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DOI: https://doi.org/10.3897/arphapreprints.e122806

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Research Article

Syafiq, Badli-Sham, Fariduddin, Izham, Aqmal-Naser, Farah, Gukaaneswaran, Nadhirah, Farhana, Shahril-Ridhwan, Joehan, Kei Li, Shu Xin, Fahmi-Ahmad, Rizal, and Ahmad | Herpetofauna of Bukit Maras, Terengganu, Peninsular Malaysia

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Abstract

We present the first checklist of herpetofauna in Bukit Maras based on surveys conducted from 2019 to 2023. Visual Encounter Surveys (VES) and drift-fenced pitfall traps were employed as collection methods. Our study documented a total of 55 herpetofauna species, comprising 23 amphibians and 32 reptiles. Among these, the critically endangered species, *Manouria emys* (according to the IUCN Red List) is a species of high conservation concern. The non-asymptotic nature of the Species Accumulation Curve (SAC) suggests that further sampling efforts could reveal additional species. Species-habitat network analysis revealed variations in species composition across different habitat types. Notably, secondary forest exhibited higher herpetofauna diversity compared to agricultural areas. Therefore, the conservation of remaining secondary forest in Bukit Maras is crucial for preserving its herpetofauna and mitigating anthropogenic impacts on this disturbed and isolated ecosystem.

Key words

Agricultural area, amphibians, anthropogenic disturbance, habitat island, reptiles, secondary forest, Southeast Asia

Academic editor: [academic editor to complete] | publication data [copyeditor/layout editor to complete]

Citation: [copyeditor/layout editor to complete]

Introduction

Peninsular Malaysia boasts remarkable biodiversity (Myers et al. 2000). However, rampant deforestation threatens this richness (Sodhi et al. 2004). Driven by factors like urban sprawl, logging, and agriculture, primary forest degradation has fragmented these once-continuous landscapes (Hadad et al. 2015; Magintan et al. 2017). This has resulted in isolated hills surrounded by human-modified areas. Research suggests these isolated hills can serve as refugia for displaced amphibians and reptiles, even harboring new species discoveries (Quah et al. 2013; Grismer et al. 2014a, 2016a). Documenting herpetofauna diversity in these areas is crucial before local populations disappear.

In the Terengganu state, over 308,000 hectares of native forest have been cleared for agricultural activities, primarily for oil palm, rubber plantation, and crop cultivation (Alam et al. 2012). While the existing body of researches showed that many herpetofauna studies have been conducted in the primary forest of this state (Grismer et al. 2013a, 2013b, 2014b, 2014c, 2015, 2016b, 2018; Chan et al. 2014; Sumarli et al. 2015, 2016; Nur Amalina et al. 2017; Shahirah-Ibrahim et al. 2018; Quah et al. 2021; Badli-Sham et al. 2023; Syafiq et al. 2023, 2024), only a few have focused on the disturbed forested areas (Badli-Sham et al. 2019; Fatihah-Syafiq et al. 2020; Komaruddin et al. 2020). Hence, there is a significant gap in knowledge on the herpetofauna of these habitats, which necessitates further study.

Bukit Maras (BM) is an isolated hill range surrounded by the human settlement and agricultural matrix. Approximately 40% of the forested area at BM have been converted to orchards. The secondary forest in these hills regenerated after the land abandonment (about 15 years ago), but this area also faces the threat of deforestation due to current expansion of orchard areas. Given the alarming rate of habitat loss, these disturbances could severely impact herpetofauna species that may rely on these habitats as refugia.

Regrettably, information on the herpetofauna in this hill is virtually unknown. To our knowledge, there is only a single inventory study in Bukit Maras but which focused on the chiropteran species (Sulaiman and Lian 2011). The study recorded a total of 14 bat species in BM, with one of the species categorized as "Near Threatened" by the IUCN Redlist. Therefore, this study aims to produce the first report of herpetofauna in BM. Bukit Maras is a non-protected area thus, this investigation could provide valuable information on what species inhabit BM before we lose them due to the deforestation.

Methods

Study area

Bukit Maras is situated in the Kuala Nerus district, Terengganu, surrounded by human settlement and agricultural areas (Fig. 1). It has a total of approximately 2200 hectares of land comprised of agricultural areas, secondary forest, and primary forest (underexplored).

There are three main sampling sites:

- Site 1 (5°25'20.98"N 103°1'18.18"E) – This hill has a large soil road from the foothill to the summit as a hiking trekking trail. The landscape is characterized by an agricultural matrix and an open area for car parking at the foothill. Crop plantation areas also can be found along the trekking trails up to 200 meters. Examples of the planted crops are durian trees (*Durio* spp.), petai trees (*Parkia speciosa*), and banana plants (*Musa* spp.). Two disturbed small streams can be found in the agricultural areas, which originated from the intact secondary and primary forest.

- Site 2 (5°24'33.77"N 103°1'27.63"E) – This hill also has a large soil road from the foothill to the summit as a hiking trekking trail. Oil palm and rubber plantations are the primary agricultural plantations here. Secondary forest vegetation situated mainly at the peak. A disturbed small stream flow through the agricultural area.

- Site 3 (5°24'35.4"N 103°00'47.4"E) – This site is a secondary forest characterized by a small stream covered by a few dipterocarp tree species left undisturbed from deforestation in the previous years. This site has the minimal disturbance compared to other two sites but the threat of deforestation for orchard expansion is imminent.

