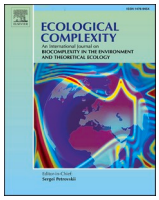
Ecological Complexity 58 (2024) 101080

Contents lists available at ScienceDirect

Ecological Complexity

journal homepage: www.elsevier.com/locate/ecocom



Original Research Article

Who notices Gymnophiona? Google Trends data reveal interesting trends for recent amphibian species

Branden Holmes [a], Janine M. Ziermann [b], Artur Strzelecki [c], Steffen Springer [d], Michael Zieger [d,*]

[a] The Recently Extinct Plants and Animals Database, Two Rocks, Australia
[b] Howard University College of Medicine, Department of Anatomy, Washington, DC, USA
[c] University of Economics in Katowice, Department of Informatics, Katowice, Poland
[d] SRH Wald-Klinikum Gera GmbH, Gera, Germany

ARTICLE INFO

Keywords:
Vertebrata
Amphibia
Caecilians
Herpetology
Search engine data
Representation index

ABSTRACT

Gymnophiona (caecilians) are inconspicuous, wormlike amphibians that are often hidden from human sight due to their aquatic or fossorial lifestyles. While Google Trends data have been widely used within conservation biology to provide information about the relative interest in species, and therefore of their flagship-making potential, as well as to identify current taxonomic biases. This study aimed to evaluate public interest in amphibians, with a particular focus on caecilians, and possible taxonomic biases of and within the class Amphibia. Google Trends data from amphibians, reptiles (sauropsids, excluding aves), and fishes (chondrichthyans + osteichthyans, excluding tetrapods) were analyzed and compared. In addition, a framework for a representation index and web representation index is presented. The introduced relative representation index was able to confirm taxonomic bias concerning Amphibia. Differences in worldwide public interest could also be evaluated within amphibians, indicating severe underrepresentation in public interest for caecilians.

1. Introduction

Recent amphibians (Lissamphibia) form a species-rich and extremely diverse group of vertebrates that includes three orders: Salientia (modern frogs, i.e., Anura, and extinct frogs), Caudata (modern salamanders, i.e., Urodela, and extinct species), and Gymnophiona (modern caecilians, i.e., Apoda, and extinct species). We follow AmphibiaWeb and use the more commonly used terms Anura, Caudata, and Gymniophiona without considering any fossil species in our analyses. The taxon Amphibia comprises over 8,000 described species according to the IUCN Red List (IUCN Red List version 2021-1), while AmphibiaWeb and Amphibian Species of the World 6.2 list over 8600 amphibian species in their databases (as of July 2023) (AmphibiaWeb, 2023; Frost, 2023). Despite this high number of species, comparable to those of mammals (Burgin et al., 2018) and birds (Callaghan et al., 2021), and despite their relatively high endangerment compared to other vertebrate groups, amphibians suffer from negative taxonomic bias. This has been shown based upon search interest data with the help of Google Trends (Holmes et al., 2022).

Google Trends provides a comparison between up to five search terms or topics to evaluate the relative public search interest of users of the Google search engine. As shown by Holmes et al. (2022), a few mammal species (e.g., lion and tiger) dominate the internet-using population's search interests in vertebrates. Since these few mammals dominated the search, and the high interest values levelled out small differences in the relative search interest, it is important to examine the introduced representation index for amphibians with a less popular reference species to work out smaller differences in more detail.

Amphibia are globally distributed, except in the polar regions, though they are concentrated in the Neotropics. It is currently largely accepted that Anura and Caudata are more closely related to each other based upon a molecular basis data than either is to Gymnophiona (Frost et al., 2006; Hillis, 1991; Hime et al., 2021). Most amphibians pass through a free swimming (aquatic) larval stage before entering, after a transformative process called metamorphosis (J. O. Reiss, 2002), the terrestrial adult stage. However, many exceptions are present and a wide range of developmental variations (e.g., direct development) and lifestyles have evolved. Larval amphibians have a wide range of feeding modes (filter feeding, carnivory, herbivory), which are often additionally classified by size (macrophagy, microphagy, megalophagy) and, while mostly terrestrial, can be found in diverse habitats (aquatic, boreal etc.) (Altig and Johnston, 1989; de-Oliveira-Nogueira et al., 2023;

* Corresponding author.
E-mail address: Michael_Zieger@icloud.com (M. Zieger).

https://doi.org/10.1016/j.ecocom.2024.101080
Received 30 July 2022; Received in revised form 9 July 2023; Accepted 25 March 2024
1476-945X/© 2024 Elsevier B.V. All rights reserved.

McDiarmid and Altig, 1999; Wells, 2007; J. M. Ziermann, 2019; J. M. Ziermann and Fratani, 2022). As adults, amphibians are generally carnivorous, with few exceptions (de-Oliveira-Nogueira et al., 2023). Most amphibians lay eggs into water bodies which are fertilized by a male; however, a variety of reproductive and developmental modes evolved (Wells, 2007). Amphibia is also the class of vertebrates at greatest risk of extinction (Wake and Vredenburg, 2008). In addition to climate change, habitat loss and human impact, amphibians are threatened by chytrid fungi (*Batrachochytrium dendrobatidis* and *B. salamandrivorans*) (Collins et al., 2009; Howard and Bickford, 2014; Parrott et al., 2017; Sodhi et al., 2008). Therefore, quantifying public interest in amphibians, and in particular the rather cryptic caecilians, is a crucial step in understanding how under-informed the public is about the different groups under threat from the current amphibian crisis.

Gymnophiona forms the smallest recent order in the class Amphibia, with only around 215 described species, and receives little public attention. They are worm-like creatures who have lost their limbs and limb girdles and are mostly fossorial or aquatic, often staying away from human view. Gymnophiona is not only the least diverse order of amphibians, but also a reclusive and relatively understudied order. These animals are often confused with snakes and worms, but have a place in a few local myths and also some folklore where they are often stigmatized, which raises concerns for their conservation (Gower and Wilkinson, 2005; Kotharambath et al., 2013). For example, in the Indian state of Kerala there are 14 vernacular words in the local Malayalam language used for caecilians, but none of these are exclusive, and are instead shared with various snake and worm species (Shamna Rajan et al., 2020).

Gymnophiona are distributed pantropically except Madagascar and east of the Wallace line (Duellman and Trueb, 1994; McDiarmid, 1994). Thus, compared with anurans they have a restricted distribution, are represented by far fewer species, are harder to see, and do not alert humans to their presence by vocalising loudly (Duellman and Trueb, 1994; Wells, 2007), resulting in relatively little interest as shown via the Google search engine. In this study, the interests of the Google-using population searching for information about different Amphibia species were examined more closely and compared with that for reptiles (sauropsids, excluding aves) and fishes (chondrichthyans + osteichthyans, excluding tetrapods). The living Amphibia orders Anura, Caudata, and Gymnophiona were studied for relative differences in interest among them.

Several factors, such as body mass, can also have an impact on public perception and attention to species (Holmes et al., 2022). Therefore, this analysis also compared and analyzed the frequency distributions of body mass for all extant Amphibia species and for the most Googled amphibians.

The study is thus intended to contribute to the framework for better analyzing data from Google Trends to better assess information about the relative interest of the public in specific species and higher taxa, identify gaps in attention, and thus help to make conservation work more effective.

The objective of this study was to quantify the public awareness of Amphibia relative to other vertebrate groups (fishes: chondrichthyans + osteichthyans, excluding tetrapods, and reptiles: sauropsids, excluding aves), with special emphasis on relative awareness of Gymnophiona in particular, and potential taxonomic biases of and within the class of Amphibia.

