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Amphibians in *Zootaxa*: 20 years documenting the global diversity of frogs, salamanders, and caecilians

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Abstract

Zootaxa is a mega-journal that since its inception, 20 years ago, has contributed to the documentation of the planet's biodiversity. Its role concerning terrestrial vertebrates has been crucial especially for amphibians, which are the most threatened class of vertebrates. As current editors of the Amphibia section, we reviewed the state of knowledge of taxonomic publications on amphibians over the last two decades (from 2001 to 2020). Our review reveals that 2,533 frogs, 259 salamanders, and 55 caecilians have been named in these 20 years, mainly in the tropical regions of South America, Asia, and Africa. More than half (57%) of these species descriptions were published in only 10 journals. At least 827 species of the new amphibians (29% of the total) were described in *Zootaxa*. This mega-journal has served also as a place of publication for monographs and systematic reviews, in addition to short articles documenting the vocalizations

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of anurans and the morphology of embryos and larvae. Its efficient evaluation process, the freedom of manuscript length, including full-color figures, and free of cost for the authors, has made *Zootaxa* a favorite for amphibian researchers. In an era of accelerating rates of biodiversity loss, documenting, describing, naming, and proposing evolutionary scenarios for species is, more than ever, an urgent task.

Key words: Anura, Caudata, Gymnophiona, natural history, taxonomy, systematics

"*The world was so recent that many things lacked names, and in order to indicate them it was necessary to point*."
—Gabriel García Márquez, One Hundred Years of Solitude

Introduction

Identifying, individuating, cataloguing, and naming the diversity of life is one of the oldest and arguably one of the most important scientific endeavours. Taxonomy—the science of discovering, describing, classifying, and naming groups of biological organisms (Mayr 1969)—provides a comparative basis for all other biological disciplines dealing with the study of life and its structure, function, and evolution. Yet, only a small fraction of the species of our planet have been discovered, described, and named (Wheeler *et al*. 2012; Larsen *et al*. 2017; Moura & Jetz 2021) and we are still far from a comprehensive inventory of the biosphere (Wheeler *et al*. 2012).

The need for taxonomic exploration does not only apply to hyperdiverse and poorly known groups for which fast-track taxonomy may be the only viable strategy for a complete inventory (Vences 2020). Increased field exploration and the integration of different lines of evidence have also revealed an astonishing number of new species in several supposedly well-studied taxa, such as amphibians. With more than 8,300 currently recognized extant species (AmphibiaWeb 2021; Frost 2021), amphibians are a species-rich group of vertebrates in which the rate of species discovery has substantially accelerated over the past decades (e.g., Hanken 1999; Köhler *et al*. 2005; Tapley *et al*. 2018; Streicher *et al.* 2020) compared to other groups of terrestrial vertebrates. Amphibians are the most threatened class of vertebrates, with a third of currently known species threatened with extinction (IUCN 2021), and the majority of species experiencing population declines (Stuart *et al.* 2004; 2008; Lips *et al.* 2005). Despite the need to understand the diversity of amphibians so that we can more accurately priorities conservation efforts, a large proportion of amphibian biodiversity remains undiscovered (Moura & Jetz 2021) and the description of new species continues to add both deep and shallow lineages to the amphibian phylogeny (Blackburn *et al.* 2019). Furthermore, many species are known only from cursory morphological description and there remains a paucity of data on their natural history, traits, ecology, conservation status, evolutionary history, and ecosystem functions.

Zootaxa emerged 20 years ago as a mega-journal that brought together taxonomists from all over the world with the aim of expertly and efficiently streamlining the processes of describing and naming animals from all corners of the planet. It rapidly became an attractive outlet for taxonomic studies. Here, we document the overall impact of *Zootaxa* on amphibian taxonomy based on papers published in this journal over a period of two decades (i.e., 2001–2020). This is based on an exhaustive review of the literature on amphibians in *Zootaxa* spanning nearly 1,150 published articles to date.

Scope and strategy of the amphibian section of *Zootaxa*

Zootaxa was conceived as a community-driven outlet for "high quality papers on any aspect of systematic zoology" (see editorial policies). The wide scope and flexibility are both an immense strength and a challenge because the section editors then have the responsibility to define the array of acceptable studies within their field.

Because of the large number of researchers working on amphibian biology, it became necessary to define the scope of studies that would be considered for publication in *Zootaxa,* beyond the obvious taxonomic revisions and new species descriptions. At present, many local and regional amphibian species inventories are taking place, often yielding valuable new distribution records and numerous important natural history observations. As a result, a large number of checklists, range extensions, and notes on the biology of amphibian species have been submitted to *Zootaxa*, necessitating a fluid approach to editorial policies that sometimes have led to inconsistent decisions

on whether a manuscript would be considered for publication. In general, the amphibian editorial team accepts such manuscripts only if they contribute data of obvious significance for amphibian taxonomy, i.e., discussions of morphological variation, diagnostic characters, or natural history traits that are important to understanding the evolutionary history of a higher taxon. Realising the importance of bioacoustics and larval morphology in amphibian taxonomy, the descriptions of calls and larvae are accepted, but must be submitted as concise "Correspondence" manuscripts if only less than three species are concerned. Larval stages of caecilians and salamanders are far less studied (see below), though some contributions have been published in *Zootaxa*.

