Received: 28 September 2022 | Revised: 7 February 2023 | Accepted: 16 February 2023

DOI: 10.1111/geb.13656

DATA ARTICLE

Global Ecology and Biogeography A Journal of Macroecology WILEY

Amphibian traits database: A global database on morphological traits of amphibians

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Handling Editor: Adam Algar

Abstract

Motivation: Amphibians are a diverse vertebrate group with more than 8,000 species, which is an important part of major terrestrial and freshwater ecosystems. Unfortunately, amphibians are experiencing a worldwide population decline. Trait information is important for understanding the causes of endangerment. Additionally, such information is essential for ecological and evolutionary studies using trait-based approaches. However, such data are scarcer for amphibians than for any other terrestrial vertebrate groups. To fill this gap, we collected morphological traits of global amphibians available from the literature and compiled a database to facilitate future studies.

Main types of variables contained: Forty-two morphological traits of Anura, 27 morphological traits of Caudata and 37 morphological traits of Gymnophiona.

Spatial location and grain: Global.

Major taxa: Amphibia.

Level of measurement: Species.

Software format: .csv.

KEYWORDS
amphibian, biodiversity, conservation, ecology, functional traits, morphology

1 | INTRODUCTION

Amphibians are a diverse vertebrate group on Earth, with more than 8,000 species (AmphibiaWeb, 2021; Frost, 2021; Womack et al., 2022). They are abundant in many terrestrial and freshwater ecosystems and are important for ecosystem functions (Díaz-García et al., 2017; Pough et al., 2016). As predators, they prey on different animals and are important parts of the food web (Moen & Wiens, 2009). They participate in the storage and exchange of materials and the flow of energy (Díaz-García et al., 2017). Due to their physiological characteristics, amphibians are sensitive to environmental changes and are widely used as indicators of environmental changes (Beebee, 1995). However, previous studies mainly focused on their species richness and phylogenetic diversity (Fritz & Rahbek, 2012). Large-scale studies based on functional diversity are rare (e.g., Ochoa-Ochoa et al., 2019; Sun et al., 2022), which is partly caused by a lack of data. In general, the level of completeness of trait data for amphibians is the lowest among terrestrial vertebrates (Etard et al., 2020). To date, the most comprehensive database of amphibians, AmphiBIO (Oliveira et al., 2017), has focused mainly on life history and ecological traits. However, ecological, physiological and behavioural traits are unavailable for a large part of the world amphibian fauna. Apart from a few exceptions, such as body size and habitats, the coverage for most traits is below 30% (Oliveira et al., 2017). More importantly, continuous morphological traits are rare in the database, except body size. Although body size is one of the most important functional traits, it is difficult to understand ecological niches and trophic interactions using body size alone. Continuous measurements of functional traits are more informative and can be used to test hypotheses about core theoretical concepts in ecology and evolutionary biology when combined with ecological and behavioural traits. Such studies on amphibians are rare. It is therefore urgent to improve our knowledge of amphibian continuous measurements.

Amphibians are the most threatened vertebrate group and are experiencing a worldwide population decline (Alroy, 2015; Stuart et al., 2004; Wake & Vredenburg, 2008). Globally, more than one third of amphibian species is in danger of extinction (IUCN, 2018; Stuart et al., 2004). Alarmingly, the proportion of data-deficient species of amphibians is the highest among all vertebrate groups (IUCN, 2018). More than 2,000 amphibian species are data deficient or not evaluated by the International Union for Conservation of Nature (IUCN; González-del-Pliego et al., 2019; IUCN, 2018). Furthermore, the diversity of amphibians is still seriously underestimated. The true species richness is greater than currently known (Köhler et al., 2005). About one third of the known species were described in the last two decades. Most of these are narrow-ranged species, which means they may be particularly vulnerable to habitat loss and climate change (Newbold et al., 2018; Platts et al., 2014). However, the extinction risk for most of these species is unknown (IUCN, 2018). Meanwhile, more than 100 amphibian species are described every year (AmphibiaWeb, 2021; Frost, 2021; Köhler et al., 2005). For these species, the threat statuses are also uncertain. To better protect the biodiversity of amphibians, it is urgent to understand the extinction risks of these species. Species extinction risks can be predicted based on traits (Chen et al., 2019; González-del-Pliego et al., 2019; Murray et al., 2011). Such approaches are especially valuable for amphibians considering the large proportion of data-deficient species (Cooper et al., 2008), but the lack of data hinders studies from precisely predicting the extinction risk.

