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Taxonomic bias in amphibian research: Are researchers responding to conservation need?

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ABSTRACT

Amphibians are very diverse, widely distributed, and the most endangered class of vertebrates. As with other taxa, effective conservation of amphibians needs to be supported by detailed scientific knowledge. However, species rich and broadly distributed taxa are typically characterized by high variability in research effort. Our objective was therefore to understand which factors (ecological and cultural) have led some amphibian species to be more researched than others. We used two proxies of research effort: i) the total number of articles on Web of Science (WoS) that mention the scientific name (or synonyms) of each species, and; ii) the number of conservation science articles on WoS that mention the scientific name (or synonyms) of each species. These measures were used as dependent variables in zero hurdle regression models with the aim of identifying the most important factors driving species-level knowledge production. Well researched species (generally, and for conservation) tend to have a longer history of scientific research, come from countries with high scientific capacity, have large body size, and to be present in man-made habitats. Endangered species tend to be less researched, generally and for conservation, possibly because they are often more difficult to study: many endangered amphibians are restricted to small, fragmented and remote habitats in countries with low scientific capacity. We conclude with a discussion of how taxonomic biases in research effort on amphibians can be addressed given the limited funds available for conservation research.

1. Introduction

Amphibians are among the most endangered vertebrate groups (Ceballos et al., 2015; Ripple et al., 2019). Several factors have been identified as responsible for amphibian population die-offs across the world - including pollution, introduction of exotic species and the infectious pathogens such as chytrids, ranaviruses, Perkinsea and trematodes - with habitat loss identified as the most high-profile threat (Berger et al., 2016; DiRenzo & Grant, 2019; Mann, Hyne, Choung, & Wilson, 2009; Scheele et al., 2019; Wake & Vredenburg, 2008). The way an amphibian responds to threats is linked to its biology, ecology and evolution (Lips, 2016) and scientific knowledge about a species is therefore essential to formulate effective conservation actions (Arlettaz et al., 2010; Canessa, Spitzen-van der Sluijs, Martel, & Pasmans, 2019; Lewis et al., 2019).

Despite the importance of scientific knowledge for conservation, many amphibian species are very poorly known (Scheele et al., 2019). Indeed, the research effort expended on different species is extremely patchy, with a few well studied species and many species that are almost unknown to science (Clark & May, 2002; Fleming & Bateman, 2016; Murray, Green, Williams, Burfield, & Brooke, 2015). The reasons for this patchiness are complex, and may include geographical variation in the allocation of financial resources for research, spatial and temporal variation in research capacity, and the intrinsic characteristics of a species that makes it an 'appropriate' research target (Clark & May, 2002). In this context, we hypothesise that species that are already well-known scientifically (both generally and by a given individual or research group), of cultural importance (e.g. threatened, invasive, economically important), and/or have traits that make them convenient to study (e.g. large, conspicuous and diurnal) will be subject to higher levels of research effort.

Here, we test the above hypothesis by: (i) quantifying research

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effort (both general and conservation-related) for all extant amphibian species based on bibliometric analysis, and; (ii) statistically identifying the main factors responsible for the observed biases in the scientific knowledge production. In other words, we seek to understand why some amphibian species are more researched than others and assess whether conservation researchers are adequately responding to perceived conservation need.

2. Methods

2.1. Global list of amphibian species

We collected a list the names of all known extant amphibian species from the online platform *Amphibian Species of the World* (www.research.amnh.org/vz/herpetology/amphibia/). Name data was retrieved using the *defrostR* package, within the R statistical environment, in February 2018. Our final dataset included 7668 species, distributed over three Orders (Anura: 6752 species, Caudata: 711 species, and Gymnophiona: 205 species). In addition to the currently accepted scientific name for each amphibian species, we also retrieved all known synonyms.

2.2. Quantification of scientific knowledge production

Based on the assumption that more intensively studied species will be the subject of a greater number of publications, we calculated as metric of research effort for every amphibian species on our list the number of conservation-themed articles indexed in WoS platform (www.webofknowledge.com) that mention its scientific name (or any of its synonym) in the title, abstract or keywords. This metric was calculated by filtering the search results to include on articles that appear in Journals in WoS's "Biodiversity and Conservation" thematic area. We perform this filtering in order to rescue works that have relevant implications for conservation.