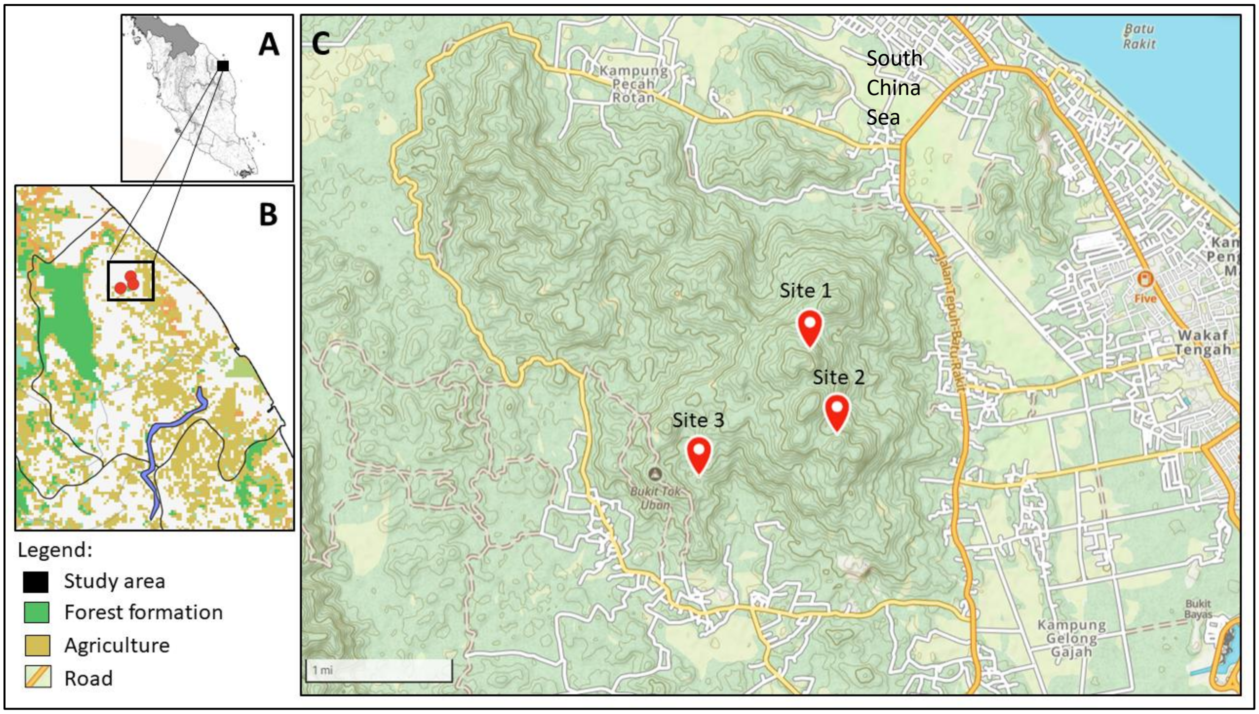

Figure 1. A. Location of Bukit Maras in Terengganu, Peninsular Malaysia. **B–C.** QGIS generated map showing the area of BM surrounded by the agricultural, rural, and urban areas.

Sample collection and preservation

The surveys were conducted opportunistically from July 2019–October 2019, 4 July 2020, 12 July 2020, 26–27 July 2020, 17 October 2020, 12–14 November 2020, 1 November 2020, 26 November 2020, 28 November 2020,15 January 2021 and between 31 December 2022 to 11 March 2023. Initially, pilot surveys were done opportunistically in 2019, and a systematic survey was in the planning for the subsequent years but due to the Covid 19 situation during the former years (2020–2021), opportunistic surveys approach was implemented at this site to standardize the sampling effort. Surveyed areas spanned the disturbed and undisturbed small streams, secondary forests, and agricultural areas. The primary forest was remained untapped due to its inaccessibility. We sampled 13 sampling points grouped into four categories: agricultural area (AA); secondary forest (SF); agricultural area stream (STA); secondary forest stream (STF) (Table 1). We divided the habitat types into these four categories as we expect these four habitat types will consist of different species composition and demonstrate the importance of each habitat for this species.

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Table 1. Habitat categories studied in Bukit Maras

Habitat	Characteristics	Sampling Site	Sampling Point
Agricultural area	Mainly composed of durian (*Durio* sp.), banana (*Musa* sp.), petai (*Parkia speciosa*), oil palm (*Elaeis guineensis*) and rubber (*Hevea brasiliensis*) plantation. Scatterly located from the foothill up to elevation of 200 metres a.s.l.	Site 1, Site 2	4
Secondary forest	Forest remnants composed mainly of native species, unmanaged environment, with formation of understory and canopy.	All sites	4
Agricultural area stream	Small stream in the agricultural area with no canopy formation	Site 1, Site 2	3
Secondary forest stream	Small stream in the agricultural area with canopy formation	Site 1, Site 3	2

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Figure 2. Habitat types in Bukit Maras **A**–**D.** agricultural area **E.** secondary forest **F.** stream at secondary forest **G**–**H.** stream at agricultural area.

To maximize the sampling effort, three types of collecting methods were employed: Visual Encounter Survey (VES), drift-fenced pitfall traps, and acoustic sampling. The samplings were executed during the day (10:00 to 13:00 h) and at night (20:00 to 23:00 h) to record both diurnal and nocturnal species. The VES activities were conducted with search parties consisting of three to four persons. This method was executed during the day and night to sample diurnal and nocturnal species in the area. A set of pitfall traps consisted of three 18L buckets and aluminum zinc as the fence. The buckets were buried two meters apart from each other and were arranged in approximately straight lines. Two sets of pitfall traps were set up randomly at different locations. The first one was deployed at the foothill near the agricultural area, and the second set was deployed at the hilly area in the secondary forest. The vocalization method also was used to record the species based on the frog calls. The recorded sound can be used for species-specific sound characteristic description in future study (Chan et al., 2020; Quah et al., 2021). A total of 816 man-hours (204 hours/person) were spent for the herpetofauna surveys.

Captured specimens were identified based on their morphological characteristic, following Berry (1975) for amphibians, Grismer (2011) for lizards, Auliya (2007) for freshwater turtles and tortoises, and Das (2012) for snakes. Photographs of live specimens were taken with the Canon 3000D and Sony A6000 digital cameras. Amphibian nomenclature follows the Amphibian Species of the World database (Frost 2024), while the reptile nomenclature follows The Reptile Database (Uetz et al. 2023). Only a few samples were taken for voucher specimens to minimize the extirpation of the current population. Euthanized voucher specimens were then preserved with 10% formalin before being transferred into 70% ethanol for long-term storage and deposited at the General Biology Lab, Universiti Malaysia Terengganu, and catalogued under UMT Zoological Collection (UMTZC).

Data analysis

The individual-based and coverage-based rarefaction and extrapolation analysis was constructed by using the "iNEXT" R package (Hsieh et al. 2016) to determine the adequacy of our sampling effort at BM and for both amphibian and reptile groups. The sampling achieves completeness when the curve is plateauing for the former and achieve completeness value which is 1.0 for the latter. This analysis permits comparison of diversity with Hill numbers of order q for unequal sampling effort between two or more sites or groups. There are three types of order q for Hill numbers namely, species richness (q=0), Shannon's diversity (q=1) and Simpson's diversity (q=3). We only utilized diversity order of species richness (q=0) for this study. We also used this analysis to compare the herpetofauna diversity between the four habitat types. For the comparison of habitat types, we combined both amphibians and reptiles data as herpetofauna data to utilize in the comparison analysis. Non-overlap curves strongly indicate significant difference and vice versa for both individual-based and coverage-based rarefaction and extrapolation curves.

