Integrative Conservation

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INTEGRATIVE CONSERVATION XTBG

RESEARCH ARTICLE OPEN ACCESS

Gaps in the Protection of the Reptiles of Myanmar—Threat Status, Endemism, Protected Area Coverage, and One Plan Approach Conservation

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Received: 5 November 2024 | **Accepted:** 16 March 2025

Editor-in-Chief & Handling Editor: Ahimsa Campos-Arceiz

Keywords: Burmese herpetodiversity | conservation breeding | distribution | protection status | sanctuaries | zoo database analysis

ABSTRACT

Herein, we improve the knowledge about Burmese terrestrial reptile diversity and its distribution with focus on threatened and endemic species providing recommendations for improved conservation measures. Out of the 212 assessed species, 20% are Burmese endemics. Of those, almost 10% are microendemics that have only been reported from one specific locality and almost 40% are regional endemics, some with very restricted distributions, which are particularly threatened. Almost 25% of all assessed species are listed as threatened or potentially threatened in the IUCN Red List. In endemics, this number increases to 50.0%. The richness of all terrestrial reptile species is consistently high, and their distribution is mostly even across Myanmar with exceptions in the northern coastal regions and in the central dry zone reaching down to the lowlands in the southern part above Mon State and Tanintharyi Region. Threatened taxa are similarly distributed but with peaks in the western Mizoram–Manipur–Kachin rain forests, Kayah–Karen montane rain forest, and in the Tenesserim–South Thailand semi-evergreen rain forest. Endemism is generally even across the country with peaks in the east and south. Analysis of protected areas revealed that the majority of all species extant in Myanmar may occur in at least one protected area, but 10% are only covered by one single protected area, while in threatened and potentially threatened categories 25.0% of the taxa have been reported exclusively from outside protected areas. In endemic species this number increases to more than 30%. CITES lists 16.0% of all species, most of them in Appendix II. According to the ZIMS database, almost 50% of all threatened and potentially threatened terrestrial reptiles are represented in zoos, with breeding successes in the last 12 months for 60%. The vast majority of 88% of all Burmese endemic species are not kept in ex situ populations, suggesting that the implementation of the One Plan Approach proposed by the IUCN Conservation Planning Specialist Group (CPSG) needs to be improved to protect the unique herpetofauna. A list of the most threatened species in need of conservation actions is provided.

Summary

In this study, the knowledge of Burmese reptile diversity and occurrence was assessed highlighting recommendations for conservation, especially for species at risk and/or species only occurring in this area. We found 212 species which are distributed in Myanmar, with 20% of them occurring only here. Among them, about half of them can be considered as at risk of population declines and/or extinction. Across the country, expected species numbers per area is high and mostly equally distributed, with exceptions in the northern coastal regions and the central dry zone. This pattern is also evident in the distribution of threatened species. The distribution of species occurring only in Myanmar is also comparatively even with areas of higher degrees of endemism in the east and south. Looking at the occurrence of species in protected areas, most of the species may occur in at least one protected area. However, among the species at risk 25% have been recorded exclusively outside of protected areas. Assessing a zoo database, about half of them are already in holdings, with 60% having successful reproduction during the last year. However, the majority of threatened species occurring only in Myanmar is currently not in holdings. Here, the implementation of the One Plan Approach proposed by the IUCN Conservation Planning Specialist Group (CPSG) needs to be improved.

- **Practitioner Points**
  - Diversity of reptiles is considered high in Myanmar, although future research efforts will likely result in the discovery of previously neglected taxa.
  - Recommendations for improvement of the protected area network are provided.
  - To improve conservation, a list of the most threatened species in need of ex-situ and in-situ actions is provided

1 | Introduction

As the world is experiencing a global biodiversity crisis with up to one million plant and animal species facing extinction in the coming decades because of human activities (Tollefson 2019), at least 1829 out of 10,196 reptile species (21.1%) are globally threatened (Cox et al. 2022). To prevent species extinction, experts agree that it is crucial to take immediate drastic actions to conserve habitats (Tollefson 2019). A recent study suggests that beyond the 15.1% of currently protected global terrestrial area, it would need an additional 35.3% of critical sites to protect biodiversity and stabilize the climate (Dinerstein et al. 2020). Considering the limited resources available, it is necessary to set priorities for nature conservation measures. Identifying biodiversity hotspots such as Myanmar is a typical approach.

Myanmar is the northwesternmost country in mainland Southeast Asia and a global hotspot with high biodiversity and many endemic species. However, Myanmar's protected terrestrial and inland water areas (PAs) cover only 44,289 km^2 (6.6%) of the total land area of 673,079 km^2 (UNEP WCMC 2022a). There has been extensive herpetological research on certain groups and regions, particularly in recent decades (e.g., Levitón et al. 2003; Platt et al. 2018; Zug 2022), but the knowledge of Myanmar's reptile fauna remains incomplete. According to IUCN (2022a), Myanmar's reptile diversity includes 316 species. Thus, the present study aimed to analyze the species richness and distribution of Myanmar's terrestrial reptiles, the conservation status, and PA coverage to provide recommendations for prioritization of conservation actions.

Following the One Plan Approach to Conservation of the IUCN's Conservation Planning Specialist Group (CPSG), which aims to combine different approaches such as in and ex situ conservation measures to create one comprehensive conservation plan for the species (Conservation Planning Specialist Group 2022), we also analyzed ex situ conservation activities, namely the global representation of Burmese reptiles in zoo holdings.

We expected that the distribution areas of many threatened, potentially threatened, and endemic species are not covered by PAs. Those species that benefit from sanctuary protection are expected to be protected by only one single PA. Endemic species that are listed in an IUCN threat category were assumed to be threatened by human impacts, and we assumed that not all of the threatened and endemic reptiles occurring in Myanmar are currently covered by One Plan Approach conservation measures, such as ex situ breeding.

2 | Methods

2.1 | Species List

This study focuses on the extant native terrestrial reptile species of Myanmar. Sea snakes and sea turtles, as well as introduced or extirpated species, were excluded from the analysis. To compile a species list, we used Zug (2022) as the primary reference for turtle and crocodile species, Wogan et al. (2008) for Squamata, and Levitón et al. (2003) for venomous snake species. For the endemism analysis Stuart and Thorbjarnarson (2003), the IUCN Red List, and Uetz et al. (2021) were inquired. We further consulted species information from IUCN (2022a), the Reptile Database (Uetz et al. 2021, 2023), and individual publications. In case of contradictory or unclear data the most recent source was considered.

The species list includes three special cases. *Gongylosoma scriptum* was added despite its IUCN (2022a) status Possibly Extinct. *Trimeresurus kanburiensis* is known with certainty from Kanchanaburi Province in western Thailand, on the border with Myanmar (Sumontha et al. 2021). Due to this close geographic proximity, the species also likely occurs in adjacent Kayin State, Myanmar, but has not yet been documented there (Levitón et al. 2003; IUCN 2022a). Since this is an Endangered species, which has potential to be recorded from Myanmar in the future, we have included it in our analyses. *Malayemys macrocephala* is currently not proven to occur in Myanmar, but in Thailand directly bordering Tanintharyi State, Myanmar (IUCN 2022a) and was documented by Platt et al. (2017) in southern Tanintharyi (Zug 2022), so could be marginally occurring and be recorded again in Myanmar in the future.

Seven species listed in Zug (2022) were not included in the species list for being introduced to or likely extirpated in

Myanmar. *Trachemys scripta* is native to southern central North America and thus does not naturally occur in Myanmar (Uetz et al. 2021; Zug 2022). Apart from reports from the nineteenth and early twentieth century, the occurrence of the Crocodylia *Crocodylus palustris* and *Gavialis gangeticus* in Myanmar cannot be confirmed and these species are presumed to be extirpated in Myanmar (IUCN 2022a; Zug 2022). Similarly, the recent occurrence of four Testudines formerly reported in Myanmar is questionable. For *Batagur affinis* and *Melanochelys tricarinata,* there are no confirmed records for Myanmar (IUCN 2022a; Zug 2022). *Batagur baska* is possibly extinct in Myanmar since its last record is from a single individual living in a pagoda pond in 2019 (IUCN 2022a; Zug 2022). The presence of *Heosemys annandalii* in Myanmar is uncertain (IUCN 2022a; Zug 2022); thus, this species was not included in the species list as well.

The final species list of all terrestrial reptile species that occur in Myanmar does not contain subspecies and species that are present on the Coco and Sunda Islands but not on mainland Myanmar. All species were listed together with their IUCN Red List status, population trend (IUCN 2022a), the date of the last assessment, and the references that indicate their distribution in Myanmar. In addition, endemic species were listed together with the grade of endemism and the location in Myanmar.

2.2 | Distribution/Spatial Data

The spatial polygons of the distribution of the species were compiled by and downloaded from IUCN (2022a). Eleven taxa were missing spatial information in Myanmar. Their habitats were separately mapped based on literature: *Boiga quincunciata, Chrysopelea paradisi, Eutropis dissimilis, Eutropis rudis, Gekko kuhli, Lygosoma haroldyoungi,* and *Python brongersmai*. The four species *Amyda ornata, Hemidactylus tenkatei, Indotyphlops jerdoni,* and *T. kanburiensis* have been excluded from the richness analysis due to missing coordinates. The PA information of Myanmar was taken from UNEP WCMC (2022a) and IUCN (2022a). The global ecoregions classification was based on Olson et al. (2001).

2.3 | Endemism

We considered different categories of endemism: species that only occur in one single location, for example, a specific spot on a riverbank, are considered as microendemic species (ME). Species that are extant in one terrestrial ecoregion of the country or in one spot on both sides of an ecoregional or country border are counted as regional endemics (RE). Taxa that are distributed in two or more different ecoregions or on the border between Myanmar and an adjacent country and also in at least one more location in Myanmar are classified as country endemics (CE).

2.4 | Data Analysis and Visualization

Our data set was analyzed using R version 4.2.0 and the additional packages "raster" (Hijmans et al. 2022), "shapefiles" (Stapler 2013), and "rredlist" (Gearty and Chamberlain 2020). Figures were created using QGIS version 3.22.7. Lists and charts were created with Microsoft Excel.

