DOI: https://doi.org/10.3897/arphapreprints.e95861

Uneven Species Occurrence and Richness of Lowland Snakes (Serpentes, Squamata) in Terengganu, Peninsular Malaysia with New Locality Records.

Muhamad Fatihah Syafiq, Baizul Hafsham Badli-Sham, Lee Grismer, Amirrudin Ahmad

Uneven Species Occurrence and Richness of Lowland Snakes (Serpentes, Squamata) in Terengganu, Peninsular Malaysia with New Locality Records.

Muhamad Fatihah Syafiq[1], Baizul Hafsyam Badli-Sham[1], Larry Lee Grismer[2] and Amirrudin B. Ahmad[1,3,*]

[1]Faculty of Science and Marine Environment, Universiti Malaysia Terengganu, 21030 Kuala Nerus, Terengganu, Malaysia
[2]Herpetology Laboratory, Department of Biology, La Sierra University, Riverside, CA, USA.
[3]Institute of Tropical Biodiversity and Sustainable Development, Universiti Malaysia Terengganu, 21030 Kuala Nerus, Terengganu, Malaysia.

*Corresponding author: Amirrudin B. Ahmad (amirrudin@umt.edu.my)

Abstract

This study documented information on the composition, diversity, richness, and temporal occurrence of snakes at Sekayu's lowland forest (SLF), Terengganu, Peninsular Malaysia for the first time. The snakes recorded within the SLF were sampled haphazardly from 2013 to 2019, employing the Visual Encounter Survey (VES) and L-shape pitfall traps with drift fences. Forty-six snake species from 37 genera belonging to the nine families were recorded, of which eleven were new records to Terengganu. Individual-based rarefaction and extrapolation curves were not reaching asymptote, indicating that additional species can be recorded at the study area. Non-parametric species richness estimators estimated and produced a range between 51 and 57 species. ACE was the best estimator based on the quantitative evaluation. All species showed some variations of the occurrence patterns across months. Fourteen species occurred only once across the sampling years, and interestingly 11 of them were detected during the rainy season. In general, the number of species richness, abundance, and rare species were high during this season. Species richness of snakes is high at SLF but sampling effort should be intensified, especially during these rainy months, to obtain a robust estimated snake species richness in SLF. Terengganu harbors considerably high species richness of snakes with a total of 71 species to date (excluding marine snakes), but snake diversity is still underestimated as only a few localities were surveyed in the past years, primarily at the northern part. Future surveys should be commenced at the central and southern parts of Terengganu to complement the current investigation.

Keywords

monsoon, reptiles, species richness estimation, species turnover, tropical rainforest

Introduction

Snake is one of the significant fauna components of the ecosystem. It plays a crucial role in predator-prey relationship (Marshall et al. 2020; D'Souza et al. 2021; Natusch et al. 2021), highly potential bio-indicators for the ecosystem including for climate change (Bickford et al. 2010; Weatherhead et al. 2012; Böhm et al. 2016; Lourenço-de-Moraes et al. 2019) and habitat degradation monitoring (Todd and Andrews 2008; Beaupre and Douglas 2009; Pike et al. 2010; Shelton et al. 2020). Regrettably, snakes received poor conservation attention compared to other reptile groups such as tortoises and turtles (Böhm et al. 2013; Saha et al. 2018; Shahirah-Ibrahim et al. 2018) and crocodiles and gharials (Martin 2008; Somaweera et al. 2019, 2020).

Malaysia is a tropical region with high endemism and richness of snakes (Roll et al. 2017). Currently, there are at least 191 species reported from Malaysia (MyBis 2021). Although snake species richness in this region is high, the distribution and genetic information are scarce due to limited sample (Quah et al. 2018a, 2018b, 2018c; Chan and Grismer 2021a). This is because snake is elusive fauna and notoriously difficult to sample due to its mobility (Barnes et al. 2017; Marshall et al. 2019; Fujishima et al. 2021; Jones et al. 2022), phenological idiosyncracies (Brown and Shine 2002; Rahman et al. 2013), cryptic morphology, and occur in low densities (Chan and Ahmad 2009; Durso et al. 2011). Therefore, it hampered the conservation efforts and ecological studies of Malaysia's snakes (Chan and Grismer 2021a, 2021b).

Terengganu's forests are still relatively understudied concerning their snake's diversity compared to other group of reptiles, and most of the information available for snakes are only from the herpetofauna checklists, derived from short-term inventories (e.g., Dring 1979; Grismer et al. 2011; Sumarli et al. 2015; Badli-Sham et al. 2019; Zakaria et al. 2019; Fatihah-Syafiq et al. 2020; Komaruddin et al. 2020). In comparison to the lizards, freshwater turtles and, tortoises groups, ecological and taxonomical study solely focusing on snakes in Terengganu is non-existed (Grismer and Chan 2008; Grismer et al. 2009; 2014a; Chan and Norhayati 2010; Chan and Chen 2011; Shahirah-Ibrahim et al. 2018).

Sekayu's lowland forest (SLF), provide a potential site for conducting an ecological study on the snake assemblage. A large part of this area resided within the Hulu Terengganu Tambahan Forest Reserve. The lowland forest included a protected area, Sekayu Recreational Forest (SRF) and Sekayu Agricultural Park (SAP). The latter was developed for agro-based tourism and ecotourism purposes. The presence of visitors at these areas may induce human-wildlife conflict, in which between human and snakes. However, data on snake species richness in SLF is rather limited to inform the parks' managers to spread the awareness and information among the visitors. Only two snake species, *Naja sumatrana* and *Tropidolaemus wagleri* are known from this locality based on Zakaria et al. (2019) checklist. Regrettably, the number is seriously underestimating the species richness of snakes from this area because of the short-term inventory executed by the study. In contrast, a few new discoveries on various faunal groups were made here. Several new species of crabs (Ng and Ahmad 2016; Ng 2020) and skinks species (Grismer et al. 2014, 2018; Sumarli et al. 2016) had been made from SLF, implying that the diversity of fauna and more specifically reptiles, is high in this underexplored forest.

Herein, we compiled a checklist of snakes from Sekayu's lowland forest (SLF) from our study and we compiled information on snakes from previous studies at other localities in Terengganu. We also examined the snake composition using our data at SLF, Terengganu, delivering information about snakes' diversity, richness, and their temporal occurrence from this locality.

Methods

Survey area

Sekayu's lowland Forest (SLF) is situated in the state of Terengganu, Peninsular Malaysia (4.9676ºN, 102.9549ºE) (Fig. 1). The Hulu Terengganu Tambahan Forest Reserve, which comprises roughly about 10,899 hectares making up the SLF. The landscape of SLF ranges from flat lowland forest to hilly terrain (area focused in this study: up to 150 m a.s.l). Primary and secondary dipterocarp forests characterized the vegetation at SLF. Two main streams coursed through the study site, namely Sungai (English: river) Bubu and Sungai Peres. These rivers consisted of fast-flowing cascades and waterfall at the upper stream, followed by rocky and sandy streams in the middle and lower parts. The former running through the Sekayu Agricultural Park (SAP) and the latter flowed through the Sekayu Recreational Forest (SRF). Within SAP and SRF, there were authority offices, roads, and public facilities such as chalets, toilets, cemented walls, wooden huts, including artificial lakes and pools built for various reasons. The mean rainfall of SLF is <250mm during the dry season (April to September) and >250mm) during the rainy season (October to March). This area having average temperature of 30ºC and high humidity (>80%) throughout the year and heavy rainfalls were experienced in the months of November to March except in February.

ARPHA Preprints Author-formatted, not peer-reviewed document posted on 05/10/2022 DOI: https://doi.org/10.3897/arphapreprints.e95861

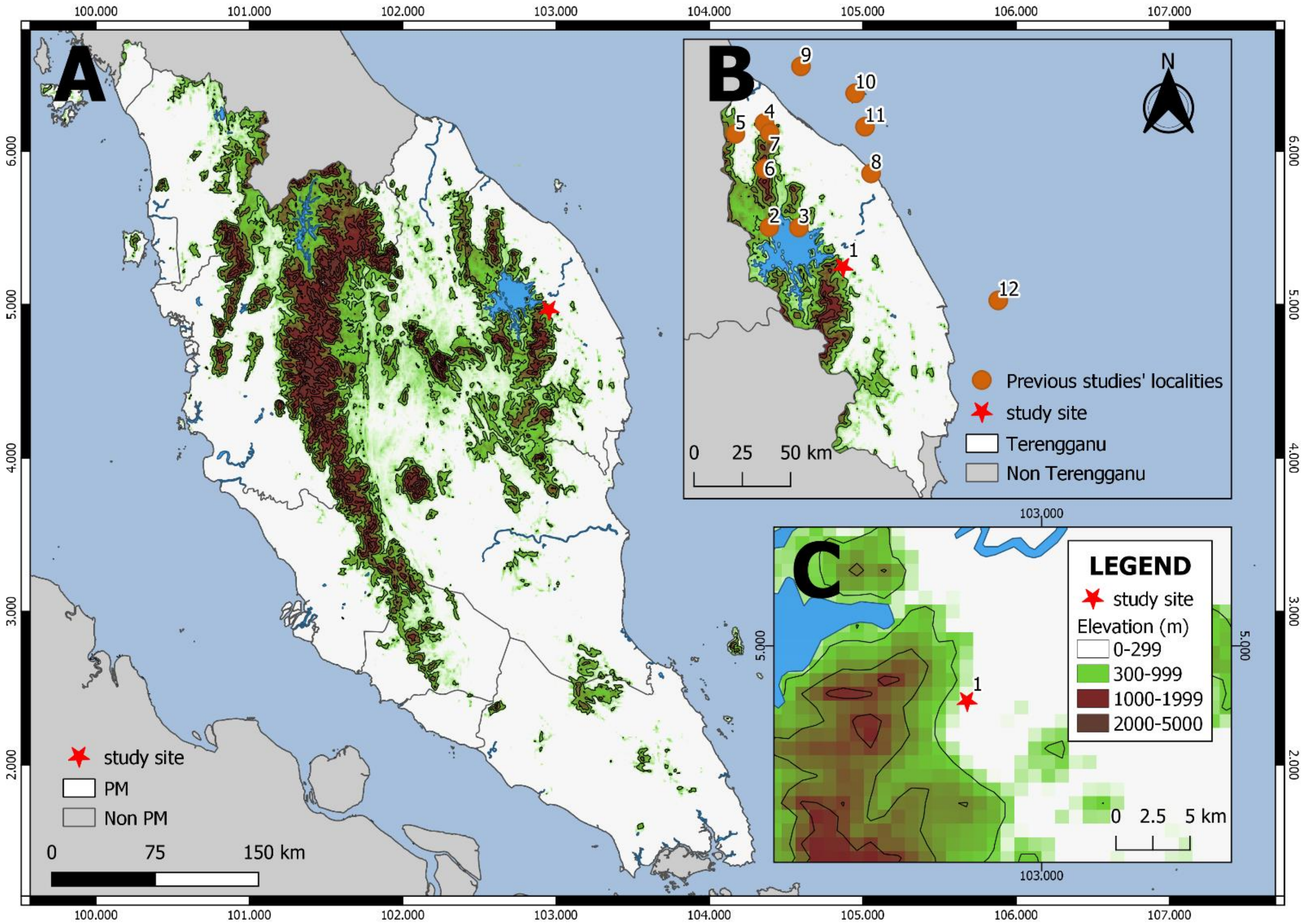

Figure 1. Map of Peninsular Malaysia (left) shows the Sekayu's lowland forest, indicated by the red star (**A**). Insets were localities of previous studies in Terengganu state where data of snakes occurrences were compiled: 1. Sekayu lowland forest 2. Tembat Forest Reserve 3. Kenyir Lake 4. Lata Belatan 5. Lata Tembakah 6. Gunung Lawit 7. Gunung Tebu 8. Universiti Malaysia Terengganu (UMT) 9. Pulau Perhentian Besar 10. Pulau Redang 11. Pulau Bidong 12. Pulau Tenggol (**B**) and the elevation of the study area (**C**).