Each amphibian species in our database was the subject of a unique search using currently accepted scientific name of the species and any synonyms (e.g. "*Hylodes gryllus*" OR "*Rana dorsalis*"). Including synonyms is an important strategy to maximize data capture and to reduce biases caused by species that have undergone one or more taxonomic revisions (Correia et al., 2018; Guala, 2016). Searches were manually conducted between March 2018 and May 2018, and considered documents registered between 1945 and 2018. We used the WoS' general search engine, that consults all databases indexed to WoS.

Our metric of research effort is conservative in that it does not count all potentially relevant articles. First, it excludes articles that only mention the common name of a species in the title, abstract or keywords. Nevertheless, we considered that the slight loss of data from excluding common names was outweighed by the reduced biases and increased replicability of using scientific names and synonyms (Correia et al., 2018). Second, it excludes articles where information on some species appears in the main text of an article, but not in the title, abstract or keywords. Our metric therefore only captures articles where the species was the focus or a major element of the research, since this will typically result in a mention in the title, abstract or keywords.

2.3. Explanatory variables

We considered a range of biocultural traits (explanatory variables) that may influence a scientists' decision to study a particular amphibian species. While some of the factors potentially affecting this decision (e.g. research funding) cannot be easily assessed for the majority of species, many factors are quantifiable for most species. Specifically, the following variables were considered for analysis:

(i) *Threat status*: researchers may be influenced by conservation need, with more research effort being directed to highly threatened species. This association should be most apparent for conservation research production. Conversely, most threatened species have small populations and restricted distributions, so may be less practical to study. The threat status of each species was retrieved from the IUCN Red List (www.iucnredlist.org). We excluded species that were classified as 'DD' (*Data Deficient*), 'EX' (*Extinct*) and 'EW' (*Extinct in the Wild*), since, by definition, for these species biological information is lacking or cannot be studied. We placed the remaining species into three categories: 'LC' (*Least Concern*), 'NT' (*Near Threatened*), and *Threatened*, which included 'VU' (*Vulnerable*), 'EN' (*Endangered*) and 'CR' (*Critically Endangered*);

(ii) *Research history* (based in the year of the first publication for each species in the platform): we theorized that, due to the iterative nature of scientific research, species that were the subject of previous research would be more likely to be the target of future research;

(iii) *Scientific capacity*: based on the % contribution of range countries to global publications in the environmental sciences (1996–2017), using data from Scimago (www.scimago.com). We reasoned that species present in countries with higher environmental science capacity would be more likely to be studied, and for those studies to be published;

(iv) *Presence in anthropic environments*: we obtained from the IUCN Red List website information on amphibian species that occur in man-made habitats, both aquatic and terrestrial. Our prediction was that species occurring in anthropogenic areas would be more researched because they can often be found close to research centers;

(v) *Body size*: there is a large body of literature that suggests that larger species of vertebrates generate more public interest (e.g. Frynta, Šimková, Lišková, & Landová, 2013; Correia, Jepson, Malhado, & Ladle, 2016; Roll et al., 2016), and may have more intrinsic appeal to researchers. Larger species may also be easier to locate and sample in the field, and may be more attractive for leveraging conservation funding. We retrieved amphibians' body size information (in millimeter) from AmphiBIO database (Oliveira, São-Pedro, Santos-Barrera, Penone, & Costa, 2017).

After removing extinct/data deficient species and those with missing data points, our final dataset used in the model contained 3468 species.

2.4. Data analysis

Because many species were not associated with even a single record in the Web of Science, our response variables contained many zeros. To account for this fact, we used a zero-inflated hurdle model. This model has two components: a hurdle component, that takes into consideration the zero counts, and a truncated count component for positive counts. To perform this analysis, we used the *pscl* R package. The variable 'research history' was, necessarily, not included in the zero hurdle models. Since several explanatory variables in our study may influence scientific research for certain amphibian species, a single model will not be able to provide an accurate representation of the current scenario. Therefore, we used a multi-model inference approach to calculate the effect of each explanatory variable on scientific research (Burnham & Anderson, 2004; Burnham, Anderson, & Huyvaert, 2011). We evaluated all possible model combinations taking into consideration the list of explanatory variables considered in this study, and identified the set of most adequate models according to AIC corrected for small sample size (AICc). We then carried out a model averaging process where using all models which had a delta AIC of less than 5 in relation to the best model (i.e. that with the lowest AICc score). All continuous explanatory variables were standardized by subtracting the variable mean to each value and dividing it the variable standard deviation before inclusion in the models. This approach allows a direct comparison of the estimated effects of each variable on research effort (Schielzeth, 2010).

