).

There are only three published data on the frog species found in Tawau Hills Park. The earliest study was done by Stuebing and Nor (1995) who recorded 31 species of frogs in three habitats - on the boundary of, within the lowland areas of Tawau Hills Park, and the area adjacent to cocoa plantations during a scientific expedition organized by Sabah Parks and Universiti Kebangsaan Malaysia Sabah Campus (UKMS) in 1989. Inger et al. (2000) conducted a comprehensive study from 1991 to 1993 and they recorded 42 frog species in the lowlands of Tawau Hills Park. The latest study was done by Kueh and Sudin (2008) with the discovery of *Gastrophrynoides borneensis* in Tawau Hills Park. These studies have documented a total of 50 species of amphibians.

Frogs are functionally vital to many ecosystems they live in, as they play significant roles in the earth's biota (Heyer et al., 1994; Werner & McPeek, 1994). They act as a biological control and beneficial environment bio-indicator. They are predators, consuming a great variety of prey, such as insects and invertebrates, and they are also prey to snakes, birds and reptiles. Even as tadpoles, they are eaten by large fishes and other animals. In addition, frogs act as a keystone species in many communities (Beebee, 1996; Stewart & Woolbright, 1996; Inger & Tan, 2010). Anuran surveys do not only provide information on distribution, abundance and density, but also aid in understanding the habitat requirements of the species and environmental variables controlling its diversity. Such information is needed for effective conservation planning and management of forests, including monitoring of anuran populations in a period of apparent global decline and management of effective nature conservation (Parris, 1999).

Methodology

Study site: Tawau Hills Park

This study was conducted in Tawau Hills National Parks or more commonly known as Tawau Hills Park (THP), Sabah (Figure 1). The park is surrounded by Ulu Kalumpang Forest Reserve on its northern side and Mt. Andrassy Forest Reserve on its south, whilst its western and southern sides have boundaries with cocoa

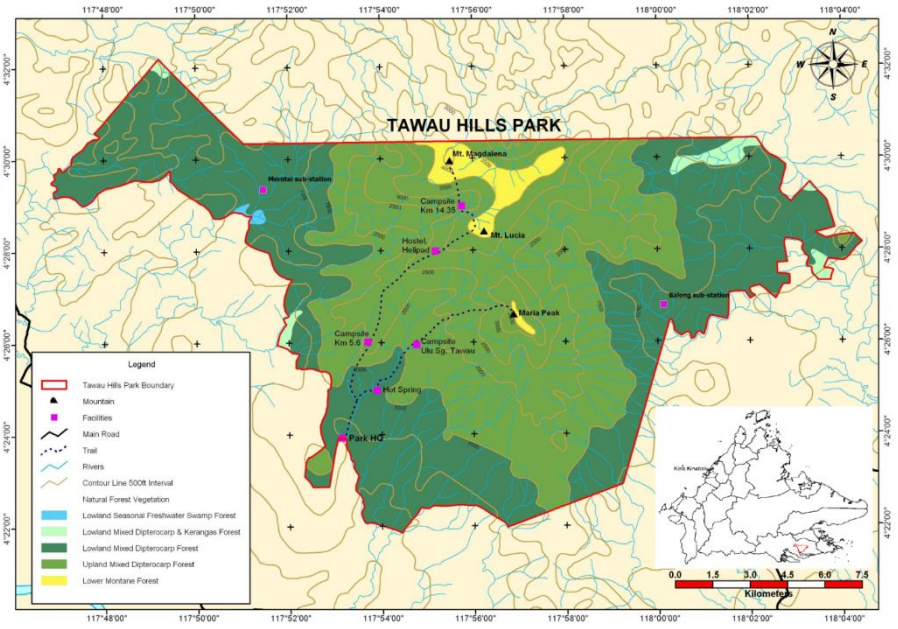

Figure 1. The physiographic of Tawau Hills Park. (Source: GIS laboratory of Institute for Tropical Biology)

and oil palm plantations. The park occupies a land area of 280 km^2, in which 60% of the park is virgin lowland dipterocarp forest, while the remaining area, particularly the lower elevations of the eastern and western areas, were logged before they were gazetted (Omar & Nais, 1995; Mohamed et al., 1999).

There are at least seven rivers in Sabah originated from Tawau Hills Park: Sg. Tawau, Sg. Kinabutan, Sg. Mantri, Sg. Balung, Sg. Merotai Kanan, Sg. Merotai Kecil and Sg. Junap. The main river system in THP is Sg. Tawau which flows through the middle of the 280 km^2 of the park forming many natural deep-water pools and waterfalls, including the Table Waterfall. There is also a hot spring feeding into one of its tributaries (Omar & Nais, 1995).

The terrain within THP is relatively rugged and hilly, with altitudes ranging from 30 m to 1,310 m. The three main peaks: Mt. Magdalena (1,310m), Mt. Lucia (1,189m) and Mt. Maria (1,067m) consist of inactive volcanoes, which were last active about 27,000 years ago. Only about 8% of the park area lies at an altitude of above 900 m, while more than 50% of the park is below an elevation of 457 m. Generally, the study site can be categorized into three different habitats, which are sub-montane forest habitat (Mt. Magdalena, Mt. Lucia and Mt. Maria),

lowland mixed dipterocarp forest habitat (lowland area around THP headquarters) and logged forest habitat (Balong sub-station and Merotai sub-station).

Sampling of frogs

Frog surveys were carried out randomly at the study area to minimise sampling bias. Visual Encounter Survey (VES) was used as the sampling method in this study (Crump & Scott, 1994; Heyer et al., 1994). Samplings were done once every six weeks with an average sampling effort of seven days for each visit from June 2009 to September 2010, covering dry and wet seasons. Sampling and observations were performed day and night for at least 3 hours at each site. Frogs were sampled using the hand-grabbing technique (Heyer, 1994; Matsui, 2006) and placed in separate plastic bags. Details, such as date and time of capture, microhabitats, and weather data were recorded on data sheets.

A total of 28 transects consisting 17 stream transects and 11 forest-floor transects were established in Tawau Hills Park: nine at the lowland area of the park, four at Balong substation, five at Merotai substation, four at Mt. Lucia, five at Mt. Maria and one at Mt. Magdalena. Each line transect was divided into stations of 10-m intervals. All stream transects were 500 m in length, except for one in Merotai substation, which was 300 m, as it was located in a very small creek. The width of each river was measured and recorded (Table 1). The length of forest floor transects were varied and established to the greatest accessibility (Table 2).

