Review

Current knowledge of amphibian diversity in Sumatra, and its significance for conservation

UMILAELA ARIFIN*[1,2,3,4]

Abstract The amphibians of the Indonesian island of Sumatra are poorly known, despite it being recognized as a biodiversity hotspot. For determining conservation priorities, up-to-date knowledge of the state of amphibian diversity in Sumatra is crucial, particularly considering the high deforestation rate on the island. To address this, I compiled and analysed a comprehensive dataset for amphibians known from Sumatra, to identify knowledge gaps and assess the significance of these data for conservation on the island and, more broadly, across Indonesia. The compilation indicates there are 135 amphibian species currently recorded for Sumatra, 55% more than the number known in 1923. Approximately 44 species have been described since 2000. Associated data on larvae and calls is lacking for many species. Although 66% of the amphibians of Sumatra are categorized as Least Concern on the IUCN Red List, this may not represent the actual conservation status of these species because many of the assessments are outdated. In addition, 14% of species have not yet been evaluated. This study highlights the need for more comprehensive studies on the amphibians of Sumatra.

Keywords Amphibia, biodiversity, calls, deforestation, endemism, Indonesia, IUCN Red List, larvae

The supplementary material for this article is available at doi.org/10.1017/S0030605323001369

Introduction

Sumatra, the westernmost of the large islands of Indonesia, is one of the most biodiverse islands (Whitten & Damanik, 2012). It is topographically heterogeneous, rises to a maximum altitude of 3,805 m, and harbours a range of ecosystems (Bihari & Lal, 1989; Whitten & Damanik, 2012). *The Amphibia of the Indo-Australian Archipelago* (van Kampen, 1923) was the first publication to provide a comprehensive list of amphibians of Sumatra, detailing 61 species of the total of 254 species recorded in the archipelago. This number has continued to increase since then, especially since 2000, as a result of extensive surveys in both the explored and previously unexplored regions of Sumatra and the application of advanced methods such as integrative taxonomy (Padial et al., 2010; Schlick-Steiner et al., 2010). In addition, there are probably many undescribed species on the island (Arifin et al., 2018a,b), as has been demonstrated elsewhere across Southeast Asia (Brown & Stuart, 2012).

Amphibian decline is a major global issue, including in Sumatra. Deforestation on the island is one of the greatest threats facing amphibians as it has led to significant loss of forest cover (Margono et al., 2014; Global Forest Watch, 2022). It has been estimated that c. 75% of the pristine forests in Southeast Asia could potentially disappear by 2100 (Sodhi et al., 2004; Rowley et al., 2010), leading to the extinction of 13–85% of the known species in this region (Bickford et al., 2012), and species could become extinct before they are even discovered (Giam et al., 2010). This significant biodiversity crisis warrants immediate conservation action (Wong et al., 2013; Pangau-Adam et al., 2015). Singapore, for example, has lost c. 95% of its original vegetation cover over 183 years, leading to at least 28% of its biodiversity becoming locally extinct (Brook et al., 2003). Conserving the forests of Sumatra and Southeast Asia is therefore of high priority (Trainor, 2007; Sodhi et al., 2008) because there is no substitute for primary forests for maintaining tropical biodiversity (Gibson et al., 2011).

Up-to-date data on the amphibians of Sumatra are important for the design of effective conservation actions. Here I compile and present a comprehensive dataset of the known extant amphibians of Sumatra, identify knowledge gaps and assess the significance of these data for conservation.

Methods

I generated a preliminary list of amphibians recorded in Sumatra from Frost (2022), on 4 April 2022, to which I incorporated data from AmphibiaWeb (2022), the IUCN Red List (2022), iNaturalist (2022), Kamsi et al. (2017), Kaprawi et al. (2020) and my own field trips to 117 sites across Sumatra (unpubl. data, 2013–2015). I also used additional sources to gather information on larvae and calls (Ecology

*Email: umilaela@gmail.com
[1]Centre for Taxonomy and Morphology, Leibniz Institute for the Analysis of Biodiversity Change, Hamburg, Germany
[2]Museum of Vertebrate Zoology, University of California Berkeley, Berkeley, California, USA
[3]IUCN Species Survival Commission Amphibian Specialist Group
[4]IUCN Species Survival Commission Indonesia Species Specialist Group

Received 13 December 2022. Revision requested 25 January 2023. Accepted 21 August 2023.

