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A review of reptile research in Malaysia in the 21st century

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Abstract. This study provides a review of reptile research in Malaysia from the years 2000–2020 to reveal trends and biases that can be leveraged to improve future research and conservation initiatives. Overall, the number of papers published shows an upward trend with an average of 10.1 papers published per year. The clear majority of papers published throughout 2000–2020 were in the field of Systematics (45%, 96 papers), followed by Inventories (32%, 67 papers), Ecology (20%, 43 papers), and Conservation (3%, 6 papers). Within the Systematics category, most papers published between 2000–2011 were solely based on morphology, while integrative taxonomic studies (morphology + DNA) began to dominate from 2012 onwards. When analysed by location, most studies were conducted in Peninsular Malaysia and its associated offshore islands (78%) while the remaining 22% of studies were exclusive to Malaysian Borneo. Our results showed that research is heterogeneous across categories, focal taxa, methods, and location. Some of these biases are inherent to the nature of the study, while others represent areas for improvement. One obvious area that could be improved is the field of conservation, which constitutes only 3% of the studies and has so far focused almost exclusively on turtles. This study highlights gaps and deficiencies in research foci and provides a roadmap for future reptile research planning in Malaysia.

Key words. biodiversity, checklist, conservation, crocodiles, ecology, lizards, snakes, systematics, turtles

INTRODUCTION

Reptiles play an important role in ecosystem function through gene dispersal, nutrient cycling, trophic action, and ecosystem engineering (de Miranda, 2017), especially in tropical regions such as Southeast Asia where their abundance and diversity are high. Within Southeast Asia, Malaysia is a megadiverse country located within a biodiversity hotspot (Myers et al., 2000; Mittermeier et al., 2005) and one of the major components of Malaysia's biodiversity is reptiles, represented by at least 191 species of snakes, 174 lizards, 24 turtles, and three crocodiles (Grismer & Quah, 2019; MyBis, 2021). In Malaysia, reptile research in the biological sciences encompasses a wide range of topics including but not limited to biodiversity inventories (e.g., Sumarli et al., 2015; Chan et al., 2019; Fatihah-Syafiq et al., 2020), taxonomy (e.g., Denzer et al., 2015; Grismer et al., 2016a; Quah et al., 2020b), new species discoveries (e.g., Pui et al., 2017; Grismer et al., 2018; Karin et al., 2018), conservation (e.g., Chen, 2017; Rahman et al., 2019), ecology (e.g., Nishizawa et al., 2018; Stewart et al., 2020; Top et al., 2020), natural history (e.g., Lardner et al., 2010; Shahriza, 2018; Quah et al., 2020a), evolution (e.g., Grismer et al., 2015; Davis et al., 2020), and proteomics/venomics (e.g., Chong et al., 2019; Tan et al., 2019), all of which have evolved with advancing technologies and progressed at a different pace, intensity, scope, depth, and breadth. The use of molecular tools has reinvigorated many fields, especially in systematics, ecology, and evolution, while traditional surveys continue to yield high numbers of new discoveries, indicating that Malaysia's biodiversity is far from being adequately understood. This lack of understanding is compounded by extensive and severe habitat loss that threatens many species (Grismer et al., 2013), some of which have yet to be discovered and some of which are destined for extinction (Grismer et al., 2016c). Therefore, two decades after the turn of the 21st century, we find it prudent to provide the first in-depth review of reptile research in Malaysia. Through extensive literature review, we provide an analysis of research patterns to reveal trends and biases that can be leveraged to improve future research and conservation initiatives.

MATERIAL AND METHODS

We performed a comprehensive literature review of reptile research publications in Malaysia (Peninsular Malaysia and Malaysian Borneo) from the years 2000–2020. Literature was obtained via keyword search in Google Scholar using the phrase "reptiles Malaysia". A small number of publications that were not captured by this search were manually supplemented by the authors. Only peer-reviewed primary

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literature was included and studies that did not directly involve material from Malaysia or in which Malaysian reptiles were not the primary focus were not considered. Reports and books were excluded because the former is not peer-reviewed by the scientific community, while the latter is largely an accumulation of information derived from the primary literature. In total, 213 publications met our criteria, all of which could be broadly grouped into the following categories:

Inventories: surveys, checklists, and measures of diversity.
Systematics: new species descriptions, taxonomic notes/ revisions, and phylogenetics.
Ecology: natural history notes, behaviour, distribution ranges, and venomics.
Conservation: studies where conservation is the main focus.

