Chapter 1

Overview of amphibians and their conservation

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Abstract

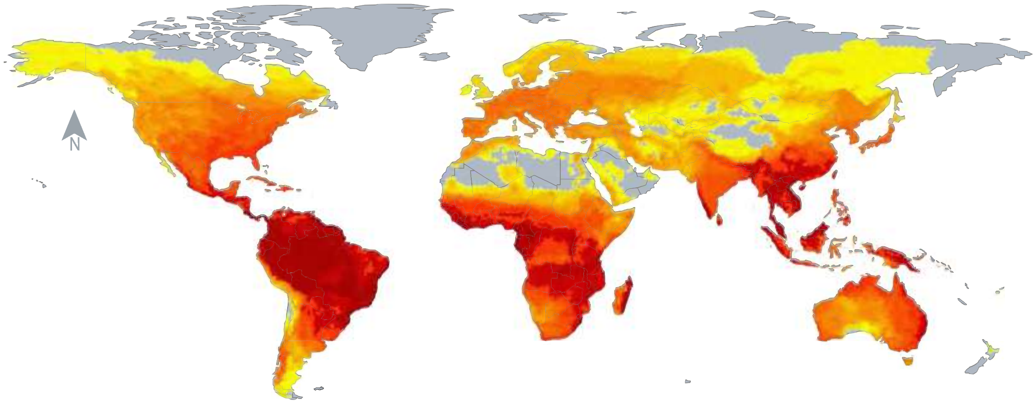
Amphibians are extraordinary and diverse organisms that have inhabited Earth for millions of years; yet, they are currently the most threatened vertebrate class, with over 40% of species at risk of extinction. Herein we offer a brief overview of the amphibians, covering aspects such as broad taxonomic classification, their geographic distribution, natural history and ecology, their importance and evolutionary uniqueness, as well as their conservation status and the global response to conserve them. We also discuss the background that informed this version of the *Amphibian Conservation Action Plan* and what is contemplated in it, as well as our aspirations for its adoption and implementation.

Introduction

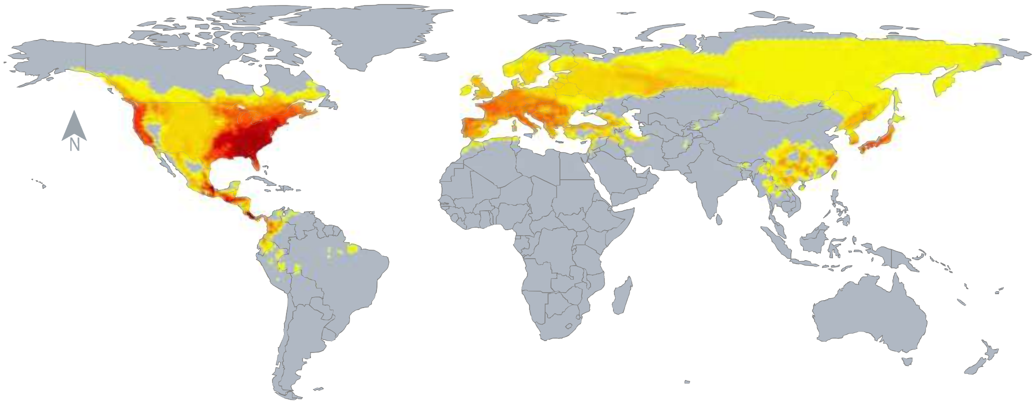
Few organisms embody transformation and renewal in the human imagination like amphibians. They have had an important presence across cultures and time, and even in the present day, many in the conservation community have fond memories of watching tadpoles in ponds and listening to frogs and toads calling into the night. Of course, well above their significance to our species, amphibians are pillars of many terrestrial food webs, keeping the cycles of life going. Yet, they are at the forefront of the current biodiversity crisis, having experienced the worst population declines and highest risk of extinction at the vertebrate class level, exacerbated by two global amphibian-specific pandemics in recent times prompted by the batrachochytrid fungi *Batrachochytrium dendrobatidis* and *B. salamandrivorans*. Despite having been resilient over geological time (early amphibians emerged in the Late Devonian, around 350–360 million years ago; Alford, Richards & McDonald, 2013; Hime et al., 2021), The IUCN Red List of Threatened Species™ (Red List) shows that over 40% of amphibians are currently at risk of extinction (IUCN, 2023; Luedtke et al., 2023) due to recent and emerging anthropogenic threats. Amphibians are in serious trouble, in no small measure because of humans, and we are in peril of losing some of the most magnificent creatures on Earth.

So, what makes amphibians the extraordinary creatures that we know and love? In the sections and chapters that follow, our global amphibian conservation community provides a synthesis of the status of amphibians, their importance, the challenges faced and the responses.

a) Anura



b) Caudata



c) Gymnophiona

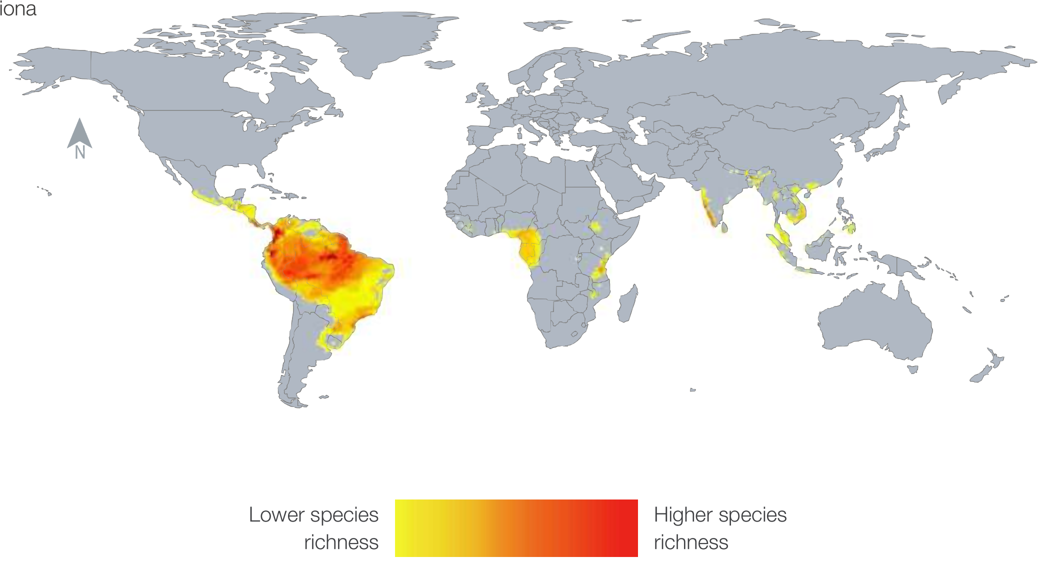


Figure 1.1: Map of known amphibian species richness, by Order, **a)** Anura, **b)** Caudata, **c)** Gymnophiona. Distribution data compiled by Kelsey Neam using "extant" or "possibly extinct" (i.e. known occurrence) range polygons from Red List assessments. Polygons coded as "possibly extant", "presence uncertain" or "extinct" were not included. Source: Amphibian distribution data provided by Amphibian Red List Authority, December 2022.

Classification

As of June 2023, there were 8649 recognised extant amphibian species (Frost, 2023; *see also* Figure 1.1); however, this number continues to grow at a rate of roughly one new species described every other day (AmphibiaWeb, 2022). Since the creation of the first comprehensive catalogue of amphibian species richness (Frost, 1985) the number of known amphibian species has more than doubled. This is an extraordinary rate of species discovery compared to that of other living vertebrate groups (Vences & Köhler, 2008).

Living amphibians occur in diverse sizes, shapes and colours, contained within three taxonomic orders: Anura (frogs and toads), Caudata (salamanders and newts) and Gymnophiona (caecilians). Anurans are the most ubiquitous and most species-rich of these orders both in terms of families and species, with 56 families and 7,614 species at the time of writing (Frost, 2023). They are followed by Caudata, with 9 families and 814 species, and Gymnophiona (10 families and 221 species; Frost, 2023).