For species-habitat network, we built two networks using both abundance and incidence data acting as links while habitat types and herpetofauna species acting as nodes (Marini et al. 2019). The analysis was performed using the "bipartite" R package (Dormann et al. 2009). All analyses were executed in RStudio software (RStudio Team 2023).

Results

A total of 55 herpetofauna species from six amphibian families (Bufonidae – 2 spp., Dicroglossidae – 5 spp., Megophryidae – 3 spp., Microhylidae – 4 spp., Ranidae – 5 spp., Rhacophoridae – 4 spp.) and nine reptile families (Agamidae – 7 spp., Gekkonidae – 7 spp., Scincidae – 4 spp., Varanidae – 1 spp., Colubridae – 9 spp., Pythonidae – 1 spp., Viperidae – 1 spp., Trionychidae – 1 spp., Testudinidae – 1 spp.) were recorded in this study (Table 2). Based on IUCN Redlist (2024), there is only single species (*Manouria emys*) listed under "Critically Endangered" status in this study, whereas the rest of the species are categorized as "Least Concern".

Table 2. A species checklist of amphibians and reptiles recorded in Bukit Maras and their IUCN status.

No	Taxa	IUCN
	AMPHIBIANS	
	Bufonidae	
1	*Duttaphrynus melanostictus* (Schneider, 1799)	LC
2	*Ingerophrynus parvus* (Boulenger, 1887)	LC
	Dicroglossidae	
3	*Fejervarya limnocharis* (Gravenhorst, 1829)	LC
4	*Limnonectes blythii* (Boulenger, 1920)	LC
5	*Limnonectes deinodon* Dehling, 2014	LC
6	*Limnonectes hascheanus* (Stoliczka, 1870)	LC
7	*Limnonectes malesianus* (Kiew, 1984)	LC
	Megophryidae	
8	*Leptobrachella sola* (Matsui, 2006)	LC
9	*Leptobrachium hendricksoni* Taylor, 1962	LC
10	*Pelobatrachus nasuta* (Schlegel, 1858)	LC
	Microhylidae	
11	*Kaloula pulchra* Gray, 1831	LC
12	*Microhyla berdmorei* (Blyth, 1856)	LC
13	*Microhyla heymonsi* Vogt, 1911	LC
14	*Microhyla mantheyi* Das, Yaakob & Sukumaran, 2007	LC
	Ranidae	
15	*Humerana miopus* (Boulenger, 1918)	LC
16	*Hylarana glandulosa* (Boulenger, 1882)	LC
17	*Hylarana labialis* (Boulenger, 1887)	LC

18	*Hylarana laterimaculata* (Barbour & Noble, 1916)	LC
19	*Hylarana nicobariensis* (Stoliczka, 1870)	LC
	Rhacophoridae	
20	*Nyctixalus pictus* (Peters, 1871)	LC
21	*Polypedates discantus* Rujirawan, Stuart & Aowphol, 2013	LC
22	*Polypedates leucomystax* (Gravenhorst, 1829)	LC
23	*Theloderma licin* McLeod & Ahmad, 2007	LC
	REPTILES	
	LIZARDS	
	Agamidae	
24	*Acanthosaura armata* (Gray, 1827)	LC
25	*Bronchocela cristatella* (Kuhl, 1820)	LC
26	*Calotes versicolor* (Daudin, 1802)	LC
27	*Draco sumatranus* Schlegel, 1844	LC
28	*Gonocephalus grandis* (Gray, 1845)	LC
29	*Gonocephalus liogaster* (Günther, 1872)	LC
30	*Leiolepis belliana* (Hardwicke & Gray, 1827)	LC
	Gekkonidae	
31	*Cyrtodactylus consobrinus* (Peters, 1871)	LC
32	*Cyrtodactylus quadrivirgatus* Taylor, 1962	LC
33	*Gehyra mutilata* (Wiegmann, 1834)	LC
34	*Gekko monarchus* (Schlegel, 1836)	LC
35	*Hemidactylus frenatus* Duméril & Bibron, 1836	LC
36	*Hemidactylus platyurus* (Schneider, 1797)	LC
37	*Hemiphyllodactylus typus* Bleeker, 1860	LC
	Scincidae	
38	*Dasia olivacea* Gray, 1839	LC
39	*Eutropis multifasciata* (Kuhl, 1820)	LC
40	*Lipinia vittigera* (Boulenger, 1894)	LC
41	*Lygosoma siamensis* Siler, Heitz, Davis, Freitas, Aowphol, Termprayoon & Grismer, 2018	LC

	Varanidae	
42	*Varanus salvator* (Laurenti, 1768)	LC
	SNAKES	
	Colubridae	
43	*Ahaetulla prasina* (Boie, 1827)	LC
44	*Boiga cynodon* (Boie, 1827)	LC
45	*Dendrelaphis caudolineatus* (Gray, 1834)	LC
46	*Dendrelaphis cyanochloris* (Wall, 1921)	LC
47	*Dendrelaphis pictus* (Gmelin, 1789)	LC
48	*Dendrelaphis striatus* (Cohn, 1905)	LC
49	*Gonyosoma oxycephalum* (Boie, 1827)	LC
50	*Lycodon subcinctus* Boie, 1827	LC
51	*Pseudorhabdion longiceps* (Cantor, 1847)	LC
	Pythonidae	
52	*Malayopython reticulatus* (Schneider, 1801)	LC
	Viperidae	
53	*Tropidolaemus wagleri* (Boie, 1827)	LC
	FRESHWATER TURTLE AND TORTOISE	
	Testudinidae	
54	*Manouria emys* (Schlegel & Müller, 1844)	CR
	Trionychidae	
55	*Dogania subplana* (Geoffroy Saint-Hilaire, 1809)	LC

Notes: IUCN STATUS: LC = Least Concerned; CR = Critically Endangered.