Asia, 2022; Frogs of Borneo, 2022; Haas et al., 2022; SoundCloud, 2022; SoundCloud, 2024). The final dataset (Supplementary Table 1) comprises, for each species: name (following Frost, 2022), author(s), year described, endemicity, IUCN Red List status and most recent assessment date, availability of information on larvae and calls, and whether the species is known only from the type locality. To examine the rate of change of the cumulative number of described species over time, I applied LOESS regression to these data. As examination of the regression line indicated marked differences in slope for the periods before and after 1950, I estimated the rate difference between these two time periods via slope estimation using simple linear regression.

Results

The cumulative number of species recorded in Sumatra has generally increased over time (Fig. 1), especially from 2000 onwards. The local regression analysis shows that the regression slope after 1950 is c. 1.4 times steeper than before 1950 (Table 1).

A total of 135 amphibian species (39% of which are endemic), representing seven families, have so far been recorded from Sumatra and the adjacent islands (Supplementary Table 1). The family Ichthyophiidae is represented by only six species, of which four are endemic to Sumatra (Fig. 2). In contrast, the Rhacophoridae is represented by 37 species, with 43% of these being endemic. This per cent endemicity is similar in several other families: Ranidae (43%), Bufonidae (43%) and Megophryidae (42%). Only one of the 13 species in the family Dicroglossidae (*Limnonectes sisikdagu*) is endemic to Sumatra (Fig. 2).

Information on larvae and calls is available for only 53% and 56% of species, respectively (Supplementary Table 1). Information on larvae is available for none of the six species of *Ichthyophis* in Sumatra (Fig. 2).

Eighty-six per cent of the total reported amphibian species in Sumatra have been evaluated and categorized on the IUCN Red List (Fig. 3, Supplementary Table 1). Approximately 66% of amphibian species are categorized as Least Concern, and 2, 3 and 2% are categorized as Near Threatened, Vulnerable and Endangered, respectively (none have been categorized as Critically Endangered). All Ichthyophiidae are categorized as Data Deficient except for *Ichthyophis paucisulcus*, which is categorized as Least Concern (Fig. 3).

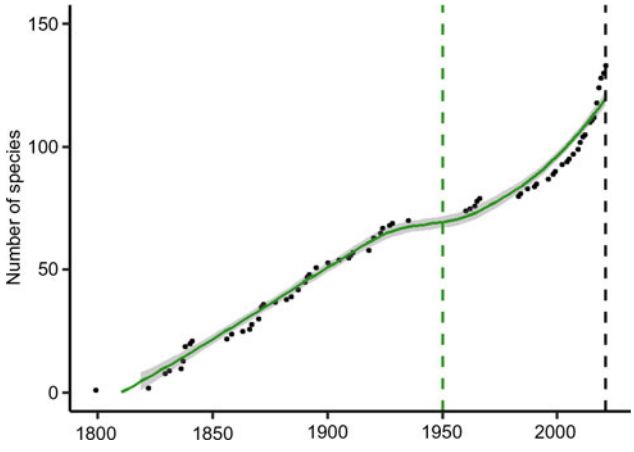

FIG. 1 Cumulative number of amphibian species in Sumatra, Indonesia, described/recorded from 1800 to April 2022. The vertical lines highlight 1950 (LOESS regression break point, with different slopes before and after this year) and 2021 (the last year of data compiled as of April 2022). The smoothed line is the LOESS regression line, with the 95% confidence interval.