Distribution

Anurans are the most widespread amphibians, occurring on all continents except Antarctica. The highest species richness is in tropical ecosystems, but they inhabit virtually all environments on Earth, except the most extreme dry or cold (Figure 1.1a). The Caudata are less species-rich and have a markedly different distribution. They are largely restricted to the Northern Hemisphere (Duellman, 1999), with highest species richness in western and eastern USA (Figure 1.1b). A single but highly species-rich family (Plethodontidae, with 512 species) has radiated into Central and South America, occurring also in southern Europe and the Korean Peninsula (Frost, 2023). Fewer species live on the Eurasian continent and the order is absent in sub-Saharan Africa, Madagascar, the Arabian Peninsula, insular Southeast Asia and Oceania. Caecilians are, by far, the least species-rich order (Figure 1.1c), but have a pantropical distribution, known from the tropics of the Americas, Africa, Asia, and the Seychelles (Gower & Wilkinson, 2005; Stuart et al., 2008).

As with much of terrestrial biodiversity, amphibian species richness drastically increases towards the Equator (e.g. Stuart et al., 2008). The Neotropics is by far the most species-rich zoogeographical zone, with Brazil having the highest number of species (1253), followed by Colombia (903 species), Peru (695 species) and Ecuador (685 species; Frost, 2023). Some species occur far from the Equator, showing remarkable adaptations to cold environments. For example, the North American wood frog (*Lithobates sylvaticus*) tolerates complete freezing during hibernation (Sinclair et al., 2013), and the Siberian salamander (*Salamandrella keyserlingii*) tolerates even more extreme temperatures that can reach as low as -35 °C (Berman, Leirikh & Meshcheryakova, 2010). Others endure extreme weather patterns at high altitude. The record holders are the frog *Pleurodema marmoratum,* breeding at 5,348 m asl in Peru (Seimon et al., 2007) and the salamander *Pseudoeurycea gadovii* recorded up to 4,250 m asl in Mexico (Solano-Zavaleta, García-Vázquez & Mendoza-Hernández, 2009).

At the other end of the spectrum, several genera of anurans and salamanders have adapted to arid areas by burrowing into the ground and forming a protective cocoon around their body in order to aestivate (Secor & Lignot, 2010). In some cases, aestivation can last up to ten months, with one extreme case of five consecutive years suggested for the Australian water-holding frog (*Ranoidea platycephala*; Secor & Lignot, 2010).

Natural history and ecology

It is difficult to capture the extent of amphibian natural history and ecology in this document. The impressive diversity in morphology, distribution, habitat use, physiology, mimicry, reproduction, behaviours, life stages, ecological attributes, and life histories easily merit several dedicated volumes (see e.g. Duellman & Trueb, 1994; Stuart et al., 2008; Wells, 2007 for a broader perspective), however, we provide a summary of amphibian biology *below*. By necessity, we have selected a handful of notable examples, but with the understanding that they are just a small sample of amphibian diversity.

Amphibians occupy a diverse variety of terrestrial and freshwater environments. All three orders have species that live underground, that are fully aquatic, fully terrestrial, and more or less everything in between. On the vertical axis they occur from deep underground aquifers and caves, through soil-dwellers, up to the tallest tree canopies. On the horizontal axis they are land or water dwellers, or alternate between both; in water, they occupy lentic and lotic habitats ranging from the world's largest lakes and rivers to the water captured in the leaf axils of plants, and even the brackish waters of estuaries.

While the amphibian life cycle is typically pictured with eggs laid in water, which develop into tadpoles that metamorphose to land-living adults, the actual diversity of amphibian life histories is manifold and spectacular. Although most amphibians do have free-living aquatic larvae (i.e. tadpoles), approximately 30% of species reproduce through direct development, which means their eggs hatch into miniature versions of adults. At least 68 amphibian species have evolved away from egg laying completely, giving birth to fully developed young (Sodhi et al., 2008). This reproductive diversity is also reflected in the vastly different fecundity and population dynamics among amphibians, requiring a variety of conservation strategies. For instance, a single Great Plains toad (*Anaxyrus cognatus*) has been documented as laying 45,000 eggs in one breeding season (Thibaudeau & Altig, 1999), while the Alpine salamander (*Salamandra atra*) gives live birth to only one to two young after three years of gestation (Häfeli, 1971). These two extremes capture but a few aspects of the 74 different reproductive modes that have been described by scientists to date (Nunes-de-Almeida, Haddad & Toledo, 2021). There are over 30 forms of parental care observed in amphibian species, ranging from basic egg guarding to very advanced behaviours (Schulte et al., 2020). Some species raise their young on their body, like the aquatic frogs *Pipa* spp*.* which hatch either tadpoles or fully developed young through the skin on their back (Rabb & Rabb, 1960). Others carry their young until fully developed in a skin pouch on their backs, such as members of the treefrog genus *Gastrotheca* (Elinson et al., 1990). Perhaps even more mystifying are those cases where the eggs are incubated inside the body cavity and are orally 'expectorated' as fully developed froglets, for instance in the vocal sac of Darwin's frog (*Rhinoderma darwinii*) and the stomach in the now extinct gastric brooding frogs (*Rheobatrachus* spp.; McDiarmid, 1978). Female *Oophaga pumilio* carry their tadpoles long distances on their backs to deposit them in the water of leaf axils of epiphytic plants and raise them exclusively on unfertilised eggs (Summers, McKeon & Heying, 2006). Still other amphibians make subterranean chambers, securing moisture for their eggs in desert sand dunes, for example *Breviceps macrops* (Minter, 2004). One final, fascinating example is the Taita caecilian (*Boulengerula taitana*), which nests underground and feeds its young the outermost layer of its own skin (Kupfer et al., 2006).

Amphibians are also diverse where body size is concerned. Measuring about 8 mm, the smallest recorded vertebrate is the frog *Paedophryne amauensis* from Papua New Guinea (Rittmeyer et al., 2012), whereas – at 32 cm – the largest anuran on record is the goliath frog, (*Conraua goliath*; Sabater-Pi, 1985). The smallest known salamander is *Thorius arboreus* from Mexico, with the largest known adult of this species measuring 20 mm snout-vent length (Hanken & Wake, 1994). The Chinese giant salamander (*Andrias davidanus*), on the other hand, is the largest amphibian reaching up to 180 cm (AmphibiaWeb, 2022). Amongst the caecilians, the longest is *Caecilia thompsoni* growing to 177 cm (Fernández-Roldán & Gómez Sánchez, 2022); whereas the smallest caecilian is *Idiocranium russeli* with several mature adults recorded at less than 10 cm (Gower et al., 2015).

Our knowledge of amphibian longevity is spotty at best, but it appears that caudates are generally more long lived than anurans (Smirina, 1994). While many species are presumed to be relatively short-lived, with a lifespan of only a few years in the case of anurans and tropical species, there are some exceptions. Long-term monitoring of New Zealand frogs (*Leiopelma* spp.) has recorded several individuals over 40 years old (Bell & Bishop, 2018). Notably, the olm (*Proteus anguinus*), a cave-dwelling salamander, has a predicted maximum lifespan of over 100 years and an average lifespan of approximately 70 years (Voituron et al., 2011).

Evolutionary uniqueness

Amphibians emerged around 350–360 million years ago (Alford, Richards & McDonald, 2013; Hime et al., 2021). While the early amphibian faunas differed dramatically from their modern counterparts, representatives of many of the currently recognised amphibian families were most likely already present when dinosaurs roamed our planet (Roelants et al., 2007). Some extant species are particularly isolated across deep evolutionary time, and 24 families have fewer than 10 species (Frost, 2023).

The Zoological Society of London (ZSL) Evolutionarily Distinct and Globally Endangered (EDGE) programme identifies these special species. Using a combined score of evolutionary distinctiveness (ED) and extinction risk (taken from the Red List), species are ranked based on their evolutionary history and threat status (Isaac et al., 2007, 2012). As of 2020, a total of 863 amphibians from all three amphibian orders were listed as EDGE species. The top-ranked anuran, salamander and caecilian are Archey's frog (*Leiopelma archeyi*), the Chinese giant salamander (*A. davidianus*) and the Mount Oku caecilian (*Crotaphatrema lamottei*), respectively (ZSL, 2020).

Conservation status

Reports of amphibian declines began to emerge in the 1950s (Bishop et al., 2012), but for a long time only as infrequent publications in the peer-reviewed literature. It was not until the First World Congress of Herpetology, held in the United Kingdom in 1989, that the disparate observations of international herpetologists raised concerns that the scope and severity of these declines were beyond what anyone had previously thought (Bishop et al., 2012; Stuart, 2012). Alarmingly, catastrophic declines were documented even in pristine environments. For example, the two Australian gastric-brooding frogs (*Rheobatrachus* spp.) disappeared in less than a year, one in the late 1970s, the other in the mid-1980s, and the Costa Rican golden toad (*Incilius periglenes*) has not been seen since 1989 (Stuart, 2012). All three species are now considered Extinct and there are many others that have suffered a similar fate. An even larger number are considered 'Possibly Extinct' because there are no known surviving subpopulations, but exhaustive surveys have yet to confirm their extinction.

