

Patterns and progress of Malaysia's amphibian research in the 21st century

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Abstract. We review the status, patterns, and progress of Malaysia's amphibian research in the 21st century (2000–2021) with the main goal of identifying areas for improvement that can help focus and prioritise future research initiatives. Between the period of January 2000–September 2021, we found 280 publications that can be broadly grouped into five categories: 1) Checklists and Biodiversity; 2) New Species, Taxonomy, and Identification; 3) Ecology and Natural History; 4) Evolution and Phylogenetics; 5) Conservation. An average of 12.7 papers were published per year and although the number of papers fluctuated, there was an overall positive trend towards higher research output. The majority of research was from the Checklists and Biodiversity (34%; 95 papers) and New Species, Taxonomy, and Identification (35%; 97 papers) categories, followed by Ecology and Natural History (21%; 59 papers), Evolution and Phylogenetics (9%; 25 papers), and Conservation (1%; four papers). Amphibian research was conducted most frequently in the Bornean states of Sarawak (45 papers) and Sabah (34 papers) and most infrequently in the states of Malacca (one paper), Negeri Sembilan (two papers), Selangor/Kuala Lumpur (two papers), Perlis (two papers), and Kelantan (three papers). Despite being a megadiverse country and a biodiversity hotspot, only four conservation studies were published over the last two decades, highlighting the urgent need for more conservation-focused research.

Key words. biodiversity, conservation, systematics, taxonomy, evolution, natural history, phylogenetics, ecology

INTRODUCTION

Herpetological research in Malaysia dates back to the 19th century. The earliest published work relevant to the region is that of Theodore Edward Cantor (1809–1860), a Danish surgeon-naturalist with the English East India Company. Between 1842–1845, he was based at Prince of Wales Island (now Pulau Pinang or Penang Island) as Superintendent of six hospitals. His 1847 monograph used names of Indian and Javan species (Cantor, 1847). Otherwise impressive for its coverage of reptiles, it listed just eight species of amphibians, including a caecilian. The only amphibian species described as new in this work was *Hylaedactylus bivittatus* Cantor,

1847, which is now considered synonymous with *Kaloula pulchra* Gray, 1831. Subsequent notable herpetological collections in the Malay Peninsula were made by Ferdinand Stoliczka (1838–1874), which focused on former centres of European trade, including Penang, Malacca, and Singapore; Stanley Smyth Flower (1871–1946) who sent specimens to London that were described by George Albert Boulenger (1858–1937) at the British Museum, London; and Arthur Lennox Butler (1873–1939), Curator of the Selangor State Museum, in 1902 and 1904, who compiled the first amphibian checklists for the Malay Peninsula listing 58 species (Butler, 1902, 1904). Additions and emendations to the list were made by Herbert Christopher Robinson (1874–1929) in 1905, by which time 63 nominal species, plus the genus "*Ixalus*", were added to the fauna. In 1848, the Scottish botanist, Hugh Low (1824–1905) compiled the first checklist of the herpetofauna of Borneo, which listed just three species of amphibians. Significant systematic research on the island started with the arrival of professional biologists from Europe, chiefly, the Italian botanist Odoardo Beccari (1843–1920); Alfred Russel Wallace (1823–1913), famously associated with the Flying Frog (*Rhacophorus nigropalmatus*); and a lineage of museum curators and associates of the Sarawak Museum, Kuching, including Edward Bartlett (ca. 1836–1908), Charles Hose (1863–1929), Alfred Hart Everett (1849–1898), Robert Walter Campbell Shelford (1872–1912), and Eric Georg Mjöberg (1882–1938). On the eastern side of Borneo, the island's tallest mountain, Gunung (=Mount) Kinabalu, received its first explorers between 1887 and 1888, when John Whitehead (1860–1899), an ornithologist, organised

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two expeditions. At the time (1890), the Bornean amphibian list contained 49 species.