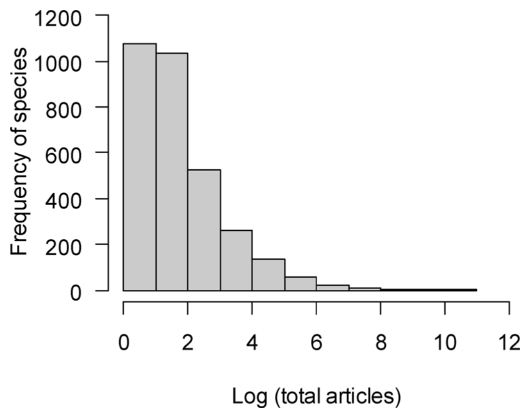

Fig. 1. Frequency distribution of amphibian species per number of articles (transformed in log) from Web of Science. Publications cover the period between 1945 and February 2018.

3. Results

From 3468 amphibian species of our dataset, 334 species (310 anurans, 18 salamanders and 6 caecilians) were not associated with any articles retrieved from WoS, from 1945 to February 2018. A total of 3134 amphibian species and 209,098 articles were retrieved. For 2720 anuran species, 177,510 articles were registered. For 361 salamander species, 30,802 articles and for 53 caecilians, 786 records were obtained. In a general scale, regarding to the distribution of number of articles, only 24 species had more than 1000 articles registered in the platform. Of these species, 9 had above 5000 articles, and 5 above 10,000. Among the species that had less than 1000 records, 13 had between 500 and 950 articles, 42 between 200 and 490, and 70 had between 100 and 190. Thus, most of the species studied (95.7 %) had below 100 WoS records (Fig. 1). The 10 most studied species including all WoS areas were classified as Least Concern the IUCN. African clawed frog (*Xenopus laevis*) had the highest number of articles, with 46,021 documents (Figure S1a). Among the 10 most studied endangered species for all areas, axolotl (*Ambystoma mexicanum*) was the most studied, with 2228 articles (Figure S1b). The Iberian ribbed newt (*Pleurodeles waltl*) had 1515 articles, and was the most researched among species classified as Near Threatened.

Filtering searches for “Biodiversity and Conservation” thematic area, we retrieved 18,824 articles about 2214 species. We recovered a total of 1926 anuran species (14,873 articles), 264 salamander species (3893 articles), and 24 caecilian species (58 articles). The 10 most studied species were again all classified as Least Concern. The common toad (*Bufo bufo*) was the most studied species, with 1395 articles (Fig. 2a). Among threatened species, the mountain yellow-legged frog (*Rana muscosa*) had the greatest number (90) of conservation articles (Fig. 2b). Of the species classified as Near Threatened according to IUCN criteria, the hellbender (*Cryptobranchus alleganiensis*) was the most studied (86 articles).

Our models revealed a very consistent pattern of associations between biocultural traits and research effort (Fig. 3). As predicted, larger amphibian species that occur in countries with higher scientific capacity were more frequently the subjects of research. Research volume also was significantly associated with species with a longer history of research. Perhaps surprisingly, more threatened species were less likely to be the subject of articles in conservation orientated journals.

4. Discussion

Most amphibians are not well studied: more than 95 % of the amphibian species in our database were associated with between zero and 100 articles. Threatened species were more likely to be associated with no articles or a low volume of articles (Fig. 3). These results do not support the argument that the global extinction risk of a species is an important driver of scientific research effort (Jarić et al., 2019; Zhang, Hu, Zhang, & Li, 2015), regarding amphibians. Thus, in general terms we can tentatively conclude that conservation need is often outweighed by other, perhaps more practical, factors when researchers are deciding which species would be the most appropriate subject of a particular scientific study. One of these practical concerns could be the local conservation need, e.g. a nationally threatened species that is not threatened at the global scale considered by the IUCN. Another important concern are factors that might increase or decrease the resources (financial and human) needed to successfully conduct a field or lab-based research project. For example, easy access to a conveniently located and abundant wild population will considerably reduce the resources needed for field-based studies. Similarly, species that have characteristics that make them easier to collect and observe (e.g. large body size, diurnal behaviour patterns) may have reduced resource requirements. Conversely, species that are conservation priorities will tend to be associated with increasing resource requirements for research since extinction risk is a reflection of population decline and fragmentation, range reduction, and rarity (Hartley & Kunin, 2003). Many endangered species are also endemic, and are restricted to remote, poorly accessible regions (Howard et al., 2015; Xing, Zhang, Fan, & Zhao, 2016) that are unlikely to have good research infrastructure.