Data collection

Surveys were executed haphazardly from the year 2013 to 2019. Most of the collections were made for a few months within the year and more surveys were done in the dry season because the SLF was closed between November and February. Collection area spanned from the low-lying to the hilly area (<300 meters), anthropomorphic areas, and along the streams. Visual Encounter Survey (VES) and drift-fenced pitfall traps were employed during the study as the collecting methods. The surveys were aggregated into two time periods: daily surveys (ranging between 10:00 a.m. to 3:00 p.m.) and nocturnal surveys (ranging between 7.00 p.m. to 12:00 p.m.). Surveys were conducted with the field parties consisting of four to five persons. The voucher specimen was collected for each species, euthanized using benzocaine, fixed with 10% formalin, and tagged with the Universiti Malaysia Terengganu Zoological Collection (UMTZC) code before being stored with 70% ethanol for long-term storage. Liver tissue was taken before the fixation with formalin and stored in 95% ethanol for future molecular studies. All vouchered specimens were deposited in the General Lab Biology, Universiti Malaysia Terengganu. Identification of species followed Cox et al. (1998) and Das (2010). The latest taxonomic nomenclature refers to The Reptile Database (Uetz et al. 2020). For the consolidated checklist and notes, the information was searched through the Google Scholar using English language terms to identify published herpetofaunal studies in Terengganu, in order to get the records of the snake species in this state. The following terms in the following combinations were used: "herpetofauna AND reptiles AND snakes AND Terengganu". Non-peer reviewed source such as technical report was excluded.

Data analysis

Pie chart, bar chart, and Rank Abundance Curve (RAC) were plotted to assess snakes' composition and species abundance distribution using Microsoft Excel. The species composition was based on cumulative abundance from all collections since 2013.The Chi-square goodness of fit test was used to fit the species abundance with four abundance models and evaluate which model best fits the dataset of snakes in Sekayu lowland forests. This test was run using the PAST software (Hammer et al. 2001). The "iNEXT" R package version 2.0.20 (Hsieh et al. 2016) was utilized by using R version 4.1.3 (R Core Team 2022), aided by RStudio integrated development environment (RStudio, 2022). The first three Hill numbers (richness, q=0; Shannon diversity index, q=1; Simpson diversity index, q=3) (Hill, 1973) were measured. The Hill numbers for these species diversity orders were then used to plot the sample rarefaction and extrapolation curve to measure the sampling effort.

The eight non-parametric species richness estimators' values: abundance-based coverage estimator (ACE), incidence-based coverage estimator (ICE), Chao 1 estimator, Chao 2 estimator, first-order Jackknife (Jack 1), second-order Jackknife (Jack 2), Michaelis–Menten Mean (MMMean), and Michaelis–Menten Runs (MMRuns), were calculated using EstimateS version 9.10 (Colwell 2005). The sample order was randomized 100 times to compute the mean estimator and species richness for each accumulation sample level. To evaluate the estimators, three quantitative evaluation measures were used: bias (scaled mean error), precision (coefficient of variation), and accuracy (scaled mean square error). The bias, precision, and accuracy were calculated following Walther and Moore (2005). Later, each of the measure values for each estimator was ranked accordingly. The value close to "0" was ranked as the number "1" rank and the rank number increased as the estimated value far from "0". The final ranking was based on a total of each estimator's number of ranks. The lowest value of the total accumulation was chosen as the best estimator.

The seriation of species presence/absence across months of the sampling years (January to December) was done using a constrained algorithm (Brower and Kile 1988). This was done using PAST software. The seriation diagram of species presence/absence was edited to represent species abundance in the respective month. Temporal indices comprised of total turnover, species appearances, and species disappearances were calculated using the "codyn" R package version 2.0.5 (Collins et al. 2008; Hallett et al. 2016). The total turnover calculated was the proportion of species richness (lost and gained) in relation to the total species in each month-to-month comparison. The turnover metric varied from 0 (no species gained or lost) to 1 (complete species replacement) (Collins 2000).

Results

Species checklist of herpetofauna in MHR

Table 1 incorporates data from this study and previous studies (Grismer et al. 2011; Sumarli et al. 2015; Nur Amalina et al. 2017; Badli-Sham et al. 2019; Zakaria et al. 2019; Fatihah-Syafiq et al. 2020; Komaruddin et al. 2020) were the snakes species that had been known to the state of Terengganu to date. This consolidated checklist documented 71 species of snakes found in Terengganu. Of this, 46 snake species from 37 genera belonging to the nine families were recorded from SLF. There were 11 new records acquired from this study, namely: *Bungarus candidus* (Fig. 2A), *Dendrelaphis haasi* (Fig. 2B), *Dendrelaphis striatus*, *Dryophiops rubescens* (Fig. 2C), *Lycodon albofuscus*, *Lycodon effraenis, Oligodon purpurascens, Oligodon signatus* (Fig. 2D), *Ptyas fusca* (Fig. 2E), *Typhlops muelleri* (Fig. 2F), and *Xenopeltis unicolor* to the state of Terengganu.

Table 1. Consolidated checklist of snakes in Terengganu. This list was compiled from results of this study as well as published works of Grismer et al. (2011)[1], Sumarli et al. (2015)[2], Nur Amalina et al. (2017)[3], Badli-Sham et al. (2019)[4], Zakaria et al. (2019)[5], Fatihah-Syafiq et al. (2020)[6], and Komaruddin et al. (2020)[7]. Asterisks (*) denoted new records. Codes were for species recorded from SLF.

ARPHA Preprints Author-formatted, not peer-reviewed document posted on 05/10/2022 DOI: https://doi.org/10.3897/arphapreprints.e95861

No	Code	Family/Species	Pulau Bidong[6]	Pulau Perhentian Besar[1]	Pulau Redang[1]	Pulau Tenggol[1]	Tembat Forest Reserve[3]	Kenyir Lake[5,7]	Lata Belatan[2]	Lata Tembakah[2]	Gunung Lawit[2]	Gunung Tebu[2]	UMT[4]	Sekayu (This study)
		Achrochordidae												
1		*Achrochordus javanicus*					x							
		Colubridae												
2	Ahmyc	*Ahaetulla mycterizans*					x							x
3	Ahpra	*Ahaetulla prasina*		x	x	x		x					x	x
4	Bocyn	*Boiga cynodon*					x							x
5	Bodra	*Boiga drapiezii*							x		x	x		x
6	Bojas	*Boiga jaspidea*					x		x					x
7	Bomel	*Boiga melanota*		x	x		x	x			x		x	x
8	Bonig	*Boiga nigriceps*									x	x		x
9		*Calamaria lumbricoidea*					x							
10	Capav	*Calamaria pavimentata*					x	x						x
11	Chorn	*Chrysopelea ornata*		x			x						x	x
12	Chpar	*Chrysopelea paradisi*					x							x
13	Chpel	*Chrysopelea pelias*					x							x
14	Cofla	*Coelognathus flavolineatus*					x	x						x
15		*Coelognathus radiatus*											x	
16	Decau	*Dendrelaphis caudolineatus*					x							x
17		*Dendrelaphis cyanochloris*										x		
18	Defor	*Dendrelaphis formosus*								x				x
19	Dehaa	*Dendrelaphis haasi**												x
20	Depic	*Dendrelaphis pictus*		x	x		x	x					x	x
21	Destr	*Dendrelaphis striatus**												x
22	Drrub	*Dryophiops rubescens**												x
23	Lyalb	*Lycodon albofuscus**												x
24	Lycap	*Lycodon capucinus*	x	x										x
25	Lyeff	*Lycodon effraenis**												x
26	Lysuba	*Lycodon subannulatus*		x										x
27	Lysubc	*Lycodon subcinctus*		x			x		x					x
28		*Gonglyosoma longicaudum*					x							
29		*Gonyosoma prasinum*					x							
30	Gooxy	*Gonyosoma oxycephalum*		x										x
31		*Oligodon octolineatus*					x							
32	Olpur	*Oligodon purpurascens**												x
33	Olsig	*Oligodon signatus**												x
34	Pslon	*Pseudorhabdion longiceps*					x							x
35		*Pseudorhabdion cf longiceps*										x		
36		*Ptyas carinata*					x							
37	Ptfus	*Ptyas fusca**												x
38		*Ptyas korros*					x							
39		*Xenelaphis hexagonotus*					x							
40	Xeuni	*Xenopeltis unicolor**												x
		Elapidae												
41	Bucan	*Bungarus candidus**												x
42		*Bungarus fasciatus*					x							
43	Bufla	*Bungarus flaviceps*					x	x						x

44	Caint	*Calliophis bivirgatus*					x		x					
45		*Calliophis intestinalis*					x							x
46	Nakou	*Naja kaouthia*					x						x	x
47	Nasum	*Naja sumatrana*					x							x
48		*Ophiophagus hannah*					x							
		Homalopsidae												
49	Enenh	*Enhydris enhydris*					x						x	x
50	Hyplu	*Hypsiscopus plumbea*					x		x				x	x
51	Hobuc	*Homalopsis buccata*					x	x					x	x
52		*Phytolopsis punctata*					x							
		Natricidae												
53		*Macrophistodon flaviceps*					x							
54		*Macrophistodon rhodomelas*								x				
55	Rhchr	*Rhabdophis chrysargos*					x				x			x
56		*Rhabdophis subminiatus*					x							
57	Xetri	*Xenochrophis trianguligerus*					x							x
58		*Xenochrophis piscator*					x							
		Pariedae												
59	Apboa	*Aplopeltura boa*										x		x
60		*Asthenodipsas laevis*					x							
61	Pacar	*Pareas carinatus*					x							x
62	Pamar	*Pareas margaritophorus*							x					x
63		*Pareas sumatranus*									x			
		Pythonidae												
64	Maret	*Malayopython reticulatus*	x	x	x	x	x						x	x
65		*Python brongersmai*					x							
		Typhlophidae												
66		*Argyrophis diardii*					x							
67	Inbra	*Indotyphlops braminus*	x	x										x
68	Armue	*Typhlops muelleri**												x
		Viperidae												
69	Trwag	*Tropidolaemus wagleri*		x			x			x				x
70		*Trimeresurus hageni*						x		x				
71		*Trimeresurus sabahi*					x				x	x		

Notes on the new record species and their distribution in Peninsular Malaysia

Bungarus candidus (Linnaeus, 1758)
Blue Krait Snake
Figure 2A

Remarks. This species can be identified by its cylindrical body with enlarged vertebral scale row; head not distinct with neck; head of black colour dorsally and connected with the first body marking forming chevron shape; body with black crossbands with white interspaces; and chin, neck and ventral of the body white. Most individuals were frequently found during rainy period, either crossing the roads or foraging near the slow-flowing stream.