To characterise research trends and patterns, we analysed the literature according to the year of publication, the number of papers published, category of research, focal taxon, and location of research. For the location analysis, we classified papers according to region (Peninsular Malaysia vs. Borneo) and states. Studies that were not focused on a particular region or state were not included in the location analysis. All analyses (descriptive statistics) were performed in R (R Core Team, 2014). The categorised bibliography of all papers used in this study is presented in the Appendix.

RESULTS

The number of papers published shows an upward trend with an average of 10.1 papers per year (Fig. 1). The year 2001 had the least number of papers (two papers), while 2008 had the most (20 papers). The clear majority of papers published throughout 2000–2020 were in the field of Systematics (45%, 96 papers), followed by Inventories (32%, 67 papers), Ecology (20%, 43 papers), and Conservation (3%, six papers) (Fig. 2A). Most of the studies within the Inventory category consisted of general herpetofaunal surveys and checklists, hence, it is not surprising that the focal taxa were mostly mixed (61 papers), whereas a small number of studies focused specifically on lizards, snakes, and turtles, while none focused exclusively on crocodiles (Fig. 2B). In the Conservation category, the majority of studies focused on turtles (five papers), with one study focused on lizards and none on crocodiles, snakes, or mixed taxa. For Ecology, a relatively balanced number of studies were conducted on lizards (14 papers), snakes (12), and turtles (10), while crocodiles and mixed taxa were the minority. Taxonomic imbalance is most evident in the Systematics category where 73 papers were published on lizards compared to 21 papers on snakes. No papers were published on crocodiles, turtles, or mixed taxa in this category (Fig. 2B).

Systematic papers dominated the literature across time (Fig. 3A). This was followed by Inventories, except for the 2016–2020 period where the number of papers in the Ecology category exceeded inventory studies. Within the Systematics category, most papers published between 2000–2011 were solely based on morphology (Fig. 3B), while integrative taxonomic studies (morphology + DNA) began to take over from 2012 onwards. When analysed by location, most studies were conducted in Peninsular Malaysia (78%) while the remaining 22% of studies were exclusive to Malaysian Borneo (Fig. 4A). The state of Pahang was the focus of most studies (27 papers), followed by Kedah and Perak (19 each), Johor (18), Terengganu (13), Sarawak (13), Sabah (9), Penang (7), Kelantan (7), Perlis (5), Malacca (2), Negeri Sembilan (1), and Selangor/Kuala Lumpur (1) (Fig. 4B).

DISCUSSION

Overall, reptile research in Malaysia shows a positive trend towards higher research output (Fig. 1) and the adoption of modern techniques (Fig. 3B). Our analyses also revealed that research foci were heterogeneous across categories (Figs. 2A, 3A), focal taxa (Fig. 2B), data types (Fig. 3B), and location (Fig. 4A, B). Some of these biases are inherent to the nature of the study (e.g., inventories are usually more general and less focused on a specific taxonomic group), while others represent areas for improvement. One obvious area that could be improved is the field of conservation, which constitutes only 3% of the studies and has so far focused almost exclusively on turtles (Fig. 2A). In addition to increasing research output, conservation studies should also target other taxonomic groups such as snakes and lizards that are not only on orders of magnitude more diverse compared to turtles but also harbour higher levels of endemic (Grismer et al., 2014a, b, 2016c) and threatened species (IUCN, 2021). Recent systematic studies have uncovered an unprecedented number of new snake and lizard species (e.g., Loredo et al., 2013; Grismer et al., 2014a–c, 2016c; Quah et al., 2019, 2020b; Wood et al., 2020), many of which are site-specific endemics that are under severe threat of extinction (Grismer et al., 2014a, c, 2016b, c), making them ideal candidates for conservation.