Described here are early collectors of the late 19th century and early 20th century. Mention needs to be made of the giant of herpetology, whose career spanned half a century on the Bornean portions of Malaysia (and elsewhere)—Robert Frederick Inger (1920–2019). Inger’s work was broad-ranging from taxonomy and systematics, to ecology and evolution, leading to both a better understanding of the regional amphibians and the production of field guides that have allowed access to the fauna for modern-day researchers. The intervening years have seen intense effort, leading to an accelerated knowledge of the amphibian fauna of Malaysia, and the start of some of the first studies on other aspects of their biology. At the turn of the 21st century, surveys and explorations continue to yield many new species discoveries, demonstrating that the amphibian diversity in Malaysia is far from being adequately understood (Stuebing & Wong, 2000; Das & Lim, 2001; Inger et al., 2001; Das & Haas, 2003; Grismer et al., 2004). Alongside these novel discoveries, the breadth of research topics also expanded to include research in the field of molecular systematics (Brown & Guttman, 2002; Stuart et al., 2006; Chan et al., 2016; Matsui et al., 2016), ecology (Preininger et al., 2007; Yolande et al., 2009; Savage et al., 2011), evolution (Chan et al., 2017, 2020), and conservation (Gillespie et al., 2012; Chan & Grismer, 2021). As research continues to develop with changing times and technologies, we review the status, patterns, and progress of Malaysia’s amphibian research in the 21st century (years 2000–2021), with the main goal of identifying areas for improvement that can help focus and prioritise future research initiatives.

MATERIAL AND METHODS

We performed a comprehensive literature review of amphibian research publications in Malaysia from January 2000 to September 2021 via Google Scholar, using the search term “(amphibia* OR anura* OR frog OR toad) AND (Malaysia OR Borneo OR Sabah OR Sarawak)”. Only peer-reviewed primary literature was included and studies that did not directly involve material from Malaysia were excluded. Additional literature that was not captured by the Google Scholar search was supplemented by the authors. In total, 280 publications were found and grouped into the following categories:

1. **Checklists and Biodiversity:** surveys, checklists, distribution, measures of diversity
2. **New Species, Taxonomy, and Identification:** new species descriptions, taxonomic revisions, morphological/larval/bioacoustic descriptions
3. **Ecology and Natural History:** natural history notes, behaviour, disease, environmental correlates
4. **Evolution and Phylogenetics:** phylogenetic relationships (excluding new species descriptions) and evolution
5. **Conservation:** conservation and outreach

To characterise research trends and patterns, we analysed the dataset according to the year of publication, number of papers, category, and geography. For geography, we classified papers according to states and region (Peninsular Malaysia vs. East Malaysia [island of Borneo excluding Kalimantan and Brunei]). Studies that were not focused on a particular state were excluded. All analyses were performed in R (R Core Team, 2014). The categorised bibliography of all papers used in this study is presented in the Appendix.

RESULTS

From January 2000 to September 2021, an average of 12.7 papers were published per year on Malaysian amphibians. The rate and number of publications were markedly different between the first and second half of the assessed period (Fig. 1A). Between the years 2000–2010, the rate of publication increased rapidly and steadily from three papers in the year 2000 to 21 papers in 2010 (Fig. 1B). From 2011–2021, the number of papers published fluctuated and showed a surprisingly downward trend (Fig. 1C).

The majority of papers published were from the New Species, Taxonomy, and Identification (35%) and Checklists and Biodiversity (34%) categories, followed by Ecology and Natural History (21%), Evolution and Phylogenetics (9%), and Conservation (1%; Fig. 2A). DNA data was first employed in a study published in 2008 and have been consistently utilised in taxonomic studies from 2012 onwards (Fig. 2B).

Checklists, biodiversity, new species, and taxonomic papers dominated the research literature across most years except for the period 2016–2021, during which papers from the Ecology and Natural History category were more numerous (Fig. 3). The number of Ecology and Natural History papers have increased significantly over the years, while Evolution and Phylogenetic studies were highest between 2016–2020.

The percentages of amphibian research conducted in East Malaysia (52%) and Peninsular Malaysia (48%) were relatively even (Fig. 4A). Research was conducted most frequently in the Bornean states of Sarawak and Sabah (45 and 34, respectively), followed by Kedah (22), Pahang (20), and Perak (12). The states of Kelantan (3), Negeri Sembilan, Perlis, and Selangor/Kuala Lumpur (2 papers each), and Malacca (1) recorded the least number of studies (Fig. 4B).