Fortunately, detailed descriptions of species' morphological traits can often be found in taxonomic literature. In such literature, the morphology of species is measured and described in detail. The data is of high quality as the traits are usually measured from multiple specimens including the holotype specimen. Furthermore, the data of both males and females are usually available as it is common to measure specimens of both sexes. Many of these traits are tightly related to ecological functions. For example, the traits of body size are related to resource use (Moen & Wiens, 2009). The traits of limbs are correlated with locomotion and habitat choices of Anura. For Caudata, traits of tails are important in locomotion (Pough et al., 2016). Other commonly used characters in taxonomy, such as eye diameter (Thomas et al., 2020) and tympanum diameter (Fox, 1995), are also related to ecological functions. In this study, we compiled the most comprehensive morphological traits database of amphibians to date. Through extensive literature searching, we collected morphological traits for 4,412 amphibian species globally. These morphological data are important for research about the ecology, evolution and conservation of amphibians from local to global scales.

2 | METHODS

2.1 | Taxonomic classification

We carried out an extensive literature review to collect the data. In total, 2,115 scientific literature sources were considered. For the taxonomic system, we considered both Amphibian Species of the World (Frost, 2021) and AmphibiaWeb (AmphibiaWeb, 2021). For each species, we collected the measurements from the species' description and recorded the mean values of the traits. Data of males and females were recorded separately. We collected measurements of adults and only recorded data from juveniles when data for adults were not available. When several resources were available for one species, we took the one that had the most morphological traits. We calculated the percentage of species that had data for each family. We also calculated the percentage of species of each zoogeographic region (Holt et al., 2013). We obtained species geographical range maps from IUCN. We extracted species ranges onto an equal area grid with Behrmann projection. The resolution of the grid was set as 100 km. For species not recorded in the IUCN database, we obtained the distribution information from open databases and species description papers. Then, we assigned each species to zoogeographic regions based on phylo-distributional data for species of amphibians (Holt et al., 2013).

2.2 | Trait collection

As the body plans are quite different among the three orders of amphibians, we collected the traits for each order separately. For Anura, we recorded the data following the measuring standards of Watters et al. (2016). In total, we collected 42 traits (Table 1) for Anura, 27 traits for Caudata (Table 2) and 37 traits for Gymnophiona (Table 3). For each species, the traits listed in the original literature were collected. Instead of focusing on certain traits, we collected as many morphological traits as possible to ensure that researchers have more options when using the database. In addition, collecting as many traits as possible makes our database more useful for other researchers, such as taxonomists.

2.3 | Data formatting

The data table is organized in .csv format for each order separately. The first three columns of the table record the taxonomy of the species, which is family, genus and binomial species name. The next column records the sex information, where M indicates male, F indicates female and J indicates juvenile. The next columns record the measurements. Traits not available are coded as 'NA'. We will update the database continuously as new species are described every year. We record the references in a separate file.

TABLE 1 Morphological measurements of Anura.

