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Research Article

Assessment of the threat status of reptile species from Vietnam - Implementation of the One Plan Approach to Conservation

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Abstract

Since the world is currently in the midst of a major biodiversity crisis, scientists have assigned high conservation priority to 36 biodiversity hotspots around the world. As part of one of the leading hotspots in terms of species richness and local endemism, Vietnam is considered a country with high conservation priority. The reptile fauna of Vietnam is known for its high level of diversity and an outstanding number of endemic species. Vietnamese reptiles are highly threatened due to habitat loss and overharvesting for domestic and international trade, traditional medicine and food, making them a group of great conservation concern. As a baseline for improved reptile conservation in Vietnam, we conducted a conservation assessment of Vietnamese reptile species by evaluating data from a variety of sources. Our study results show that approximately 32.9% (n = 159) of the total reptile species (n = 484) present in Vietnam are endemic to the country, of which more than half are only known from their type locality and about one-third restricted to a particular subregion, making the species particularly vulnerable to threats. Furthermore, 33.5% (n = 53) of 158 endemic taxa included in the protected area analysis have not yet been recorded from any protected area. Among all 418 Vietnamese reptile species listed on the IUCN Red List, 17.7% (n = 74) are threatened with extinction, 46.0% (n = 34) of the total 74 threatened species are endemic to Vietnam. The fact that 135 species are either listed as DD or have not yet been evaluated by the IUCN highlights the urgency of further research. Moreover, only very few species are protected by national or international legislation, and further assessments are needed to protect reptiles of particular concern. A Zoological Information Management System (ZIMS) analysis revealed that 22.5% (n = 109) of all reptiles occurring in Vietnam and only 6.3% (n = 10) of the endemic Vietnamese reptiles are currently kept in zoos worldwide. Although 60.8% (n = 45) of the threatened reptiles (n = 74) from Vietnam are currently held in zoos, only 23.5 (n = 8) of the endemic threatened species (n = 34) are held there. Following the IUCN CPSG`s One Plan Approach to Conservation, it is therefore recommended to increase the number of threatened and endemic species in breeding stations and zoos to maintain assurance populations, suitable for restocking measures.

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Despite ongoing efforts in Vietnam, further conservation measures are required. We therefore also identify areas of highest reptile diversity and with the largest number of threatened species and provide a list of 50 most threatened species (10% of total species) as a guide for further research and conservation action in Vietnam.

Key words: Conservation breeding, diversity, endemic species, protected area coverage, reptile conservation, threat analysis, Vietnam

Introduction

The world is currently in the midst of a major biodiversity crisis, associated with significant biodiversity loss and extinction rates far outpacing normal background extinction rates. While some predict a sixth mass extinction, others fear that we may be right in the midst of it already (Barnosky et al. 2011; Pievani et al. 2014; Ceballos et al. 2015; McCallum 2015; Ceballos et al. 2017). Our planet's biodiversity is changing immensely, and at a pace that would not have occurred without humankind's influence (Pimm et al. 1995; Cowie et al. 2022; Rull 2022). At this rate, up to one million plant and animal species could disappear (IPEBS 2019; Tollefson 2019), and extinction rates are expected to be even higher due to numerous species still remaining unidentified (Lees and Pimm 2015; Melville et al. 2021).

As the number of threatened species in need of conservation efforts is greater than the available resources, it is important to prioritize most threatened taxa and areas with the greatest number of endemic and threatened species. To this end, regions with high levels of biodiversity and facing critical anthropogenic threats have been identified (Myers et al. 2000). To date, 36 global biodiversity hotspots characterized by significant habitat loss have been assigned a high priority for conservation (Myers et al. 2000). Many of them may face significant future threats due to increased anthropogenic pressure and climate change effects (Cremene et al. 2005; Malcolm et al. 2006; Habel et al. 2019).

One of the leading hotspots in terms of endemism is the Indo-Burma region, which is composed of southern China and the mainland of Southeast Asia, including Vietnam (Myers et al. 2000). Due to its high level of endemism combined with the accelerating rate of habitat loss and overexploitation, Vietnam is considered a country with top conservation priority (Myers et al. 2000; Sterling et al. 2006). The country possesses a broad variety of rare and endemic species and its herpetofauna has been recognized as one of the most diverse in the world (Stolton et al. 2004; Adler 2009). A vast number of reptile and amphibian species have been discovered from Vietnam over the past decades, with many microendemic taxa including those known only from type localities so far (e.g., Bain and Hurley 2011; Ngo et al. 2022). With decreasing range, the risk of extinction generally increases (Chichorro et al. 2019). Therefore, species occuring exclusively in small areas or which are restricted to their type locality are particularly threatened and thus require more protection (Meiri et al. 2017).

To protect both biodiversity and natural habitats, the government of Vietnam established the first protected area, Cuc Phuong National Park, in 1962 (Sterling et al. 2006). Since then, the number of national parks (NP) has grown to 34, accounting for approximately 3% of the total land area, with the last one being

established in 2020, i.e., Song Thanh NP. Additionally, the country maintains 88 nature reserves, 22 marine protected areas, 1 wetland protected area and 8 Ramsar sites (Wetlands of International Importance) (Stolton et al. 2004; Le et al. 2018; VEA 2020; Protected Planet 2022).

However, many species still suffer from habitat loss and degradation, overexploitation, invasive species, disease, climate change, and pollution, and are highly vulnerable to extinction (Sterling et al. 2006; Drury 2011; Blair et al. 2017; Blair et al. 2022). To reverse the trend, *in situ* conservation reinforced by *ex situ* measures has been proposed in the One Plan Approach to Conservation (OPA) developed by the Conservation Planning Specialist Group (CPSG) of the International Union for Conservation of Nature (IUCN) Species Survival Commission (SSC). In order to reduce the gap between the management of wild and *ex situ* populations, reintroduction of certain species into their natural habitat can take place when the protection level improves to prevent targeted species from extinction (Conde et al. 2013; Seddon et al. 2014a, b). In this regard, modern zoos can play a crucial role by not only conducting or financially supporting *in situ* conservation projects, but also by protecting species from extinction through the build-up of conservation breeding programs for subsequent release (Gilbert et al. 2017; Gusset 2019; Wahle et al. 2021; Krzikowski et al. 2022). This approach aims to bring together all responsible parties and considers the *in situ* and *ex situ* populations as a single unit with a view to developing a conservation plan for the entire population (Gusset 2019; Traylor-Holzer et al. 2019; Wahle et al. 2021). As modern ark, the "conservation zoo" provides space, expertise, time and funds for threatened species.

Globally, reptiles have been considered a group of special conservation concern (Böhm et al. 2013; Stanford et al. 2020; Cox et al. 2022). They play an important role in almost all ecosystems and often have relatively small distribution ranges, making them vulnerable to anthropogenic threats. While about 11% of the 11,460 reptile species described so far (Uetz et al. 2022) have still not been assessed by the IUCN, an additional 14.7% of the 10148 species assessed are listed as Data Deficient. Approximately 21% of the reptile species assessed up to now are considered to be threatened with extinction (Cox et al. 2022). In particular, agricultural expansion poses the greatest threat to reptiles. The resulting habitat loss is, among other places, particular evident in the mainland of Southeast Asia (Böhm et al. 2013).

As Vietnam's herpetofauna is among the richest in the world (Adler et al. 2009; Nguyen et al. 2009) and especially threatened due to habitat loss and being overharvested for traditional medicine, trade, and food (Van Schingen et al. 2015; Janssen and Indenbaum 2019; Pham et al. 2019a, b; Le et al. 2020), it is critical to assess the conservation status of Vietnamese species. Following the recently published study on amphibians in Vietnam (Krzikowski et al. 2022) we herein provide a detailed assessment of Vietnam's reptile fauna in light of the One Plan Approach. In order to establish a baseline for improved reptile conservation in Vietnam, an up-to-date list of all reptile species extant in Vietnam was compiled and they were then evaluated individually for their IUCN Red List status, listing in national legislations and the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), distribution range, potential occurrence in protected areas, and whether an ex situ component in zoos or other institutions already exists. Finally, we provide a list of those species that are particularly important to be considered for further OPA measures in the future.

Methods

Species list

The list of extant reptile species in Vietnam was based on Nguyen et al. (2009). The species list also comprised sea snakes and sea turtles (except for the protected area coverage analysis, see below). We then cross-checked each account with the reptile database (https://reptile-database.reptarium.cz/, Uetz et al. 2022) and new publications were included using the search engine Google Scholar (https//:scholar.google.com) to document taxonomic changes and species records in Vietnam after 2009 (see Suppl. material 1: tables S1–S5).

We generally followed the taxonomy of Nguyen et al. (2009). However, while Homalopsinae, Pareatinae, Psammophiinae, and Xenodermatinae were classified as subfamilies of Colubridae (Serpentes) in Nguyen et al. (2009), this study followed Pyron et al. (2011) in placing Psammophiinae in the family of Lamprophiidae and elevating the other subfamilies to the family level. In addition, the genus *Psammodynastes*, including the species *P. pulverulentus*, was transferred from the subfamily Natricinae (Colubridae: Serpentes) to the family Lamprophiidae (Pyron et al. 2011).

Conservation status

The extinction risk assessment of the reptile species extant in Vietnam was undertaken using the IUCN Red List of Threatened Species on the 5th of January 2022 (IUCN 2022) using automatized searches via the rredlist package for R 4.2.2 (Chamberlain 2022). We considered species either Not-threatened, which compromise Least Concern (LC) and Near Threatened (NT), threatened with extinction, which compromise Vulnerable (VU), Endangered (EN) and Critically Endangered (CR), or unclassifiable, which compromise Data Deficient (DD) and Not Evaluated (NE). No species on the list were listed as Extinct (EX) or Extinct in the Wild (EW). We further analysed the recorded species with respect to inclusion in the three appendices (I-III) of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES)(CITES 2021a, b).

