

Assessment of the threat status of the amphibians in Vietnam - Implementation of the One Plan Approach

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Abstract

The current decline in global biodiversity is most evident in amphibians with 41% percent of all species worldwide classified as threatened with extinction. Hence, a major challenge in amphibian conservation is the high number of threatened species, leading to a common approach of identifying priority species and regions for conservation efforts. As a part of one of 36 globally designated biodiversity hotspots, Vietnam is considered to be of particular importance for conservation action. To improve amphibian conservation in Vietnam, this study provides an updated species list and assesses their threat status by compiling data from a variety of sources. Furthermore, a Zoological Information Management System (ZIMS) analysis was conducted to determine the representation of extant amphibians from Vietnam in zoos worldwide. The batrachofauna of Vietnam is characterized by a high level of species richness and local endemism as well as a high rate of new discoveries, with more than half of the endemic species reported exclusively from their type locality, making them especially vulnerable to extinction. Up to 18% of all amphibians extant in Vietnam and 28% of endemic species are classified as threatened with extinction by the IUCN. In many cases,

the IUCN Red List status is either missing or outdated, highlighting the urgent need of action. Around 14% of endemic amphibian species have been recorded exclusively from unprotected areas, suggesting prioritization for further research and conservation measures. The continuing decline in many species remains an unresolved problem. As a guide for future research and conservation measures, a list of the top 57 species was compiled. In addition, according to the ZIMS analysis, only 8% of threatened and 3% of endemic amphibian taxa from Vietnam are currently kept in zoos worldwide, and a richness analysis revealed that the highest density of husbandries is found in Europe and North America. To achieve maximum outcome for the conservation of threatened species, this study recommends a general shift by zoos towards maintaining species in greater need of captive assurance populations and breeding programs to support integrative strategies that combine *in situ* and *ex situ* conservation efforts following the IUCN's One Plan Approach.

Keywords

Amphibian conservation, conservation breeding, diversity analysis, endemic species, protected area coverage, threatened with extinction

Introduction

As a profound consequence of humankind's global impact on the natural environment, a biodiversity crisis is currently taking place (Wake and Vredenburg 2008; Tollefson 2019; Melville et al. 2021). This rapid biodiversity decline is most evident in amphibians (Gascon et al. 2007; Bishop et al. 2012; Clulow et al. 2014), of which currently more than 40% of all species in the world are under the risk of extinction (IUCN 2021). Amphibians are considered particularly vulnerable to changes, as many species have narrow habitat preferences and restricted geographic ranges (Purvis et al. 2000; Wake and Vredenburg 2008). They also occupy environments that are subject to a multitude of primarily human-caused drivers of decline (Pabijan et al. 2020).

Major threats to the amphibian species are habitat degradation and fragmentation, introduction of invasive species, over-exploitation, and climate change (Gascon et al. 2007; Halliday 2008; Bishop et al. 2012; Hussain and Pandit 2012; Meredith et al. 2016). Additionally, amphibians have been affected by the pathogenic fungi *Batrachochytrium dendrobatidis* and *B. salamandrivorans* which can induce chytridiomycosis (Kilpatrick et al. 2010; Martel et al. 2013). This disease has already been linked to the extinction of several amphibian species (Schloegel et al. 2006; Vredenburg et al. 2010). Decreasing amphibian populations are of particular concern because they are indicators of environmental stress and ecosystem health (Blaustein and Wake 1995; Welsh and Ollivier 1998; Bishop et al. 2012). Their precipitous decline serves as a warning that we are in a period of significant environmental degradation (Baillie et al. 2004). Amphibians are integral components of many ecosystems on every continent except Antarctica and may represent an important link between aquatic and terrestrial ecosystems (Whiles et al. 2006). Being predators, prey, or herbivores, and thus contributing to the trophic dynamics of many communities, the loss of amphibians is likely to have cascade impacts on other species (Blaustein 1994; Blaustein and Kiesecker 2002). Therefore, the severe amphibian declines demand urgent and collective actions to prevent another large-scale species extinction (Isaac et al. 2012; Pabijan et al. 2020).

The disappearance of amphibians is perhaps the most significant taxon-specific extinction event that conservationists are facing (Zippel et al. 2011). A major challenge in amphibian conservation is the high number of species facing extinction worldwide, as it far exceeds the resources available (Mittermeier et al. 1998; Myers et al. 2000; Mittermeier et al. 2011). Therefore, scientists are facing hurdles in determining the best approach to save the maximum number of species with the available resources and identifying which species should be prioritized initially (Myers et al. 2000). Since habitat loss is a key threat to nine out of ten threatened amphibian species (Baillie et al. 2004), it is important to identify, safeguard, and possibly extend protection, especially for sites where high rates of threatened species occur (Semlitsch 2003). Furthermore, endemic species with restricted ranges are more at risk of extinction than those with larger ranges (Meiri et al. 2017). Thus, biodiversity hotspots with high concentrations of endemic and threatened species need to be identified (Myers 1990; Mittermeier et al. 1998; Eken et al. 2004). Additionally, in cases where over-exploitation, habitat loss or pollution is the clear driver of extinction, captive assurance colonies need to be held in suitable programs, such as in zoos or conservation breeding stations, so that habitat restoration efforts and reintroductions can be a viable conservation strategy (Clulow et al. 2014).

Vietnam is located in the Indo-Burma region, one of the 36 global biodiversity hotspots, which constitute focal points for conservation efforts (Myers et al. 2000; Stork and Habel 2014; Noss et al. 2015). Due to an excessive rate of habitat loss and a large number of endemic species, Vietnam is regarded as an important area with high biodiversity conservation priority (Myers et al. 2000). In terms of biodiversity, the country is recognized as one of the top nations in the world with high species richness (Sterling et al. 2006), particularly the herpetofauna (Adler 2009). An extraordinarily large number of new species has been described from Vietnam in the last decades, in particular amphibians and reptiles (e.g., Ziegler and Nguyen 2019, see below).

The first major herpetological summary was published by Morice (1875), listing 13 amphibian species for Vietnam. From 1947, Rene Bourret published a series of papers and books on the herpetofauna of Vietnam, Laos, and Cambodia, documenting a total of 171 amphibians for the Indochinese region (Nguyen 2006). Because of the Indochinese Wars, biodiversity exploration was interrupted during the period from 1954 to 1975. Since 1975, a surge in herpetological studies of Vietnam has resulted in an enormous increase of our knowledge in this group of vertebrates (Nguyen 2006). The most recent herpetological list for Vietnam by Nguyen et al. (2009) reported 174 species of amphibians. Moreover, a large number of new amphibian discoveries from Vietnam in the last three decades also highlighted the mega-diversity of the country (Ziegler and Nguyen 2019). The outcomes of the studies and the resulting greater knowledge of the batrachofauna of Vietnam are essential for species conservation, as these data form a foundation for developing effective conservation programs.

In terms of nature conservation, the most important policy of Vietnam was the establishment of a protected area network. In 1962, the first Vietnamese National Park (NP), Cuc Phuong NP, was established in northern Vietnam. Three decades later, in 1995 with the ongoing loss of habitat and over-exploitation of the fauna and flora, the

government decided to counteract by expanding the network of existing NPs and protected areas (PAs) (Sterling et al. 2006). Since then, the number of PAs has increased to a total of 33 NPs, 59 nature reserves, and 13 habitat and species conservation areas in Vietnam, including two world heritage sites (Stolton et al. 2004; Le et al. 2018, VEA 2020). With 1,077,236 ha in total, the NPs cover about 3% of the country's area and there are plans to increase this number even further. Of the current 33 NPs, 24 are managed by provincial authorities, while the Vietnam Administration of Forestry (VNFOREST) is responsible for the other six (Le et al. 2018).

As there is no conservation assessment of endemic and threatened terrestrial vertebrate species in Vietnam available, this study focuses on amphibians. As a basis for improved conservation of Vietnamese amphibians, we analyzed the species diversity of amphibians in the country, their threat status according to IUCN (2021), national legislations as well as their distribution with particular focus on endemic and micro-endemic species. Considering the One Plan Approach, supported by the IUCN, that aims to develop integrative strategies to combine *in situ* and *ex situ* measures with groups of experts for the purpose of improved species conservation, another goal of this study was to analyze the representation of extant amphibian species from Vietnam in zoos worldwide. Such an approach has already been performed for amphibians globally (Jacken et al. 2020), but not yet for a particular region in Southeast Asia. As this study presents a topical review of the amphibian fauna of Vietnam, the first objective was to provide an updated species list for all amphibian species extant in Vietnam. We further identified hotspots based on species-level metrics (e.g., species richness, endemism, and extinction vulnerability). We assessed the proportion of endemic and threatened species, and the coverage of their distribution areas by protected areas to compile a list of the taxa, which face the greatest risk of extinction and hence are in highest need of attention in conservation work.

Methods

Species list

To identify which amphibians occur in Vietnam, the most recent list published by Nguyen et al. (2009) was used as an initial starting point. To document species records in Vietnam after 2009 and any taxonomic revisions, we searched the online databases, e.g., Amphibian Species of the World (Frost 2021) and Amphibia Web (2021). Data collection for this study was conducted between May and June 2021. Species record was verified case by case and the cut-off date was set to 30th June 2021. Data obtained from ZIMS was updated on the 20th of March 2022.