Distribution. This species is known from a few localities from the states of Kedah, Kelantan and Johor (Grismer and Pan 2008; Muin et al. 2017; Ayob et al. 2020).

Dendrelaphis haasi van Rooijen and Vogel, 2008
Haas’ Bronzeback Snake
Figure 2B

Remarks. This species can be identified by its slender body; head of orangish to light brown colour dorsally; narrow postocular stripe covering less than half of the temporal region, with some black spots at the lower temporal region; and dull ventrolateral stripe. The species was found sleeping on a twig and leaf of a ornamental tree (0.5 m height from the ground) in the plant nursery situated adjacent to the secondary forest.

Distribution. van Rooijen and Vogel (2008) stated that this species is widely distributed in Peninsular Malaysia but Pulau Tioman was the only locality mentioned in their article. Since then, no succeeding article has been known to report the occurrence of this species in another locality virtually. This study reported the first locality record of this species in Peninsular Malaysia's continental specifically in the state of Terengganu.

Dendrelaphis striatus (Cohn, 1905)
Banded Bronzeback Snake

Remarks. This species can be identified by its slender body; head of bronze brown in colour; thick black stripe extending from the snout passing through the eye and ended at the neck region; neck yellow when inflated; body yellow at the anterior and blue at the posterior with oblique black band. The species was found sleeping during night at the ornamental tree near the Sekayu Recreational Forest authority's office.

Distribution. This species is widely distributed in Peninsular Malaysia (MyBis 2021) but the record of occurrence of this species specifically from Terengganu state in a published documentation is virtually unavailable to our knowledge.

Dryophiops rubescens (Gray, 1834)
Brown Whip Snake
Figure 2C

Remarks. This species can be identified by its slender but laterally compressed body; head of light greyish brown dorsally with three distinct short brown stripe at the occipital region; thick dark brown stripe extending from snout, through the eye to the nape area; body greyish to brown colour dorsally with dark brown and cream spots. The species was found sleeping on a twig of a dipterocarp tree (2 m height above ground) situated near the stream.

Distribution. This species is widely distributed in Peninsular Malaysia (MyBis 2021) but the record of occurrence of this species specifically from Terengganu state in a published documentation is virtually unavailable to our knowledge.

Lycodon albofuscus (Duméril, Bibron & Duméril, 1854)
Dark Wolf Snake

Remarks. This species can be identified by its elongated, slender body; elongated, depressed head; blunt snout; dorsal body uniformly grey in colour; ventral pale; dorsal scale strongly keeled. An individual was found at night, crossing the established trail adjacent to the secondary forest, near a fast-flowing stream.

Distribution. This species was recorded from a few localities such as Pasoh Forest Reserve, Krau Wildlife Reserve, and Pulau Tioman (MyBis 2021) but the record of occurrence of this species specifically from Terengganu state in a published documentation is virtually unavailable to our knowledge.

Lycodon effraenis Cantor, 1847
Brown Wolf Snake
Remarks. This species can be identified by its slender body, head of dark brown with white stripes extending from snout, passing through the eye and ending before the nape; dorsal body dark brown in

colour with white irregular-shaped crossbands. The species was found sleeping on the tree vines (2 m height above ground) situated near a slow-flowing rocky stream.

Distribution. The species has been reported from the states of Kelantan, Johor and Pahang (MyBis 2021). This study augmented the information on this species' distribution with additional reported locality.

Oligodon purpurascens (Schlegel, 1837)
Brown Kukri Snake

Remarks. This species can be identified by its robust body; head of dark purplish with brown ocular bars; dorsal body dark brown with faint blotches and irregular crossbands. The species was observed at night on the ground near a slow-flowing stream.

Distribution. This species is widely distributed in Peninsular Malaysia (MyBis 2021) but the record of occurrence of this species specifically from Terengganu state in a published documentation is virtually unavailable to our knowledge.

Oligodon signatus (Günther, 1864)
Barred Kukri Snake
Figure 2D

Remarks. This species can be identified by its robust body; head of light brown colour dorsally with dark brown ocular bars; dorsal body dark brown with reddish brown triangular markings; first red crossbar had a chevron-pattern pointing towards the head. The species was found on the leaf litter substrate near the slow-flowing stream.

Distribution. Based on Chan and Ahmad (2009), this rare species was reported to occur in the states of Selangor, Melaka, Johor, Pahang and Negeri Sembilan. This study augmented the information on this species' distribution with additional reported locality.

Ptyas fusca (Günther, 1858)
White-bellied Rat Snake
Figure 2E

Remarks. This species can be identified by olive green body dorsally; white ventral; black stripes at the lateral side of posterior body and tail. The species was found sleeping on a twig (3 m height above the ground) during a rainy day at night.

Distribution. This species was reported from Pahang and Johor (MyBis 2021). This study augmented the information on this species' distribution with additional reported locality.

Typhlops muelleri (Schlegel, 1839)
Müller's Blind Snake
Figure 2F

Remarks. This species can be identified by its cylindrical body; head of black colour dorsally; head indistinct with neck; vestigial eyes; dorsum black; ventral white; tail with sharp, terminal spine. The species was found foraging at night at the man-made drainage.

Distribution. This species was reported from Perak, Pahang and Johor (MyBis 2021). This study augmented the information on this species' distribution with additional reported locality.

Xenopeltis unicolor Reinwardt, 1827
Sunbeam Snake

Remarks. This species can be identified by its relatively robust body; body and head brown in colour dorsally but produce iridescent colour under strong light; ventral white; body scale smooth. The species was found foraging at night on the ground (sandy substrate) near the large fast-flowing stream.

Distribution. This species was reported from Kedah, Pulau Pinang, Negeri Sembilan, and Pahang (MyBis 2021). This study augmented the information on this species' distribution with additional reported locality.

Figure 2. Reptile species of new record in Terengganu recorded in SLF **A** *Bungarus candidus* **B** *Dendrelaphis haasi* **C** *Dryophiops rubescens* **D** *Oligodon signatus* **E** *Ptyas fusca* **F** *Typhlops muelleri.*

Species abundance distribution and composition

Family Colubridae (89 individuals) has the highest number of individuals recorded (Fig. 3), followed by Elapidae (11 individuals), Paridae, Viperidae (10 individuals), Typhlopidae (nine individuals), Pythonidae (seven individuals), Homalopsidae (six individuals), and Xenopeltidae (three individuals). Genera-wise, family Colubridae had the highest number of genera (14 genera), followed by Elapidae (three genera), Homalopsidae, Paridae, Typhlopidae (two genera), and the rest of the family with only one genus each. Concerning species richness, the family Colubridae was the most species-rich taxon (30 species), followed by Elapidae (five species), Paridae (three species), Homalopsidae, and Typhlopidae (two species), and the rest of the family with one species, respectively (Table 1).

ARPHA Preprints Author-formatted, not peer-reviewed document posted on 05/10/2022 DOI: https://doi.org/10.3897/arphapreprints.e95861

Figure 4 showed that there are two dominant species with *Tropidolaemus wagleri* had the highest number of individuals (10 individuals). Seven species were doubletons. Singletons in the rank abundance curve hereafter were considered as rare species recorded in this study. Thirteen rare species were recorded, while the rests were intermediately abundant species. The species abundance distribution of snakes in SLF best fitted the geometric series model (X^2 = 1.65).

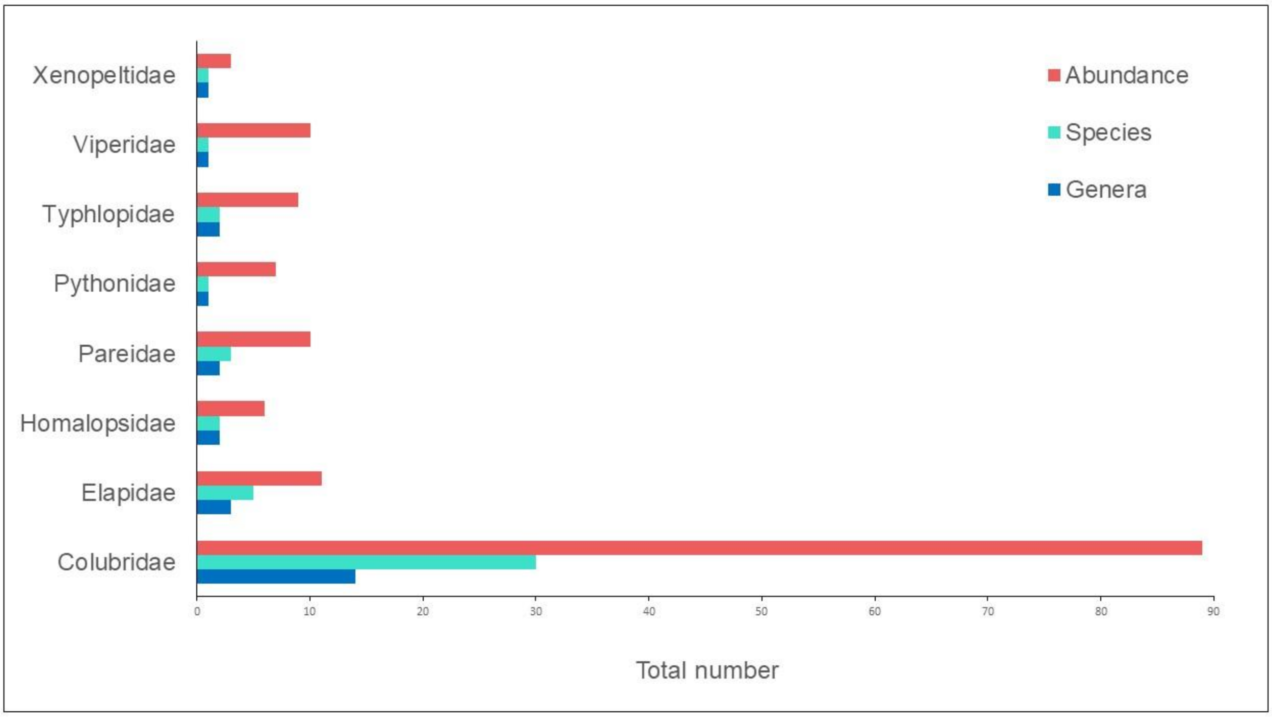

Figure 3. Each snake family's total abundance, species, and genera inhabit Sekayu Lowland Forest.