In response to the widespread concerns, a global push began to better understand the causes of these extinctions and declines, and to determine the conservation actions that might halt this trend (*see* 'Global response' section in this chapter for details). In 2001, IUCN, Conservation International, and NatureServe began the Global Amphibian Assessment (GAA), the first-ever comprehensive extinction risk evaluation of all 5,743 amphibian species described at the time. The assessment results, published in 2004, were devastating: amphibians were declared the most threatened vertebrate group, with 32.5% of species categorised as threatened on the 2004 Red List (Stuart et al., 2004). Furthermore, 22.5% of the species were classified as Data Deficient (DD), having too little or too uncertain data to make a reliable assessment. Employing the Red List best estimate approach (IUCN, 2022) the same proportion of DD species was assumed to be threatened as the data sufficient species, which provided a total estimate of 40% of all amphibians threatened with extinction.

In addition to providing a snapshot of the current conservation status of amphibians, undertaking regular comprehensive updates of all species also provides an opportunity to monitor conservation status over time. The Red List Index (RLI) is an indicator developed by IUCN to illustrate the changing conservation status of a group of species based on genuine improvements or deteriorations in Red List category. This biodiversity indicator has become widely used to compare the status of various taxonomic groups, as well as, for example, a measure of progress towards the UN Convention on Biological Diversity targets (Butchart et al., 2007; Secretariat of the Convention on Biological Diversity, 2020). The first GAA also estimated what the Red List category would have been in 1980, based on current knowledge, to calculate an RLI for 1980 to 2004. It showed a significant downward trend, equivalent to an increase of 30% of species listed in a higher threat category in 2004 compared to 1980 (Butchart et al.,

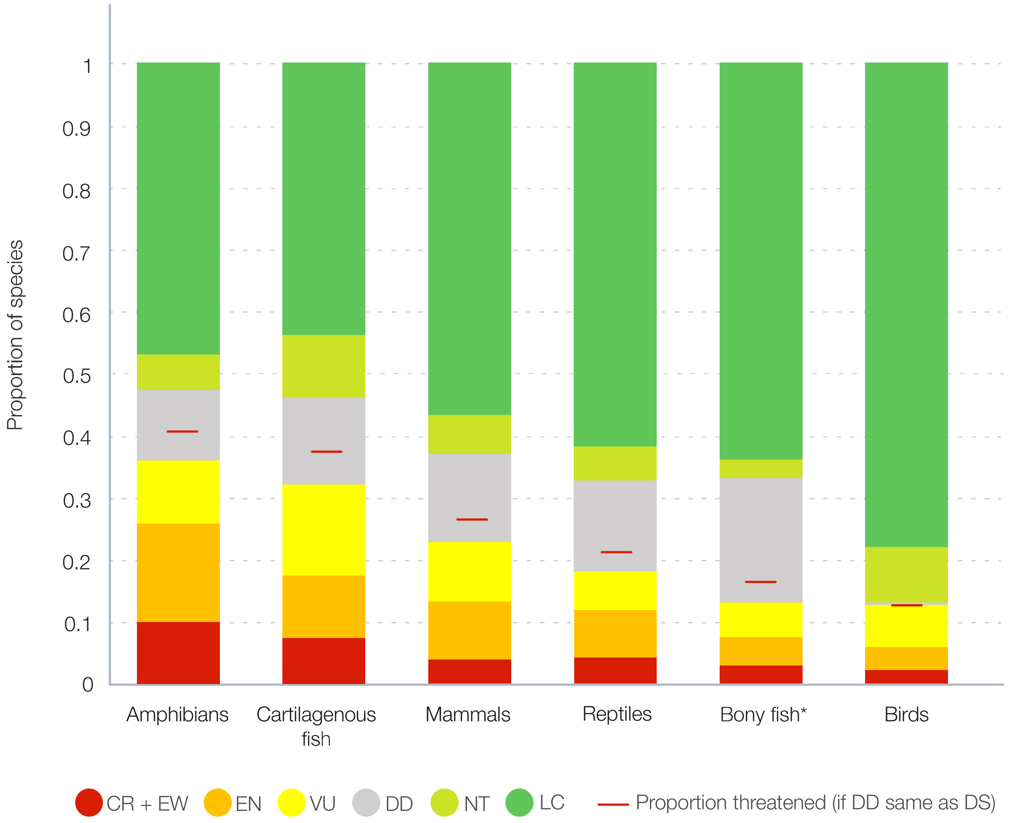


Figure 1.2. Proportion of extant species in each Red List category by vertebrate group. CR + EW – Critically Endangered plus Extinct in the Wild, EN – Endangered, VU – Vulnerable, DD – Data Deficient, NT – Near Threatened, LC – Least Concern. Red line indicates the estimated proportion of species classified as threatened if Data Deficient species are threatened in the same proportion as data sufficient (DS) species. EW species were included with CR because numbers are small and would not have been visible on this chart. Extinct species are not included on this chart. * An asterisk denotes groups where not all species have been assessed. Data Source: IUCN Red List version 2022-2 (downloaded 14th June 2023) and Luedtke et al,. 2023.

2005). This highlighted amphibians as one of the most rapidly declining taxonomic groups (Secretariat of the Convention on Biological Diversity, 2020). An analysis using the RLI to assess the impact of conservation on amphibians, birds and mammals found that while conservation efforts were having an appreciable effect on the trend in conservation status for birds and mammals, this was not the case for amphibians (Hoffmann et al., 2010).

To remain current, a Red List assessment for a species should be updated every 10 years, which is considered the minimum standard for providing the most up-to-date information to conservation efforts and tracking trends through the RLI at regular intervals. The ASG launched the second Global Amphibian Assessment (GAA2) in 2015, which was completed in 2022, and now includes more than 8,000 species (*see* Chapter 2 for this and other related challenges). The GAA2 results confirm that amphibians remain the most threatened vertebrate group, with an estimated 41% of species currently within threatened categories (Figure 1.2; IUCN, 2023; Luedtke et al., 2023). The GAA2 results show that 37 amphibian species are known to have become Extinct since 1500, with a further 185 species considered to be likely extinctions (classified as Critically Endangered, tagged Possibly Extinct), while three species are known or considered likely to survive only in captivity (classified as Extinct in the Wild, or Critically Endangered tagged as Possibly Extinct in the Wild). The GAA2 also provides a third data point for the RLI, giving an indication of the conservation status of amphibians as a group; this indicates that the trend in amphibian extinction risk continues to deteriorate over time, although the rate of deterioration has slowed slightly (Luedtke et al, 2023).

There has been a substantial amount of research on amphibians since the first GAA, some of which was no doubt spurred by the response of the herpetological community to the plight of amphibians highlighted on the Red List. This new research has provided sufficient information for many species to be comprehensively assessed and hence removed from their previous Data Deficient category; the proportion of Data Deficient species has decreased from 22.5% in the first GAA to 11.3% in the GAA2.

However, it should be noted that some species will always be difficult to remove from the Data Deficient category. For example, species known only from the type specimen, the provenance of which is unknown, or where there is considerable taxonomic uncertainty, to the point that a species name may not refer to a valid biological species.

As well as Data Deficient species, almost all amphibians would benefit from more information on their distribution, population, ecology, and threats. Thus, the recommendations of this publication will not only serve to direct the focus of conservation actions on the ground, but will also inform and improve conservation assessments. Each chapter specifies the research needed to inform these actions and inform future Global Amphibian Assessments, completing the Assess-Plan-Act conservation cycle of the Species Survival Commission.

Vulnerability to threats

Amphibians can be particularly vulnerable to threats; they are often adapted to spend different parts of their life cycle in specific habitats, terrestrial and aquatic, and as a result they are vulnerable to changes in both environments. Many species, particularly those in tropical regions, have very small distributions, and large proportions of a population can be affected by changes to a relatively small area. Their habitat-specific life stages also mean that amphibians often consume different types of food as larvae and adults, increasing their potential for ingesting toxins and their exposure to parasites. In addition, amphibians are ectotherms, and are therefore sensitive to temperature changes, while their moist permeable skin leaves them exposed to desiccation and to pollutants in the water and air. Many species have low vagility and are unable to move to effectively escape environmental threats; this particularly constrains species that would have to cross unfavourable environments to reach new habitat, such as those inhabiting mountaintops or small islands. These factors compound to increase the vulnerability of many amphibians to anthropogenic threats. As well as these aspects, there are also indirect factors, including that amphibians are not considered to be charismatic relative to many mammals and birds, leading to amphibians receiving overall less attention from researchers, conservation practitioners, and conservation funding than these other taxa (Ceríaco, 2012; Tarrant, Kruger & du Preez, 2016; Tomažič, 2011; *also see* Chapter 2).