A
B
C
D
E
F

Figure 3. Amphibians from Bukit Maras **A.** *Duttaphrynus melanostictus* **B.** *Ingerophrynus parvus* **C.** *Fejevarya limnocharis* **D.** *Limnonectes deinodon* **E.** *Leptobrachium hendricksonii* **F.**

Megophrys nasuta **G.** *Microhyla heymonsi* **H.** *Microhyla mantheyi* **I.** *Humerana miopus* **J.** *Hylarana labialis* **K.** *Polypedates leucomystax* **L.** *Theloderma licin*

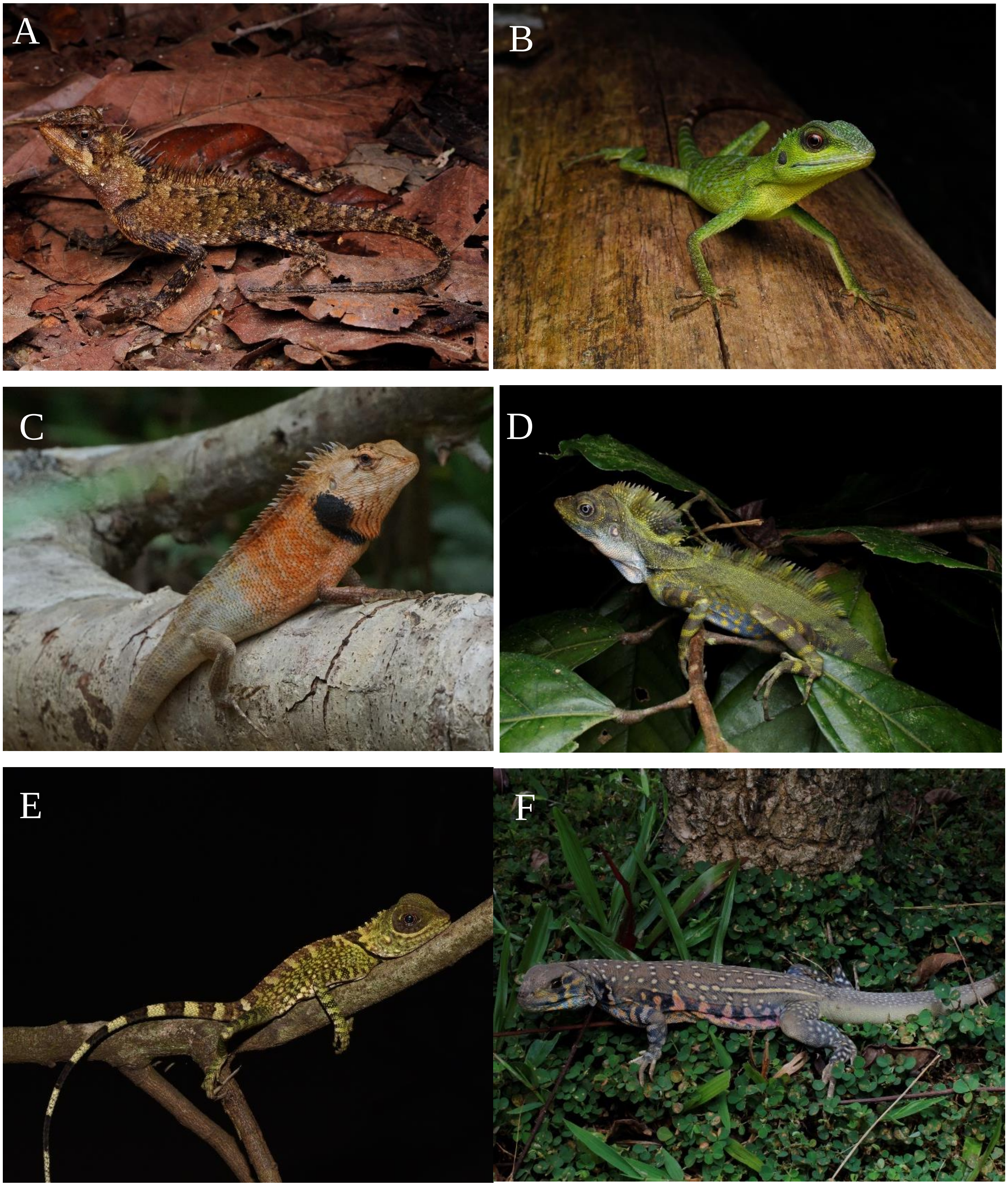

Figure 4. Lizards from Bukit Maras **A.** *Acanthosaura armata* **B.** *Bronchocela cristatella* **C.** *Calotes versicolor* **D.** *Gonocephalus grandis* **E.** *Gonocephalus liogaster* **F.** *Leiolepis belliana* **G.** *Cyrtodactylus consobrinus* **H.** *Cyrtodactylus quadrivirvagtus* **I.** *Gekko monarchus* **J.** *Hemiphyllodactylus typus* **K.** *Lygosoma siamensis* **L.** *Lipinia vittigera*


A
B
C
D
E
F

Figure 5. Freshwater tortoise and turtle and snakes from Bukit Maras **A.** *Ahaetulla prasina* **B.** *Boiga cynodon* **C.** *Dendrelaphis caudolineatus* **D.** *Dendrelaphis cyanochloris* **E.** *Dendrelaphis pictus* **F.** *Dendrelaphis striatus* **G.** *Gonyosoma oxycephalum* **H.** *Lycodon subcinctus* **I.** *Malayopython reticulatus* **J.** *Tropidolaemus wagleri* **K.** *Manouria emys* **L.** *Dogania subplana*

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The individual-based rarefaction and extrapolation curves for the total herpetofauna and each of amphibian and reptilian assemblages implied that additional species can be detected in BM when more sampling efforts are executed as the extrapolated curves for all three showed no sign of plateauing just yet. At the extrapolated curves, it is estimated that 60 herpetofauna species can be discover in BM, which to be specific a potential discovery of an additional two species of amphibians and three species of reptiles with additional efforts. Coverage-based rarefaction and extrapolation curves are in accord with the individual-based rarefaction and extrapolation curves as the curves approaching the sampling completeness value. All curves are non-overlapped which indicated that the species richness (q=0) for all curves are significantly different.