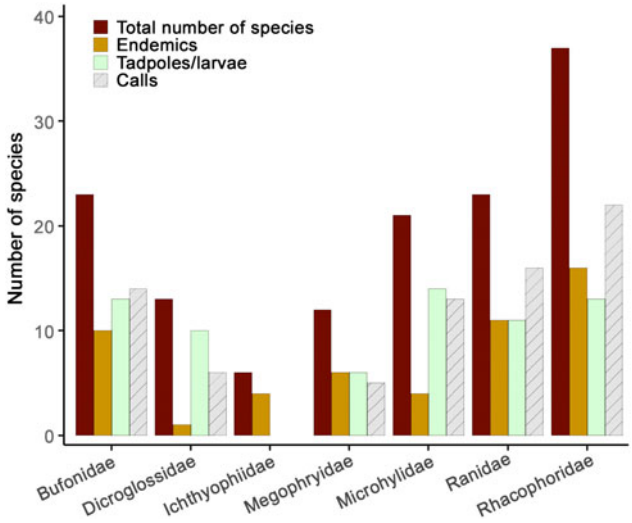

FIG. 2 The total number of amphibian species recorded in Sumatra as of April 2022, and the number of these that are endemic and for which information is available on larvae and calls, by family.

TABLE 1 Non-parametric local regression analysis for cumulative number of described species against year of publication (Fig. 1), with slope of regression before and after 1950. The slope after 1950 is 1.4 times steeper than before 1950.

	Slope	SE of the explanatory variable (year of publication)	P	Model adjusted R^2
Before 1950	0.578	0.014	< 0.0001	0.980
After 1950	0.806	0.080	< 0.0001	0.780

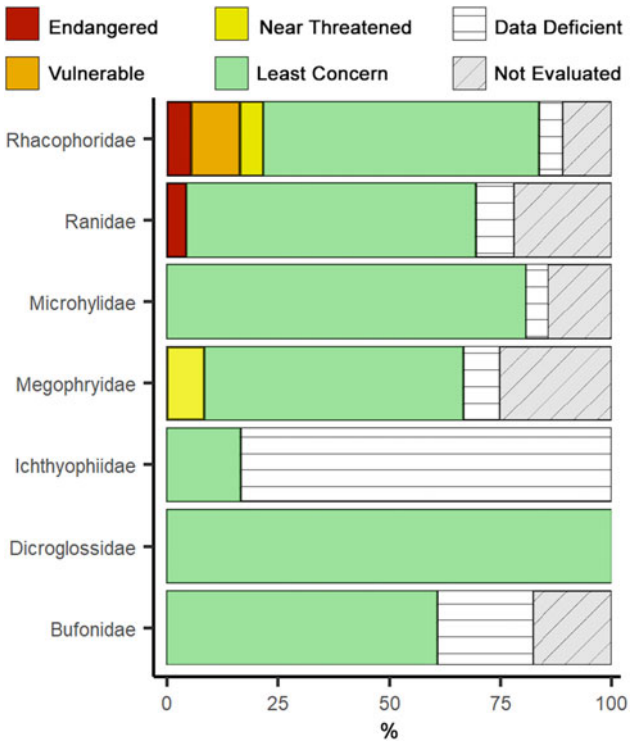

FIG. 3 For the total number of amphibian species recorded in Sumatra as of April 2022, the per cent that have not yet been evaluated for the IUCN Red List (Not Evaluated) and have been categorized as Data Deficient, Least Concern, Vulnerable and Endangered (none have been categorized as Critically Endangered), by family.

Discussion

Amphibian diversity in Sumatra

The information compiled here shows that our knowledge of the amphibians of Sumatra has improved over time (Fig. 1), from 61 species known in the early 20th century (van Kampen, 1923) to 135 species. Approximately 60% of this increase occurred in the past 2 decades (Supplementary Table 1), with a mean of three amphibian species being described annually. This increase is a result of greater recent survey effort compared to previous decades (Brown & Stuart, 2012). The cumulative number of known species has not yet reached an asymptote, (Fig. 1), suggesting that additional species may yet be discovered. Greater survey effort has been a result of national and transnational collaborations: over the years analysed, multi-author publications have become more common than single-author publications describing new amphibian species in Sumatra. Only three of the 44 new species described or recorded during 2002–2022 were published by a single author (Supplementary Table 1).