To compare the distribution of PAs with localities of all extant, threatened, and endemic species, species richness analyses were performed measuring the number of species in grid cells of 100×100 m. Therefore, we used range polygons provided by IUCN as baseline and computed the occurrence of preferred habitat types as stated in the respective species accounts by IUCN based on a high-resolution habitat map provided by Jung et al. (2020). Additionally, the number of species potentially occurring in PAs was computed. As proposed by Crisp et al. (2001), the relative habitat size of all species in a grid cell, corrected with the total number of species in this cell was calculated as corrected weighted endemism (CWE). For this index, species were weighted by the inverse of their range size. Therefore, species with smaller range sizes were weighted more strongly than those with large ranges. Subsequently, this value was divided by the local species richness in the grid cell.

2.5 | Conservation Status Analysis

The conservation status of each species was extracted from the IUCN Red List (2022a) between August 15 and August 31, 2022 for Squamata and the four Testudines *Geochelone platynota*, *Indotestudo elongata*, *Manouria emys* and *M. impressa*, and on July 27, 2023 for the remaining Testudines and *C. porosus*. We differentiated between the following categories: DD (Data Deficient), LC (Least Concern), NT (Near Threatened), VU (Vulnerable), EN (Endangered), CR (Critically Endangered), EW (Extinct in the Wild) (IUCN 2022a).

To evaluate whether a species can be assigned to a threatened category (VU, EN, or CR), the IUCN uses five different criteria (IUCN 2022b):

1. Population size reduction.
2. Geographic range in the form of either extent of occurrence (EOO) and/or area of occupancy (AOO).
3. Small population size and decline.
4. Very small or restricted population.
5. Quantitative analysis indicating the probability of extinction in the wild.

Additionally, it was checked whether a species was listed in the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) appendices. The data were assessed on August 31, 2022.

2.6 | Zoo Database Analysis

The Zoological Information Management System (ZIMS, Species360) is an online and real-time database, which currently covers more than 1200 aquariums, zoos, universities, research and governmental members, and holds knowledge of more than 22,000 species (Species360 2022a). Collection information from

the ZIMS database was used to gain an overview of threatened and endemic terrestrial reptiles occurring in Myanmar, which are held in zoos worldwide. For that purpose, the number and sex of kept individuals, keeping institutions, and successful reproduction within the last 12 months were extracted on August 18, 2023. It is possible that the ZIMS data does not exactly represent the actual ex situ situation, as some data may be obsolete or have not yet been entered in the database, and some institutions do not participate in ZIMS. In case a species could not be found in ZIMS, the Reptile Database (Uetz et al. 2023) was consulted to identify potential synonyms. In those cases, and whenever a species was found but no holding record was available, a search in the zoo species list (ZTL) database was performed. ZTL is a webpage that collects and catalogs information about the current and former vertebrate populations of zoos and other public animal facilities as well as about the individual animal species in the European Association of Zoos and Aquaria (EAZA) area (Zootierliste 2022).

3 | Results

3.1 | The Terrestrial Reptile Fauna of Myanmar

In total, 212 terrestrial reptile species were recorded in Myanmar (see Appendix), accounting for 1.8% of all globally recorded reptile species ($n = 12{,}060$: Uetz et al. 2023). Most of the species ($n = 187$) belonged to the order Squamata, 24 belonged to the order Testudines, only 1 species was representative of the Crocodylia (Figure 1a).

3.2 | Distribution and Richness

The richness of terrestrial reptile species is consistently high across the country, with exceptions in the northern coastal regions and in the central dry zone reaching down to the lowlands in the southern part, that is, the Mon State and the Tanintharyi regions. To the north, the highest species richness can be found in the ecoregions of the northern triangle subtropical forests and Mizoram–Manipur–Kachin rain forests. To the east the northern Indochina subtropical forests harbor the most species. Another peak in species richness can be found in the southern Tanintharyi Region in coastal and evergreen rain forests. On the west side of the country the coastal and Mizoram–Manipur–Kachin rain forests and the Chin Hills–Arakan Yoma montane forests are species-rich ecoregions (Figure 2).

The distribution of threatened species is generally similar but with peaks in the western Mizoram–Manipur–Kachin rain forests, Kayah–Karen montane rain forest, and in the Tenesserim–South Thailand semi-evergreen rain forest (Figure 2).

Our analysis of the distribution of terrestrial reptile species occurring in PAs revealed that the three PAs containing the most species in total are the Gulf of Mottama ($n = 117$), the Hukaung Valley Wildlife Sanctuary ($n = 107$), and the Taninthayi Nature Reserve ($n = 105$). Most PAs potentially harbor between 70 and 90 species. The least richness of taxa ($n = 57$) is distributed in the Moscos Islands Wildlife Sanctuary in the south of Myanmar (Figure 2).

The highest number of threatened species occur in the Gulf of Mottama ($n = 16$) and the Kaylatha Wildlife Sanctuary ($n = 14$). Each of the 13 threatened taxa occur in the Taninthayi Nature Reserve, Meinmahla Kyun Wildlife Sanctuary, Kyeikhtiyoe Wildlife Sanctuary, Meinmahla Kyun Wildlife Sanctuary, and Se Taung Wildlife Sanctuary. The Hkakaborazi National Park in the Eastern Himalayan alpine shrub and meadows of Myanmar harbors the lowest number of threatened reptile species ($n = 2$) (Figure 2).

Mapping the CWE, the distribution of CWE is generally even across the country with peaks in the east and south of Myanmar. These areas include the eastern part of the Northern Indochina subtropical forests, southern parts of coastal rain forests as well as Irrawaddy moist deciduous forests and Tenasserim-South Thailand semi-evergreen rain forests. The Eastern Himalayan alpine shrub and meadows and Nujiang Langcang Gorge alpine conifer and mixed forests show the lowest value for CWE (Figure 2).

3.3 | Endemism

About 44 of the 212 (20.8%) terrestrial reptile species of Myanmar are endemic (Table 1). Out of the 24 turtle species, 7 (29.2%) are endemic, belonging to the families Geoemydidae, Trionychidae (3 species each, 42.9%), and Testudinidae (1 species, 14.2%), while the other 37 endemics are representatives of the order Squamata. Among those, the family Gekkonidae is most species rich (16 species, 42.1%), followed by Colubridae (9 species, 23.7%), Agamidae (5 species, 13.2%), Elapidae (3 species, 7.9%), Scincidae (2 species, 5.2%), and Viperidae and Pythonidae with one species each (2.6% each) (Figure 1a). Analyzing their spatial distributions, 23 species (52.3%) are CE, 17 (38.6%) RE, and 4 (9.1%) microendemics (Table 1).

3.4 | IUCN Red List Status

Of the 212 assessed species, 29 (13.7%) are listed as threatened: 9 VU, 10 each EN and CR. Nineteen species (9.0%) are DD. Counting those DD species as potentially threatened increases the percentage to 22.6% ($n = 48$) (Figure 1b). In 80 out of 212 cases (37.7%), the statuses are older than 10 years (Table 1).

Out of all threatened and potentially threatened species occurring in Myanmar, 19 (39.6%) belong to the order Testudines and 29 (60.4%) to the Squamata. Among the former the family Geoemydidae is the richest in species with 9 (47.4%) species, followed by Trionychidae (5 species, 26.3%), Testudinidae (4 species, 21.1%), and Platysternidae with 1 species (5.3%). Among the latter the family Gekkonidae comprises 11 (33.3%) of the threatened species, followed by Colubridae with 4 species (12.1%), Elapidae and Viperidae with 3 species each (9.1%), Pythonidae, Varanidae, and Agamidae with 2 species each (6.1%), and Sibynophiidae and Natricidae with 1 species each (3.1%) (Figure 1a).

Out of the 44 endemic terrestrial reptile species of Myanmar, 11 (25.0%) are listed as threatened: 3 VU, 4 each EN and CR. One-quarter of the endemic species are listed as DD (25.0%, $n = 11$).

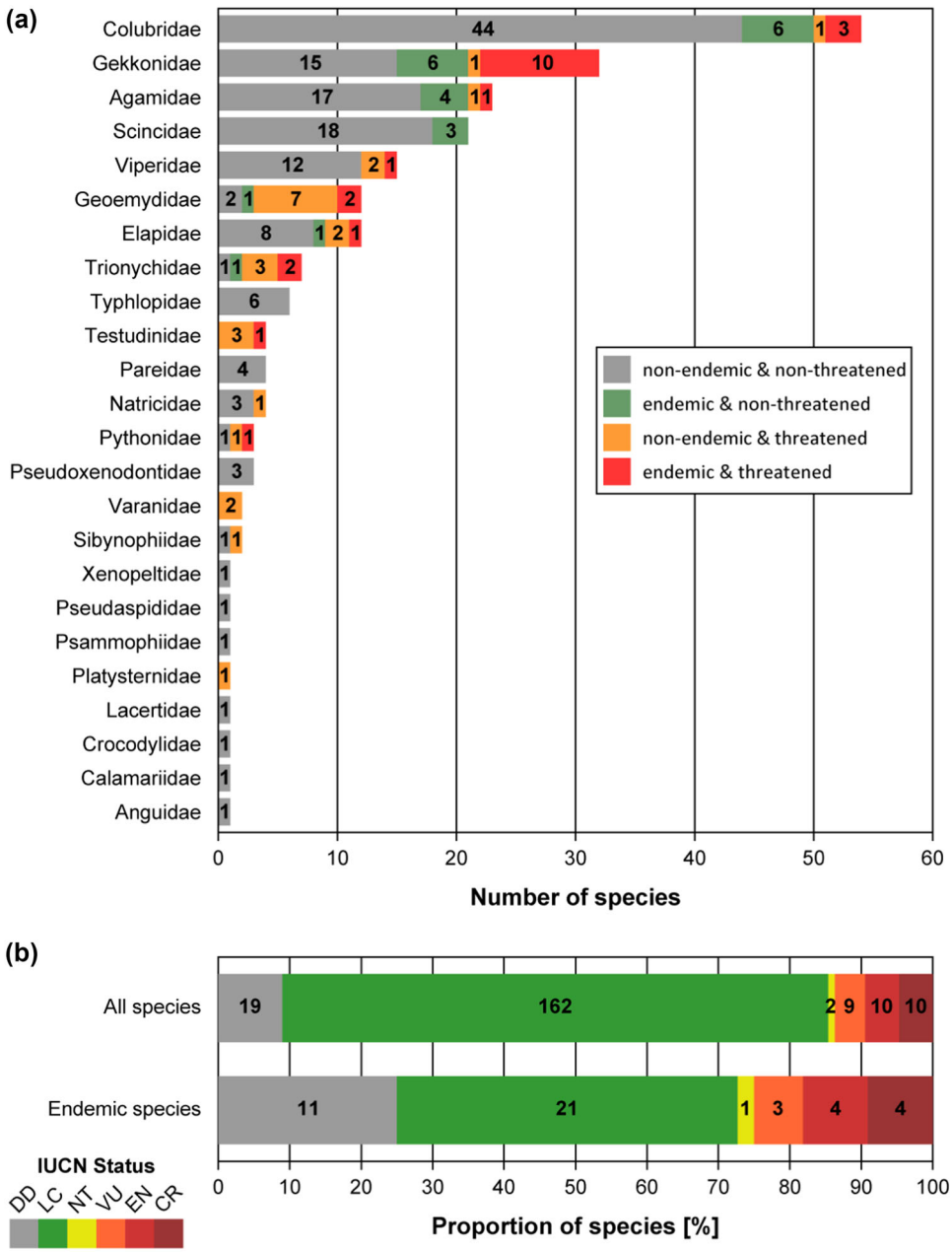

FIGURE 1 | (a) Families of the orders Squamata, Testudines, and Crocodylia occurring in Myanmar and the respective number of non-endemic, endemic, non-threatened, and threatened species. (b) Comparison of the IUCN status of all reptiles and endemic reptiles in Myanmar.