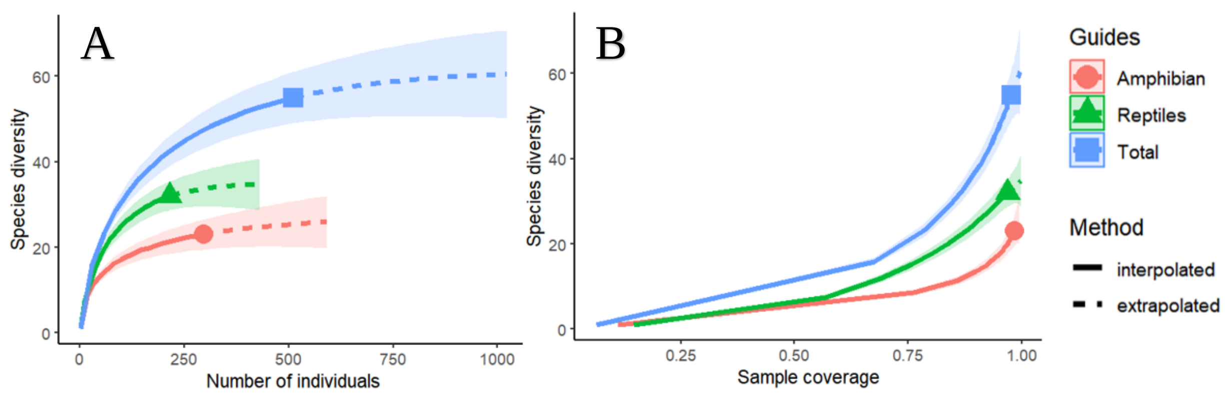

Figure 6. A. Individual-based rarefaction (solid line segment) and extrapolation (dotted line segment) sampling curves with 95% confidence interval (shaded areas) (left panel) and **B.** coverage-based rarefaction (solid line segment) and extrapolation (dotted line segment) sampling curves with 95% confidence interval (shaded areas) (right panel) for herpetofauna sampled in Bukit Maras, Terengganu, Peninsular Malaysia.

In general, the *Calotes versicolor* had the highest abundance compared to other species in Bukit Maras. It also contributed the highest number of individuals in agricultural area (AA). The AA is also the site with the highest number of individuals occupied by the herpetofauna. Species richness-wise, the seconday forest (SF) had the highest number of species among the habitats. The *Fejevarya limnocharis* had the highest number of frequency as it can be found across all four habitats. Each of the habitat type composed of different set of species composition (Fig. 7). In specific, there are 36 species of herpetofauna in SF and the highest number of individuals is *Eutropis multifasciata* (12 individuals), followed by *Microhyla heymonsi* (11 individuals) and

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Limnonectes hascheanus (7 individuals). Meanwhile, AA had only 17 species and dominated by *C. versicolor* (68 individuals), followed by *Hemidactylus frenatus* (17 individuals) and *Duttaphrynus melanostictus* (15 individuals). For riparian areas, stream of secondary forest (STF) had 16 species, and dominated by *Limnonectes deinodo*n (36 individuals), followed by *Hylarana labialis* (25 individuals) and *Leptobrachium hendricksoni* (16 individuals). On the other hand, stream of agricultural area (STA) had only nine species, dominated by *Polypedates leucomystax* (23 individuals), followed by *Fejevarya limnocharis* (19 individuals) and *H. labialis* (17 individuals).

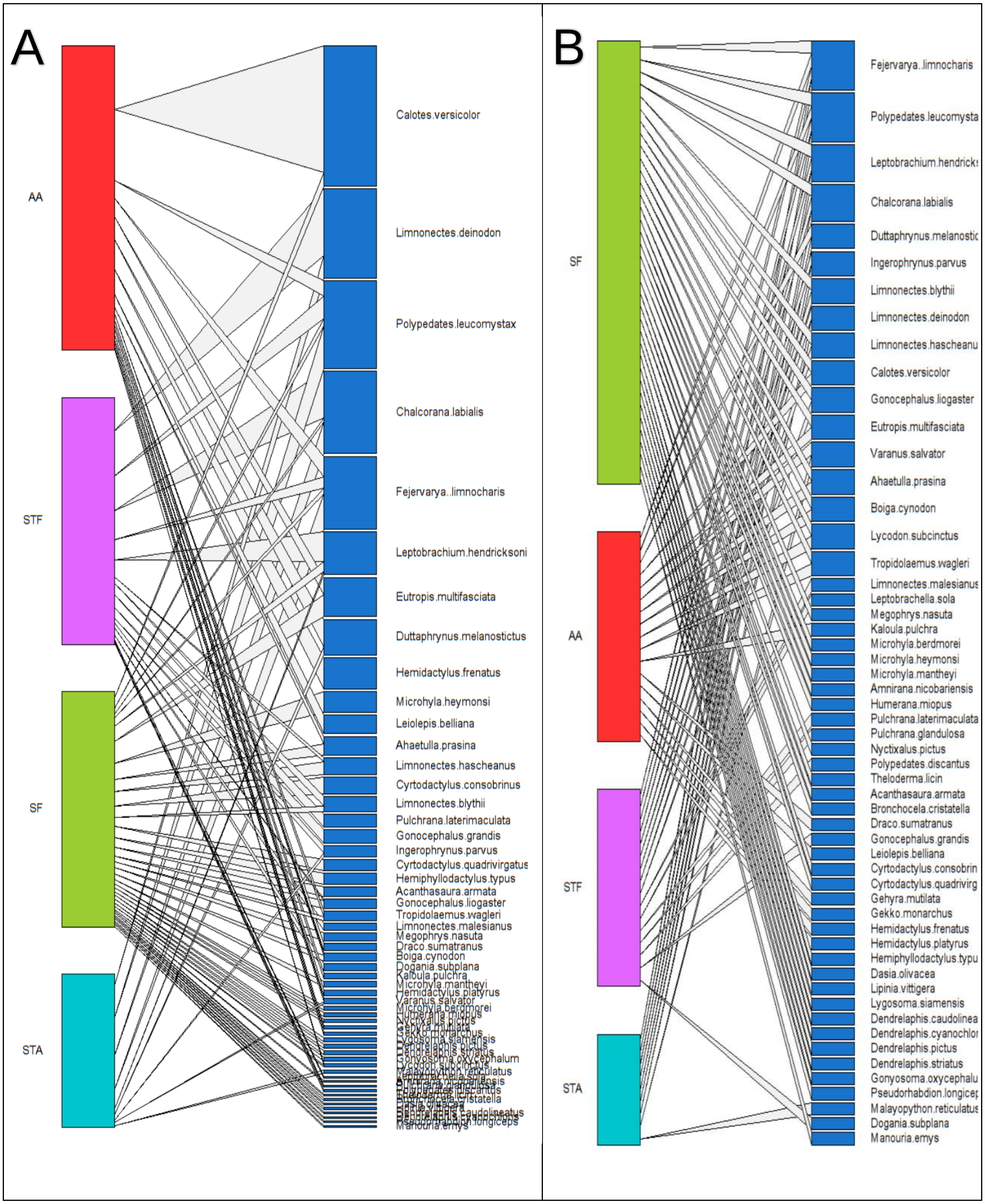

Figure 7. Species-habitat network in Bukit Maras. **A.** Abundance-based species-habitat network **B.** Incidence-based species-habitat network. The left panel represents nodes for habitat types while the right panel represents nodes for each species. The width of the links represents the

number of individuals (abundance-based) and frequency of occurrence (incidence-based). The nodes are arranged from the highest to lowest (abundance/frequency).