The following research questions (RQ) are set in this study:

RQ1: How can different taxa be represented based on data from Google Trends?
RQ2: Are different taxa comparable in terms of popularity over the Internet?

2. Methods & data

In this study, data comes from two sources. The first source is the Google Trends service provided by Google. It is the source for our representation index. The second source is the number of results reported by the Google search engine for English names of species. The search engine was queried for each species name. It is the source for our web page representation index. Based on the collected data two indexes are proposed: representation index (Google Trends) and web page representation index (results from Google search engine). Additionally, we have used the body mass data gathered from the literature. The research flow method was as follows:

2.1. Google Trends data

Google Trends data have been widely used for investigations (e.g., Davies et al., 2018; Holmes et al., 2022; Proulx et al., 2014; Zieger and Springer, 2019). By default, Google offers the comparison of up to five search terms or topics. If the search query that contains the peak value is included in each data set, and remains the peak value, it is possible to compare more than the five data sets using Google Trends. Therefore, all data are normalized to this peak value (see Holmes et al., 2022).

In this study, data were collected with the following settings in Google Trends. The period was set from 2004 to present with a monthly data resolution. Google Trends data were collected during October–November 2021, if not stated otherwise. Complete years were used for the evaluation, i.e., the beginning was January 2004, and the end was December 2020. The region was selected as worldwide, and all categories and web search were set. In this study, topics rather than search terms were used because they are more informative as described elsewhere (Holmes et al., 2022). Topics are a group of search strings that share the same concept in any language, as opposed to search terms which are single search strings and therefore less comparable when trying to compare topics rather than search strings.

The most Googled species from the three extant vertebrate classes reptiles (sauropsids, excluding aves), amphibians (including orders as far as data were available), and fishes (chondrichthyans + osteichthyans, excluding tetrapods) were identified from previous studies (Davies et al., 2018; Holmes et al., 2022). The most Googled species of the three extant classes, the great white shark (*Carcharodon carcharias*), was identified using Google Trends topics and then used as the standardized peak value. Since a new specimen of the goblin shark (*Mitsukurina owstoni*) was caught in 2014 (Driggers et al., 2014), it likely generated a lot of media attention, leading to an unusually high peak in interest on Google Trends. This search interest, for example, was also set in relation to the selected reference species.

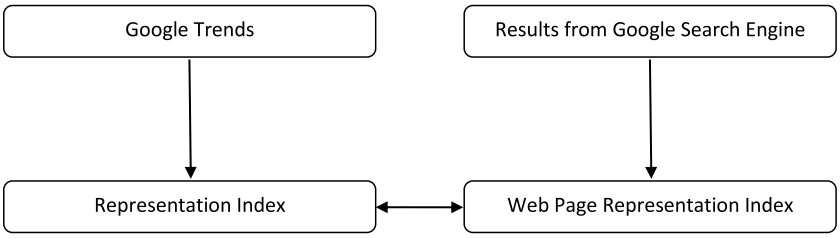
The American bullfrog (*Lithobates catesbeianus*), the most Googled species among the Amphibia species identified by Davies et al. (2018), was used as a reference species for the closer examination of the three amphibian orders.

The selected reference topics were used as a reference in all requests to Google Trends in order to standardize all results on the same peak value as indicated. Average relative monthly search interest S_i for each of the m most Googled species i during the examined period was calculated as well as its mean M_j for the taxon j as follows:

$$M_j = \sum_{i=1}^{m} S_i : \mathrm{m}$$

According to Holmes et al. (2022) m=20 species were examined for comparison of the three extant vertebrate classes reptiles (sauropsids excluding aves), amphibians, and fishes (chondrichthyans + osteichthyans, excluding tetrapods).

Since Davies et al. (2018) only provided data for 52 amphibian species that were not omitted from their analysis or that had an insufficient search volume and the vast majority of the species were Anura,



only m=10 species (first 10 according to Davies et al. (2018)) were included in the analysis of this study instead of 20 species. This study used 10 Caudata species which were identified by Davies et al. (2018). For the Gymnophiona, we were forced to use the 10 existing taxonomic families as search topics instead of individual species because not enough species with sufficient search volumes could be identified (Davies et al., 2018). This serves to highlight the severe underrepresentation of individual species of caecilians among Google searches, and therefore near total lack of search interest in them.

This study is based on the most Googled species identified by the work of Davies et al. (2018). In addition, well-known species such as the African clawed frog (*Xenopus laevis*), the axolotl (*Ambystoma mexicanum*), and *Typhlonectes natans* which not only play an important role in aquaristics but also in research, were originally evaluated with the help of Google Trends. One further species of caecilian, *Atretochoana eiselti*, showed a massive spike in search interest in August 2012 which corresponds to widespread media reports of its rediscovery and alleged resemblance to the human penis (Butler, 2012; Wrenn, 2012). But none of these species returned enough search data to be listed by Davies et al. (2018) and therefore were not included in the evaluation process.

2.2. Internet representation

The Google search engine was used to identify the number of web content as search results.

Google rank web pages (single Internet documents with unique URL (Uniform Resource Locators)), while websites are collections of web pages (Ganapathy, 2019).

Data were collected during October–November 2021, if not stated otherwise, with the following settings in Google.com: all results and any time. The operator quotation was used in Google.com for English names, e.g., “American bullfrog”, to obtain a list containing only results with the exact term. Otherwise, Google would have shown all pages containing all words from the query, but not necessarily next to each other and in the exact order.

In two cases some single keywords for English names, e.g., olm (*Proteus anguinus*) or hellbender (*Cryptobranchus alleganiensis*), refer to many objects. "Hellbender" for instance stands for the hellbender salamander and a character in Marvel's 'Guardians of the Galaxy'. Therefore, single names were used as *olm salamander* or *hellbender salamander* but without quotations. Gymnophiona families were used as single term without quotation in Google search.

For the Google Trends analysis performed, the topics were selected based on the suggestions made by Google Trends. For the analysis of the web content, analogous to the naming of the topics, the English names for the searched species were used as far as possible, rather than their binomial names or names in other languages.

The list of species names for Anura is American bullfrog (1); Cane toad (2); Australian green tree frog (3); Long-nosed horned frog (4); Goliath frog (5); Green and golden bell frog (6); Wood frog (7); *Ranoidea chloris* (8); Spring peeper (9); Tomato frogs (10). The list of species names for Caudata is Tiger salamander (1); Plateau tiger salamander (2); Common mudpuppy (3); Northern crested newt (4); Chinese giant salamander (5); Red salamander (6); Olm salamander (7); Fire salamander (8); Hellbender salamander (9); Spotted-tail salamander (10). The list of names for Gymnophiona is Caeciliidae (1); Chikilidae (2); Dermophiidae (3); Herpelidae (4); Ichthyophiidae (5); Indotyphlidae (6); Rhinatrematidae (7); Siphonopidae (8); Scolecomorphidae (9); Typhlonectidae (10).

2.3. Representation index

A representation index RI_j that relates the average of the relative search interest for the 20 most popular to the total number of species n_j in a taxon j over the course of the investigated period was introduced by Holmes et al. (2022):

$$RI_j = M_j : \ n_j$$

In this study, the years in the investigation period were considered individually and an annual RI_j was calculated for each year from the Google Trends data. In order to determine whether a certain taxon j was over- or underrepresented, the relative representation index rRI_j (Holmes et al., 2022) values were also determined as the annual rRI_j for each year and averaged, and the mean and standard deviation were determined. Statistically, p-values were calculated using the Student's t-test. For the analysis of the amphibian orders, 10 instead of 20 topics were evaluated in accordance with the Google Trends analysis.