It is important to note that the diverse and ubiquitous threats that affect species currently assessed as threatened also affect non-threatened and Data Deficient species. More details on most of the threats and how they impact amphibians can be found in the relevant chapters throughout this document.

Importance of amphibians

The value of a species is often translated into the benefits it provides to humanity and interpreted in monetary or utilisation value. It is, however, important to look at the value of a species from a different point of view: the intrinsic value of a species. Here, we look at how human societies have relied on amphibians for their development and how we still rely on them, rather than how human societies can benefit from exploiting amphibians (Doak et al., 2014). This is one example of the viewpoints available, and even within the field of conservation alternatives can be found. For instance, some may focus on the evolutionary value of a given species, and others may focus on its representation and connectedness within the environment.

The history of humans and amphibians is more tightly linked than it is generally expressed or understood, in terms of culture, medical development, disease and pest control, and much more – acknowledging a cultural bias. Early human populations were attracted to wetlands and other fertile ecosystems due to their richness in primary producers, a preference generally matching with that of all vertebrates (Pérez, Schuster & Jofré, 2018; Small & Cohen, 2004), resulting in the establishment of human settlements in habitats also favoured by amphibians. Human societies have relied and continue to rely on amphibians as a food source (Das, 2011; Mbaiwa, 2011), in hunting practices (Myers, Daly & Malkin, 1978), fishing or controlling water quality. For example, a Chilean giant frog (*Calyptocephalella gayi*) was placed inside water wells as a bioindicator of water quality in central Chile (personal communication A. V. Sánchez), and Ranidae and Bufonidae are used for a similar purpose in Indonesia (Mardiastuti et al., 2021).

A notable benefit derived from amphibians is their use in traditional and modern human healthcare (Clarke, 1997; Crnobrnja-Isailović et al., 2020). These include, for instance, the crucifix frog (*Notaden bennettii*) from Australia, whose secretions are used for biological glues in human medicine (Zhu, Chuah & Wang, 2018). Another example is that of antibiotics developed from amphibian antimicrobial polypeptides, and the amphibian skin polypeptide Gaegurin 4 is effective against both gram-positive and gram-negative bacteria (Won, Kang & Lee, 2009).

Amphibians have also contributed to the foundations of some technologies. For instance, this file is available through the internet, which most people access through a Wi-Fi connection. The algorithms used in Wi-Fi networks were developed with the help of the call properties of *Dryophytes japonicus*, a northeast Asian treefrog (Hernández & Blum, 2012). This species has also benefited human culture through technological advancements such as the distributed graph colouring theory (Hernández Pibernat, 2012) and medical analgesic developments (Zhu et al., 2014), and it may provide other benefits to human medicine as it is able to survive temperatures as low as -35 °C (Berman, Meshcheryakova & Bulakhova, 2016) and its physiological adaptations have been studied in space (Yamashita et al., 1997). These examples based on a single species are a very short list of how humans need amphibians in their everyday lives.

The important place of amphibians in human culture, both positive and negative, is explored in depth in Chapter 8 on Communication and Education. Some of the oldest documented examples include early Egyptian and Greek fertility symbols represented by frogs (Cooper, 1992; Das, 2011). Another is ‘Jin Chan’, or the money toad, which is considered to bring prosperity and good fortune in some East Asian cultures. By contrast, treefrogs in Korean culture are linked to carelessness. Popular Korean tales tell the story of a young treefrog burying his dead mother by a riverside. Her actual wish was to be buried elsewhere. However, she was attempting to outsmart her son after a lifetime of his ignoring her advice. The plot twist is that this was the first time he ever listened to her, which resulted in her still getting the opposite of her wishes, even after her death. Divine power is also revealed through amphibians, such as the devastating plague of frogs in the Old Testament of the Bible.

Many contemporary human populations are less exposed to disease and pests thanks to chemical and medical advancements, but this was not the case a few centuries ago when natural control vectors against pest and disease were the only means of regulation and treatment (e.g. Mohneke, 2011). Amphibian predation on both adult and larval mosquitoes and flies has been a form of vector control that decreases pathogen transmission to humans, including deadly diseases such as malaria and dengue (DuRant & Hopkins, 2008). An increase in the incidence of malaria was recently shown to have been associated with the collapse of amphibian communities in Central America – an unexpected occurrence in a century that has been characterised by widespread chemical control measures of arthropod vectors and successful disease eradication through vaccinations (Springborn et al., 2022). Amphibians also act as pest control in agricultural habitats as many are generalist feeders and ingest all types of invertebrates, including pests such as locusts (Attademo, Peltzer & Lajmanovich, 2005), thus naturally improving crop yields, especially rice (Teng et al., 2016) and soybean (Attademo, Peltzer & Lajmanovich, 2005).

Most terrestrial and freshwater ecosystems are dependent on amphibians for the multiple ecological roles they provide (reviewed by Valencia-Aguilar, Cortés-Gómez & Ruiz-Agudelo, 2013). Humans benefit directly from intact ecosystems in which amphibian populations are healthy and functional. Termed 'ecosystem services', direct benefits are generally divided into provisioning, regulating, cultural and supporting services (Millennium Ecosystem Assessment, 2005). Indirect benefits include regulating ecosystem services, such as pollination, seed dispersal, climate regulation, carbon sequestration, and the control of pests and diseases. The diversity of life modes, ecology and behaviours of amphibians makes them important nodes in food webs, both as prey and predators. The transition from primary to secondary consumers when metamorphosing also results in an energy flow in ecosystems (Davic & Welsh Jr., 2004). This is especially important for nutrients present in higher concentration in the aquatic habitat compared to the terrestrial one, for instance nitrogen, but also in the other direction, when amphibians bring nutrients to water bodies when spawning (Earl et al., 2011; Semlitsch, O'Donnell & Thompson III, 2014). In addition, due to their ectothermic physiology, amphibians use comparatively less energy than homeotherms, and thus convert more of their diet into organic biomass (Pough, 1980, 1983). Amphibians can make up a significant proportion of vertebrate biomass in temperate and tropical ecosystems, for example salamanders in North American forests (Burton & Likens, 1975). In addition, amphibians affect the composition of ecosystems by enhancing soil aeration and consequently soil productivity (Seale, 1980). As a result, they also benefit soil and water quality, an especially important factor in view of the need for water security. Global amphibian declines have also been recorded as causing population-level impacts in other taxa, reducing survival of their predators (Zipkin et al., 2020), and subsequent levels up the food chain as a cascade of biodiversity loss. It is important to understand that the roles and functions of amphibians in the ecosystem are still not fully understood, and the roles that each species might play needs to be fulfilled as a small missing link could result in greater ecological deficits, threatening the ecosystems on which all species on Earth depend.

Finally, some of the more distinctive amphibians can be flagships for their own conservation efforts. For instance, the Chile Darwin's frog is used as an emblem on local beer, clothing, toys, and a restaurant (personal communication A. V. Sánchez). In many countries amphibians are of interest to tourists, some even providing frog-focused tours, e.g. in Madagascar and Costa Rica. The revenue derived from ecotourism can contribute funding for protected areas, provides wages to guides, and inspiration for locally sold handcraft (Loubser, Mouton & Nel, 2001; Morrison et al., 2012).

Global response

The universal importance of amphibians compels us to act to rectify their human-caused declines. Some actions can be targeted to specific local conditions and needs, and as such implemented at a local scale. Whereas a global response is required for others because the threats affecting amphibians are global in scope and nature – climate change, disease, trade, and invasive species all span across borders. Moreover, species ranges do not respect political boundaries and their survival is dependent on a coordinated collaborative international response. The first *Amphibian Conservation Action Plan* (ACAP; Gascon et al., 2007) was the output of the Amphibian Conservation Summit held in 2005. It was the amphibian conservation community's response to global amphibian declines, highlighted by the GAA, "because it is morally irresponsible to document amphibian declines and extinctions without also designing and promoting a response to this global crisis" (Gascon et al., 2007).

