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RESEARCH ARTICLE

Gaps in the protection of the amphibians of Myanmar—threat status, endemism, protected area coverage and One Plan Approach conservation

Marie Borgwerth[1] | **Carolin Scholten**[1] | **Aung Lin**[2] | **Myint Kyaw Thura**[3] | **Larry Lee Grismer**[4,5] | **Thomas Ziegler**[1,6] | **Dennis Rödder**[7]

[1]Institute of Zoology, University of Cologne, Cologne, Germany

[2]Fauna and Flora International, Yangon, Myanmar

[3]Myanmar Environment Sustainable Conservation, Yangon, Myanmar

[4]Herpetology Laboratory, Department of Biology, La Sierra University, Riverside, California, USA

[5]Department of Herpetology, San Diego Natural History Museum, San Diego, California, USA

[6]AG Zoologischer Garten Köln, Cologne, Germany

[7]Museum Koenig Bonn, Leibniz Institute for the Analysis of Biodiversity Change, Bonn, Germany

Correspondence

Dennis Rödder, Museum Koenig Bonn, Leibniz Institute for the Analysis of Biodiversity Change, Adenauerallee 127, 53113 Bonn, Germany.
Email: d.roedder@leibniz-lib.de

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Abstract

Currently, 41% of amphibian species are threatened with extinction, leading to the ongoing amphibian crisis. In Myanmar, the amphibian diversity is still poorly understood, and, as a result, many conservation gaps remain. To increase the knowledge about Myanmar's amphibians and thus provide an opportunity to fill the gaps in conservation in the country, we assess the species in greater detail. To do so, we compile a species list of the amphibians of Myanmar through various sources and evaluate their threat status using the IUCN Red list. We perform richness analyses to compare the distribution areas of the amphibian species of Myanmar to the distribution of the protected areas (PAs) in the country. We evaluate the representation of Myanmar's amphibians in zoos worldwide through the Zoological Information Management System (ZIMS) to check the implementation of the One Plan Approach to Conservation. Our results suggest that there are 152 amphibian species extant in Myanmar, of which 25 are endemic to the country. 4.6% ($n = 7$) of all species are classified as threatened, but counting those with insufficient available data as possibly threatened increases the number to 44.1% ($n = 67$). Of them, 40 species are not covered by any of Myanmar's PAs. That includes 28.6% of the threatened, 35.7% of the potentially threatened, and 48% of the endemic species. According to the ZIMS database, none of Myanmar's threatened, potentially threatened, or endemic amphibian species are kept in any zoo or aquarium worldwide, suggesting that the One Plan Approach is not sufficiently implemented as a conservation measure for Myanmar's amphibians. With this study, we show conspicuous gaps in the protection of Myanmar's amphibians and provide a list of the 36 most threatened species, recommending a possible prioritization for upcoming conservation actions.

KEYWORDS

amphibians, captive breeding, ex situ, gap analysis, in situ, Myanmar, protected area coverage

Plain language summary

Currently, 41% of amphibian species are threatened with extinction, leading to the ongoing amphibian crisis. The amphibians of Myanmar are not well studied, and as a result, many conservation gaps remain. To increase the knowledge about Myanmar's amphibians and thus

provide an opportunity to fill the gaps in conservation in the country, we assess the species regarding their diversity, distribution, threat status, and their protection through protected areas (PAs), laying particular focus on endemic species (species only occurring in Myanmar). We found that 44.1% of Myanmar's amphibian species can be classified as possibly threatened, including 88% of the endemic species. Furthermore, 26.3% of species are not protected through any PA, including 48% of the endemic species. Most of these unprotected species are found in the south of Myanmar, which is why extended protection measures should concentrate on this part of the country for the time being. This study also compiles a list of the most threatened species, which should be used as a reference point for prioritization as well.

1 | INTRODUCTION

According to the Red List of Threatened Species of the International Union for Conservation of Nature, 41% of amphibian species face an imminent risk of extinction (IUCN, 2023). Considering the number of amphibians listed as data deficient, the number of threatened amphibian species is estimated to be 55% (Silla & Byrne, 2018), which would correspond to over 4750 species. They are particularly vulnerable because of narrow habitat preferences and limited distributions (Meredith et al., 2016; Sheridan & Stuart, 2018), as well as their specific needs towards those habitats regarding conditions of moisture, temperature, pH, refuge, and food (Bishop et al., 2012). The permeability of their skin makes them unable to withstand significant changes in these factors, but, at the same time, they occupy the ecosystems currently experiencing the most drastic changes: freshwater ecosystems in tropical forests (Bishop et al., 2012; Meredith et al., 2016). A further problem results from their incomplete and still poorly understood taxonomy (Mulcahy et al., 2018). Amphibians comprise many cryptic species. Therefore, possibly threatened species may be overlooked and are driven to extinction before being recognized (Stuart et al., 2006). Furthermore, the available data on many already recognized species is still scarce likely hampering conservation efforts. This is particularly dangerous considering species with insufficient data are more likely to be threatened than species assessed adequately (Bland et al., 2014, cited after Meredith et al., 2016).

The causes of the amphibian crisis are numerous and include anthropogenic threats like habitat change, habitat destruction, or habitat loss (e.g., Auliya et al., 2023; Cheng et al., 2011; Zaw et al., 2020), overexploitation and the trade underlining it (e.g., Auliya et al., 2023; Rao et al., 2014; Silla & Byrne, 2018; Zaw et al., 2020). The trade entails risks, like the release of specimens in naïve habitats, therefore possibly displacing native species (Ribeiro et al., 2019) through predation, competition, or the introduction of diseases (Bishop et al., 2012; Collins & Storfer, 2003). Other general threats to amphibians around the world are pollution through (chemical) contaminants, and climate change (e.g., Blaustein et al., 2010; Hayes et al., 2010; Luedtke et al., 2023).

Practitioner points

- 44.1% (67 species) of Myanmar's amphibian species can be classified as possibly threatened, this includes 88% of the endemic species.
- 40 species of Myanmar's amphibians are not protected through any protected area, this includes 48% of the endemic species.
- Most of the unprotected amphibian species are located in the South of Myanmar.
- The One Plan Approach is not sufficiently implemented as a protective measure for Myanmar's amphibians.
- This study provides a list of the 36 most threatened amphibian species, recommending a possible prioritization for upcoming conservation actions.
- More information is needed about Myanmar's amphibian species and more protection measures should be put in place for them.