Resource requirements for scientific studies increase enormously when researchers need to travel internationally, meaning that most field-based studies are conducted in the researcher’s country of residence. This explains why amphibian species that are resident in countries with high capacity in environmental science are more researched, both generally and also for conservation. Indeed, European and North American anurans included some of the most studied species with conservation-related focus. Financial resource restrictions on amphibian research may be particularly severe: recent research suggests that amphibians, even if threatened, receive less investment for conservation (Davies et al., 2018).

‘Researchability’ is also predicted to vary with how much scientific knowledge already exists about a species (dos Santos et al., in press; Engemann et al., 2015), since science is an iterative process that constantly builds on the results of previous studies. This is reflected in the positive association between years since first publication and research volume. Researchers working on a poorly known endangered species may therefore require a much greater research effort to generate data of sufficient interest and novelty for an international journal. If such publications are a significant factor in career advancement, this may lead to risk-averseness among conservation researchers (Wilson, McBride, Bode, & Possingham, 2006) and their students. Indeed, Tim Caro recently observed a growing tendency of graduate students studying animal behaviour to work on common species that are considered, in some way, to be similar to a species of conservation concern (Caro, 2007). Caro attributes this trend to the fact that rare species are “difficult to locate and result in small sample sizes” (Caro, 2007) - presumably leading to studies that are difficult to publish. In summary, our results broadly support the notion that there may often be conflict between what needs to be studied (for conservation) and the career aspirations of researchers.

Although endangered amphibian species in general have notably fewer articles than non-endangered species, there are some interesting exceptions. The axolotl (*Ambystoma mexicanum*), for example, is currently declining due to anthropic activities (Ayala, Ramos, Merlo, & Zambrano, 2018) but is well represented in the scientific literature. This is due to the fact that the axolotl is commonly used as a model organism for development science because of its high regenerative capacity (McCusker, Diaz-Castillo, Sosnik, Phan, & Gardiner, 2016; Nowoshilow et al., 2018). Moreover, some well-studied non-threatened species on our list may soon become threatened. This may be the case for both the common toad (*Bufo bufo*) and common frog (*Rana temporaria*). These species presented 1395 and 831 articles related to conservation,