It is difficult to assess the impact of the first ACAP, since it was developed among a suite of actions,

Figure 1.3. ASG, AArk and ASA work together on the global response to amphibian declines, under the shared Vision "Amphibians thriving in nature". Source: Adapted from a figure developed by the Amphibian Survival Alliance.

all parts of a global push to increase awareness of amphibian declines and to include amphibians in conservation priorities. The Summit prompted some major organisational changes. Firstly, the IUCN SSC Amphibian Specialist Group was constituted, bringing together the existing IUCN Groups: the Declining Amphibian Population Task Force, the Global Amphibian Assessment team, and the Global Amphibian Specialist Group (Bishop et al., 2012). Subsequently, the Amphibian Ark (AArk) was formed in 2006 with the aim of supporting implementation of the ex situ goals in the ACAP (Amphibian Ark, 2012). Finally, the Amphibian Survival Alliance (ASA) was set up following the IUCN SSC's Amphibian Mini-Summit in 2009, with the aim of coordinating organisations working on amphibian conservation (Bishop et al., 2012).

These three organisations – ASG, AArk and ASA – work together on the global response under the shared Vision "Amphibians thriving in nature" (Figure 1.3). Meanwhile, the ACAP has certainly been widely cited to support amphibian conservation action, but the impact remains insufficient, as amphibians are still the most threatened vertebrate class (IUCN, 2023; Luedtke et al., 2023).

A second version of the ACAP was developed in 2015, moving to an online 'living document' format, with the aim of updating it in real time. However, after completion it became clear that this format was not as impactful as the ASG had envisioned; users found it difficult to navigate and it was particularly hard for those with unreliable internet connections. As such, when we set out to work on this third iteration of the ACAP, our desire was to be more strategic. A survey was conducted from mid-August to mid-September 2019 to understand how the amphibian conservation community used the existing versions of the ACAP, and how it might be improved to better inform conservation action. In terms of document format, the survey results clearly indicated a strong preference for a PDF, rather than the living document, as well as the need for an Executive Summary. In terms of content, respondents recommended more clearly linking evidence on the effectiveness of interventions to ACAP recommendations, and a clearer expression of how global priorities can be implemented as manageable projects. We have strived to answer these needs when working on this update.

Through the process of re-imagining what ACAP could be, with the survey feedback in mind, we concluded that it was not possible for one document to answer all the needs of the amphibian conservation community. Rather, it would be useful for ACAP to become two partner documents. The first being this document, which gathers the most up to date evidence on subjects related to amphibian conservation, providing a solid, citable, academic basis for action. The second is an action-driven, more user-friendly source of practical solutions to be published after this document. Together, these documents form the third ACAP, covering the period of 2023–2033.

Our aim is for the two documents to guide and support amphibian conservation activities worldwide, being used as a framework for research and conservation, driving action and providing evidence-based advice to all involved in this sphere of work – conservation organisations, governments, funders and the public – on how to address threats to amphibians and meet global conservation targets. While the scope of ACAP is global, many actions will need to be targeted at a local scale, and we have provided case studies throughout with examples of how global goals can be applied to a variety of contexts.

We were mindful that this version of ACAP should be a product of the broader amphibian conservation community. Thus, we endeavoured to be as inclusive as possible in the status review. As such, individual chapters were drafted collaboratively by ASG's Thematic Working Groups, with introductory material drafted by members of the ASG Secretariat. This draft document was made publicly available for open consultation with a request for feedback from the whole amphibian conservation community. Finally, it was independently peer-reviewed before publication. As such, we have aimed to develop a scientifically robust text, which resulted from a collaborative effort from the amphibian conservation community, and we are grateful to everyone who has and is supporting the process throughout.

This document consists of two introductory chapters and twelve thematic chapters divided into three sections:

Threats – Chapters 3–7 on climate change; ecotoxicology; habitat loss; infectious diseases; and trade and sustainable use.

Informing decision-making – Chapters 8–10 on communications and education; conservation planning; and surveys and monitoring.

Species management – Chapters 11–14 on conservation breeding; assisted reproductive technologies and biobanking; genomics; and translocations.

Amphibian conservation is a multi-faceted field and collaboration is critical to our success. In addition, overlap exists between these chapters as indeed many of them are interdisciplinary. Because of this, the chapters could be arranged in several different ways. Likewise, we appreciate the scope for additional subjects to be included within this document.

For example, we have discussed creating new ASG Thematic Working Groups to address invasive species and habitat restoration. However, during the timeframe of drafting this document expert groups were not yet available to cover these subjects. We look forward to their inclusion in future versions.

This document covers the ten-year period, 2023–2033. This timeframe was chosen based on the global scope of the ACAP, the time required to make progress on broad issues, and the resources required to update this document, balanced with likely advances in knowledge that will need to be incorporated into conservation decision-making.

As we have seen, evaluating the impact of previous ACAP versions is difficult. While still challenging to achieve with a document such as this, we aim to improve on measuring and communicating impact and use of this version. Academically, we can track citations in journals. The use of a digital object identifier (DOI) for this version will permit us to track online mentions of ACAP more widely, including in policy documents, news, blogs and social media. Recording mentions will allow us to measure how effectively we have communicated the existence of an updated ACAP document, and its academic use. However, while awareness of the updated ACAP is important, it is also necessary to assess the extent and type of use on the ground. The real challenge will be whether we can measure if the existence and use of ACAP results in positive outcomes and, ultimately, impacts the conservation status of individual species.

As a first step, assessing ACAP use by the conservation community will be achieved by obtaining feedback from the global community. Regional Groups are ideally positioned to report on local/regional advances, in a format which measures ASG's own adoption and on the ground implementation of ACAP recommendations. Similarly, a process to track implementation by our sister organisations – ASA and AArk – will be put in place. This can then be extended to the partners of these three organisations. As a final ambition, together we will also seek ways to understand whether the uptake and promotion of ACAP drives new resources to conservation initiatives and research (e.g. influences the priorities of funding mechanisms).

The ultimate aim is to improve the conservation status of amphibian species, with fewer species classified as threatened. To track this, regular reassessments will be needed to identify and capture genuine improvements in the Red List. Eventually, this should result in an improved or stabilised Red List Index (Butchart et al., 2005). Changes such as this are unlikely to occur within the ten-year timeframe of this ACAP due to the time necessary to improve species status to the extent that this would be reflected on the Red List, but we believe this to be a worthy long-term vision for the conservation community and humankind as a whole. Smaller, more localised improvements in species status must be tracked by local monitoring efforts in the meantime.

Our aim is that through implementation of this document, and future versions of ACAP, amphibians will no longer be the most threatened vertebrate class as threats will have decreased for all taxa, and we will see all amphibian species thriving in nature.

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References

Alford, R. A., Richards, S. J. & McDonald, K. R. (2013). Biodiversity of amphibians. *Encyclopedia of Biodiversity: Second edition*, 1, 169–178. https://doi.org/10.1016/B978-0-12-384719-5.00254-9

Amphibian Ark. (2012). *Amphibian Ark: Five years since the launch*. https://www.amphibianark.org/pdf/AArk-5-year-report.pdf

AmphibiaWeb. (2022). *AmphibiaWeb*. University of California, Berkeley, CA, USA.

Attademo, A. M., Peltzer, P. M. & Lajmanovich, R. C. (2005). Amphibians occurring in soybean and implications for biological control in Argentina. *Agriculture, Ecosystems and Environment*, *106*, 389–394. https://doi.org/10.1016/j.agee.2004.08.012

Bell, B. D. & Bishop, P. J. (2018). Status of decline and conservation of frogs in New Zealand. In H. Heatwole & J. Rowley (Eds.), *Status of conservation and decline of amphibians: Australia, New Zealand, and Pacific Islands.* Amphibian Biology series. Volume 11. (pp. 151–165). CSIRO Publishing.

Berman, D. I., Leirikh, A. N. & Meshcheryakova, E. N. (2010). The Schrenck newt (*Salamandrella schrenckii*, Amphibia, Caudata, Hynobiidae) is the second amphibian that withstands extremely low temperatures. *Doklady Biological Sciences, 431*(1), 131–134. https://doi.org/10.1134/S0012496610020171

Berman, D. I., Meshcheryakova, E. N. & Bulakhova, N. A. (2016). The Japanese tree frog (*Hyla japonica*), one of the most cold-resistant species of amphibians. *Doklady Biological Sciences, 471*, 276–279. https://doi.org/10.1134/S0012496616060065

Bishop, P. J., Angulo, A., Lewis, J. P., Moore, R. D., Razbb, G .B., & Garcia Moreno, J. (2012). The amphibian extinction crisis - what will it take to put the action into the Amphibian Conservation Action Plan? *S.A.P.I.EN.S*, *5*(2), 97–111.