The diversity order of species richness (q=0) for both curves for secondary forest (SF) and secondary forest's stream (STF) are not yet approaching asymptote even at the extrapolated curves indicating that more species can be discovered in both habitats. On the other hand, both curves for agricultural area (AA) and agricultural area's stream (STA) showed a sign of levelling off at the extrapolated curves indicating that the sampling in these areas are almost complete.

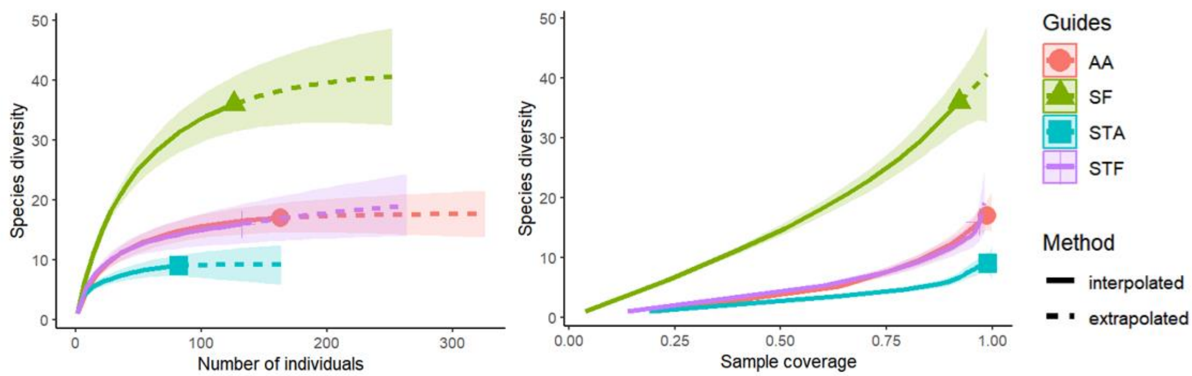

Figure 8. A. Individual-based rarefaction (solid line segment) and extrapolation (dotted line segment) sampling curves with 95% confidence interval (shaded areas) and **B.** coverage-based rarefaction (solid line segment) and extrapolation (dotted line segment) sampling curves with 95% confidence interval (shaded areas) for the herpetofauna data of four habitat types: green (secondary forest); red (agricultural area). The solid dots/triangles represent the reference samples. Hill numbers of order (q = 0) or species richness was measured for both curves.

Discussion

The forested area at the human-induced landscape is disappearing at an unprecedented rate, leaving "islands" of forest remnants (Sodhi et al. 2010). This habitat may become refuge to the perturbed herpetofauna and our study demonstrated that by documenting a total of 55 species of herpetofauna in Bukit Maras. This record is a preliminary checklist and additional species record in this baseline data is promising, as indicated by the non-asymptotic individual rarefaction and extrapolation curves. The extrapolated curves indicated that an additional five herpetofauna species can be found with additional efforts. Some species of herpetofauna particularly snakes can be elusive and previous study on temporal snake diversity in Terengganu suggested that surveys should be intensified especially during the raining season (Syafiq et al. 2023). This would not only increase the chance to encounter elusive snake species but as well as amphibian species (Badli-Sham et al. 2023).

Bukit Maras is a disturbed landscape dominated by secondary forest and agricultural areas. Herpetofauna are sensitive to land-use changes (Sodhi et al. 2008). The ongoing orchard expansion threatens the discovery of new species and the persistence of elusive ones. Our findings, aligning with previous research, show that secondary forests have higher herpetofauna diversity compared to agricultural areas (Fig. 8). This difference is likely due to species loss in agricultural areas, where suitable habitat is limited (Fig. 7). Forest-dwelling herpetofauna, known for their high site fidelity (Vitt and Caldwell 2001; Hillers et al. 2008), are particularly vulnerable to local extirpation in such modified habitats. Studies in oil palm plantations (Gillespie et al. 2012; Faruk et al. 2013) demonstrate a similar pattern, with generalist species dominating disturbed areas. Our results in the agricultural areas of Bukit Maras reflect this trend. Without action to curb orchard expansion, biotic homogenization, where species diversity reduced and dominated by only a few common species, is a looming threat.

The presence of the critically endangered species, *Manouria emys* tortoise in the secondary forest highlights the high conservation value of Bukit Maras' remaining forests. This discovery underscores the urgency for immediate action by policymakers, local authorities, and the public to protect these vital habitats.

Given the widespread occurrence of secondary forests around human settlements, practical conservation efforts should focus on preserving these areas and their riparian zones (Chazdon et al. 2009; Pirnat and Hladnik 2016). While not a perfect substitute for primary forests, secondary forests can support a significant diversity of herpetofauna (Thompson and Donnelly 2018). Their mix of vegetation and microhabitats from both primary and disturbed forests creates a more favourable environment for herpetofauna compared to other human-modified landscapes (Luja et al. 2008). Protecting these secondary forests can serve as a buffer zone, mitigating anthropogenic disturbances and safeguarding the remaining herpetofauna in Bukit Maras.

Conclusion

Our study helps fill a critical knowledge gap by investigating the herpetofauna of isolated hills within Terengganu's human-modified landscape. This research focused on Bukit Maras, but similar isolated hills in Terengganu, such as Besar Hill, Chendering Hill, and Jong Hill, warrant further investigation using similar methods. Further surveys in Bukit Maras' northern region could reveal additional species. This study provides valuable baseline data for future monitoring efforts to assess the impacts of environmental changes on herpetofauna in human-modified landscapes.

Acknowledgements

We thank Universiti Malaysia Terengganu for the research equipment used during this study. The first author (MFS) is deeply grateful for the Tuanku Canselor Scholarship, generously funded by Universiti Malaysia Terengganu, which greatly supported first author throughout his study. We also thank to all undergraduate students for their assistance in the field. The Department of Wildlife and National Parks is dully acknowledged for permission to conduct this study (Permit no.: T-00563-16-17). We thank the anonymous reviewer for their helpful comments.

Authors' Contributions

MFS collected the data, served as authority on species identification, provide photograph of the specimens, analyzed the data, wrote, and revised the manuscript. BHBS collected the data, served as authority on species identification, provide photograph of the specimens and constructed the map figure. SAF, MIMAW, MAN, FHA, GK, NNS, NFN, MS-R, JA, TKL, NSX, MFA, SAR collected the data. ABA conceptualized the study design, analyzed the data and revised the manuscript.