Countermeasures aimed at halting the extinction of amphibians include the establishment of protected areas (PAs), conservation breeding, the spreading of education and awareness about the amphibian crisis, legal protection, and policies, especially regarding the trade in amphibians (Fog & Wederknich, 2016; Hussain & Pandit, 2012; Silla & Byrne, 2018; Stiles et al., 2016). The approach of conservation breeding is auspicious as it has been successfully established for several threatened amphibian species (Silla & Byrne, 2018). It may be "the only practical conservation option left for some species whose habitats are dwindling" (Schwartz et al., 2017). Through this, it is possible to integrate ex-situ and in-situ conservation measures and follow the One Plan Approach to

conservation, developed by the Conservation Planning Specialist Group (CPSG) of the IUCN (Byers et al., 2013). A multi-methodological approach that attempts to develop management strategies and conservation measures that combine the protection of wild populations and that of ex-situ populations (e.g., populations kept in a zoo) (CPSG, 2024a). It has been suggested in previous studies as an important conservation measure for amphibians (e.g., Krzikowski et al., 2022) and the case study on the Pickersgill's reed frogs in South Africa is one example showing the success of this approach (see CPSG, 2024b).

The establishment of integrated conservation measures focuses on the Southeast Asian area, among others, as it contains multiple biodiversity hotspots but at the same time faces one of the highest deforestation rates in the world (Krzikowski et al., 2022; Sheridan & Stuart, 2018). The largest country of mainland Southeast Asia that is often overlooked in studies concerning the area (A. Poyarkov Jr. et al., 2019; Zaw et al., 2019; Zug, 2022) and still has many conservation gaps, especially regarding its herpetofauna (Mi et al., 2023), is Myanmar (formerly Burma). It harbors approximately 150 species of amphibians (Zug, 2022), is an important component of the Indo-Burma biodiversity hotspot (Gan et al., 2020), and contains a diversity of ecosystems with lowland and montane habitats and varying climatic conditions (Huang et al., 2021; Huang, Morley, et al., 2023; Mandle et al., 2017).

Herpetologically, Myanmar is not well studied (Gan et al., 2020; Mulcahy et al., 2018; Zaw et al., 2019). The first more extensive studies of the herpetofauna in Myanmar started in 1997 with the research of Joseph B. Slowinski and George R. Zug (in collaboration with the Chatthin Wildlife Sanctuary staff). The Myanmar Herpetology Survey (MHS) of G. R. Zug started formally in 1999 and ended in September 2010. Daniel G. Mulcahy conducted further studies on a larger scale, like herpetological surveys of southern Tanintharyi, in collaboration with Fauna & Flora International's Myanmar Programme. The more open policy of the Myanmar government allowed further studies by other zoologists, such as the surveys of the karst habitats of *Cyrtodactylus* and other geckos by L. Lee Grismer's group. Other studies on Myanmar have been conducted, for example, by Steven G. Platt, Nikolay A. Poyarkov, Gunther Köhler, and their teams. But, since the return of the military to Myanmar in 2021, further studies are difficult to conduct, and the knowledge about the herpetofauna in Myanmar will remain incomplete (Zug, 2022).

However, planning conservation actions depends on accurate data to successfully counter population declines (Schwartz et al., 2017). To increase the knowledge of the herpetofauna of Myanmar and thus provide an opportunity to fill the gaps in conservation in this country, following the approach by Krzikowski et al. (2022) for the amphibians of Vietnam, this study assessed the amphibians of Myanmar regarding their distribution, their threat status according to the Red List of the IUCN, and their protection through PAs and different legislations and efforts, laying particular focus on endemic and threatened species. Considering the mentioned concept of the One Plan Approach to combine in-situ and ex-situ conservation, the representation of the amphibian species extant in Myanmar in zoos and aquariums worldwide was also conducted. Finally, we compiled a list of the amphibian species that are most at risk of extinction and should, therefore, be prioritized when planning future conservation measures in Myanmar.

2 | MATERIALS & METHODS

2.1 | Species list

First, a species list was created based on Zug (2022) and Amphibian Species of the World (Frost, 2023). Species only listed as possibly or probably occurring in Myanmar were excluded. In the next step, the list was cross-checked with those species marked as "Extant" in Myanmar by the IUCN Red List. This species list was then refined, starting with the species not matching between the three sources. Further sources were used in this process, like the website Amphibia Web (2023) and recent papers (A. Poyarkov Jr et al., 2019; Al-Razi et al., 2020; Chunskul et al., 2021; Dever, 2017; Dinesh et al., 2020; Gan et al., 2020; Garg & Biju, 2021; Hasan et al., 2019; Huang, Liu, et al., 2023; Köhler, Vargas, et al., 2021; 2021; Lalremsanga, 2022; Lalronunga et al., 2021; Liu et al., 2020; Lyu et al., 2023; Mahapatra et al., 2022; Mahony et al., 2022; McLeod, 2010; Mogali et al., 2022; Muansanga et al., 2021; Mulcahy et al., 2018; Ojha et al., 2021; Pham et al., 2020; Rahman et al., 2022; Rao, 2022; Sailo et al., 2022; Schmitz & Ziegler, 2016; Sheridan & Stuart, 2018; Tang et al., 2020; Wang et al., 2020; Wangyal & Jamtsho, 2022; Wu et al., 2021; Wu et al., 2022; Yu et al., 2018; Yu et al., 2020; Zhang et al., 2022; Zug & Mulcahy, 2020). The taxonomy of the online reference "Amphibian Species of the World" (ASW) from the "American Museum of Natural History" was adopted unless more recent papers suggested a different taxonomy. The cut-off date for the list was set for December 5, 2023. The final species list can be found in the Supporting Information S1: SI1.

The list was later analyzed to determine how many different families of the three orders of amphibians occur in Myanmar and how many species of each family are represented in the country. We analyzed the species list and their threat status (see below) using the program R version 4.3.0 (R Core Team, 2023) and RStudio (2023), and the packages "ggplot2" (Wickham, 2016), "ggrepel" (Slowikowski, 2023), "tidyverse" (Wickham et al., 2019), "dplyr"

(Wickham et al., 2023), "ggforce" (Pedersen, 2022), and "scales" (Wickham et al., 2022).

A second list was created containing the species excluded from the official list because they were only listed as possibly or probably occurring in Myanmar in the sources used. The list also includes species where there were discrepancies between the different sources that could not be clearly elucidated until December 5, 2023, as there are still some gaps in the knowledge of some species. However, those species most likely occur in Myanmar as well and therefore should not be forgotten. The list can be found in the Appendix (SI2).