2.4. Web page representation index

A representation index RI_{jweb} that relates sum S_{jweb} of web pages W_i for the m most popular species i to the total number of species n_j in a taxon j for the time of the request to Google was used as:

$$S_{jweb} = \sum_{i=1}^{m} W_i$$

$$RI_{jweb} = S_{jweb} : \ n_j$$

As a first approximation, it is neglected that web pages dealing with two or more of the examined species or websites providing different web pages can be counted multiple times.

For t comparable taxa j, the relative representation index rRI_{jweb} for web pages was calculated based on the expected value RI_{expweb} for each taxon j as:

$$RI_{expweb} = \sum_{j=1}^{t} S_{jweb} : \ \sum_{j=1}^{t} n_j$$

$$rRI_{jweb} = RI_{jweb} \ : \ RI_{expweb}$$

2.5. Body mass data

The body mass data are based mainly on the raw data from O'Gorman and Hone (2012), which were kindly provided by Eoin J. O'Gorman (pers. comm., 29 June 2021). Following Holmes et al. (2022), the frequency distribution of the $\log_{10}$ of species body mass [g] was calculated as a percentage of the total number of species for each log level.

3. Results

Google Trends data were accessed for 20 selected Amphibia species (Fig. 1A) and compared with the two extant classes reptiles (sauropsids, excluding aves) and fishes (chondrichthyans + osteichthyans, excluding tetrapods) (data not shown [see Table Supplement 1, Figure Supplement 1A]).

Relative search interest in reptiles (sauropsids, excluding aves) and fishes (chondrichthyans + osteichthyans, excluding tetrapods) was dominant in comparison with Amphibia species. This could be proven by the mean of the average relative monthly search interest for all 20 species combined (data not shown [see Fig. Suppl. 1B]).

The relative representation index was calculated for each year and averaged (Fig. 1B). The numbers of species were used according to the estimated number of described species in IUCN Red List version 2021-1. The index shows a significant underrepresentation ($p << 0.001$) for

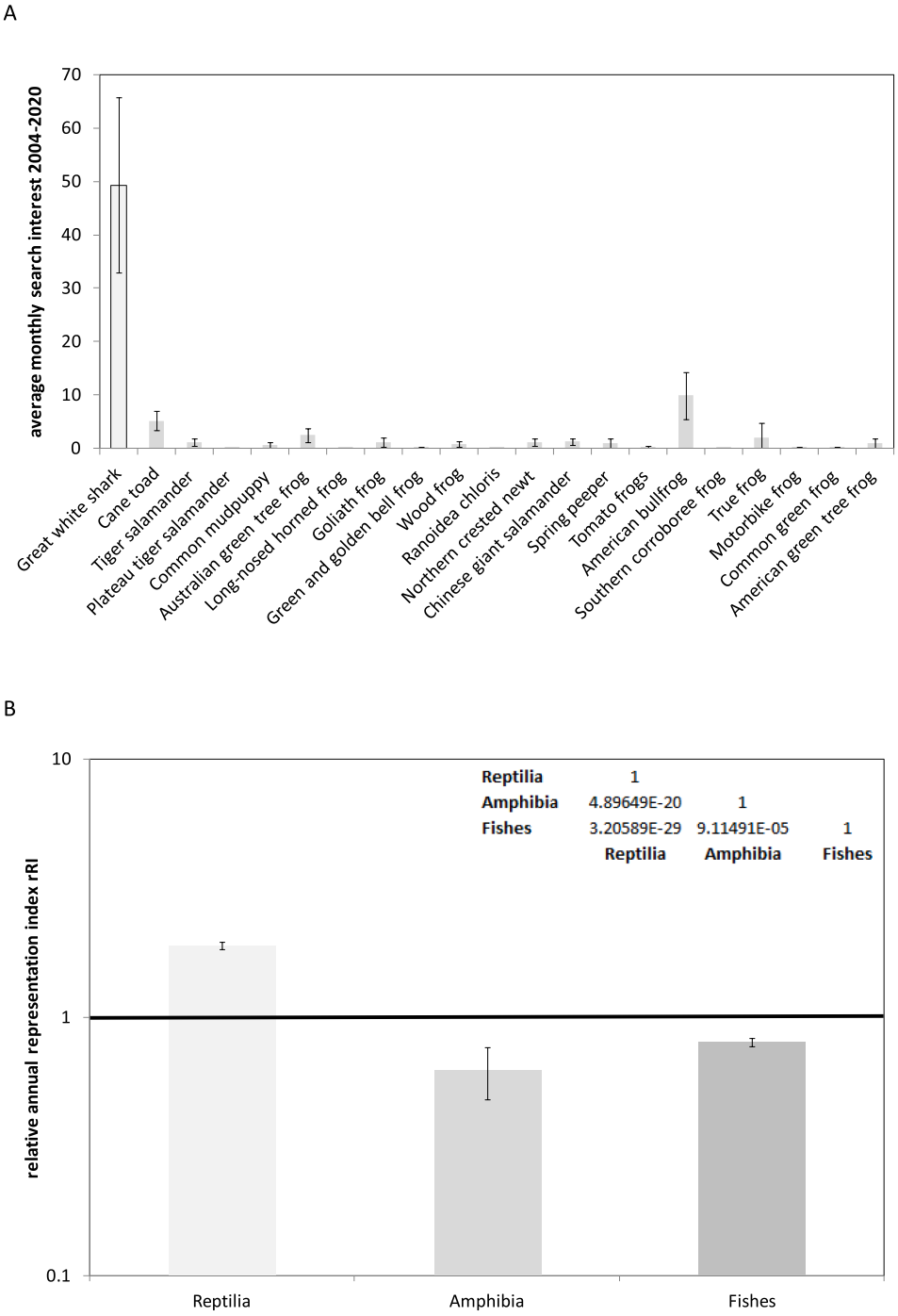


Fig. 1. (A) Average relative monthly search interest for the 20 most Googled species (according to Davies et al., 2018): Monthly Google Trends data for the search topics indicated were obtained from 2004 – 2020 and averaged. Mean values ± standard deviations are shown for species of Amphibia. The search topic "Great white shark" was used as reference in each request in Google Trends. As far as possible, topics were selected based on the suggestions made by Google Trends and Google Trends values <1 were considered 0. (B) Mean values ± standard deviation of the annual relative representation index rRI_j of the three examined vertebrate taxa (period: 2004-2020): An annual relative representation index rRI_j greater than 1 indicates a relative overrepresentation and rRI_j less than 1 indicates a relative underrepresentation. Google Trends values <1 were considered 0. Student's t-test was calculated, and p-values are shown as insert.

Amphibia in comparison with the other two taxa [reptiles (sauropsids, excluding aves) and fishes (chondrichthyans + osteichthyans, excluding tetrapods)]. The results show the significant overrepresentation of Reptilia compared to all other examined taxa (Fig. 1B).

With the great white shark as reference, the African clawed frog generated a medium average relative monthly search interest ($S_{X.laevis}$ = 2.5) compared to the American bullfrog (Fig. 1A). Deviating from the aforementioned research by Davies et al. (2018), the search topic axolotl generated unexpectedly high values ($S_{A.mexicanum}$ = 19.4), which may be due to its cultural importance in Mexico, use in regeneration research, and recreational importance as a common pet.