Not considering manuscripts currently under review (April 2021), we have processed approximately 1,600 manuscripts. Along with the approximately 1,150 amphibian papers published in *Zootaxa*, this indicates an overall acceptance rate of approximately 72%, though this rate has varied over time.

Editorial team

The steady increase in manuscripts on amphibian taxonomy received over the years required widening the community of specialized editors. In its 20-year history, 18 editors have served in the journal (Appendix 1). Currently, there are 13 active editors, with three dedicated exclusively to manuscripts focusing on either calls, or embryos and larvae. This group has achieved an average return time between reception and acceptance of manuscripts of 120 calendar days.

Methods

New taxa. To collate the number of amphibian species globally named during the last 20 years, we obtained from AmphibiaWeb, the list of species between 2004 and 2020 (AmphibiaWeb 2020; until December 31). For 2001 to 2003, we filtered the information from Amphibian Species of the World (Frost 2021). We eliminated publications where subspecies were elevated to species, acts of synonymy, and articles without formal description of new species. For convenience, we here assigned all species to families according to Frost (2021) but emphasize that some of us prefer slightly differing family-level classification, i.e., those proposed by Blackburn & Wake (2011) or implemented in AmphibiaWeb (2021).

Larval and embryonic stages. We compiled a list of articles that included descriptions of tadpoles from the general dataset. We included descriptions of embryos of species with endotrophic development (including direct) and of larval salamanders. We counted all contributions, and then classified them following three criteria: taxonomy; whether they are part of a new species description or exclusively larval accounts; and whether they include descriptions of external morphology, buccopharyngeal anatomy, and/or skeletal morphology. We calculated absolute values and percentages of total contributions, both for contributions (i.e., published papers) and descriptions (i.e., there can be more than one description in a single paper).

Calls. The list of articles including descriptions of advertisement or other calls was manually filtered from the general dataset of all published articles. We considered that a manuscript contained a call description if it presented numerical data and/or an image that allowed for the extraction of numerical data from it (as a sonogram or oscillogram). We classified described call types according to their function and calculated the number of contributions per species, genus, and family. Onomatopoetic or metaphoric descriptions (e.g., "this frog species sounds like 'ribbit'"; "a drop falling into a vase"; "the species presents a melodious call") were not considered as descriptions (although the few of those present in *Zootaxa* papers are usually reported in a historical context).

Results

We obtained a working matrix of 2,847 rows (i.e., extant species) described from 2001 to 2020 and published in 176 journals and books. In these two decades, 2,533 frogs, 259 salamanders, and 55 caecilians have been named, mainly in the tropical regions of South America, Asia, and Africa. Over half (57%) of these species' descriptions were published in only 10 journals (Fig. 1). Of the 56 extant amphibian families currently recognised, *Zootaxa* has contributed to the knowledge of new species, calls, larvae, and embryos at varying levels for 50 of these (Table 1).

In addition to alpha taxonomic studies, some high-impact systematic studies (e.g., Hedges *et al.* 2008; Guayasamin *et al.* 2009; Padial *et al.* 2014; Castroviejo-Fisher *et al.* 2015) have been published in *Zootaxa* (especially from the Neotropics: e.g., Brachycephaloidea, Centrolenidae, Hemiphractidae). In 20 years, *Zootaxa* has published a total of 1,125 (only 70 of them are open access) papers focused on amphibians (correspondences, articles, and monographs). These publications mainly concern nomenclatural issues, phylogenetic studies, and—especially—descriptions of species, tadpoles, calls, and osteology (Fig. 2).