The spread of ecological papers was quite balanced across lizards, snakes, and turtles but could be increased for crocodiles (Fig. 2B). This is more pertinent in Borneo where there is crocodile-based ecotourism and a relatively higher incidence of human-crocodile conflict and hence, a more urgent need to better understand crocodile ecology (Evans et al., 2016; Hassan et al., 2019). However, it is encouraging to see an approximately three-fold increase in ecological studies over the last five years (Fig. 3A). In the field of systematics, the use of molecular tools has not only facilitated and accelerated the discovery of new species (Fig. 3B) but also provided deeper insights into the evolutionary history and biogeography of reptiles (e.g., Johnson et al., 2012; Grismer et al., 2015; Davis et al., 2020). However, apart from phylogenetic systematic research, there is a clear lack of evolutionary and genomic studies, which represent a promising avenue for future research.

As demonstrated by Grismer & Quah (2019: fig. 1) for lizards, the herpetofaunal diversity of Peninsular Malaysia is still greatly underestimated and probably even worse so

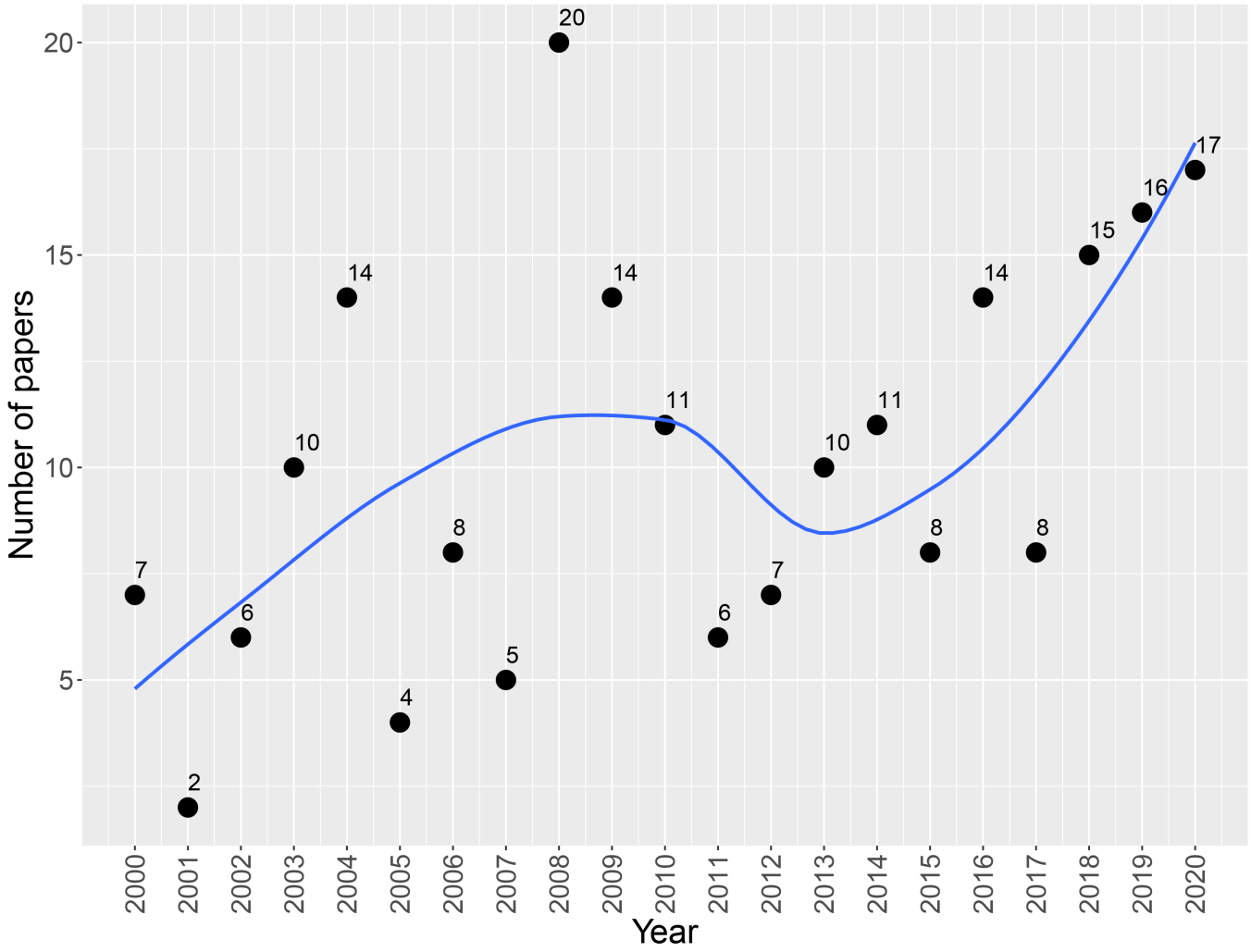

Fig. 1. Scatter plot showing the number of reptile research papers published by year from 2000–2020. The blue line represents the regression line obtained using a local polynomial regression fitting method.