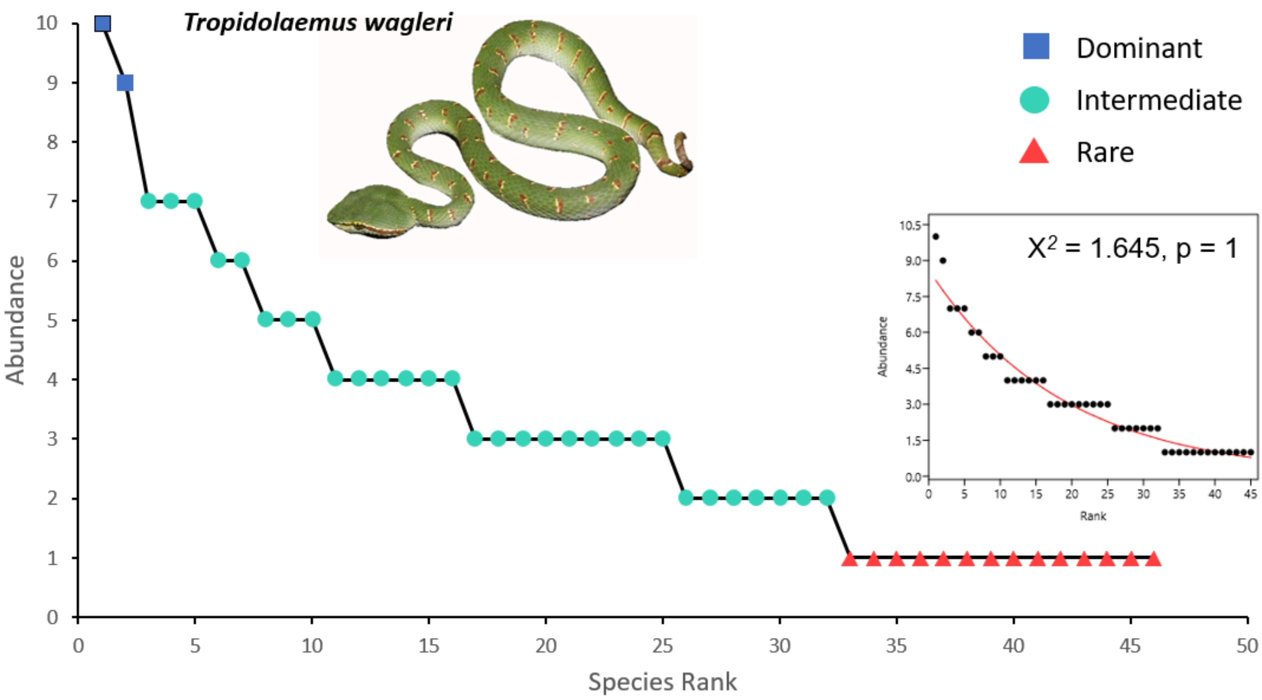

Figure 4. Rank abundance curve for snakes in Sekayu Lowland Forest. The X-axis indicates species rank and species richness, while Y-axis denotes the numerical abundance of each species. Species were ranked from the most abundant to the rare species. The blue rectangle represents dominant species, the green circle represents intermediate species, and the red triangle represents rare species. The inset curve was the best fitted geometric series (X^2 = 1.645) model curve obtained from PAST software. Inset on the main curve was the photograph of the most abundant snake species, *Tropidolaemus wagleri* recorded in this study.

ARPHA Preprints Author-formatted, not peer-reviewed document posted on 05/10/2022 DOI: https://doi.org/10.3897/arphapreprints.e95861

Sampling effort and species richness estimation

Individual-based rarefaction and extrapolation curves demonstrated that the curve for diversity measures of species richness (q=0) was still not reaching asymptote, even after the sample size was doubled to 300 individuals by the extrapolation (Fig. 5). The curves for diversity measures of Shannon's diversity (q=1) and Simpson's diversity (q=2) were also showed an inclining trend and not stabilized even when the sample size increased and extrapolated. Having said that, the Simpson's diversity (q=2) was superficially approaching asymptotic with the increasing abundant.

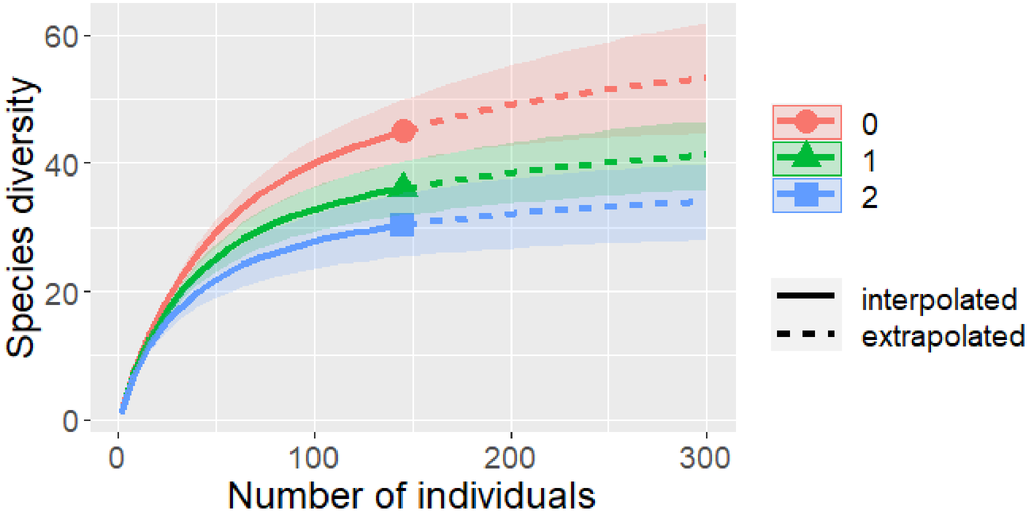

Figure 5. Individual-based rarefaction (solid line segment) and extrapolation (dashed line segment) sampling curves with 95% confidence intervals (shaded areas) for diversity orders: q = 0 (species richness), q = 1 (Shannon's diversity), q = 2 (Simpson's diversity).

Table 2 showed that the estimated values from the non-parametric species richness estimators. The generated values were varied between 51 and 73 species. An additional five to 27 species were expected by the non-parametric species richness estimators from the observed species richness. The least bias estimator was MMMeans. All estimators seem to be highly accurate except the two coverage-based estimators, ICE and ACE. However, ACE shows the most accurate species richness estimator in this study while MMRuns was the least accurate. Based on the final ranking, ACE was chosen as the best estimator to estimate the species richness of snakes in SLF, while the MMRuns estimator had the worst performance.

Table 2. Estimated values from eight non-parametric species richness estimators with their evaluation measures: bias, precision, and accuracy. Value "0" indicates no bias, high precision, and high accuracy. The ranking of eight non-parametric estimators was based on their performance of each measure. The final ranking for each estimator was measure based on the summation of their performance (= total rank accumulation).

No.	Estimators	Estimated value	Bias	Precision	Accuracy	Total Rank	Final Ranking
	Sobs (n=46)						
1.	ACE	52.48	-0.14 (2)	0.13 (2)	0.02 (1)	5	1
2.	ICE	54.45	0.19 (3)	1.84 (3)	0.64 (7)	13	6
3.	Chao 1	54.68	-0.20 (4)	0 (1)	0.05 (2)	7	2
4.	Chao 2	51.13	-0.24 (6)	0 (1)	0.10 (3)	10	5
5.	Jack 1	57.25	-0.22 (5)	0 (1)	0.11 (4)	10	5
6.	Jack 2	60.04	-0.19 (3)	0 (1)	0.15 (5)	9	4
7.	MMRuns	73.19	1.50 (7)	0 (1)	9.40 (8)	16	7
8.	MMMeans	66.79	0.05 (1)	0 (1)	0.16 (6)	8	3

Temporal occurrence of snakes across the sampling years

ARPHA Preprints Author-formatted, not peer-reviewed document posted on 05/10/2022 DOI: https://doi.org/10.3897/arphapreprints.e95861

The data of 46 species of snakes recorded at SLF showed that more snake species were observed in October (26 species) while December had the lowest number of species observed (two species) (Fig. 6). *Pareas carinatus* was the most frequently detected species in October (4 individuals). The species that were detected thrice in the respective month across the sampling years were: July = *Indotyphlops braminus*; September = *Tropidolaemus wagleri*; October = *Boiga cynodon,* and *Boiga drapiezii*; December = *Dendrelaphis caudolineatus*. The species that were detected twice in the respective month across the sampling years were: February = *Xenochrophis trianguligerus* and *Xenopeltis unicolor*; March = *Boiga jaspidea*; July = *Boiga drapiezii*, *Dendrelaphis caudolineatus,* and *Dendrelaphis pictus*; August = *Dendrelaphis pictus*, *Homalopsis buccata,* and *Tropidolaemus wagleri*; September = *Boiga nigriceps* and *Ptyas fusca*; October = *Ahaetulla prasina, Boiga melanota*, *Dendrelaphis striatus, Malayopython reticulatus*, and *Tropidolaemus wagleri*; November = *Boiga melanota*, *Bungarus candidus* (Fig. 2A), *Dendrelaphis striatus, Indotyphlops braminus*, *Malayopython reticulatus*, and *Tropidolaemus wagleri*. The rest of the species occurred only once throughout the months across the sampling years. In general, many species were recorded during early monsoon months (October – November) but less during monsoon (December – January). However, the data showed that singletons/unique observation (black square) of snakes did not restrict in either monsoon (e.g, January) or non-monsoon (April – June) months.

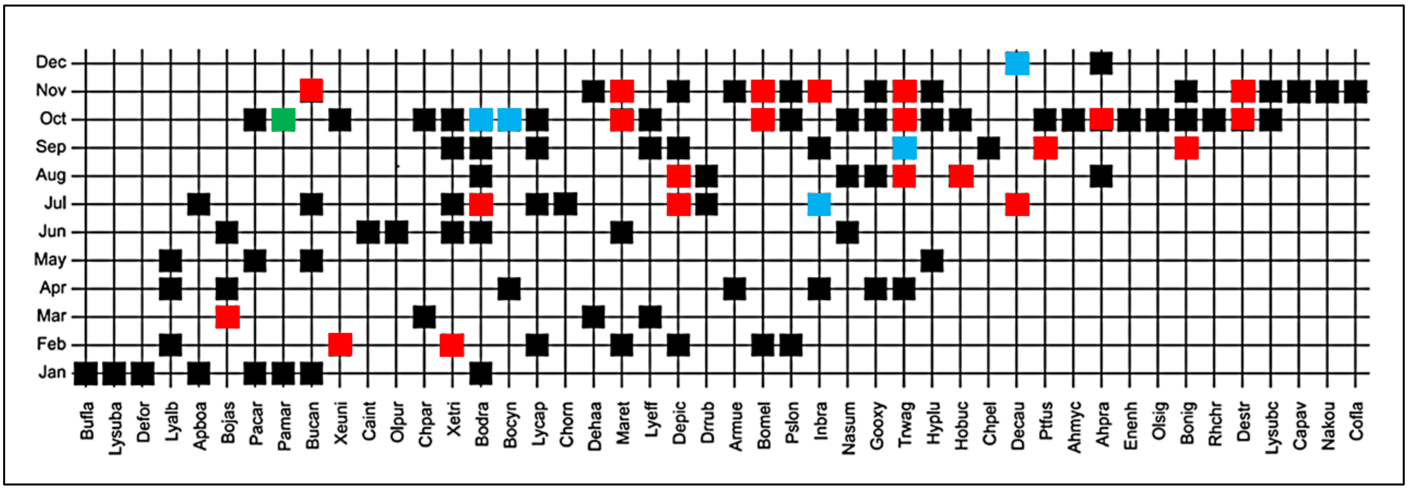

Figure 6. The seriation diagram of the species abundance in respective months over the sampling years (2013 – 2019). X-axis indicates species name, Y-axis indicates months. Note: black rectangle = one individual, red rectangle = two individuals, blue rectangle = three individuals, green rectangle = four individuals. See Table 1 for species codes.