2.2 | Distribution

Richness analyses were performed to compare the distribution areas of the amphibian species of Myanmar to the distribution of the PAAs in Myanmar. Therefore, the distribution data of most species was downloaded from the IUCN (2023). The distribution of species that were missing a polygon shapefile or point data in Myanmar or were not listed on the IUCN at all was assessed through literature confirming their occurrence in Myanmar, Amphibia Web (2023), and The Global Biodiversity Information Facility (GBIF, 2023) (SI3). For the species *Amolops latopalmatus, Feihyla wuguanfui, Kurixalus yangi, Leptobrachium rakhinense, Microhyla hmongorum, Micryletta aishani, Nanorana chayuensis, Occidozyga magnapustulosa, Odorrana andersonii, Oreolalax jingdongensis, Polypedates braueri, and Sphaerotheca* cf. *breviceps* no specific coordinates were found and they were excluded from the spatial analyses. *Sphaerotheca* cf. *breviceps* represents most likely a cryptic species currently hidden under the name. The nominal form is unlikely to be found in Myanmar.

For each species, we downloaded habitat information from the respective IUCN Red List accounts using the "rredlist" package for R (Gearty et al., 2022). Subsequently, distribution and habitat information was combined by first rasterizing all vectorized distribution information in R using the "terra" package (Hijmans, 2023) to match the spatial resolution of gridded habitat data (Jung et al., 2020) matching the IUCN habitat categories. Finally, the number of species per grid cell of 100 × 100 m was summarized by overlaying all presence-absence maps.

The PA information of Myanmar was taken from UNEP-WCMC and IUCN (2023), and the distribution of the species was described using the ecoregions of Myanmar (see Figure 1a).

We also analyzed which of the threatened, potentially threatened, and endemic species are protected by a PA and which are not. In this process, the mentioned species without a polygon or specific coordinates for Myanmar were excluded.

2.3 | Endemism

Patterns of endemism may help prioritize conservation efforts (Morrone, 2008), as species with small distributions are particularly vulnerable to changes in their environment (Wake & Vredenburg, 2008) and therefore need specific conservation actions to prevent extinction. Considering the vulnerability of endemic species, this study focused on the species endemic to Myanmar and differentiated between three extents of endemism: species distributed in two or more ecoregions were classified as "Country Endemic" (CE), species only occurring in one ecoregion but in multiple different locations within this ecoregion were classified as "Regional Endemic" (RE), and species only occurring in one specific location (one specific village or township or only the type locality) were classified as "Microendemic" (ME).

2.4 | Threat status

To classify the threat status of the species in Myanmar, this study used the threat status given in the IUCN Red List. The nine categories into which the species can be classified are: Not Evaluated (NE), Data Deficient (DD), Least Concern (LC), Near Threatened (NT), Vulnerable (VU), Endangered (EN), Critically Endangered (CR), Extinct in the Wild (EW), Extinct (EX). Species classified as VU, EN, or CR were considered as threatened with extinction. The threat status is considered outdated 10 years after the last assessment (IUCN, 2023). The IUCN Red List status for each species was collected on August 28, 2023, and updated on December 5, 2023. These data were analyzed by comparing the number of species in each category, once for all amphibian species occurring in Myanmar and once specifically for the endemic species only.

As described above, the trade in amphibians significantly impacts their population declines. Therefore, the three appendices of CITES (The Convention on International Trade in Endangered Species of Wild Fauna and Flora) were searched for amphibian species occurring in Myanmar to further investigate the threat statuses of the species (CITES, 2023a). Myanmar joined the convention on June 13, 1997 (CITES, 2023b).

2.5 | Zoological information and management system analysis

The One Plan Approach suggests to combine in-situ and ex-situ conservation efforts. Therefore, the number of amphibian species and their respective individuals kept in zoos and aquariums around the world was determined through the Zoological Information and Management System (ZIMS). The number of zoos and aquariums keeping species

occurring in Myanmar and the numbers of specifically endemic and threatened species were also determined. The data was updated on December 15, 2023.

ZIMS is a web-based information system that zoos, aquariums, and wildlife institutions use to collect information about the animals they keep (ZIMS, 2023). While ZIMS contains the most