Table 1. River transects established at different localities in Tawau Hills Park

Transect	Name	Transect Length	Locality	River Width
RT1	Sg. Tawau 1	500 m	Lowland	7.5 m
RT2	Sg. Tawau 2	500 m	Lowland	7.5 m
RT3	Sg. Gelas	500 m	Lowland	8 m
RT4	Sg. belakang rest house 10km	500 m	Lucia (10km)	3.5 m
RT5	Sg. Balong	500 m	Balong	10.5 m
RT6	Sg. Papaya	500 m	Balong	4.5 m
RT7	Sg. Api Kecil	300 m	Merotai	2 m
RT8	Sg. Merotai Kanan	500 m	Merotai	11 m
RT9	Sg. Limau	500 m	Merotai	3.5 m
RT10	Lucia Waterfall 1	500 m	Lucia	3.5 m
RT11	Lucia Waterfall 2	500 m	Lucia	3.5 m
RT12	Gelas Waterfall	500 m	Lowland	2.5 m
RT13	Hotspring	500 m	Lowland	5.5 m
RT14	Sg. Tawau 1	500 m	Maria	8 m
RT15	Sg. Tawau 2	500 m	Maria	8 m

RT16	Sg. Maria 1	500 m	Maria	8 m
RT17	Sg. Maria 2	500 m	Maria	8 m

Table 2. Forest floor transects established at different localities in Tawau

Transect	Forest Floor Transects	Length	Locality
FT1	Trail along Sg. Tawau	2000m	Lowland
FT2	Lowland Botanical Garden	3000m	Lowland
FT3	Trail Lucia (km-3 to 5)	3000m	Lowland
FT4	Trail Lucia (km-6 to 9)	4000m	Lucia
FT5	Trail Sg. Kecil	1000m	Balong
FT6	Trail Sg. Papaya	1000m	Balong
FT7	Trail Canopy	2000m	Lowland
FT8	Trail Sg. Api Kecil	500m	Merotai
FT9	Trail Sg. Limau	1000m	Merotai
FT10	Trail Magdalena (km-14 to 17)	4000m	Magdalena
FT11	Trail Maria	3000m	Maria

Specimen Identification and Preservation

All specimens were taxonomically identified to species based on morphological characteristics keys by Malkmus et al. (2002); and Inger and Stuebing (2005). Only selected frog specimens were euthanized using chlorobutanol and fixed in 10% formalin. Specimens are kept in 90% ethyl alcohol for long-term storage (Heyer, 1994; Matsui, 2006) in BORNEENSIS, the wet specimen collection centre at the Institute for Tropical Biology and Conservation, Universiti Malaysia Sabah.

Species Diversity Indices

A biological community has an attribute termed as species diversity, and various approaches have been suggested to measure this parameter (Colwell, 2005; Baumgärtner, 2006; Lamb et al., 2009). Four diversity indices were used in this study: Shannon Index, Simpsons Diversity Index, Margalef Diversity Index and Brillouin Index. In addition, species rarefaction curves and species accumulation curves were produced to estimate the possible total number of species occurring in THP and evaluate sampling effort (Krebs, 1999; Thompson et al., 2003; Colwell et al., 2004).

Results

Frogs recorded in Tawau Hills Park

Overall, 51 species of frogs comprising six families were recorded throughout this study. Of these species, 18 species are new records to Tawau Hills Park (Table 3).

Table 3: Frog species recorded in year 1995, 2000 and current study

	Species name	1995	2000	Current study
Megophryidae				
1	*Leptobrachella gracilis*	+		
2	*Leptobrachium abbotti**	+	+	+
3	*Leptobrachium hendricksoni*			+
4	*Leptobrachium montanum**			+
5	*Leptolalax dringi**		+	+
6	*Leptolalax pictus**			+
7	*Megophrys nasuta*	+	+	+
Bufonidae				
8	*Ansonia fuliginea**			+
9	*Ansonia leptopus*	+	+	
10	*Ansonia longidigita**			+
11	*Ansonia spinulifer**		+	+
12	*Ingerophrynus divergen**	+	+	+
13	*Phrynoidis juxtaspera*	+	+	+
14	*Rentapia hosii*	+	+	+
Microhylidae				
15	*Chaperina fusca*		+	+
16	*Kalophrynus heterochirus**		+	+
17	*Kalophrynus pleurostigma*		+	
18	*Kalophrynus subterrestris**			+
19	*Kalophrynus punctatus*	+		
20	*Kaloula baleata*	+	+	
21	*Metaphrynella sundana*	+	+	
22	*Microhyla borneensis*		+	+
23	*Microhyla perparva**		+	
Ranidae				
24	*Amninara nicobariensis*	+		
25	*Huia cavitympanum**		+	+
26	*Meristogenys orphnocnemis**	+	+	+
27	*Meristogenys phaeomerus**			+
28	*Meristogenys whiteheadi**			+
29	*Meristogenys sp.*	+		
30	*Hylarana chalconota*	+	+	+

31	*Hylarana erythraea*			+
32	*Hylarana luctuosa*			+
33	*Hylarana picturata*		+	+
34	*Hylarana signata*	+		
35	*Odorrana hosii*	+	+	+
36	*Staurois latopalmatus**	+	+	+
37	*Staurois natator*	+	+	+
38	*Staurois tuberilinguis**			+
39	*Staurois parvus*			+
Dicroglossidae				
40	*Fejervarya limnocharis*		+	+
41	*Limnonectes finchi**	+	+	+
42	*Limnonectes kuhlii*	+	+	+
43	*Limnonectes leporinus**	+	+	+
44	*Limnonectes maleisianus*			+
45	*Limnonectes palavanensis*		+	+
46	*Limnonectes paramacrodon*	+	+	
47	*Occidozyga baluensis*	+	+	+
48	*Occidozyga laevis*			+
Rhacophoridae				
49	*Nyctixalus pictus*	+	+	
50	*Philautus aurantium**	+		+
51	*Philautus hosii**		+	+
52	*Philautus petersi*			+
53	*Polypedates colletti*			+
54	*Polypedates leucomystax*	+	+	+
55	*Polypedates macrotis*	+	+	+
56	*Polypedates otilophus*		+	+
57	*Rhacophorus appendiculatus*	+	+	+
58	*Rhacophorus bimaculatus*		+	
59	*Rhacophorus dulitensis*	+	+	
60	*Rhacophorus everetti*			+
61	*Rhacophorus gauni**	+	+	+
62	*Rhacophorus harrissoni**		+	+
63	*Rhacophorus kajau**		+	
64	*Rhacophorus nigropalmatus*		+	
65	*Rhacophorus borneensis*			+
66	*Rhacophorus pardalis*	+		+
67	*Rhacophorus rufipes**		+	+
	Subtotal	**31**	**42**	**51**

+ Presence of frog.
*Species endemic to the island of Borneo
Source: Stuebing and Nor, 1995; Inger et al., 2000
Note: *Gastrophrynoides borneensis* (Anura: Microhylidae) was discovered in 2008 (Kueh & Sudin, 2008), hence, the total recorded frog species in THP is Now 68 species.