Broad geographical surveys for both adults and larvae and the application of integrated taxonomy approaches (Arifin et al., 2018b) are key to accelerating species discovery, especially in a biodiversity-rich region such as Sumatra. Over the past 2 centuries, taxonomic studies of frogs have been exclusively based on morphological characteristics (Brown & Stuart, 2012) and primarily examined mature individuals. This approach has limitations in the tropics, where large numbers of amphibians are cryptic (Elmer et al., 2007; McLeod, 2010; Guarnizo et al., 2015). Dring (1983, 1987) was one of the first proponents of integrative taxonomy in Southeast Asia. Describing species according to more than one data type (i.e. morphological, molecular, ecological, bioacoustical) is now common practice (Brown & Stuart, 2012). As a result of this approach, the rate of discovery of newly described species in the region has accelerated (Joppa & Pfaff, 2011; Brown & Stuart, 2012). Nevertheless, there is no general consensus regarding the minimum or maximum number of characteristics required to delineate a species. Taxa could vary in the number of combined characteristics adequate to define a species (Valdecasas et al., 2008; Padial & De la Riva, 2010). Furthermore, it is advisable to combine characteristics of adults and larvae as both are equally important (Arifin et al., 2018b, 2021).

Knowledge gaps and challenges

Choice of survey methods could inadvertently lead to gaps in our knowledge of some groups of amphibians. The compiled data suggest that the frog family Rhacophoridae has the highest number of extant species in Sumatra (37), and the Ichthyophiidae (caecilians) has the lowest number (6). This difference is probably in part a result of the choice of survey methods. Amphibian inventories usually focus on riparian habitats and primarily use opportunistic methods or visual encounter surveys/transects (Heyer et al., 1994). Caecilians live underground and are difficult to find, and therefore they are more effectively surveyed using pitfall traps, or observed when they come to the surface after heavy rains (U. Arifin, pers. obs., 2008). Using pitfall traps in combination with visual encounter surveys/transects has been recommended to ensure comprehensive species inventories (Ribeiro-Junior et al., 2011; Sung et al., 2011).

Several recently described species (e.g. *Pulchrana fantastica* and *Sumaterana dabulescens*) have been recorded in areas both previously explored and unexplored for amphibians (Arifin et al., 2018a,b). This suggests more amphibian surveys are required across the island, especially as the deforestation rate remains high (Margono et al., 2014; Global Forest Watch, 2022).

Further surveys are also required for clarifying the status of the 52 species endemic to Sumatra and of the 16 species categorized as Data Deficient, only two of which (*Ichthyophis nigroflavus* and *Philautus petersi*) are not endemic to Sumatra. Nineteen of the endemic species have only been recorded from their type locality. The endemic *Pulchrana debussyi*, for example, has been categorized as

Data Deficient since 2014 (IUCN SSC Amphibian Specialist Group, 2018). Until a recent observation in Batang Gadis National Park (Kaprawi et al., 2020), the only information available for this species was from the original description (van Kampen, 1910).

Re-evaluation of conservation status is also required for Sumatran species in other IUCN Red List categories, including Least Concern. In tropical regions, so-called cryptic species (two or more species hidden under one species name) may be overlooked. For example, the Sumatran endemic species formerly known as *Huia sumatrana* was previously thought to be a single species with a Sumatra-wide distribution. Using integrated taxonomy approaches and thorough geographical surveys, it has been determined that this taxon comprises at least three distinct lineages (Arifin et al., 2021). In addition, it is important to document the biology of larvae in addition to that of adults (Arifin et al., 2021), as information on larvae and calls is available for only 53 and 56% of species in Sumatra, respectively. Incorporating bioacoustics data is crucial for species delimitation (Chan et al., 2020).