Including those, the percentage of threatened endemic species increases to 50.0% ($n = 22$) (Figure 1b). In 13 out of 44 cases (29.5%), the statuses are older than 10 years (Table 1).

Focusing on threatened and potentially threatened endemic species, five species (22.7%) belong to the order Testudines, two each (each 40.0%) in the families Geoemydidae and Trionychidae and one (20.0%) in the family Testudinidae, while 17 (77.3%) are part of the Squamata. Amidst the Squamata the family Gekkonidae comprises 10 (58.8%) threatened species, followed by Colubridae with three (17.7%) and Agamidae, Elapidae, Pythonidae, and Viperidae with one species each (5.9%) (Figure 1a). For all 11 threatened endemic species (25%), the IUCN Red List status was justified by naming a criterion (IUCN 2022a).

Cyrtodactylus brevidactylus, *C. wakeorum,* and *Naja mandalayensis* occur in severely fragmented or very few habitats with a continuing decline in the area, extent and/or quality of their habitats, and are hence listed as threatened under criterion B1ab(iii). In these cases, this is caused by rock extraction, logging and deforestation. *N. mandalayensis* is additionally suffering a continuing decline in the number of mature individuals (criterion B1ab(v)), which is a result of commercial exploitation for food and medicine. *T. kanburiensis* is listed under criterion B1ab(iv) due to a continuous decline in the number of its locations. *Batagur trivittata, Cyrtodactylus chrysopylos,* and *Python kyaiktiyo* have very small or restricted populations and are therefore listed under criterion D. *B. trivittata* is additionally listed under the criteria A2bcd and B1ab(i, ii, iii)+2ab(i, ii, iii), because it is suffering an extreme population reduction to one

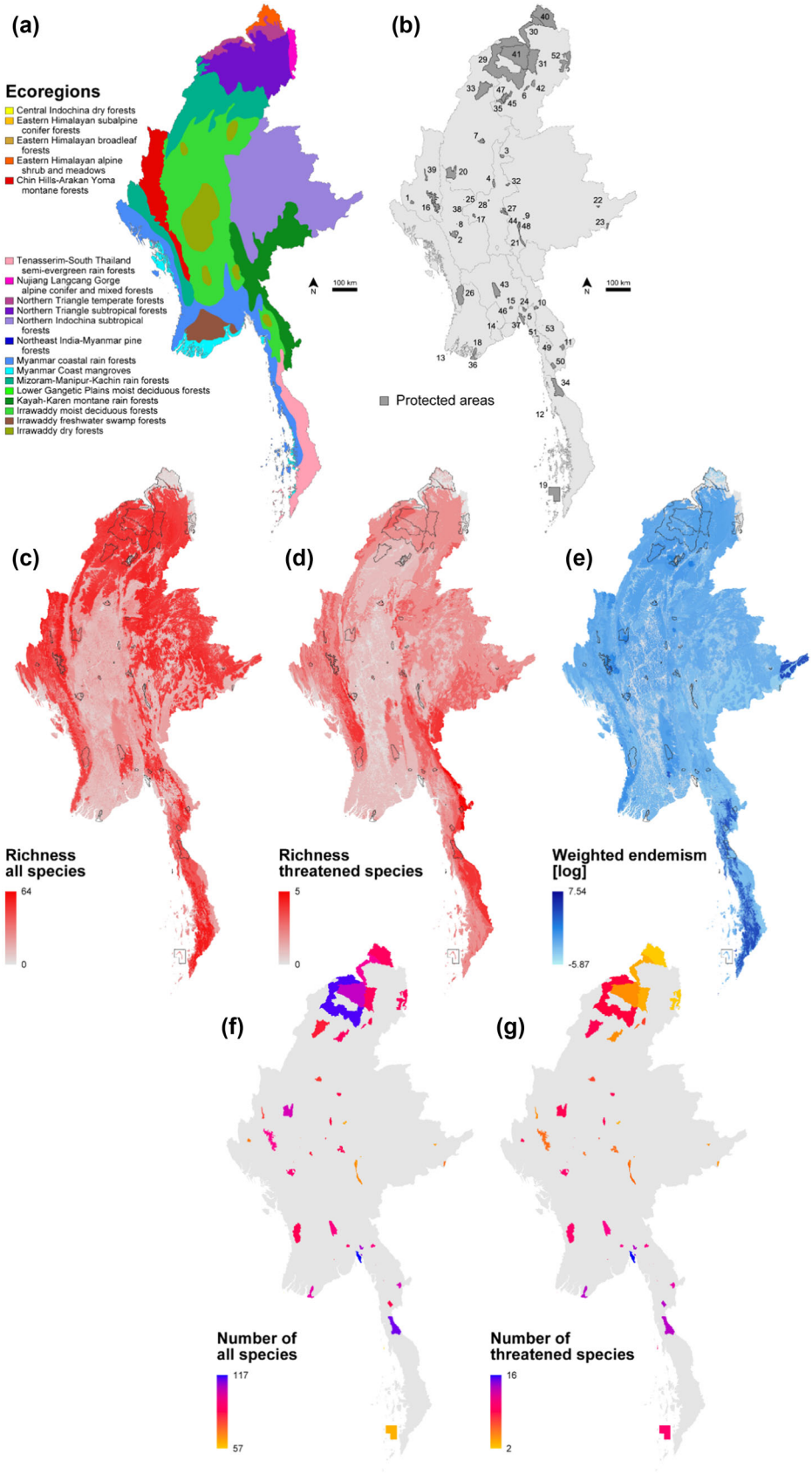

FIGURE 2 | Legend on next page.

remaining subpopulation consisting of less than a dozen mature individuals due to collection of eggs, juveniles, and adults, resulting in a similarly extreme decline in EOO and AOO while it is also threatened by a decline in habitat quality and extent due to gold dredging and a planned hydroelectric reservoir. The number of mature individuals of *C. chrysopylos* is below 1000. *Python kyaiktiyo* has a very restricted AOO. It is only known from one location, the Kyaiktiyo Wildlife Sanctuary at Yetagon Myaung, Mon State (IUCN 2022a). According to IUCN (2022a) it is heavily traded for skin, food, and medicine as well as illegal pet trade. *G. platynota* is listed under criterion A1cd. It was formerly Extinct In The Wild as there had been an extensive loss of individuals through over-collection and habitat loss. These reasons for the decline have now been ceased and the species has been successfully reintroduced. The testudines *Chitra vandijki, Morenia ocellata,* and *Nilssonia formosa* are listed under the criterion A2cd + 4 cd. They have and probably will further be experiencing population reduction continually caused by exploitation and habitat loss (IUCN 2022b).

3.5 | CITES

In total, 34 out of 212 (16.0%) assessed species are listed in the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) (Table 1). The turtle species *C. vandijki, G. platynota, M. ocellata* and *Platysternon megacephalum* and the crocodile *C. porosus* are listed in Appendix I. *B. trivittata, Cuora amboinensis, C. mouhotii, Cyclemys fusca, C. oldhamii, Dogania subplana, Gekko gecko, Heosemys depressa, H. grandis, H. spinosa, I. elongata, Lissemys punctata, L. scutata, M. macrocephala, M. emys, M. impressa, Melanochelys trijuga, Naja kaouthia, N. mandalayensis, N. siamensis, N. formosa, Ophiophagus hannah, Pelochelys cantorii, Python bivittatus, P. brongersmai, P. kyaiktiyo, Siebenrockiella crassicollis, Varanus dumerilii,* and *Varanus rudicollis* are listed in Appendix II (UNEP WCMC 2022b).

3.6 | In Situ Protection of Terrestrial Reptiles/ Protected Area Coverage

All species with available data are included. Species may not occur here if their distribution is not covered by PAs, if their habitats are not within PAs or if no habitat information is provided by IUCN. The distribution areas of 35 (16.5%) out of 212 analyzed terrestrial reptile species are not covered by PAs in Myanmar (Table 1). To provide a clearer overview the results of the protected area coverage analysis have been subclassified into threatened and DD species as well as threatened and DD endemic species.

First, of the 29 threatened species, 22 (75.8%) are covered by PAs. The currently known distribution of the threatened species *T. kanburiensis* lies outside of Myanmar and is therefore not covered by Burmese PAs (Figure S1). The other species are *Heosemys spinosa*, *L. punctata*, *M. emys*, *Pelochelys cantorii,* and *S. crassicollis* (all CE, Table 1, Figure S1). There is no habitat information provided by IUCN (2022a) for *Amyda ornata* (CE).

Of the 19 species listed as DD, 13 (68.4%) are covered by PAs. The distribution area of six (31.6%) species is outside of PAs: the gecko species *Cyrtodactylus consobrinoides, C. lenya, C. payarhtanensis*, the agamid species *Diploderma hamptoni*, and the colubrid snake species *Lycodon kundui* and *Oligodon hamptoni* (Table 1 and Figure S2). All these mentioned species are endemic.

Of the 22 non-threatened endemic species, 21 (95.5%) are covered by PAs. One species (4.5%), *Oligodon mcdougalli*, only occupies two relatively small habitats along the west coast, which are not covered by PAs (Table 1 and Figure S3). Of the 11 threatened endemic species, 10 (90.9%) are covered by PAs (Table 1).