for Malaysian Borneo (Davis et al., 2020). Although Borneo is well-known for being an evolutionary hotspot (de Bruyn et al., 2014), the proportion of reptile research conducted there is substantially lower compared to Peninsular Malaysia (22% vs. 78%; Fig. 4A). Many areas in Borneo remain poorly explored and the potential for new discoveries is extremely high (Das, 2003; Das et al., 2008; Grismer & Chan, 2009; Pui & Das, 2017; Pui et al., 2017; Quah et al., 2019, 2020b). Within Borneo, the state of Sabah has received less research attention compared to Sarawak, whereas in Peninsular Malaysia, the states of Selangor, Negeri Sembilan, Malacca, Perlis, Penang, and Kelantan are comparatively less studied (Fig. 4B). Even in the highly urbanised and densely populated state of Selangor, a new species of lizard was discovered from Batu Caves, which is only 11 km from the capital of Kuala Lumpur and is one of the most visited tourist areas in the country (Grismer et al., 2014d). Therefore, new discoveries are highly likely in the other understudied states where suitable habitats are also more extensive. It is difficult to pinpoint the exact factors contributing to the disparity in reptile research between Peninsular Malaysia and Borneo as the reasons could be multifarious. These could potentially include differences in permitting procedures, accessibility to field sites, and geography. Peninsular Malaysia is approximately 35% smaller than the Bornean states of Sabah and Sarawak combined and is well-connected via an extensive network of highways that provide easy access to all states. In contrast, the Pan-Borneo highway that connects major cities in Borneo has yet to be completed. Additionally, some remote areas such as Mulu National Park are only realistically accessible by air. These challenges likely play a role in slowing down research efforts in Borneo.

Inevitably, some papers could have eluded our literature review. However, this study is not meant to capture the entirety of reptile research or knowledge in Malaysia but is focused on revealing broad trends and patterns. Although books were not included in our study, we note that some books may also contain novel information that was not previously published in the primary literature (Grismer, 2011a, b) and are valuable resources that aggregate published and unpublished research data. In conclusion, our study revealed several key areas that are currently lacking in Malaysian reptile research including: (1) general inventories/surveys to understudied regions/states (especially Borneo) where the potential for new species discoveries is still high; (2) increased focus on understudied groups such snakes, crocodiles, and turtles; (3)