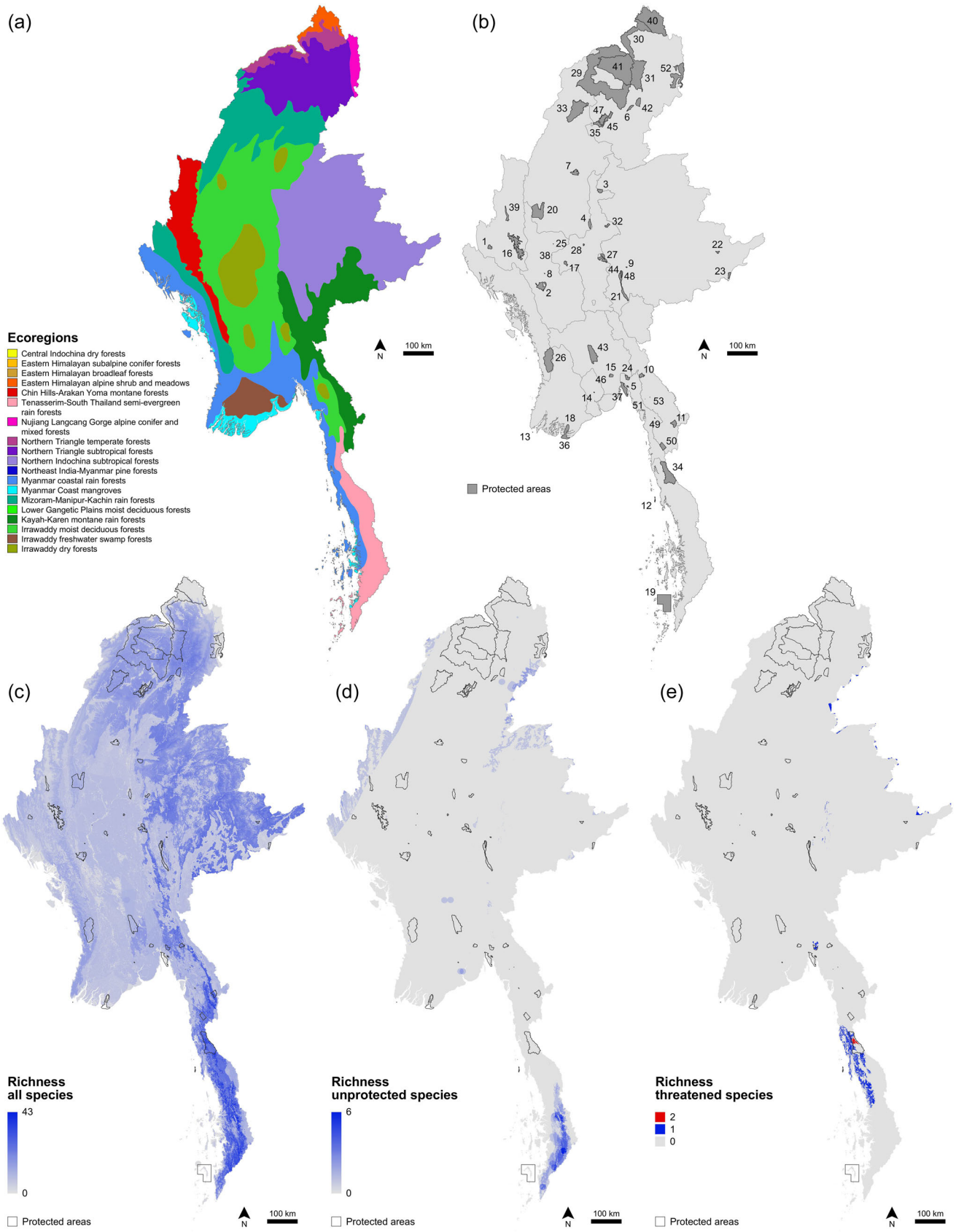

FIGURE 1 (See caption on next page).

extensive set of data for ex situ populations of wildlife worldwide, the use of ZIMS is not mandatory. So, not all ex situ populations and individuals can be found in the system. It is also important to note that the system is not always entirely up to date, as the institutions often do not report every change in their populations right away.

3 | RESULTS

3.1 | Species richness

There are 152 amphibian species recorded so far from Myanmar (SI1). Of those, 145 belong to the order Anura (ca. 95%), five to the Caudata (ca. 3%), and two to the Gymnophiona (ca. 1%). They belong to 10 families (see Figure 2a) and 49 genera, with the genus *Hylarana* in the family Ranidae being the most species-rich in the country with 15 species.

3.2 | Endemism

Of the 152 amphibian species occurring in Myanmar, 25 (16.4%) are endemic (see Table 1). 22 (88%) belong to the order Anura and three (12%) to the salamanders. No Gymnophiona extant in Myanmar is endemic to the country. The family with the most endemic species is Ranidae, with six frog species (24%), followed by the frog family Dicroglossidae with five endemic species (20%), and the frog family Rhacophoridae with four species (16%). After that, the three families, Bufonidae, Microhylidae, and the salamander family Salamandridae follow with three species (each 12%). The family with the least number of endemic species is the Megophryidae with one species (4%). Of the 25 endemic species, ten were classified as CE (40%), seven as RE (28%), and eight as ME (32%) (see Table 1).

3.3 | Threat status

Even though only seven (4.6%; *Ansonia kyaiktiyonensis, Ansonia thinthinae, Hylarana roberti, Leptobrachium rakhinense, Nanorana yunnanensis, Oreolalax jingdongensis, Tylototriton shanorum*) of the 152 amphibian species extant in Myanmar are classified as threatened, this number could be higher considering the 27.6% of species with insufficient available data. Counting those as potentially threatened increases Myanmar's threatened amphibian species to 49 (32.2%). Of those, 43 belong to the order Anura, four to the Caudata, and two to the Gymnophiona. The family with the most threatened species is Ranidae, with 13 species, then follow the families Dicroglossidae and Rhacophoridae, with eight species. For 22 (14.5%) of the 152 species occurring in Myanmar, the IUCN Red List threat status is older than 10 years (Figure 2b and Supporting Information S1: SI1).

Five of the seven species classified as threatened are endemic to Myanmar, and for over 65% of the endemic species, there is only insufficient information available. Considering those 17 species with insufficient data as potentially threatened, the number of threatened endemic species becomes as high as 22 (88% of all endemic species). The family with the most threatened endemic species is Ranidae, with five species, followed by Dicroglossidae and Rhacophoridae, with four species each. After that, follow the families Bufonidae and Salamandridae with three species and Microhylidae with two species. The family with the smallest number of threatened endemic species is Megophryidae, with one species. For two (8%) of the 25 species endemic to Myanmar, the IUCN Red List threat status is older than 10 years (see Figure 2b and SI1).

3.4 | CITES

Six (3.9%) out of the 152 amphibian species in Myanmar are listed in the Appendices of the Convention on International Trade in Endangered Species of Wild

FIGURE 1 (a) Map of the ecoregions in Myanmar. (b) Map of the protected areas (PAs) in Myanmar. Administrative subdivisions (states and regions) are bordered by grey lines. PAs are highlighted in the dark grey: 1 = Kyauk Pan Taung Wildlife Sanctuary, 2 = Shwesettaw Wildlife Sanctuary, 3 = Shwe-U-Daung Wildlife Sanctuary, 4 = Minwuntaung Wildlife Sanctuary, 5 = Kaylatha Wildlife Sanctuary, 6 = Pidaung Wildlife Sanctuary, 7 = Chatthin Wildlife Sanctuary, 8 = Wetthikan Bird Sanctuary, 9 = Taunggyi Bird Sanctuary, 10 = Kahilu Wildlife Sanctuary, 11 = Mulayit Wildlife Sanctuary, 12 = Moscos Islands Wildlife Sanctuary, 13 = Thamihla Kyun Wildlife Sanctuary, 14 = Hlawga Park, 15 = Moeyungyi Wetland Wildlife Sanctuary, 16 = Natmataung National Park, 17 = Popa Mountain Park, 18 = Meinmahla Kyun Wildlife Sanctuary, 19 = Lampi Marine National Park, 20 = Alaungdaw Katthapa National Park, 21 = Inlay Lake Wildlife Sanctuary, 22 = Loimwe Protected Area, 23 = Parsar Protected Area, 24 = Kyeikhtiyoe Wildlife Sanctuary, 25 = Lawkananda Sanctuary, 26 = Rakhine Yoma Elephant Range, 27 = Panlaung and Padalin Cave Wildlife Sanctuary, 28 = Minsontaung Wildlife Sanctuary, 29 = Hukaung Valley Wildlife Sanctuary (extension), 30 = Hponkanrazi Wildlife Sanctuary, 31 = Bumpha Bum Wildife Sanctuary, 32 = Pyin-O-Lwin Bird Sanctuary, 33 = Htamanthi Wildlife Sanctuary, 34 = Taninthayi Nature Reserve, 35 = Indawgyi Wildlife Sanctuary, 36 = Meinmahla Kyun Wildlife Sanctuary, 37 = Gulf of Mottama, 38 = Chungponkan Wildlife Sanctuary, 39 = Bwe Par Taung National Park, 40 = Hkakaborazi National Park, 41 = Hugaung Valley Wildlife Sanctuary, 42 = Inkhain Bum National Park, 43 = North Zamrari Wildlife Sanctuary, 44 = Inlay Wetland W.S, 45 = Indawgyi W.S, 46 = Moyungyi Wetland W.S, 47 = Indawgyi Wildlife Sanctuary, 48 = Inlay Lake Ramsar Site, 49 = Hpabaubg Taung Managed Nature Reserve, 50 = Se Taung Wildlife Sanctuary, 51 = Htaungwi Taung Geo-features Significant Area, 52 = Emawbum National Park, 53 = Ichasaya Cave Wildlife Sanctuary. (c) Species richness of all amphibian species in Myanmar. (d) Species richness of unprotected species. (e) Species richness of threatened species (created with QGIS version 3.28.1 and spatial data from UNEP-WCMC and IUCN [2023], and Olson et al. [2001]).