Significance for conservation

Although 66% of the known amphibian species of Sumatra are categorized as Least Concern, many of the assessments are out of date. For example, *Microhyla heymonsi*, a widespread species in East and Southeast Asia (Frost, 2022), was categorized as Least Concern in 2004 and this assessment needs updating (van Dijk et al., 2004). There has been subsequent research on frogs formerly known as *M. heymonsi*, leading to taxonomic changes for several populations. Populations currently recognized as *M. heymonsi* require re-evaluation, as the true *M. heymonsi* may only occur on the islands of Taiwan and Hainan and in southern China (Garg et al., 2022).

Approximately 30 species of amphibian in Indonesia are reported to be threatened (Summary Statistics Table 5 in IUCN, 2022). This number could, however, be higher as not all species have been assessed for the IUCN Red List and, as suggested by the absence of an asymptote in the cumulative number of species described over time in Sumatra (Fig. 1), more species may yet be discovered. Frost (2022) lists 8,485 amphibian species worldwide, which is c. 57% of an estimated 15,000 species (Chapman, 2009). Documenting amphibian diversity and distribution patterns (Inger et al., 2009; McLeod et al., 2011) is necessary for conservation. Given the current biodiversity crisis, accurate taxonomy and diversity estimates for amphibians are increasingly important (Brown & Stuart, 2012) for planning conservation management strategies in Indonesia and elsewhere. Describing unknown species and rediscovering reportedly extinct species (Ladle et al., 2011; Scheffers et al., 2011; Roberts & Fisher, 2020; Long & Rodriguez, 2022) will help to highlight the remarkable biodiversity of Sumatra, improve knowledge of the amphibian communities on the island, and will be key for designing effective conservation strategies (Scheffers et al., 2012). Similarly, information on species diversity and distributions across geographical regions, including on species richness and endemism, can support the prioritization of areas for conservation (Azevedo-Ramos & Galatti, 2002).

To conclude, I make five recommendations for improving knowledge of the amphibians of Sumatra: (1) increase survey effort in both explored and unexplored areas, for both adults and larvae; (2) improve survey efficiency, considering the biology of the targeted taxa and their preferred habitats in selecting the most appropriate methods; (3) apply integrative taxonomy approaches to confirm and validate the identity of species; (4) document associated data on calls, larvae and distributions; and (5) re-assess species with out-of-date Red List assessments.

Acknowledgements I thank Ulfah Mardhiah for her assistance with data analyses; all members of the McGuire lab at the University of California Berkeley for their feedback during the development of this text; and Josh Robertson, Matthew Linkie and two anonymous reviewers for their constructive feedback. This study was carried out during the author's Marie Skłodowska-Curie Actions (MSCA) Fellowship period.

Funding This research did not receive any specific grant from funding agencies in the public, commercial or not-for-profit sectors.

Conflicts of interest None.

Ethical standards This study abided by the *Oryx* guidelines on ethical standards.

Data availability Data presented here include information from publicly available databases (AmphibiaWeb, 2022; Ecology Asia, 2022; Frogs of Borneo, 2022; iNaturalist, 2022; IUCN Red List, 2022; SoundCloud, 2022; SoundCloud, 2024). The full compiled dataset is presented in Supplementary Table 1.

References

AmphibiaWeb (2022) *Amphibia Web*. University of California, Berkeley, USA. amphibiaweb.org [accessed April 2022].

Arifin, U., Cahyadi, G., Smart, U., Jankowski, A. & Haas, A. (2018a) A new species of the genus *Pulchrana* Dubois, 1992 (Amphibia: Ranidae) from Sumatra, Indonesia. *Raffles Bulletin of Zoology*, 66, 277–299.

Arifin, U., Chan, K.O., Smart, U., Hertwig, S.T., Smith, E.N., Iskandar, D.T. & Haas, A. (2021) Revisiting the phylogenetic predicament of the genus *Huia* (Amphibia: Ranidae) using molecular data and tadpole morphology. *Zoological Journal of the Linnean Society*, 193, 673–699.