National regulations were examined by evaluating the appendices of national decrees and the listing in the Vietnam Red Data Book. In Vietnam, species are primarily protected by two national decrees. While the first one, Decree No. 64/2019, lists species with highest conservation priority, the second, Decree 84/2021, largely follows CITES in listing species that are threatened by trade and/or overexploitation. Threatened species are also listed in the Vietnam Red Data Book which uses the IUCN Red List Categories. If a species is endemic to Vietnam, its status in the Vietnam Red Data Book may differ from the global IUCN Red List status. The latest version of the Vietnam Red Data Book has been published in 2007 (Tran et al. 2007) and is thus outdated, but an updated version is already under preparation (Krzikowski et al. 2022).

Vietnam and its biogeographic subregions

The study follows Bain and Hurley (2011) in dividing Vietnam into 13 different geographic subregions, namely Northwest Uplands (NWU), Northeast Uplands (NEU), Northern Annamites (NAN), Northeast Lowlands (NEL), Northern Coast

(NC), Northern Islands (NIS), Central Annamites (CAN), Central-South Vietnam Lowlands (CSL), Central Coast (CC), Southern Annamites (SAN), Mekong Delta (MEK), Southern Coast (SC) and Southern Islands (SIS) (see Fig. 1). Originally, Bain and Hurley (2011) referred their study area as Indochina, which was defined as Laos, Cambodia, and Vietnam, and split it into 19 subregions based on topographic and geographic criteria, including locations on the coast, island groups, mountain ranges and associated lowland regions and major river systems and their deltas. However, six of these subregions do not occur in Vietnam and are therefore irrelevant for this study. The 13 subregions occurring in Vietnam are assigned to different regions: Uplands, Lowlands, Coasts and Islands, all characterized by distinct climatic conditions and vegetation characteristics. Uplands are defined as locations above 450 meters, and locations below 450 meters are considered lowlands (Bain and Hurley 2011).

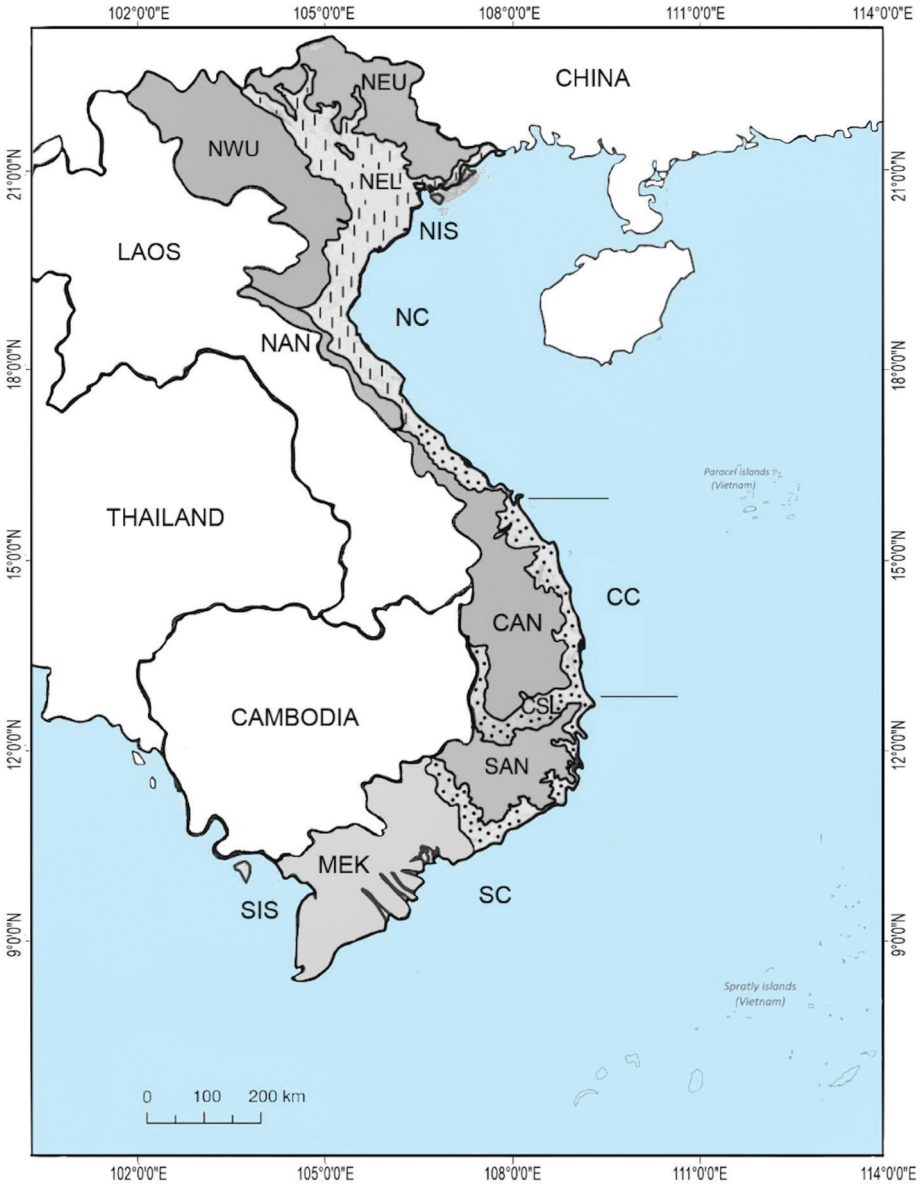

Figure 1. Map of Vietnam with its 13 subregions; adopted and modified from Bain and Hurley (2011).

Distribution

Information on the current distribution of each species extant in Vietnam was obtained based on the most recent species list by Nguyen et al. (2009), entries in the Reptile Database, distribution data from the IUCN Red List and the following publications: Bain and Hurley (2011), Wang et al. (2018, 2021), Nguyen LT et al. (2016, 2018a, b, 2020), Thao (2020), Nguyen, TQ et al. (2010b, 2017, 2018a, b), Hoang et al. (2018), Luu et al. (2015a, b, 2020a,c), Ngo et al. (2016, 2018, 2019a, b, 2021, 2022), Orlov et al. (2008, 2021), Grismer et al. (2015, 2019a, b, 2020, 2021a, b), Tung et al. (2018), Ostrowski et al. (2021), Murdoch et al. (2019), Pham et al. (2015, 2019a, b, 2020), Neang et al. (2020), Meiri et al. (2018), Ziegler et al. (2010, 2014, 2015a, b, c, d, 2019b, 2020a, b, c, d), Hecht et al. (2013), Le DT et al. (2018, 2020), Le DO et al. (2021), Richmond et al. (2021), Linh et al. (2019), Poyarkov Jr et al. (2019a, b, c), Siler et al. (2018), Wang et al. (2013), Van et al. (2014), Mallik et al. (2020), Le et al. (2021), Van Nguyen et al. (2019), Holden et al. (2021), Geissler et al. (2011a) Ren et al. (2018), Do et al. (2017), Nguyen SN et al. (2016, 2017), Amarasinghe et al. (2015), Rasmussen et al. (2011, 2012), Kurniawan et al. (2021), Ding et al. (2020), Li et al. (2021), Miller et al. (2020), Farkas et al. (2019), TTWG (2021), Chen et al. (2021), David et al. (2008), Sy (2019), Tan et al. (2019).

Species endemic to Vietnam and the Indochinese Region were identified and their level of endemism was further analysed, viz. whether these species are endemic to a specific subregion, region or on a macroregional or local level. The three macroregions were identified as North, Central or South, each representing up to four regions including uplands (elevations above 450m), lowlands (elevations below 450m), coasts or islands. For this purpose, the 13 subregions according to Bain and Hurley (2011) (n = 13: Northwest Uplands (NWU), Northeast Uplands (NEU), Northern Annamites (NAN), Northeast Lowlands (NEL), Northern Coast (NC), Northern Islands (NIS), Central Annamites (CAN), Central-South Lowlands (CSL), Central Coast (CC), Southern Annamites (SAN), Mekong Delta (MEK), Southern Coast (SC), Southern Islands (SIS)) were used as distribution measures.

For each species, we extracted detailed information on preferred habitats from the IUCN Red List using the rredlist package for R (Chamberlain 2022). Gridded information on habitat availability with a spatial resolution of 100 m was obtained from Jung et al. (2020) and intersected with the range information. Subsequently, we intersected the presence-absence maps of all terrestrial and limnic species (n = 454, excluding the 30 marine species, see Suppl. material 1: table S16) with the protected area network and extracted the potential of each species to occur in a given reserve. Furthermore, we created species richness maps by stacking the single presence-absence maps. Areas of high local endemism were identified using the corrected weighted endemism approach of Crisp et al. (2001).

Vietnamese reptiles in global ex situ facilities

For this analysis, the Zoological Information Management System (ZIMS) was used to identify which reptile species extant in Vietnam are currently kept in zoos worldwide and which species are currently managed in studbooks or other coordinated breeding programs. In addition, data on the number of held individuals and the number of keeping institutions was recorded for each species (ZIMS 2022). By using this approach, we could examine which of the species

extant in Vietnam were already represented in *ex situ* facilities and how many of the species were considered threatened or were endemic to Vietnam. Based on the results, the proportion of threatened and endemic species extant in Vietnam not yet kept in zoos or other institutions globally was calculated. Since participation in ZIMS is voluntary and some data may not be up to date, some held populations may have been omitted. In order to increase coverage, the data obtained from ZIMS were compared with those available on the website "Zootierliste" (ZTL, List of Zoo Animals – Zootierliste 2022). Nevertheless, the database includes only facilities from Europe. ZTL also does not have other detailed information such as breeding success and thus only was checked for additional species holdings, viz. those not available in ZIMS.