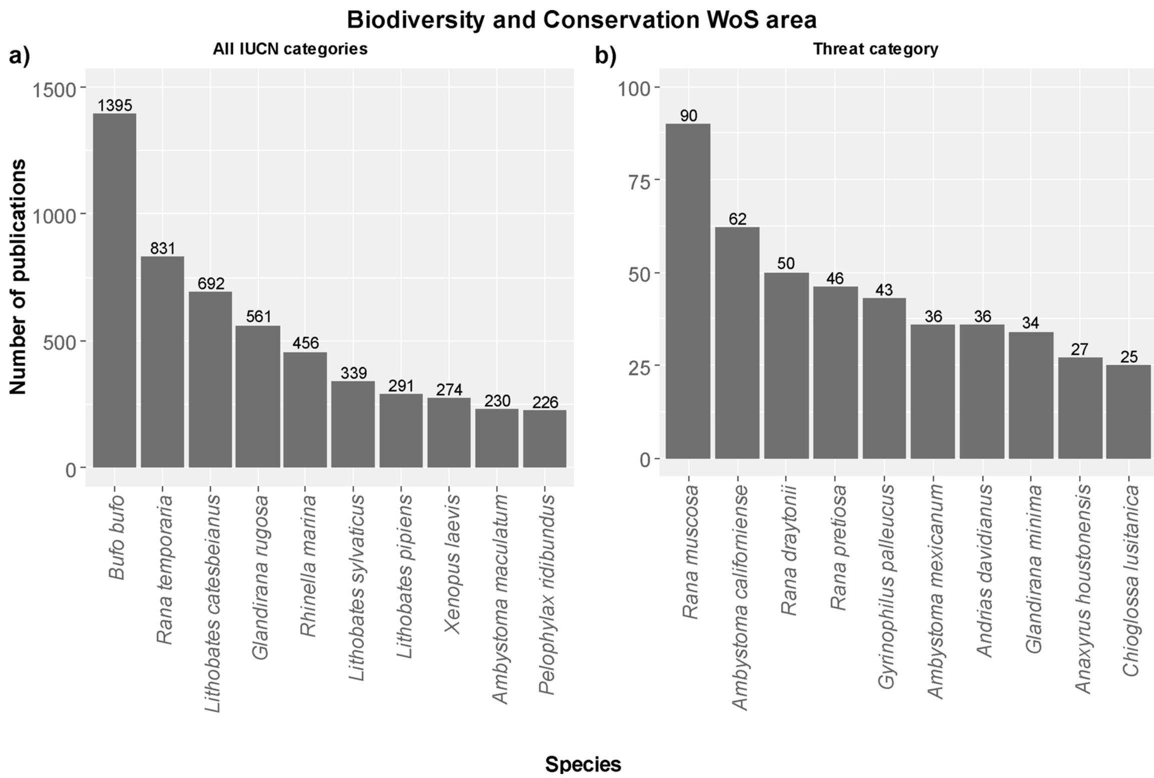

Fig. 2. The 10 most studied amphibian species in "Biodiversity and Conservation" WoS thematic area, considering all categories (a) and only threat level (b) according IUCN Red List. These 10 most studied species for all IUCN categories were classified as Least Concern.

respectively, and 13,025 and 10,693 articles for all thematic areas. Although widely distributed, classified as Least Concern and with stable trends in IUCN, common toad populations have been suffering local declines due to pollution, agricultural activities and road mortalities (Dmowski, Rossa, Kowalska, & Krasnodebska-Ostrega, 2015; Guillot et al., 2016; Kaczmarski, Kolenda, Rozenblut-Kościsty, & Sośnicka, 2016; Salazar, Montgomery, Thresher, & Macdonald, 2016). In addition, this species is victim to *Bufonid herpesvirus 1*, a severe dermatitis which has caused mortality of these organisms in Switzerland (Origgi et al., 2018). Likewise, the common frog, though relatively abundant in Europe, is susceptible to *Ranavirus* and *Batrachochytrium dendrobatidis*, that have already been implicated in the extinction of several amphibian species (Bayley, Hill, & Feist, 2013; Price et al., 2015). As pointed out by Petrovan and Schmidt (2016), common toads and common frogs have suffered considerable declines in the United Kingdom and Switzerland, even though they are widespread species. These authors highlight the need for more research into common amphibian abundance trends rather than focusing only on the most endangered species, as the decline of common species can drastically affect ecosystem functions. This fact may reflect the reason why our research has presented a larger number of articles for these and others widespread and non-threatened species according the IUCN, thus perhaps demonstrating an interest of researchers in a threat level locally experienced by the species.

The American bullfrog (*Lithobates catesbeianus*) was the second most researched species, possibly reflecting its commercial importance as a food species for human consumption and its use as a biological control agent (Dias et al., 2009; Mendoza et al., 2012). This species is also invasive, having been introduced into many regions around the globe (Mikula, 2015; Silva, Reis, Feio, & Filho, 2009). Similarly, the Japanese wrinkled frog (*Glandirana rugosa*), which was also highly targeted by researchers, was introduced on the Hawaii Island as a biological control of pests, presenting an impact on the local fauna, specially to endemic organisms (Kleeck & Holland, 2018). Something similar happened with the cane toad (*Rhinella marina*), a highly invasive species, causing many native organisms to decline (Griffiths & McKay, 2007; Tingley & Shine, 2011; Ward-Fear, Greenlees, & Shine, 2016). These cases demonstrate that even though these species are not considered threatened, studying them can contribute positively to conservation.