This study adds 18 species to the existing herpetofaunal checklist of THP. The newly documented species are: Leptobrachium hendricksoni, L. montanum, Lepotolalax pictus, Ansonia fuliginea, A. longidigita, Kalophrynus subterrestris, Meristogenys phaeomerus, M. whiteheadi, Hylarana erythraea, H. luctuosa, Staurois tuberilinguis, S. parvus, Limnonectes maleisianus, Occidozyga laevis, Philautus petersi, Polypedates colletti, Rhacophorus everetti and Rh. borneensis. Overall, 25 species of frogs from the checklist are endemic to the island of Borneo and among these 23 were encountered during this study.

Frog Abundance

A total of 925 individuals of frogs were encountered throughout the 16 months of sampling, from June 2009 until September 2010. The number of individuals encountered for each species at six different localities are indicated in Table 4.

Lowland area at THP Headquarters had the highest abundance with 467 individuals encountered, followed by Mt. Maria (143 individuals), Balong Substation (123 individuals), Mt. Lucia (90 individuals), Merotai Substation (73 individuals) and the lowest abundance was at Mt. Magdelena (29 individuals) as shown in Table 4.

Table 4. Number of individuals encountered for each frog species at six different localities in THP

Species name	HQ	Balong Substation	Merotai Substation	Mt. Magdalena	Mt. Lucia	Mt. Maria	Total
Megophryidae							
*Leptobrachium abbotti**	15	0	2	1	0	0	18
Leptobrachium hendricksoni	27	3	0	0	0	0	30
*Leptobrachium montanum**, LU	0	0	0	0	2	0	2
*Leptolalax dringi**	22	15	0	0	0	9	46
*Leptolalax pictus**, LU	0	0	0	0	7	0	7
Megophrys nasuta	4	0	0	2	1	0	7
Subtotal	68	18	2	3	10	9	110
Bufonidae							
*Ansonia fuliginea**	0	0	0	2	8	0	10
*Ansonia longidigita**	31	0	0	0	1	0	32

*Ansonia spinulifer**, HQ	2	0	0	0	0	0	2
*Ingerophrynus divergen**	6	1	0	0	0	0	7
Phrynoidis juxtaspera	6	2	6	0	0	2	16
Rentapia hosii	9	1	0	0	0	0	10
Subtotal	54	4	6	2	9	2	77
Microhylidae							
Chaperina fusca	6	1	0	0	0	0	7
*Kalophrynus heterochirus**, MG	0	0	0	1	0	0	1
*Kalophrynus subterrestris**	1	0	0	2	0	0	3
Microhyla borneensis	6	6	0	0	0	0	12
Subtotal	13	7	0	3	0	0	23
Ranidae							
*Huia cavitympanum**	4	0	0	0	0	4	8
*Meristogenys orphnocnemis**	42	16	2	0	16	17	93
*Meristogenys phaeomerus**	6	1	1	2	4	5	19
*Meristogenys whiteheadi**, MG	0	0	0	1	0	0	1
Hylarana chalconata	38	2	12	0	0	8	60
Hylarana erythraea	15	0	0	0	0	1	16
Odorrana hosii	30	3	0	0	0	20	53
Hylarana luctuosa HQ	1	0	0	0	0	0	1
Hylarana picturata	15	19	4	0	0	5	43
*Staurois latopalmatus**	2	0	0	0	0	16	18
Staurois natator	18	0	0	0	8	13	39
Staurois parvus MG	0	0	0	1	0	0	1
*Staurois tuberilinguis**	8	0	0	0	3	1	12
Subtotal	179	41	19	4	31	90	364
Dicroglossidae							
Fejervarya	1	2	0	0	0	0	3

limnocharis							
*Limnonectes finchi**	13	0	0	0	1	0	14
Limnonectes kuhlii	22	7	15	0	16	12	72
*Limnonectes leporinus**	40	19	20	0	0	15	94
Limnonectes malesianus [HQ]	2	0	0	0	0	0	2
Limnonectes palavanensis	2	0	0	2	7	0	11
Occidozyga baluensis	12	1	1	0	2	0	16
Occidozyga laevis [BA]	0	14	0	0	0	0	14
Subtotal	92	43	36	2	26	27	226
Rhacophoridae							
*Philautus aurantium**, [LU]	0	0	0	0	2	0	2
*Philautus hosii**	13	0	0	0	12	0	25
Philautus petersi [MG]	0	0	0	12	0	0	12
Polypedates colletti [HQ]	1	0	0	0	0	0	1
Polypedates leucomystax [HQ]	15	0	0	0	0	0	15
Polypedates macrotis [HQ]	8	0	0	0	0	0	8
Polypedates otilophus	3	0	1	0	0	0	4
Rhacophorus appendiculatus	3	0	7	0	0	0	10
Rhacophorus everetti [MG]	0	0	0	3	0	0	3
*Rhacophorus gauni**, [ME]	0	0	2	0	0	0	2
*Rhacophorus harrissoni**	2	0	0	0	0	2	4
Rhacophorus pardalis	14	10	0	0	0	7	31
Rhacophorus borneensis [HQ]	1	0	0	0	0	0	1
*Rhacophorus rufipes**	1	0	0	0	0	6	7
Subtotal	61	10	10	15	14	15	125
Total	467	123	73	29	90	143	925

*Species endemic to the island of Borneo.

[HQ] Species found only at lowland headquarters of THP.
[BA] Species found only at Balong Substation.
[ME] Species found only at Merotai Substation.
[LU] Species found only at highland Mt Lucia.
[MG] Species found only at highland Mt Magdelena.

Dominancy of Frog Family

Based on the number of individuals in each family (Figure 2), frog species in THP was dominated by Ranidae, with 364 individuals encountered (39.4%), followed by Dicroglossidae (226 individuals; 24.4%), Rhacophoridae (125 individuals; 13.5%), Megophryidae (110 individuals; 11.9%), Bufonidae (77 individuals; 8.3%) and Microhylidae (23 individuals; 2.5%).