Diversity analysis

In order to identify major geographic patterns in the distribution of zoos keeping Vietnamese taxa, we computed for each facility the Shannon index (Weaver and Shannon 1949) taking both the number of different taxa and number of individuals per species into acount. The georeferenced localities of each facility were subsequently mapped and coded according to the number of individuals and the respective indices.

Top 50 list

As a guideline for further conservation action regarding reptiles in Vietnam, we compiled a Top 50 list of species likely to benefit most from conservation efforts based on the data of this study. For this purpose, a rating system was established and points were assigned for 1) IUCN Red List status, 2) year of latest assessment, 3) level of endemism 4) *ex situ* populations, 5) inclusion in legislation and 6) no occurrence in protected areas. For more detailed information about the categories and the evaluation, see Suppl. material 1: table S19.

Results

Reptile diversity

With a total of 484 reptile species, representing all orders, Vietnam harbors 4.2% of the global reptile diversity (Table 1). The order Testudines was the highest represented, comprising 8.6% (n = 31) of the global species richness, followed by Serpentes with 6.2% (n = 244), Crocodylia with 3.7% (n = 1) and Sauria with 2.9% (n = 208) (see Table 1). The order Squamata, with its suborders Sauria and Serpentes, accounted for 93.4% (n = 452) of all 484 reptile species recorded in Vietnam. Specifically, more than half of the squamates were snakes (54%, n = 244), the others belonged to the suborder of lizards (n = 208). Roughly 6.4% (n = 31) of all species in Vietnam (n = 484) belonged to the order Testudines and 0.2% (n = 1) to Crocodylia, which is represented by only one extant species. All of the species belonged to 28 families and 123 genera. The most speciose family was Colubridae with 134 species, followed by Gekkonidae with 93 species. Containing a total of 50 species, the genus *Cyrtodactylus* had the highest species richness (Sauria, Gekkonidae) (13 most species rich genera, Suppl. material 1: table S6).

Table 1. Reptile fauna worldwide, in Vietnam and Vietnamese endemics (percentage compared to global scale). Data for the number of reptiles worldwide were compiled using the Reptile Database (Uetz et al. 2022).

(Sub)order	Worldwide	Vietnam	Vietnamese endemics
Crocodylia	27	1 (3.7%)	0 (0%)
Sauria	7144	208 (2.9%)	119 (1.7%)
Serpentes	3956	244 (6.2%)	37 (0.9%)
Testudines	360	31 (8.6%)	3 (0.8%)
Total	11460	484 (4.2%)	159 (1.4%)

Out of the total 484 reptile species extant in Vietnam, 38.2% (n = 185) were endemic to the Indochinese region, whereas the proportion of Vietnamese endemic species was 32.9% (n = 159). With 74.8% (n = 119), the order Sauria possessed the most species among Vietnamese endemic species, followed by Serpentes and Testudines with 23.2% (n = 37) and 2% (n = 3), respectively.

IUCN Red List status

An IUCN Red List status was available for 418 out of 484 reptile species reported from Vietnam, representing a total of 86.4% (See Fig. 2). Percentage-wise, 13.6 (n = 66) of the 484 Vietnamese reptile species had not yet been assessed by the IUCN, including 29 lizard species, 34 snakes and three turtles.

Among all 418 reptile species assessed by the IUCN, 17.7% (n = 74) were threatened with extinction. 20 of these species were classified as Critically Endangered (CR), 22 species as Endangered (EN), and 32 species as Vulnerable (VU) (Table 2). Measured in absolute numbers, lizards were found to be the most threatened order (31 species), followed by turtles with 27 threatened species, snakes with 15 threatened species, and one crocodile species classified as Critically Endangered. In terms of relative proportions of threatened and non-threatened species within each order, Crocodylia was the most threatened

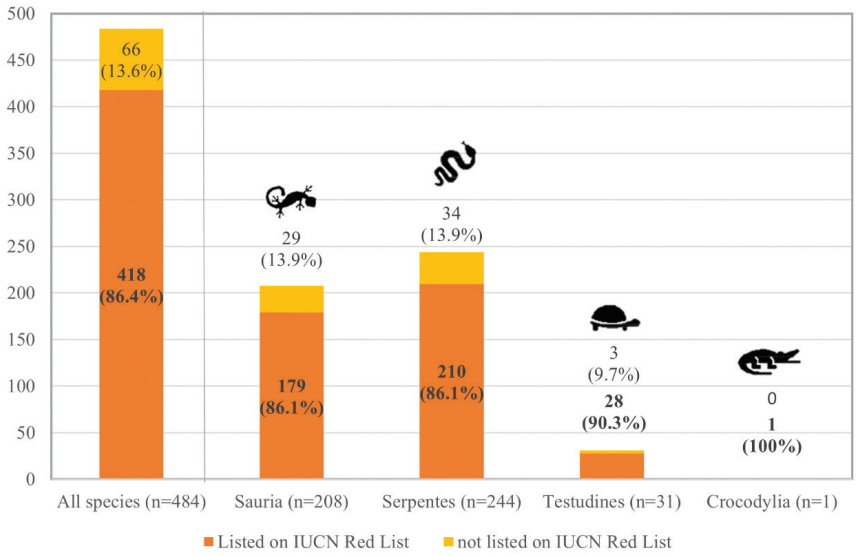

Figure 2. Listing on the IUCN Red List of threatened species. Total number of Vietnamese reptile species listed and not listed in total and separated by order.

Table 2. Vietnamese reptile species and their IUCN Red List status, including endemics.

	IUCN Red List status						No status (NE)	Total
	CR	EN	VU	NT	LC	DD		
All Vietnamese reptile species								
Crocodylia	1	0	0	0	0	0	0	1
Sauria	4	9	18	7	110	31	29	208
Serpentes	0	4	11	4	153	38	34	244
Testudines	15	9	3	1	0	0	3	31
Total	20	22	32	12	263	69	66	484
Endemics								
Sauria	4	8	15	4	35	28	25	119
Serpentes	0	2	2	1	0	15	17	37
Testudines	3	0	0	0	0	0	0	3
Total	7	10	17	5	35	43	42	159

order with 100% (n = 1), immediately followed by Testudines, with 96.4% threatened species (27 out of 28 listed turtle species). Lizards with 17.3% (31 out of 179 listed species) and snakes with 7.1% (15 out of 210 listed species) were much less threatened. More than half (61.5%; n = 110) of the lizards listed (n = 179) and two-thirds (72.9%; n = 153) of the snakes (n = 210) were considered LC, and about one-fifth of each of these orders was listed as DD.

In the IUCN Red List, 73.6% (n = 117) of all endemic species from Vietnam (n = 159) were included. While 36.8% (43 species) were classified as DD, 29.1% (34 species) were considered threatened with extinction and the remaining 34.1% (40 species) non-threatened (see Table 2, see examples in Fig. 3). While the endemic species from Vietnam evaluated by the IUCN accounted for 28% (n = 117) of all assessed species (n = 418), they also covered 45.9% (34 of 74 species) of all species assessed as threatened. They made up 35.0% (n = 7) of all CR species (n = 20), 45.5% (n = 10) of all EN species (n = 22), and 53.1% (n = 17) of all VU species (n = 32).

Listing in CITES and Vietnam's decrees

Appendix I of CITES included 13 reptile species from Vietnam: nine turtles, three lizards, and one crocodile. A total of 34 species were listed in appendix II, including 18 turtles, nine snakes, and seven lizards. Only two turtles were not listed in CITES appendices I or II. *Mauremys sinensis* was listed in appendix III and *Amyda ornata* was not included in any appendix (Table 3).

Similar to CITES, Decree No. 84/2021 contains appendices I and II, listing a total of 42 species. All lizards (n = 10) listed in Decree No. 84/2021 were identical to those in CITES, as were the listings of eight snakes. The ninth snake species, *Ophiophagus hannah*, however, was included in appendix I whereas internationally it was listed in appendix II. Identical national and international listings were also found for 17 turtles. Seven species were found in CITES but not in Decree No. 84/2021, two species were listed in Decree No. 84/2021 but not in CITES and three species were placed in appendix I in Decree No. 84/2021 but only in appendix II in CITES (Table 3).

Figure 3. Threatened endemic reptile species from Vietnam **A** *Cuora picturata* (IUCN: CR) **B** *Leiolepis guentherpetersi* (IUCN: EN) **C** *Boiga bourreti* (IUCN: EN) **D** *Trimeresurus truongsonensis* (IUCN: EN) (Photos: C. T. Pham (**A**) A. Rauhaus (**B**) T. Ziegler (**C, D**)).

The Vietnam Red Data Book comprises a total of 41 reptiles with 20 turtles (CR: 5, EN: 10, VU: 5), 15 snakes (CR: 2, EN: 6, VU: 7), five lizards (EN: 2, VU: 3) and one crocodile (CR: 1). Of 74 species categorized as threatened by the IUCN, 41 species (55.4%) of the IUCN listed threatened reptiles, were present in the Vietnam Red Data Book. Only six species shared the same status between the IUCN Red List and the Vietnam Red Data Book. As for 32 species with different status, 21 were evaluated as more threatened in the Vietnam Red Data Book than by the IUCN Red List. The other eleven, however, were assigned more threatened status by the IUCN Red List than in the Vietnam Red Data Book. *Cuora cyclornata* was listed in the Vietnam Red List (CR) but had not been evaluated by the IUCN. In addition, 30 of the 33 threatened endemic reptiles in the IUCN Red List were not incorporated in the Vietnam Red Data Book. Only three threatened endemic species, all belonging to the order Testudines, were listed in the Vietnam Red Data Book: *Cuora picturata*, *Mauremys annamensis* and *Rafetus swinhoei*. The latest Red Data Book was published in 2007 and while 18 threatened species were described after the publication, three snakes and nine lizards had been described before and could have been included.