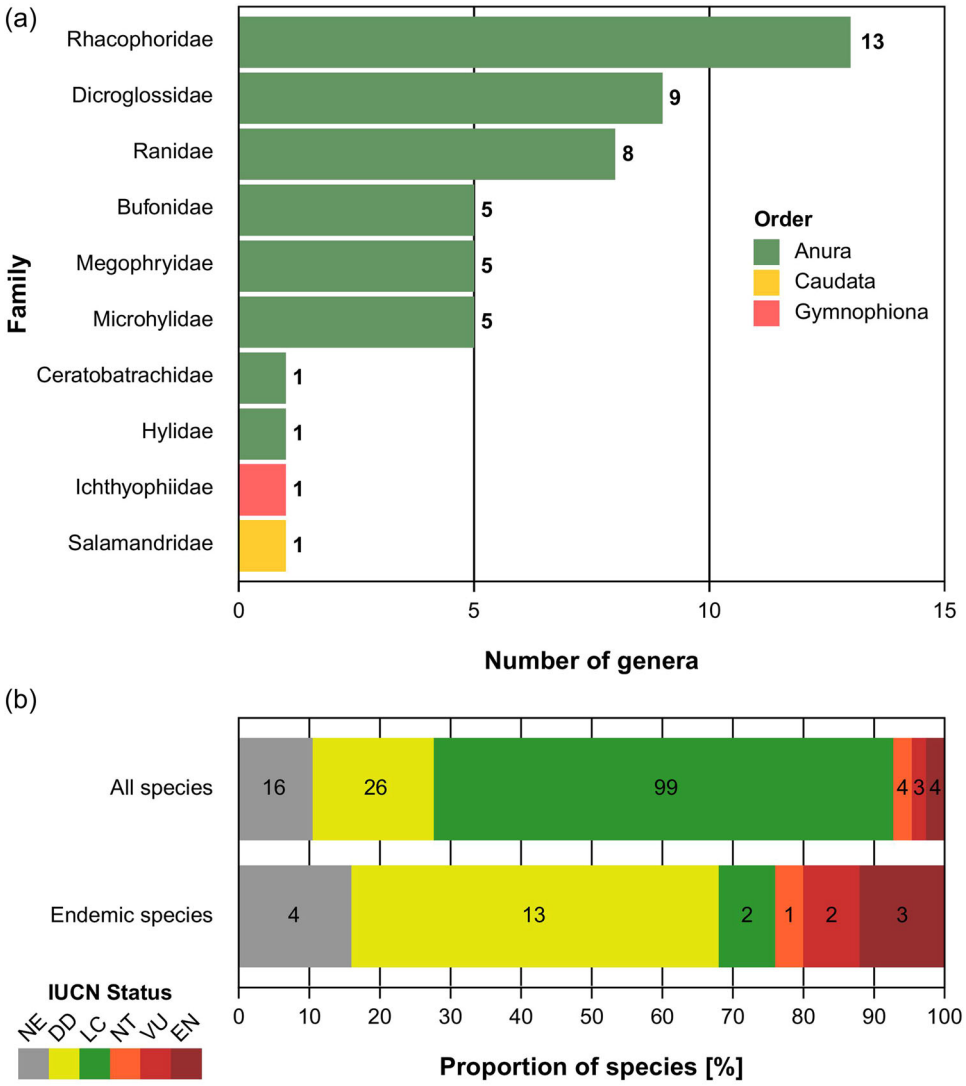

FIGURE 2 (a) Families of the amphibians of Myanmar. Shown with the number of genera within the families and the order they belong to. (b) Distribution of IUCN categories within all and endemic amphibian species of Myanmar. Colors correspond to different threat categories (NE = not endangered; DD = data deficient; LC = least concern; NT = near threatened; VU = vulnerable; EN = endangered). Percentage share and number of species (inside the blocks) of each category are shown.

Fauna and Flora (CITES). Out of those, only *Hoplobatrachus tigerinus* belongs to the order Anura. The other five species (*Tylototriton kachinorum, T. ngarsuensis, T. panwaensis, T. shanorum, T. verrucosus*) belong to the order Caudata. The six species are listed in Appendix II of CITES (CITES, 2023c). Half of the species are endemic to Myanmar; one is threatened, and three are potentially threatened.

3.5 | Spatial analysis of species richness

Myanmar has 53 PAs, which cover 6.6% (44,289 km^2) of the roughly 673,079 km^2 land area, and 0.5% (2,457 km^2) of the roughly 514,147 km^2 marine and coastal area (UNEP-WCMC and IUCN, 2023, see Figure 1b).

The number of amphibian species in Myanmar is generally high in the eastern part of the country along the Shan Plateau all the way down to peninsular Myanmar in the South, whereas on the western side towards the border to India and the coastal regions, there are rather fewer species. It is noticeable that in the far eastern and southern regions where the highest numbers of species are found, there is also a lack of larger PAs, as the biggest PAs are located in the North (Figure 1c).

Considering only species whose distribution is outside any PA the allocation is different. There is a peak in the far south of the country in the Tenasserim-South Thailand semi-evergreen rain forests in Tanintharyi, but elsewhere the number of species is relatively low. The only other minor peaks are in the northeast of Myanmar in southeast Kachin and northern Shan, as well as in the northwest of Myanmar in Sagaing and Chin on the border to India (Figure 1d).

3.6 | Protected area coverage

Out of the 152 species occurring in Myanmar, the distribution area of 144 could be compared to the PAs

TABLE 1 List of endemic amphibian species in Myanmar, with respective IUCN status, grade of endemism (CE = country endemic; RE = regional endemic; ME = microendemic), and distribution (sources for distribution can be found in Supporting Information).