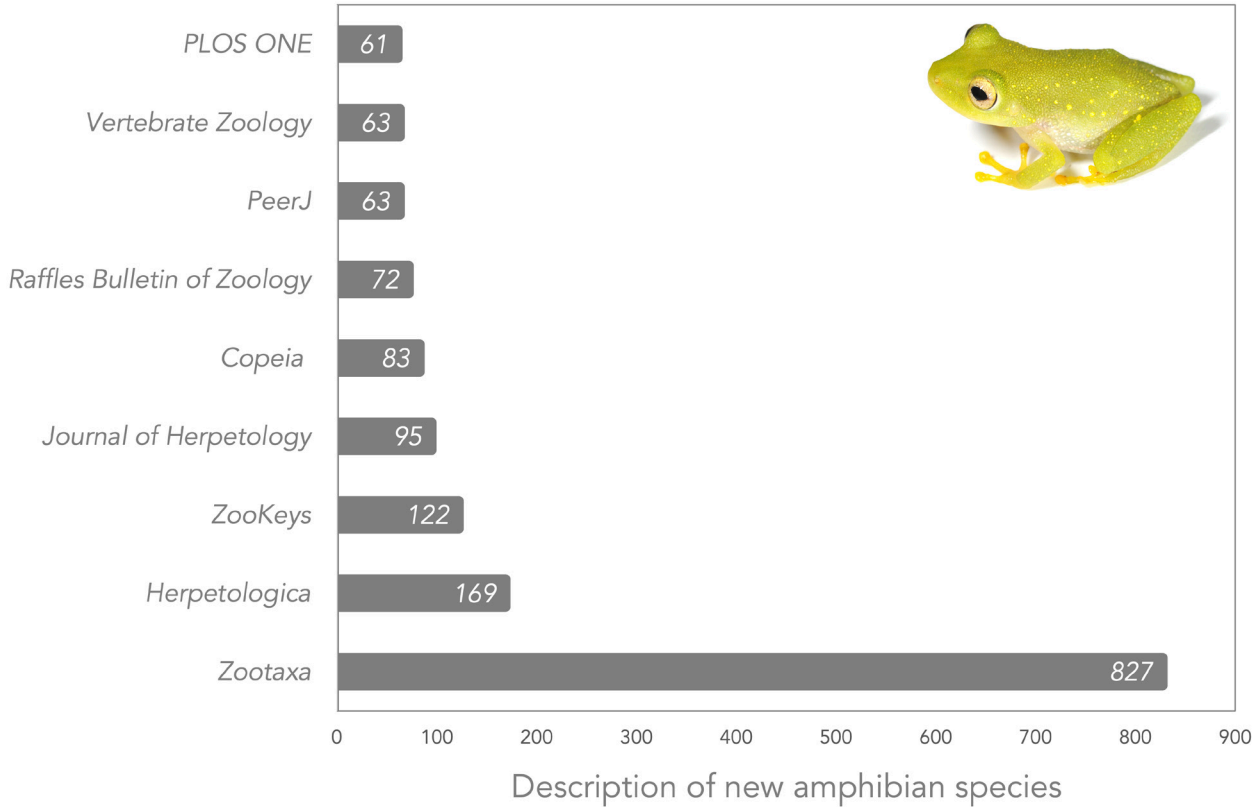

FIGURE 1. Number of new amphibian species descriptions published in the top 10 journals during the periods 2001–2020. Three of these journals did not yet exist in 2001: *Zookeys* (since 2008), *PLoS ONE* (since 2012), and *PeerJ* (since 2013). The frog in the upper right is *Pristimantis jaguensis*.

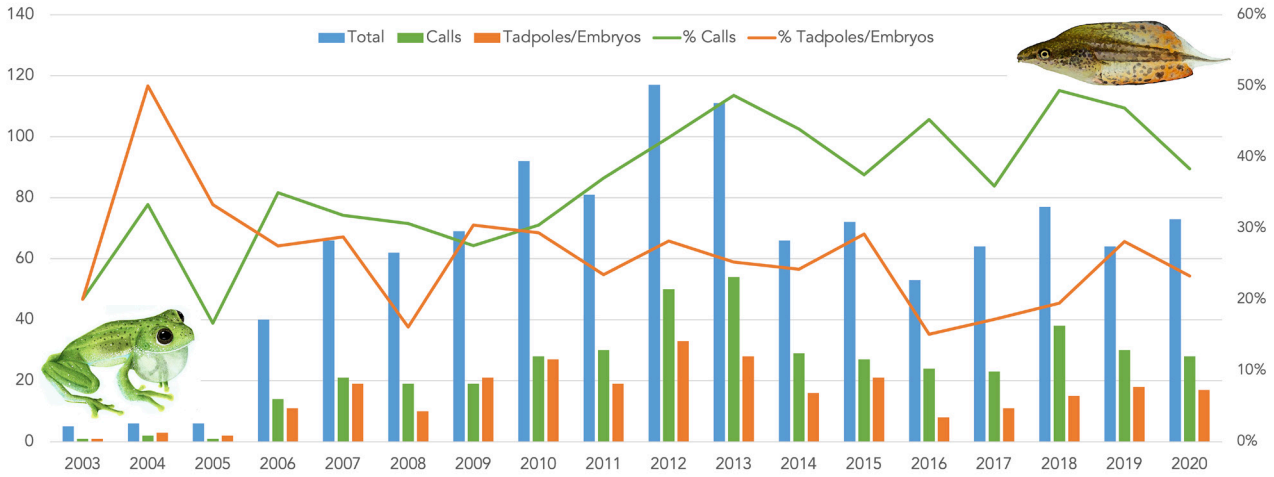

FIGURE 2. Number of contributions to *Zootaxa* per year. Blue, in total; green, contributions that include anuran call descriptions; orange, contributions that include tadpole and/or embryo descriptions. Lines indicate percentages of contributions including call (green) and tadpole or embryo descriptions (orange). The illustration in the lower left is *Centrolene savagei* (by Ana Ospina) and the tadpole in the upper right is *Dendropsophus minutus* (by Tiago Pezzuti).