In Decree No. 64/2019, consisting of species of high conservation priority, 15 reptiles, comprising two lizards, one snake, and 12 turtles, were incorporated. All of the species, except for the two lizard species, were also listed in the Vietnam Red Data Book as either CR or EN. Only four of the species, namely *Cnemaspis psychedelica*, *Cuora picturata*, *Mauremys annamensis* and *Rafetus swinhoei*, are endemic to Vietnam.

Table 3. Threat status of reptile species extant in Vietnam, including sea turtles, listed in CITES, Decree 64/2019, Decree 84/2021 or the Vietnam Red Data Book and their IUCN Red List status. Endemic: *: species is endemic to Vietnam; ** species is endemic to the Indochinese Region. *Rafetus swinhoei* is considered endemic to Vietnam because the population in China is no longer viable with the only known extant male being sterile.

Species	Endemic	IUCN Red List status	Vietnam Red Data Book	Decree 64/2019	Decree 84/2021	CITES
Crocodylia						
Crocodylus siamensis		CR	CR		IB	I
Sauria						
Cnemaspis psychedelica	*	EN		Yes	IB	I
Gekko gecko		LC	VU		IIB	II
Goniurosaurus araneus		EN			IIB	II
Goniurosaurus catbaensis	*	EN			IIB	II
Goniurosaurus huuliensis	*	CR			IIB	II
Goniurosaurus lichtenfelderi		VU			IIB	II
Goniurosaurus luii		VU			IIB	II
Leiolepis reevesii		LC	VU			
Physignathus cocincinus		VU	VU			
Shinisaurus crocodilurus vietnamensis	*	EN		Yes	IB	I
Varanus bengalensis nebulosus		NT	EN		IB	I
Varanus salvator		LC	EN		IIB	II
Serpentes						
Azemiops feae		LC	VU			
Bungarus fasciatus		LC	EN			
Coelognathus radiatus		LC	VU			
Elaphe moellendorffi		VU	VU			
Euprepiophis mandarinus		LC	VU			
Gonyosoma prasinum		LC	VU			
Malayopython reticulatus		LC	CR		IIB	II
Naja atra		VU	EN		IIB	II
Naja kaouthia		LC	EN		IIB	II
Naja siamensis		VU	EN		IIB	II
Ophiophagus hannah		VU	CR	Yes	IB	II
Oreocryptophis porphyraceus		LC	VU			
Ptyas korros		NT	EN			
Ptyas mucosa		LC	EN		IIB	II
Python bivittatus		VU			IIB	II
Python brongersmai		LC			IIB	II
Python curtus		LC			IIB	II
Subsessor bocourti		LC	VU			
Testudines						
Amyda ornata		NE			IIB	
Caretta caretta		VU	CR	Yes		I
Chelonia mydas		EN	EN	Yes		I
Cuora amboinensis		EN	VU		IIB	II

Species	Endemic	IUCN Red List status	Vietnam Red Data Book	Decree 64/2019	Decree 84/2021	CITES
Cuora bourreti	**	CR	EN	Yes	IB	I
Cuora cyclornata		NE	CR	Yes	IB	II
Cuora galbinifrons		CR	EN	Yes	IB	II
Cuora mouhotii		EN			IIB	II
Cuora picturata		CR	EN	Yes	IB	I
Cyclemys oldhami		EN			IIB	II
Cyclemys pulchristriata	**	EN			IIB	II
Dermochelys coriacea		VU	CR	Yes		I
Eretmochelys imbricata		CR	EN	Yes		I
Geoemyda spengleri		EN			IIB	II
Heosemys annandalii		CR	EN		IIB	II
Heosemys grandis		CR	VU		IIB	II
Indotestudo elongata		CR	EN			II
Lepidochelys olivacea		VU	EN	Yes		I
Malayemys subtrijuga	**	NT	VU		IIB	II
Manouria impressa		EN	VU		IIB	II
Mauremys annamensis	*	CR	CR	Yes	IB	I
Mauremys mutica		CR			IIB	II
Mauremys sinensis		CR				III
Palea steindachneri		CR	VU		IIB	II
Pelochelys cantorii		CR	EN	Yes	IB	II
Platysternon megacephalum		CR	EN		IB	I
Rafetus swinhoei	*	CR	CR	Yes	IB	II
Sacalia quadriocellata		CR			IIB	II
Siebenrockiella crassicollis		EN			IIB	II

Distribution

The diversity of the reptile fauna varied among the different subregions of Vietnam. The highest species diversity among the 13 subregions occurred in the Northwestern Uplands with 172 reptile species, followed by the Northeastern Lowlands with 166 and Northeastern Uplands and the Central Annamites with 164 species each. The highest endemic species richness was found in the Central Annamites subregion with 32 species (Fig. 4B, Suppl. material 1: table S7). Looking further at the distribution of endemic species, 89.9% (n = 143, out of total 159) were endemic to one of the three macroregions with most of them found in Southern Vietnam (59 species out of 143, 41.3%), followed by Northern Vietnam (48, 33.6%) and Central Vietnam (36, 25.2%). While 135 species (84.9%) out of total 159 endemics were recorded from just one region, 22 were documented from two regions and the remaining two from three regions. No endemic reptile species was recorded from all four regions (Uplands, Lowlands, Coasts and Islands) (Suppl. material 1: tables S8, S9, S15).

The 135 species occuring in just one region were considered regional endemics. Only four of the regional endemic reptiles (3.0%) occured in two subregions, the other 97.0% (131 species) were exclusively found in one subregion

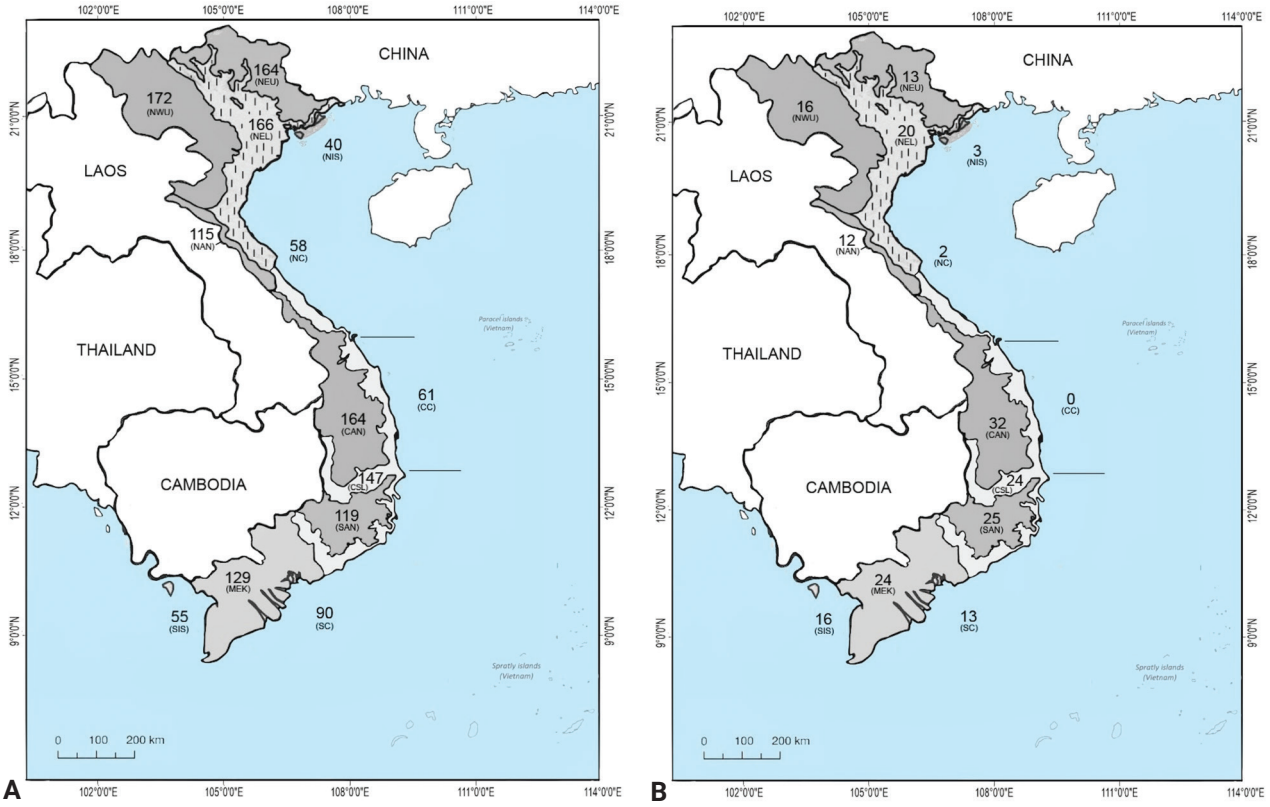

Figure 4. Map of Vietnam with its 13 subregions and number of recorded reptile species, separated by different factors **A** number of recorded reptile species per subregion among total 484 species **B** number of Vietnamese endemic reptile species per subregion among total 159 species.

only, and thus considered subregional endemics (Suppl. material 1: table S11). Approximately 74.0% of the subregional endemics (n = 131) were lizards (97 species) and the other 26.0% were snakes (34 species). None of the subregional endemics was a turtle. Of the endemic species belonging to the order Sauria (119 species), 81% (n = 97) were subregional endemics and distributed in 12 of the 13 subregions. For the order Serpentes, 92% (n = 34) of the 37 endemic species were subregional endemics, occurring in 11 subregions. Among the 13 subregions, most subregional endemics were restricted to the Central Annamites subregion, where 21 of the 131 subregional endemic species (16%) occured (Fig. 5, Suppl. material 1: table S11).