Species	IUCN status	Grade of endemism	Distribution
Hylarana margariana	DD	CE	The eastern part of Shwegu township, west Bhamo, Kachin; generally Kachin
Amolops latopalmatus	NE	CE	Extreme southern Myanmar (Tanintharyi)
Amolops longimanus	DD	ME	Kambaiti Village, Kachin (2000 m asl)
Amolops marmoratus	LC	CE	Mon, Shan, Kayin, Kayah, Bago, Kachin, Mandalay, Tanintharyi
Ansonia kyaiktiyoensis	EN	ME	Kyaiktiyo Pagoda, Mon (1033 m asl)
Ansonia thinthinae	EN	RE	Me Kyauklonegyi Stream in Tanintharyi Nature Reserve
Duttaphrynus crocus	DD	RE	Two closely situated localities adjacent to Rakhine Yoma Elephant Sanctuary (Gwa Township, Rakhine)
Feihyla punctata	DD	CE	Gwa Township (Rakhine); Ngaputaw Township (Ayeyarwady)
Fejervarya kupitzi	NT	CE	Alaungdaw Kathapa National Park (Sagaing), Bago Yoma (Bago)
Hylarana oatesii	DD	CE	Bago, Yangon
Hylarana roberti	VU	CE	Dewei (Tanintharyi)
Kalophrynus anya	LC	CE	Chattin Wildlife Sanctuary (Sagaing); South-central Kachin
Leptobrachium rakhinense	EN	CE	Rakhine Hills (Rakhine, Bago)
Limnonectes bagoensis	NE	CE	Bago, Yangon
Limnonectes bagoyoma	NE	RE	Bago Yoma mountain range (Bago)
Microhyla fodiens	DD	ME	Kan Pauk (Yesagyo Township, Magway, 230 m asl)
Microhyla irrawaddy	DD	RE	Suburbs of Pakokku city on the bank of the Irrawaddy River (Pakokku, Magway); in the vicinity of Kan Pauk village (Yesagyo Township, Pakokku, Magway)
Nanorana feae	DD	RE	Kakhyen Hills (Kachin)
Occidozyga myanhessei	NE	RE	Dawei (Bago); East Yangon University, Mingalardon (Yangon)
Philautus cinerascens	DD	ME	Ataran River, east of Moulmein (Mon, Type locality)
Philautus tytthus	DD	ME	Htingnam (Kachin, Type locality)
Rhacophorus turpes	DD	ME	Htingnam (Kachin, Type locality)
Tylototriton kachinorum	DD	ME	Slopes of Ingyn Taung Mountain (Mohnyin Township, southern part of Kachin Hills, Kachin)
Tylototriton ngarsuensis	DD	ME	Baw Hto Chang in Ngar Su Village (Ywnagan Township, Taunggyi, Shan, 1212 m asl)
Tylototriton shanorum	VU	RE	Taunggyi, Kalaw, Pindaya, Nyaungshwe, Pinlaung townships (Shan)

of Myanmar. Our results suggest that 40 of the 144 species (27.8%) have a distribution area outside any PA. Out of those 40 species, two (*Nanorana yunnanensis* and *Tylototriton shanorum*) are threatened according to the IUCN (VU, EN, CR), and 15 are potentially threatened (IUCN status DD or NE). Of these 17 species, 12 are endemic to Myanmar. Hence, 28.6% of the threatened, 35.7% of the potentially threatened, and 48% of the endemic amphibian species in Myanmar are not protected through any PA (see Table 2 & Supporting Information S1: SI4).

Twenty-three (16%) of the 144 species, whose distribution was compared to the PAs of Myanmar, are only covered by one PA. Three of those species (*Ansonia kyaiktiyoensis, A. thinthinae*, and *Hylarana roberti*) are considered threatened by the IUCN (VU, EN, CR), and eight are potentially threatened (NE or DD). Of those 11 species, six are endemic to Myanmar. There is one more endemic species on this list, that is classified as LC (*Kalophrynus anya*). Hence, 42.8% of the threatened, 19% of the potentially threatened, and 28% of the endemic amphibian species in Myanmar are only covered by one PA (see Table 3).

3.7 | ZIMS analysis

Of the 152 species occurring in Myanmar, 19 are held in zoos worldwide (12.5%). They almost all

TABLE 2 Amphibian species in Myanmar that are not covered by any protected area. Listed with IUCN Red List status and endemism status (NoE = not endemic, CE = country endemic, RE = regional endemic, ME = microendemic).

Species	IUCN status	Endemism status
Hylarana margariana	DD	CE
Amolops longimanus	DD	ME
Amolops panhai	LC	NoE
Amolops viridimaculatus	LC	NoE
Clinotarsus alticola	LC	NoE
Duttaphrynus crocus	DD	RE
Euphlyctis cyanophlyctis	LC	NoE
Hoplobatrachus litoralis	LC	NoE
Hylarana eschatia	LC	NoE
Hylarana malayana	NE	NoE
Hylarana oatesii	DD	CE
Hylarana tytleri	LC	NoE
Ingerana borealis	LC	NoE
Leptobrachium huashen	LC	NoE
Leptomantis cyanopunctatus	LC	NoE
Limnonectes bagoyoma	NE	RE
Microhyla mantheyi	LC	NoE
Nanorana feae	DD	RE
Nanorana yunnanensis	EN	NoE
Nyctixalus pictus	LC	NoE
Occidozyga myanhessei	NE	RE
Odorrana hosii	LC	NoE
Odorrana livida	DD	NoE
Orixalus carinensis	DD	NoE
Philautus cinerascens	DD	ME
Philautus tytthus	DD	ME
Polypedates discantus	NE	NoE
Polypedates megacephalus	LC	NoE
Polypedates teraiensis	LC	NoE
Pterorana khare	LC	NoE
Raorchestes andersoni	LC	NoE
Raorchestes longchuanensis	LC	NoE
Rhacophorus nigropalmatus	LC	NoE
Rhacophorus norhayatiae	LC	NoE
Rhacophorus turpes	DD	ME
Tylototriton ngarsuensis	DD	ME
Tylototriton shanorum	VU	RE
Tylototriton verrucosus	NT	NoE
Xenophrys glandulosa	LC	NoE
Zhangixalus dennysi	LC	NoE

belong to the order Anura except *Tylototriton verrucosus*, which belongs to the Caudata. None of Myanmar's threatened or potentially threatened (DD, NE) species and none of the endemic species are kept in any zoo or aquarium worldwide (see Table 4 and Supporting Information S1: SI5).

Concerning the One Plan Approach, all of the species which are currently kept are also found in other countries, so the individuals/populations are not necessarily descended from founder animals from Myanmar. Although they correspond to the same species, they should not be used for reintroduction in Myanmar. It is also important to mention again that this study only analyzed the ZIMS database. This database is not used by every zoo or aquarium, so some species may be kept somewhere else, e.g., there may be stations or other institutions in Myanmar that hold endangered or endemic species.