TABLE 1. Number of descriptions in *Zootaxa* (since 2001) of new species, calls, and larvae (including embryos of species with endotrophic development), grouped by family.

Family	Species	Calls	Tadpoles	Family	Species	Calls	Tadpoles
ANURA							
Alsodidae	3	1	2	Limnodynastidae	0	0	1
Alytidae	0	0	3	Mantellidae	28	49	43
Aromobatidae	29	45	29	Megophryidae	63	41	22
Arthroleptidae	4	0	12	Microhylidae	80	91	48
Batrachylidae	0	0	2	Myobatrachidae	8	7	6
Brachycephalidae	7	12	0	Nasikabatrachidae	0	1	2
Brevicipitidae	8	12	0	Nyctibatrachidae	15	3	1
Bufonidae	57	47	46	Odontophrynidae	13	16	19
Centrolenidae	17	34	6	Pelobatidae	0	0	1
Ceratobatrachidae	12	13	2	Pelodytidae	2	3	3
Ceratophryidae	0	1	2	Petropedetidae	3	0	4
Craugastoridae	84	34	0	Phrynobatrachidae	9	2	0
Cycloramphidae	2	1	3	Pipidae	1	3	2
Dendrobatidae	28	72	65	Ptychadenidae	1	0	2
Dicroglossidae	26	18	6	Pyxicephalidae	10	37	20
Eleutherodactylidae	14	30	0	Ranidae	17	2	16
Hemiphractidae	15	16	6	Ranixalidae	1	0	0
Hylidae	82	148	117	Rhacophoridae	44	27	14
Hylodidae	1	1	18	Rhinodermatidae	0	0	2
Hyperoliidae	12	22	8	Telmatobiidae	1	0	13
Leptodactylidae	29	118	70				
CAUDATA							
Hynobiidae	17	0	15	Salamandridae	17	0	3
Plethodontidae	38	0	3				
GYMNOPHIONA							
Chikilidae	3	0	0	Siphonopidae	6	0	0
Indotyphlidae	11	0	0	Typhlonectidae	1	0	0
Herpelidae	2	0	0	Rhinatrematidae	2	0	0
Ichthyophiidae	4	0	0				

New taxa

The publications in *Zootaxa* includes the description of 25 new genera and 839 new species (Fig. 3), 12 of which were later synonymized. Of the 2,678 extant amphibian species described in the most recent two decades in all journals, 827 currently recognized species were published in *Zootaxa* (mainly anurans: 726 species), representing approximately 31% of all amphibian species described during this time (Fig. 1). This exceeds the combined total of new species described in the next nine journals ranked by number of species descriptions (786 species) and exceeds the number of species described in the second-ranked journal by a factor of nearly five. This positions *Zootaxa* as the world-leading taxonomic journal for amphibians in the 21st century. The highest number of new species published in *Zootaxa* was between 2010 and 2013 (Fig. 4). The regions with the highest taxonomic contributions to the journal are those with much of their landmass in the tropics, led by South America and with Asia not far behind (Fig. 5).


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FIGURE 3. Examples of amphibian species named in studies published in *Zootaxa* (photo credit in parentheses). A. *Abavorana nazgul* (Evan Quah); B. *Agalychnis terranova* (Giovanni Chaves-Portilla); C. *Andinobates victimatus* (Jhonattan Vanegas); D. *Anomaloglossus mitaraka* (Antoine Fouquet); E. *Ansonia kyaiktiyoensis* (Evan Quah); F. *Bolitoglossa caldwellae* (Pedro Peloso); G. *Boophis sandrae* (Miguel Vences); H. *Centrolene charapita* (Santiago Castroviejo-Fisher); I. *Dendropsophus manonegra* (Andrés Forero); J. *Hemiphractus elioti* (Brad Wilson); K. *Hypogeophis pti* (David Gower); L. *Litoria bella* (Jodi Rowley); M. *Nyctimantis pomba* (Pedro Peloso); N. *Physalaemus feioi* (Diego Santana); O. *Phyzelaphryne nimio* (Santiago Castroviejo-Fisher); P. *Pristimantis zorro* (Mauricio Rivera-Correa); Q. *Ranitomeya benedicta* (Evan Twomey); R. *Rhacophorus vampyrus* (Jodi Rowley); S. *Rhaebo lynchi* (Khristian Venegas-Valencia); T. *Stumpffia kibomena* (Frank Glaw/Miguel Vences); U. *Tylototriton ngarsuensis* (Evan Quah).