Distribution

Distribution data followed Nguyen et al. (2009) and were augmented by online databases, Amphibian Species of the World (Frost 2021) and Amphibia Web (2021),

the IUCN Red List (IUCN 2021) and the following publications: Ohler et al. (2000, 2011), Ohler and Grosjean (2005), Bain et al. (2003, 2007, 2009a-b), Bain and Nguyen (2004), Nguyen et al. (2005, 2008, 2013, 2014a-b, 2016, 2018a-b, 2020a-b), Orlov et al. (2006, 2012), Orlov (2008), Hendrix et al. (2008), Dubois and Ohler (2009), Rowley and Cao (2009), Rowley et al. (2011a-b, 2012a-b, 2013, 2014, 2015, 2016, 2017, 2020), Matsui et al. (2010), Tran et al. (2010), Stuart et al. (2011), Chan et al. (2013), Luu et al. (2013), Milto et al. (2013), Nishikawa et al. (2013), Ostroshabov et al. (2013), Le et al. (2014, 2015a-b, 2021a), Le and Do (2019), Pham et al. (2014, 2015, 2016a-b, 2017a-c, 2018a-b, 2019a-d, 2020a-d), Ziegler et al. (2014), Vassilieva et al. (2014), Geissler et al. (2015), McLeod et al. (2015), Gawor et al. (2016), Poyarkov et al. (2017, 2018a-c, 2021a), Yu et al. (2017, 2019a-b), Chen et al. (2018), Duong et al. (2018), Sheridan and Stuart (2018), Tapley et al. (2018), Kropachev et al. (2019), Luong et al. (2019, 2021), Bernardes et al. (2020), Cutajar et al. (2020), Ninh et al. (2020), Ong et al. (2020), Wu et al. (2020), Gorin et al. (2021), Hoang et al. (2021), Tran and Le (2021), and Zheng et al. (2021).

Species endemic to the Indochinese Region and Vietnam were determined following the definition by Bain and Hurley (2011) of the Indochinese Region as containing three countries, Cambodia, Laos, and Vietnam. Further investigations into whether endemic species in Vietnam are restricted to a local, provincial, regional or macro-regional level, and how wide their distribution areas cover within the country, were carried out. We used geographic regions and administrative units of Vietnam as measures of distribution areas (Fig. 1, Suppl. material 1: Table S10).

Following the compilation of distribution ranges of all amphibians extant in Vietnam, the protected area coverage of micro-endemic species was assessed. The localities of the species were obtained from the sources listed above and were plotted on PAs maps using software package QGIS 3.18.3 (QGIS Development Team 2021).

Subregions of Vietnam

Vietnam is located in the Northeast of mainland Southeast Asia. It stretches along the eastern edge of the Indochinese Peninsula to the Gulf of Thailand and borders the southern Chinese provinces of Yunnan and Guangxi to the North and the Lao People's Republic to the West. The southern part of the country borders Cambodia and maintains maritime borders with Thailand, the Philippines, Indonesia, and Malaysia. In terms of administration, there are 58 provinces in Vietnam, as well as five centrally administered cities called municipalities (Sterling et al. 2006). Geographically, two fertile river deltas lie in the North and South, with a narrow strip of forests and mountains in between as a link. In total, Vietnam covers a land area of 330,591 km². Vietnam's climate is subtropical with four seasons in the North and tropical with a dry and a rainy season in the South. On the high plateaus in central Vietnam, the temperature is generally lower and the climate more humid, with dry seasons typically lasting only three months (Sterling et al. 2006).

This study followed Sterling et al. (2006) in dividing the country into eight geographic regions and three macro-regions, northern, central, and southern Vietnam.

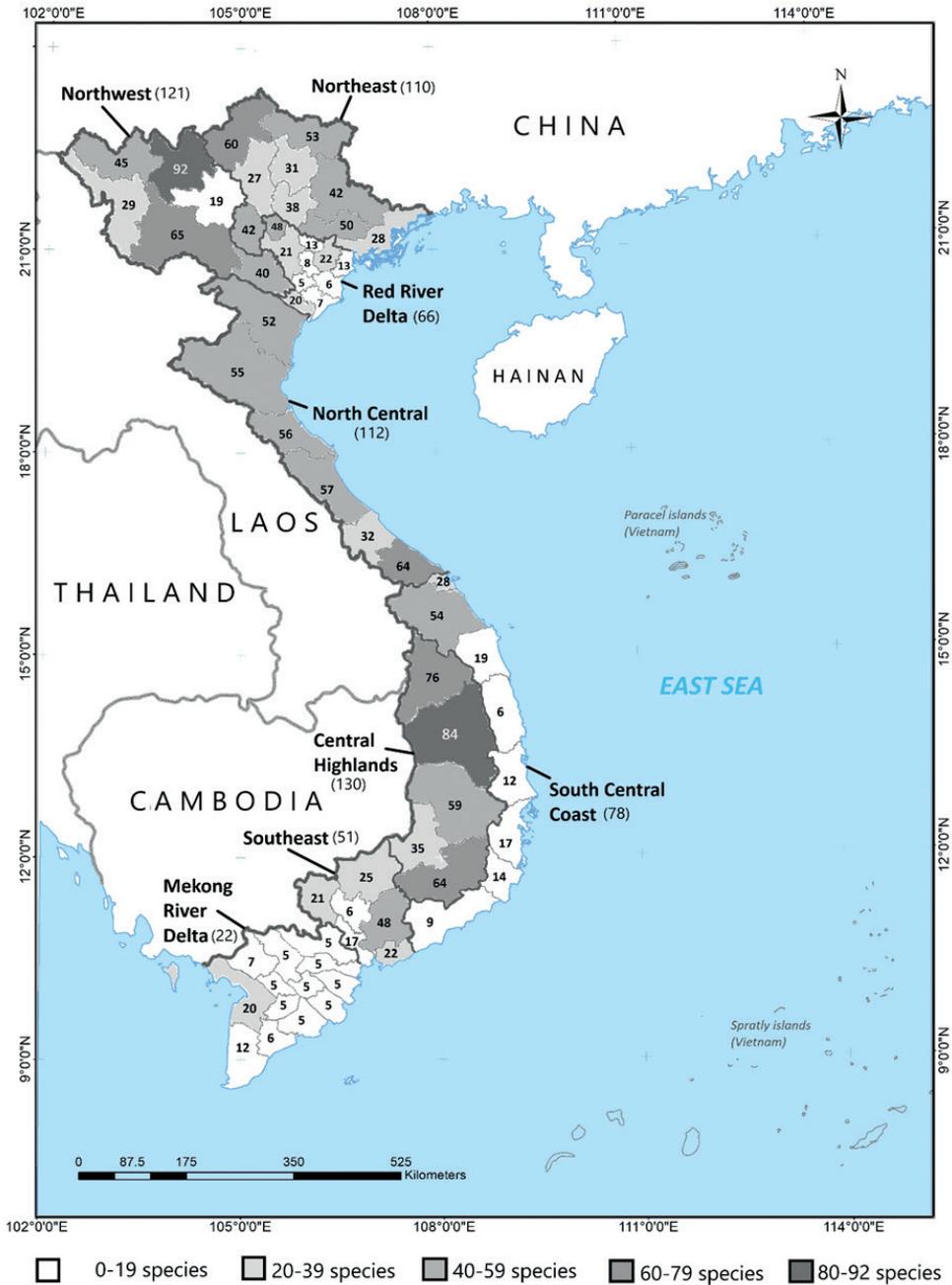


Figure 1. Number of recorded amphibian species per province and region. Map of Vietnam with its eight regions, 58 provinces, and five municipalities and the respective number of recorded amphibian species per province and per region (see respective references in Material and Methods). Adopted and modified from IEBR archive.

Northern Vietnam consists of three regions, Northwest (NW), Northeast (NE) and Red River Delta (RRD). Central Vietnam also contains three regions, North Central (NC), South Central Coast (SCC) and the Central Highlands (CH). The remaining two regions, Southeast (SE) and Mekong River Delta (MRD), form the third macro-region, southern Vietnam. The regions vary in their geography, biogeographic history, and climate, which have shaped different flora and fauna communities (Sterling et al. 2006).

Threat status

Information on the threat status of each species was first retrieved from the IUCN Red List of Threatened Species (IUCN 2021) which allocates taxa to one of nine IUCN Red List Categories: Not Evaluated (NE), Data Deficient (DD), Least Concern (LC), Near Threatened (NT), Vulnerable (VU), Endangered (EN), Critically Endangered (CR), Extinct in the Wild (EW), and Extinct (EX). Those rated VU, EN and CR were classified as threatened with extinction (IUCN 2021). The IUCN aims to update the extinction risk assessments of each species at least every 10 years, as the IUCN status is considered invalid 10 years after its publication.

To further determine threat statuses of each species, the inclusion of species in the three appendices of CITES (Convention on International Trade in Endangered Species of Wild Flora and Fauna) was reviewed (CITES 2021a). Vietnam joined CITES in 1994 (CITES 2021b).

After checking their listings in the international regulations, species in the Vietnam Red Data Book and in the appendices of national decrees were documented. At the national level, species in Vietnam are under protection by the Governmental Decree No. 64/2019 and Decree No. 06/2019. The former lists species with the highest conservation priority, whereas the latter lists threatened and rare forest-dwelling species that are protected by law. Furthermore, Decree No. 06/2019 is designed to implement CITES at the national legislative level, thus including species listed in CITES appendices. In addition to these two decrees, threatened species are catalogued in the Vietnam Red Data Book, with the latest version published in 2007 (Tran et al. 2007). This version is outdated; however, scientists at the Institute of Ecology and Biological Resources are presently working on a new edition. Generally, the Vietnam Red Data Book is based on the IUCN Red List criteria and uses the IUCN categories. If a species is not endemic to a country, the threat classifications for national populations in the National Red List may differ from those assessed by the IUCN (IUCN 2021).