Based on the presence/absence data, rare species that occurred only once (unique species) across the sampling years were more during pre-monsoon month (October) and monsoon months (November and January) (Fig. 7). Unique species were reported during dry season as well (June and July). Species such as *Bungarus flaviceps*, *Dendrelaphis formosus*, and *Lycodon subannulatus* were detected only in January while *Calliophis intestinalis* and *Oligodon purpurascens* were seen once in June and *Chyropelea ornata* was detected in July. Other species like *Chrysopelea pelias* was detected in September only. In October, four unique species were recorded namely *Ahaetulla mycterizans*, *Enhydris enhydris*, *Oligodon signatus,* and *Rhabdophis chrysargos* and in November, *Calamaria pavimentata*, *Coelognathus flavolineatus*, and *Naja kaouthia* were recorded.

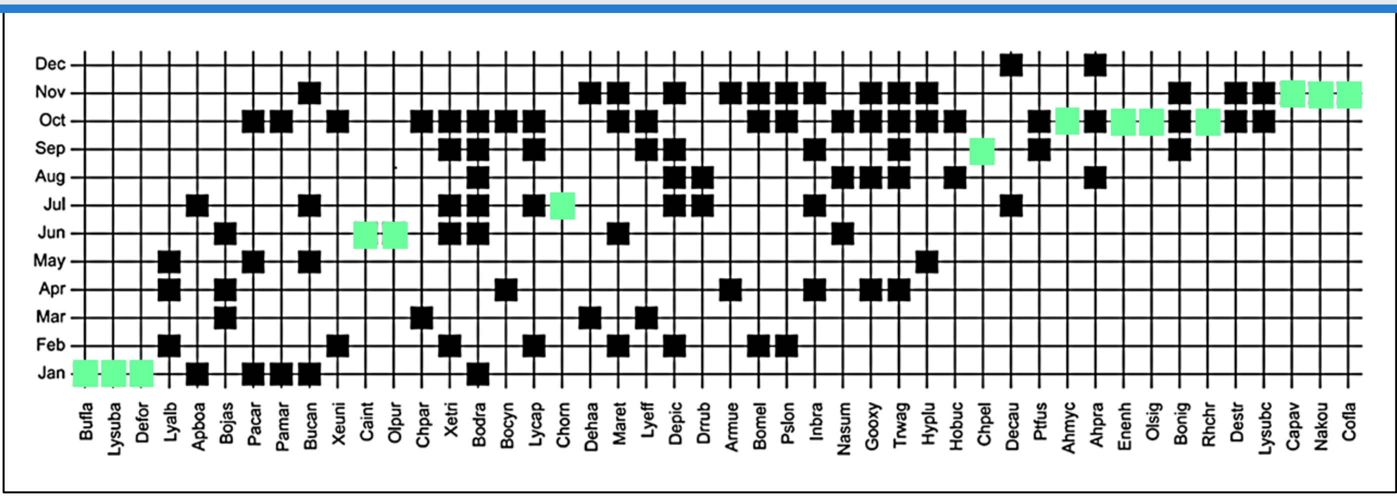

Figure 7. The seriation diagram of the species presence in respective months over the sampling years. X-axis indicates species name, Y-axis indicates months. Note: Turquoise rectangle = only one individual found across the months over the sampling years. See Table 1 for species codes.

Turnover index values varied over time in this study (Fig. 8). Species appearance was the highest, and species disappearance was the lowest between September-October. Species appearance dropped drastically starting from the month September-October to November-December coincided with the monsoon season. On the contrary, species disappearance rocketed from September-October to November-December as the monsoon season arrived.

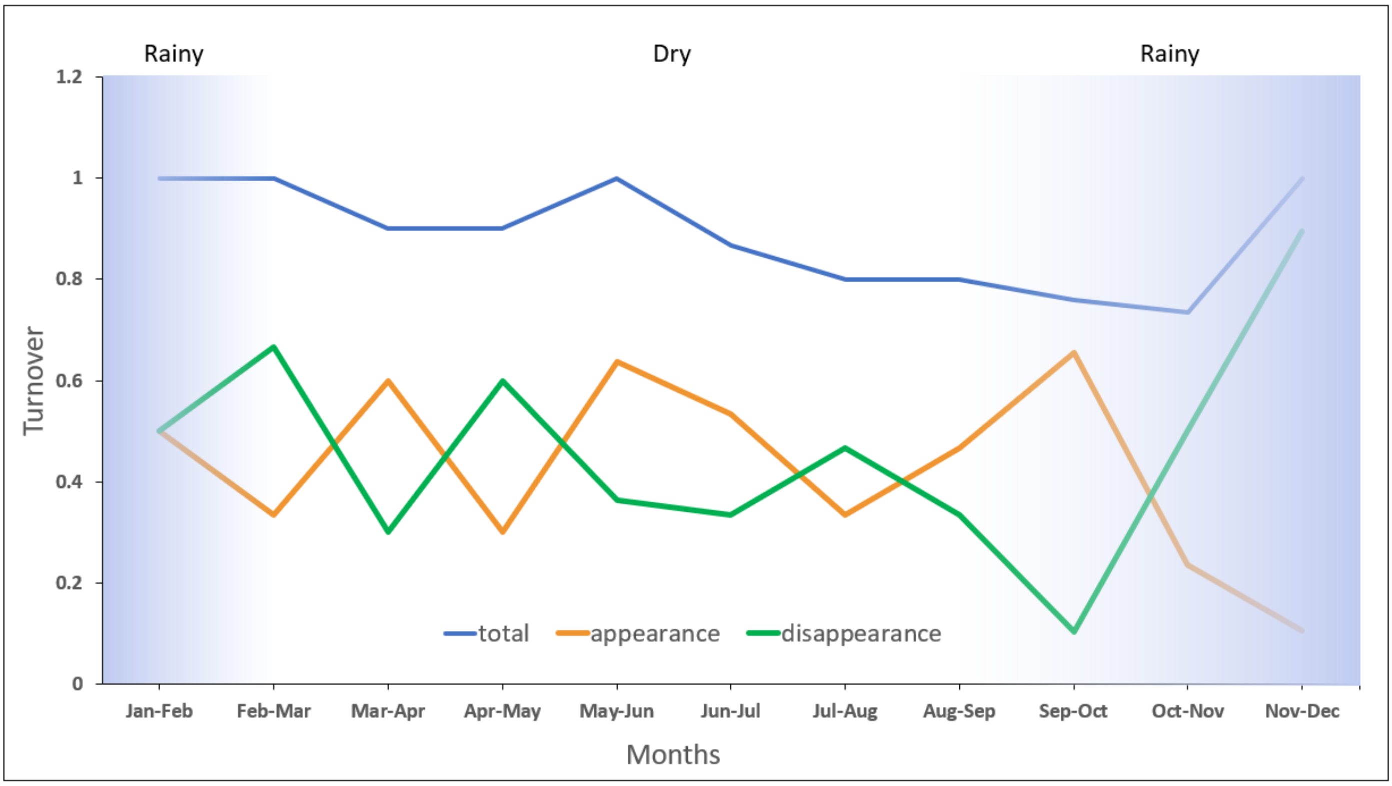

Figure 8. The turnover plot depicts the cumulative month-to-month total turnover with species appearances and disappearances. The blue shaded area indicated the rainy season, while the non-shaded area indicated the dry season.

Discussion

This study elevated the current knowledge of reptiles in Terengganu regarding the new records, species richness, and temporal occurrence of snakes species at Sekayu's lowland forest (SLF). The number of snake species found in SLF represents 64% of the total recorded snake species found in Terengganu (Table 1). To date, SLF was regarded as the locality with the highest species richness of snakes in Terengganu. Tembat Forest Reserve, a site comparable with SLF due to the employment of similar methods and efforts, had lesser two species from SLF, of which Nur Amalina et al. (2017)

obtained a total of 44 species. Interestingly, this finding is not surprising because these two sites are located closely, implying that the species richness and composition between these sites might be similar. Future studies that compare the reptile diversity (snakes in particular) between these sites should be conducted to elucidate the species distribution and diversity pattern and intersite similarity of the two locations.

Eleven new records were obtained in this study. The newly recorded snake species were *Bungarus candidus* (Fig. 2A), *Dendrelaphis haasi* (Fig. 2B), *Dendrelaphis striatus*, *Dryophiops rubescens* (Fig. 2C), *Lycodon albofuscus*, *Lycodon effraenis, Oligodon purpurascens, Oligodon signatus* (Fig. 2D)*, Ptyas fusca* (Fig. 2E)*, Typhlops muelleri* (Fig. 2F)*,* and *Xenopeltis unicolor.* These species were not found in other localities in Terengganu including the offshore islands (Table 1). However, these species are widespread and distributed around Peninsular Malaysia (MyBis 2021). The consensus is that snake is elusive, and some species have cryptic-looking morphology (such as in the case of *D. rubescens* that almost resembles and well-blended with their environment). Hence low detectability of snakes species during inventories can occur (Durso et al. 2011; Ward et al. 2017; Frazao et al. 2020; Asad et al. 2021). This factor may explain why these four species were not observed in other localities in Terengganu's forested area.

Two species ranked as the topmost abundant snakes in SLF which were *Tropidolaemus wagleri* (10 individuals) and *Boiga drapiezii* (nine individuals). The widespread distribution range and many occurrence records (Vogel et al. 2007; iNaturalist 2021) of the former species may be indicated that the species is readily detected. The availability of suitable habitats and prey sources are other factors that may also contribute to the abundance of this species. The small number of dominant species (two species) with large proportions of rare species (14 singletons) resulted in the high unevenness of SLF's snake assemblage (Fig. 4). The geometric series model was chosen as the best model to describe species abundance distribution for SLF's snake assemblage (Magurran 2004). The large proportions of the singleton resulted from the rarity and elusiveness of these 14 species, namely: *Ahaetulla mycterizans*, *Bungarus flaviceps*, *Calamaria pavimentata*, *Calliophis intestinalis*, *Chrysopelea ornata*, *Chrysopelea pelias*, *Coelognathus flavolineatus*, *Dendrelaphis formosus*, *Enhydris enhydris*, *Lycodon subannulatus*, *Naja kaouthia*, *Oligodon purpurascens*, *Oligodon signatus*, and *Rhabdophis chrysargos*, clearly shaped the species distribution pattern. These species only occurred once across the sampling years (Fig. 7). Despite being sampled relatively well, these species were really hard to spot and highly elusive species.

Figure 5 demonstrated that the sampling of snake species in SLF is not yet to be completed. The species diversities showed an inclining trend and were not yet stabilized. Hence, the observed species richness from this study may not represent the true species richness of snakes in SLF. This may also be true for the abundance and evenness of the snake assemblages. This study attempted to estimate the species richness of snakes in SLF. Based on Table 2, an additional of five to 27 species could be discovered with continuous sampling in the future. However, some of these estimation values could be over-estimated due to the biasness, precision, and accuracy of the estimators used. This study evaluated the utilized estimators and found that the ACE estimator performed the best among the estimators (Table 3). The ACE estimator was moderately precise but had relatively low biasness and was highly accurate (Table 2). The performance of low biasness and high precision of the ACE estimator in this study is also shown by the performance of this estimator in the study by Hortal et al. (2006). According to the latter study, the ACE estimator's advantage is that it is non-sensitive to the grain sizes (sampling effort units). Snake richness and abundance in the snake inventories can be varied from different sites and times (e.g., Sumarli et al. 2015; Nur Amalina et al. 2017). Hence, an estimator with such an advantage is crucial to estimate the snake species richness. According to this estimator, 54 snakes were estimated to be discovered at SLF, adding six species to the observed species richness in this study.