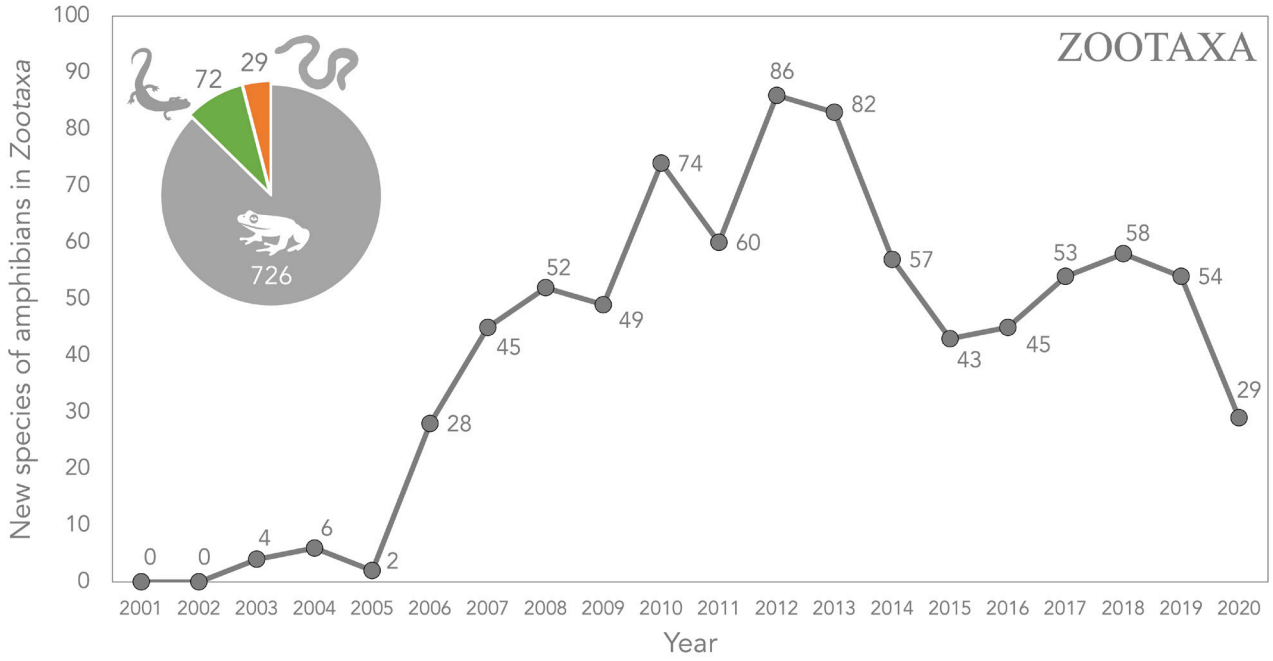

FIGURE 4. Number of new amphibian species descriptions per year published in Zootaxa in the period 2001–2020. Note that the most productive period was between 2010 and 2013. In the upper left corner, descriptions by order, the order Anura being the most important in terms of numbers of new species.

Anurans. Toads and frogs (order Anura) are the most species-rich order of amphibians, with 7,338 currently recognized extant species (Frost, 2021), and more than 10% of this diversity has been described in *Zootaxa* during the last 20 years (i.e., 726 species of 217 genera, and in 41 currently recognized families). Most of these species were discovered from South America, Asia, and Africa, with the following ranking countries: Brazil (145 species), Peru (71), India (63), Papua New Guinea (46), China (42), Ecuador (42), Colombia (40), Madagascar (40), Viet Nam (38), and Venezuela (26). The species-rich anuran families Craugastoridae, Hylidae, and Microhylidae are those in which the highest number of new species have been discovered and described compared to other families (Table 1); the most represented genera are: *Pristimantis* (52), *Leptobrachella* (28), *Cophixalus* (19), *Scinax* (17), *Boophis* (15), and *Limnonectes* (15). Other significant contributions on Anura (although not quantified here) include species redescriptions (e.g., Lavilla *et. al.* 2010a, 2010b, Xiong *et al*. 2011), and evaluations of taxonomic status (i.e., synonymies or resurrections; Scott *et al.* 2013; Kamei & Biju 2016) or other details related to taxonomy (e.g., type locality rectifications and neotype designations; Pimenta *et al.* 2007; Channing & Becker 2019).

Caudates. Salamanders (order Caudata) are the order with the second most number of new species published in *Zootaxa*, with 72 species from 20 genera, representing almost 10% of the known diversity (i.e., 766 species, Frost 2021). Most of caudate diversity is concentrated in the northern hemisphere (AmphibiaWeb 2021; Frost 2021), and this is reflected in the ranking of countries with the most species described in *Zootaxa*: China (12 species), Japan (12), Honduras (9), Costa Rica (7), Mexico (5), and USA (5). The species described belong to only three of

the nine currently recognized families (Plethodontidae, Hynobiidae, and Salamandridae), and the genera with the largest number of new species in Zootaxa are: *Bolitoglossa* (15), *Hynobius* (9), *Onychodactylus* (7), *Nototriton* (6), and *Oedipina* (6). With a few exceptions (e.g., Montori *et al*. 2008), almost all of the contributions in *Zootaxa* are taxonomic reviews and/or species descriptions, with the majority including molecular phylogenetic analyses.