Regarding the distribution of endemic species and their IUCN Red List status, most threatened species (44.1%) were endemic to Southern Vietnam (15 out of 34 threatened species, CR: 2; EN: 2; VU: 11), further 23.5% of the threatened species (8 species, CR: 1; EN: 5; VU: 2) were endemic to Northern Vietnam and six species (CR: 3; VU: 3) to Central Vietnam. In terms of only subregional endemic species (n = 131), a considerable number (31%, 41 species) had not yet been evaluated by the IUCN and a further 27% (36 species) were assessed as DD. In percentage terms, 35% (n = 26) of all threatened species (74 species) were endemic on the subregional level (CR: 4; EN: 7; VU: 15). The subregion with most threatened subregional endemics was the Mekong Delta with seven threatened species (CR: 1; VU: 6), followed by the Southern Islands (SIS) with five threatened endemics (EN: 2; VU: 3) and the Central-Southern Lowlands (CSL) with three threatened species (CR: 1; VU: 2) (Suppl. material 1: tables S12–S14).

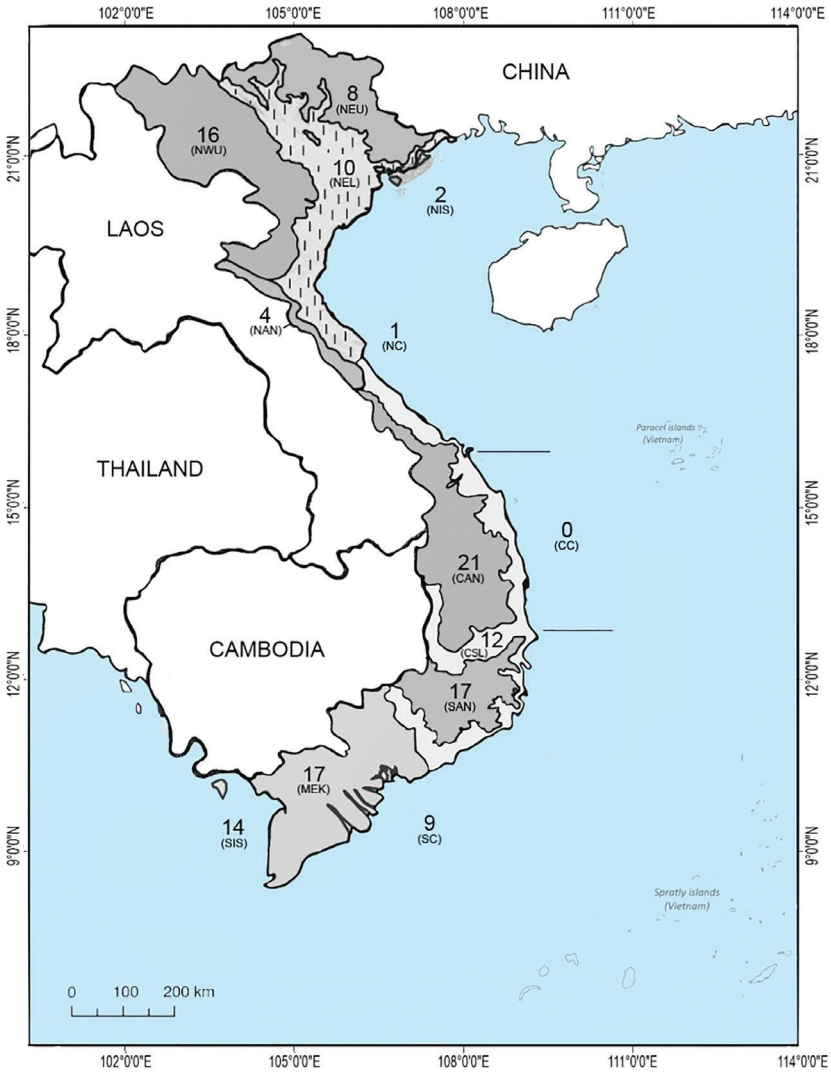

Figure 5. Map of Vietnam with its 13 subregions and number of subregional endemic reptile species (n = 131).

Further analyses showed that while 43 species of subregional endemics (n = 131) occured in multiple locations within their respective subregion, 88 species did not. These species were endemic at the local level, which means they were exclusively reported from their type localities and represented a majority of endemic species at 55.3% (n = 88) (Table 4).

Table 4. Distribution range of Vietnamese endemic reptile species, separated by size of area in which they occur.

Distribution	Description	Number of species	Percentage
Local	Type locality only	88	55%
Subregional	Multiple locations within one subregion	43	27%
Regional	Multiple locations within a region in one or two macroregions	4	3%
Macroregional	Multiple locations in two or more regions within a macroregion	13	8%
Widespread	Multiple locations in two macroregions	8	5%
Countrywide	Multiple locations in all three macroregions	3	2%
Total		159	100%

Coverage by protected areas

A total of 78 out of the 454 terrestrial and limnic reptile species included in the protected area analysis had not been reported from any protected area and are not likely to be covered. Of the species, 53 were endemic and 19 were threatened. Up to 32.1% (n = 17) of the 53 endemic species not yet found in any protected area were considered threatened (CR: 4; EN: 2; VU: 11) and another 52.8% were still listed as DD (20 species) or NE (8 species). As many as 27 of the 53 endemic species were only reported from their type locality. Another 15.1% (8 species) were subregional endemics (Figs 6, 7, Suppl. material 1: table S17).

Ex situ keeping of Vietnamese reptiles

The ZIMS analysis showed that 109 out of 484 reptile species reported to occur in Vietnam (22.5%) were held in zoos around the world. A total of 17 of the species were either endemic to Indochina (n = 7) or to Vietnam (n = 10). Thus, 6.3% of all endemic Vietnamese reptiles (10 of 159 species) were represented in zoo husbandries. According to ZIMS, the other 93.7% (n = 149) of 159 endemic reptile species were not kept in any zoo. The held endemic species consisted of seven lizards, two turtles, and one snake.

According to the IUCN Red List, 41.3% of the 109 species held were considered threatened with extinction (45 species; CR: 15; EN: 16; VU: 14) (Table 5). A further 3.7% were classified either as DD (n = 3) or NE (n = 1), 4.6% categorized as NT (n = 5) and 50.4% considered LC (n = 55) (Suppl. material 1: table S18). The 45 threatened species kept in zoos worldwide accounted for a total of 60.8% (n = 45) of all 74 threatened species extant in Vietnam (see Fig. 8 for examples). In terms of ten endemic reptile species held in zoos (n = 10), eight were categorized as threatened (CR: 3; EN: 4; VU: 1) and two as DD. As a result, 23.5% (n = 8) of all Vietnamese threatened endemic reptile species (n = 34) were held in institutions globally.

Regarding the breeding success of reptile species reported from Vietnam in zoo holdings, 49 species (45.0%) out of 109 reproduced within the last 12 months. A total of 25 of these 49 species (51.0%) were classified as threatened (CR: 10; EN: 10; VU: 5) and eight (14%) were endemic to Vietnam. Three species with most hatchlings were all evaluated as threatened but are not endemic to Vietnam, namely *Indotestudo elongata*, *Cuora amboinensis* and *Heosemys grandis*, thus their source of the breeding stock must not derive necessarily from Vietnam.

According to the ZTL, 108 reptile species extant in Vietnam were kept in European institutions. A total of 18 of these species were not included in ZIMS, the other 90 species were included in both databases (ZIMS and ZTL) and 19 species were listed in ZIMS but not in ZTL (Table 5, Suppl. material 1: table S17). As many as 40 of the 108 species (37.0%) were classified as threatened (CR: 15; EN: 14; VU: 11), four as NT (3.7%), 60 as LC (55.5%), three as DD, and one Not Evaluated (NE), *Acanthosaura murphyi*. Therefore, 54.1% (n = 40) of all 74 threatened species were represented in institutions in Europe according to the ZTL.

In terms of coordinated *ex situ* populations, four Vietnamese turtle species are both managed in AZA (Association of Zoos and Aquaria) studbooks and EAZA (European Association of Zoos and Aquaria) Ex situ programs (EEP), namely *Cuora bourreti*, *C. galbinifrons*, *C. picturata* and *Mauremys annamensis*.