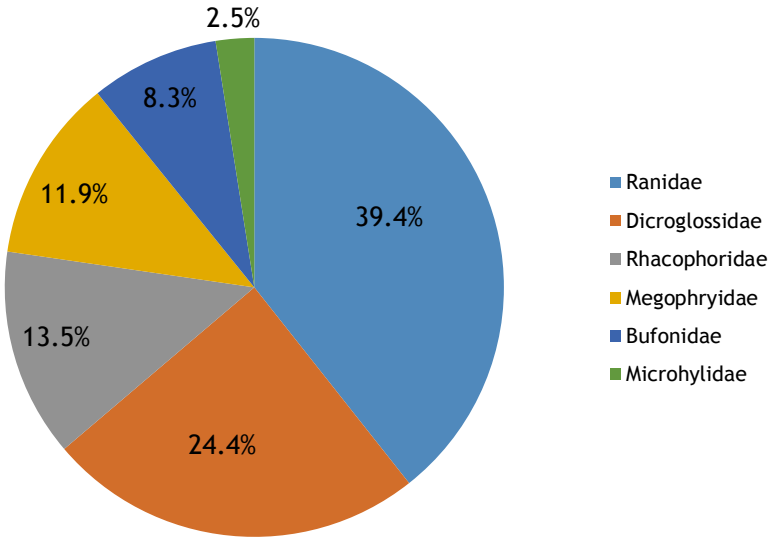

Figure 2. Dominance of frogs encountered in THP.

Abundance Rank

Limnonectes leporinus from the family Dicroglossidae was the most abundant species (94 individuals or 10.2%) in Tawau Hills Park; followed by *Meristogenys orphnocnemis* from Ranidae (93 individuals or 10%) and *Limnonectes kuhlii* from Dicroglossidae (72 individuals or 7.8%). The abundance of these three species (28%) comprises more than a quarter of the total number of individuals encountered in THP. In contrast, *Kalophrynus heterochirus*, *Hylarana luctuosa*,

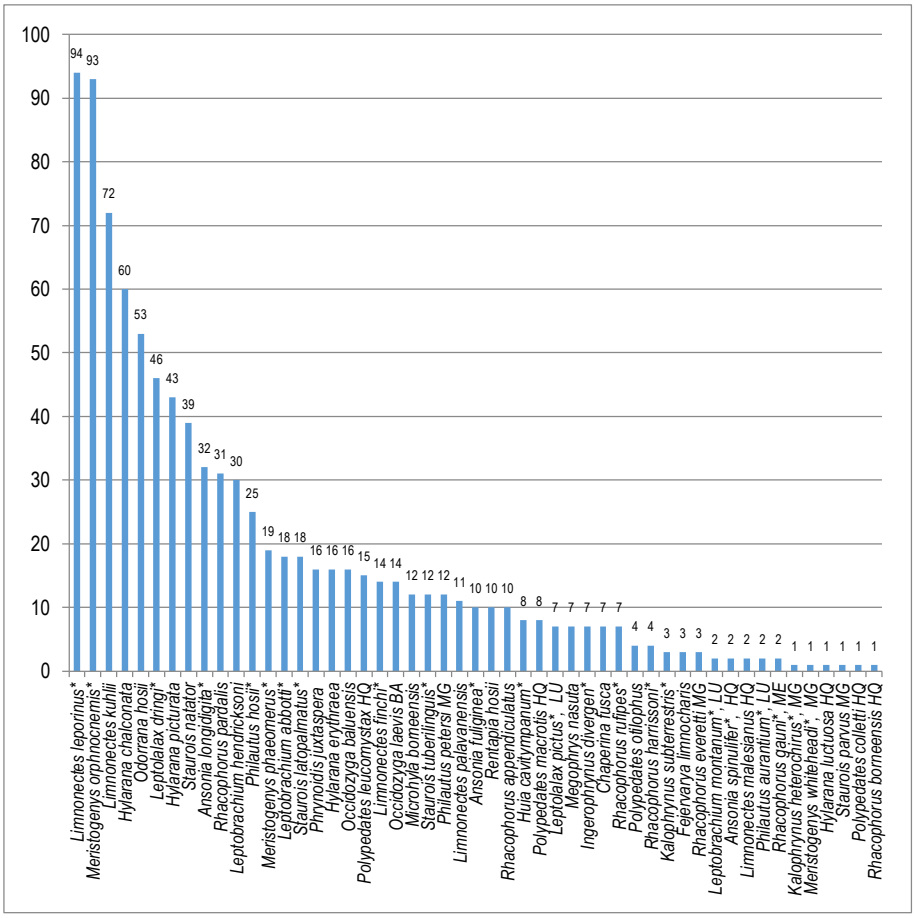

Figure 3. Abundance rank of frog species found in Tawau Hills Park.

Meristogenys whiteheadi, *Staurois parvus*, *Polypedates colletti*, and *Rhacophorus borneensis* were rare species, which were only found once (Figure 3). *Meristogenys orphnocnemis* was the most abundant species (42 individuals or 8.99%) found at headquarters of THP{, followed by *Limnonectes leporinus* (40 individuals or 8.56%), and *Hylarana chalconota* (38 individuals or 8.14). On the other hand, *Kalophrynus subterrestris*, *Hylarana luctosa*, *Fejervarya limnocharis*, *Polypedates colletti*, *Rhacophorus borneensis*, and *Rh. rufipes* were species found only once.

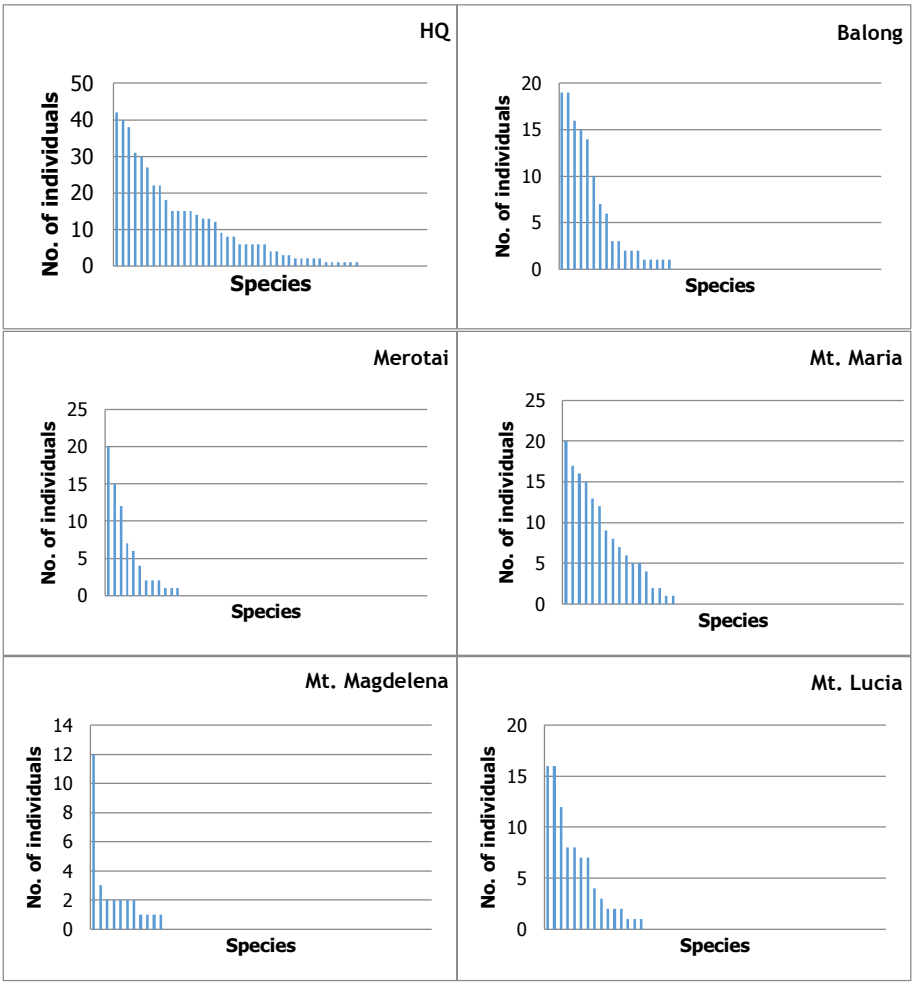

Figure 4. The abundance rank of frogs at each locality.