DISCUSSION

From the year 2006 onwards, there was a surge in Malaysian amphibian research output. Interestingly, our results showed a slight decline in research output over the last 10 years (2011–2021; Fig. 1C). This could be partly attributed to certain outliers. For example, 26 papers were published in 2014, whereas only eight papers were published the following year in 2015. However, the average number of papers published during the 2011–2021 period (16.5 papers) was

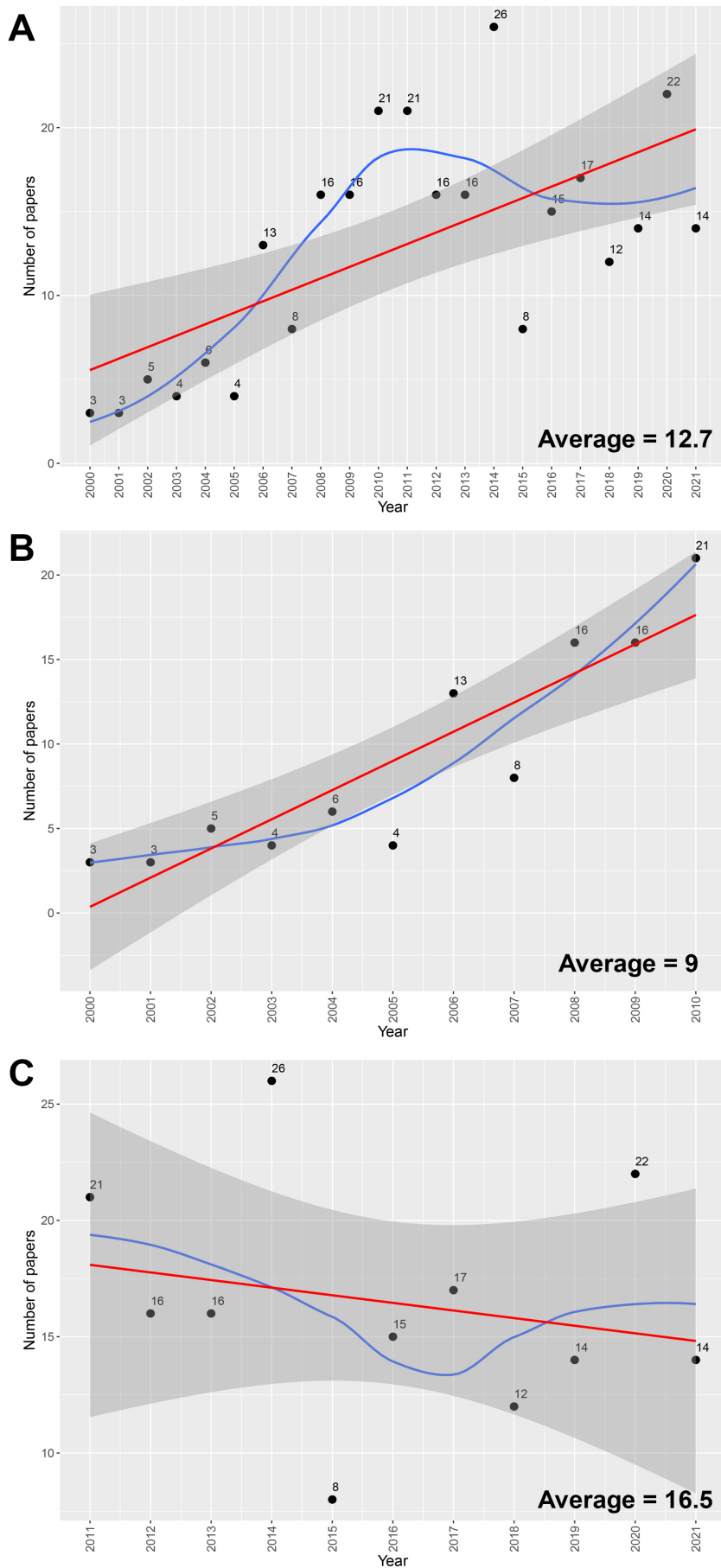


Fig. 1. The number of amphibian research papers published between January 2000 and September 2021 (A); the years 2000–2010 (B); and the years 2011–2021 (C). Regression lines are shown in blue (local polynomial regression fitting method) and red (linear regression method). Grey shading represents the 95% confidence interval of the linear regression model. Numbers next to points represent the total number of papers published that year.