Ex situ populations

Regarding the representation of Vietnamese amphibians in zoos worldwide, data on the species and the number of individuals held in registered collections as well as the

number of institutions keeping extant amphibians in Vietnam was obtained via the Zoological Information Management System (ZIMS 2022). In a second step, we quantified how many amphibian species extant in Vietnam are represented in zoos worldwide and the respective proportions of endemic and threatened species. ZIMS is a web-based, real-time data collection system which captures both animal husbandry and medical information (ZIMS 2022). It allows zoo and aquarium staff members to enter, check, and revise animal records from zoos globally. The software contains data on gender distributions as well as reports of successful reproduction within the last 12 months. Participation in ZIMS is not mandatory for zoos and not all zoos have added their collection data to the system. Thus, to analyze additional holdings, we further searched the website “Zootierliste” (ZTL, Zoo Animals’ list) (Graf et al. 2021). This database contains information on the current and former animal holdings of European zoos and other public animal husbandries which are entered by registered users. The ZTL does not contain information on the number of individuals of the different species kept in zoos and their breeding success. Only the number of keeping institutions obtained via the ZTL database are represented in this study to get a most complete species inventory.

For non-endemic taxa, if those known to occur in Vietnam are listed in ZIMS or ZTL, they do not necessarily derive from the country, as founders of the captive population may come from other range states.

Diversity analysis

The geographic distribution of holdings, including their covered diversity was assessed in R based on the coordinates of the relevant zoos obtained from ZIMS. The total number of zoos per country, the number of individuals per species kept in each zoo and Shannon-Weaver Index ($H = -\sum p_i \log(b) p_i$) were computed using package Vegan (Oksanen et al. 2020). In this index, p_i refers to the proportion of species i and $\log(b)$ is the natural logarithm.

Results

Amphibian diversity

Of the 174 amphibian species listed for Vietnam by Nguyen et al. (2009), 154 species were incorporated in the species list. The other 20 species (18 frog species and 2 salamander species) were excluded, either because they are no longer considered to be extant in Vietnam, because populations in Vietnam have been assigned to a different species, or because they are junior synonyms of other species (see references in Suppl. material 1: Table S1). Additionally, a total of 48 species have been assigned to new genera and one additional species has been removed from its last accepted genus but has

not yet been assigned to a new genus (Suppl. material 1: Table S2). Moreover, a total of 86 species have been newly described from Vietnam since Nguyen et al. (2009) (Suppl. material 1: Table S3). One additional species, namely *Amolops daorum*, was described from Vietnam by Bain et al. (2003) prior to the species list by Nguyen et al. (2009) but was considered a junior synonym of *A. mengyangensis* by Ohler (2007). However, this hypothesis was rejected by Stuart et al. (2010), leading to the inclusion of *Amolops daorum* in the amphibian species list of Vietnam presented in this study. Additionally, 34 new country records for Vietnam (Suppl. material 1: Table S4) have been added to the final species list of this study, consisting of a total of 275 amphibian species for Vietnam (Suppl. material 1: Table S5) or 3,3% of the global amphibian diversity. All three orders of amphibians are represented, including 3.6% of the Anura, 1% of the Caudata, and 1.9% of the Gymnophiona (Table 1). All of the species belong to 53 genera and most species fall within the order Anura (n = 263 or approximately 96%), while the rest are members of the order Caudata (n = 8 or nearly 3%) and the order Gymnophiona (n = 4 or more than 1%) (Table 1).

In Vietnam, the order Anura contains eight families, Caudata and Gymnophiona contain only one family each. In the order Anura, Rhacophoridae is the most diverse family with 75 recorded species. The family Salamandridae is the unique representative of the order Caudata in Vietnam, with eight members belonging to one subfamily. The family Ichthyophiidae, a member of the order Gymnophiona, is represented with four species. The ten most speciose genera account for 55% of all amphibians in the country and are listed in Table 2.

Table 1. Number of Vietnamese amphibians compared to the global amphibian diversity. Data for the global amphibian species richness was retrieved from the Amphibian Species of the World (Frost 2021).

Order	Worldwide	Vietnam	Vietnamese endemics
Anura	7361	263	88
Caudata	766	8	5
Gymnophiona	213	4	2
Total	8340	275	95

Table 2. Ten most speciose genera of amphibians in Vietnam.

Genus	Number of species	Subfamily	Family	Order
<i>Leptobrachella</i>	27	Leptobrachiinae	Megophryidae	Anura
<i>Odorrana</i>	24	–	Ranidae	Anura
<i>Amolops</i>	15	–	Ranidae	Anura
<i>Rhacophorus</i>	15	Rhacophorinae	Rhacophoridae	Anura
<i>Theloderma</i>	15	Rhacophorinae	Rhacophoridae	Anura
<i>Microhyla</i>	14	Microhylinae	Microhylidae	Anura
<i>Leptobrachium</i>	11	Leptobrachiinae	Megophryidae	Anura
<i>Gracixalus</i>	11	Rhacophorinae	Rhacophoridae	Anura
<i>Limnonectes</i>	10	Dicroglossinae	Dicroglossidae	Anura
<i>Panophrys</i>	10	Megophryinae	Megophryidae	Anura

Distribution

The diversity of local amphibian faunas differed among the geographic regions and provinces of Vietnam (Fig. 1). The highest species diversity among the eight regions was recorded for the Central Highlands (130 species), Northwest (121 species), North Central (112 species) and Northeast (110 species). Regarding the species richness per province, the ten provinces with the highest number of species were Lao Cai (92 species), Gia Lai (84 species), Kon Tum (76 species), Son La (65 species), Lam Dong (64 species), Thua Thien-Hue (64 species), Ha Giang (60 species), Dak Lak (59 species), Quang Binh (57 species), and Ha Tinh (56 species) (Fig. 1). Table 2 shows the similarities between the different amphibian faunas of the eight regions. Species similarity based on Sørensen's similarity index varied from 0.22 to 0.64 between the regions. The highest similarity between the regions of Vietnam was found between Northwest and Northeast with a similarity index value of 0.64. Overall, it was shown that regions of the same macro-region appeared more ecologically similar to each other (similarity index value > 0.5) than to regions of other macro-regions (similarity index value ≤ 0.5), which shared fewer species. An exception to this was the Red River Delta region of the North macro-region, whose species composition was only 0.34 similar to that of the Northwest region (Table 3).

Table 3. Species similarity (measured by Sørensen index) between eight geographic regions of Vietnam.

Region	NW	NE	RRD	NC	SCC	CH	SE	MRD
NW	1	0.64	0.34	0.54	0.3	0.35	0.35	0.22
NE		1	0.61	0.54	0.29	0.35	0.36	0.23
RRD			1	0.55	0.36	0.41	0.5	0.32
NC				1	0.59	0.57	0.42	0.24
SCC					1	0.6	0.47	0.26
CH						1	0.53	0.25
SE							1	0.55
MRD								1

Endemism

Approximately 49.1% of the recorded species (135 of 275) of amphibians in Vietnam are endemic to the Indochinese Region. The proportion of the country endemism is 34.5% (95 of 275 species). In percentage terms, 93% of the endemic species from Vietnam belong to the order Anura (n = 88), 5% to the Caudata (n = 5), and 2% to the Gymnophiona (n = 2) (Table 1). More than half of all endemic species are members of the anuran families Megophryidae (n = 28) and Rhacophoridae (n = 28) (56 out of 95 species or 59%) (see in Suppl. material 1: Table S4 for more information).

More than half of all endemic amphibian species from Vietnam are reported exclusively from their type locality (n = 54) (Fig. 2). One species, namely *Oreolalax sterlingae*, occurs in multiple locations in a single province. Another 12 species are distributed in between two and four provinces in one region. One-fifth of all endemic