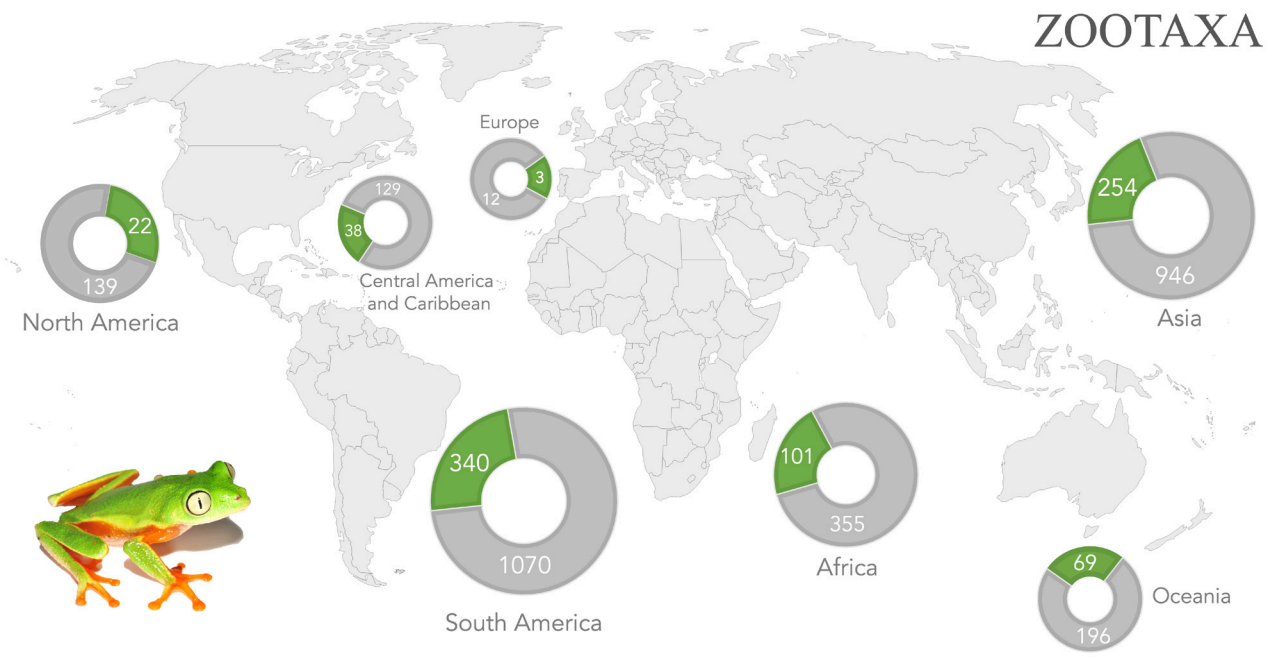

FIGURE 5. Contributions of new species of amphibians described in 2001–2020 by regions. In green, descriptions in *Zootaxa* compared to descriptions in other journals where new species have been published. The frog in the lower left is *Agalychnis buckleyi*.

Caecilians. Of the currently recognised 214 extant species of caecilians (order Gymnophiona; AmphibiaWeb 2021; Frost 2021), 55 have been described after 2000, with 29 of these (53%) having been described in *Zootaxa*—13.6% of all currently recognised species. The 29 species described in *Zootaxa* are from seven of the 10 currently recognised families and from six countries: India (15 species), Brazil (7), Kenya (3), Seychelles (2), Myanmar (1), and Guyana (1). Patterns in new descriptions of caecilian species in *Zootaxa* are generally similar to those in other journals over this same time period—in terms of numbers of genera and families with new species descriptions (10 and 7 for *Zootaxa*; 10 and 6 for other journals) and proportions of descriptions including at least one author from the country of the type locality (79 and 77%, respectively) and of descriptions that included DNA sequence data (28 and 27%, respectively). The vast majority of manuscripts about caecilians submitted to *Zootaxa* have been descriptions of new species. The few exceptions are other contributions to caecilian systematics, including two species-level synonymies (Gower *et al.* 2013; Kamei & Biju 2016) and the systematic review providing the now widely-implemented 10-family classification (Wilkinson *et al*. 2011).

Larval and embryonic stages

Our survey shows that 25% of all *Zootaxa* amphibian papers include descriptions of non-adult specimens. The majority of these contributions involve larval stages of species with biphasic development, and only a small percentage deal with embryos of species with endotrophic development. By far, most studies published in *Zootaxa* described larval stages of frogs, whereas those dealing with larval stages of salamanders only account for 2% of the publications. This reflects a general research trend in amphibian systematics given that salamanders (and caecilians) are less species-rich than frogs and because most new species of salamanders are plethodontids, of which the majority of species have direct development and thus lack a larval stage. No larval caecilians have been described in *Zootaxa*, though at least six of the 29 species named in the journal are likely to have larvae (Ichthyophiidae and Rhinatrematidae: San Mauro *et al.* 2014).