The turnover index was the highest during these pair of months: Jan-Feb, Feb-Mar, May-Jun, and Nov-Dec. The value "1" of the turnover index indicated complete species replacement between the paired of months. Jan-Feb and Feb-Mar are the months of transition from rainy to dry season. We posited that the species associated with the rainy season or high humidity were eventually replaced with the species related to the pre-dry season or required moderate to low humidity during the following months. Based on Figure 6, we were able to detect that some species that were found during the Jan-Feb and Feb-Mar were also found in other months during the dry and pre-rainy seasons, namely: *Aplopeltura boa* (Jan and Jul), *Boiga drapiezii* (Jan, Jun, Jul, Aug, Sep and Oct), *Boiga jaspidea* (Mar, Apr, and Jun), *Boiga melanota* (Feb, Oct and Nov), *Bungarus candidus* (Jan, May, Jul and Nov), *Chrysopelea paradisi* (Mar and October), *Dendrelaphis haasi* (March and November), *Dendrelaphis pictus* (February, July, August, Sep and Nov), *Lycodon albofuscus* (Feb, Apr and May), *Lycodon capucinus* (Feb, Jul, Sep and Oct), *Lycodon effraenis* (Mar, Sep and Oct), *Malayopython reticulatus* (Feb, Jun, Oct, and Nov), *Pareas carinatus* (Jan, May and Oct), *Pareas margaritophorus* (Jan and Oct), *Pseudorhabdion longiceps* (Feb, Oct and Nov), *Xenochrophis trianguligerus* (Jan, Jun, July, Sep and Oct), and *Xenopeltis unicolor* (Feb and Oct).

The months of May-June were in the middle of the dry season. The species found in May were *Bungarus candidus*, *Hypsiscopus plumbea*, *Lycodon albofuscus*, and *Pareas carinatus*. Meanwhile, the species found in June were *Boiga drapiezii*, *Boiga jaspidea*, *Calliophis intestinalis*, *Malayopython reticulatus*, *Naja sumatrana*, *Oligodon purpurascens*, and *Xenochrophis trianguligerus*. Both months showed a different observed species, indicating complete species replacement from May to June. The same pattern of difference with the different composition of snake species was also observed between the months Nov-Dec. This explained the high value of the turnover index for both pairs of months, May-Jun and Nov-Dec. In addition, no species was found consistently every month across the 12 months of the sampling years. The difference in the observed species between the months might be beset by the phenological idiosyncracies and elusiveness of the snakes (Durso et al. 2011; Rahman et al. 2013; Ward et al. 2017). A study by Kery (2002) in Europe demonstrated that the probability of finding snake species might vary depending on habitat, year, season, the area surveyed, the population size of the species, and the observer. Hence, the occurrence of the snake species in the respective months in this study may or may not also apply to the same snake assemblages in other localities in Terengganu. However, we provided essential information on which months the respective snake species can be detected in this study. For instance, some species were repeatedly found in the same month over the sampling years (Fig. 6).

The snake species richness was the highest in Oct (Fig. 6). Consequently, species appearances were the highest during the transition of Sep to Oct (Fig. 8). The month of Sep marked the beginning of the monsoon season. Asad et al. (2021) demonstrated that snake species occurrence in Borneo was positively associated with humidity and rainfall. Although we did not statistically test the relationship between the rainfall and the snake assemblage, we postulated that the increase of humidity and the rainy season in Oct might also influence species richness and abundance (Fig. 6; Fig. 8). Some of the species were found twice to four times during this month over the sampling years. The species were *Ahaetulla prasina, Boiga cynodon*, *Boiga drapiezii*, *Boiga melanota*, *Dendrelaphis striatus*, *Malayopython reticulatus*, *Pareas carinatus,* and *Tropidolaemus wagleri* (Fig. 6). The snake species' high occurrence may also coincide with increased prey activity during the rainy season (Brown and Shine 2002; Natusch et al. 2021) and signalled the onset of hunting period for the snake species (Natusch et al. 2022). Figure 7 showed that 14 species only occurred once across the sampling years. Of these, 11 rare species were found during the rainy season (Jan, Sep, Oct, and Nov). Though Dec is also in the rainy season, the species appearance was the lowest, and species disappearance was the highest at this month (Fig. 8). The heavy rain might interrupt the visual of the search parties hence causing low species richness observed this month. Nonetheless, common species, namely *Ahaetulla prasina* (found two times across the years) and *Dendrelaphis caudolineatus* (found fives time across the years) still can be observed during this month. Overall, these results elucidated that effort to sample snake species in SLF could be maximized during these rainy months to improve snake detection.

The other three rare species; *Calliophis intestinalis*, *Chrysopelea ornata*, and *Oligodon purpurascens* were found during the dry season. Sperry and Whitehead (2008) found that the loss and shift in water availability increased the activity of terrestrial snake (*Elaphe obsoleta*) in USA. This might be the case for the occurrence of terrestrial species of the former and latter species. The terrestrial snakes may prefer to be close to the riparian areas during the dry season (Asad et al. 2021), hence increased the detectability of these species at our sampling sites (Fig. 6; Fig. 8). Study that investigates and correlates the snakes species richness and abundance with the rainfall and sampling sites (i.e. riparian versus hilly areas) in Terengganu should be conducted to test this hypothesis. We hope the information from our study can stimulate such study.

Herpetofaunal studies in riparian forests in Peninsular Malaysia have demonstrated that this forest type harbor significant number of species richness not only limited to reptiles but also amphibians, with localities' new record and species (e.g., Chan et al. 2020; Badli-Sham et al. 2021; Fatihah-Syafiq et al. 2021; Quah et al. 2021). Previous studies suggested that riparian habitats should be preserved to reduce the extinction risk of many snake species as this habitat support high species richness of snakes (Todd et al. 2017; Guzy et al. 2019). Todd et al. (2017) discovered that human-dominated landscapes exacerbated snake species richness that consume small vertebrates and species that associates with aquatic habitat, and the species with these traits occurred more in natural landscape. Many of the observed species in Sekayu Lowland Forest (SLF) have the similar traits, thus explained the high species richness of snakes in this area. This number reflecting the need of sustainable management of SLF particularly in the remaining undisturbed habitat of this area to safeguard the snake species.

Conclusion

Despite SLF located within the forest reserve, many of the riparian forests within such reserves in Terengganu are quickly transformed into the recreational areas (e.g., Lata Belatan and Lata Tembakah). This is worrying because unsustainable development and other anthropogenic activities can affect the reptile species richness, particularly snakes (Gillespie et al. 2015; Bauder et al. 2020; Doherty et al. 2020; Mohd Izam et al. 2021). SLF had become the major source of new reptile species discoveries in Terengganu (Grismer et al. 2014b, 2018; Sumarli et al. 2016) This implied that the remaining intact forests in SLF and other riparian forested areas in Terengganu should be preserved so that some species are not loss before it was officially described (e.g., Grismer et al. 2016; Nur Amalina et al. 2017). The fact that SLF has two frequented localities by local visitors, the possibility of human-wildlife conflict between human and snakes is high. The information available from this study is hope to benefit park's authorities in SLF to inform and spread awareness among the visitors to reduce such human-wildlife conflict. Overall, the results of this study echo the SLF's paramount importance as a potential conservation area for snakes of the Terengganu.

Acknowledgment

We are grateful to our field associates namely Associate Professor Dr. Evan S. H. Quah and Mr. Daicus Belabut for their assistance and guidance in completing this article. We also wish to express thanks to all Universiti Malaysia Terengganu's staffs and students for their participation in the field sampling. In particular, we thank Syed Ahmad Rizal, Mohd Luqman Hakim bin Ismail, Mohamad Aqmal bin Mohd Naser, Muhammad Fahmi bin Ahmad, Nur Izwan Anas, and Muhamad Izzathusna. Specifically, we thank Universiti Malaysia Terengganu for research equipment use during this study. We are also deeply grateful to the Department of Wildlife and National Parks Malaysia (DWNP) (research permit: T-00563-16-17), Department of Forestry Peninsular Malaysia (JPSM), Forestry Department of Terengganu, Sekayu Recreational Forest staffs, Agriculture Department of Terengganu, and Sekayu Agricultural Park's authorities for permission to conduct the study. We thank anonymous reviewers for the insightful comments.

References

Asad S, Ng ST, Sikui J, Rodel M-O (2021) Variable detectability and El-Nino associations with riparian snakes in Sabah, Malaysian Boreno. Journal of Tropical Ecology 38(1): 25-30.

Ayob N, Mustapha MA, Senawi J, Ahmad N (2020) Herpetofauna roadkills on Langkawi Island, Peninsular Malaysia: The influence of landscape and season on mortality distribution. Sains Malaysiana 49(10): 2373–2382.

Badli-Sham BH, Shahirah-Ibrahim N, Xian GS, Syamila-Noh H, Shukor NSAA, Shafie FA, Daud NM, Razak FAA, Rosli R, Aziz AAA, Mohammad FNF, Kamaruzzaman MF, Mohamad S, Dzu K, Shariffudin A, Najwa-Sawawi S, Ahmad A (2019) Herpetofauna of Universiti Malaysia Terengganu campus: Sustaining biodiversity in Campus Green area. Journal of Sustainability Science and Management 14 (1): 11-28.

Badli-Sham BH, Fatihah-Syafiq M, Halim M-RA, Ahmad AB (2021) Amphibian diversity of the Ulu Muda Forest Reserve, Kedah, Peninsular Malaysia. Malayan Nature Journal 73(3): 341-348.

Barnes CH, Strine CT, Suwanwaree P, Hill JG III (2017) Movement and home range of green pit vipers (*Trimeresurus* spp.) in a rural landscape in north-east Thailand. Herpetological Bulletin 142: 19–28.

Bauder JM, Breininger DR, Bolt, MR, Legare ML, Jenkins CL, Rothermel BB, McGarigal K (2020) Movement barriers, habitat heterogeneity or both? Testing hypothesized effects of landscape features on home range sizes in eastern indigo snakes. Journal of Zoology 311(3): 204-216.

Beaupre SJ, Douglas LE (2009) Snakes as indicators and monitors of ecosystem properties. In: Mullin SJ, Seigel RA (Eds) Snakes: Ecology and Conservation. Cornell University Press, New York, 244–261.

Bickford D, Howard S, Ng D, Sheridan J (2010) Impact of climate change on the amphibians and reptiles of Southeast Asia. Biodiversity and Conservation 19: 1043-1062.