As discussed by Holmes et al. (2022), the frequency distributions of species body mass of amphibians, reptiles (sauropsids, excluding aves) and fishes (chondrichthyans + osteichthyans, excluding tetrapods) of all extant species and for the 20 most Googled species reveal a right shift of the peak value for the 20 most Googled species by at least one log level. As an example, the frequency distributions of species body mass are shown for Amphibia in Fig. 2A.

The three Amphibia orders Anura (Fig. 3A), Caudata, and Gymnophiona (data not shown [see Table Suppl. 2, Fig. Suppl. 3A]), were evaluated with the most Googled Amphibia single species, the American bullfrog (*Lithobates catesbeianus*), as a reference. Mean values of the average relative monthly search interest from each 10 most popular species (Anura, Caudata) or families (Gymnophiona) also show an extremely low relative search interest for Gymnophiona (data not shown [see Fig. Suppl. 3B]). Gymnophiona were examined at family and not at the species level because there were not enough species with sufficient search volumes. For example, even *Typhlonectes natans*, commonly called “rubber eel”, which is also sold in the pet trade and for which Google Trends (as of June 2023) provides an own search topic referred to as *T. natans*, generated only a negligible search volume in relation to the American bullfrog as reference.

The relative representation index was calculated for each year and averaged as shown in Fig. 3B. The numbers of species were used according to AmphibiaWeb for the Amphibia orders Anura (7,404 species), Caudata (766 species), and Gymnophiona (214 species) (according to AmphibiaWeb (https://amphibiaweb.org), University of California, Berkeley, CA, USA; data accessed: October 2021). The low interest for Gymnophiona is evidenced by the annual relative representation index $rRI_{Gymnophiona}$, which is far below 1 indicating the relative underrepresentation of this taxon (Fig. 3B).

The frequency distributions of species body mass for all extant species and for the 10 most Googled species is shown for Anura and Caudata (Fig. 2B, 2C). Since families instead of species were used as search topics in the Gymnophiona, weight assignment was not meaningful here.

The web content was evaluated for orders Anura, Caudata, and Gymnophiona. Again, species excluded by Davies et al. (2018) like axolotl could also generate high values of search results (axolotl ca. 2E+07 web pages). A similar situation arises for *Typhlonectes natans*, which is common in aquaristics, with about 1E+04 web pages for "*Typhlonectes natans*" and with a similar amount of web pages for the general term "rubber eel" (each in quotation marks, as of June 2023). Sum S_{jweb} of web pages was lowest for Gymnophiona families ($S_{Gymnophionaweb}$ ca. 2.1E+05) and by order of magnitude higher for Anura and Caudata ($S_{Anuraweb}$ ca. 3.3E+06, $S_{Caudataweb}$ ca. 2.2E+06). Taking into account the number of species, the picture was put into perspective. The relative representation index rRI_{jweb} was calculated on the basis of the expected value for each taxon as shown in Table 1. It indicates a clear overrepresentation of Caudata. Additionally, to compare the relation of information search to the available information (web) content, the relation of mean annual rRI_j to rRI_{jweb} was calculated (Tab. 1).

4. Discussion

Clear trends can be demonstrated on the basis of this investigation. In agreement with a previous study (Holmes et al., 2022), the underrepresentation of Amphibia in the search interests of the population by comparison, especially with Reptilia, was shown. Moreover, there are clear indications that certain orders of Amphibia, specifically the Gymnophiona, receive significantly less attention than others. This shows that Google Trends, in combination with a representation index, is a valuable tool for investigations about public interest in different taxa.

Since the most Googled species by Davies et al. (2018) did not contain Gymnophiona because of insufficient search interest, families instead of species were examined for this taxon. Popular names of frogs and salamanders are used by scientists and citizens, while family names are not commonly known by citizens. This may also have a role in search volumes. It cannot be ruled out that individual Gymnophiona species, e.g., *Typhlonectes natans*, may show some interest, which in view of the small number of species compared to other amphibian orders, could then have an impact on the representation index.

The number of web pages (sum $S_{Gymnophionaweb}$) has also confirmed the low representation of Gymnophiona. The search interest was also related to the available information content in the Internet. However, the current status (2021) of the web content was compared with the relative search traffic of the past years. Caudata have shown a clear overrepresentation in both search interest and web page number based relative indices, whereas Anura were slightly underrepresented for both parameters, because of their high number of described species. Gymnophiona have shown a strong underrepresentation in search interest, which corresponds to a relatively low number of web pages. But the relationship between the need for information and the information offered shows that gymnophionans are the subject of relatively low search interest in relation to the relatively large size of available web content in the Google search engine for them. A higher value indicates a high need for information compared to that on offer. While low values express an inverse relationship.

Relative web representation index $rRI_{Gymnophionaweb}$ is actually relatively high for Gymnophiona, probably due to the low number of species, though it should not be forgotten that the existing families were used as a criterion for the search. This may cover the information on offer quite well. In the future, there may be a good opportunity to modify the web index and compare higher taxonomic units than species.

In answer to the first research question, a representation index was proposed. This index shows the search interest expressed by Internet users in the Google search engine for species of a taxon in relation to the number of species, which can therefore be used to compare different taxa.

In answering the second research question, a web page representation index was proposed. This index shows the content coverage over the web pages on species of a taxon in relation to the species number. Also, the same three amphibian orders in this study were compared.

However, the relation of search interest to web content available in search engine does not take into account the interest behind the creation of such websites or web pages. As Holmes et al. (2022) have already shown for the five vertebrate classes, a trend towards a higher weight in the most frequently googled vertebrate species was confirmed in this study by a closer examination of Amphibia. In addition, this trend could also be shown for the Amphibia orders Anura and Caudata. This observed trend could be explained by several factors. Heavier species tend to be larger and therefore more visible. They also tend to have a larger range of distribution (Reiss, 1988), resulting in more people being aware of them. Another issue is that larger species also tend to be more often in conflict with humans (great white shark near beaches, elephants and big cats in Asia and Africa, American bullfrog as invasive species) (Kansky and Knight, 2014; Nyhus, 2016). Some limitations are imposed by using the database that generates body mass data by extrapolating length-weight relationship (O’Gorman and Hone, 2012).

Therefore, further investigations on Gymnophiona with regard to the search interest of all known species and their weight distribution would be useful. In the case of the Gymnophiona species, an investigation of