Code	Name	Measurement	Completeness (%; total)	Completeness (%; male)	Completeness (%; female)
SVL	Snout–vent length	Direct line distance from tip of snout to posterior margin of vent	96.71	74.52	62.41
SUL	Snout–urostyle length	From the tip of the snout to the posterior end of the urostyle	3.57	2.58	2.30
HL	Head length	From the posterior of the jaws to the tip of the snout	86.06	68.10	56.61
HW	Head width	Greatest distance between the left and right articulations of jaw	96.21	73.82	62.16
ED	Eye diameter	Horizontally from the anterior to posterior corner of the eye	87.49	67.83	56.54
TD	Tympanum diameter	Greatest horizontal width of the tympanum	66.54	51.83	43.26
ETD	Eye–tympanum distance	From the anterior margin of the tympanum to the posterior corner of the eye	13.55	11.59	9.21
IOD	Interorbital distance	The shortest distance between the anterior corners of the orbits	60.85	48.14	41.58
IND	Internarial distance	Shortest distance between the inner margins of the nostrils	64.19	51.49	41.31
UEW	Upper eyelid width	Greatest width of the upper eyelid margins, measured perpendicular to the anterior–posterior axis	40.44	31.67	27.91
EN	Eye–nostril distance	From the anterior corner of the eye to the posterior margin of the nostril	67.01	50.17	41.90
SL	Snout length	Distance from the tip of the snout to the anterior corner of the eye	40.96	34.70	27.93
NS	Snout–nostril length	Distance from the centre of the external nares to the tip of the snout	23.80	19.27	15.73
HAL	Hand length	From the base of the outer palmar tubercle to the tip of finger IV	45.34	38.71	30.78
FLL	Forearm length	From the flexed elbow to the base of the outer palmar tubercle	27.79	23.80	18.77
LAL	Lower arm length	Distance from the elbow to the tip of finger IV	15.26	14.44	11.84
UAL	Upper arm length	From the body to the elbow	4.06	3.22	2.58
FL	Foot length	From the base of the inner metatarsal tubercle to the tip of toe IV	66.32	54.26	44.53
TL	Tibia length	Distance from the outer surface of the flexed knee to the heel/tibiotarsal inflection	91.46	70.18	58.87
THL	Thigh length	Distance from the vent to the knee	39.87	33.58	26.87
TSL	Tarsus length	From the tibiotarsal articulation to the base of the inner metatarsal tubercle	15.80	12.68	9.26
HLL	Hind-limb length	Measured from vent to tip of toe IV	18.25	15.68	13.03
TFL	Tarsus–foot length	From the tibiotarsal articulation to the tip of toe IV	5.65	4.88	4.26
IMT	Inner metatarsal tubercle length	The greatest length of the inner metatarsal tubercle	12.56	10.50	8.62
Fin1L	Finger I length	From the proximal margin of the palmar tubercle to the tip of finger I	9.93	8.20	7.06

(Continues)

TABLE 1 (Continued)

Code	Name	Measurement	Completeness (%; total)	Completeness (%; male)	Completeness (%; female)
Fin2L	Finger II length	From the proximal margin of the palmar tubercle to the tip of finger II	8.74	6.98	6.09
Fin3L	Finger III length	From the proximal edge of the palmar tubercle to the tip of finger III	11.81	9.41	7.60
Fin4L	Finger IV length	From the proximal edge of the palmar tubercle to the tip of finger IV	6.19	5.05	4.26
Toe1L	Toe I length	From the metatarsal tubercle to the tip of toe I	7.36	5.65	5.20
Toe2L	Toe II length	From the metatarsal tubercle to the tip of toe II	4.11	3.17	2.95
Toe3L	Toe III length	From the metatarsal tubercle to the tip of toe III	4.93	3.81	3.34
Toe4L	Toe IV length	From the metatarsal tubercle to the tip of toe IV	9.39	7.23	5.84
Toe5L	Toe V length	From the metatarsal tubercle to the tip of toe V	4.51	3.37	3.19
Fin1DW	Finger I disc width	The widest horizontal diameter of finger I	1.11	0.92	0.50
Fin2DW	Finger II disc width	The widest horizontal diameter of finger II	0.54	0.42	0.37
Fin3DW	Finger III disc width	The widest horizontal diameter of finger III	22.68	18	13.72
Fin4DW	Finger IV disc width	The widest horizontal diameter of finger IV	1.63	1.54	0.79
Toe1DW	Toe I disc width	The greatest horizontal distance between the edges of toe I disc	0.64	0.45	0.25
Toe2DW	Toe II disc width	The greatest horizontal distance between the edges of toe II disc	0.42	0.35	0.20
Toe3DW	Toe III disc width	The greatest horizontal distance between the edges of toe III disc	1.09	0.67	0.64
Toe4DW	Toe IV disc width	The greatest horizontal distance between the edges of toe IV disc	16.57	12.80	9.53
Toe5DW	Toe V disc width	The greatest horizontal distance between the edges of toe V disc	0.50	0.42	0.20

Note: Completeness means the percentage of species in the database for which a value for that trait is given.