4 | DISCUSSION

When compiling the species list of the amphibians in Myanmar, it became evident that for a number of species information on the distribution area is still scarce, and also the taxonomy of several species is unclear (Mulcahy et al., 2018). There are many species groups containing more than one species, and cryptic species associated with the country, and therefore, the number of amphibians occurring in Myanmar is certainly much higher than currently recognized.

That lack of information is also evident in the 16 species of this study not listed on the IUCN Red List, the 26 species only listed with insufficient data, and the 22 species whose last IUCN assessment was more than 10 years ago. With this total of 60 species, there is insufficient information on 39.5% of the amphibians in Myanmar. Considering that species with insufficient data are more likely to be threatened than those assessed adequately, this is particularly concerning (Bland et al., 2014, cited after Meredith et al., 2016). It could bring the number of threatened species in Myanmar from the officially classified seven to 67 species. This would correspond to roughly 43% of all amphibians in Myanmar. Furthermore, most of the endemic species in Myanmar (18 species, 72%) are not assessed adequately by the IUCN. This is all the more worrying because endemic species are inherently more threatened on their own due to their narrow habitat preferences and small distribution areas (Meredith et al., 2016; Sheridan & Stuart, 2018). Add to this fact that there is only insufficient information available about them, and the number of endangered endemic amphibian species in Myanmar could very likely include 23 species, not just the five species currently officially classified as threatened. That would correspond to 92% of the endemic species in Myanmar.

TABLE 3 Amphibian species in Myanmar that are only covered by one protected area. Listed with the IUCN Red List status, the endemism status (NoE = not endemic, CE = country endemic, RE = regional endemic, ME = microendemic), and the protected area covering them.

Species	IUCN status	Endemism status	Protected area
Amolops putaoensis	NE	NoE	Hponkanrazi Wildlife Sanctuary
Ansonia kyaiktiyoensis	EN	ME	Kyeikhtiyoe Wildlife Sanctuary
Ansonia thinthinae	EN	RE	Taninthayi Nature Reserve
Feihyla punctata	DD	CE	Rakhine Yoma Elephant Range
Hylarana humeralis	LC	NoE	Inkhain Bum National Park
Hylarana roberti	VU	RE	Taninthayi Nature Reserve
Ichthyophis multicolor	DD	NoE	Hlawga Park
Kalophrynus anya	LC	CE	Shwe-U-Daung Wildlife Sanctuary
Kaloula latidisca	DD	NoE	Lampi Marine National Park
Leptobrachium chapaense	LC	NoE	Shwe-U-Daung Wildlife Sanctuary
Limnonectes bagoensis	NE	CE	Hlawga Park
Limnonectes bannaensis	LC	NoE	Loimwe Protected Area
Limnonectes hascheanus	LC	NoE	Taninthayi Nature Reserve
Limnonectes kohchangae	LC	NoE	Taninthayi Nature Reserve
Micryletta lineata	LC	NoE	Taninthayi Nature Reserve
Nanorana arnoldi	DD	NoE	Hkakaborazi National Park
Nasutixalus jerdonii	LC	NoE	Hponkanrazi Wildlife Sanctuary
Odorrana macrotympana	DD	NoE	Htamanthi Wildlife Sanctuary
Rhacophorus verrucopus	NT	NoE	Htamanthi Wildlife Sanctuary
Sphaerotheca cf. breviceps	LC	NoE	Hlawga Park,
Tylototriton kachinorum	DD	ME	Hukaung Valley Wildlife Sanctuary (extension)
Zhangixalus burmanus	LC	NoE	Hkakaborazi National Park
Zhangixalus smaragdinus	LC	NoE	Taninthayi Nature Reserve

According to Luedtke et al. (2023), the overall proportion of amphibian species classified as DD on the IUCN Red List has decreased from 22.5% in 2004 to 11.3% in 2022. However, according to the results presented herein, this same proportion is still at 17.1% for Myanmar's amphibians, well above the average of 11.3%. Luedtke et al. explain the decline in this proportion for all amphibians in part by the fact that more information is available on amphibians compared to 2004. The fact that the figure for Myanmar's amphibians has remained high illustrates once again the lack of relevant knowledge about the species there and shows that Myanmar is not a high priority for herpetological research. Further studies on the amphibian species of Myanmar are necessary to assess which species actually occur in the country and which are threatened and need conservation actions. A lot more information is needed to be able to initiate appropriate protective measures should they be required.

The protective measures that already exist, for example, Myanmar's Conservation of Biodiversity and Protected Area Law of 2018 are not sufficient. The law has the objective to carry out the protection and conservation of wild fauna, wild flora, ecosystems and migratory animals. Therefore, the official list of protected species published in 2020 lists Myanmar's endangered species and categorizes them according to their degree of protection. However, *Tylototriton verrucosus* and *T. shanorum* are the only amphibian species represented on this list. Another example of insufficient protective measures for amphibians is the 53 PAs located throughout the country. It is noticeable in Figure 1c that most of the PAs in Myanmar are not located in the very species-rich areas in the east and south of the country. Those conservation gaps could stem from the fact that amphibians were not the focus of previous studies addressing the protection of Myanmar's nature (Mi et al., 2023; Zug, 2022). Thus, for future planning of PAs, amphibians should play a more significant role, and the focus should be mainly on the south of the country, as this is where most of the still unprotected species are located. Another reason for the lack of PAs in Myanmar's species-rich regions could be the fact that only 6.6%

TABLE 4 Amphibian species occurring in Myanmar and kept in zoos and/or aquariums worldwide. Listed with IUCN status, the number of kept individuals in total across institutions, the number of hatchings in the last 12 months, the total number of institutions and the number of regions in which the species are kept, and the number of EAZA institutions out of the institutions keeping the species.

Species	IUCN status	Individuals	Hatchings	Total institutions (regions)	EAZA institutions
Duttaphrynus melanostictus	LC	2026	270	24 (3)	15
Ingerophrynus parvus	LC	11	0	1 (1)	1
Phrynoidis asper	LC	78	0	13 (2)	3
Euphlyctis cyanophlyctis	LC	3	0	1 (1)	0
Hoplobatrachus tigerinus	LC	3	0	1 (1)	0
Hylarana cubitalis	LC	262	0	4 (1)	4
Hylarana erythraea	LC	9	0	2 (1)	2
Hylarana nigrovittata	LC	138	10	2 (1)	2
Occidozyga lima	LC	72	0	2 (2)	1
Glyphoglossus guttulatus	LC	1	0	1 (1)	1
Kaloula pulchra	LC	59	0	17 (5)	7
Microhyla butleri	LC	8	0	2 (1)	1
Nyctixalus pictus	LC	163	105	10 (2)	5
Polypedates leucomystax	LC	193	0	12 (3)	10
Polypedates megacephalus	LC	235	0	11 (1)	10
Rhacophorus kio	LC	3	0	2 (1)	0
Rhacophorus nigropalmatus	LC	38	0	2 (1)	2
Theloderma asperum	LC	32	0	5 (2)	1
Tylototriton verrucosus	NT	133	35	15 (1)	10

of the country's land area is covered by PAs anyways, which is not even half of the 15.1% protected land area average worldwide (Dinerstein et al., 2020; UNEP-WCMC and IUCN, 2023).