Iberian ribbed newt (*Pleurodeles waltl*), despite having shown a low number of works (34 articles), was among the most researched species in the 'Near Threatened' category. This species endemic at Iberian Peninsula and Morocco (Beukema et al., 2013) presented a significant decline highly due to the habitat loss, invasive species and mortality on the roads (Montori, Llórente, Santos, & Carretero, 2002). These aspects can make *P. waltl* attractive for conservation research, although the fact that it is an endemic and declining species can make it less accessible. The mountain yellow-legged frog (*Rana muscosa*) was the most studied threatened species, although it was only associated with 90 documents in our database. In comparison, the common toad (*Bufo bufo*), which was the most studied species for conservation production, had 1395 articles in that area. The (relatively) high conservation output for *R. muscosa* can be explained by its presence in a high scientific capacity country (the USA), even though it is physically small and is restricted to the state of California. Its populations have declined rapidly in recent decades due to a combination of predation by introduced fish species, exposure to pesticides and chytridiomycosis infection (Poorten, Knapp, & Rosenblum, 2017; Rachowicz & Briggs, 2007; Sparling et al., 2015). Despite these factors that have led *R. muscosa* to the threatened level, research on this species combined with practical conservation actions has favoured its population increase. One example of such actions is the removal of introduced non-native fish species, which has enable the recovery of anuran populations of this and other species (Knapp et al., 2016; Poorten et al., 2017). Furthermore, scientific research on these organisms can yield valuable results in several aspects. Studying their abundance, for example, has allowed to detect changes in the abundance of species that are affected by several life stages of these frogs, such as aquatic macroinvertebrates. In addition, because it occurs in