Burton, T.M. & Likens, G.E. (1975). Salamander populations and biomass in the Hubbard Brook Experimental Forest, New Hampshire. *Copeia*, *1975*(3), 541–546. https://doi.org/10.2307/1443655

Butchart, S. H. M., Akçakaya, H. R., Chanson, J., Baillie, J. E. M., Collen, B., Quader, S., ... Hilton-Taylor, C. (2007). Improvements to the Red List Index. *PLoS One*, *1*, e140. https://doi.org/10.1371/journal.pone.0000140

Butchart, S. H. M., Stattersfield, A. J., Baillie, J., Bennun, L. A., Stuart, S. N., Akçakaya, H. R., ... Mace, G. M. (2005). Using Red List Indices to measure progress towards the 2010 target and beyond. *Philosophical Transactions of the Royal Society B: Biological Sciences, 360*, 255–268. https://doi.org/10.1098/rstb.2004.1583

Ceríaco, L. M. P. (2012). Human attitudes towards herpetofauna: The influence of folklore and negative values on the conservation of amphibians and reptiles in Portugal. *Journal of Ethnobiology and Ethnomedicine*, *8*, 8. doi:10.1186/1746-4269-8-8

Clarke, B. T. (1997). The natural history of amphibian skin secretions, their normal functioning and potential medical applications. *Biological Reviews*, 72(3), 365–379. https://doi.org/10.1017/S0006323197005045

Cooper, J. (1992). *Symbolic and Mythological Animals*. HarperCollins.

Crnobrnja-Isailović, J., Jovanović, B., Čubrić, T., Ćorović, J., & Gopčević, K. (2020). The benefits of active substances in amphibians and reptiles and the jeopardy of losing those species forever. In *Biodiversity and Biomedicine: Our future* (pp. 107–122). https://doi.org/10.1016/b978-0-12-819541-3.00007-4

Das, I. (2011). Man meets Frog: perceptions, use and conservation of amphibians by indgenous people. In H. Heatwole & M. Wilkinson (Eds.), *Amphibian Biology. Vol. 10. Conservation and Decline of Amphibians: Ecological Aspects, Effect of Humans, and Management* (pp. 3383–3468). Surrey Beatty & Sons.

Davic, R. D. & Welsh Jr., H. H. (2004). On the ecological roles of salamanders. *Annual Review of Ecology, Evolution, and Systematics, 35,* 405–434. https://doi.org/10.1146/annurev.ecolsys.35.112202.130116

Doak, D. F., Bakker, V. J., Goldstein, B. E., & Hale, B. (2014). What is the future of conservation? *Trends in Ecology and Evolution, 29*(2), 77–81. https://doi.org/10.1016/j.tree.2013.10.013

Duellman, W. E. (1999). *Patterns of distribution of amphibians: A global perspective*. The Johns Hopkins University Press. https://doi.org/10.56021/9780801861154

Duellman, W. E. & Trueb, L. (1994). *Biology of Amphibians*. The Johns Hopkins University Press. https://doi.org/10.56021/9780801847806

DuRant, S. E. & Hopkins, W. A. (2008). Amphibian predation on larval mosquitoes. *Canadian Journal of Zoology, 86*, 1159–1164. https://doi.org/10.1139/Z08-097

Earl, J. E., Luhring, T. M., Williams, B. K., & Semlitsch, R. D. (2011). Biomass export of salamanders and anurans from ponds is affected differentially by changes in canopy cover. *Freshwater Biology, 56*, 2473–2482. https://doi.org/10.1111/j.1365-2427.2011.02672.x

Elinson, R. P., Del Pino, E. M., Townsend, D. S., Cuesta, F. C., & Eichhorn, P. (1990). A practical guide to the developmental biology of terrestrial-breeding frogs. *Biological Bulletin*, *179*(2), 163–177. https://doi.org/10.2307/1541765

Fernández-Roldán, J. D. & Gómez Sánchez, D. A. (2022). First record of feeding and defensive behaviour in Thompson's caecilian *Caecilia thompsoni* from the Upper Magdalena Valley, Tolima, Colombia. *The Herpetological Bulletin,159*, 29–31. https://doi.org/10.33256/hb159.2931

Frost, D. R. (1985). *Amphibian Species of the World (Vol. 1).* Allen press.

Frost, D. R. (2023). *Amphibian Species of the World: An online reference. Version 6.1*. American Museum of Natural History, New York, USA. https://doi.org/doi.org/10.5531/db.vz.0001

Gascon, C., Collins, J. P., Moore, R. D., Church, D. R., McKay, J. E., & Mendelson III, J. R. (2007). *Amphibian Conservation Action Plan: Proceedings IUCN/SSC Amphibian Conservation Summit 2005*. IUCN/SSC Amphibian Specialist

Group. Gower, D. J., Kouete, M. T., Doherty-Bone, T. M., Ndeme, E. S., & Wilkinson, M. (2015). Rediscovery, natural history, and conservation status of *Idiocranium russeli* Parker, 1936 (Amphibia: Gymnophiona: Indotyphlidae). *Journal of Natural History*, *49*(3–4), 233–253. https://doi.org/10.1080/00222933.2014.939733

Gower, D. J. & Wilkinson, M. (2005). Conservation biology of caecilian amphibians. *Conservation Biology*, *19*(1), 45–55. https://doi.org/10.1111/j.1523-1739.2005.00589.x

Häfeli, H. P. (1971). Zur Fortpflanzungsbiologie des Alpensalamanders (*Salamandra atra* Laur [Reproductive biology of the alpine salamander (*Salamandra atra* Laur)]. *Revue Suisse de Zoologie*, *78*(2), 235–293. https://doi.org/10.5962/bhl.part.97062

Hanken, J. & Wake, D. B. (1994). Five new species of minute salamanders, genus *Thorius* (Caudata: Plethodontidae), from Northern Oaxaca, Mexico. *Copeia*, *1994*(3), 573. https://doi.org/10.2307/1447174

Hernández, H. & Blum, C. (2012). Distributed graph coloring: an approach based on the calling behavior of Japanese tree frogs. *Swarm Intelligence*, *6*(2), 117–150. https://doi.org/10.1007/s11721-012-0067-2

Hernández Pibernat, H. (2012). *Swarm intelligence techniques for optimization and management tasks insensor networks*. Universitat Politècnica de Catalunya, Barcelona, Spain.

Hime, P. M., Lemmon, A. R., Lemmon, E. C. M., Prendini, E., Brown, J. M., Thomson, R. C., Kratovil, J. D., Noonan, B. P., Pyron, R. A., Peloso, P. L. V., Kortyna, M. L., Keogh, J. S., Donnellan, S. C., Lockridge Muller, R., Raxworthy, C. J., Kunte, K., Ron, S. R., Das, S., Gaitonde, N., ... Weisrock, D. W. (2021). Phylogenomics reveals ancient gene tree discordance in the amphibian tree of life. *Systematic Biology*, *70*, 49–66. https://doi.org/10.1093/sysbio/syaa034

Hoffmann, M., Hilton-Taylor, C., Angulo, A., Böhm, M., Brooks, T. M., Butchart, S. H. M., Carpenter, K. E., Chanson, J., Collen, B., Cox, N. A., Darwall, W. R. T., Dulvy, N. K., Harrison, L. R., Katariya, V., Pollock, C. M., Quader, S., Richman, N. I., Rodrigues, A. S. L., Tognelli, M. F., … Stuart, S.N. (2010). The impact of conservation on the status of the world's vertebrates. *Science*, *330*(6010), 1503–1509. https://doi.org/10.1126/science.1194442

Isaac, N. J. B., Redding, D. W., Meredith, H. M. R., & Safi, K. (2012). Phylogenetically-informed priorities for amphibian conservation. *PLoS One*, *7*(8), e43912. https://doi.org/10.1371/journal.pone.0043912

Isaac, N. J. B., Turvey, S. T., Collen, B., Waterman, C., & Baillie, J. E. M. (2007). Mammals on the EDGE: Conservation priorities based on threat and phylogeny. *PLoS One*, *2*(3). https://doi.org/10.1371/journal.pone.0000296

IUCN (2022). *Guidelines for reporting on proportion threatened. Version 1.2. Annex 1 of the Guidelines for appropriate uses of IUCN Red List data (Version 4.0)*. https://www.iucnredlist.org/resources/guidelines-forappropriate-uses-of-red-list-data

IUCN (2023). *The IUCN Red List of Threatened Species. Version 2022-1.* https://www.iucnredlist.org

Kupfer, A., Müller, H., Antoniazzi, M. M., Jared, C., Greven, H., Nussbaum, R. A., & Wilkinson, M. (2006). Parental investment by skin feeding in a caecilian amphibian. *Nature*, *440*(7086), 926–929. https://doi.org/10.1038/nature04403

Loubser, G. J. J., Mouton, P. le F. N., & Nel, J. A. J. (2001). The ecotourism potential of herpetofauna in the Namaqua National Park, South Africa. *African Journal of Wildlife Research*, *31*(1–2), 13–23.