Of the 212 analyzed species, 22 (10.3%) taxa were covered by only one PA (Table 1). This is 12.4% of all species covered by PAs ($n = 177$). Six of the 22 (27.2%) species are listed as threatened: two each VU, EN, and CR. Five (22.7%) are DD. Twelve (54.5%) species are endemic. Five (41.7%) of the mentioned threatened species are endemic. Two (16.7%) endemic species are DD.

Of all 212 analyzed species, 34 (16.0%) taxa are not covered by PAs (Table 1). Six of them (17.6%) are listed as threatened: one VU, three EN, and two CR. Six (17.6%) are DD. Eight (23.5%) species are endemic. One of those species, *T. kanburiensis*, is listed as EN (12.5%). All the mentioned DD species are endemic.

3.7 | Ex Situ Keeping of Burmese Reptiles

A total of 24 Burmese endemics and threatened terrestrial non-endemic reptile species occurring in Myanmar are kept in ex

FIGURE 2 | Maps of Myanmar showing (a) the 19 ecoregions according to Olson et al. (2001) and (b) protected areas of Myanmar after UNEP-WCMC (2022a): 1 = Shwesettaw WS; 2 = Shwe-U-Daung WS; 3 = Minwuntaung W. S.; 4 = Kaylatha WS; 5 = Pidaung WS; 6 = Chatthin WS; 7 = Wetthikan BS; 8 = Taunggyi B. S.; 9 = Kahilu WS; 10 = Mulayit WS; 11 = Moscos Islands WS; 12 = Thamihla Kyun WS; 13 = Hlawga Park; 14 = Moeyungyi Wetland WS; 15 = Natmataung NP; 16 = Popa Mountain Park; 17 = Meinmahla Kyun WS; 18 = Lampi Marine NP; 19 = Alaungdaw Katthapa NP; 20 = Inlay Lake WS; 21 = Loimwe PA; 22 = Parsar PA; 23 = Kyeikhtiyoe WS; 24 = Lawkananda Sanctuary; 25 = Rakhine Yoma Elephant Range; 26 = Panlaung and Padalin Cave WS; 27 = Minsontaung WS; 28 = Hukaung Valley WS (extension); 29 = Hponkanrazi WS; 30 = Bumpha Bum WS; 31 = Pyin-O-Lwin BS; 32 = Htamanthi WS; 33 = Taninthayi NR; 34 = Indawgyi WS; 35 = Meinmahla Kyun WS; 36 = Gulf of Mottama; 37 = Chungponkan WS; 38 = Bwe Par Taung NP; 39 = Hkakaborazi NP; 40 = Hugaung Valley WS; 41 = Inkhain Bum NP; 42 = North Zamrari WS; 43 = Inlay Lake WS; 44 = Indawgyi WS; 45 = Moyungyi Wetland WS; 46 = Indawgyi WS; 47 = Inlay Lake Ramsar Site; 48 = Hpabaubg Taung Managed NR; 49 = Se Taung WS; 50 = Htaungwi Taung Geo-features significant area; 51 = Emawbum NP; 52 = Ichasaya Cave WS; 53 = Kyauk Pan Taung WS. Species richness of Burmese reptiles: (c) all species, (d) threatened species, and (e) corrected weighted endemism. Number of species occurring in each protected area for (f) all species and (g) threatened species.

TABLE 1 | IUCN Red List categories of all species in numbers; Endemism (CE: country endemic; RE: regional endemic; ME: microendemic) sorted by IUCN Red List category, and protected area coverage of all species except *Amyda ornata* sorted by endemism and IUCN Red List category. Green background indicates the "not threatened" categories (LC, NT), yellow background indicates the "threatened" categories (VU, EN, CR), gray background indicates the "potentially threatened" category (DD), and yellow background indicates the sum of "threatened" and "potentially threatened" categories (VU, EN, CR, DD). Broader cells contain the sum of all cells bordering directly above, except when separated by a bold border. CITES listings sorted by Appendices (IUCN 2022a; UNEP WCMC 2022b).

			IUCN red list					
Threat status:		Status older than 10 years	LC	NT	VU	EN	CR	DD
			162	2	9	10	10	19
		80	Not threatened: 164		Threatened: 29			
					Threatened and potentially threatened: 48			
					212			
Endemism	Non-endemic:	67	142		18			8
					26			
					168			
	CE: 23 Endemic:	13	22		11			11
	RE: 17				22			
	ME: 4				44			
In situ: protected area (PA) coverage	Covered by one PA:	Endemic:	5		5			2
					12			
		Non-endemic:	6		1			3
					10			
		Total:	11		6			5
					11			
					22			
	Covered by one or more PA:	Endemic:	21		10			5
					36			
		Non-endemic:	121		12			8
					141			
		total:	142		22			13
					35			
					177			
	Not covered:	Endemic:	1		1			6
					8			
		Non- endemic:	21		5			0
					26			
		Total:	22		6			6
					12			
					34			
CITES	Total listed: 34	Appendix I:	5		Appendix II:			30

situ populations according to the ZIMS database (Table 2). Seven (29.2%) of them belong to the order Squamata and 17 (70.8%) to the Testudines.

Nineteen out of 26 (73.1%) threatened and potentially threatened non-endemic species are kept in zoos (Table 2). These are *Cuora amboinensis, C. mouhotii, Cyclemys oldhamii, Elaphe taeniura, H. depressa, H. grandis, H. spinosa, I. elongata, L. punctata, M. emys, M. impressa, Naja siamensis, Ophiophagus hannah, Pelochelys cantorii, Platysternon megacephalum, Python bivittatus, S. crassicollis*, *V. dumerilii,* and *V. rudicollis*. The largest population exists for *I. elongata* with 953 kept individuals worldwide. *P. cantorii* represents the smallest kept group with four individuals. Most threatened and potentially

TABLE 2 | ZIMS ex situ holdings and breeding successes in the last 12 months sorted by endemism and IUCN Red List threat status (Species360 2022b).

Order (endemicity)	species (IUCN assessment)	Continent	Institutions	Breeding success		Individuals			
				Institutions	Individuals	Male	Female	Other	Total
Testudines (non-endemic)	*Cuora amboinensis* (EN)	Asia	17	1	97	60	74	489	806
		Europe	29	3	5	39	44	63	
		North America	13	1	3	15	12	9	
		Oceania	1				1		
	Cuora mouhotii (EN)	Asia	5			5	8	4	56
		Europe	7	1	2	2	2	15	
		North America	5			5	7	8	
	Cyclemys oldhamii (EN)	Asia	3			3	5	3	13
		Europe	1					2	
	Heosemys depressa (CR)	Asia	1			1	2	1	34
		Europe	1			2	1		
		North America	5	1	2	7	11	9	
	Heosemys grandis (CR)	Asia	12	2	19	51	58	225	481
		Europe	19	1	5	23	33	55	
		North America	8			15	8	13	
	Heosemys spinosa (EN)	Asia	5			5	5	17	159
		Europe	16	1	1	20	21	15	
		North America	13	2	5	20	19	36	
		Oceania	1			1			
	Indotestudo elongata (CR)	Asia	17	3	140	120	152	508	953
		Europe	27	1	4	42	41	27	
		North America	10	1	2	18	7	13	
		Oceania	4	1	1	6	15	4	
	Lissemys punctata (VU)	Asia	8			34	42	43	121
		North America	1				2		
	Manouria emys (CR)	Asia	7	1	6	8	14	39	107
		Europe	6			0	4	15	
		North America	5			5	5	17	
	Manouria impressa (EN)	Asia	5			5	2	1	31

(Continues)

TABLE 2 | (Continued)

Order (endemicity)	species (IUCN assessment)	Continent	Institutions	Breeding success		Individuals			
				Institutions	Individuals	Male	Female	Other	Total
		Europe	1	1	2	1	3	3	
		North America	5	1	7	3	6	7	
	Pelochelys cantorii (CR)	Europe	2			1		3	4
	Platysternon megacephalum (CR)	Asia	3			3	1	21	57
		Europe	3	1	1	3	4	4	
		North America	6			2	4	15	
	Siebenrockiella crassicollis (EN)	Asia	10			11	9	31	121
		Europe	11	1	2	14	24	25	
		North America	2			3	2	2	
Testudines (endemic)	*Batagur trivittata* (CR)	Asia	1			9	12		21
	Geochelone platynota (CR)	Asia	8	1	1	65	20	24	299
		Europe	10			21	1	19	
		North America	19	2	17	52	47	50	
	Lissemys scutata (LC)	Asia	1					1	1
	Morenia ocellata (EN)	Asia	2					2	2
Squamata (non-endemic)	*Elaphe taeniura* (VU)	Asia	5			4	6	4	65
		Europe	22	1	2	17	14	17	
		North America	2			1	2		
	Naja siamensis (VU)	Asia	2			1	1	3	25
		Europe	2			2	2		
		North America	5			2	3	3	
		Oceania	1			5	3		
	Ophiophagus hannah (VU)	Africa	2			5	2		95
		Asia	9			14	7	2	
		Europe	9	1	4	7	6	4	
		North America	28	1	3	25	16	6	
		Oceania	1			1		0	
	Python bivittatus (VU)	Africa	7			5	9	16	458
		Asia	29	1	1	30	31	65	

(Continues)

TABLE 2 | (Continued)

Order (endemicity)	species (IUCN assessment)	Continent	Institutions	Breeding success		Individuals			
				Institutions	Individuals	Male	Female	Other	Total
		Europe	78			47	51	71	
		North America	61			43	31	10	
		Oceania	8	1	3	13	17	5	
		South America	10			10	4		
	Varanus dumerilii (DD)	Asia	1					2	10
		Europe	2			2	1	4	
		North America	1			1			
	Varanus rudicollis (DD)	Asia	2					2	12
		Europe	6			3	4	3	
Squamata (endemic)	*Trimeresurus kanburiensis* (EN)	Europe	3			2	1	3	7
		North America	1			1			

threatened non-endemic species are held in Asia and Europe ($n = 18$), followed by North America ($n = 16$), Oceania ($n = 6$), Africa ($n = 2$), and South America ($n = 1$) (Table 2). There have been breeding successes in the last 12 months for 13 threatened and potentially threatened non-endemic species (50.0%) (Table 2): *C. amboinensis, C. mouhotii, E. taeniura, H. depressa, H. grandis, H. spinosa, I. elongata, M. emys, M. impressa, O. hannah, P. megacephalum, P. bivittatus,* and *S. crassicollis*. *I. elongata* was bred in six institutions, *C. amboinensis* in five institutions. *H. grandis* and *H. spinosa* were each bred in three institutions, *M. impressa, O. hannah,* and *P. bivittatus* in two institutions each. *C. mouhotii*, *E. taeniura, H. depressa, M. emys, P. megacephalum,* and *S. crassicollis* were each bred in one institution.