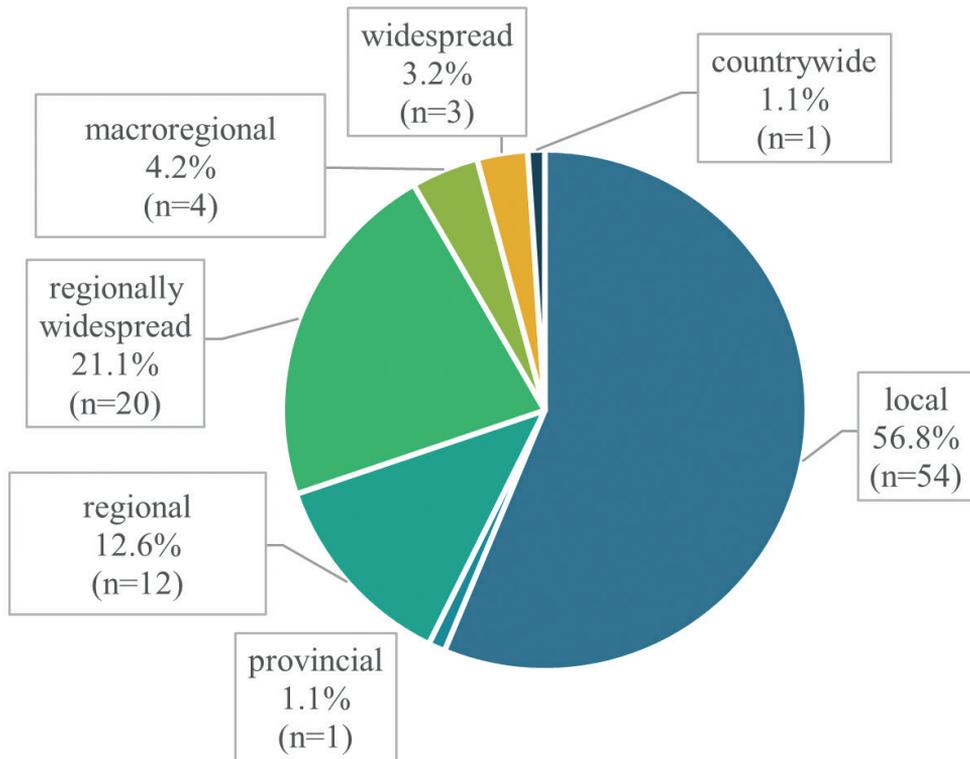


Figure 2. Distribution range of endemic amphibians from Vietnam ($n = 95$). Records separated according to the size of the area where the species is recorded. Distributions are described as follows: local - type locality only; provincial - multiple locations in one province; regional - 2–4 provinces in same region; regionally widespread - 2–9 provinces in 2–3 regions of the same macro-region.

taxa are regionally widespread ($n = 20$) occupying from two to nine provinces in two or three regions. Macroregional endemism is known for four species, while three species inhabit areas in six or more provinces in two macro-regions and are classified as widespread. Only *Microhyla picta* has been reported in all three macro-regions.

Regarding the distribution among the three macro-regions, 87 species are endemic to one of them: 33 species to northern Vietnam, 53 species to central Vietnam, and 1 species to southern Vietnam (Suppl. material 1: Table S6). Another seven species are endemic to two adjacent macro-regions, either the North and the Central or the Central and the South. About 70% (67 out of 95 endemic species) are recorded exclusively from one region (Fig. 3).

These 67 regional endemic species consist of 61 frog species, four salamander species, and two caecilian species (Suppl. material 1: Table S7). The Central Highlands, with 39% species endemic to this region, contain the most regionally endemic amphibians ($n = 26$), followed by NE ($n = 14$ or 21%), and NW ($n = 11$ or 16%) (Fig. 3).

Four-fifths of all regional endemic species occur in one province only (55 of 67 species) and are therefore classified as local endemics (Fig. 4).



Figure 3. Distribution of regionally endemic amphibian species in Vietnam. Map of Vietnam with its eight geographic regions and the respective number of regional endemics per region. Adopted and modified from IEBR archive. (See Suppl. material 1: Table S8 for more details related to the distribution of regional endemic species).



Figure 4. Distribution of provincially endemic amphibian species in Vietnam. Map of Vietnam with its 58 provinces and five municipalities and the respective number of provincially endemic amphibian species in bold. The number in brackets indicates the total number of endemic amphibian species from Vietnam for the province including the provincial endemics. Adopted from IEBR archive.

Further data about the differences in the distribution of endemic species belonging to the orders Anura, Caudata and Gymnophiona is presented in Suppl. material 1: Table S9. All endemic Gymnophiona species (two of two endemic species) are endemic at the provincial level, as well as 58% of endemic anuran species (n = 51) and 40% of endemic Caudata species (n = 2) (Fig. 4 and Suppl. material 1: Table S10).

Threat status

IUCN Red List status

A total of 203 species were included in the IUCN Red List (IUCN 2021), representing 73.8% of all amphibians extant in Vietnam. A quarter (or 72 species) known from Vietnam have not been assessed by the IUCN Red List, comprising 67 species of the order Anura, three of the order Caudata and two of the order Gymnophiona (Fig. 5).

In percentage terms, 25% of all Vietnamese amphibians assessed by the IUCN are considered threatened with extinction (50 out of 203 available statuses; CR = three species, EN = 25 species, VU = 22 species) (Fig. 6A). Based on absolute numbers, frogs are most threatened (n = 47), salamanders are second most threatened (n = 3), and caecilians are not considered threatened with extinction (n = 0) (Fig. 6B–D). In terms of the relative proportions of threatened and non- threatened species within the orders, salamanders are the most threatened, with 60% of the listed species classified as threatened with extinction, frogs are the second most threatened taxon with 24% of the species listed as threatened and caecilians are listed as non-threatened with 100% classified as LC. Approximately one sixth of all frogs are currently classified as DD. More than half of all species conservation statuses (104 out of 203 available statuses)

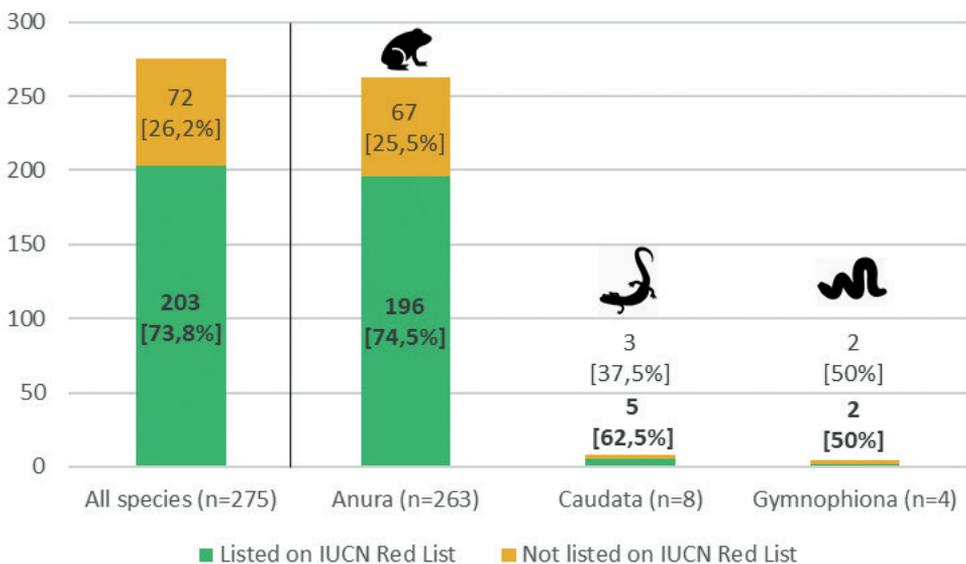


Figure 5. Listing of amphibian species extant in Vietnam on the IUCN Red List (IUCN 2021).

are older than 10 years and therefore no longer valid. IUCN Red List status is outdated for 79% of all species classified as DD (26 out of 33 species), for 20% of the total 50 species classified as threatened (VU: 5 out of 22 species, EN: 5 out of 25, CR: 0 out of 3) and for 85% of the species classified as NT (11 out of 13).

Up to 44 country endemic species are included in the IUCN Red List, representing 46% of all amphibian species endemic to Vietnam. For 51 endemic species recorded from Vietnam, no IUCN Red List status is available. For 30% of the assessed species, insufficient data is available, and they are classified as DD (n = 13). Of the remaining 31 species, 87% are classified as threatened with extinction (n = 27) (example species presented in Fig. 7), and 13% as LC (n = 4). While endemic species evaluated by the IUCN constitute only 22% of all evaluated species, they contribute to 67% of all CR species, 68% of all EN species, and 41% of all VU species. Regarding the distribution of endemic species (n = 95) and their IUCN Red List status, 63% of threatened species (17 out of 27 threatened species, EN: 11; VU: 6) are endemic to central Vietnam. Another 30% (CR: 2; EN: 4; VU:2) of threatened taxa are endemic to northern Vietnam, while no species endemic to southern Vietnam are classified as threatened with extinction by the IUCN (Suppl. material 1: Table S11).

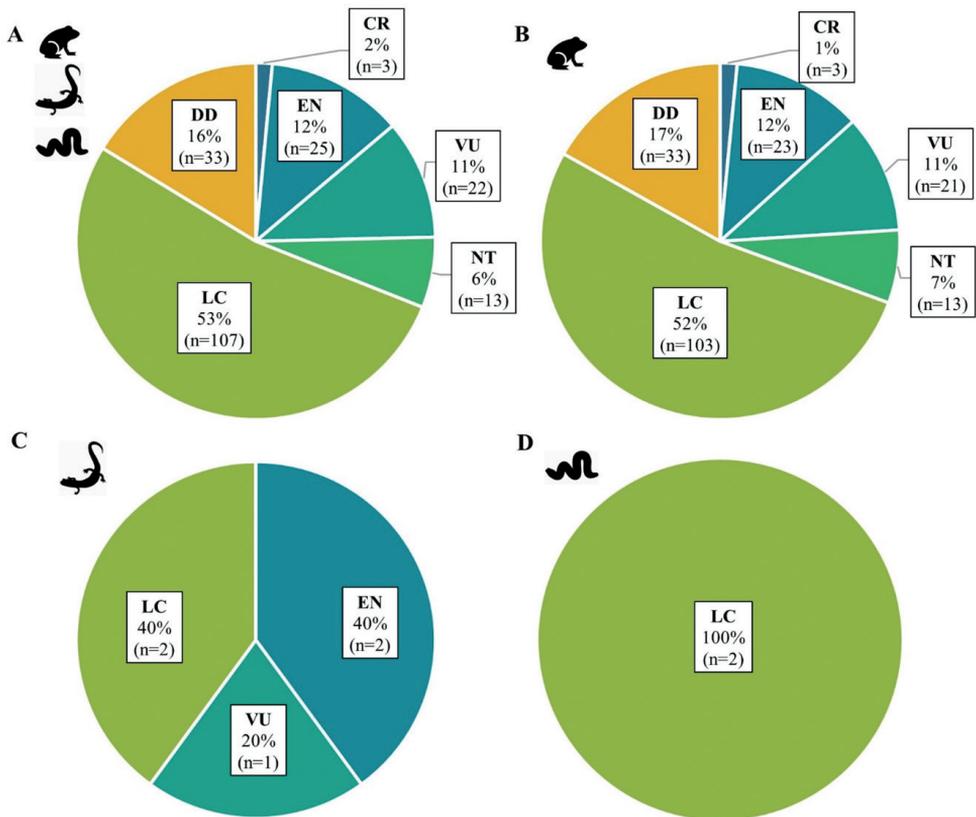


Figure 6. Distribution of IUCN Red List statuses of the Vietnamese amphibian taxa for which a status was available. **A** all orders **B** Anura **C** Caudata **D** Gymnophiona (IUCN 2021).