The frog species with the highest abundance found at Balong substation were *Hylarana picturata* and *Limnonectes leporinus* (19 individuals or 15.45%), followed by *Meristogenys orphnocnemis* (16 individuals or 13%). There were five singleton frog species found which were *Ingerophrynus divergens, Rentapia hosii, Chaperina fusca, M. phaeomerus and Occidozyga baluensis* (Figure 4).

Limnonectes leporinus (20 individuals or 27.4%) was the most abundant species found at Merotai substation, followed by *L. kuhlii* (15 individuals or 20.55%) and *Hylarana chalconota* (12 individuals or 16.44%). On the contrary, *Meristogenys*

phaeomerus, Occidozyga baluensis and *Polypedates otilophus* were species found only once at Merotai substation (Figure 4).

The total frog individuals found at Mt. Magdalena was 29 individuals with *Philautus petersi* (12 individuals or 41.38%) as the most abundant species found, followed by *Rhacophorus everetti* (3 individuals or 13%). There were four species with only one individual found; these were *Leptobrachium abbotti, Kalophrynus heterochirus, Meristogenys whiteheadi* and *Staurois parvus* (Figure 4).

The most abundant frog species found at Mt. Lucia were *Meristogenys orphnocnemis* and *Limnonectes kuhlii* (16 individuals or 17.78%), followed by *Philautus hosii* (12 individuals or 13.33). There were three singleton species found, namely *Megophrys nasuta, Ansonia longidigita and Limnonectes finchii* (Figure 4).

Odorrana hosii (20 individuals or 13.99%) recorded the highest abundance at Mt. Maria, followed by *Meristogenys orphnocnemis* (17 individuals or 11.89%), and *Staurois latopalmatus* (12 individuals or 11.19%). *Hylarana erythraea* and *Staurois tuberilinguis* were found only once (Figure 4).

Species diversity Indices

The results of the four diversity indices for frog sampling at six localities in THP are summarized in Table 5 and Figure 5. Four diversity indices applied in this study show no significant difference overall (One sample T-test, df = 3, $P > 0.05$).

Table 5. Four diversity indices accounted for frog sampling in Tawau Hills Park

Sample	Shannon Index	Simpsons Index	Margalef Index	Brillouin Index
Overall	3.357	20.938	7.329	3.248
THP Headquarters	3.244	21.198	6.345	3.091
Balong Substation	2.439	10.031	3.533	2.227
Merotai Substation	2.038	6.473	2.564	1.818
Mount Lucia	2.366	9.627	3.111	2.128
Mount Maria	2.575	12.337	3.224	2.381
Mount Magdelena	1.986	5.487	2.970	1.587

Based on pooling data from all 28 transects surveyed and 16 months of sampling period, the species accumulation curve almost levelled off and reached asymptote starting from the 41st survey (Figure 6). This suggests that most frog species within THP have now been encountered.

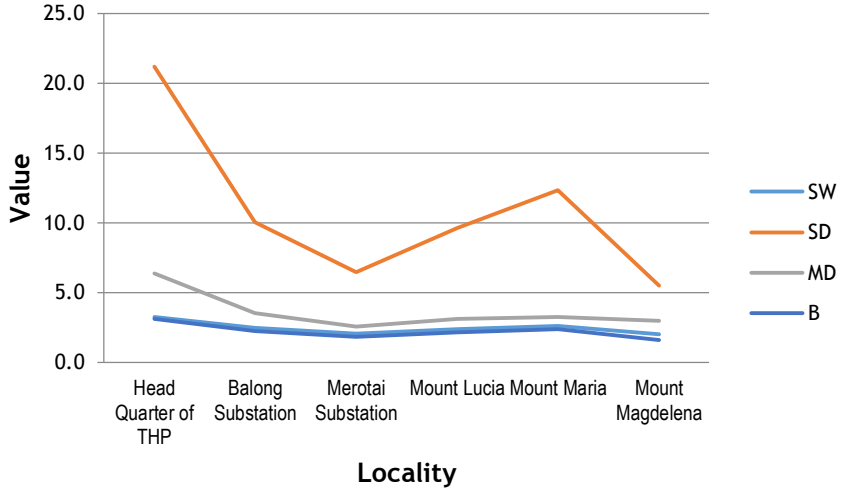

Figure 5. The diversity indices at each locality.

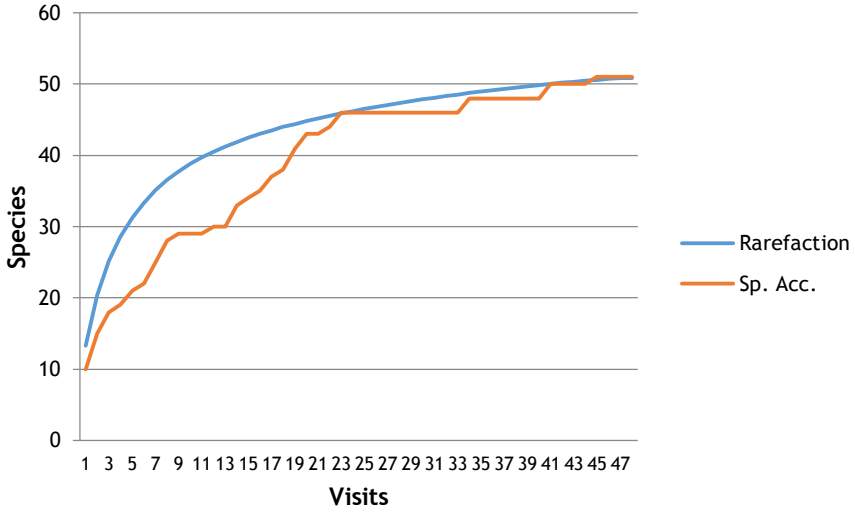

Figure 6. Species accumulation curve fitted on rarefaction curve.