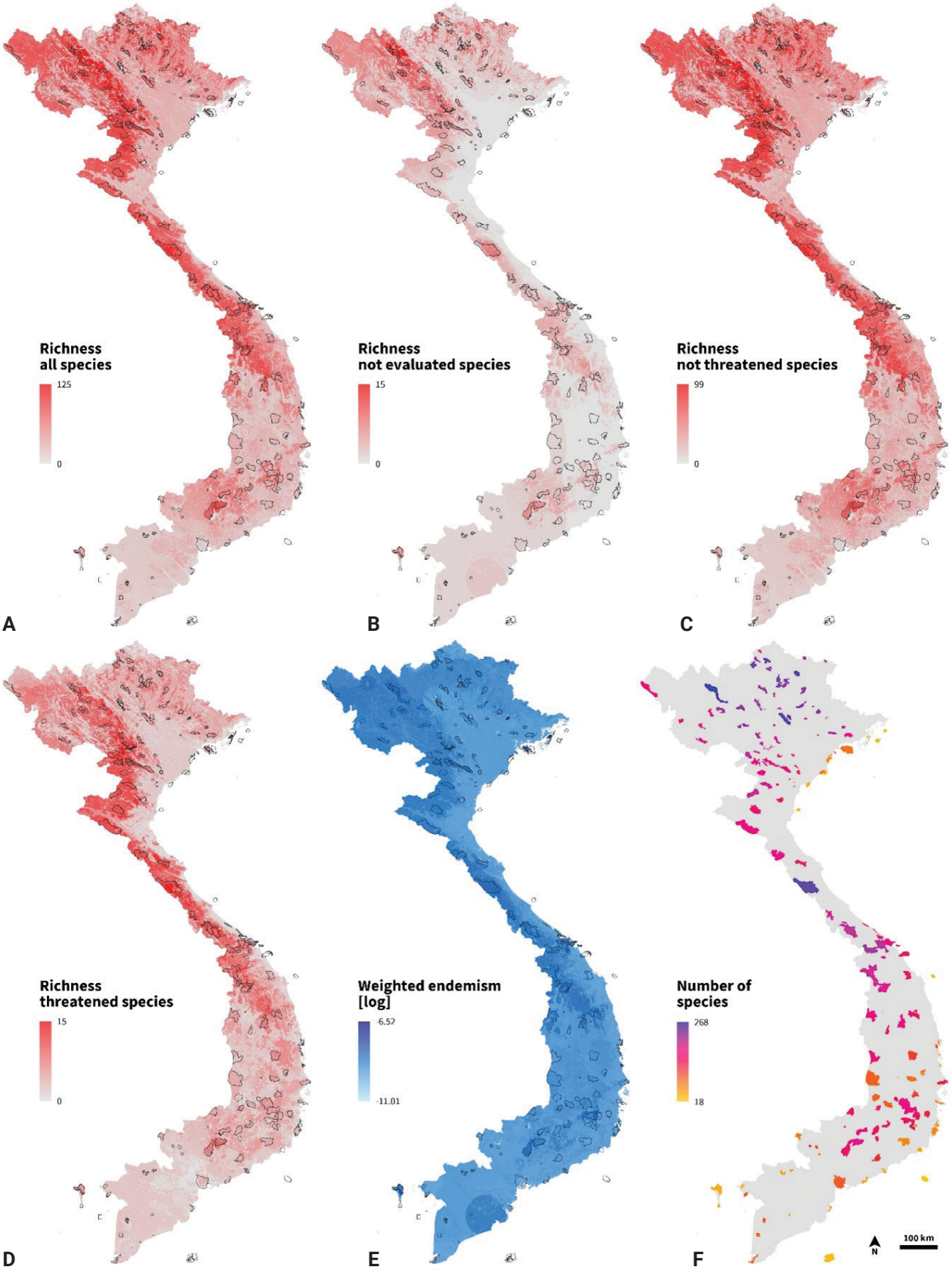

Figure 6. Species richness across the mainland of Vietnam and Vietnam's protected areas **A** all 454 terrestrial reptile species extant in Vietnam **B** all NE species **C** all not threatened species **D** all threatened species **E** weighted endemism of all reptiles **F** number of reptiles within each protected area.

Figure 7. Microendemic reptile species from Vietnam not yet recorded in any protected area **A** *Cyrtodactylus gialaiensis* **B** *Gekko truongi* **C** *Achalinus juliani* **D** *Calamaria gialaiensis* (Photos: H. Ngo (**A**) T. M. Phung (**B**) T. Ziegler (**C, D**)).

Table 5. Representation of threatened Vietnamese reptile species held according to ZIMS (n = 45) and ZTL (n = 40), including sea turtles. Species: **: species is endemic to the Indochinese Region, *: species is endemic to Vietnam. IUCN status: IUCN Red List status (IUCN 2022). Institutions: number of institutions. Individuals: number of individuals. Breeding institutions: Number of institutions which bred in the past 12 month. Hatchings: Offspring in the past 12 months.

Species	IUCN status	ZIMS				ZTL
		Institutions (regions)	Individuals	Breeding institutions	Hatchings	
Crocodylia						
Crocodylus siamensis	CR	33 (3)	268	–	–	30
Sauria						
Cnemaspis psychedelica *	EN	7 (2)	34	2	3	–
Gekko badenii *	EN	15 (2)	56	2	4	24
Goniurosaurus araneus **	EN	1 (1)	7	1	2	3
Goniurosaurus catbaensis *	EN	1 (1)	16	1	6	–
Goniurosaurus huuliensis *	CR	1 (1)	23	1	13	2
Goniurosaurus lichtenfelderi	VU	3 (2)	11	1	3	2
Goniurosaurus luii	VU	4 (1)	21	1	2	4
Physignathus cocincinus	VU	76 (3)	348	2	19	–
Shinisaurus crocodilurus vietnamensis *	EN	3 (1)	19	1	8	4
Serpentes						
Deinagkistrodon acutus	VU	3 (2)	10	1	2	8

Species	IUCN status	ZIMS				ZTL
		Institutions (regions)	Individuals	Breeding institutions	Hatchings	
Boiga bourreti	EN	–	–	–	–	1
Elaphe moellendorffi	VU	6 (3)	17	–	–	11
Elaphe taeniura	VU	26 (3)	58	–	–	42
Lycodon paucifasciatus *	VU	1 (1)	6	–	–	–
Naja atra	VU	1 (1)	1	–	–	5
Naja siamensis	VU	9 (4)	23	–	–	11
Ophiophagus hannah	VU	52 (5)	95	–	–	26
Protobothrops sieversorum	VU	1 (1)	2	–	–	1
Protobothrops trungkhanhensis	EN	1 (1)	2	–	–	1
Python bivittatus	VU	261 (6)	767	6	33	268
Testudines						
Caretta caretta	VU	26 (4)	346	–	–	42
Chelonia mydas	EN	38 (5)	977	–	–	50
Cuora amboinensis	EN	52 (4)	596	2	71	41
Cuora bourreti **	CR	15 (3)	83	3	9	6
Cuora galbinifrons	CR	24 (3)	88	2	6	8
Cuora mouhotii	EN	18 (3)	61	1	1	14
Cuora picturata *	CR	5 (3)	43	1	1	5
Cyclemys atripons	EN	2 (2)	4	–	–	–
Cyclemys oldhami	EN	3 (1)	13	–	–	3
Cyclemys pulchristriata	EN	2 (1)	10	–	–	2
Dermochelys coriacea	VU	1 (1)	2	–	–	–
Eretmochelys imbricata	CR	12 (5)	61	–	–	11
Geoemyda spengleri **	EN	41 (2)	263	2	5	15
Heosemys annandalii	CR	21 (3)	228	2	5	3
Heosemys grandis	CR	37 (3)	419	4	38	28
Indotestudo elongata	CR	53 (4)	917	9	89	32
Lepidochelys olivacea	VU	3 (3)	4	–	–	2
Manouria impressa	EN	10 (3)	25	1	2	3
Mauremys annamensis *	CR	40 (3)	224	2	6	34
Mauremys mutica	CR	17 (3)	178	–	–	9
Mauremys sinensis	CR	44 (3)	307	–	–	39
Pelochelys cantorii	CR	2 (1)	4	–	–	1
Platysternon megacephalum	CR	13 (3)	48	4	15	6
Sacalia quadriocellata	CR	12 (3)	74	1	3	6
Siebenrockiella crassicollis	EN	24 (3)	122	1	1	17

Further, there are five additional species managed only in AZA studbooks (*Cuora mouhotii*, *Geoemyda spengleri*, *Heosemys annandalii*, *Manouria impressa*, *Sacalia quadriocellata*) and four managed only in EAZA EEPs (*Cuora amboinensis*, *Mauremys mutica*, *M. sinensis*, *Siebenrockiella crassicollis*). There are three AZA studbooks for Vietnamese Squamata, namely *Shinisaurus crocodilurus*, *Malayopython reticulatus* and *Ophiophagus hannah*. Within the EAZA, there is currently only one monitoring program (Mon-T) for *Gonyosoma boulengeri*.

Figure 8. Threatened reptile species from Vietnam already in *ex situ* conservation breeding programs **A** *Mauremys annamensis* (CITES: I; IUCN: CR; Vietnam Red Data Book: CR) **B** *Cnemaspis psychedelica* (CITES: I; IUCN: EN) **C** *Gekko badenii* (IUCN: EN) **D** *Goniurosaurus huuliensis* (CITES: II; IUCN: CR) (Photos: T. Q. Nguyen (**A**) T. Ziegler (**B, D**) T. M. Phung (**C**)).

Diversity analysis

An analysis of the spatial coverage of ZIMS-registered zoos holding reptile species from or occurring in Vietnam revealed that the greatest densities are found in Europe, followed by North America. This was true for all Vietnamese reptile species, as well as when only considering endemic species (Fig. 9A, B).

Top 50 list

In the end, 55 species were included in the Top 50 list as 5 additional species had the same score (12 points). All taxa in the list were endemic to Vietnam and 80.0% (n = 44 out of 55) have only been recorded from their type localities. Subregional endemic species accounted for 14.5% (n = 8). Most of the species (65.5%) were DD (n = 27) or NE (n = 9) species and another 23.6% (n = 13) were listed as threatened with extinction (CR: 3; VU: 10). The Top Five species were all scored at 17 points and are only known from their type localities. They have no *ex situ* component and do not occur in any protected area (Table 6). Three of those species were listed as DD. The other two species, namely *Cyrtodactylus gialaiensis* and *C. nigriocularis*, were listed as CR.