Arifin, U., Smart, U., Hertwig, S.T., Smith, E.N., Iskandar, D.T. & Haas, A. (2018b) Molecular phylogenetic analysis of a taxonomically unstable ranid from Sumatra, Indonesia, reveals a new genus with gastromyzophorous tadpoles and two new species. *Zoosystematics and Evolution*, 94, 163–193.

Azevedo-Ramos, C. & Galatti, U. (2002) Patterns of amphibian diversity in Brazilian Amazonia: conservation implications. *Biological Conservation*, 103, 103–111.

Bickford, D.P., Poo, S. & Posa, M.R.C. (2012) Southeast Asian biodiversity crisis. In *Biotic Evolution and Environmental Change in Southeast Asia* (eds G. David, J. Kenneth, R. James, R. Brian, R. Lukas & W. Suzanne), pp. 79–114. Cambridge University Press, Cambridge, UK.

Bihari, M. & Lal, C.B. (1989) Species composition, density and basal cover of tropical rainforests of central Sumatra. *Tropical Ecology*, 30, 118–137.

Brook, B.W., Sodhi, N.S. & Ng, P.K. (2003) Catastrophic extinctions follow deforestation in Singapore. *Nature*, 424, 420–423.

Brown, R.M. & Stuart, B.L. (2012) Patterns of biodiversity discovery through time: an historical analysis of amphibian species discoveries in the Southeast Asian mainland and island archipelagos. In *Biotic Evolution and Environmental Change in Southeast Asia* (eds G. David, J. Kenneth, R. James, R. Brian, R. Lukas & W. Suzanne), pp. 348–389. Cambridge University Press, Cambridge, UK.

Chan, K.O., Abraham, R.K., Grismer, L.L. & Brown, R.M. (2020) A systematic review of the *Pulchrana picturata* complex, with the description of a new species from Peninsular Malaysia, Sumatra, and southern Thailand. *Raffles Bulletin of Zoology*, 68, 880–890.

Chapman, A.D. (2009) *Numbers of living species in Australia and the world*. Australian Biological Resources Study, Canberra, Australia. dcceew.gov.au/science-research/abrs/publications/other/numbers-living-species [accessed September 2023].

Dring, J. (1983) Frogs of the genus *Leptobrachella* (Pelobatidae). *Amphibia–Reptilia*, 4, 89–102.

Dring, J. (1987) Bornean treefrogs of the genus *Philautus* (Rhacophoridae). *Amphibia–Reptilia*, 8, 19–47.

Ecology Asia (2022) *Ecology Asia*. *ecologyasia*.com/html-menu/frog-calls.htm [accessed April 2022].

Elmer, K.R., Dávila, J.A. & Lougheed, S.C. (2007) Cryptic diversity and deep divergence in an upper Amazonian leaflitter frog, *Eleutherodactylus ockendeni*. *BMC Evolutionary Biology*, 7, 1–14.

Frogs of Borneo (2022) *Frogs of Borneo*. frogsofborneo.org [accessed April 2022].

Frost, D.R. (2022) *Amphibian species of the world: an online reference*. Version 6.0. American Museum of Natural History, New York, USA. amphibiansoftheworld.amnh.org [Accessed September 2023].

Garg, S., Sivaperuman, C., Gokulakrishnan, G., Chandramouli, S.R. & Biju, S.D. (2022) Hiding in plain sight: rain water puddles in Nicobar Islands of India reveal abundance of a new frog species of the genus *Microhyla* Tschudi, 1838 (Anura, Microhylidae). *Zoological Studies*, 60, e2.

Giam, X., Ng, T.H., Yap, V.B. & Tan, H.T. (2010) The extent of undiscovered species in Southeast Asia. *Biodiversity and Conservation*, 19, 943–954.

Gibson, L., Lee, T.M., Koh, L.P., Brook, B.W., Gardner, T.A., Barlow, J. et al. (2011) Primary forests are irreplaceable for sustaining tropical biodiversity. *Nature*, 478, 378–381.