Discussion

Throughout this study, a total of 51 frog species were identified in Tawau Hills Park, Sabah, with 33 frog species recorded previously (Stuebing & Nor, 1995; Inger et al., 2000). Inger and his group (2000) added 18 frog species to the amphibian checklist of THP in 2000, while this study, similarly supplemented 18 frog species to the list, bringing the total number of species identified in Tawau Hills Park to 68 species. Of the 68 species encountered in THP, they represent approximately 42% of the total frog species found in Borneo, with 24% of the species endemic to the island. The result correspondingly represents 62% of the total frog species found in Sabah.

Results of pooling data from 28 transects surveyed in this study show the species accumulation curve almost levelled off and reached asymptote starting from the 41st survey (Figure 6) in this study that was conducted up to 48 visits. This suggests that most frog species within THP had been encountered. Nevertheless, the increment in number of frog species in THP also suggests there may be more frog species to be found in future.

There were 16 frog species listed previously and not encountered during this study (Table 3). Among them, *Leptobrachella gracilis, Kalophrynus punctatus, Meristogenys sp., Amnirana nicobariensis*, and *Hylarana signata* were species encountered during the first survey in 1995 but not found in the subsequent study (Stuebing & Nor, 1995). Their absence during the survey could be due to their secretive habit or they were well hidden. Habitat loss and human disturbance may possibly contribute to this as well as the park is now open partly as a recreation area for both local and international tourists.

As shown in the results (Table 4), the frog individuals obtained were different at each locality. The lowland areas at the park headquarters had high abundance compared with the other five sampling sites. The abundance of frogs can be reflected by the availability of prey in habitats (Duellman & Trueb, 1994). The THP headquarters is home to a variety of microhabitats that promote the growth of green algae and aquatic organisms. This in turn enriches the availability of prey for frogs (Duellman & Trueb, 1994), leading to higher frog abundance around the headquarters.

More than half of the park lies below 457 m a.s.l, allowing easy access to most rivers, while approximately 8% of the park areas lies above 900 m a.s.l, which hampers the establishment of transects due to the difficult terrain.

Mt. Magdalena had the least abundance among the sampling sites (Table 4). High altitude is one of the rationales for this. The abundance of frogs is related to the availability of breeding sites and frogs distribute correspondingly to appropriate nursery sites for reproduction. As there are not many suitable breeding sites or water sources with the increasing altitude (Wong, 1994), only specialist frogs exhibiting breeding behaviour independent of water bodies will likely be present at higher altitudes (Wong, 1994; Rahbek, 1995). In addition, physical changes such as lower temperature, reduced rainfall and reduced aquatic microhabitats also influence the distribution of frogs in higher altitudes. Steep slopes and limited access in that area were the main reasons only one forest floor transect but no river transect was established.

Limnonectes leporinus, *Meristogenys orphnocnemis* and *Limnonectes kuhlii* were the three most abundant species encountered in THP (Table 4). This is consistent with the results recorded in most amphibian studies in Borneo (Kitayama, 1992; Inger & Voris, 1993; Stuebing & Nor, 1995; Voris & Inger, 1995; Maklarin et al., 1999; Inger et al., 2000; Traeholt et al., 2007; Grafe & Keller, 2009; Keller et al., 2009; Grafe et al., 2010; Inger & Tan, 2010). These are the common frogs found along rivers in both primary and old secondary forests.

In this study, *L. leporinus* was present at all lowland sampling sites and on Mt. Maria at 907 m a.s.l. The fact that this species was present at Mt. Maria was surprising as it is a lowland specialist (Inger & Stuebing, 2005; IUCN, 2018) There were 15 individuals of *L. leporinus* at Mt. Maria, suggesting its occurrence was not a coincidence. This finding indicates this species may travel from the downstream of Sg. Tawau to the upstream at Mt. Maria, as this species is also present at the same river at a lower elevation.

In addition, *M. orphnocnemis* and *L. kuhlii* were present at all sampling sites, except at Mt. Magdalena (Table 4). Both species are riparian species (Inger & Stuebing, 2005; Inger & Tan, 2010), thus, it is not likely to be found elsewhere. At all sampling sites where both *L. leporinus* and *L. kuhlii* co-existed, the abundance of *L. leporinus* was approximately double that of *L. kuhlii*. This incident is reliable, as according to Inger and Stuebing (2005), *L. kuhlii* is very common along medium sized streams but their existence is rare where *L. leporinus* is abundant.

There were six singleton species found in this study, of which *Kalophrynus heterochirus*, *Meristogenys whiteheadi* and *Staurois parvus* were found at Mt. Magdalena sampling sites, and *Hylarana luctuosa*, *Polypedates colletti* and

Rhacophorus borneensis in the lowland area around the headquarters of THP (Figure 4). All, except for *H. luctuosa* and *Rh. borneensis*, were not considered as rare species elsewhere (Inger & Stuebing, 2005), yet it seems that they are dwindling in the park and its surrounding habitat. As for the situation of *H. luctuosa* and *Rh. borneensis*, it appears to be the general trend in most amphibian studies as not enough data is available to make an assessment among fossorial (*H. luctuosa*) and arboreal (*Rh. borneensis*) frogs. In fact, none of the arboreal frogs can be regarded as highly abundant in those studies (May, 1975). The lack of quantitative abundance data for arboreal frogs suggests there is a need to develop appropriate frog sampling methods to access the vegetation above three meters from ground (Grafe & Keller, 2009).

According to the frog descriptions by Inger and Stuebing (2005), out of the 148 species of frogs listed in Borneo, there are only 17 montane species found above 900 m a.s.l., and of these four are new records at THP (Table 3). *Philautus petersi* and *Rhacophorus everetti* were only found on Mt. Magdalena at the elevation of 1,216 m a.s.l. and 1,198 m a.s.l., respectively, *while Leptobrachium montanum* was only found on Mt. Lucia sampling site at 1,088 m a.s.l. (Table 4). These montane species have narrow habitat tolerance as they confine themselves only in high elevation microhabitats and microclimates (Inger & Stuebing, 2005). They are well adapted to low temperature and high humidity. These frog species may be incompetent at a slightly higher temperature occurring in lowlands or they may require more moisture, usually occurring in the highlands due to thick fog (Inger, 1999; 2005). As the altitude increases, the drainage basin gets smaller and lesser and these frog species have little to no dependence on water bodies for breeding. *Philautus petersi* has a life cycle that is completely independent of water bodies, as their larvae undergoes a process of development within the egg as a tiny froglet, not as a tadpole (Malkmus et al., 2002; Inger & Stuebing, 2005).