Luedtke, J., Chanson, J., Neam, K., Hobin, L., Maciel, A. O., Catenazzi, A., Borzée, A., Hamidy, A., Aowphol, A., Jean, A., Sosa-Bartuano, Á., Fong G., A., de Silva, A., Fouquet, A., Angulo, A., Kidov, A. A., Muñoz Saravia, A., Diesmos, A. C., Tominaga, A., … Stuart, S. N. (2023). Ongoing declines for the world's amphibians in the face of emerging threats. *Nature, 622,* 308-314. https://doi.org/10.1038/s41586-023-06578-4

Mardiastuti, A., Masy'ud, B., Ginoga, L. N., Sastranegara, H., & Sutopo. (2021). Wildlife species used as traditional medicine by local people in Indonesia. *Biodiversitas, 22*(1), 329–337. https://doi.org/10.13057/biodiv/d220140

Mbaiwa, J. E. (2011). Changes on traditional livelihood activities and lifestyles caused by tourism development in the Okavango Delta, Botswana.

Tourism Management, *32*(5), 1050–1060. https://doi.org/10.1016/j.tourman.2010.09.002

McDiarmid, R. W. (1978). Evolution of parental care in frogs. In G. M. Burghardt & M. Bekoff (Eds.) *The development of behavior: Comparative and evolutionary aspects* (pp. 127–147). Garland STPM Press.

Millennium Ecosystem Assessment (2005). *Ecosystems and Human Well-Being: Wetlands and Water. Synthesis*.

Minter, L. R. (2004). *Breviceps macrops* Boulenger, 1907. In L. R. Minter, M.

Burger, J. A. Harrison, H. H. Barack, P. J. Bishop & D. Kloepfer (Eds.), *Atlas and Red Data Book of the Frogs of South Africa, Lesotho and Swaziland* (SI/MAB Ser). Smithsonian Institution.

Mohneke, M. (2011). *(Un) sustainable use of frogs in West Africa and resulting consequences for the ecosystem*. Humboldt-Universität zu Berlin, Berlin, Germany.

Morrison, C., Simpkins, C., Castley, J. G., & Buckley, R. C. (2012). Tourism and the conservation of Critically Endangered frogs. *PLoS One*, *7*(9), e43757. https://doi.org/10.1371/journal.pone.0043757

Myers, C. W., Daly, J. W. & Malkin, B. (1978). A dangerously toxic new frog (*Phyllobates*) used by Emberá Indians of western Colombia, with discussion of blowgun fabrication and dart poisoning. *Bulletin of the American Museum of Natural History*, *161*(2), 307–366.

Nunes-de-Almeida, C. H. L., Haddad, C. F. B. & Toledo, L. F. (2021). A revised classification of the amphibian reproductive modes. *Salamandra*, *57*(3), 413–427.

Pérez, A. E., Schuster, V. & Jofré, D. P. (2018). Amphibiomorphic modeled and painted pottery from Argentine Patagonia and Central-Southern Chile. Functional interpretation and identification of species based on mimetic and aposematic traits. *Open Archaeology*, *4*, 394–405. https://doi.org/10.1515/ opar-2018-0026

Pough, F. H. (1980). The advantages of ectothermy for tetrapods. *The American Naturalist*, *115*(1), 92–112. https://doi.org/10.1086/283547

Pough, F. H. (1983). Amphibians and reptiles as low-energy systems. In W. P. Aspey & S. I. Lustick (Eds.), *Behavioral energetics: The cost of survival in vertebrates* (pp. 141–188). Ohio State University Press.

Rabb, G. B. & Rabb, M. S. (1960). On the mating and egg-laying behavior of the Surinam toad, *Pipa pipa*. *Copeia*, *1960*(4), 271–276. https://doi.org/10.2307/1439751

Rittmeyer, E. N., Allison, A., Gründler, M. C., Thompson, D. K., & Austin, C. C. (2012). Ecological guild evolution and the discovery of the world's smallest vertebrate. *PLoS One*, *7*(1), e29797. https://doi.org/10.1371/journal.pone.0029797

Roelants, K., Gower, D. J., Wilkinson, M., Loader, S. P., Biju, S. D., Guillaume, K., ... Bossuyt, F. (2007). Global patterns of diversification in the history of modern amphibians. *Proceeding of the National Academy of Sciences, USA, 104*(3), 887–892. https://doi.org/10.1073/pnas.0608378104

Sabater-Pi, J. (1985). Contribution to the biology of the giant frog (*Conraua goliath*, Boulenger). *Amphibia-Reptilia*, *6*(2), 143–153. https://doi.org/10.1163/156853885X00047

Schulte, L. M., Ringler, E., Rojas, B., & Stynoski, J. (2020). Developments in amphibian parental care research: history, present advances, and future perspectives. *Herpetological Monographs*, *34*, 71–97. https://doi.org/10.1655/HERPMONOGRAPHS-D-19-00002.1

Seale, D. B. (1980). Influence of amphibian larvae on primary production, nutrient flux, and competition in a pond ecosystem. *Ecology*, *61*(6), 1531–1550. https://doi.org/10.2307/1939059

Secor, S. M. & Lignot, J. -H. (2010). Morphological plasticity of vertebrate aestivation. In C. A. Navas & J. E. Carvalho (eds.), *Aestivation: Molecular and Physiological Aspects*. Springer. https://doi.org/10.1016/0302-4598(80)85023-9

Secretariat of the Convention on Biological Diversity (2020). *Global Biodiversity Outlook 5*.

Seimon, T. A., Seimon, A., Daszak, P., Halloy, S. R. P., Schloegel, L. M., Aguilar, C. A., ... Simmons, J. E. (2007). Upward range extension of Andean anurans and chytridiomycosis to extreme elevations in response to tropical deglaciation. *Global Change Biology*, *13*, 288–299. https://doi.org/10.1111/j.1365-2486.2006.01278.x

Semlitsch, R. D., O'Donnell, K. M. & Thompson III, F. R. (2014). Abundance, biomass production, nutrient content, and the possible role of terrestrial salamanders in Missouri Ozark forest ecosystems. *Canadian Journal of Zoology*, *92*, 997–1004. https://doi.org/10.1139/cjz-2014-0141

Sinclair, B. J., Stinziano, J. R., Williams, C. M., MacMillan, H. A., Marshall, K. E., & Storey, K. B. (2013). Real-time measurement of metabolic rate during freezing and thawing of the wood frog, *Rana sylvatica*: implications for overwinter energy use. *Journal of Experimental Biology*, *216*, 292–302. https://doi.org/10.1242/jeb.076331

Small, C. & Cohen, J. E. (2004). Continental physiography, climate, and the global distribution of human population. *Current Anthropology*, *45*(2), 269–277. https://doi.org/10.2105/ajph.66.7.696

Smirina, E. M. (1994). Age determination and longevity in amphibians. *Gerontology*, *40*, 133–146. https://doi.org/10.1159/000213583

Sodhi, N. S., Bickford, D., Diesmos, A. C., Lee, T. M., Koh, L. P., Brook, B. W., Sekercioglu, C. H., & Bradshaw, C. J. A. (2008). Measuring the meltdown: Drivers of global amphibian extinction and decline. *PLoS One*, *3*(2), e1636. https://doi.org/10.1371/journal.pone.0001636

Solano-Zavaleta, I., García-Vázquez, U. O. & Mendoza-Hernández, A. A. (2009). Notas sobre la distribución geográfica de las salamandras *Pseudoeurycea gadovii* y *Pseudoeurycea melanomolga* (Caudata: Plethodontidae). *Revista Mexicana de Biodiversidad*, 80, 575–577. https://doi.org/10.22201/ib.20078706e.2009.002.631

Springborn, M. R., Weill, J. A., Lips, K. R., Ibáñez, R., & Ghosh, A. (2022). Amphibian collapses increased malaria incidence in Central America. *Environmental Research Letters*, 17, 104012. https://doi.org/10.1088/1748-9326/ac8e1d

Stuart, S., Hoffmann, M., Chanson, J., Cox, N., Berridge, R., Ramani, P., & Young, B. (2008). *Threatened Amphibians of the World*. Lynx Edicions, IUCN and Conservation International.