Eight out of 29 (27.6%) threatened species are currently not represented in ex situ holdings (Table 3). The number of DD

TABLE 3 | Species listed as data deficient or threatened in the IUCN Red List and not currently represented in ex situ holdings (according to Species360 2022b).

Order	Species	IUCN status
Testudines	*Amyda ornata*	VU
	Chitra vandijki	CR
	Nilssonia formosa	CR
Squamata	*Blythia reticulata*	DD
	Cyrtodactylus brevidactylus	EN
	Cyrtodactylus chrysopylos	VU
	Cyrtodactylus consobrinoides	DD
	Cyrtodactylus feae	DD
	Cyrtodactylus lenya	DD
	Cyrtodactylus mandalayensis	DD
	Cyrtodactylus payarhtanensis	DD
	Cyrtodactylus russelli	DD
	Cyrtodactylus tamaiensis	DD
	Cyrtodactylus variegatus	DD
	Cyrtodactylus wakeorum	EN
	Diploderma hamptoni	DD
	Japalura sagittifera	DD
	Lycodon kundui	DD
	Naja mandalayensis	VU
	Oligodon hamptoni	DD
	Oligodon torquatus	DD
	Protobothrops kaulbacki	DD
	Python kyaiktiyo	VU
	Sibynophis bistrigatus	DD
	Trimeresurus medoensis	DD

species currently not represented in ex situ holdings is 17 out of 19 (89.5%) (Table 3).

Five (11.4%) out of 44 endemic species are kept in zoos according to ZIMS (Table 2): *G. platynota* with 299 individuals, *B. trivittata* with 21 individuals, *T. kanburiensis* with seven individuals, *M. ocellata* with two individuals, and *Lissemys scutata* with one individual. All except *T. kanburiensis* are held in Asia, *G. platynota* and *T. kanburiensis* have ex situ populations in Europe and North America. In all, 28.8% ($n = 86$) of *G. platynota* individuals are kept in the John L. Behler Chelonian Conservation Center. Only *G. platynota* had breeding successes in the last 12 months (Table 2). It was bred in the Singapore Zoo in Singapore, the Dallas Zoo in Texas, and in the afore mentioned John L. Behler Chelonian Conservation Center. The additional search in the zoo species list database did not generate any further results.

4 | Discussion

Our analysis of the reptile fauna of Myanmar revealed that there are currently 212 known terrestrial reptile species, which accounts for 1.8% of all globally recorded reptile species. This number highlights Myanmar as a global biodiversity hotspot. However, a Web of Science query with the terms Myanmar AND reptile* in March 2025 resulted in 89 papers, with 41 of them published after 2020 suggesting that the actual number might be higher as it can be expected that further research will result in the discovery of further taxa as research on the herpetofauna of Myanmar has only recently increased.

The richness analysis comprising all species disclosed that the highest richness can be found in the Northern Triangle subtropical forests, Mizoram–Manipur–Kachin rain forests, Northern Indochina subtropical forests, southern Tanintharyi Region in coastal and evergreen rain forests, the coastal and Mizoram–Manipur–Kachin rain forests and the Chin Hills–Arakan Yoma montane forests. Additionally, the Kayah–Karen montane and Tenesserim–South Thailand semi-evergreen rain forests are rich in threatened species. By comparing this distribution pattern with the allocation of the PAs in Myanmar, a discrepancy becomes evident. The currently established PAs are spread over the country, commonly not focusing on reptile species-rich areas. Areas hosting a high number of threatened reptiles in the eastern and southeastern regions reaching down the Malay Peninsula are lacking protection. The same applies to the areas there containing peaks in endemic species richness. The richness analysis focusing on species covered by PAs showed that the PAs in the south of Myanmar contain the highest number of threatened species. At the same time the total area covered by PAs in the south is very low compared to the ones in other areas of the country. To save a high number of threatened and endemic species it is recommended to prioritize the southern parts of Myanmar for conservation efforts in the shape of PA establishment.

Through our endemism analysis, we discovered that 44 of the 212 (20.8%) terrestrial reptile species of Myanmar are endemic. In total, 23 species of them (52.3%) are CE, 17 (38.6%) RE, and 4 (9.1%) microendemics.

Although ME species naturally have a higher extinction risk because their distribution range is very restricted, it was assumed that not all the analyzed ME are covered by an IUCN Red List threat status. Indeed, the analysis shows discrepancies. *Cyrtodactylus lenya* and *C. payarhtanensis* are ME species listed as DD. Due to their very restricted distribution pattern and missing PA coverage they are vulnerable to sudden changes in their environment and therefore are recommended to get an IUCN protection status. Additionally, in this context the species *C. consobrinoides* and *C. tamaiensis* also need to receive a protection status. They are listed as DD and are RE with very small regional distribution patterns, which are not covered by PAs.

It was assumed that all endemic species listed as LC in the IUCN Red List are at least CE or RE with a wider distribution. *Cyrtodactylus gansi*, *O. mcdougalli,* and *Sphenomorphus orientalis* are examples of LC species which are RE with rather restricted distributions. The habitats of *C. gansi* and *S. orientalis* are partly inside the Natmataung National Park in the west of Myanmar. *O. mcdougalli* only inhabits two relatively small spots at the coast not covered by PAs. Considering the current anthropogenic climate change and the resulting global sea level rise there is a potential risk of expulsion in the next decades or sooner. Small distribution areas generally hold an increased risk of that or even of extinction because human influences or natural events could quickly change the environment and in consequence the whole habitat of a species. Summing this up, the recommendation for *C. gansi* and *S. orientalis* is consideration to change their status to at least NT. The assessment for the classification of *O. mcdougalli* as LC has been made in 2011 and is therefore outdated. Considering the sparse distribution, a threatened category is recommended here to set a basis for further protection measures.

The analysis showed that 78.6% of all distribution areas of (potentially) threatened and endemic species are covered by PAs. The species *T. kanburiensis*, which is assumed to occur across the border, would be covered by the Taninthayi Nature Reserve. Therefore, it can be reasoned that all Burmese endemic species listed as threatened are covered by PAs. The distribution range of the CR *M. emys* and *Pelochelys cantorii* are not covered by PAs, which reveals the need for in situ protection. Focusing on DD and therefore potentially threatened taxa, the known distributions of six species, *Cyrtodactylus consobrinoides, C. lenya, C. payarhtanensis, D. hamptoni, L. kundui* and *O. hamptoni*, are outside of PAs. All of them are REs with highly restricted distribution areas, making them vulnerable to environmental changes. Hence, the recommendation for these species is to assign them as threatened species in the IUCN Red List to set a base for further conservation actions. Of the 22 evaluated endemic species which are listed as non-threatened (LC, NT) 21 are covered by PAs. The only taxon which is not is *O. mcdougalli*.

It was assumed that threatened endemic species are threatened by human impacts. There have been 11 cases in which the IUCN names a criterion as reason for their assessment: *B. trivittata, C. vandijki, C. brevidactylus*, *C. chrysopylos, C. wakeorum*, *G. platynota, N. mandalayensis*, *M. ocellata, N. formosa, Python kyaiktiyo* and *G. platynota*. In 10 out of 11 cases the

reasons for the threat status of the species were direct human impacts like rock extraction, logging, deforestation, commercial exploitation for food and medicine, over-collection, and illegal pet trade. These circumstances are threats that could drive the species to CR, EW, or EX in a short time. In the case of *C. chrysopylos* the very low number of mature individuals is referable to the restricted occurrence in a single cave. According to IUCN (2022a) threats in the surrounding forest are not likely to have significant impacts on this gecko. Nevertheless, research is recommended to confirm that the risk for extinction is not higher than presently recognized (IUCN 2022a).

Interestingly, the species *Cyrtodactylus chrysopylos* is listed as VU by IUCN (2022a), but the species in fact is quite common and seemingly deserves a listing update (L. Grismer, pers. comm.). Our data suggest a significant update of the species list retrieved from the IUCN Red List. The IUCN aim to update the status of species at least every 10 years was not realized in 37.7% of all reviewed cases, which highlights the fact that Myanmar is a country that is not in the focus of many researchers and nature conservationists around the world. In the 21st century there have been different field records and regional herpetological inventories (e.g., Levitón et al. 2003; Platt et al. 2018; Zug 2022), which are an important contribution to improve knowledge about the Burmese herpetofauna.

The CITES listing analysis revealed that only 34 out of 212 (16.0%) assessed species are listed. By assessing the threat status of all species, it becomes clear that there are more species that should be included in one of the convention's appendices. A suggested orientation for this is provided in the list of the 13 most threatened species (see Table 4).

The analysis confirmed that 10.4% of the analyzed species are only covered by a single PA. For non-endemic taxa listed as LC, this is usually sufficient since they are considered to be widely spread and protected in more than one country. Such a low level of protection is problematic for (potentially) threatened and endemic species. PAs are fixed in their location and therefore vulnerable to negative influences like human impacts or severe natural events. For a species in need of conservation, it is therefore beneficial to be protected by more than one PA. In Myanmar, the majority (54.5%) of species only covered by one PA are endemic. In all, 58.3% of those are (potentially) threatened: *B. trivittata*, *C. brevidactylus, C. chrysopylos, C. feae, C. tamaiensis, C. wakeorum*, and *Python kyaiktiyo*. Especially for these reptiles it would be beneficial to be protected in other distribution areas as well, in addition to the one PA they are currently living in.

The number of PAs in Myanmar is currently both below the global average of 15.1% and the 50% goal (Dinerstein et al. 2020). Since Myanmar is a biodiversity hotspot, applying this goal to the country could ensure the survival of rare threatened and endemic species, providing them with a safe space to grow in individual numbers and build stable populations, which would support the stability of the ecosystems.