As for *Ansonia fuliginea* which was expected to only occur at a higher elevation above 2,000m a.s.l (Inger et al., 2000), it was found in both the Mt. Magdalena (1,304m a.s.l) and Mt. Lucia (1,007m a.s.l) sampling sites. As no amphibian survey was carried out in the highland areas of THP before, it was not surprising that *A. fuliginea* was only found in this study. Navas (2006) had suggested that the plasticity of frog thermal physiology will determine the ability of frogs to adapt along different altitudinal gradients and that plasticity might be related to the evolutionary history of a taxon. Hence, the study result suggests that *A. fuliginea* has exhibited great agility in its thermal physiology, allowing this species to distribute in different altitudinal gradients rather than its own

gradient range as stated in a previous study. In addition, suitable microclimate and microhabitat availability could be a determining factor for the distribution of this species as well.

There were only 17 frog species present at the lowland area with an elevation of near sea level to 700m a.s.l. (headquarters of THP, Balong substation and Merotai substation). These frog species are confined to the lowland tropical forest, that is to say, they are not adapted to montane areas (Inger & Stuebing, 2005). These frog species are adapted to flat terrain, in turn, eliminating clear streams and moderate to strong currents which these frogs require for breeding. This suggests that these species are well adapted and are associated to disturbed areas, as well as to human activities (Duellman, 1999; Inger, 1999; Inger, 2005). However, this could not be applied to *H. luctuosa*, *P. colletti* and *R. borneensis*, as these species are rare, only encountered once and also new records to THP, simultaneously.

Occidozyga laevis was only found in Balong substation, whereas *Rhacophorus gauni* was only found in Merotai substation. These two frog species adapted themselves to the forest edge and cultivated plantations as Balong and Merotai substations border oil palm and cocoa plantations. Frog species that live in relatively disturbed, modified and open environment have adaptations either physiologically or behaviourally. These adaptations enable them to withstand or avoid unfavourable extremes of heat or humidity (Inger, 2005). However, there was no significant evidence to prove these occurrences, as more time is needed to observe their behaviour and collect data. Yet, this result can serve as the baseline for a future study.

Throughout the study, *Meristogenys phaeomerus* was the only species found in all six sampling sites, indicating high tolerance for broad habitat types, ranging from low to high elevation, from forest to plantation areas and from riparian to forest areas far from water source.

Results of this study imply that THP has considerably high species diversity and richness of frogs (Table 5) as compared to other areas in Borneo; for instance, Ulu Temburung National Park in Brunei with 66 frog species, Nanga Tekalit in Sarawak with 60 frog species, Crocker Range National Park with 59 frog species and Segaham in Sarawak with 47 frog species (Inger, 2003; Das, 2006; Grafe & Keller, 2009).

The high species diversity and species richness found in THP may be due to the various habitat types in this park. Sampling sites at various elevations is one of the reasons many species were found. The three peaks, Mt. Magdelena, Mt. Lucia, and Mt. Maria provide primary montane and submontane microhabitats for specialist frog species, such as *Rhacophorus everetti* (mossy tree frog) at Mt. Magdelena, since mossy forest only occurs on this mountain (Stuebing and Nor, 1995; Inger et al., 1996; Richards, 1996; Malkmus et al., 2002; Inger & Stuebing, 2005).

Lowland forests and hill forests are also present in THP, apart from montane forests. These two types of forests provide different types of microhabitats to lowland frog species, particularly those needing swift, torrential streams and rivers to breed but occurring below 900m a.s.l. (Grafe & Keller, 2009). Apart from that, tree canopy in lowland primary rainforests provides shelter for arboreal species, such as *Rhacophorus borneensis* (Borneo flying frog). This species remains within the canopies and only descends to breed around semi-permanent pools on forest floor (Richards, 1996; Inger & Stuebing, 2005; Inger & Tan, 2010).

Conclusion

A total of 28 transects were established and surveyed in six sampling sites - headquarters of THP, Balong substation, Merotai substation, Mount Magdalena, Mt Lucia and Mount Maria. A total of 925 individuals of frogs were found, from 51 species comprising six families. This study has successfully added 18 new frog species to the checklist of frogs in Tawau Hills Park. The park headquarters is located in the lowland area and had the highest abundance with 467 individuals from 40 frog species, while Mount Magdalena is the least abundant with only 29 individuals from 11 species. The Shannon Diversity Index of frogs in this study was 3.357, indicating that THP has high frog biodiversity.

References

Allan JD. 1995. *Stream Ecology: Structure and function of running water*, pp. 24. London: Kluwer Academic Publishers.

Baumgärtner S. 2006. *Why the measurement of species diversity requires prior value judgments*, pp.1- 24. Bergheimer: University of Heidelberg.

Beebee TJC. 1996. *Ecology and Conservation of Amphibians*, pp. 132-133, 146-166,179-180. United Kingdom: Chapman and Hall.

Crump ML, Scott NJ. 1994. *In* Heyer, W. R., Donnelly, M. A., McDiarmid, R. W., Hayek, L. C., and Foster, M. S (ed). *Measuring and Monitoring Biological Diversity: Standard Methods for Amphibians.* Washington: Smithsonian Institution Press.

Colwell RK. 2005. *EstimateS: Statistical estimation of species richness and shared species from samples*. Version 7.5. User's Guide and application published at: http://purl.oclc.org/estimates

Colwell RK, Mao CX, Chang J. 2004. Interpolating, and Comparing Incidence-based Species Accumulative Curves. *Ecology* **85(10):** 2717-2727.

Das I. 2006. Crocker Range National Park, Sabah, as a refuge for Borneo's montane herpetofauna. . *Amphibian and Reptile Conservation* **4(1):** 3-11.

Das I, Haas A. 2010. New species of Microhyla from Sarawak: Old World's smallest frogs crawl out of miniature pitcher plants on Borneo (Amphibia: Anura: Microhylidae). *Zootaxa* **2571:** 37-52.

Duellman WE, Trueb L. 1994. *Biology of Amphibians*. London: The Johns Hopkins University Press.

Duellman WE. 1999. Global Distribution of Amphibians: Patterns, Conservation, and Future Challenges. *In* Duellman, William E. (edt.) *Patterns of Distribution of Amphibians: A Global Perspective*. Baltimore: The John Hopkins University Press.

Frost DR. 2012. Amphibian Species of the World: an Online Reference. Version 5.6 (01 October 2012). Electronic Database accessible at http://research.amnh.org/vz/herpetology/amphibia/. American Museum of Natural History, New York, USA.

Grafe TU, Keller A. 2009. A Bornean amphibian hotspot: the lowland mixed dipterocarp rainforest at Ulu Temburong National Park, Brunei Darussalam. *Salamandra* **45(1):** 25-38.

Grafe TU, Goutte S, Ahmadsah HH, Konopik O, Scharmann M, Bauer U. 2010. Updated checklist of the amphibian of the Ulu Temburong National Park and Brunei Darussalam. *Scientia Bruneiana* **11:** 53-59.