Considering the regional endemic species, 67% have not been evaluated by the IUCN (n = 45), 6% are classified as DD (n = 4) and 27% are considered threatened with extinction (n = 18; CR: 2; EN: 12; VU: 4). Among species classified as threatened with extinction, 11 species are endemic to the Central Highlands region, four species to the Northeast and three species to the Northwest (Table 4).

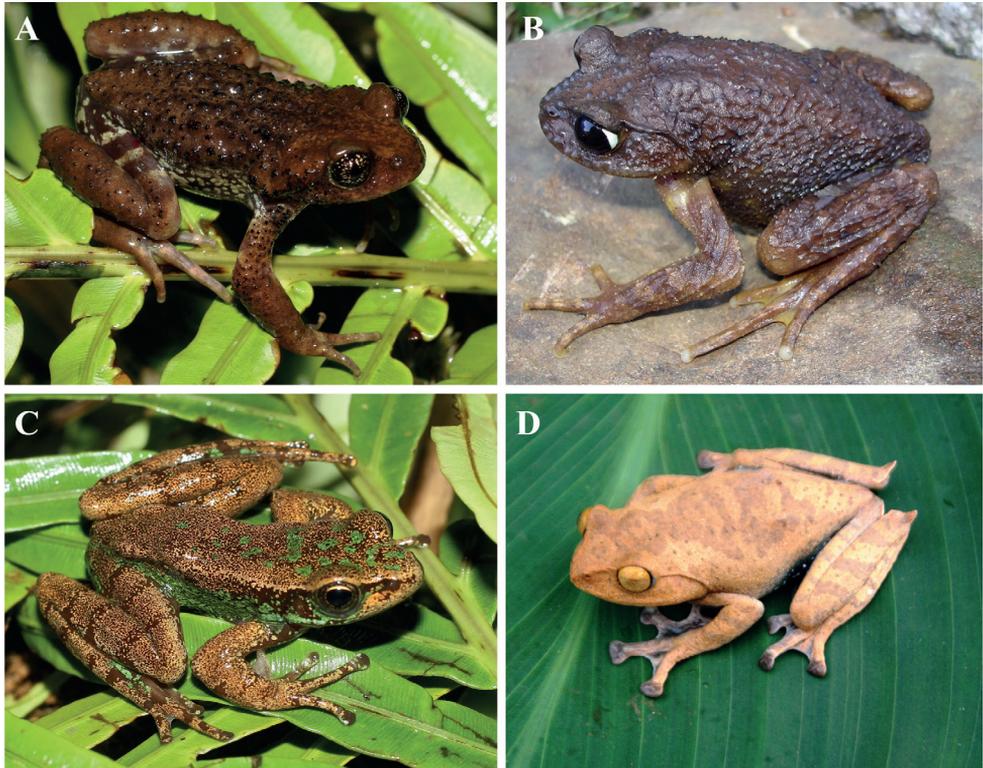


Figure 7. Threatened endemic amphibian species from Vietnam **A** *Oreolalax sterlingae* (IUCN: CR) **B** *Leptobrachium ngoclinense* (IUCN: EN) **C** *Amolops minutus* (IUCN: EN) **D** *Rhacophorus vampyrus* (IUCN: EN) (Photos: T. Q. Nguyen and C. T. Pham).

Table 4. Distribution of amphibian species from Vietnam endemic to one region (n = 67) and their IUCN Red List status.

Region	IUCN (2021)						Not Evaluated	Total
	CR	EN	VU	NT	LC	DD		
Northwest	2	1	0	0	0	0	8	11
Northeast	0	2	2	0	0	2	8	14
Red River Delta	0	0	0	0	0	0	3	3
North Central	0	0	0	0	0	0	6	6
South Central Coast	0	0	0	0	0	0	6	6
Central Highlands	0	9	2	0	0	2	13	26
Southeast	0	0	0	0	0	0	1	1
Mekong River Delta	0	0	0	0	0	0	0	0
Total	2	12	4	0	0	4	45	67

Regarding the threat statuses of local endemic species, no status was available for species belonging to the orders Caudata ($n = 2$) and Gymnophiona ($n = 2$) and for two-thirds of the in total 51 local endemic species belonging to the order Anura ($n = 34$). Of the 17 species for which a status was available, 13 species were classified as threatened with extinction (CR: 2; EN: 9; VU: 2) and four species were classified as DD (Suppl. material 1: Table S12).

Legislative inclusion of amphibians from Vietnam

Two genera of amphibians, which are also extant in Vietnam, are listed in CITES Appendix II. Both genera belong to the order Caudata, namely *Paramesotriton*, represented by two species in Vietnam and *Tylototriton*, represented by five species, four of which are endemic to Vietnam. Accordingly, only 2.5% of the total species and 4.2% of the endemic species extant in Vietnam are included in CITES. Of the total 49 species evaluated as threatened in Vietnam, only three species are included in Appendix II, namely *Paramesotriton guangxiensis* (EN), *Tylototriton vietnamensis* (EN), and *Tylototriton zieglerei* (VU). On national legislative level, *Paramesotriton deloustali* and *Tylototriton* spp. are listed in Group II of Decree No. 06 represented by six species. The List of Threatened Reptiles and Amphibians in the Vietnam Red Data Book lists 12 threatened amphibian species: nine frog species (CR: 1, EN: 6, VU: 2), two salamander species (EN: 2) and one caecilian species (VU: 1). For one species, the conservation status in the Vietnam Red Data Book and on the IUCN Red List is identical while 11 species are classified as more threatened in the Vietnam Red Data Book than on the IUCN Red List. Of the 95 endemic species for Vietnam, two are listed in the Red Data Book, namely *Quasipaa delacouri* and *Tylototriton vietnamensis*. Another 25 species have been evaluated as threatened with extinction by the IUCN but are not included in the Vietnam Red List. While the latest version of the Vietnam Red List was published in 2007, 18 of the threatened endemic species were described after 2007 and six frog species were described before that year. An additional species, namely *Amolops minutus*, was described in the year 2007.

Coverage by protected areas

Of the total 95 endemic species for Vietnam, 82 have been documented within one or more PAs while 13 have been recorded exclusively from locations in unprotected areas (Table 5, Fig. 8). Regarding their IUCN Red List status, two of the 13 amphibian species are classified as threatened (EN: 2), two are classified as DD and no status was available for the remaining nine species.

An overview of the distributions of local endemic species, species classified as threatened, and endemic species exclusively recorded in unprotected areas in Northern Vietnam is presented in Fig. 9 and for central Vietnam and southeastern Vietnam in Fig. 10. Since there are no species endemic to the Mekong River Delta, no detailed illustration of this region is presented here. Regarding the localities of species recorded exclusively in unprotected areas, *Zhangixalus jodiae*, *Odorrana mutschmanni*, *Quasipaa acanthophora*,

Table 5. Endemic amphibian species from Vietnam not yet recorded in any protected area and the provinces from where the species have been recorded so far. *: species is endemic to this province. Additional information: IUCN Red List status.