The zoo database analysis confirmed that not all (potentially) threatened and endemic reptiles occurring in Myanmar are currently benefitting from One Plan Approach conservation. In total, 88.6% of endemics and 26.9% of (potentially) threatened non-endemic species are not kept in ex situ populations. The lists in the ex situ keeping results are suggested to serve as an overview of the species that would make sense to be kept and bred in stations or zoos, since they are either listed as threatened or DD and not currently represented in zoos around the world.

Non-endemic species that are kept in large numbers are not specifically restricted to Myanmar, and thus founders of ex situ populations may derive from other countries and not explicitly from Myanmar. This applies to *I. elongata, Cuora amboinensis, Python bivittatus, Heosemys grandis, H. spinosa, Lissemys punctata, S. crassicollis, M. emys, Ophiophagus hannah,* and *Elaphe taeniura*. For some species kept ex situ the problem is that a substantial proportion of the entire zoo population either consists of only male or female groups, single individuals or one single couple. This prevents or impedes breeding successes and will eventually lead to the death of the population held in those institutions if they do not choose to get fitting individuals or give their animals to other zoos with suitable population structures. This is the case for *Cyclemys oldhamii, Lissemys punctata, L. scutata, Naja siamensis, Manouria impressa, M. ocellata, Pelochelys cantorii, Varanus dumerilii*, *V. rudicollis,* and *T. kanburiensis*. The biggest population exists for *I. elongata* with 953 individuals. Approximately half of them ($n = 420$) live in the Angkor Centre for Conservation of Biodiversity. While such centers are a useful approach to increase the total number of individuals, in another step it would be important to distribute a number of those animals to other institutions and therefore establish more populations in different places, because in case of an emergency occurring to a particular conservation center a large portion of the ex situ population would be lost at once. The same applies for the Critically Endangered Myanmar Roofed Turtle, *B. trivittata*, that is considered one of the 25 most endangered turtle species. Once on the brink of extinction with fewer than a dozen individuals remaining, the species now numbers close to a thousand held individuals; and efforts to supplement wild populations are ongoing with experimental releases of head-started turtles (Stanford et al. 2018); a good example for the potential of One Plan Approach conservation through linking ex situ with in situ activities. Currently the ex situ population is mainly kept in four assurance colonies (three in Myanmar and one in Singapore), and there are only 12 individuals kept in ZIMS institutions.

The smallest populations are kept for the threatened and potentially threatened species *H. depressa* ($n = 34$) (CR), also listed among the 50 most threatened turtle species worldwide (Stanford et al. 2018); *M. impressa* ($n = 31$) (EN), *N. siamensis* ($n = 21$) (VU), *C. oldhamii* ($n = 13$) (EN), *V. rudicollis* ($n = 12$) (DD), *V. dumerilii* ($n = 10$) (DD), *P. cantorii* ($n = 4$) (CR), *M. ocellata* ($n = 2$) (EN), *L. scutata* ($n = 1$) (LC), and the Burmese RE *T. kanburiensis* ($n = 7$) (EN). For those species it would make sense to build larger and more stable assurance populations. The only endemic taxa kept are *B. trivittata, G. platynota, L. scutata, M. ocellata,* and *T. kanburiensis*. In total, 28.8% of all kept individuals of *G. platynota* are part of one conservation center. *G. platynota*, the Burmese Star Tortoise, endemic to the dry zone of central Myanmar, represents another example of successful ex situ conservation breeding (Figure 3). The species is listed as Critically Endangered by the IUCN Red

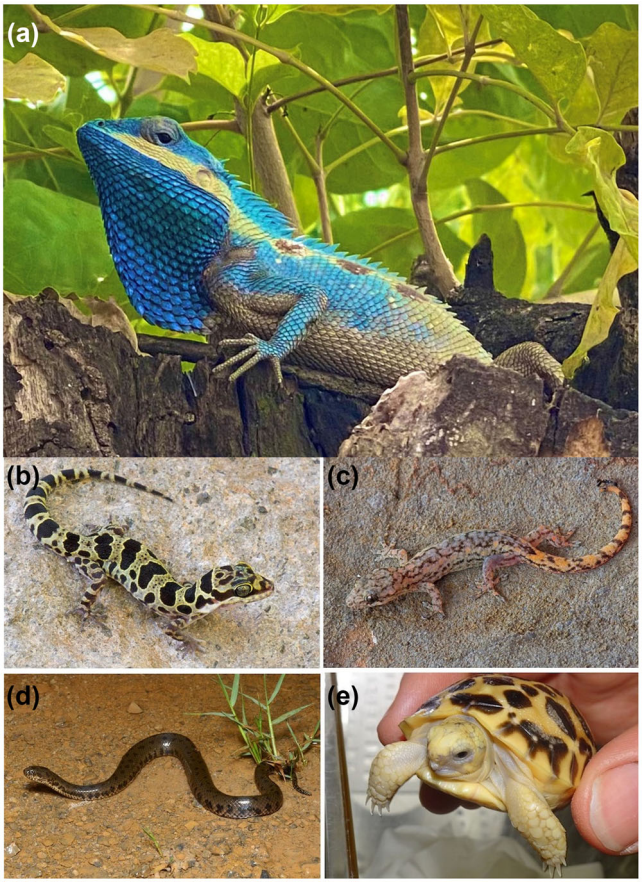

FIGURE 3 | (a) *Calotes goetzi*, a taxon widely distributed in Myanmar (photo: L. L. Grismer). (b) *Cyrtodactylus myintkyawthurai*, (c) *Hemiphyllodactylus montawaensis,* and (d) *Gyiophis salweenensis*, just recently described, microendemic taxa not yet covered by any protective measures (photos: L. L. Grismer). (e) *Geochelone platynota* offspring from Cologne Zoo, an example for successful ex situ keeping and conservation breeding of threatened species (photo: T. Ziegler).

List and a few years ago it was considered to be functionally extinct in the wild. The reasons for this were mainly collection of individuals for food, for the use in traditional Asian medicine and for the international pet trade as well as destruction of its habitat. In a last attempt to prevent the species from extinction, a National Action Plan was established in 2012. The species was successfully reproduced in large numbers in captive breeding centers in Myanmar and subsequently reintroduced to two closely guarded wildlife sanctuary sites resulting in an increasing, breeding population (Platt et al. 2017; Stanford et al. 2018). Being among the 25+ most threatened turtle species worldwide, *G. platynota* was also prioritized in the Regional Collection Plan for Chelonians by the EAZA (Goetz et al. 2019). The first ex situ breeding events in European zoos succeeded in 2011 in Rotterdam Zoo and Zájezd Zoo Park. Subsequently, in 2018 the species was bred in Cologne Zoo, with the parent individuals deriving from a large confiscation in 2011 (Rauhaus et al. 2021). The rescue and subsequent breeding of these individuals that were most likely stolen either from one of the breeding centers in Myanmar or caught from the wild for the illegal pet trade could finally contribute to the establishment of an official European Endangered Species Program (EEP) to build up a managed assurance colony among European zoos.

Today, the species is held in 10 European zoos. Ex situ colonies outside of the origin country could prove important in the future to serve as additional assurance populations, for example, in case of disease outbreaks or in the current situation of political unrest in Myanmar. For most endemic species, there is no ex situ conservation at all. For ME, threatened or potentially threatened species such as *C. brevidactylus, C. chrysopylos, C. lenya,* and *C. payarhtanensis* this means a considerable risk for extinction if their current habitat becomes uninhabitable. For these species it is strongly recommended to establish populations in zoos as soon as possible. Also, the attempt for REs should be to build populations in zoos since many of them only inhabit small regional areas which are not covered by PAs. This is the case for *O. mcdougalli, C. consobrinoides, C. tamaiensis, D. hamptomi, L. kundui,* and *O. hamptoni*.

The fact that Burmese ecosystems are widely undisturbed and understudied highlights potential for more research in this country. There are many species whose presence in Myanmar is uncertain and there are also species that are yet undescribed and therefore not listed at all in the IUCN Red List and in this study.

Summing up the results of the analyses of this study, a list was created containing the 13 species that are most in need of conservation efforts (Table 4). Not included in our analyses was *Trimeresurus ayeyarwadyensis*, a species which just recently was described after our analyses were already done and the manuscript finalized (Chan et al. 2023). The species so far was found at Hlawga Park in the Yangon region and Pyapon and Myaungmya districts in the Ayeyarwady region. It is a good example underlining the previously mentioned, widely unexplored state of Burmese herpetodiversity.

5 | Conclusions

Our analysis of Myanmar's reptile fauna highlights both the high biodiversity of the country and its existing protection gaps. Myanmar is a major biodiversity hotspot although research efforts on its herpetofauna have just started and future research will likely result in higher species numbers. Despite the relatively even species richness within the country, our results suggest that threatened and endemic species often occur in regions with low protected area coverage, especially in the southern and eastern parts of the country. Nearly 25% of the assessed species are considered threatened or potentially threatened, according to the IUCN. Especially among endemics of which about 30% are not covered by protected areas. Our results highlight that IUCN's One Plan Approach is currently not sufficiently implemented for Myanmar's reptiles. While almost 50% of threatened or potentially threatened species are in zoological facilities, the majority of endemic species are absent from ex situ programs which could be important back-up populations. Focus of further efforts should be on species characterized by small distribution areas to develop long-term conservation strategies. Our study shows the urgent need for better integration of protected areas with targeted species conservation programs closing conservation gaps to secure Myanmar's reptile population in the long term.

TABLE 4 | Top 13 list of terrestrial reptile species that are most in need of conservation efforts with their current IUCN Red List status, grade of endemism (if available), PA coverage (C (1) = covered by one PA; NC = not covered), threats (if available), and recommended conservation actions.

Species Name	IUCN status	Grade of endemism	PA coverage	Threats	Recommended conservation actions
Cyrtodactylus brevidactylus	EN	ME	C (1)	Rock extraction; hotel construction.	Ex situ conservation.
Cyrtodactylus chrysopylos	VU	ME	C (1)		Research to identify threats in the surrounding forest; ex situ conservation.
Cyrtodactylus lenya	DD	ME	NC		PA coverage; IUCN threat status; ex situ conservation.
Cyrtodactylus payarhtanensis	DD	ME	NC		PA coverage; IUCN threat status; ex situ conservation.
Oligodon mcdougalli	LC	RE	NC		PA coverage; IUCN threat status (needs update); ex situ conservation.
Cyrtodactylus consobrinoides	DD	RE	NC		PA coverage; IUCN threat status; ex situ conservation.
Cyrtodactylus tamaiensis	DD	RE	NC		PA coverage; IUCN threat status; ex situ conservation.
Manouria emys	CR		NC	Exploitation; forest loss; subsistence collection; poaching.	PA coverage; education and protection projects in situ.
Diploderma hamptoni	DD	RE	NC		PA coverage; IUCN threat status; ex situ conservation.
Lycodon kundui	DD	RE	NC		PA coverage; IUCN threat status; ex situ conservation.
Oligodon hamptoni	DD	RE	NC		PA coverage; IUCN threat status; ex situ conservation.
Cyrtodactylus wakeorum	EN	RE	C (1)	Logging.	More PA coverage; ex situ conservation.
Python kyaiktiyo	VU	RE	C (1)	Trade; used as medicine; illegal pet trade.	Research; education and protection projects in situ; ex situ conservation.