Heyer WR, Donnelly MA, McDiarmid RW, Hayek LC, Foster MS. 1994. *Measuring and Monitoring Biological Diversity Standard Methods for Amphibians*, pp. 24. Washington and London: Smithsonian Institution Press.

Inger RF. 1999. Distribution of Amphibians in Southern Asia and Adjacent Islands. *In* Duellman, William E. (edt.) *Patterns of Distribution of Amphibians: A Global Perspective*. Baltimore: The John Hopkins University Press.

Inger RF. 2003. Sampling Biodiversity in Bornean Frogs. *The Natural History Journal of Chulalongkorn University* **3(1):** 9-15.

Inger RF. 2005. The Systematics and Zoogeogrphy of the Amphibia of Borneo. Fieldiana: Zoology, pp. 52-402.

Inger RF, Stuebing RB. 2005. *A Field Guide to the Frogs of Borneo (Second edition)*. Kota Kinabalu: Natural History Publications (Borneo) Sdn. Bhd.

Inger RF, Tan FL. 2010. *The Natural History of Amphibians and Reptiles in Sabah*. 2nd Edition. Kota Kinabalu: Natural History Publications (Borneo) Sdn. Bhd.

Inger RF, Voris HK. 1993. A comparison of amphibian commuities through time and from place in Bornean forests. *Journal of Tropical Ecology* **9:** 409-433.

Inger RF, Tan FL, Paul Y. 2000. The frog fauna of three parks in Sabah, Malaysia – Kinabalu Park, Crocker Range Park, and Tawau Hills Park. *Sabah Parks Nature Journal* **3(2000):** 7-28.

IUCN SSC Amphibian Specialist Group 2018. *Limnonectes leporinus*. *The IUCN Red List of Threatened Species* 2018: e.T58348A114921455. Downloaded on 28 June 2019.

Keller A, Rodel MO, Linsenmair KE, Grafe TU. 2009. The importance of environmental heterogeneity for species diversity and assemblage structure in Bornean stream frogs. *Journal of Animal Ecology* **78:** 305-314.

Kitayama K. 1992. An altitudinal transect study of the vegetation on Mount Kinabalu, Borneo. *Vegetatio* **102:** 149-171.

Krebs CJ. 1999. *Ecological Methodology* 2nd Ed., pp. 410-454. United States of America: Benjamin/ Cummings imprint.

Kueh BH, Sudin A. 2008. Gastrophrynoides borneensis range extension. *Herpetological Review* **39(3):** 363.

Lamb EG, Bayne E, Holloway G, Schieck J, Boutin S, Herbers J, Haughland DL. 2009. Indices for monitoring biodiversity change: Are some more effective than others? *Ecological Indicator* **9(2009):** 432-444.

Maklarin L, Paul Y, Satie A. 1999. A comparative study of the amphibian population in reference to habitat disturbance across an elevational gradient in Kinabalu Park, Sabah, Malaysia. *Sabah Parks Nature Journal* **2:** 27-44.

Malkmus R, Manthey U, Vogel G, Hoffmann P, Kosuch J. 2002. *Amphibian and Reptiles of Mount Kinabalu (North Borneo)*, pp. 88. Rugell: A.R.G. Gantner Verlag Kommanditgesellschaft.

Matsui M. 2006. Collecting and Preserving Amphibians. *In* Yoshiaki Hashimoto, Homathevi Rahman, Maryati Mohamed (eds). *Inventory and Collection Second Edition No. 56- Total Protocal for Understanding of Biodiversity*, pp. 175- 181. Institute for Tropical Biology and Conservation, Universiti Malaysia Sabah, and Japan International Cooperation Agency (JICA).

May RM. 1975. Patterns of species abundance and diversity. *In* Cody, M. L. and Diamond, J. M. (eds*). Ecology and evolution of communities*, pp. 81-119. Cambridge: Harvard University Press.

Mohamed AL, Ibrahim AZ, Akin S, Awang Z, Salleh H. 1999. Notes on the flowering plants of Tawau Hills Park, Sabah. *ASEAN review of Biodiversity and Environmental Conservation*.

Navas CA. 2006. Patterns of Distribution of Anurans in High Andean Tropical Elevations: Insights from Integrating Biogeography and Evolutionary Physiology, pp. 82-91. *Int. Comparative Biology Volume 46*.

Omar S, Nais J. 1995. Tawau Hils Park: An Overview. *In* Ismail Ghazally, Omar Shiraj and Laily Bin Din. *A Scientific Journey through Borneo, Tawau Hills Park, Sabah,* pp. 1-6. Malaysia: Pelanduk Publications.

Parris KM. 1999. Review: Amphibian surveys in forest and woodlands. *Contemporary Herpetology* **1999(1):** 1-14.

Rahbek C. 1995. The Elevatinal Gradient of Species Richness: A Uniform Pattern? *Ecography* **18(2):** 200-205.

Richards PW. 1996. *The Tropical Rain Forest*. 2nd Edition, pp. 173-175. United State of America: Cambridge University Press.

Stewart MM, Woolbright LL. 1996. Amphibian. *In* Reagen, D. P. and Waide, R. B. *The food web of the tropical rain forest*, pp. 363-398. Chicago: University of Chicago Press.

Stuebing RB, Nor SM. 1995. Notes of the Terrestrial Vertebrate Fauna of Tawau Hills Park, Sabah. *In* Ismail, G., Omar, S. and Laily, B. D. *A Scientific Journey Through Borneo, Tawau Hills Park, Sabah,* pp.151-162. Malaysia: Pelanduk Publications.

Thompson GG, Withers PC, Pianka ER, Thompson SA. 2003. Assessing biodiversity with species accumulation curves: Inventories of small reptiles by pit-trapping in Western Australia. *Austral Ecology* **28:** 361-383.

Traeholt C, Lundahl SLL, Pedeko D, Pilang V, Banggilon B, Dullah S, Bunggou M R. Sulaiman M. 2007. Preliminary Survey of Amphibians in Maliau Basin Conservation Area, Sabah, Malaysia. Sabah: *Sabah Parks Nature Journal* **8(2007):** 21-39.

Voris HK, Inger RF. 1995. Frog abundance along streams in Bornean forests. *Journal of Conservation Biology* **9(3):** 679-683.

Werner EE, McPeek MA. 1994. Direct and indirect effects of predators on two anuran species along an environmental gradient. *Ecology* **75(5):** 1368-1382.

Wong A. 1994. Population Ecology of Amphibians in Different Altitudes of Kinabalu Park. *Sabah Museum Journal Vol. 1, No. 2*, pp. 29-38. Kota Kinabalu: Sabah Museum.