Stuart, S. N. (2012). Responding to the amphibian crisis: Too little, too late? *Alytes*, *29*(1–4), 9–12.

Stuart, S. N., Chanson, J. S., Cox, N. A., Young, B. E., Rodrigues, A. S. L., Fischman, D. L., & Waller, R. W. (2004). Status and trends of amphibian declines and extinctions worldwide. *Science*, *306*(5702), 1783–1786. https://doi.org/10.1126/science.1103538

Summers, K., McKeon, C. S. & Heying, H. (2006). The evolution of parental care and egg size: a comparative analysis in frogs. *Proceedings of the Royal*

Society B: Biological Sciences, *273*, 687–692. https://doi.org/10.1098/rspb.2005.3368

Tarrant, J., Kruger, D. & du Preez, L. H. (2016). Do public attitudes affect conservation effort? Using a questionnaire-based survey to assess perceptions, beliefs and superstitions associated with frogs in South Africa. *African Zoology*, *51*(1), 13–20. https://doi.org/10.1080/15627020.2015.1122554

Teng, Q., Hu, X. -F., Luo, F., Cheng, C., Ge, X., Yang, M., & Liu, L. (2016). Influences of introducing frogs in the paddy fields on soil properties and rice growth. *Journal of Soils and Sediments*, *16*, 51–61. https://doi.org/10.1007/s11368-015-1183-6

Thibaudeau, G. & Altig, R. (1999). Endotrophic Anurans: development and evolution. In R. W. McDiarmid & R. Altig (Eds.), *Tadpoles: The Biology of Anuran Larvae* (pp. 295–337). University of Chicago Press.

Tomažič, I. (2011b). Seventh graders' direct experience with, and feelings toward, amphibians and some other nonhuman animals. *Society and Animals*, *19*(3), 225–247. https://doi.org/10.1163/156853011X578901

Valencia-Aguilar, A., Cortés-Gómez, A. M. & Ruiz-Agudelo, C. A. (2013). Ecosystem services provided by amphibians and reptiles in Neotropical ecosystems. *International Journal of Biodiversity Science, Ecosystem Services and Management*, *9*, 257–272. https://doi.org/10.1080/21513732.2013.821168

Vences, M. & Köhler, J. (2008). Global diversity of amphibians (Amphibia) in freshwater. *Hydrobiologia*, *595*, 569–580. https://doi.org/10.1007/978-1-4020-8259-7_54

Voituron, Y., de Fraipont, M., Issartel, J., Guillaume, O., & Clobert, J. (2011). Extreme lifespan of the human fish (*Proteus anguinus*): A challenge for ageing mechanisms. *Biology Letters*, *7*(1), 105–107. https://doi.org/10.1098/rsbl.2010.0539

Wells, K. D. (2007). *The Ecology and Behavior of Amphibians*. Chicago: The University of Chicago Press. https://doi.org/10.7208/chicago/9780226893334.001.0001

Won, H. -S., Kang, S. -J. & Lee, B. -J. (2009). Action mechanism and structural requirements of the antimicrobial peptides, gaegurins. *Biochimica et Biophysica Acta*, *1788*(8), 1620–1629. https://doi.org/10.1016/j. bbamem.2008.10.021

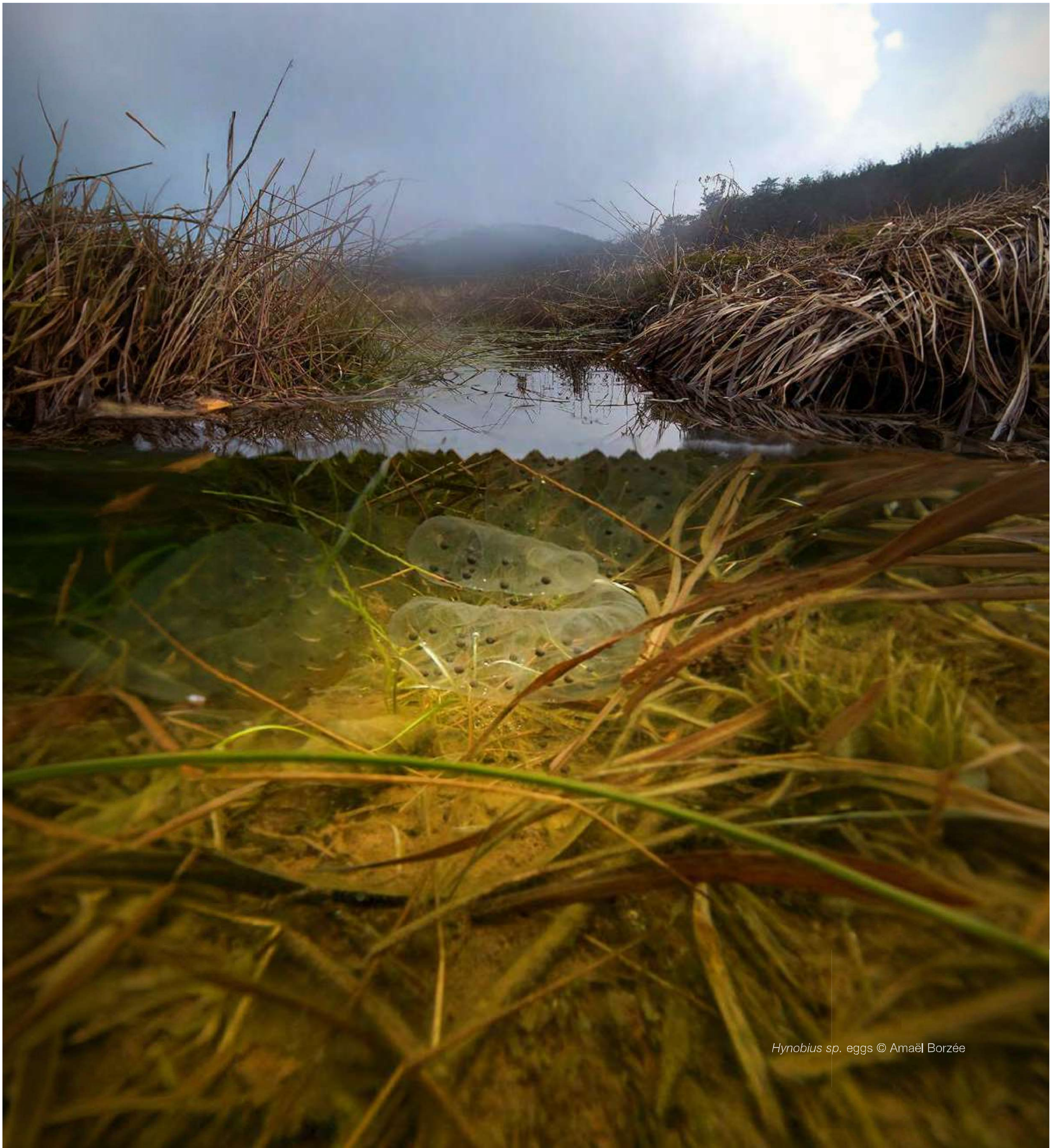
Yamashita, M., Izumi-Kurotani, A., Mogami, Y., Okuno, M., Naitoh, T., & Wassersug, R. J. (1997). The Frog in Space (FRIS) experiment onboard Space Station Mir: final report and follow-on studies. *Biological Ssciences in Space = Uchū Seibutsu Kagaku*, *11*(4), 313–320. https://doi.org/10.2187/ bss.11.313

Zhu, W., Chuah, Y. J. & Wang, D. -A. (2018). Bioadhesives for internal medical applications: A review. *Acta Biomaterialia*, *74*, 1–16. https://doi.org/10.1016/j.actbio.2018.04.034

Zhu, Y., Li, Z., Liu, H., He, X., Zhang, Y., Jin, J., Che, J., Li, C., Chen, W., Lai, R., & Liu, J. (2014). Novel analgesic peptides from the tree frog of *Hyla japonica*. *Biochimie*, *99*, 38–43. https://doi.org/10.1016/j.biochi.2013.10.017

Zipkin, E. F., DiRenzo, G. V., Ray, J. M., Rossman, S., & Lips, K. R. (2020). Tropical snake diversity collapses after widespread amphibian loss. *Science*, *367*(6479), 814–816. https://doi.org/10.1126/science.aay5733

ZSL (2020). *Edge of Existence*. https://www.edgeofexistence.org



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