Böhm M, Collen B, Baillie JEM, Bowles P, Chanson J, Cox N, Hammerson G, Hoffmann M, Livingstone SR, Ram M, Rhodin AGJ, Stuart SN, van Dijk PP, Young B, Afuang LE, Aghasyan A, Garcia A, Aguilar C, Ajtic R, Akarsu F, Alencar LRV, Allison A, Ananjeva N, Anderson S, Andren C, Ariano-Sanchez D, Arredondo JC, Auliya M, Austin CC, Avci A, Baker PJ, Barreto-Lima AF, Barrio-Amoros CL, Basu D, Bates MF, Batistella A, Bauer A, Bennett D, Bohme W, Broadley D, Brown R, Burgess J, Captain A, Carreira S, Castaneda MDR, Castro F, Catenazzi A, Cedeno-Vazquez JR, Chapple DG, Cheylan M, Cisneros-Heredia DF, Cogalniceanu D, Cogger H, Corti C, Costa GC, Couper PJ, Courtney T, Crnobrnja-Isailovic J, Pierre-Andre C, Crother B, Cruz F, Daltry JC, Daniels RJR, Das I, de Silva A, Diesmos AC, Dirsken L, Doan TM, Dodd Jr. CK, Doody JS, Dorcas ME, Filho JDDB, Egan VT, Mouden EHE, Flores-Villela O, Franca FGR, Frost D, Gadsden H, Gamble T, Ganesh SR, Garcia MA, Garcia-Perez JE, Gatus J, Gaulke M, Geniez P, Georges A, Gerlach J, Goldberg S, Juan-Carlos TG, Gower DJ, Grant T, Greenbaum E, Grieco C, Guo P, Hamilton AM, Hare K, Hedges SB, Heideman N, Hilton-Taylor C, Hicthmough R, Hollingsworth B, Hutchinson M, Ineich I, Iverson J, Jaksic FM, Jenkins R, Joger U, Jose R, Kaska Y, Kaya U, Keogh JS, Kohler G, Kuchling G, Kumlutas Y, Kwet A, Marca EL, Lamar W, Lane A, Lardner B, Latta C, Latta G, Lau M, Lavin P, Lawson D, LeBreton M, Lehr E, Limpus D, Lipczynski, Lobo AS, Lopez-Luna MA, Luiselli L, Lukoschek V, Lundberg M, Lymberakis P, Macey R, Magnusson WE, Mahler DL, Malhotra A, Mariaux J, Maritz B, Marques OAV, Marquez R, martins M, Masterson G, Mateo JA, Mathew R, Mathews N, Mayer G, McCranie JR, Measey GJ, Mendoza-Quijano F, Menegon M, Metrailler S, Milton DA, Montgomery C, Morato SAA, Mott T, Munoz-Alonso A, Murphy J, Nhuyen TQ, Nilson G, Nogueira C, Nunez H, Orlov N, Ota H, Ottenwalder J, Papenfuss T, Pasachnik S, Passos P, Pauwels OSG, Perez-Buitrago N, Perez-Mellado V, Pianka ER, Plegezuelos J, Pollock C, Ponce-Campos P, Powell R, Pupin F, Diaz GEQ, Radder R, Ramer J, Rasmussen AR, Raxworthy C, Reynolds R, Richman N, Lico EL, Risevato E, Rivas G, da Rocha PLB, Marker-Oliver R, Schettino LR, Roosenburg WM, Ross JP, Sadek R, Sanders K, Santos-Barrera G, Schleich HH, Schmidt BR, Schmitz A, Sharifi M, Shea G, Hai-Tao S, Shine R, Sindaco R, Slimani T, Somaweera R, Spawls S, Stafford P, Stuebing R, Sweet S, Sy E, Temple HJ, Tognelli MF, Tolley K, Tolson PJ, Tuniyez B, Tuniyez S, Uzum N, van Buurt G, Sluys MN, Velasco A, Vences M, Vesely M, Vinke S, Vinke T, Vogel G, Vogrin M, Vogt RC, Wearn OR, Werner YL, Whiting MJ, Wiewandt T, Wilkinson J, Wilson B, Wren S, Zamin T, Zhou K, Zug G (2013) The conservation's status of the world's reptiles. Biological Conservation 157: 372-385.

Böhm M, Cook D, Ma H, Davidson AD, García A, Tapley B, Pearce-Kelly P, Carr J (2016) Hot and bothered: using trait-based approaches to assess climate change vulnerability in reptiles. Biological Conservation 204: 32-41.

Brower JC, Kile KM (1988) Sedation of an original data matrix as applied to paleoecology. Lethaia 21: 79-93.

Brown GP, Shine R (2002) Influence of weather conditions on activity of tropical snakes. Austral Ecology 27: 596-605.

Camerlengo A, Demmler MI (1997) Wind-driven circulation of Peninsula Malaysia eastern continental shelf. Scientia Marina 61(2): 203-211.

Chan KO, Ahmad N (2009) Distribution and natural history notes on some poorly known frogs and snakes from Peninsular Malaysia. Herpetological Review 40(3): 294–301.

Chan KO, Norhayati A (2010) A new insular species of *Cyrtodactylus* (Squamata: Gekkonidae) from north-eastern Peninsular Malaysia, Malaysia. Zootaxa 2389: 47-56.

Chan EH, Chen PN (2011) Nesting activity and clutch size of *Batagur affinis edwardmolli* from the Setiu River, Terengganu, Malaysia. Chelonian Conversation and Biology 10(1): 129-132.

Chan KO, Abraham RK, Badli-Sham BH (2020) A revision of the Asian tree toad complex *Rentapia hosii* (Anura: Bufonidae) with the description of a new species from Peninsular Malaysia. Raffles Bulletin of Zoology 68: 595–607.

Chan KO, Grismer LL (2021a) Integrating spatial, phylogenetic, and threat assessment data from frogs and lizards to identify areas for conservation priorities in Peninsular Malaysia. Global Ecology and Conservation 28: e01650.

Chan KO, Grismer LL (2021b) A review of reptile research in Malaysia in the 21st century. Raffles of Bulletin of Zoology 69: 364-376.

Collins SL, Micheli F, Hartt L (2000) A method to determine rates and patterns of variability in ecological communities. Oikos 91(2): 285–293.

Collins SL, Suding KN, Cleland EE, Batty M, Pennings SC, Gross KL, Grace JB, Gough L, Fargione JE, Clark CM (2008) Rank clocks and plant community dynamics. Ecology 89: 3534–3541.

Colwell, RK (2005) EstimateS: Statistical estimation of species richness and shared species from samples. Version 8.0. User's Guide and application http://purl.oclc.org/estimates.

Cox MJ, van Dijk PP, Nabithabhata J, Thirakhupt K (1998) A Photographic Guide to Snakes and Other Reptiles Of Peninsular Malaysia, Singapore and Thailand. Ralph Curtis Publishing, Sanibel, FL, 144 pp.

Das I (2010) A Field Guide to the Reptiles of South-East Asia. New Holland Publishers (UK) Ltd, London, 376 pp.

Doherty TS, Balouch S, Bell K, Burns TJ, Feldman A, Fist C, Garvey TF, Jessop TS, Meiri S, Driscoll DA (2020) Reptile responses to anthropogenic habitat modification: A global meta-analysis. Global Ecology and Biogeography 29: 1265–1279.

Dring JCM (1979) Amphibians and reptiles from northern Terengganu, Malaysia, with descriptions of two new geckos: *Cnemaspis* and *Cyrtodactylus*. Bulletin of the British Museum of Natural History 34: 181–241.

D'souza A, Gale GA, Marshall BM, Khamcha D, Waengsothorn S, Strine CT (2021) Space use and activity of *Boiga cyanea* – A major songbird nest predator in a seasonal tropical forest in Thailand. Global Ecology and Conservation 32: e01875.

Durso AM, Willson JD, Winne CT (2011) Needles in haystacks: Estimating detection probability and occupancy of rare and cryptic snakes. Biological Conservation 144: 1508–1515.

Fatihah-Syafiq M, Badli-Sham BS, Fahmi-Ahmad M, Aqmal-Naser M, Rizal SA, Azmi MSA, Grismer LL, Ahmad AB (2020) Checklist of herpetofauna in the severely degraded ecosystem of Bidong Island, Peninsular Malaysia, South China Sea. Zookeys 985: 143-162.

Fatihah-Syafiq M, Badli-Sham BH, Halim MRA, Ahmad A (2021) Checklist of reptiles in Sungai Muda sub-catchment, Ulu Muda Forest Reserve, Kedah, Peninsular Malaysia. Malayan Nature Journal 73(3): 331-339.

Frazao L, Oliveira ME, Menin M, Campos J, Almeida A, Kaefer IL, Hrbek T (2020) Species richness and composition of snake assemblages in poorly accessible areas in the Brazilian Amazonia. Biota Neotropica 20(1): e20180661.

Fujishima K, Tomonori K, Kojima Y, Hossman M, Nishikawa K (2021) Short-term movements of *Boiga nigriceps* (Günther, 1863) with notes on its diet (Squamata: Colubridae). Herpetological Notes 14: 83-89.

Gillespie GR, Howard S, Stroud JT, Ul-Hassanah A, Campling M, Lardner B, Scroggie MP, Kusrini M (2015) Responses of tropical forest herpetofauna to moderate anthropogenic disturbance and effects of natural habitat variation in Sulawesi, Indonesia. Biological Conservation 192: 161–173.

Grismer LL, Chan KO (2008) A new species of *Cnemaspis* Strauch 1887 (Squamata: Gekkonidae) from Pulau Perhentian Besar, Terengganu, Peninsular Malaysia. Zootaxa 1771: 1-15.

Grismer LL, Pan KA (2008) Diversity, endemism and conservation of the amphibians and reptiles of sounthern Peninsular Malaysia and its offshore islands. Herpetological Review 39(3): 270–281.

Grismer LL, Wood PL Jr., Grismer JL (2009) A new insular skink of the genus *Sphenomorpus* Strauch 1887 (Squamata: Scincidae) from Pulau Perhentian Besar, Terengganu, Peninsular Malaysia. Tropical Life Sciences Research 20: 51-69.

Grismer LL, Grismer JL, Wood Jr. PL, Ngo VT, Neang T, Chan KO (2011) Herpetology on the fringes of the Sunda Shelf: A discussion of discovery, taxonomy, and biogeography. Bonner Zoologische Monographien 57: 57-97.

Grismer LL, Wood Jr. PL, Ahmad AB, Sumarli ASI, Vazquez JJ, Ismail LHB, Nance R, Mohd-Amin MAB, Othman MNAB, Rizal SA, Kuss M, Murdoch M, Cobos A (2014a) A new species of insular rock gecko (Genus *Cnemaspis* Strauch, 1887) from the Bidong Archipelago, Terengganu, Peninsular Malaysia. Zootaxa 3755: 447-456.

Grismer LL, Ismail LHB, Awang MT, Rizal SA, Ahmad AB (2014b) A new species of lowland skink (genus *Lipinia* Gray, 1845) from northeastern Peninsular Malaysia. Zootaxa 3821(4): 457-464.

Grismer LL, Wood PL Jr, Syafiq MF, Badli-Sham BH, Rizal SA, Ahmad AB, Quah ESH (2016) On the taxonomy and phylogeny of the skinks *Lipinia sekayuensis* Grismer, Ismail, Awang, Rizal, & Ahmad and *Lipinia surda* Boulenger from Peninsular Malaysia. Zootaxa 4147(1): 59–66.

Grismer LL, Wood Jr PL, Ahmad AB, Baizul-Hafsyam BS, Afiq-Shuhaimi M, Rizal SA, Quah ESH (2018) Two new *Tytthoscincus* Linkem, Diesmos, & Brown (Squamata; Scincidae) from Peninsular

Malaysia and another case of microsyntopy between ecologically specialised, unrelated, leaf-litter species. Zootaxa 4425(1): 87-107.

Guzy JC, Halloran KM, Homyack JA, Thornton-Frost JE, Willson JD (2019) Differential responses of amphibian and reptile assemblage to size of riparian buffers within managed forests. Ecological Application 29(8): e01995.

Hallett LM, Jones SK, Macdonald AAM, Jones MB, Flynn DFB, Ripplinger J, Slaughter P, Gries C, Collins SL, Poisot T (2016) Codyn: An R package of community dynamics metrics. Methods Ecology and Evolution 7(10): 1146-1151.