Author Contributions

Carolin Scholten: writing – original draft, visualization, investigation, formal analysis, data curation. **Aurelia Richter:** writing – review and editing, investigation, formal analysis, data curation. **Aung Lin:** writing – review and editing, validation. **Myint Kyaw Thura:** validation, writing – review and editing. **Anna Rauhaus:** methodology, writing – review and editing, resources, investigation. **Lee Grismer:** investigation, writing – review and editing, validation, data curation. **Thomas Ziegler:** conceptualization, writing – review and editing, supervision, resources, validation, project administration. **Dennis Rödder:** methodology, conceptualization, writing – review and editing, visualization, software, formal analysis, supervision, data curation, project administration.

Acknowledgements

We are grateful to Morris Flecks who helped with the design of the figures. Comments of Ahimsa Campos-Arceiz, Luu Vinh, Pham The Cuong, and Ursula Bott helped to improve the manuscript.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are available from ZIMS. Restrictions apply to the availability of these data, which were used under license for this study. Data are available from the author(s) with the permission of ZIMS.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section.

Appendix

See Table A1.

TABLE A1 | List of terrestrial reptile species occurring in Myanmar with IUCN Red List status, population trend, and references; endemic species are marked in bold.

Species name	IUCN status	Population trend	References
Acanthosaura crucigera	LC	Unknown	IUCN (2022a), Uetz et al. (2021), Trivalairat et al. (2020)
Acanthosaura lepidogaster	LC	Unknown	IUCN (2022a), Uetz et al. (2021)
Ahaetulla nasuta	LC	Stable	IUCN (2022a)
Ahaetulla prasina	LC	Stable	IUCN (2022a)
Archelaphe bella	LC	Unknown	IUCN (2022a), Schulz et al. (2011)
Argyrophis diardii	LC	Stable	IUCN (2022a), Uetz (2021b), Zug and Mulcahy (2020)
Argyrophis muelleri	LC	Unknown	IUCN (2022a)
Azemiops feae	LC	Unknown	Levitón et al. (2003)
Blythia reticulata	DD	Unknown	IUCN (2022a), Uetz et al. (2021), Biakzuala et al. (2021)
Boiga cyanea	LC	Stable	IUCN (2022a), Uetz et al. (2021)
Boiga multomaculata	LC	Stable	IUCN (2022a), Uetz et al. (2021)
Boiga ochracea	LC	Unknown	IUCN (2022a)
Boiga quincunciata	LC	Unknown	IUCN (2022a), Uetz (2021), Ganesh et al. (2021)
Boiga siamensis	LC	Unknown	IUCN (2022a), Uetz (2021)
Boiga walli	LC	Unknown	IUCN (2022a)
Bronchocela burmana	LC	Unknown	IUCN (2022a), Uetz (2021b), Mulcahy et al. (2021)
Bungarus bungaroides	LC	Unknown	Levitón et al. (2003)
Bungarus fasciatus	LC	Stable	Levitón et al. (2003)
Bungarus flaviceps	LC	Unknown	Levitón et al. (2003)
Bungarus magnimaculatus	LC	Unknown	Levitón et al. (2003)
Bungarus multicinctus	LC	Decreasing	IUCN (2022a)
Bungarus niger	LC	Unknown	IUCN (2022a)
Calamaria pavimentata	LC	Unknown	IUCN (2022a), Uetz (2021b), Hecht et al. (2013)
Calliophis maculiceps	LC	Unknown	Levitón et al. (2003)
Calotes chincollium	LC	Stable	IUCN (2022a), Uetz (2021), Vindum et al. (2003)
Calotes emma	LC	Stable	IUCN (2022a), Uetz (2021), Saijuntha et al. (2020)
Calotes htunwini	LC	Unknown	IUCN (2022a), Uetz (2021), Gowande et al. (2021)
Calotes irawadi	LC	Unknown	IUCN (2022a), Uetz (2021), Gowande et al. (2021)
Calotes jerdoni	LC	Unknown	IUCN (2022a), Uetz (2021), Giri et al. (2019)
Calotes mystaceus	LC	Stable	IUCN (2022a), Uetz (2021), Hartmann et al. (2013)
Calotes versicolor	LC	Stable	IUCN (2022a), Uetz (2021), Zug et al. (2010)
Chrysopelea ornata	LC	Stable	IUCN (2022a), Uetz (2021)
Chrysopelea paradisi	LC	Stable	IUCN (2022a)
Cnemaspis siamensis	LC	Stable	IUCN (2022a), Uetz (2021b), Khandekar et al. (2020)
Coelognathus flavolineatus	LC	Stable	IUCN (2022a), Uetz (2021)

(Continues)

TABLE A1 | (Continued)

Species name	IUCN status	Population trend	References
Coelognathus radiatus	LC	Unknown	IUCN (2022a), Uetz (2021)
Cristidorsa planidorsata	LC	Decreasing	IUCN (2022a), Uetz (2021)
Cyrtodactylus annandalei	LC	Unknown	IUCN (2022a), Uetz (2021), Liu and Rao (2021)
Cyrtodactylus ayeyarwadyensis	NT	Unknown	IUCN (2022a)
Cyrtodactylus brevidactylus	EN	Unknown	IUCN (2022a), Uetz (2021), Liu and Rao (2021)
Cyrtodactylus brevipalmatus	LC	Unknown	IUCN (2022a)
Cyrtodactylus chrysopylos	VU	Unknown	IUCN (2022a), Uetz (2021), Liu and Rao (2021)
Cyrtodactylus consobrinoides	DD	Unknown	IUCN (2022a), Uetz (2021)
Cyrtodactylus feae	DD	Unknown	IUCN (2022a), Uetz (2021), Liu and Rao (2021)
Cyrtodactylus gansi	LC	Unknown	IUCN (2022a), Uetz (2021), Liu and Rao (2021)
Cyrtodactylus lenya	DD	Unknown	IUCN (2022a), Uetz (2021), Connette et al. (2017)
Cyrtodactylus mandalayensis	DD	Unknown	IUCN (2022a), Uetz (2021), Mahony (2009)
Cyrtodactylus oldhami	LC	Stable	IUCN (2022a), Uetz (2021)
Cyrtodactylus payarhtanensis	DD	Unknown	IUCN (2022a), Uetz (2021)
Cyrtodactylus peguensis	LC	Unknown	IUCN (2022a), Uetz (2021), Liu and Rao (2021)
Cyrtodactylus russelli	DD	Unknown	IUCN (2022a), Uetz (2021), Liu and Rao (2021)
Cyrtodactylus slowinskii	LC	Unknown	IUCN (2022a), Uetz (2021), Liu and Rao (2021)
Cyrtodactylus tamaiensis	DD	Unknown	IUCN (2022a), Uetz (2021), Mahony (2009)
Cyrtodactylus variegatus	DD	Unknown	IUCN (2022a), Kunya et al. (2014), Das (2010)
Cyrtodactylus wakeorum	EN	Unknown	IUCN (2022a), Uetz (2021), Bauer (2003)
Daboia siamensis	LC	Decreasing	IUCN (2022a), Uetz (2021)
Dasia olivacea	LC	Stable	IUCN (2022a), Uetz (2021), Geissler and Kupfer (2019)
Dendrelaphis biloreatus	LC	Unknown	IUCN (2022a)
Dendrelaphis cyanochloris	LC	Unknown	IUCN (2022a), Uetz (2021)
Dendrelaphis nigroserratus	LC	Unknown	IUCN (2022a), Uetz (2021)
Dendrelaphis pictus	LC	Unknown	IUCN (2022a), Uetz (2021)
Dendrelaphis subocularis	LC	Unknown	IUCN (2022a), Uetz (2021)
Dendrelaphis walli	LC	Unknown	IUCN (2022a), Uetz (2021)
Diploderma hamptoni	DD	Unknown	IUCN (2022a), Uetz (2021), Denzer et al. (2019)
Dopasia gracilis	LC	Decreasing	IUCN (2022a), Uetz (2021)
Draco blanfordii	LC	Stable	IUCN (2022a), Uetz (2021), Wogan et al. (2008)
Draco maculatus	LC	Decreasing	IUCN (2022a), Uetz (2021)
Draco taeniopterus	LC	Unknown	IUCN (2022a), Uetz (2021), Goldberg and Grismer (2015)
Elaphe cantoris	LC	Stable	IUCN (2022a), Uetz (2021)
Elaphe taeniura	VU	Decreasing	IUCN (2022a)
Euprepiophis mandarinus	LC	Decreasing	IUCN (2022a)
Eutropis dissimilis	LC	Unknown	IUCN (2022a), Datta-Roy et al. (2015)
Eutropis multifasciata	LC	Stable	IUCN (2022a), Uetz (2021), Barley et al. (2015)
Eutropis quadricarinata	LC	Unknown	IUCN (2022a), Uetz (2021), Amarasinghe et al. (2017)
Eutropis rudis	LC	Stable	IUCN (2022a), Amarasinghe et al. (2020)
Gehyra mutilata	LC	Stable	IUCN (2022a)
Gekko gecko	LC	Unknown	IUCN (2022a), Uetz (2021)
Gekko kuhli	LC	Stable	IUCN (2022a), Uetz (2021)

(Continues)

TABLE A1 | (Continued)