Global Forest Watch (2022) *Global Forest Watch - Indonesia*. globalforestwatch.org/dashboards/country/IDN [accessed April 2022].

Guarnizo, C.E., Paz, A., Munoz-Ortiz, A., Flechas, S.V., Mendez-Narvaez, J. & Crawford, A.J. (2015) DNA Barcoding survey of anurans across the Eastern Cordillera of Colombia and the impact of the Andes on cryptic diversity. *PLOS One*, 10, e0127312.

Haas, A., Das, I., Hertwig, S.T., Bublies, P. & Schulz-Schaeffer, R. (2022) *A Guide to the Tadpoles of Borneo*. Tredition, Hamburg, Germany.

Heyer, R., Donnelly, M. A., Foster, M. & Mcdiarmid, R. (eds) (1994) *Measuring and Monitoring Biological Diversity: Standard Methods for Amphibians*. Smithsonian Institution, Washington, DC, USA.

iNaturalist (2022) inaturalist.org [accessed April 2022].

Inger, R.F., Stuart, B.L. & Iskandar, D.T. (2009) Systematics of a widespread Southeast Asian frog, *Rana chalconota* (Amphibia: Anura: Ranidae). *Zoological Journal of the Linnean Society*, 155, 123–147.

IUCN (2022) *The IUCN Red List of Threatened Species 2022-1*. iucnredlist.org [accessed April 2022].

IUCN SSC (Species Survival Commission) Amphibian Specialist Group (2018) *Pulchrana debussyi*. In *The IUCN Red List of Threatened Species* 2018. dx.doi.org/10.2305/IUCN.UK.2018-1.RLTS.T58587A96365567.en.

Joppa, L.N. & Pfaff, A. (2011) Global protected area impacts. *Proceedings of the Royal Society B: Biological Sciences*, 278, 1633–1638.

Kamsi, M., Handayani, S., Siregar, A.J. & Fredriksson, G. (2017) *Buku Panduan Lapangan Amfibi dan Reptil Kawasan Hutan Batang Toru*. Yayasan Ekosistem Lestari, Sumatra, Indonesia.

Kaprawi, F., Alhadi, F., Hamidy, A., Nopandry, B., Kirschey, T. & Permana, J. (2020) *Panduan Lapangan Amfibi di Taman Nasional Batang Gadis Sumatera Utara*. Perkumpulan Amfibi Reptil Sumatra, Sumatra, Indonesia.

Ladle, R., Jepson, P., Malhado, A., Jennings, S. & Barua, M. (2011) Perspective: the causes and biogeographical significance of species' rediscovery. *Frontiers of Biogeography*, 3, 111–118.

Long, B. & Rodriguez J.P. (2022) Lost but not forgotten: a new nomenclature to support a call to rediscover and conserve lost species. *Oryx*, 56, 481–482.

Margono, B.A., Potapov, P.V., Turubanova, S., Stolle, F. & Hansen, M.C. (2014) Primary forest cover loss in Indonesia over 2000–2012. *Nature Climate Change*, 4, 730–735.

McLeod, D.S. (2010) Of Least Concern? Systematics of a cryptic species complex: *Limnonectes kuhlii* (Amphibia: Anura: Dicroglossidae). *Molecular Phylogenetics and Evolution*, 56, 991–1000.

McLeod, D.S., Horner, S.J., Husted, C., Barley, A. & Iskandar, D. (2011) 'Same-same, but different': an unusual new species of the *Limnonectes kuhlii* complex from West Sumatra (Anura: Dicroglossidae). *Zootaxa*, 2883, 52–64.

Padial, J.M. & De la Riva, I. (2010) A response to recent proposals for integrative taxonomy. *Biological Journal of the Linnean Society*, 101, 747–756.

Padial, J.M., Miralles, A., De la Riva, I. & Vences, M. (2010) The integrative future of taxonomy. *Frontiers in Zoology*, 7, 1–14.