Order	Species	Province(s)	IUCN (2021)
Anura	<i>Limnonectes phuyenensis</i>	Phu Yen *	–
	<i>Leptobrachella kalonensis</i>	Binh Thuan *	–
	<i>Leptobrachella macrops</i>	Phu Yen, Dak Lak	–
	<i>Leptobrachella pyrrhops</i>	Lam Dong *	–
	<i>Leptobrachium xanthospilum</i>	Gia Lai *	DD
	<i>Microhyla aurantiventris</i>	Gia Lai *	–
	<i>Nanohyla nanapollexa</i>	Quang Nam, Kon Tum	DD
	<i>Amolops minutus</i>	Lai Chau *	EN
	<i>Amolops ottorum</i>	Son La *	–
	<i>Odorrana mutschmanni</i>	Cao Bang *	–
	<i>Theloderma ryabovi</i>	Kon Tum *	EN
	<i>Zhangixalus jodiae</i>	Ha Giang *	–
	Caudata	<i>Tylotriton sparreboomi</i>	Lai Chau *
Total	13		

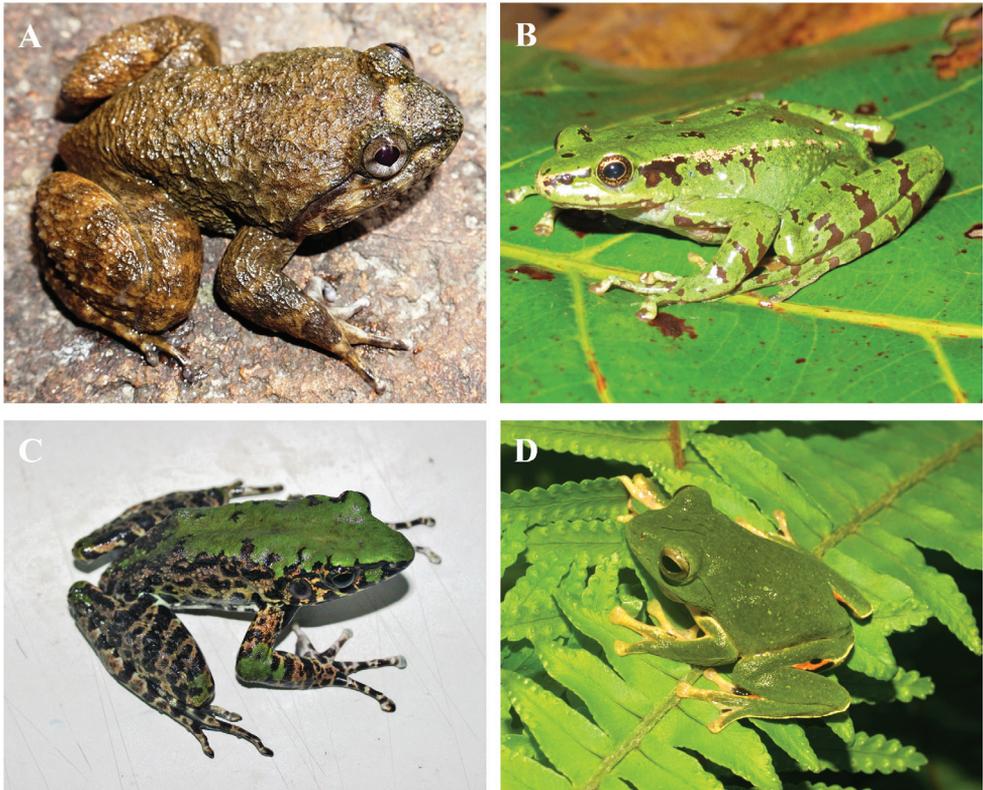


Figure 8. Microendemic amphibian species from Vietnam not yet recorded in any protected area. **A** *Limnonectes phuyenensis* (Phu Yen) **B** *Amolops ottorum* (Son La) **C** *Odorrana mutschmanni* (Cao Bang) **D** *Zhangixalus jodiae* (Ha Giang) (Photos: C. T. Pham, A. V. Pham and T. T. Nguyen).

close proximity (<50 km) to protected areas, namely *Leptobranchella kalonensis*, *L. macrops*, *L. pyrrophops*, *Leptobranchium xanthospilum*, *Microhyla aurantiventris*, *Nanohyla nanapollexa*, *Theلودerma ryabovi*, and *Limnonectes phuyenensis* (Fig. 10).

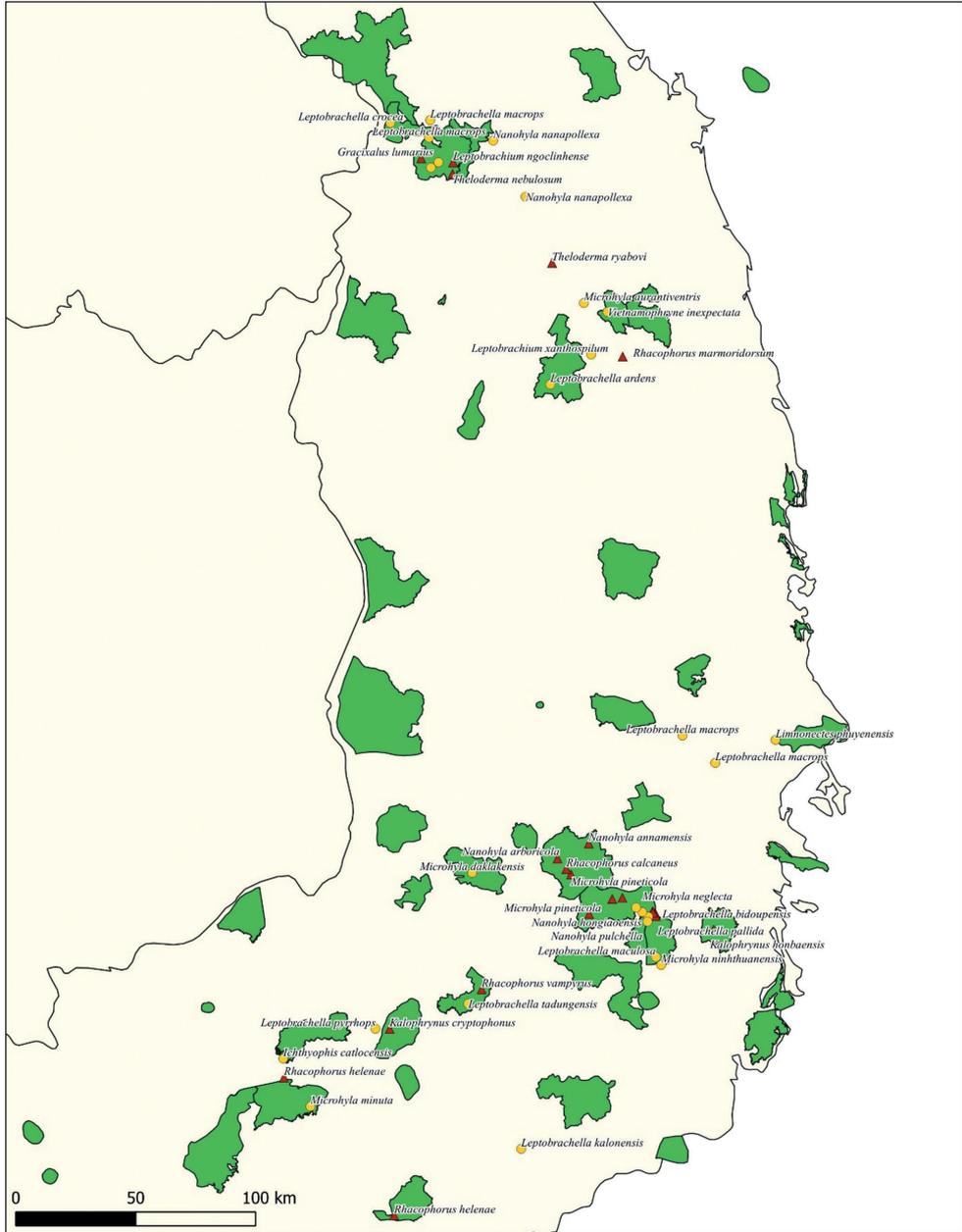


Figure 10. Distribution of protected areas in the mainland of central Vietnam with localities of endemic and threatened endemic species. Green shapes: Protected Areas; Yellow circles: Localities of endemic species; Red triangles: Localities of threatened endemic species.

Vietnamese amphibians *ex situ*

ZIMS

According to ZIMS data, 29 of the total 275 amphibian species reported to occur in Vietnam are represented in global zoos, including four Vietnamese endemic species (Table 6). Thus, 95.8% of the endemic amphibian species from Vietnam are not currently held in zoos ($n = 91$). Approximately 17% of the species held are classified as threatened by the IUCN, namely *Theloderma bicolor*, *T. ryabovi*, *Paramesotriton quangxiensis*, *Tylototriton vietnamensis*, and *T. zieglerei* (5 species; EN: 4; VU: 1), with a further 3% listed as NT (1 species), 76% as LC (22 species) and 3% as NE (1 species). Four threatened species held in ZIMS institutions worldwide account for only 8% of the 50 amphibian species in Vietnam classified as threatened. Of the 29 species kept in total, 13 (45%) were held in only one institution, four species (14%) in two zoos, one species (3%) in three zoos, two species (7%) in four zoos, eight species (26%) in five to 19 zoos and one species (3%), namely *Theloderma corticale*, in 89 zoos.

Of all amphibian species reported to occur in Vietnam and held in zoos, seven (24%) are represented by fewer than 10 individuals in ZIMS institutions; twelve (41%) with between 10 and 93 individuals; seven (24%) with between 118 and 291 individuals; two (7%) with between 509 and 654 individuals; and one (3%), *Duttaphrynus melanostictus*, with 1923 individuals. In terms of breeding success, reproduction of 38% of the species held in zoos (11 out of 29 species) were recorded within the last 12 months, including four endemic species from Vietnam and Indochina, namely *Ingerophrynus galeatus*, *Microhyla ninhthuanensis*, *Tylototriton vietnamensis*, and *T. zieglerei* (examples of threatened species already in *ex situ* conservation programs are presented in Fig. 11). Considering the distribution of amphibian populations in zoos worldwide, five of the 29 amphibian species known from Vietnam and being held are represented in zoos in Asia, including zoos in Singapore, Dubai, and India, but none in either of the two ZIMS member institutions in Vietnam. All four endemic amphibian species from Vietnam are held exclusively in European zoos.