3 | RESULTS AND DISCUSSION

We provide the most comprehensive morphological trait database of amphibians to date. In total, our database covers 4,412 species and accounts for more than half of the global amphibian fauna. The database encompasses 4,038 species of Anura (about 55.07% of known species), which covers 45 families and two superfamilies. Three families, Ascaphidae, Conrauidae and Heleophrynidae, are not covered. As these families have only a few species in total, this has little impact on the completeness of the database. Among the 47 families/superfamilies, 30 have at least 50% of their known species included in our database (Figure 1a). Our database will facilitate in-depth comparative works in these groups, especially in some species-rich groups, such as Brachycephaloidea, Microhylidae, Ranidae, Rhacophoridae, Mantellidae and Megophrydae. For Caudata and Gymnophiona, we collected data for about 33.59 and 53.74% of species, respectively, which covers all families. This database includes amphibian species inhabiting the 19 zoogeographic regions of the globe (Holt et al., 2013). The trait data cover on average 50.4% of species per region. Among all the zoogeographic regions (Holt et al., 2013), the region representing Europe, Central Asia and East Asia has the highest completeness level (Figure 2). Madagascar has the second highest completeness level, which may be attributed to great biodiversity discovering works in recent years (Vieites et al., 2009). Many species were descripted in recent years. The traits of these species and other closely related species are measured and described in detail.

The data completeness is high for traits that are commonly used as functional characters. For Anura, 12 traits are recorded for each species on average. The most complete trait is that of body length, which is provided for all species. The snout–vent length is given

TABLE 2 Morphological measurements of Caudata.

Code	Name	Measurement	Completeness (%; total)	Completeness (%; male)	Completeness (%; female)
TOL	Total length	Distance from the tip of the snout to the tail tip	32.82	25.10	23.94
SVL	Snout–vent length	Distance from the tip of the snout to the posterior margin of the vent	94.59	71.04	64.09
TRL	Trunk length	Distance from the gular fold to the anterior margin of the vent	21.62	15.83	11.58
AGS	Axilla–groin distance	Distance between the axilla and the groin	67.18	52.12	47.49
HL	Head length	Distance from the tip of the snout to the posterior edge of the parotoid gland	86.49	64.48	59.85
HW	Head width	Maximum head width	85.71	63.32	56.76
IOD	Interocular distance	Distance between the anterior corner of each eye	51.35	39.77	32.43
ED	Eye diameter	Horizontal distance across eye	49.42	37.84	31.66
ELL	Eyelid length	Length of the upper eyelid	10.81	5.02	5.02
UEW	Upper eyelid width	Greatest width of the upper eyelid margins	26.25	16.99	13.90
EN	Eye to nostril	Distance between eye and nostril	17.37	13.51	10.81
IND	Internostril distance	Distance between the medial margins of the nares	46.72	35.91	31.27
SL	Snout length	Distance from anterior border of eye to tip of snout	36.29	30.12	27.03
TL	Tail length	Distance from the posterior edge of the vent to the tail tip	84.94	60.23	54.44
TW	Tail width	Tail width measured at base	44.40	32.82	27.03
TH	Tail height	Tail height measured at mid-level of tail	30.12	25.87	22.39
TAH	Tail height at base	Tail height measured at base	23.94	15.83	12.36
MTAW	Medial tail width	Tail width at mid-level of tail	15.06	11.20	8.11
SG	Snout to gular fold	Distance measured from tip of snout to gular fold	7.34	5.41	3.47
SF	Snout to forelimb	Distance measured from tip of snout to forelimb	8.88	4.25	5.79
FLL	Forelimb length	Distance measured from point of body insertion to tip of longest finger	73.36	51.74	45.17
HLL	Hindlimb length	Distance measured from point of body insertion to tip of longest toe	71.43	49.81	43.63
Fin2L	Finger II length	Length from finger base to tip of finger II	10.81	6.56	4.63
Fin3L	Finger III length	Length from finger base to tip of finger III	14.29	9.65	8.11
Toe3L	Toe III length	Length from toe base to tip of toe III	23.94	15.83	14.29
Toe5L	Toe V length	Length from toe base to tip of toe V	13.51	7.72	5.41
VL	Vent length	Distance measured from the anterior to the posterior end of the vent	9.27	6.95	4.25

Note: Completeness means the percentage of species in the database for which a value for that trait is given.

for 96.71% of species. For other species, body length is measured as snout–urostyle length. We record 11 traits of the head. Among these traits, the most complete is head width, which is recorded for 96.21% of species. Head length is included for 86.06% of species. Eye and tympanum diameter are given for 87.49 and 66.54% of species, respectively. We collected 10 traits about the limbs. For

TABLE 3 Morphological measurements of Gymnophiona.