Pangau-Adam, M., Mühlenberg, M. & Waltert, M. (2015) Rainforest disturbance affects population density of the northern cassowary *Casuarius unappendiculatus* in Papua, Indonesia. *Oryx*, 49, 735–742.

Ribeiro-Júnior, M.A., Rossi, R.V., Miranda, C.L. & Ávila-Pires, T.C. (2011) Influence of pitfall trap size and design on herpetofauna and small mammal studies in a Neotropical forest. *Zoologia* (*Curitiba*), 28, 80–91.

Roberts, D.L. & Fisher, M. (2020) Schrödinger's cat extinction paradox. *Oryx*, 2020, 54, 143–144.

Rowley, J., Brown, R., Bain, R., Kusrini, M., Inger, R., Stuart, B. et al. (2010) Impending conservation crisis for Southeast Asian amphibians. *Biology Letters*, 6, 336–338.

Scheffers, B.R., Joppa, L.N., Pimm, S.L. & Laurence, W.F. (2012) What we know and don't know about Earth's missing biodiversity. *Trends in Ecology and Evolution*, 27, 501–510.

Scheffers, B.R., Yong, D.L., Harris, J.B.C., Giam, X. & Sodhi, N.S. (2011) The world's rediscovered species: back from the brink? *PLOS One*, 6, e22531.

Schlick-Steiner, B.C., Steiner, F.M., Seifert, B., Stauffer, C., Christian, E. & Crozier, R.H. (2010) Integrative taxonomy: a multisource approach to exploring biodiversity. *Annual Review of Entomology*, 55, 421–438.

Sodhi, N.S., Bickford, D., Diesmos, A.C., Lee, T.M., Koh, L.P., Brook, B.W. et al. (2008) Measuring the meltdown: drivers of global amphibian extinction and decline. *PLOS One*, 3, e1636.

Sodhi, N.S., Koh, L.P., Brook, B.W. & Ng, P.K.L. (2004) Southeast Asian biodiversity: an impending disaster. *Trends in Ecology and Evolution*, 19, 654–660.

SoundCloud (2022) *Frog voices of Borneo*. soundcloud.com/frogvoicesofborneo [accessed April 2022].

SoundCloud (2024) *Herpetological Society of Singapore*. soundcloud.com/user-594921597 [accessed April 2024].

Sung, Y.H., Karraker, N.E. & Hau, B.C. (2011) Evaluation of the effectiveness of three survey methods for sampling terrestrial herpetofauna in south China. *Herpetological Conservation and Biology*, 6, 479–489.

Trainor, C.R. (2007) Changes in bird species composition on a remote and well-forested Wallacean Island, South-East Asia. *Biological Conservation*, 140, 373–385.

Valdecasas, A.G., Williams, D. & Wheeler, Q.D. (2008) 'Integrative taxonomy' then and now: a response to Dayrat (2005) *Biological Journal of the Linnean Society*, 93, 211–216.

Van Dijk, P.P., Iskandar, D., Kuangyang, L., Wenhao, C., Baorong, G., Ermi, Z. & Dutta, S. (2004) *Microhyla heymonsi*. In *The IUCN Red List of Threatened Species* 2004. dx.doi.org/10.2305/IUCN.UK.2004.RLTS.T57882A11685861.en.

Van Kampen, P.N. (1910) Beitrag zur Kenntnis der Amphibienlarven des indischen Archipels. *Natuurkundig Tijdschrift voor Nederlandsch-Indië*, 69, 25–48.

Van Kampen, P.N. (1923) *The Amphibia of the Indo-Australian Archipelago*. EJ Brill, Leiden, The Netherlands.

Whitten, T. & Damanik, S.J. (2012) *Ecology of Sumatra*. Tuttle Publishing, Clarendon, USA.

Wong, W.M., Leader-Williams, N. & Linkie, M. (2013) Quantifying changes in sun bear distribution and their forest habitat in Sumatra. *Animal Conservation*, 16, 216–223.