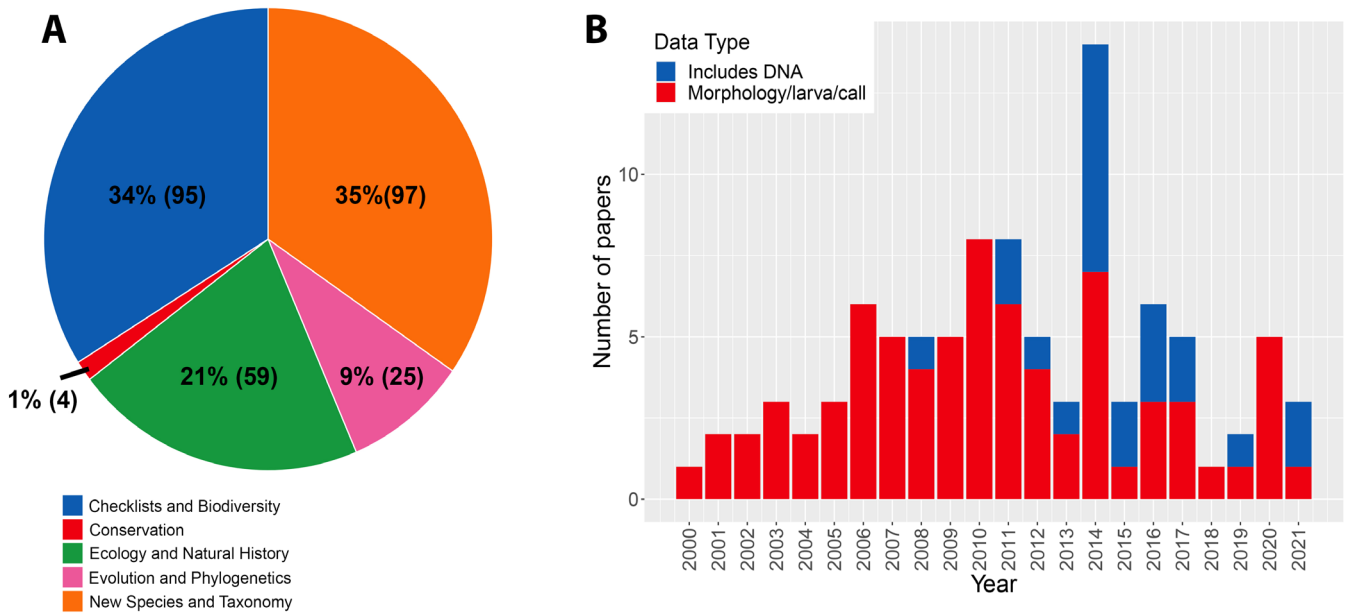


Fig. 2. Percentage and number of papers published (in parenthesis) by category between January 2000 and September 2021 (A); the number of papers published in the New Species and Taxonomy category, grouped by data type (B).