Code	Name	Measurement	Completeness (%; total)	Completeness (%; male)	Completeness (%; female)
TOL	Total length	Distance from the tip of the snout to the tail tip	98.26	45.22	38.26
TL	Tail length	Distance from the posterior edge of the vent to the tail tip	46.96	23.48	20
TRL	Trunk length	Distance from first collar groove to posterior end of vent	8.70	5.22	2.61
SVL	Snout–vent length	Distance from the tip of the snout to the posterior margin of the vent	1.74	0	0
VL	Vent length	Distance between anterior edge and posterior edge of the vent	8.70	5.22	3.48
BW1	Body width 1	Body width measured at first nuchal groove	28.70	13.91	13.04
BW2	Body width 2	Body width measured at middle of the body	87.83	43.48	36.52
BW3	Body width 3	Body width measured at the anterior edge of vent disc	40	25.22	23.48
HL	Head length	Distance from tip of snout to first collar groove	34.78	20.87	17.39
HW1	Head width at jaw angle	Head width measured at jaw angle	86.09	42.61	36.52
HW2	Head width at occiput	Head width measured at lateral edge of first nuchal groove	34.78	18.26	14.78
LJL	Lower jaw length	Distance from tip of lower jaw to jaw angle	18.26	6.96	7.83
SL	Snout length	Distance from tip of snout to jaw angle	34.78	13.91	13.91
IOD	Interorbital distance	Distance between the anterior corner of each eye	53.91	25.22	22.61
IND	Internostril distance	Distance between the medial margins of the nares	66.96	40.87	35.65
EN	Eye–nostril distance	Distance between eye and nostril	53.91	25.22	22.61
TE	Tentacle–eye distance	Distance between eye and tentacle	56.52	26.09	20.87
TN	Tentacle–nostril distance	Distance between tentacle and nostril	82.61	44.35	36.52
ITD	Intertentacle distance	Distance between tentacles	48.70	33.04	28.70
ED	Eye diameter	Horizontal distance across eye	5.22	2.61	3.48
TLP	Tentacle–lip distance	Distance between tentacle and margin of lip	27.83	16.52	15.65
NS	Nostril–snout distance	Distance between nostril and tip of snout	12.17	11.30	9.57
TS	Tentacle–snout distance	Distance between tentacle and tip of snout	18.26	14.78	14.78
TJ	Tentacle–jaw distance	Distance between tentacle and jaw angle	17.39	10.43	9.57
EJ	Eye–jaw distance	Distance between eye and jaw angle	19.13	9.57	8.70
NJ	Nostril–jaw distance	Distance between nostril and jaw angle	13.91	11.30	12.17
SJ	Snout–jaw distance	Distance between tip of snout and jaw angle	26.09	19.13	19.13
TAW	Tail width at posterior vent	Tail width measured at posterior vent	9.57	6.09	4.35
STFG	Snout to 1st collar groove	Distance from snout to first collar groove	53.91	22.61	19.13
STSG	Snout to 2nd collar groove	Distance from snout to second collar groove	30.43	8.70	4.35
STTG	Snout to 3rd collar groove	Distance from snout to third collar groove	30.43	7.83	4.35
TA1	Total annuli 1	Total number of annuli counted in dorsal view	93.04	42.61	35.65
TA2	Total annuli 2	Total number of annuli counted in ventral view	10.43	5.22	6.09
PVA	Post-vent annuli	Total number of annuli counted from posterior edge of the vent	25.22	10.43	5.22
VA	Vent annuli	Number of annuli interrupted by vent	23.48	13.04	7.83
C1	1st collar length	Length of first collar, measured laterally	31.30	24.35	20
C2	2nd collar length	Length of second collar, measured laterally	28.70	23.48	19.13

Note: Completeness means the percentage of species in the database for which a value for that trait is given.