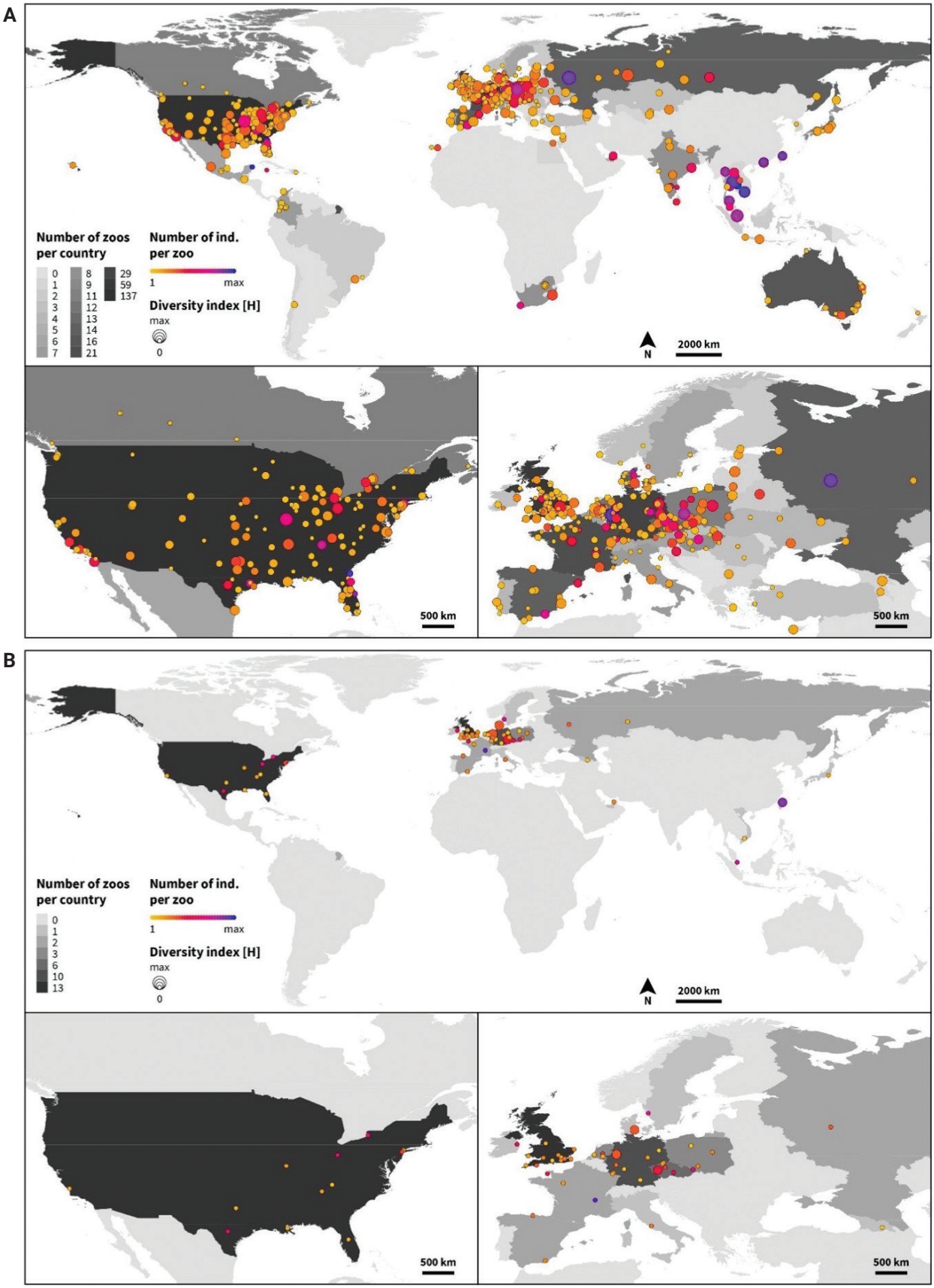

Figure 9. Geographic overview of zoo-held reptiles from or occurring in Vietnam (according to ZIMS). Countries are shaded according to the number of ZIMS members. Individual zoos are colored based on the number of individuals per zoo **A** all reptile species reported from Vietnam **B** only Vietnamese endemic reptile species.

Table 6. Top 55 list of species likely to benefit most from conservation efforts. CR, EN, VU, DD, NE: IUCN Red List Status (IUCN 2022). Type locality only: species that have received points are known exclusively from their type locality. Subregional endemic: species that have received points are endemic to one subregion. No occurrence in protected area: Species does not occur in any protected area within Vietnam. No *ex situ* populations: species that have received points are not held in zoos according to ZIMS. Not listed in national/international legislations: Species that have received points are not listed in CITES, Decree 64/2019 or Decree 84/2021. Points were given if the respective criteria were met. The highest score to be achieved was 17 points. For more detailed information about the scores see Suppl. material 1: table S19.

Species	Points
Argyrophis giadinhensis	17
Calamaria gialaiensis	17
Cyrtodactylus gialaiensis	17
Cyrtodactylus nigriocularis	17
Oligodon moricei	17
Acanthosaura brachypoda	16
Bronchocela orlovi	16
Cnemaspis aurantiacopes	16
Cyrtodactylus dati	16
Cyrtodactylus martini	16
Emoia laobaoensis	16
Eutropis darevskii	16
Gekko truongi	16
Pseudocophotis kontumensis	16
Scincella darevskii	16
Scincella rara	16
Sphenomorphus bacboensis	16
Sphenomorphus sheai	16
Ahaetulla rufusoculara	15
Calamaria sangi	15
Cyrtodactylus phumyensis	15
Cyrtodactylus thochuensis	15
Oligodon macrurus	15
Oligodon rostralis	15
Trimeresurus honsonensis	15
Cnemaspis caudanivea	14
Cnemaspis nuicamensis	14
Cyrtodactylus badenensis	14
Cyrtodactylus bichnganae	14
Cyrtodactylus grismeri	14
Cyrtodactylus huongsonensis	14
Cyrtodactylus huynhi	14
Gekko russelltraini	14
Gekko vietnamensis	14
Hemiphyllodactylus zugi	14
Achalinus juliani	13

Species	Points
Cyrtodactylus septimontium	13
Cyrtodactylus sonlaensis	13
Leiolepis guentherpetersi	13
Parafimbrios vietnamensis	13
Calamaria abramovi	12
Calamaria concolor	12
Calamaria thanhi	12
Cnemaspis tucdupensis	12
Cyrtodactylus chauquangensis	12
Cyrtodactylus cucdongensis	12
Cyrtodactylus eisenmanae	12
Cyrtodactylus hontreensis	12
Cyrtodactylus kingsadai	12
Cyrtodactylus takouensis	12
Enhydris innominata	12
Fimbrios smithi	12
Oligodon annamensis	12
Oligodon saintgironsi	12
Opisthotropis cucae	12

Discussion

As Vietnam has a very rich reptile diversity and the description rate of new species has still remained high, this study presents the current state of knowledge but it is unlikely that it represents the actual state of Vietnam's reptile fauna. Since the publication of Nguyen et al. (2009), which forms the basis for this study, 112 additional new reptile species have been described from Vietnam (Uetz et al. 2022). Especially in the last three years, the number of new species descriptions has been remarkably high. In 2019, 18 new reptile species were described, eight of which are endemic to Vietnam. In both 2020 and 2021, 10 species endemic to Vietnam were discovered. While in 2020, a total of 12 species were discovered, in 2021, there were only 11. In addition, 35 new country records have been documented since 2009 and some reptile species known from neighboring countries reported only from sites close to the border with Vietnam and thus are expected to be found from Vietnam soon. On the other hand, 32 species have been removed from the list because the populations in Vietnam belong to a different species or the species have now been synonymized with others. Another 69 species have been reassigned to different genera, which shows how much the taxonomy is still in transition and further research is required to perform taxonomic revisions and uncover cryptic diversity.

Conservation status

Given that only 86.4% (n = 418 out of 484) of the reptiles present in Vietnam have been evaluated by the IUCN Red List and not all threatened or endemic species are sufficiently protected by international and national legislation, further efforts need to be made to protect and conserve these species. An im-

portant step in that direction were two decisions at the nineteenth meeting of the Conference of the Parties (CoP) of CITES in November 2022 towards improved international protection of two reptile species occuring in Vietnam: The Green Water Dragon (*Physignathus cocincinus*) has been included in appendix II and the Indochinese Box Turtle (*Cuora galbinifrons*) has been transferred from appendix II to appendix I, both jointly proposed by Vietnam and the European Union (CITES 2022). We found that only 51.4% (n = 38 out of 74) of all threatened reptile species from Vietnam and only 3.8% (n = 6 out of 159) of all Vietnamese endemic reptile species have been included in CITES and likewise Decree 84/2021 does not list all threatened and endemic reptile species. Most notably, seven threatened turtle species have been incorporated in CITES but not in Decree 84/2021. With 96.4% (n = 27), of all 28 species listed on the IUCN Red List, listed as threatened, turtles are one of the most threatened vertebrate groups and need improved protection measures to ensure their survival.

As a study on the trade of reptiles in Vietnam has shown, *Diploderma chapaensis* and *Leiolepis guttata* have been traded in large quantities and should have been listed in the old version of the Decree (Decree 06/2019) (Janssen and Indenbaum 2019). Nonetheless, the two species were not considered in the new version (Decree 84/2021). The national legislation is apparently up to date, having been issued every two years (2019 and 2021), but many threatened and endemic species remain missing from the decrees. Consequently, re-evaluation and incorporation of additional threatened endemic species is recommended, as Vietnamese reptiles are considered to be particularly threatened by trade (Janssen and Indenbaum 2019). With regard to Decree 64/2019, only four of the 34 threatened endemic species are listed as high conservation priority, and it is recommended that the other threatened endemic species undergo further review as well. More research is also of great importance for the 69 species classified as DD as otherwise no conservation action can be undertaken and their extinction is more likely than for already assessed species (Howard and Bickford 2014; Bland et al. 2015). Furthermore, priority should also be given to the 66 species that have not yet been assessed in order to enable their assignment to a threat status; and the ones with their status being considered outdated as they have passed the 10 years validation mark. However, most of the species that have not yet been assessed have not been assessed because they have only recently been recognized and herpetologists are in the process of collecting data for IUCN assessments. The fact that endemic reptile species account for 32.9% (n = 159) of all 484 reptile species occurring in Vietnam, while representing 46.0% of all threatened reptile species (34 of 74 species), highlights that species with smaller or restricted ranges are more likely to be threatened and therefore should be protected to a greater extent (Meiri et al. 2017).

Distribution

In terms of distribution, our data only reflect the current state of scientific knowledge, but not the actual distribution of reptile species in Vietnam. This is especially evident for recently described species that have just been reported from their type locality. Further research could expand their distribution ranges. Moreover, as some Vietnamese endemic reptile species occur close to the

borders of adjacent countries such as Laos, Cambodia or China, additional studies might discover new records of the taxa from these countries in the near future. For instance, *Cyrtodactylus dati*, which is found very close to the Cambodian border and is likely to occur there as well but has not yet been confirmed (Uetz et al. 2022). Therefore, some of the species listed as endemic might be in other categories in the future with new data from additional studies.