Hammer Ø, Harper DAT, Ryan PD (2001) PAST: Paleontological Statistics Software Package for Education and Data Analysis. Palaeontologica Electronica 4(1): 9.

Hill MO (1973) Diversity and evenness: A unifying notation and its consequences. Ecology 54: 427-432.

Hortal J, Borges PAV, Gaspar C (2006) Evaluating the performance of species richness estimators: Sensitivity to sample grain size. Journal of Animal Ecology 75: 274–287.

Hsieh TC, Ma KH, Chao A (2016) iNEXT: An R package for rarefaction and extrapolation of species diversity (Hill numbers). Methods in Ecology and Evolution 7: 1451–1456.

iNaturalist (2021) https://www.inaturalist.org.

Jones MD, Marshall BM, Smith SN, Crane M, Silva I, Artchawakom T, Suwanwaree P, Waengsothorn S, Wüster W, Goode M, Strine CT (2022) How do King Cobras move across a major highway? Unintentional wildlife crossing structures may facilitate movement. Ecology and Evolution 12: e8691.

Kery M (2002) Inferring the absence of a species: a case study of snakes. The Journal of Wildlife Management 66(2): 330-338.

Komaruddin SA, Mohamad NA, Fatihah-Syafiq M, Sham BHB, Mamat MA, Zakaria N (2020) Dataset of reptiles in fragmented forests at Tasik Kenyir, Hulu Terengganu, Malaysia. Data in Brief 28: 104994.

Lourenço-de-Moraes R, Lansac-Toha FM, Schwind LTF, Arrieira RL, Rosa RR, Terribile LC, Lemes P, Rangel TF, Diniz-Filho JAFD, Bastos RP, Bailly D (2019) Climate change will decrease the range size of snake species under negligible protection in the Brazilian Atlantic Forest hotspot. Scientific Reports 9: 8523.

Magurran A (2004) Measuring Biological Diversity. Blackwell Science Ltd, Oxford, 264 pp.

Marshall BM, Strine CT, Jones MD, Artchawakom T, Silva I, Suwanwaree P, Goode, M (2019) Space fit for a king: Spatial ecology of king cobras (*Ophiophagus hannah*) in Sakaerat Biosphere Reserve, Northeastern Thailand. Amphibia-Reptilia 40(2):163–178.

Marshall BM, Crane M, Silva I, Strine CT, Jones MD, Hodges CW, Suwanwaree P, Artchawakom T, Waengsothorn S, Goode M (2020) No room to roam: King cobras reduce movement in agriculture. Movement Ecology 8(1): 33.

Martin S (2008) Global diversity of crocodiles (Crocodilia, Reptilia) in freshwater. Hydrobiologia 595: 587-591.

Mohd Izam NA, Shukor MN, Ahmad A, Grismer LL, Norhayati A (2021) Malayan Nature Journal 73(2): 177-186.

Muin MMA, Evan QSH, Shahrul Anuar MS, Nur Munira A, Nur Juliani S, Mohd Yusof O, Rahmad Z, Asyraf M (2017) Annotated checklist of herpetofauna of Gunung Basor Forest Reserve, Pergau, Kelantan. In: Zahari I, Mohd Radhi CA, Razali AR, Nur Najwa DA, Suryani MN, Latiff A (Eds) Gunung Basor dan Tasik Pergau, Kelantan: Kepelbagaian Biologi Jabatan Perhutanan Negeri Kelantan: Kelantan.

MyBis (2021) Malaysia Biodiversity Information System (https://www.mybis.gov.my)

Natusch DJD, Lyons JA, Shine R (2021) Rainforest pythons flexibly adjust foraging ecology to exploit seasonal concentrations of prey. Journal of Zoology 313: 114–123.

Natusch D, Lyons J, Shine R (2022) Spatial ecology, activity patterns, and habitat use by giant pythons (*Simalia amethistina*) in tropical Australia. Scientific Reports 12(1): 1-10.

Ng PK, Ahmad AB (2016) A new genus and new species for an unusual semi-terrestrial potamid crab (Decapoda: Brachyura) with a bilobed mandibular palp from Peninsular Malaysia. Journal of Crustacean Biology 36(6): 823-832.

Ng PK (2020) Revision of the freshwater crabs of the *Johora tahanensis* (Bott, 1966) species group (Crustacea, Brachyura, Potamidae), with a key to the genus. ZooKeys 994: 1-34.

Nur Amalina MI, Azhari M, Norshaqinah A, Nor Azrin NA, Shukor MN, Aisah MS, Amirrudin A, Grismer LL, Norhayati A (2017) Species composition of amphibians and reptiles in Tembat Forest Reserve, Hulu Terengganu. Malaysian Applied Biology 46(4): 119-129.

Pike DA, Croak BM, Webb JK, Shine R (2010) Subtle - but easily reversible – anthropogenic disturbance seriously degrades habitat quality for rock-dwelling reptiles. Animal Conservation 13: 411–418.

Quah ESH, Grismer LL, Jetten T, Wood Jr PL, Miralles A, Shahrul Anuar MS, Guek KHP & Brady ML (2018a) The rediscovery of Schaefer's spine-jawed snake (*Xenophidion schaeferi* Günther & Manthey, 1995) (Serpentes, Xenophidiidae) from Peninsular Malaysia with notes on its variation and the first record of the genus from Sumatra, Indonesia. Zootaxa 4441(2): 366–378.

Quah ESH, Lim KKP, Leong EHH, Shahrul Anuar MS (2018b) Identification and a new record from Penang Island of the rare red-bellied reed snake (*Calamaria albiventer*) (Gray, 1835) (Serpentes: Calamariinae). Raffles Bulletin of Zoology 66: 486–493.

Quah ESH, Wood PL, Grismer LL, Sah SAM (2018c) On the taxonomy and phylogeny of the rare Selangor Mud Snake (*Raclitia indica*) Gray (Serpentes, Homalopsidae) from Peninsular Malaysia. Zootaxa 4514(1): 53–64.

Quah ESH, Badli-Sham BH, Rahman MF-SA, Ahmad A, Chan KO (2021) A new record and range extension for *Philautus davidlabangi* (Amphibia: Rhacophoridae) from Peninsular Malaysia. Herpetology Notes 14: 1181-1186.

Rahman SC, Rashid SMA, Das K, Jenkins C, Luiselli L (2013) Monsoon does matter: Annual activity patterns in a snake assemblage from Bangladesh. The Herpetological Journal 23: 203–208.

Roll U, Feldman A, Novosolov M, Allison A, Bauer AM, Bernard R, Böhm M, Castro-Herrera F, Chirio L, Collen B, Colli GR, Dabool L, Das I, Doan TM, Grismer LL, Hoogmoed M, Itescu Y, Kraus F, LeBreton M, Lewin A, Martins M, Maza E, Meirte D, Nagy ZT, Nogueira CDC, Pauwels OSG, Pincheira-Donoso D, Powney GD, Sindaco R, Tallowin OJS, Torres-Carvajal O, Trape J-F, Vidan E, Uetz P, Wagner P, Wang Y, Orme CDL, Grenyer R, Meiri S (2017) The global distribution of tetrapods reveals a need for targeted reptile conservation. Nature Ecology and Evolution 1: 1677–1682.

R Core Team (2022). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org/.

R Studio Team. (2020). RStudio: Integrated Development for R. https://rstudio.com.

Saha A, McRae L, Dodd CK, Gadsden H, Hare KM, Lukoschek V, Böhm M (2018) Tracking global population trends: Population time-series data and a Living Plant Index for Reptiles. Journal of Herpetology 52: 259–268.

Shahirah-Ibrahim N, Badli-Sham BH, Shafie NJ, Ahmad A (2018) Species diversity of freshwater turtles and tortoises in Terengganu, Malaysia. Journal of Sustainability Science and Management Monograph 1: 1-27.

Shelton MB, Phillips SS, Goldingay RL (2020) Habitat requirements of an arboreal Australian snake (*Hoplocephalus bitorquatus*) are influenced by hollow abundance in living trees. Forest Ecology and Management 455: 117675.

Somaweera R, Brien ML, Sonneman T, Didham RK, Webber BL (2019) Absence of evidence is not evidence of absence: Knowledge shortfalls threaten the effective conservation of freshwater crocodiles. Global Ecology and Conservation 20: e00773.

Somaweera R, Nifong JC, Rosenblatt AE, Brien ML, Combrink X, Elsey RM, Grigg G, Magnusson WE, Mazzotti F, Pearcy A, Platt SG, Shirley MH, Tellez M, van der Ploeg J, Webb GJ, Whitaker R, Webber BL (2020) The ecological importance of crocodylians: towards evidence-based justification for their conservation. Biological Reviews 95: 936-959.

Sperry JH, Weatherhead PJ (2008) Prey-mediated effects of drought on condition and survival of a terrestrial snake. Ecology 89: 2770–2776.

Sumarli AX, Grismer LL, Anuar S, Muin MA, Quah ESH. 2015. First report on the amphibians and reptiles of a remote mountain, Gunung Tebu in northeastern Peninsular Malaysia. Check List **11:** 1-32.

Sumarli A, Grismer LL, Wood Jr, PL, Ahmad AB, Rizal S, Ismail LH, Izam NAM, Ahmad N, Linkem CW (2016) The first riparian skink (Genus: *Sphenomorphus* Strauch, 1887) from Peninsular Malaysia and its relationship to other Indochinese and Sundaic species. Zootaxa 4173(1): 29-44.

Todd BD, Andrews KM (2008) Response of a reptile guild to forest harvesting. Conservation Biology 22: 753–761.

Todd BD, Nowakowski AJ, Rose JP, Price SJ (2017) Species traits explaining sensitivity of snakes to human land use estimated from citizen science data. Biological Conservation 206: 31–36.

Uetz P, Freed P, Hosek J (eds.) (2020) The Reptile Database. http://www.reptile-database.org.

van Rooijen J, Vogel G (2008) Contributions to a review of the *Dendrelaphis pictus* complex (Serpentes: Colubridae)–1. Description of a sympatric species. Amphibia Reptilia 29: 101–115

Vogel G, David P, Lutz M, van Rooijen J, Vidal N (2007) Revision of the *Tropidolaemus wagleri*-complex (Serpentes: Viperidae: Crotalinae). I. Definition of included taxa and redescription of *Tropidolaemus wagleri* (Boie, 1827). Zootaxa 1644: 1-40.

Walther BA, Moore JL (2005) The concepts of bias, precision and accuracy, and their use in testing the performance of species richness estimators, with a literature review of estimator performance. Ecography 28: 815-829.

Ward RJ, Griffiths RA, Wilkinson JW and Cornish N (2017) Optimising monitoring efforts for secretive snakes: a comparison of occupancy and N-mixture models for assessment of population status. Scientific Reports 7: 18074.

Weatherhead PJ, Sperry JH, Carfagno GLF, Blouin-Demers G (2012) Latitudinal variation in thermal ecology of North American Ratsnakes and its implications for the effect of climate warming on snakes. Journal of Thermal Biology 37: 273–281.

Zakaria AA, Rahim NAA, Ahmad AB, Abdullah MT (2019) Species richness estimation of reptiles in selected sites of Tasik Kenyir, Hulu Terengganu, Malaysia. In: Abdullah MT, Mohammad A, Nor Zalipah M, Safiih Lola M (Eds) Greater Kenyir Landscapes. Springer Nature, Switzerland, 159-170.