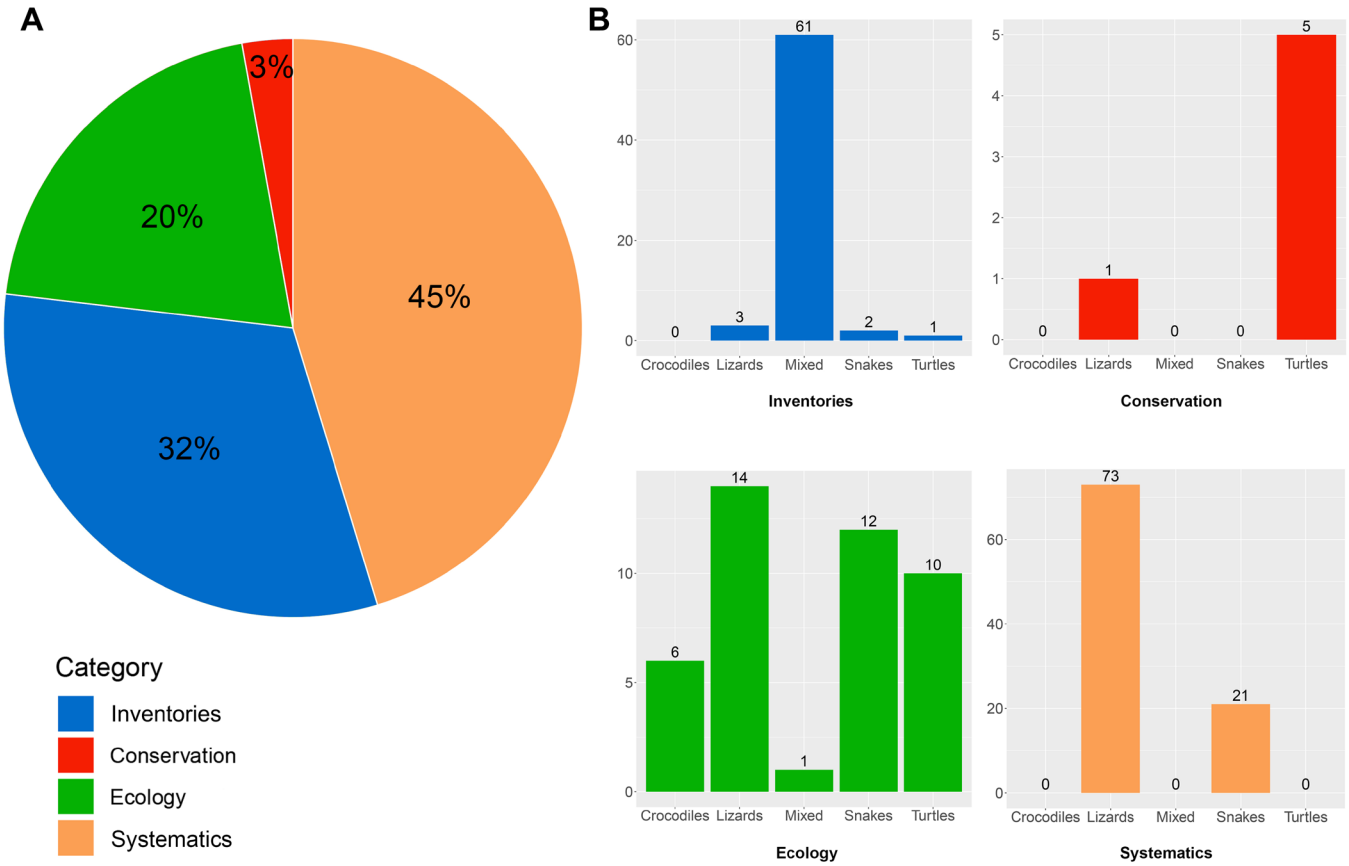

Fig. 2. Percentage of papers published by category (A); number of papers published in each category according to taxonomic group (B).