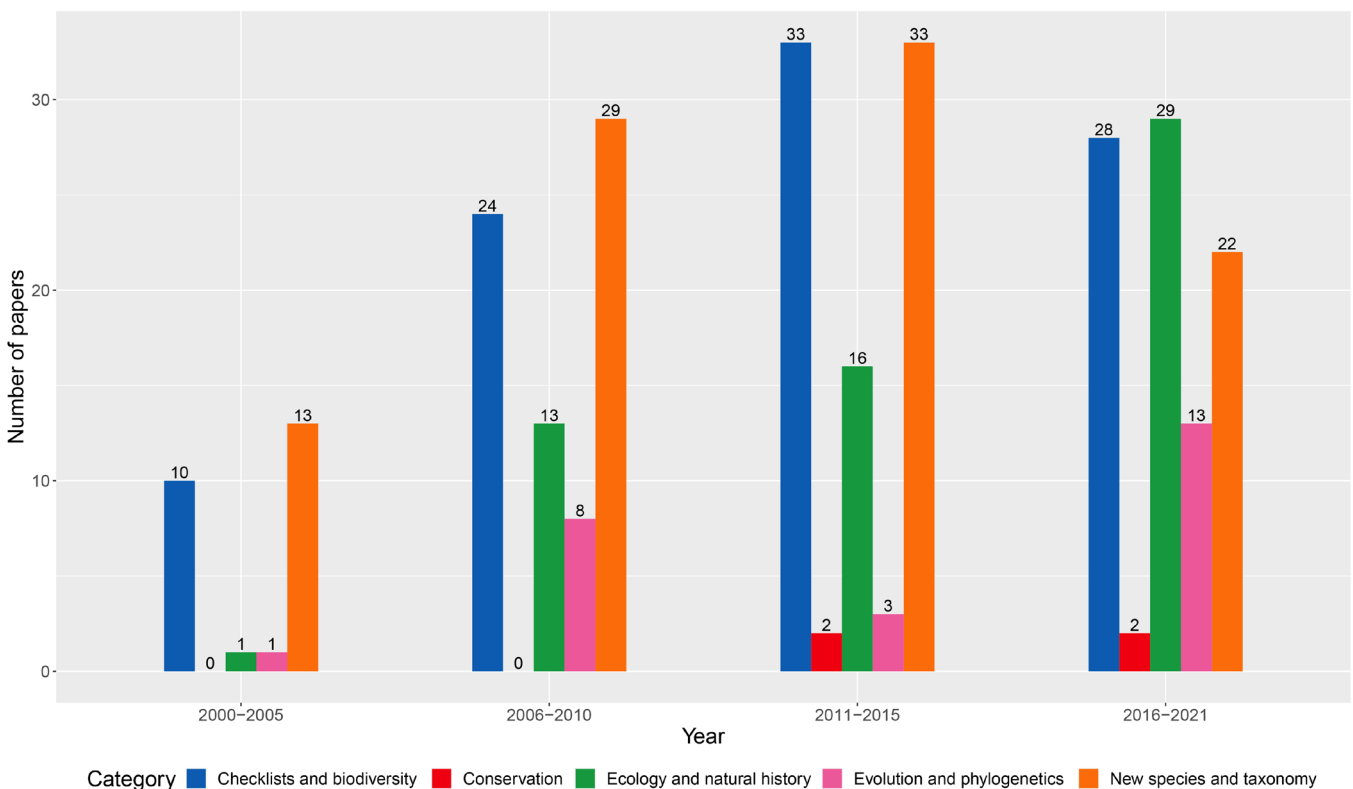


Fig. 3. Bar plots grouped by category and binned into 5-year periods. Numbers above bars represent the total number of papers published in each category.

significantly higher compared to ten years prior (nine papers) and is also higher than the 21-year average of 12.7 papers. Despite the contrasting trajectories, amphibian research in Malaysia shows an overall positive trend towards higher research output.

The vast majority of publications (69%) were related to checklists, biodiversity, new species, and taxonomy. Moreover, at least 70 new taxa were described from

2000–2021, indicating that the biodiversity of amphibians in Malaysia is far from being fully understood, and further underscores the need for more of such studies. The number of papers published by state shows that some regions are poorly studied. This most notably includes the states of Perlis, Negeri Sembilan, Melaka, Kelantan, Selangor/Kuala Lumpur, and Terengganu. Research in some of these areas has resulted in numerous important discoveries (Chan et al., 2011, 2018; Chan, Wood, et al., 2014), indicating that these