References

Alam MM, Morshed MD, Siwar C, Murad M (2012) Initiatives and challenges of agricultural crop sector in East Coast Economic Region (ECER) development projects in Malaysia.

American-Eurasian Journal of Agricultural & Environmental Sciences 12 (7): 922–931. https://ssrn.com/abstract=2942578

Auliya M (2007) An identification guide to the tortoises and freshwater turtles of Brunei Darussalam, Indonesia, Malaysia, Papua New Guinea, Philippines, Singapore and Timor Leste. TRAFFIC Southeast Asia, Petaling Jaya, Malaysia, 99 pp.

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, Syafiq MF, Aziz MSA, Jalil NRM, Awang MT, Othman MNA, Aziz AAA, Dzu K, Wahab NAA, Jamil NL, Ismail MA, Azman WAAW, Wei OX, Jamaha NAN, Aqmal-Naser M, Fahmi-Ahmad M, Shahirah-Ibrahim N, Rizal SA, Belabut DM, Chan KO, Quah ESH, Grismer LL, Ahmad AB (2023) A decade of amphibian studies (Animalia, Amphibia) at Sekayu lowland forest, Hulu Terengganu, Peninsular Malaysia. Zookeys 1157: 43–93.

Berry PY (1975) The amphibian fauna of Peninsular Malaysia. Tropical Press, Kuala Lumpur, Malaysia, 127 pp.

Chan KO, Wood Jr PL, Anuar S, Muin MA, Quah ESH, Sumarli AXY, Grismer LL (2014) A new species of upland Stream Toad of the genus *Ansonia* Stoliczka, 1870 (Anura: Bufonidae) from northeastern Peninsular Malaysia. Zootaxa 3764 (4): 427–440. https://doi.org/10.11646/zootaxa.3764.4.3

Chan KO, Muin MA, Badli-Sham BH, Fatihah-Syafiq M, Abraham RK, Ahmad A, Zakaria R (2020). Identification and species delimitation of the enigmatic Marsh Frog *Pulchrana rawa* (Matsui, Mumpuni, and Hamidy, 2012): Second confirmed specimen and first country record for Malaysia. Journal of Herpetology 54(3): 282–288.

Chazdon RL, Peres CA, Dent D, Sheil D, Lugo AE, Lamb D, Stork NE, Millers SE (2009) The potential for species conservation in tropical secondary forests. Conservation Biology 23(6): 1406–1417. 10.1111/j.1523-1739.2009.01338.x

Das I (2012) Naturalist's guide to the snakes of South-East Asia: Malaysia, Singapore, Thailand, Myanmar, Borneo, Sumatra, Java and Bali. John Beaufoy Publishing, Oxford, England, 160 pp.

Dormann CF, Fruend J, Bluethgen N, Gruber B (2009) Indices, graphs and null models: analyzing bipartite ecological networks. Open Ecology Journal 2:7–24. http://dx.doi.org/10.2174/1874213000902010007

Faruk A, Belabut D, Ahmad N, Knell RJ, Garner TWJ (2013) Effects of oil-palm plantations on diversity of tropical Anurans. Conservation Biology 27: 615–624. 10.1111/cobi.12062

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. 10.3897/zookeys.985.54737

Frost DR (2024) Amphibian Species of the World. American Museum of Natural History, New York, USA. https://amphibiansoftheworld.amnh.org/. Accessed on: 2024–03–11.

Gillespie GR, Ahmad E, Elahan B, Evans A, Ancrenaz M, Goossens B, Scroggie MP (2012) Conservation of amphibians in Borneo: Relative value of secondary tropical forest and non-forest habitats. Biological Conservation 152: 136–144. https://doi.org/10.1016/j.biocon.2012.03.023

Grismer LL (2011) Lizards of Peninsular Malaysia, Singapore, and their adjacent archipelagos: Their description, distribution, and natural history. Edition Chimaira, Frankfurt am Main, Germany, 728 pp.

Grismer LL, Anuar S, Muin MA, Quah ESH, Wood Jr PL (2013a) Phylogenetic relationships and description of a new upland species of Bent-toed Gecko (*Cyrtodactylus* Gray, 1827) of the

C. sworderi complex from northeastern Peninsular Malaysia. Zootaxa 3613 (3): 239–252. https://doi.org/10.11646/zootaxa.3616.3.2

Grismer LL, Wood Jr PL, Anuar S, Muin MA, Quah ESH, McGuire JA, Brown RM, Tri NV, Thai PH (2013b) Integrative taxonomy uncovers high levels of cryptic species diversity in *Hemiphyllodactylus* Bleeker, 1860 (Squamata: Gekkonidae) and the description of a new species from Peninsular Malaysia. Zoological Journal of the Linnean Society 169 (4): 849–880. https://doi.org/10.11646/zootaxa.3616.3.2

Grismer LL, Wood PL Jr, Chan KO, Anuar S (2014a) Cyrts in the city: A new Bent-toed Gecko (Genus *Cyrtodactylus*) is the only endemic species of vertebrate from Batu Caves, Selangor, Peninsular Malaysia. Zootaxa 3774(4): 318–394. https://doi.org/10.11646/zootaxa.3774.4.6

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. https://doi.org/10.11646/zootaxa.3821.4.4

Grismer LL, Wood JrPL, Anuar S, Quah ESH, Muin MA, Mohamed M, Onn CK, Sumarli AX, Loredo AI, Heinz HM (2014c). The phylogenetic relationships of three new species of the *Cyrtodactylus pulchellus* complex (Squamata: Gekkonidae) from poorly explored regions in northeastern Peninsular Malaysia. Zootaxa 3786 (3): 359–381. https://doi.org/10.11646/zootaxa.3786.3.6

Grismer LL, Wood JrPL, Anuar S, Quah ESH, Muin MA, Onn CK, Sumarli AX, Loredo AI (2015) Repeated evolution of sympatric, palaeoendemic species in closely related, co-distributed lineages of *Hemiphyllodactylus* Bleeker, 1860 (Squamata: Gekkonidae) across a sky-island archipelago in Peninsular Malaysia. Zoological Journal of the Linnean Society 174(4): 859–876. https://doi.org/10.1111/zoj.12254

Grismer LL, Muin MA, Wood Jr. PL, Anuar S, Linkem CW (2016a) The transfer of two clades of Malaysian *Sphenomorphus* Fitzinger (Squamata: Scincidae) into the genus *Tytthoscincus* Linkem, Diesmos, & Brown and the description of a new Malaysian swamp-dwelling species. Zootaxa 4092(2): 231–242.