Species name	IUCN status	Population trend	References
Gekko lionotum	LC	Stable	IUCN (2022a), Uetz (2021)
Geochelone platynota	CR	Increasing	IUCN (2022a)
Gongylosoma scripta	LC	Unknown	IUCN (2022a)
Gonyosoma oxycephalum	LC	Decreasing	IUCN (2022a), Uetz (2021)
Gonyosoma prasinum	LC	Unknown	IUCN (2022a), David et al. (2022)
Hebius clerki	LC	Unknown	IUCN (2022a), Uetz (2021)
Hebius modestus	LC	Unknown	IUCN (2022a), Uetz (2021), David et al. (2021)
Hemidactylus aquilonius	LC	Unknown	IUCN (2022a), Uetz (2021)
Hemidactylus brookii	LC	Unknown	IUCN (2022a), Uetz (2021)
Hemidactylus frenatus	LC	Stable	IUCN (2022a), Uetz (2021), Bauer et al. (2013)
Hemidactylus garnotii	LC	Stable	IUCN (2022a), Uetz (2021), Bauer et al. (2013)
Hemidactylus karenorum	LC	Stable	IUCN (2022a); Uetz (2021); Srianthan et al. (2018)
Hemidactylus platyurus	LC	Increasing	IUCN (2022a), Uetz (2021), Zug et al. (2007)
Hemidactylus tenkatei	LC	Unknown	IUCN (2022a), Uetz (2021), Mahony (2011)
Hemidactylus thayene	LC	Stable	IUCN (2022a), Uetz (2021), Rösler and Scheidt (2013)
Hemiphyllodactylus yunnanensis	LC	Unknown	IUCN (2022a), Uetz (2021), Heinicke et al. (2011)
Indotestudo elongata	CR	Decreasing	Zug (2022)
Indotyphlops albiceps	LC	Unknown	IUCN (2022a), Neang et al. (2017)
Indotyphlops braminus	LC	Increasing	IUCN (2022a)
Indotyphlops jerdoni	LC	Unknown	IUCN (2022a), Uetz (2021)
Indotyphlops porrectus	LC	Unknown	IUCN (2022a), Uetz (2021)
Isopachys borealis	LC	Unknown	IUCN (2022a), Uetz (2021)
Japalura sagittifera	DD	Unknown	IUCN (2022a), Uetz (2021), Denzer et al. (2019)
Leiolepis belliana	LC	Stable	IUCN (2022a), Uetz (2021), Ananjeva et al. (2007)
Leiolepis peguensis	LC	Unknown	IUCN (2022a), Uetz (2021), Promnun et al. (2021)
Liopeltis frenatus	LC	Unknown	IUCN (2022a)
Liopeltis stoliczkae	LC	Unknown	IUCN (2022a)
Lipinia vittigera	LC	Unknown	IUCN (2022a), Uetz (2021), Bucklitsch et al. (2012)
Lycodon aulicus	LC	Stable	IUCN (2022a)
Lycodon capucinus	LC	Stable	IUCN (2022a), Uetz (2021); Ngo et al. (2022)
Lycodon davisonii	LC	Stable	IUCN (2022a)
Lycodon fasciatus	LC	Stable	IUCN (2022a)
Lycodon jara	LC	Stable	Wogan et al. (2008)
Lycodon kundui	DD	Unknown	IUCN (2022a)
Lycodon septentrionalis	LC	Unknown	IUCN (2022a), Neang et al. (2014)
Lycodon subcinctus	LC		Wogan et al. (2008)
Lycodon zawi	LC	Unknown	IUCN (2022a)
Lygosoma albopunctata	LC	Unknown	IUCN (2022a)
Lygosoma anguinum	LC	Unknown	IUCN (2022a), Uetz (2021), Zug and Miller (2016)
Lygosoma haroldyoungi	LC	Unknown	IUCN (2022a), Uetz (2021), Chuaynkern et al. (2013)
Lygosoma lineolatum	LC	Stable	IUCN (2022a), Uetz (2021)
Lygosoma popae	LC	Unknown	IUCN (2022a), Uetz (2021)
Manouria emys	CR	Decreasing	Zug (2022)

(Continues)

TABLE A1 | (Continued)

Species name	IUCN status	Population trend	References
Manouria impressa	EN	Decreasing	Zug (2022)
Naja kaouthia	LC	Decreasing	Levitón et al. (2003)
Naja mandalayensis	VU	Decreasing	Levitón et al. (2003)
Naja siamensis	VU	Decreasing	IUCN (2022a)
Oligodon albocinctus	LC	Unknown	IUCN (2022a), Uetz (2021), Hasan et al. (2013)
Oligodon catenatus	LC	Decreasing	IUCN (2022a), Uetz (2021)
Oligodon cinereus	LC	Stable	IUCN (2022a), Uetz (2021)
Oligodon cruentatus	LC	Unknown	IUCN (2022a), Uetz (2021)
Oligodon cyclurus	LC	Stable	IUCN (2022a)
Oligodon dorsalis	LC	Stable	IUCN (2022a), Uetz (2021)
Oligodon fasciolatus	LC	Stable	IUCN (2022a), Uetz (2021)
Oligodon hamptoni	DD	Unknown	IUCN (2022a)
Oligodon mcdougalli	LC	Unknown	IUCN (2022a)
Oligodon planiceps	LC	Unknown	IUCN (2022a), Green (2010)
Oligodon splendidus	LC	Unknown	IUCN (2022a)
Oligodon theobaldi	LC	Decreasing	IUCN (2022a), Green (2010)
Oligodon torquatus	DD	Decreasing	IUCN (2022a)
Ophiophagus hannah	VU	Decreasing	IUCN (2022a)
Oreocryptophis porphyraceus	LC	Unknown	IUCN (2022a), Uetz (2021)
Ovophis monticola	LC	Unknown	Levitón et al. (2003)
Pareas carinatus	LC	Decreasing	IUCN (2022a)
Pareas hamptoni	LC	Unknown	IUCN (2022a), Uetz (2021), Vogel (2010)
Pareas margaritophorus	LC	Stable	IUCN (2022a), Vogel et al. (2020)
Pareas monticola	LC	Stable	Wogan et al. (2008)
Plagiopholis blakewayi	LC	Unknown	IUCN (2022a), Uetz (2021)
Plagiopholis nuchalis	LC	Unknown	IUCN (2022a), Uetz (2021)
Protobothrops jerdonii	LC	Unknown	Levitón et al. (2003)
Protobothrops kaulbacki	DD	Unknown	Levitón et al. (2003)
Protobothrops mucrosquamatus	LC	Unknown	Levitón et al. (2003)
Psammodynastes pulverulentus	LC	Stable	IUCN (2022a), Miller and Zug (2016)
Psammophis indochinensis	LC	Stable	IUCN (2022a), Uetz (2021), Hartmann et al. (2011)
Pseudocalotes kakhienensis	LC	Unknown	IUCN (2022a), Uetz (2021)
Pseudocalotes kingdonwardi	LC	Stable	IUCN (2022a), Uetz (2021), Ananjeva et al. (2007)
Pseudocalotes kingdonwardi	LC	Unknown	IUCN (2022a), Uetz (2021), Harvey et al. (2017)
Pseudoxenodon macrops	LC	Unknown	IUCN (2022a), Uetz (2021)
Ptyas doriae	LC	Stable	IUCN (2022a), Meetei et al. (2018)
Ptyas korros	NT	Decreasing	IUCN (2022a), Uetz (2021)
Ptyas mucosa	LC	Decreasing	IUCN (2022a)
Ptyas nigromarginata	LC	Decreasing	IUCN (2022a), Uetz (2021), Gernot and Sjon (2013)
Ptyctolaemus collicristatus	LC	Unknown	IUCN (2022a), Uetz (2021), Schulte et al. (2004)
Ptyctolaemus gularis	LC	Stable	IUCN (2022a), Uetz (2021), Karunarathna et al. (2020)
Python bivittatus	VU	Decreasing	IUCN (2022a)
Python brongersmai	LC	Increasing	IUCN (2022a), Zug et al. (2011)

(Continues)

TABLE A1 | (Continued)

Species name	IUCN status	Population trend	References
Python kyaiktiyo	VU	Unknown	IUCN (2022a), Uetz (2021), Zug et al. (2011)
Rhabdophis himalayanus	LC	Unknown	IUCN (2022a), Uetz (2021), Das et al. (2021)
Scincella doriae	LC	Unknown	IUCN (2022a), Uetz (2021), Datta-Roy et al. (2013)
Scincella melanosticta	LC	Stable	IUCN (2022a), Uetz (2021)
Scincella punctatolineata	LC	Unknown	IUCN (2022a), Uetz (2021)
Scincella reevesii	LC	Stable	IUCN (2022a), Uetz (2021), Datta-Roy et al. (2013)
Scincella victoriana	LC	Stable	IUCN (2022a), Uetz (2021), Wogan et al. (2008)
Sibynophis bistrigatus	DD	Unknown	IUCN (2022a), Uetz (2021), Wogan et al. (2008)
Sibynophis collaris	LC	Unknown	IUCN (2022a), Uetz (2021)
Sinomicrurus macclellandi	LC	Unknown	Levitón et al. (2003), IUCN (2022a), Mirza et al. (2020)
Sphenomorphus indicus	LC	Stable	IUCN (2022a), Uetz (2021), T. Nguyen et al. (2015)
Sphenomorphus orientalis	LC	Stable	IUCN (2022a), Uetz (2021)
Subdoluseps bowringii	LC	Stable	IUCN (2022a); Uetz (2021)
Takydromus sexlineatus	LC	Stable	IUCN (2022a), Uetz (2021)
Toenayar novemcarinata	LC	Stable	IUCN (2022a), Uetz (2021)
Trimeresurus albolabris	LC	Stable	Levitón et al. (2003)
Trimeresurus erythrurus	LC	Stable	Levitón et al. (2003)
Trimeresurus fucatus	LC	Unknown	IUCN (2022a), Uetz (2021), Vogel et al. (2004)
Trimeresurus gumprechti	LC	Stable	IUCN (2022a), Uetz (2021)
Trimeresurus kanburiensis	EN	Unknown	IUCN (2022a), Sumontha et al. (2021)
Trimeresurus medoensis	DD	Unknown	Levitón et al. (2003)
Trimeresurus popeiorum	LC	Unknown	Levitón et al. (2003)
Trimeresurus purpureomaculatus	LC	Stable	Levitón et al. (2003)
Trimeresurus stejnegeri	LC	Stable	Levitón et al. (2003)
Varanus dumerilii	DD	Unknown	IUCN (2022a), Uetz (2021), Koch et al. (2013)
Varanus rudicollis	DD	Unknown	IUCN (2022a), Uetz (2021), Koch et al. (2013)
Xenopeltis unicolor	LC	Stable	IUCN (2022a), Uetz (2021)