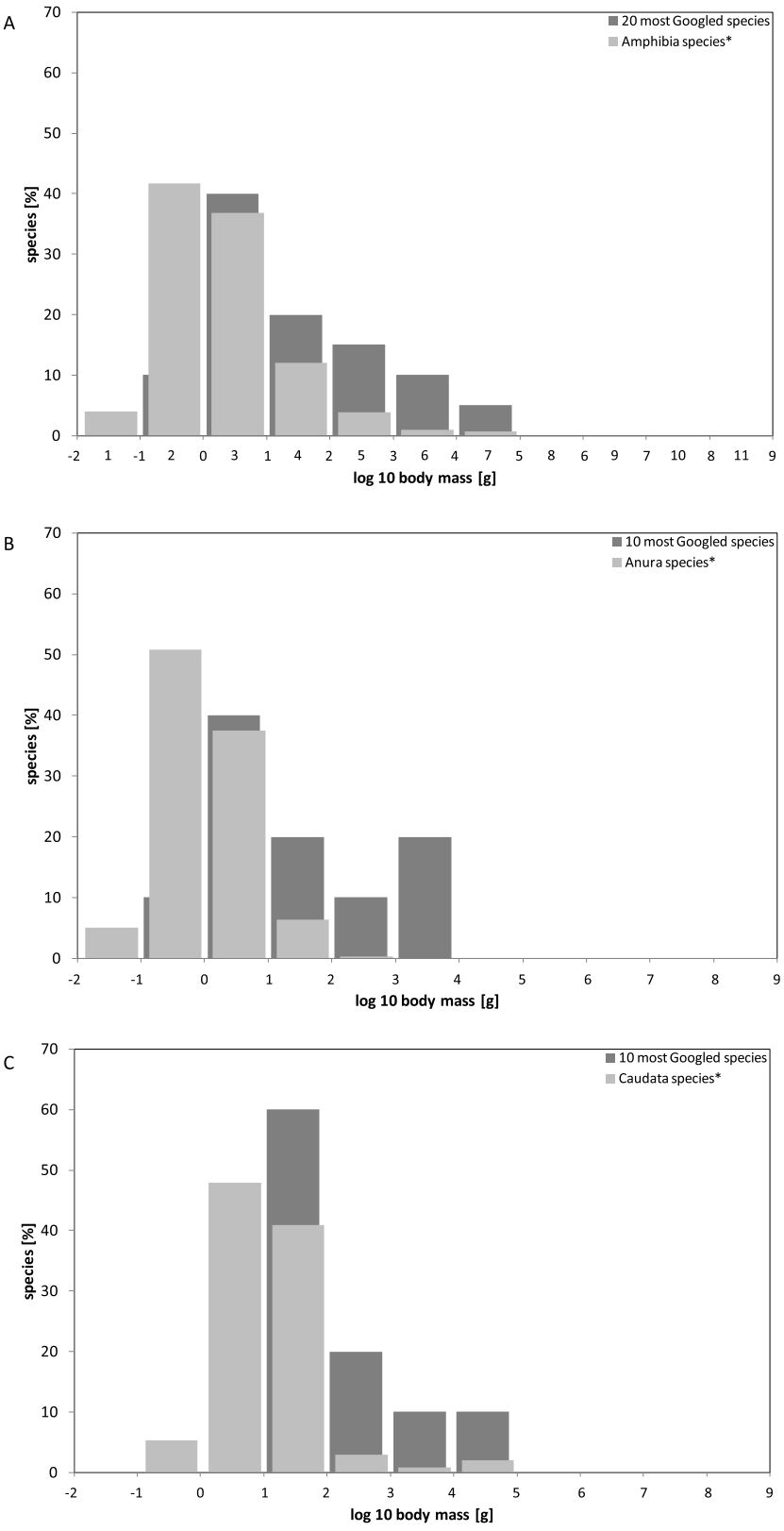


Fig. 2. Frequency distribution of species body mass of Amphibia: Distribution for extant species of Amphibia (A) (according to O'Gorman & Hone, 2012) and for the 20 most Googled species (according to Fig. 1A) are shown. Distribution of species body mass of Anura (B) and Caudata (C) for extant species (according to O'Gorman & Hone, 2012) and for the 10 most Googled species are shown as indicated. Body mass data were kindly provided by Eoin J. O'Gorman (O'Gorman & Hone, 2012) and were used also for the most Googled animals where available or data are a best estimate (Holmes et al., 2022). Frequency is shown as a percentage of the respective total number. [* according to E. OGorman data]

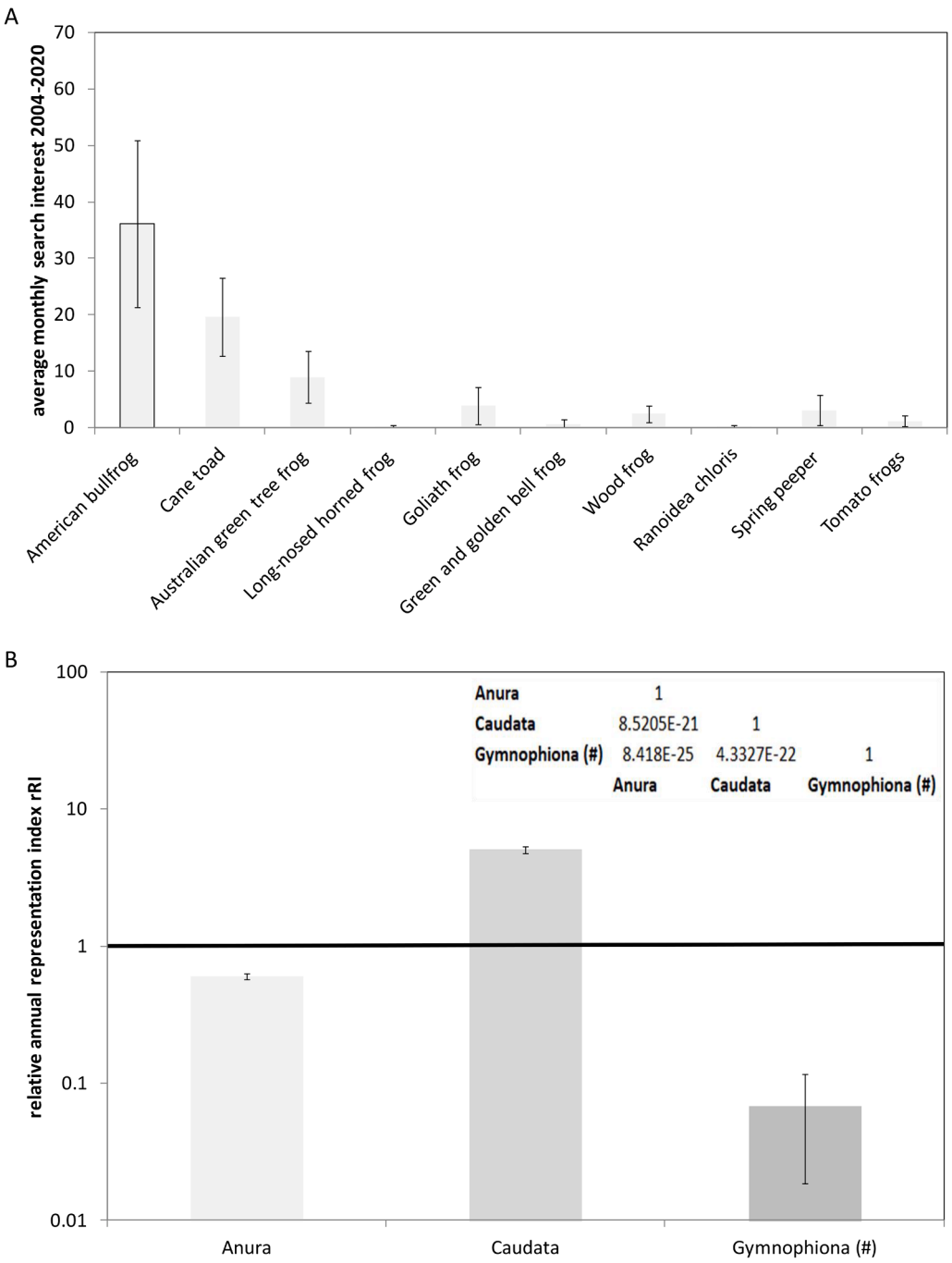


Fig. 3. (A) Average relative monthly search interest for the 10 most Googled species of order Anura (according to Davies et al., 2018): Monthly Google Trends data for the search topics indicated were obtained from 2004 – 2020 and averaged. Mean values ± standard deviations are shown. The search topic "American bullfrog" was used as reference in each request in Google Trends. As far as possible, topics were selected based on the suggestions made by Google Trends and Google Trends values <1 were considered 0. Search term was used, if no topic was available. (B) Mean values ± standard deviation of the annual relative representation index rRI_j (period: 2004-2020): An annual relative representation index rRI_j greater than 1 indicates a relative overrepresentation and rRI_j less than 1 indicates a relative underrepresentation. Google Trends values <1 were considered 0. Student's t-test was calculated, and p-values are shown as insert. (# families instead species)

the length instead of the weight data could also be expedient. Showing exceptional large or long specimens, might reach more public interest as often extremes do. Increased awareness would also improve conservation efforts. Additional research should be done for the evaluation of differences in the regional attention for this taxon in the world, to see to what degree it reflects the groups' natural geographical range.