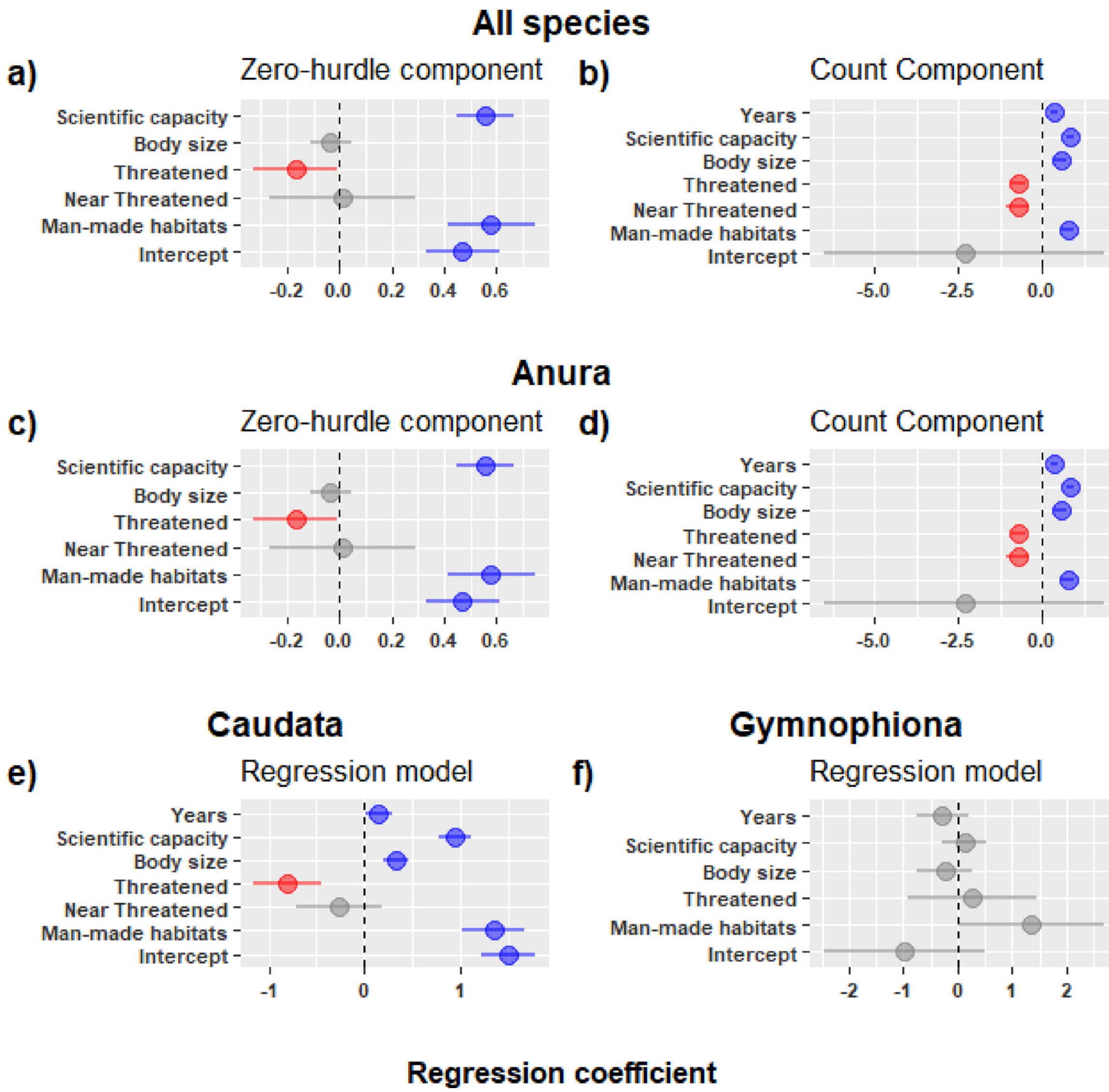

Fig. 3. Coefficient estimates (95 % confidence intervals), showing direction and magnitude of effects of explanatory variables on conservation scientific production for all amphibian species, for zero and count Hurdle models (a and b). We perform analysis for each amphibian order separately (c–f), but for Caudata and Gymnophiona, which had a very low amount of zeros, we make common regression model (blue and red symbols represent positive and negative effects, respectively; grey represents no effect).
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widely protected habitats, i.e., unaltered by development, *R. muscosa* becomes ideal as a model of study on amphibian decline due to causes that are not related to habitat loss. *Rana muscosa* was the first anuran species found to host anti-Bd bacteria on the skin, thus contributing to the control of Bd (*Batrachochytrium dendrobatidis*) outbreaks in persistent populations, and encouraging research into this innate immunity mechanism in other anuran species (Reinke, Miller, & Janzen, 2019).

In general, our findings were able to present an overview of the current scenario of the research effort directions for amphibians. However, from our discoveries it is also possible to identify others taxa which have ecological and/or evolutionary traits similar to amphibians and that may present resembling patterns of research effort. Similarly, it is also possible to investigate whether the research effort for these others taxa would follow different patterns from those of amphibians, and how this would relate to their threat levels and conservation efforts. In addition, Davies et al. (2018) pointed out that public interest in endangered species of birds and mammals has motivated conservationist investments. On the other hand, threatened species of amphibians, reptiles and fishes, which are comparatively less known to the public, receive smaller conservation investments (Davies et al., 2018). Therefore, identifying potentially emblematic amphibian species from our outcomes, and promoting them in conservation programs can contribute to the preservation of both the amphibian community and other biological groups.

5. Conclusions

As a taxonomic group, Amphibians are among the most threatened vertebrates on Earth due to the impact of man-made climate change, habitat loss and fragmentation, pollution and emerging diseases (Collins, Crump, & Lovejoy III, 2009; Sodhi et al., 2008). Conserving the world's amphibian species in the face of these threats requires: i) robust scientific knowledge, and; ii) organizations and individuals with the capacity to use this knowledge to mount effective conservation interventions: so-called 'evidence-based conservation' (Sutherland, Pullin, Dolman, & Knight, 2004). Our study demonstrates that one of the barriers to evidence-based conservation of amphibians is the lack of knowledge about many species, especially those identified as being at risk of extinction. However, although scientific knowledge is essential, by itself it is not a sufficient measure for a species to be conserved. In this context, an adequate communication between research and public actions is highly necessary for efficient conservation strategies may be perform (Arlettaz et al., 2010; Canessa et al., 2019; Grant, Muths, Schmidt, & Petrovan, 2019; Lewis et al., 2019). For this to occur, it is essential that public initiatives consider the generating causes of the decline of species, as climate change, which are responsible for several losses of amphibians (Winter et al., 2016). Nevertheless, our analysis also suggests some possible strategies to reduce the biases in research effort. Firstly, dedicated research funding streams targeted at endangered species may be effective at counter-balancing the advantages of working on more abundant species. In addition, as indicated by Winter et al. (2016), scientists should also focus on those under-represented species. In this context, the EDGE of Existence Programme, of Zoological Society of London, which aims to awareness and raise funds to conserve unique and threatened species, is an important example of an initiative that can motivate research on such species. Secondly, there is enormous scope for increasing international collaboration for research on endangered amphibians, with the aim of reducing the negative impact of low environmental science capacity in some developing countries. Finally, editors and reviewers for conservation journals could adopt a more critical attitude to studies that use abundant species as proxies for ecologically similar endangered species, foregrounding the value of research on rarely studied amphibians where the conservation need is the greatest.

Declarations of interest

None.

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