Contributions describing tadpoles increased in number from 2006 and thereafter stabilized around 15–30% of the total number of papers per year. Overall, *Zootaxa* has published 280 papers in which 637 larvae or embryos of 588 currently recognized species are described. This includes what may be the only recent case in which a frog species is named on the basis of a holotype that is a tadpole instead of an adult specimen (*Clinotarsus penelope*; Grosjean *et al*. 2015). Of the total number of tadpole descriptions, 29% are included as part of studies that describe and name new species. This highlights both that *Zootaxa* is an attractive outlet for researchers interested in tadpole biology and that amphibian taxonomists are increasingly considering tadpole descriptions as pertinent and important to describing a species. Finally, most tadpole descriptions are of external morphology, with < 30% describing internal anatomy, such as traits of the buccopharyngeal cavity and larval skeleton (in a 2:1 proportion).

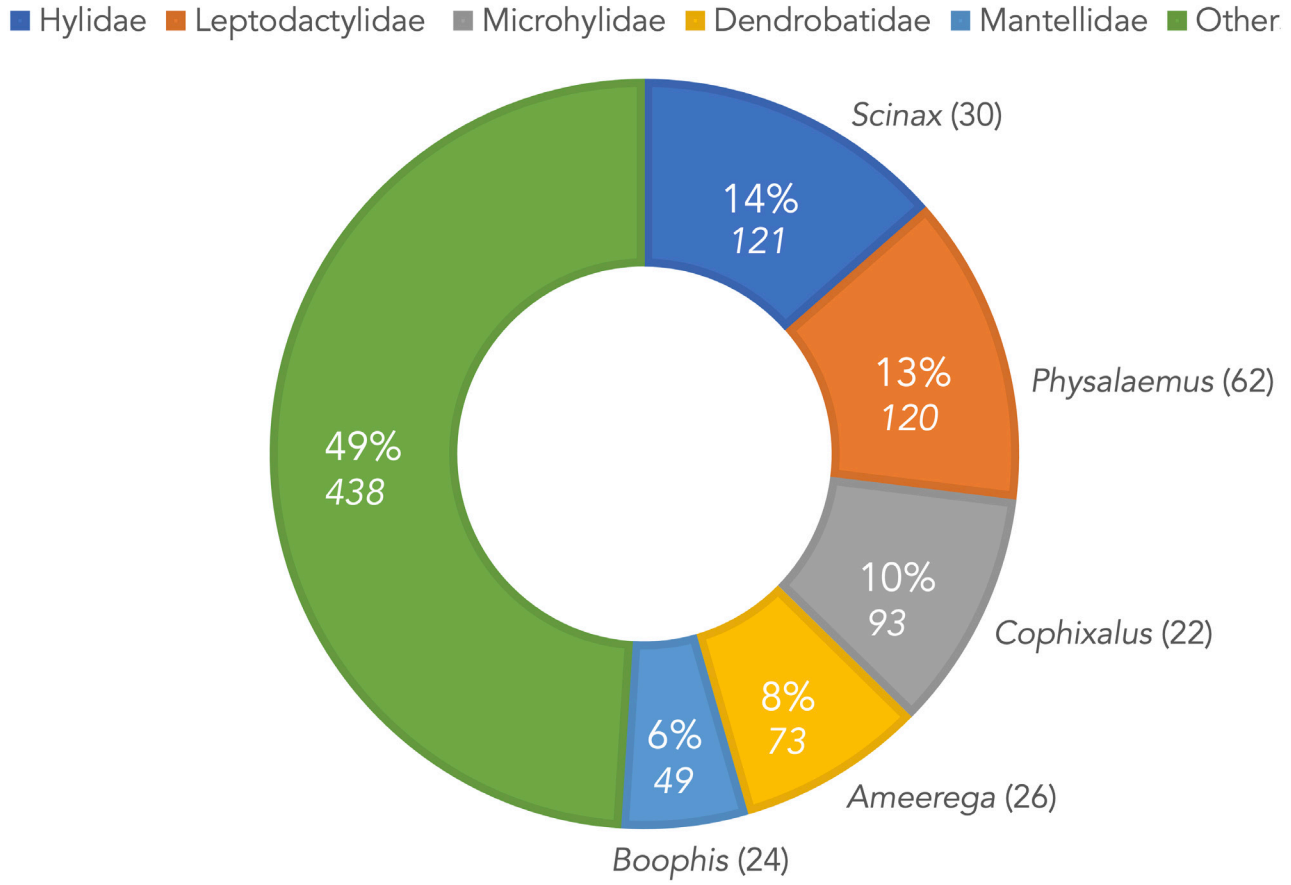

FIGURE 6. Described anuran calls in *Zootaxa* grouped. Values in italic are the absolute value of the number of call descriptions for the respective taxon.