ZTL

ZTL listed 36 species of amphibians reported to occur in Vietnam in European zoos including three Vietnamese endemic species (Table 6). Of all species, 26 are listed in both ZIMS and ZTL, 10 only in the ZTL and three only in ZIMS (Fig. 12). Of the 36 captive held species according to ZTL, six (17%) are classified as threatened by the IUCN, namely *Bombina microdeladigitata*, *Theloderma bicolor*, *T. ryabovi*, *Paramesotriton quangxiensis*, *Tylototriton vietnamensis*, and *T. zieglerei* (EN:4; VU:2), one (3%) as NT, 27 (75%) as LC ($n = 27$), and each one (3%) as DD and NE. Therefore, only six of the total 49 amphibian species from Vietnam classified as threatened are represented in European zoos according to the ZTL.

Table 6. Representation of amphibian species reported to occur in Vietnam in ZIMS institutions (n = 25) and ZTL institutions (n = 36). Species: *: species is endemic to Vietnam, **: species is endemic to the Indochinese Region. IUCN status: IUCN Red List status (IUCN 2021), those rated as threatened in bold. Institutions: Number of institutions in number of regions. Individuals: Number of individuals. Hatchings: Offspring in the past 12 months. The following species, *Sylvirana cubitalis*, *S. maasonensis* and *S. nigrovittata*, were listed in ZIMS under the former genus name *Hylarana*.

Species	IUCN status	ZIMS			ZTL
		Institutions (Regions)	Individuals	Hatchings	Institutions
<i>Bombina microdeladigitora</i>	VU	–	–	–	3
<i>Bufo gargarizans</i>	LC	4 (1)	154	0	2
<i>Duttaphrynus melanostictus</i>	LC	19 (3)	1923	103	18
<i>Ingerophrynus galeatus</i> **	LC	5 (1)	93	120	12
<i>Phrynooidis asper</i>	LC	14 (3)	61	0	3
<i>Euphlyctis cyanophlyctis</i>	LC	1 (1)	3	0	–
<i>Occidozyga lima</i>	LC	3 (1)	12	0	5
<i>Occidozyga martensii</i>	LC	–	–	–	1
<i>Hyla chinensis</i>	LC	1 (1)	1	0	2
<i>Leptobrachium chapaense</i>	LC	–	–	–	1
<i>Glyphoglossus guttulatus</i>	LC	1 (1)	10	0	2
<i>Kaloula pulchra</i>	LC	18 (5)	64	0	12
<i>Microhyla butleri</i>	LC	1 (1)	6	0	1
<i>Microhyla heymonsi</i>	LC	–	–	–	1
<i>Microhyla ninhthuanensis</i> *	NE	1 (1)	89	88	–
<i>Microhyla pulchra</i>	LC	1 (1)	1	0	1
<i>Hylarana erythraea</i>	LC	–	–	–	3
<i>Hylarana taipehensis</i>	LC	–	–	–	1
<i>Sylvirana guentheri</i>	LC	–	–	–	1
<i>Sylvirana cubitalis</i>	LC	7 (1)	291	63	8
<i>Sylvirana maasonensis</i>	LC	1 (1)	29	0	1
<i>Sylvirana nigrovittata</i>	LC	2 (1)	157	–	3
<i>Kurixalus bisacculus</i>	LC	2 (1)	124	100	4
<i>Kurixalus odontotarsus</i>	LC	1 (1)	19	0	2
<i>Nyctixalus pictus</i>	NT	10 (2)	128	38	6
<i>Polypedates megacephalus</i>	LC	11 (1)	509	57	10
<i>Rhacophorus kio</i>	LC	2 (1)	3	0	2
<i>Rhacophorus orlovi</i> **	LC	1 (1)	42	0	–
<i>Theloderma bicolor</i>	EN	9 (1)	118	48	11
<i>Theloderma corticale</i>	LC	89 (3)	654	105	69
<i>Theloderma gordonii</i>	LC	1 (1)	3	0	2
<i>Theloderma ryabovi</i> *	EN	1 (1)	2	0	2
<i>Zhangixalus dennysi</i>	LC	–	–	–	20
<i>Zhangixalus duboisi</i>	DD	–	–	–	1
<i>Zhangixalus feae</i>	LC	–	–	–	7
<i>Paramesotriton deloustali</i>	LC	1 (1)	32	0	1
<i>Paramesotriton guangxiensis</i>	EN	2 (1)	10	0	2
<i>Tylotriton vietnamensis</i> *	EN	4 (1)	154	13	4
<i>Tylotriton zieglerei</i> *	VU	1 (1)	69	87	1



Figure 11. Threatened Vietnamese amphibian species already in *ex situ* conservation breeding programs (Cologne Zoo, Germany). **A** *Ingerophrynus galeatus* in amplexus (Vietnam Red Data Book: VU) **B** *Paramesotriton deloustali* offspring (CITES: II) **C** *Tylotriton zieglerei* (CITES: II, IUCN: VU) **D** young *Tylotriton vietnamensis* (CITES: II, IUCN: EN) (Photos: A. Rauhaus and T. Ziegler)

Diversity analysis

Analyzing the spatial coverage of ZIMS listed zoos keeping amphibian species from Vietnam clearly shows that the highest density is found in Europe and North America (Fig. 13). However, it needs to be noted that this pattern may also reflect the overall higher densities of ZIMS members in these regions.

Discussion

Although mostly up to date, the data of this study unlikely reflects the actual species number of Vietnam's amphibian fauna. Since the cut-off date for our species list (June 2021), another six new species were described from Vietnam and are not included in this study: *Gracixalus zieglerei* Le, Do, Tran, Nguyen, Orlov, Ninh & Nguyen, 2021, *Vietnamophryne cuongi* Nguyen, Hoang, Jianping, Orlov, Ninh, Nguyen, Nguyen & Ziegler, 2021, *Leptobranchella graminicola* Nguyen, Tapley, Nguyen, Luong & Rowley, 2021, *Boulenophrys frigida* (Tapley, Cutajar, Nguyen, Portway, Mahony, Nguy-

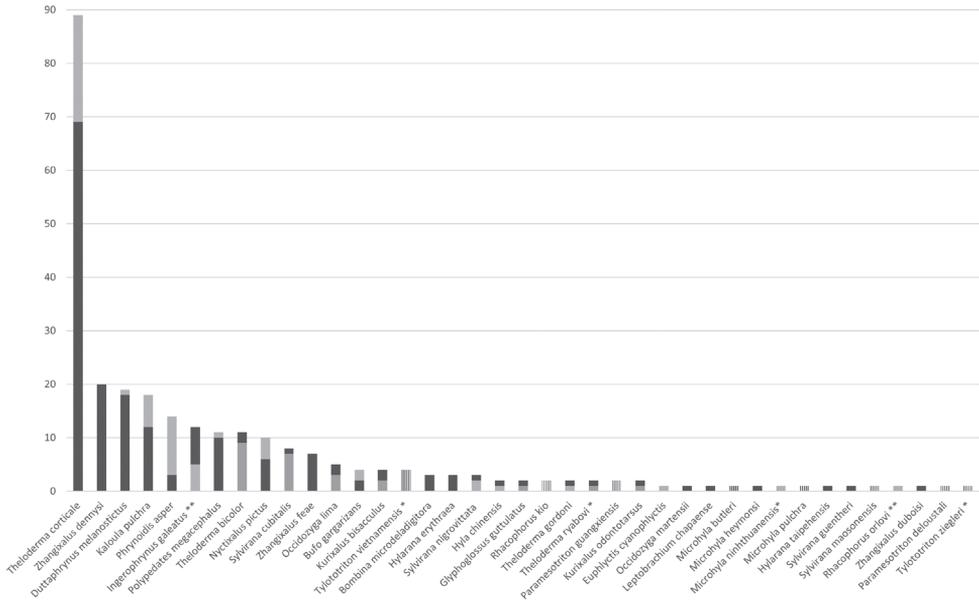


Figure 12. Number of institutions maintaining amphibians reported to occur in Vietnam (after ZIMS and ZTL). Light grey column: Number of institutions after ZIMS; Dark grey column: Number of institutions after ZTL; Striped column: Number of institutions identical after ZIMS and ZTL. *: species is endemic to Vietnam, **: species is endemic to the Indochinese Region.

en, Harding, Luong & Rowley, 2021), *Micryletta melanops* Poyarkov, Nguyen, Yang & Gorin, 2021, and *Theloderma khoii* Ninh, Nguyen, Nguyen, Hoang, Siliyavong, Nguyen, Le, Le & Ziegler, 2022. The new species discovery rate of amphibians from Vietnam is still high, as indicated by the 88 newly described species in the last decade, highlighting the outstanding amphibian diversity of the country. In addition, since the publication of the amphibian checklist by Nguyen et al. (2009), a total of 33 new country records have been documented from Vietnam, and there are an additional 12 amphibian species found in localities near the border between neighboring countries and Vietnam that are expected to occur in Vietnam. It is thus certain that additional new species will be described or recorded from Vietnam in the near future. On the other hand, taxonomic revisions, which are warranted for some of the existing taxa, may also alter the number of currently recognized amphibians in the country. For example, based on studies undertaken over the last decade, 20 of the 174 amphibian species listed by Nguyen et al. (2009) have been excluded from Vietnam, while 48 were reassigned to other genera. Moreover, the distribution data presented herein reliably reflect current scientific knowledge, but certainly do not represent the actual distribution of many species, in particular those only recently described and so far, only known from their type localities. Additionally, some of the endemic species occurring close to border areas are expected to be distributed in adjacent countries and therefore not endemic after all, such as *Limnonectes nguyenorum* McLeod, Kurlbaum & Hoang, 2015 which has recently been reported from China as well (Liu et al. 2022).