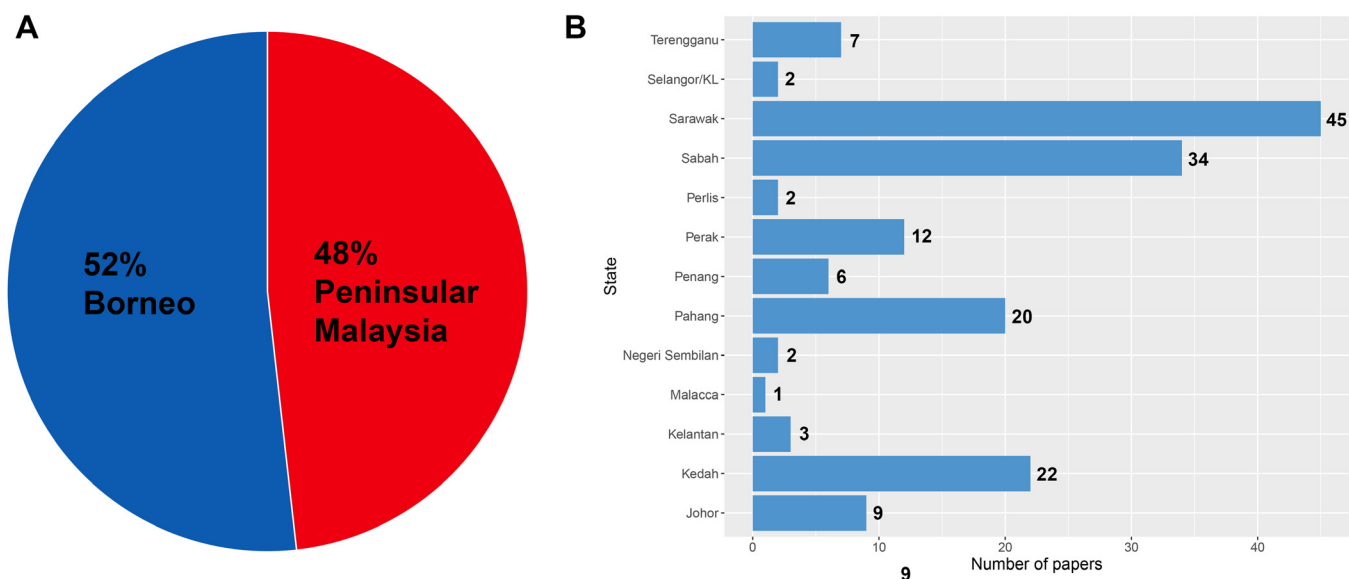


Fig. 4. Number of papers published by region (A) and state (B). Only studies that were explicitly conducted within a particular region or state were included.

areas are still poorly studied and should be prioritised for future research. However, states that have received more research attention such as Sarawak, Sabah, Perak, Pahang, and Kedah also continue to produce new discoveries (Quah et al., 2011; Chan et al., 2014; Davis et al., 2016; Waser et al., 2016; Fukuyama et al., 2021) and thus, research intensity in these states should not be reduced.

Over the years, the number of papers on ecology and natural history have increased, particularly in the last five years where this number has increased by almost two-fold (Fig. 3). However, it should be mentioned that a substantial portion of papers in this category consist of short natural history observations (see Appendix). Although the importance of such observations should not be downplayed, more robust and hypothesis-driven ecological studies are needed to provide deeper insights into amphibian ecology to guide resource management programs.

Only a single paper on evolution and phylogenetics was published between 2000–2005. This could be due to the lack of expertise and the high cost of genetic sequencing during that period. Advances in genetic sequencing technology, coupled with a concomitant reduction in sequencing cost and collaborations with international partners saw a rise in genetic research between 2006–2021. These, including more recent studies involving genome-scale data (Chan et al., 2020a, b; Chan et al., 2020; Chan et al., 2021), indicate that amphibian research in Malaysia is keeping abreast with the latest developments in the field of genetics and evolutionary biology.

One notable research gap is the lack of conservation-based research. Despite being a megadiverse country and a biodiversity hotspot, only four conservation-centric papers have been published over the last two decades. Research in this field is urgently needed as Malaysia is one of the countries with the highest rate of deforestation (Hansen et al.,

2013) with almost 30% of its amphibian species threatened (MyBis, 2021). Moreover, a recent conservation study that integrated spatial, evolutionary, and threat assessment data, identified ten areas of high conservation value in Peninsular Malaysia, many of which were not afforded adequate levels of protection (Chan & Grismer, 2021), thereby highlighting the importance and urgency for more conservation-based research.

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APPENDIX

Categorised bibliography of all papers used in this study, arranged in alphabetical order.

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