Calls

Many frogs produce vocalizations, a communication mode that is very rare or absent in salamanders and caecilians (Brodie 1978, Duellman & Trueb 1986; Wells 2007, Bradley & Eason 2018). In frogs, because calls are related to reproduction and serve as an efficient means of pre-mating isolation (Heyer *et al*. 1990), they can serve as evidence for species delimitation and thus are of importance for taxonomy. In fact, a review paper published in *Zootaxa* by Köhler *et al*. (2017) has become one of the standard methodological references for the use of bioacoustics in amphibian taxonomy. The papers published in *Zootaxa* that deal with amphibian vocalizations generally address advertisement calls, and less frequently release, distress, and aggressive calls. Overall, 39% of the total number of *Zootaxa* papers on amphibians include descriptions of 907 anuran calls from 810 currently recognised species. Call descriptions are the primary focus of 70 papers. In addition, 11 papers described previously unknown adult morphological variation and also included calls. The fact that these are not descriptions of new species demonstrates the importance that calls, especially advertisement calls, have gained in anuran systematics.

The majority of papers that include call descriptions describe the advertisement call of a single species (61.12%; 178 of 291). Also, most species have a single description of their calls (Fig. 6). But there are also examples of a single species having its call described multiple times, such as *Physalaemus olfersii*, for which four *Zootaxa* publications included bioacoustic descriptions. *Physalaemus olfersii* was first described in 1856 and has been compared with many recently described species of *Physalaemus*. *Physalaemus* is also the genus with the most call descriptions overall, with 62 call descriptions for 45 species, representing 94% of the 49 currently recognized species of the genus (Hepp & Pombal 2020).

Conclusions and perspectives

Zootaxa has played an important role in accelerating the description of amphibian species, as well as serving as an outlet for valuable data on calls, tadpoles, larvae, and embryos. The reasons for this are difficult to assess here, though several factors may synergistically explain this success. First, there is a growing number of researchers with access to new amphibian species that are interested in describing this diversity, using multiple sources of evidence. Second, the publication model implemented by *Zootaxa* includes an effective editorial process and rolling publication of new articles, without restrictions on either manuscript length or number of figures. The lack of page charges or charges for color plates for the on-line version, as well as low Open Access fees, means that publication is open to a large audience of researchers regardless of their access to funds to support publication costs. Only 6% of all articles in *Zootaxa* on amphibians are open access, suggesting that—even the costs are low—most authors lack the resources to pay these fees and, therefore, a preference for *Zootaxa* on journals that charge the authors.

The exploration of pristine and/or poorly inventoried regions as well as the shelves of of scientific collections are likely to continue to result in the discovery of new species of amphibians for the foreseeable future. The integrative approach adopted over the past 20 years by authors of new amphibian species, including teams of multiple scientists with varied expertise, has led to many new species having rich associated data on their biology and natural history. In the coming years, we anticipate an increase in larval or embryonic data for amphibian species that are poorly characterized (salamanders, caecilians, and direct-developing frogs) and the expansion of the toolkit used by amphibian taxonomists (e.g., microbiomes, chemical compounds, isotopes). It seems certain that *Zootaxa* will continue to serve as a productive outlet for documenting amphibian biodiversity.

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APPENDIX 1. Chronological list of *Zootaxa* editors, indicating their period of activity, taxa, topics, and the geographic range for which each one was/is responsible.

Editors	Year's interval	Taxa	Scope	Geographic range
Mark Wilkinson	2001–2004	Amphibia and Reptilia	All topics	World
Salvador Carranza	2004–2006	Amphibia and Reptilia	All topics	World
Miguel Vences *	2006–present	Amphibia	All topics	World
Santiago Castroviejo-Fisher	2008–present	Amphibia/Anura/Centrolenidae/ Hemiphractidae **	All topics	Neotropics
José Padial	2008–2018	Amphibia/Anura/Brachycephaloidea	All topics	Neotropics
David Gower	2008–present	Amphibia/Gymnophiona	All topics	World
Victor G.D. Orrico	2012–present	Amphibia/Anura/Hylidae	All topics	World
Jason L. Brown	2012–2015	Amphibia/Anura/Dendrobatoidea	All topics	Neotropics
Jodi Rowley	2012–present	Amphibia/Anura	All topics	Oceania
Diego Baldo	2013–present	Amphibia/Anura/"Leptodactylids" ***	All topics	Neotropics
Pedro Ivo Simões	2015–2019	Amphibia/Anura	Calls	World
Evan Twomey	2015–present	Amphibia/Anura/Dendrobatoidea	All topics	Neotropics
María Florencia Vera Candioti	2015–present	Amphibia/Anura	Tadpoles	World
David Blackburn	2017–present	Amphibia/Anura	All topics	Africa
Mauricio Rivera-Correa	2018–present	Amphibia/Anura/Brachycephaloidea	All topics	Neotropics
Chan Kin Onn	2019–present	Amphibia/Anura	All topics	SE Asia
Evan Quah	2019–present	Amphibia/Anura	All topics	SE Asia
Priscilia Gambale	2019–present	Amphibia/Anura	Calls	World

(*) Senior Editor. (**) Editor of Hylidae from 2008 to 2012. (***) Alsodidae, Ceratophryidae, Hylodidae, Leptodactylidae, Limnomedusidae, Odontophrynidae, and Telmatobiidae.