There are many possible reasons for the discrepancies in search interest between Caudata, Anura, and Gymnophiona, some of which are presented here. Where not prohibited by law, both Anura (frogs) and Caudata (salamanders) are kept as pets, which is rarely the case for caecilians. An exception is *Typhlonectes natans*, a caecilian available in pet stores and bred by aquarists and in some zoos and aquariums (Gower and Wilkinson, 2005; Reinhard and Kupfer, 2022; Sheehy et al., 2021). This is directly related to the daily exposure of people to amphibians. Frogs and toads can be easily heard calling in many parts of the world, and salamander and frogs are commonly seen in moist forests, swamps, close to streams and ponds over large part of the globe. They are also frequently present in zoological gardens. Frogs and salamanders are also

Table 1
Mean annual relative representation index rRI_j (period: 2004-2020), relative representation index rRI_{jweb} for web pages (October - November 2021), and relation rRI_j / rRI_{jweb} are shown for Amphibia orders Anura, Caudata, and Gymnophiona. (# families instead species)

taxon j	rRI_j	rRI_{jweb}	rRI_j: rRI_{jweb}
Anura	0.60	0.65	0.93
Caudata	5.09	4.23	1.20
Gymnophiona (#)	0.07	1.47	0.05

part of culture, legends, myths and may be related to religion (Crump, 2015; Voss et al., 2009; Yang, 2016). Some salamanders and frogs even became symbols for countries (e.g., the olm, *Proteus anguinus*, in Slovenia (Aljančič, 2019); Mexican axolotl, *Ambystoma mexicanum*, in Mexico (Bride et al., 2008); Puerto Rican coquí frog, *Eleutherodactylus coqui*, in Puerto Rico (Westrick et al., 2022)). Unique appearance (e.g., the extremely flat Surinam toad, *Pipa pipa*), striking drawings and colours, health benefits or toxicity (e.g., Poison dart frogs, Dendrobatidae), being used as food in cooking, being kept in research or as (exotic) pets (e.g., *Xenopus* and Axolotl), or being considered cuddly, certainly play a role in the attractiveness and thus public interest in certain species or taxa (Measey et al., 2019). Caecilians (Gymnophiona), however, are largely invisible burrowing in soil or being aquatic and are restricted to the wet tropics of South and Central America, Africa, and southern Asia. Furthermore, their wormlike and often colourless appearance makes them less attractive to the broader public. Moreover, caecilians are often confused with snakes or worms and are often stigmatized, which has implications for their conservation (Gower and Wilkinson, 2005; Kotharambath et al., 2013).

While Google Trends indicates that amphibians in general seem not to be very popular in public searches, it is evident that occasionally specific species break through as the 'American bullfrog' shows. However, even this relatively commonly searched frog is significantly less often searched as the 'Great white shark'. The American bullfrog was often in the media due to its size and as an invasive species outside its natural habitat where it diminishes local populations of small mammals and other amphibians due to its large appetite (Ficetola et al., 2007). Due to its more negative image, the American bullfrog is not ideal to change the perception of the public or increase the public's interest in preservation of amphibians and their habitats. Therefore, our results are important to increase the awareness of need to focus on more suitable species to highlight to the public.

All of this contributes to the relative low interest observed in the Google Trends analyses. However, due to the ecological sensitivity of most amphibians, they can be used as indicators for the health of a biotope. Climate change, destruction of habitat, increased air and water pollution, all contribute to the decline of amphibians, in particular frogs and caecilians (Campbell Grant et al., 2020). Sparking an increased public interest in amphibians can result in actions to improve global protection of habitats, which will not only benefit amphibians, but also many insects as well as other taxa (Mi et al., 2023). Therefore, it is important to increase public knowledge about amphibians and their incredible diversity and adaptability (J. M. Ziermann and Fratani, 2022), to foster scientific advancements and to help ensure ecosystems are protected from human activities that have globally negative impacts (e.g., deforestation of the Brazilian Amazon; (Silva et al., 2018; Wearn et al., 2012)).

5. Conclusions

The data from Google Trends have already proven their usability for various scientific questions (Springer et al., 2021). Nevertheless, some limitations are known to exist with this data, which result, especially with small search volumes, from the fact that Google uses samples of its dataset for analysis to avoid heavy resource use (Zieger and Springer, 2019). The exact details of the data collection and analysis process, as well as the improvements made to the Google Trends data collection system, have not been disclosed in detail to the public by Google (Myburgh, 2022; Springer et al., 2023). In addition, Google is not the most popular search engine in all parts of the world, so different regions are differentially represented here (Springer et al., 2021), and relatively small data sets were used in the present study, which make reliable statistical analysis difficult.

The recent study is based on the preliminary study by Davies et al. (2018). However, both studies differ in that Davies et al. (2018) used search terms, while here search topics were used, and were able to extend the timeframe to 2020. The addition of species not included by Davies et al. (2018) revealed another limitation of that previous work. For example, they did not consider well-known and important for research species such as the axolotl (Reiß et al., 2015), which generated a high relative search interest in the present, extended, work. The unexpectedly high values for the axolotl indicate that individual species that were not considered in the investigations can nevertheless have a significant influence on the representation index. Yet, the inclusion of the axolotl in the present study would only have contributed to an even stronger emphasis on the annual relative representation index for the order Caudata. For the species *Typhlonectes natans* corresponding websites were also found, which underlines not least the importance in aquaristics. The investigation was limited to the families of Gymnophiona. Therefore, variations with other search terms are possible. If the number of web pages would increase due to the inclusion of *T. natans*, the web page representation index would increase. This is an indicator that the study can be further refined and provides the framework for future work.

A representation index and a Web page representation index were presented. The former can be used to show the public search interest in the Google search engine for species of a taxon in relation to the number of species. The web page representation shows the content coverage over the web pages on species of a taxon in relation to the species number. These indices are also adaptable and can be used for different taxa. This framework can be used, among other things, to make conservation work more effective in the future.

This research identifies bias in the perception of Gymnophiona, where a lack of attention to and knowledge of the unique biology of limbless amphibians may also affect our understanding of the evolution or ecology of all amphibians in certain aspects. For example, the unique adaptations of the skin in amphibians to different degrees of moisture, the variability of locomotion or feeding styles, or the diversity of breeding and developmental modes.

Based on our study, it is evident that scientists, in particular herpetologists, should make a concerted effort to bring more attention to amphibians. While there are numerous great scientific journals (e.g., Amphibia-Reptilia, Herpetological Conservation and Biology, Ichthyology & Herpetology) as well as some for hobby-herpetologists (e.g., Reptiles) the community is still quite exclusive and rarely contributes to the overturning of the common misconception that amphibians are reptiles instead of their own class.