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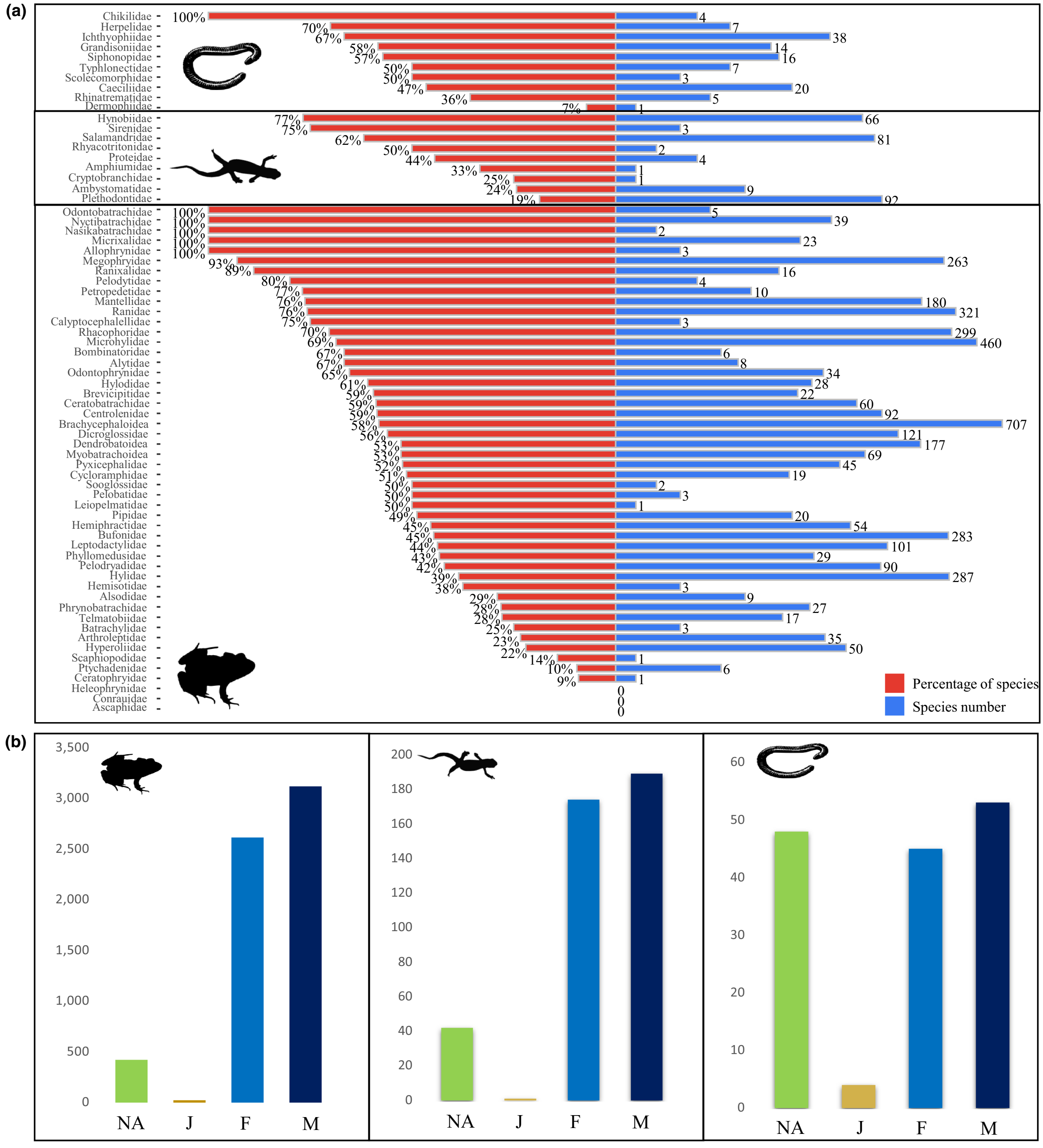

FIGURE 1 (a) Species with trait information. The blue bars indicate the number of species for which we collected traits. The red bars indicate the percentage of the total number of species in each family that is included in the database. (b) Number of species of each sex in the database for the three orders of amphibians. NA = not available; J = juvenile; F = female; M = male. Silhouettes were downloaded from PhyloPic (www.phylopic.org).

the forelimbs, hand length has the highest completeness (45.34%). For the hindlimbs, tibia length is given for 91.46% of species and foot length for 66.32% of species. The completeness of other traits is listed in Table 1. We also collect 18 traits about fingers and toes (Table 1). For Caudata, the total length is recorded for 32.82% of species. For most of the other species, the total length can be obtained by the sum of the snout–vent length and tail length. We also collected trunk length and axilla–groin distance, which are given for 21.62 and 67.18% of species, respectively (Table 2). We collected nine traits about the morphology of the head. The