Not all 159 endemic species identified in the study are evenly distributed, but rather spread across the 13 different subregions. This pattern is in concert with previous findings on amphibians (Geissler et al. 2015). Particularly relevant are those species that are only known from their type locality or endemic to a subregion and therefore well adapted to microclimatic conditions and special habitat characteristics. With 131 species (82.4%), they represent a majority of endemic species and draw attention to the need to establish local conservation areas to safeguard the microendemic species. The Central Annamites (CAN) subregion should be a priority for increased reptile conservation efforts, as this subregion harbors most local and subregional endemics including 21 endemic species, 12 of which are classified as DD. However, the Mekong Delta (MEK) subregion and the Southern Islands (SIS) should also be prioritized in this regard, as they also have high endemic species richness and harbor most threatened species (MEK: 7; SIS: 5).

Approximately 33.5% (n = 53) of all terrestrial and limnic endemic reptile species (n = 158) have not been reported from any protected area in Vietnam and 17 of these species are considered threatened with extinction (CR: 4; EN: 2; VU: 11). Another 20 species have exclusively been reported from their type locality. For these species as well as for the 20 species considered DD and the eight species which have not been evaluated yet, their conservation status assessment should be undertaken as quickly as possible to design appropriate conservation measures in due time.

Ex situ populations

According to ZIMS, only ten of the 109 reptile species kept are endemic and 45 reptile species are considered threatened. Thus, 60.8% (n = 45 out of 74) of all threatened reptile species reported to occur in Vietnam are represented in zoos, but only eight of them are threatened endemic species. A slight majority of the reptile species held (50.5%; n = 55 out of 109) is classified as LC. On the other hand, the ZTL only lists 108 species and they differ from those reported in ZIMS. Although more LC species are listed in the ZTL (55.5%; n = 60 out of 108), one threatened species not listed in ZIMS is also included, namely *Boiga bourreti*. Despite potentially incomplete data, our analysis suggests that only a few of the reptile species present in Vietnam are kept in zoos (22.5%; n = 109 out of 484) and the number of endemic species is even smaller with only 6.3% (n = 10 out of 159) of the endemic species maintained in zoos worldwide. For the species, the number of kept individuals is limited (except for *Mauremys annamensis*). It is therefore recommended to increase the number of endemic and especially threatened endemic reptile species in zoos in order to maintain assurance *ex situ* populations of these species, so that in the event of a natural disaster, overcollection or disease outbreak, a complete extinction of these species can be prevented. However, acquiring these species presents a challenge and it is important to point out that we certainly do not recommend buying wild-caught in-

dividuals of threatened species, as this could fuel the trade and contribute to the decrease or loss of natural populations. We would rather recommend focusing on threatened species that are already kept in zoological collections, in breeding stations or at reputable breeders. It is important to invest in cooperations with partners and stations in the country to build up legal captive breeding programs. If it is necessary to aquire wild caught animals to build up a new reserve population, this should of course be in consultation with the respective authorities. There is already rising awareness on the need to shift towards threatened species in managed breeding programs within zoological collections, as was reflected by the latest decisions on recently developed regional collection plans (RCPs) within EAZA taxon advisory groups. For example, in the frame of the RCP for chelonian species, a number of EEPs was lately established amongst others for threatened Vietnamese turtle species in the genera *Cuora* and *Mauremys* (Goetz et al. 2019). Moreover, during the latest regional collection plan for lizards, it was decided to set up EEPs for the two Endangered lizard species *Cnemaspis psychedelica* and *Shinisaurus crocodilurus* as well as monitoring programs (Mon-T) for all five *Goniurosaurus* species from Vietnam (Cizelj et al. 2023).

Non-endemic species present more challenging conditions for reintroduction. If the origin of the populations is uncertain, zoos must first carry out genetic studies to assign their populations to a country of origin and to exclude genetic contamination, when reasonable, as this is the only way that successful reintroduction can take place. Since ZIMS and the ZTL do not list all institutions worldwide that keep and breed reptile species, local facilities are not included in the evaluation. However, these facilities can play a very important role in the development of conservation breeding programs, as local stations such as the Me Linh Station for Biodiversity in northern Vietnam may already keep and breed protected reptile species (Ziegler et al. 2015c, 2019c). Through international cooperation, species can thus be transferred to conservation breeding programs in zoos around the world, e.g., conservation breeding initiatives both in the country of origin and abroad were jointly built up for threatened Vietnamese Tiger gecko species (*Goniurosaurus* spp.), the Psychedelic Rock Gecko (*Cnemaspis psychedelica*), or the Vietnamese Crocodile Lizard (*Shinisaurus crocodilurus vietnamensis*), combining research and *ex situ* efforts in Vietnam and Europe (Ziegler et al. 2016, 2019c; Ngo et al. 2020; Nguyen et al. 2021; Van Schingen-Khan et al. 2022; Ziegler and Rauhaus 2022). In-country facilities have the advantage for quick and easy restocking measures, more distant facilities and zoos, respectively, are advantageous in case of disease outbreaks, natural catastrophes or political unrests.

In order to protect threatened species and meet the objectives of the One Plan Approach, *ex situ* populations must be included in global conservation planning of the respective species. The *ex situ* efforts are intended to support the *in situ* conservation efforts and, in the best case, *ex situ* populations can be reintroduced into the wild. However, since the capacity of zoos is not unlimited, not all threatened species can be protected in this manner. Breeding of species is therefore particularly recommended for species whose drivers of extinction are pollution, disease or habitat loss (Clulow et al. 2014) and in the case of Vietnam especially those which are threatened by overexploitation, as for example turtles, crocodile lizards, and psychedelic rock geckos (Van Schingen 2015; Lee et al. 2020). To determine to which level an *ex situ* component is required or beneficial for the conservation strategy of a species, the IUCN Species Survival Commission has published guide-

lines on the use of *ex situ* management for species conservation. In some cases *ex situ* management can be a primary part of a conservation strategy while in others it will be of secondary importance, supporting other interventions (IUCN/SSC 2014).

All recommendations should be understood as a starting point for improved reptile conservation. Since the range size of a species can play a major role in its survival (Meiri et al. 2017), the distribution range of all species should be analyzed in more detail. Meiri et al. (2017) have done such an analysis for lizards, but, for example for snakes, only little information is available. Updated distribution ranges for turtles, including Vietnamese species, have been compiled and published by the Turtle Taxonomy Working Group in 2021 (TTWG 2021), but similar to the other orders more detailed and up to date information is required as most of the turtle species extant in Vietnam (96%; n = 27) are threatened with extinction. Related to the range size, the habitats of species should also be studied in greater detail to identify habitat specialists and habitat generalists, as the specialists are often less adaptable to change and thus more vulnerable. It is therefore recommended that further conservation measures should be initiated for particularly threatened species having severely restricted distribution ranges, such as *Cyrtodactylus nigriocularis*, *Cnemaspis psychedelica*, or *Cuora picturata*. Other species used to occupy a much broader region, but their distributions have shrunk considerably due to habitat loss and overexploitation. For example, while *Mauremys annamensis* and *Cuora cyclornata* are likely extinct in the wild, *Rafetus swinhoei* is on the brink of extinction and restricted to one or a few small lakes in northern Vietnam. In April of 2023, the last known female of this species in Hanoi, Vietnam, died of unknown causes, leaving little hope to recover its population. Both *Mauremys annamensis* and *Rafetus swinhoei* have also not been recorded in any protected area and are thus of utmost importance to consider for further conservation work. Whereas ex situ programmes have been implemented in time for *Mauremys annamensis*, unfortunately, no such initiative has been established for *Rafetus swinhoei*. However, Ziegler et al. (2021) have shown that build up of conservation breeding for softshell turtles can be established, when action is taken in time.

The Top 50 list provided in the results section (Table 6) should be taken into account when planning new conservation measures, as the species listed are those currently most threatened with extinction as our study revealed. Especially the Top 5 species should be given attention, as these species would benefit most from further protection measures.

Cyrtodactylus gialaiensis (Place 3), for example, was only discovered in 2017 and up to now no obvious natural habitat has been recognized, as the species was only found in coffee plantations (Luu et al. 2017; Luu et al. 2020b). On the other hand, *Cyrtodactylus nigriocularis* (Place 4) is restricted to a few caves and under extreme pressure of human activities threatening the very small population (Nguyen et al. 2018c). This again highlights the particular need for immediate research and conservation efforts for all the species included in the Top 50 List (Table 6).

Conclusion

Conservation of reptiles in Vietnam needs to be comprehensively evaluated through extended research and prioritizing conservation measures. In particular, support is needed for the most threatened endemic species identified in this

study. It is also important to focus on additional efforts to assess the status of 69 DD and 66 NE species in order to be able to protect them more effectively in the future. Successful protection of the species requires the incorporation of both *in situ* and *ex situ* conservation actions. In particular, the most threatened endemic species must be included in national and international legislations to provide them with additional support. In the implementation of the One Plan Approach, international institutions such as zoos and local facilities play a key role in offering expertise, capacity, and financial resources to support both *in situ* and *ex situ* conservation measures. Since more than half of all Vietnamese reptile species in zoos are classified as LC and only 6.3% (n = 10) of 159 Vietnamese endemic species are maintained *ex situ*, it is crucial that zoos consider shifting their focus to commit more resources for threatened endemic species both through supporting in situ projects and building up ex situ assurance colonies to be able to supply surplus individuals from breeding programs for *in situ* conservation programs, once needed.

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Additional information

Conflict of interest

The authors have declared that no competing interests exist.

Ethical statement

No ethical statement was reported.

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Data availability

All of the data that support the findings of this study are available in the main text or Supplementary Information.

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Supplementary material 1

Species list, distribution, endemism, status, threats

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