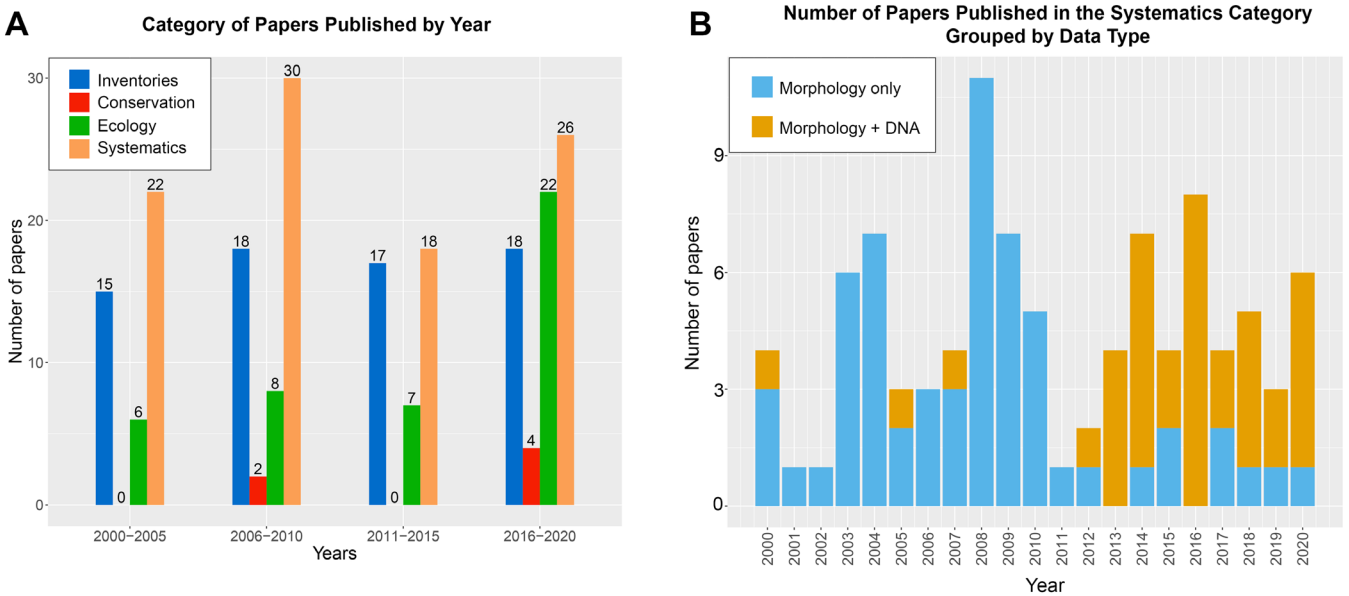

Fig. 3. Bar plots grouped by category. Numbers above bars represent the total number of papers published in each category (A); number of papers published in the systematics category, grouped by data type (B).

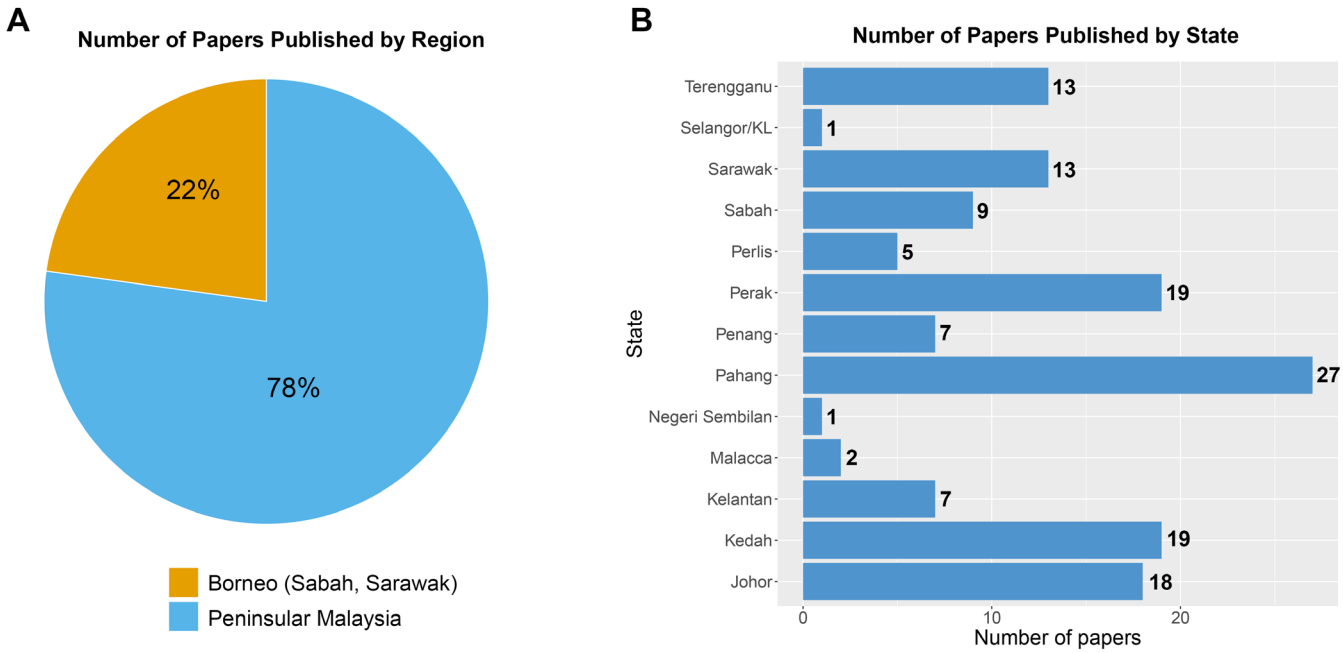

Fig. 4. Number of papers published according to region (A) and states (B).

more research in the fields of conservation, ecology, and evolution and; (4) research involving genome-level data.

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APPENDIX

Bibliography of literature used in this study, grouped by category, and arranged alphabetically.

Conservation

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