CRediT authorship contribution statement

Branden Holmes: Idea & Conceptualization, Investigation, Validation & Analysis, Writing, Review & Editing. **Janine M. Ziermann:** Investigation, Validation & Analysis, Writing, Review & Editing. **Artur Strzelecki** Methodology, Investigation, Validation & Analysis, Writing, Review & Editing. **Steffen Springer:** Validation & Analysis, Visualization, Writing, Review & Editing. **Michael Zieger:** Idea & Conceptualization, Methodology, Investigation, Validation & Analysis, Writing, Review & Editing, Supervision.

Financial support

This research received no specific grant from any funding agency, whether commercial or not-for-profit.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Unless otherwise stated, only freely accessible data sources were used.

Acknowledgements

We thank Eoin J. O'Gorman for sharing raw data on species body mass and we thank the Editor-in-Chief Jurek Kolasa and the anonymous reviewers, who made it possible for us to significantly improve our research with their valuable suggestions.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.ecocom.2024.101080.

References

Aljančič, G., 2019. History of research on Proteus anguinus Laurenti 1768 in Slovenia /Zgodovina raziskovanja človeške ribice (Proteus anguinus Laurenti 1768) v Sloveniji. Folia Biologica et Geologica 60 (1), 39. https://doi.org/10.3986/fbg0050.

Altig, R., Johnston, G.F., 1989. Guilds of Anuran Larvae: Relationships among Developmental Modes, Morphologies, and Habitats. Herpetol. Monogr. 3, 81. https://doi.org/10.2307/1466987.

AmphibiaWeb. 2023. University of California, Berkeley, CA, USA. https://amphibiaweb.org/.

Bride, I.G., Griffiths, R.A., Meléndez-herrada, A., Mckay, J.E., 2008. Flying an amphibian flagship: conservation of the Axolotl Ambystoma mexicanum through nature tourism at Lake Xochimilco, Mexico. Int. Zoo Yearbook 42 (1), 116–124. https://doi.org/10.1111/j.1748-1090.2008.00044.x.

Burgin, C.J., Colella, J.P., Kahn, P.L., Upham, N.S., 2018. How many species of mammals are there? J. Mammal. 99 (1), 1–14. https://doi.org/10.1093/jmammal/gyx147.

Butler, R.A., 2012. 'Penis snake' discovered in Brazil is actually a rare species of amphibian. Mongabay.Com. https://news.mongabay.com/2012/08/penis-snake-discovered-in-brazil-is-actually-a-rare-species-of-amphibian/.

Callaghan, C.T., Nakagawa, S., Cornwell, W.K., 2021. Global abundance estimates for 9,700 bird species. Proc. Natl. Acad. Sci. 118 (21) https://doi.org/10.1073/pnas.2023170118.

Campbell Grant, E.H., Miller, D.A.W., Muths, E, 2020. A Synthesis of Evidence of Drivers of Amphibian Declines. Herpetologica 76 (2), 101. https://doi.org/10.1655/0018-0831-76.2.101.

Collins, J.P., Crump, M.L., Lovejoy III, T.E., 2009. Extinction in Our Times: Global Amphibian Decline. Oxford University Press.

Crump, M.L., 2015. Eye of Newt and Toe of Frog, Adder's Fork and Lizard's Leg: The Lore and Mythology of Amphibians and Reptiles. University of Chicago Press. https://doi.org/10.7208/9780226116143.

Davies, T., Cowley, A., Bennie, J., Leyshon, C., Inger, R., Carter, H., Robinson, B., Duffy, J., Casalegno, S., Lambert, G., Gaston, K., 2018. Popular interest in vertebrates does not reflect extinction risk and is associated with bias in conservation investment. PLoS. One 13 (9), e0203694. https://doi.org/10.1371/journal.pone.0203694.

de-Oliveira-Nogueira, C.H., Souza, U.F., Machado, T.M., Figueiredo-de-Andrade, C.A., Mônico, A.T., Sazima, I., Sazima, M., Toledo, L.F., 2023. Between fruits, flowers and nectar: The extraordinary diet of the frog Xenohyla truncata. Food Webs 35, e00281. https://doi.org/10.1016/j.fooweb.2023.e00281.

Driggers, W.B., Davis, K.S., Moore, C., Carlson, J.K., 2014. New record of a goblin shark Mitsukurina owstoni (Lamniformes: Mitsukurinidae) in the western North Atlantic Ocean. Mar. Biodivers. Records 7, e96. https://doi.org/10.1017/S1755267214000876.

Duellman, W.E., Trueb, L., 1994. Biology of amphibians. JHU Press.

Ficetola, G.F., Thuiller, W., Miaud, C., 2007. Prediction and validation of the potential global distribution of a problematic alien invasive species — the American bullfrog. Divers. Distrib. 13 (4), 476–485. https://doi.org/10.1111/j.1472-4642.2007.00377.x.

Frost, D.R., 2023. Amphibian Species of the World 6.2, an Online Reference. American Museum of Natural History. https://amphibiansoftheworld.amnh.org/.

Frost, D.R., Grant, T., Faivovich, J., Bain, R.H., Haas, A., Haddad, C.F., Wheeler, W.C, 2006. The amphibian tree of life. Bull. Am. Museum Nat. Hist. 2006 (297), 1–291. https://doi.org/10.1206/0003-0090(2006)297[0001:TATOL]2.0.CO;2.

Ganapathy, A., 2019. Mobile Remote Content Feed Editing in Content Management System. Eng. Int. 7 (2), 85–94. https://doi.org/10.18034/ei.v7i2.545.

Gower, D.J., Wilkinson, M., 2005. Conservation Biology of Caecilian Amphibians. Conserv. Biol. 19 (1), 45–55. https://doi.org/10.1111/j.1523-1739.2005.00589.x.

Hillis, D.M, 1991. The phylogeny of amphibians: current knowledge and the role of cytogenetics. In: Green, D.M., Sessions, S.K. (Eds.), Amphibian Cytogenetics and Evolution. Academic Press, pp. 7–31.

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., Mueller, R.L., 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. Syst. Biol. 70 (1), 49–66. https://doi.org/10.1093/sysbio/syaa034.

Holmes, B., Strzelecki, A., Springer, S., Zieger, M., 2022. Google Trends data reveal a sharp trend: teeth and claws attract more interest than feathers, hooves or fins. Environ. Conserv. 49 (2), 65–73. https://doi.org/10.1017/S037689292200011X.

Howard, S.D., Bickford, D.P., 2014. Amphibians over the edge: silent extinction risk of Data Deficient species. Divers. Distrib. 20 (7), 837–846. https://doi.org/10.1111/ddi.12218.

Kansky, R., Knight, A.T., 2014. Key factors driving attitudes towards large mammals in conflict with humans. Biol. Conserv. 179, 93–105. https://doi.org/10.1016/j.biocon.2014.09.008.

Kotharambath, R., Reston, S.B., Divya, L., Akbarsha, M.A., Oommen, O.V., 2013. Caecilians-The limbless elusive amphibians: In the backdrop of Kerala region of the Western Ghats. Rare Animals of India. Bentham Science Publishers, pp. 3–34.

McDiarmid, R.W., 1994. Amphibian diversity and natural history: an overview. In: Heyer, R., Donnelly, M.A., Foster, M., McDiarmid, R. (Eds.), Measuring and monitoring biological diversity: Standard methods for amphibians. Smithsonian Institution, pp. 5–15.