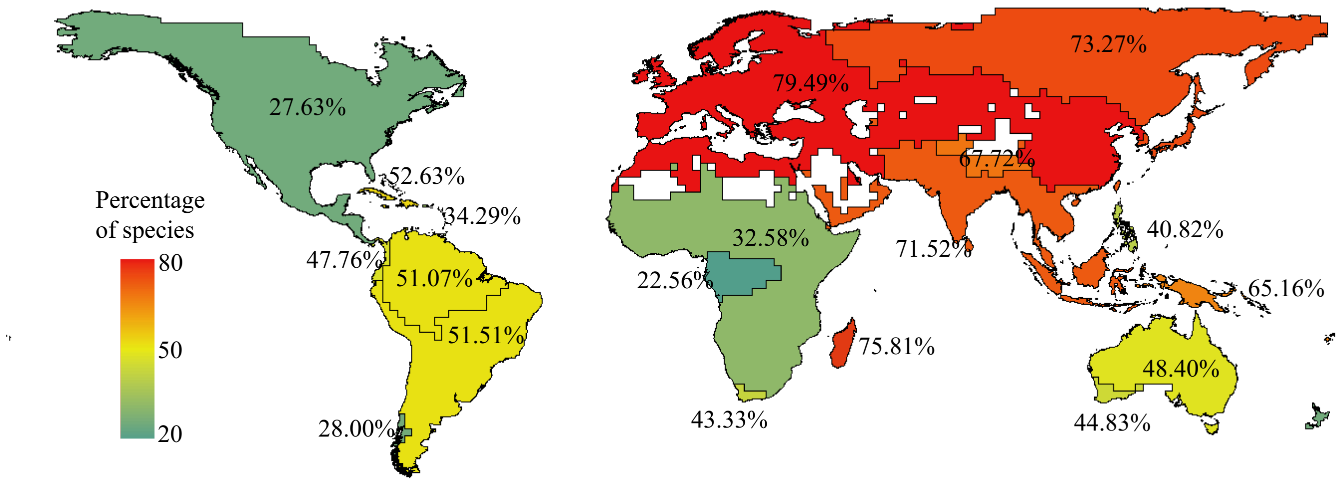

FIGURE 2 Percentage of species included in the database in each zoogeographic region.

completeness is high for the head length (86.49%) and head width (85.71%). We collected five traits about the tail, which are important for the locomotion of Caudata. Among these traits, tail length, tail width and tail height are available for 84.94, 44.40 and 30.12% of species, respectively (Table 2). Forelimb and hindlimb lengths are available for 73.36 and 71.43% of species, respectively (Table 2). For Gymnophiona, we collected 37 traits (Table 3). Total length is given for 98.26% of known species. Snout–vent length and tail length are recorded in other species. For all three orders, we collected information on both males and females. Our database contains 3,346 records of males, 2,819 records of females and 31 of juveniles (Figure 1b). In total, 2,279 species have data from both sexes, which will greatly facilitate comparative works considering sex dimorphism.

Ecological and behavioural traits, such as habitats, body sizes and breeding strategies, are available in AmphiBIO, which is the most comprehensive database for amphibians to date. It is noticeable that the habitat information from AmphiBIO is different from those used in previous studies (Moen et al., 2013; Moen & Wiens, 2017). In contrast to AmphiBIO, our database focuses on continuous morphological traits. This database is the most comprehensive global-scale database on amphibian morphology. Combining with ecological, physiological and behavioural trait data, which are available in other databases (Oliveira et al., 2017), our database can be used to test hypotheses about core theoretical concepts of ecology, evolutionary biology and biogeography. It will be useful in studying diversity formation, ecological speciation, functional structure of communities and functional diversity patterns from local to global scales. We collected all available traits to build the database. However, we suggest the users of the database select a subset of traits based on their research objectives and biological information before analysis. Because the correlations between ecological function and some traits are not clear, using all traits together may create noise as some of them may not be related to ecological functions. As new species are described every year, we will update the database and progressively fill taxonomic gaps in the future.

ACKNOWLEDGMENTS

Many thanks to Prof. Jing Che and Yaping Zhang for suggestions on the manuscript. We thank Yao Liu for assisting with data collecting. This work was supported by the Strategic Priority Research Program of Chinese Academy of Sciences (#XDB31000000), National Natural Science Foundation of China (NSFC) under grant no. 32170445, and the Fundamental Research Funds for the Central Universities (#lzujbky-2021-48).

CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

This database is publicly available through figshare (https://doi.org/10.6084/m9.figshare.21159229).

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How to cite this article: Huang, N., Sun, X., Song, Y., Yuan, Z., & Zhou, W. (2023). Amphibian traits database: A global database on morphological traits of amphibians. *Global Ecology and Biogeography*, *32*, 633–641. https://doi.org/10.1111/geb.13656