Grismer LL, Wood JrPL, Syafiq MF, Badli-Sham BH, Rizal SA, Ahmad AB, Quah ESH (2016b) 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. https://doi.org/10.11646/zootaxa.4147.1.3

Grismer LL, Wood JrPL, 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. https://doi.org/10.11646/zootaxa.4425.1.5

Haddad NM, Brudvig LA, Clobert J, Davies KF, Gonzalez A, Holt RD, Cook WM (2015) Habitat fragmentation and its lasting impact on Earth's ecosystems. Science Advances 1(2): e1500052. https://doi.org/10.1126/sciadv.1500052

Hillers A, Veith M, Rödel MO (2008) Effects of forest fragmentation and habitat degradation on west African leaf-litter frogs. Conservation Biology 22: 762–772. https://doi.org/10.1016/j.actao.2015.09.003

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. https://doi.org/10.1111/2041-210X.12613

IUCN (2024) The IUCN Red List of Threatened Species 2024. International Union for Conservation of Nature, Gland, Switzerland. https://www.iucnredlist.org. Accessed on: 2024–03–11.

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. https://doi.org/10.1016/j.dib.2019.104994

Luja VH, Herrando-P'erez S, Gonza'lez-Solis D, Luiselli L (2008) Secondary rain forests are not havens for reptile species in tropical Mexico. Biotropica 40: 747–757. https://doi.org/10.1111/j.1744-7429.2008.00439.x

Magintan D, Nor, S.M., Ean, T.P., Lechner, A.M., Azhar, B. (2017). The conservation value of unlogged and logged forests for native mammals on the East Coast of Peninsular Malaysia. Journal for Nature Conservation 40: 113–119. https://doi.org/10.1016/j.jnc.2017.10.005

Marini L, Bartomeus I, Rader R, Lami F (2019) Species-habitat networks: A tool to improve landscape management for conservation. Journal of Applied Ecology 56: 923–928.

Myers N, Mittermeier RA, Mittermeier CG, Fonseca GABD, Kent J (2000) Biodiversity hotspots for conservation priorities. Nature 403: 853–858. https://doi.org/10.1038/35002501

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, Terengganu, Peninsular Malaysia. Malaysian Applied Biology 46(4): 119–129.

Pirnat J, Hladnik D (2016) Connectivity as a tool in the prioritisation and protection of sub-urban forest patches in landscape conservation planning. Landscape and Urban Planning 153: 129–139. https://doi.org/10.1016/j.landurbplan.2016.05.013

Quah ESH, Sah SAM, Muin MA, Rahman NAA, Mustafa FS, Grismer LL (2013) Species diversity of herpetofauna of Bukit Panchor State Park, Penang, Peninsular Malaysia. Malayan Nature Journal 64(4): 193–211.

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.

RStudio Team (2023) RStudio: Integrated Development for R. Boston, USA. https://rstudio.com. Accessed on: 2024–02–21

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.

Sodhi NS, Koh LP, Brook BW, Ng PKL (2004) Southeast Asian biodiversity: An impending disaster. Trends in Ecology and Evolution 19: 654–660. 10.1016/j.tree.2004.09.006

Sodhi NS, Bickford D, Diesmos AC, Lee TM, Koh LP, Brook BW, Sekercioglu CH, Bradshaw CJA, (2008) Measuring the meltdown: Drivers of global amphibian extinction and decline. PLoS One 3(2): e1636. https://doi.org/10.1371/journal.pone.0001636

Sodhi NS, Koh LP, Clements R, Wanger TC, Hill JK, Hamer KC, Clough Y, Tscharntke T, Posa MRC, Lee TM (2010) Conserving Southeast Asian forest biodiversity in human-modified landscapes. Biological Conservation 143: 2375–2384. https://doi.org/10.1016/j.biocon.2009.12.029

Sulaiman MH, Lian CJ (2011) A checklist of chiropterans from a disturbed forest at Bukit Maras, Terengganu. Malayan Nature Journal 63(4): 667–672.

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(4): 1–32. https://doi.org/10.15560/11.4.1679

Sumarli A, Grismer LL, Wood Jr, PL, Ahmad AB, Rizal S, Ismail LH, Izam NAM, Ahmad N, Linkem C W (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. https://doi.org/10.11646/zootaxa.4173.1.3

Syafiq MF, Badli-Sham BH, Grismer LL, Ahmad AB (2023) Uneven species occurrence and richness of lowland snakes (Serpentes, Squamata) in Terengganu, Peninsular Malaysia, with new locality records. ZooKeys 1168: 11–39. https://doi.org/10.3897/zookeys.1168.95833

Syafiq MF, Badli-Sham BH, Ibrahim NS, Ismail LH, Amin MAM, Xian GS, Ariffin RAM, Afiq-Suhaimi, M, Men LK, Danelo DA, Aqmal-Naser M, Fahmi-Ahmad M, Rizal SA, Belabut DM, Quah ESH, Ahmad, A. B. (2024) Taxonomic composition, diversity, and conservation status of reptilian fauna at Sekayu Lowland Forests, Terengganu, Peninsular Malaysia. Russian Journal of Herpetology 31(1): 14–23. https://doi.org/10.30906/1026-2296-2024-31-1-14-23

Thompson ME, Donnelly MA (2018) Effects of secondary forest succession on amphibians and reptiles: A review and meta-analysis. Copeia 106 (1): 10–19. https://doi.org/10.1643/CH-17-654

Uetz P, Freed P, Aguilar R, Reyes F, Kudera J, Hosek J (2023) The Reptile Database. Czech Republic. http://www.reptile-database.org. Accessed on: 2024–03–11

Vitt LJ, Caldwell JP (2001) The effects of logging on reptiles and amphibians of tropical forests. In: Fimbel, R.A., Grajal, A., Robinson, J. (Eds.), The Cutting Edge: Conserving Wildlife in Logged Tropical Forests. Columbia University Press, New York, 239–259.

Appendix

Table A. List of voucher specimens from Bukit Maras catalogued with the UMTZC voucher code numbers.

Voucher No. (UMTZC)	Species Name
1701	*Gonocephalus liogaster*
1705	*Cyrtodactylus quadrivirgatus*
1706	*Phrynoides aspera*
1772	*Hylarana nicobarensis*
1773	*Calotes versicolor*
1774	*Eutropis multifasciata*
1882	*Cyrtodactylus consobrinus*
1823	*Hemiphyllodactylus typus*
1825	*Limnonectes deinodon*
1828	*Hylarana labialis*
1831	*Pseudorhabdion longiceps*