McDiarmid, R.W., Altig, R., 1999. Tadpoles: The Biology of Anuran Larvae. University of Chicago Press.

Measey, J., Basson, A., Rebelo, A.D., Nunes, A.L., Vimercati, G., Louw, M., Mohanty, N. P., 2019. Why Have a Pet Amphibian? Insights From YouTube. Front. Ecol. Evol. 7 https://doi.org/10.3389/fevo.2019.00052.

Mi, C., Ma, L., Yang, M., Li, X., Meiri, S., Roll, U., Oskyrko, O., Pincheira-Donoso, D., Harvey, L.P., Jablonski, D., Safaei-Mahroo, B., Ghaffari, H., Smid, J., Jarvie, S., Kimani, R.M., Masroor, R., Kazemi, S.M., Nneji, L.M., Fokoua, A.M.T., Du, W., 2023. Global Protected Areas as refuges for amphibians and reptiles under climate change. Nat. Commun. 14 (1), 1389. https://doi.org/10.1038/s41467-023-36987-y.

Myburgh, P.H., 2022. Infodemiologists Beware: Recent Changes to the Google Health Trends API Result in Incomparable Data as of 1 January 2022. Int. J. Environ. Res. Public Health 19 (22), 15396. https://doi.org/10.3390/ijerph192215396.

Nyhus, P.J., 2016. Human–Wildlife Conflict and Coexistence. Annu Rev. Environ. Resour. 41 (1), 143–171. https://doi.org/10.1146/annurev-environ-110615-085634.

O'Gorman, E.J., Hone, D.W.E., 2012. Body Size Distribution of the Dinosaurs. PLoS. One 7 (12), e51925. https://doi.org/10.1371/journal.pone.0051925.

Parrott, J.C., Shepack, A., Burkart, D., LaBumbard, B., Scimè, P., Baruch, E., Catenazzi, A., 2017. Survey of Pathogenic Chytrid Fungi (Batrachochytrium dendrobatidis and B. salamandrivorans) in Salamanders from Three Mountain Ranges in Europe and the Americas. EcoHealth 14 (2), 296–302. https://doi.org/10.1007/s10393-016-1188-7.

Proulx, R., Massicotte, P., Pépino, M., 2014. Googling Trends in Conservation Biology. Conserv. Biol. 28 (1), 44–51. https://doi.org/10.1111/cobi.12131.

Reinhard, S., Kupfer, A., 2022. Maternal investment in the viviparous caecilian amphibian Typhlonectes natans (Gymnophiona: Typhlonectidae). Zool. Anz. 296, 33–36. https://doi.org/10.1016/j.jcz.2021.11.002.

Reiß, C., Olsson, L., Hoßfeld, U., 2015. The history of the oldest self-sustaining laboratory animal: 150 years of axolotl research. J. Exp. Zool. Part B: Mol. Dev. Evol. 324 (5), 393–404. https://doi.org/10.1002/jez.b.22617.

Reiss, J.O., 2002. The phylogeny of amphibian metamorphosis. Zoology 105 (2), 85–96. https://doi.org/10.1078/0944-2006-00059.

Reiss, M., 1988. Scaling of home range size: Body size, metabolic needs and ecology. Trends. Ecol. Evol. 3 (3), 85–86. https://doi.org/10.1016/0169-5347(88)90025-0.

Shamna Rajan, P., Radhakrishnan, M., Oommen, O. V., C, A., K, M. Y., Anusree, T., V, V. P., A., Vengot, R., & Kotharambath, R. (2020). The non-specificity of caecilian (amphibia: Gymnophiona) names in a vernacular language in the Indian state of Kerala. In A. B. Kumar, P. N. Krishnan, A. G. Pandurangan, C. K. Peethambaran, & C. Sureshkumar (Eds.), *Perspectives on Biodiversity of India* (Vol. 4, pp. 350–353). Centre for Innovation in Science and Social Action.

Sheehy, C., Blackburn, D., Kouete, M., Gestring, K., Laurie, K., Prechtel, A., Suarez, E., Talley, B., 2021. First record of a caecilian (order Gymnophiona, Typhlonectes natans) in Florida and in the United States. Reptiles Amphibians 28 (2), 355–357. https://doi.org/10.17161/randa.v28i2.15629.

Silva, Y.B.da S.e, Ribeiro, B.R., Thiesen Brum, F., Soares-Filho, B., Loyola, R., Michalski, F, 2018. Combined exposure to hydroelectric expansion, climate change and forest loss jeopardies amphibians in the Brazilian Amazon. Divers. Distributions 24 (8), 1072–1082. https://doi.org/10.1111/ddi.12745.

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.
Springer, S., Strzelecki, A., Zieger, M., 2023. Maximum generable interest: A universal standard for Google Trends search queries. Healthcare Analytics, 100158. https://doi.org/10.1016/j.health.2023.100158.
Springer, S., Zieger, M., Strzelecki, A., 2021. The rise of infodemiology and infoveillance during COVID-19 crisis. One Health 13 (April), 100288. https://doi.org/10.1016/j.onehlt.2021.100288.
Voss, S.R., Epperlein, H.H., Tanaka, E.M., 2009. Ambystoma mexicanum, the Axolotl: A Versatile Amphibian Model for Regeneration, Development, and Evolution Studies. Cold. Spring. Harb. Protoc. 2009 (8), pdb.emo128. https://doi.org/10.1101/pdb.emo128.
Wake, D.B., Vredenburg, V.T., 2008. Are we in the midst of the sixth mass extinction? A view from the world of amphibians. Proc. Natl. Acad. Sci. 105 (supplement_1), 11466–11473. https://doi.org/10.1073/pnas.0801921105.
Wearn, O.R., Reuman, D.C., Ewers, R.M., 2012. Extinction Debt and Windows of Conservation Opportunity in the Brazilian Amazon. Science 337 (6091), 228–232. https://doi.org/10.1126/science.1219013.
Wells, K.D., 2007. The Ecology and Behavior of Amphibians. University of Chicago Press.
Westrick, S.E., Laslo, M., Fischer, E.K., 2022. The big potential of the small frog Eleutherodactylus coqui. Elife 11. https://doi.org/10.7554/eLife.73401.
Wrenn, E., 2012. Scientists Discover New Species Of "Blind Snake" In Brazilian River That Looks Remarkably Like A Piece Of The Human Anatomy (And Stop Sniggering). DailyMail. https://www.dailymail.co.uk/sciencetech/article-2182158/Scientists-discover-new-species-blind-snake-Brazilian-river-stop-sniggering-back.html.
Yang, S., 2016. Frogs and Toads in Chinese Myths, Legends, and Folklore. Chin. Am. : Hist. Perspectives 84, 77–82.
Zieger, M., Springer, S., 2019. Thylacine and Tasmanian devil: between hope and reality – a lesson to be learnt from Google Trends search data. Aust. J. Zool. 67 (4), 221. https://doi.org/10.1071/ZO20073.
Ziermann, J.M., 2019. Diversity of Heads, Jaws, and Cephalic Muscles in Amphibians. In: Ziermann, J., Diaz Jr, R., Diogo, R. (Eds.), Heads, Jaws, and Muscles. Springer, pp. 143–170. https://doi.org/10.1007/978-3-319-93560-7_7.
Ziermann, J.M., Fratani, J., 2022. Fascinating adaptations in amphibians. Zool. Anz. 298, 131–135. https://doi.org/10.1016/j.jcz.2022.04.003.