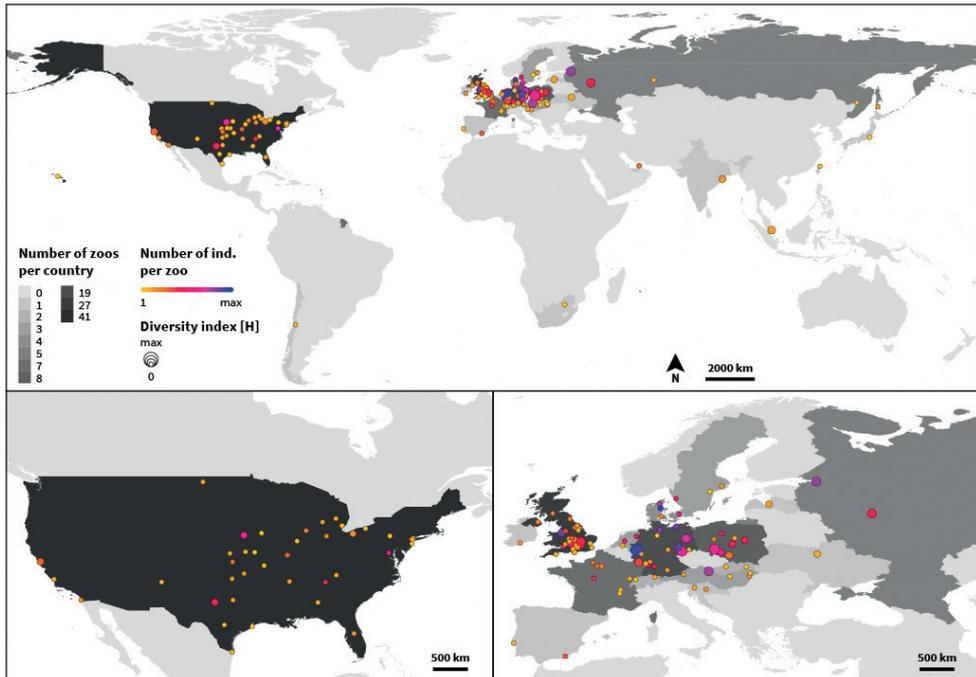


Figure 13. Geographic overview of amphibian species reported from Vietnam kept in zoos listed in ZIMS. Countries are shaded according to the number of zoos keeping specimens. Single zoos are highlighted as colored dots referring to the number of individuals per zoo. The size of the dots represents the H = Shannon Weaver Index. North America and Europe are highlighted with the highest density of zoos.

Amphibian endemism is not distributed evenly across the landscape of Vietnam with highest numbers of endemic species found in the Central Highlands (26 species endemic to this region), Northeast (14 species), and Northwest (11 species). The data are relatively consistent with the high species richness recorded in the regions. Specifically, the Central Highlands should be prioritized for amphibian conservation as most provincial and local endemic species are located in this region ($n = 22$) as well as most species classified as threatened by the IUCN Red List ($n = 11$). More than half of the 95 endemic species ($n = 54$, 57%) are only known from their type localities, emphasizing the importance of establishing local protected areas and strengthening the already existing protected area network particularly the tropical montane forests in the provinces of Kon Tum, Lam Dong and Lao Cai, for which high numbers of endemic species were recorded.

Only 73.8% of amphibians extant in Vietnam have been assigned an IUCN Red List category and not all the amphibians classified as threatened by the IUCN are protected by national legislations, highlighting the possibility of more far-reaching measures for species protection and conservation. It is noted that Decree No. 64/2019 did not include any amphibian species in the high conservation priority list. Re-evaluation and possible inclusion of endemic and threatened amphibians is highly recommended. More than half of all available threat statuses are outdated and there are differences

in quality of the respective reports between previous and more recent reports (IUCN 2021), thus reaffirming the importance of re-evaluations. Further research is especially needed for 33 species classified as DD since DD species are more likely to become extinct than assessed species (Howard and Bickford 2014; Bland et al. 2015). According to the IUCN Standards and Petitions Committee (2019), the species classified as DD should be prioritized by the scientific community to generate data that will allow their proper classification into a threat category. Continued collection of basic biological and ecological information is also particularly relevant for the 51 endemic species that have not yet been evaluated by the IUCN, so that their threat status can be properly assessed.

As only four amphibian species endemic to Vietnam are listed on CITES Appendices, the other 91 endemic species are recommended to be monitored for negative impacts from the trade. In addition, an updated version of the Vietnam Red Data Book is urgently required because conservation statuses of many species from Vietnam have changed substantially since its publication in 2007.

A total of 13 endemic species (14% of all endemics) are recorded exclusively from unprotected areas. Of these species, only *Amolops minutus* (EN) and *Thelederma ryabovi* (EN), have been classified by the IUCN as threatened and should be prioritized for further research into their distribution and threats to design appropriate conservation actions, including protected area coverage.

To achieve the goals of the One Plan Approach, the integration of *ex situ* populations into global species conservation planning and implementation must be strengthened. According to the Convention on Biological Diversity, *ex situ* efforts are recommended to function as a supporting measure to *in situ* efforts and ideally enable reintroductions of captive populations into the wild when it is possible. Since the exact origin of most of the kept amphibian populations is not evident in ZIMS, genetic analyses are recommended to determine their provenance or priority should be placed on species or their populations with known geographic origins and endemic species from Vietnam, respectively. As zoos and other husbandry facilities only have limited resources, the selection of species should be well planned and ideally focused on species with a greater need of captive assurance populations and breeding programs. It is also important to further investigate and determine which species would benefit the most from *ex situ* efforts on a species-by-species basis; as a starting point, range-restricted species could be prioritized. As a specific recommendation resulting from the data compiled herein, a list of top 50 species which might profit most from research and/or conservation efforts was compiled. A ranking scheme was used to generate the list, with points given for 1) Level of endemism, 2) IUCN Red List status, and 3) Not recorded in any protected area. An additional seven species were added because they received the same scores as those ranked from 26 to 50 (Suppl. material 1: Table S13).

Although the data from ZIMS and ZTL are not complete, it is apparent from these zoo databases that only a few amphibian species from Vietnam are present in zoos worldwide. Of the species held in zoos, only a small fraction is kept in more than a hundred individuals each. Overall, a majority of held species are not a priority

for conservation (listed as LC) and threatened taxa are underrepresented in zoos. We therefore recommend a general shift from common, non-threatened display species towards establishing *ex situ* populations of threatened species to address the amphibian crisis. In addition, nearly two-thirds of the held species are only present in one or two institutions. For the maintenance of healthy *ex situ* populations, a network of keeping facilities is recommended (e.g., Ziegler et al. 2020). It is also important to maintain multiple safeguard populations against unforeseen events (such as disease outbreaks or natural catastrophes) (e.g., Jacken et al. 2020). Only 11 out of 29 held amphibian species exceed the criterion of at least four holding institutions suggested by Jacken et al. (2020). Of the five threatened species (according to IUCN 2021) kept in zoos, only two, *Theiloderma bicolor* and *Tylototriton vietnamensis*, are currently held in four or more institutions. Of the 13 endemic amphibian species from Vietnam which are recorded exclusively from unprotected areas, only a single species, *Theiloderma ryabovi* (EN), is present in zoos with very few individuals in a single institution according to ZIMS. However, it can be assumed that more amphibian species and a larger number of individuals are kept and bred in captive-breeding centers in the country of origin (Harding et al. 2015) or elsewhere. Local holdings such as in the Me Linh Station for Biodiversity in Vinh Phuc Province, which also include amphibian populations (Ziegler et al. 2016), are not listed in either the ZIMS or the ZTL database. These in country facilities play a special role in developing conservation breeding programs for threatened amphibian species. The map showing the distribution of regional endemic or even micro-endemic amphibians in Vietnam underlines the necessity of scientific institutions and stations in the respective regions to consider conservation of these taxa a top priority, as they are the only ones on site and able to implement effective conservation breeding projects. As an additional measure, co-operation with zoos worldwide is recommended.

Conclusion

Conservation of amphibians in Vietnam could be further improved through continued field research, as well as more targeted support for the highly threatened endemic species analyzed in this study. Monitoring programs are considered especially important for 28 threatened species endemic to Vietnam to assess their population status. Further research is also crucial for the 63 endemic species not yet evaluated by the IUCN or classified as DD and the 13 endemic species exclusively recorded from unprotected areas. Besides threat status assessment, strengthening or establishing new protected areas should be considered, where required. Captive facilities in Vietnam in concert with international zoos should consider shifting their focus towards threatened amphibian species. In particular, regional stations and captive facilities can play a critical role in improving amphibian conservation through making the establishment of husbandry and breeding programs for threatened and microendemic amphibian species a top priority, following the IUCN's One Plan Approach.

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Supplementary material I

Assessment of the threat status of the amphibians in Vietnam - Implementation of the One Plan Approach

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Data type: Original data

Explanation note: Species list, endemic species, new records, distribution, top 57 list.

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