The lack of PAs can also be seen through the two (out of seven) threatened and 15 (out of 42) potentially threatened species with distributions outside of any PA. Out of those 17 species, 12 are also endemic to Myanmar. Further conservation measures should be considered for all these species to save them from extinction, with some of the species higher on the priority list as they are more vulnerable, like the species *T. shanorum*, as it is the only species threatened as well as endemic. However, other species like *Hylarana margariana* or *Occidozyga myanhessei*, who may only be considered possibly threatened should not be forgotten (see SI6).

The protection by one PA is sufficient for non-endemic species that are not threatened. Threatened and/or endemic species, on the other hand, need more protection, as PAs usually represent a static area that is limited in its ability to respond to external changes due to its insufficient dynamics and is therefore vulnerable to rapid environmental changes (D'Aloia et al., 2019). That is why, in this study, it was analyzed if any of the threatened, potentially threatened (again, here are only DD and NE species included, not species with an IUCN assessment older than 10 years), and endemic species, whom PAs cover, are only covered by a single one. This must be confirmed, as three (out of seven) threatened and eight (out of 42) potentially threatened species are only covered by one PA. Out of those 11 species, six are endemic to Myanmar. One more endemic species is covered only by one PA, which is not considered threatened. We suggest that all those species should be considered for further conservation actions, like for example ex situ protection, with the threatened species (*Ansonia kyaiktiyoensis, A. thinthinae*, and *Hylarana roberti*) at a higher level of priority, even though species like *T. kachinorum*, which is "only" possibly threatened but microendemic or the not threatened but endemic *Kalophrynus anya* should not be overlooked (see Supporting Information S1: SI6).

The analyses of this study demonstrate the large gaps still to be found in the protection of Myanmar's amphibians and the urgency behind taking further conservation action. It becomes clear how much the species suffer under the ongoing global amphibian crisis and yet are not the focus of attention when it comes to preserving the world's biomes, even though, with 41% of species threatened with extinction, they are the vertebrate group

most at risk (IUCN, 2023). It should also be noted that the species whose last assessment by the IUCN was more than 10 years ago, but which are not classified as threatened (VU, EN, CR) or as DD or NE were not considered as potentially threatened in this study. Under the "worst case scenario", these 18 species could also be threatened, adding to the list of species for which conservation action is needed. This could also be true for the eight species whose PA coverage could not be verified due to a lack of data regarding their distribution. *Amolops latopalmatus*, in particular, if not present in any PA, may require further protection measures as it is an endemic species. This shows once again that there is a knowledge gap for many amphibian species that needs to be addressed. Therefore, it is recommended to reevaluate all species whose last assessment by the IUCN was more than 10 years ago and study the distribution of the other species in greater detail.

Interpretation of our results needs to acknowledge data gaps and limitations. New species inventories may result in a better understanding of local amphibian diversity. This already becomes evident as some species lacking IUCN range data are listed in GBIF, which provides detailed coordinates of occurrences. Updating especially older IUCN assessments may hence result in a refined understanding of species distributions, likely enlarging ranges that might result in species being discovered in more PAs. On the other hand, ongoing habitat transformation may limit habitat availability and, ultimately also, ranges. Hence, the results of our spatial analyses provide a snapshot reflecting current knowledge, and they should be updated as soon as more data becomes available.

Another countermeasure that should be implemented is the mentioned conservation breeding, as none of the threatened, potentially threatened (again, here are only DD and NE species included, not species with an IUCN assessment, i.e., older than 10 years), or endemic amphibian species are being kept in any zoo or aquarium worldwide at the moment (at least none are recorded in ZIMS).

This is concerning because integrating ex situ and in situ protection, as stated in the One Plan Approach, may be "the only practical conservation option left for some species whose habitats are dwindling" (Schwartz et al., 2017, p. 2). Species that could fall into this category are *Tylototriton shanorum*, a threatened endemic species that is currently not protected by any PA, or *Amolops longimanus, Philautus cinerascens, P. tytthus, Rhacophorus turpes*, and *Tylototriton ngarsuensis* as they are microendemics considered as possibly threatened without protection through PAs. All those species could greatly benefit from ex-situ protection, and it would ensure that they do not become extinct while the planning of the protection of their habitats takes place. It would be beneficial if at least some of the holdings of the species were placed in facilities and stations in Myanmar itself, especially holdings of the country's endemic and endangered species. Some could already exist and are simply not recorded in the ZIMS database, which was used as the only means of verifying the species' holdings in this study.

5 | CONCLUSION

This study serves as an overview of the situation of the amphibians in Myanmar and is intended to expand the work of Zug (2022) by analyzing and classifying amphibians specifically in terms of their threat status and conservation. The aim is to create an impetus to expand the protection of amphibians in Myanmar. Therefore, the results of this study have been compiled into a list containing the 36 amphibian species of Myanmar that are most in need of further protection and should, therefore, be prioritized in future conservation planning (Supporting Information S1: SI6). Also, this study has shown that there is still a significant gap in knowledge about Myanmar's amphibians, which should be addressed in future studies, and that although some conservation measures are already in place, especially Myanmar's threatened, and endemic amphibian species are still largely unprotected and thus at risk of extinction.

AUTHOR CONTRIBUTIONS

Marie Borgwerth: Writing—original draft; data curation; formal analysis; investigation; methodology; software; visualization; data curation. **Carolin Scholten**: Writing—original draft; formal analysis; investigation; methodology; software; visualization. **Aung Lin**: Writing—review and editing. **Myint Kyaw Thura**: Writing—review and editing. **Larry Lee Grismer**: Conceptualization; data curation; investigation; writing—review and editing; resources. **Thomas Ziegler**: Conceptualization; investigation; writing—review and editing. project administration; resources; supervision. **Dennis Rödder**: Conceptualization; data curation; formal analysis; investigation; methodology; software; visualization; writing—review and editing; project administration; resources; supervision.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from IUCN Red List (https://www.iucnredlist.org/resources/grid) and the respective cited references. Data extracted from ZIMS are restricted to members only.

ORCID

Dennis Rödder http://orcid.org/0000-0002-6108-1639

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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