UNIVERSIDADE FEDERAL DE ALAGOAS
INSTITUTO DE CIÊNCIAS BIOLÓGICAS E DA SAÚDE
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QUAL O NOSSO INTERESSE NOS ANFÍBIOS? UMA ABORDAGEM CIENCIOMÉTRICA

Maceió - Alagoas

Abril/2019

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Dissertação apresentada ao Programa de Pós-Graduação em Diversidade Biológica e Conservação nos Trópicos do Instituto de Ciências Biológicas e da Saúde, Universidade Federal de Alagoas, como requisito para obtenção do grau de mestre em Ciências Biológicas na área de Biodiversidade.

Orientadora: Tamí Mott
Coorientadores: Marcos Vinícius Carneiro Vital
Richard James Ladle

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Qual o nosso interesse nos anfíbios? Uma abordagem cienciométrica

Dissertação apresentada ao Programa de Pós-Graduação em Diversidade Biológica e Conservação nos Trópicos, Instituto de Ciências Biológicas e da Saúde da Universidade Federal de Alagoas, como requisito para obtenção do título de Mestre em CIÊNCIAS BIOLÓGICAS na área da Biodiversidade.

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“Mestre não é quem sempre ensina, mas quem de repente aprende.”

Guimarães Rosa, em *Grande Sertão: Veredas*.

Resumo

Atividades antrópicas contribuem de forma crescente para o declínio e a extinção de muitas espécies em todo o mundo. Assim, para conservar espécies ameaçadas, é essencial ter conhecimento biológico, ecológico e cultural suficientes para selecionar, delinear e implementar intervenções conservacionistas apropriadas. No entanto, o esforço de pesquisa para as diferentes espécies é extremamente desigual devido a vários fatores intrínsecos, populacionais e socioeconômicos. Neste estudo, nós quantificamos o conhecimento científico geral e sobre conservação das espécies de anfíbios do mundo inteiro, e identificamos os fatores que estão mais fortemente associados com a alta e a baixa produção de conhecimento. Adotamos uma abordagem conhecida como Hurdle Model para avaliar os fatores que influenciam a produção científica sobre os anfíbios. Nossos resultados demonstram que, geralmente, as espécies ameaçadas são bem menos pesquisadas do que aquelas que não correm risco de extinção. Por sofrerem com a fragmentação de seus hábitats, serem endêmicas e viverem em áreas menores, as espécies ameaçadas podem ser menos acessíveis aos pesquisadores. Enquanto isso, espécies mais estudadas têm vários usos para cientistas e o público geral. Além disso, os cientistas tendem a estudar espécies descritas há mais tempo, assim como aquelas que ocorrem em países com maior capacidade científica e em hábitats artificiais, com desenvolvimento larval, maior frequência reprodutiva e maior tamanho corporal. Este padrão foi observado na produção científica geral e sobre conservação de anfíbios. Uma vez que estudos anteriores demonstraram que espécies ameaçadas de mamíferos e aves são mais interessantes para o público e para os cientistas, e têm maiores investimentos em conservação, programas conservacionistas podem contribuir para uma maior visibilidade das espécies de anfíbios ameaçadas de extinção.

Palavras-chave: Biodiversidade, Conservação, Esforço de pesquisa, Conhecimento científico, Tendências de pesquisa.

Abstract

Anthropic activities contribute increasingly to the decline and extinction of many species around the globe. Thus, to conserve threatened species, it is essential to have sufficient biological, ecological and cultural knowledge to support the choice, design and implementation of appropriate conservation interventions. However, research efforts on different species are extremely patchy due to several intrinsic, populational and socio-economic factors. Here, we quantify the general and conservation scientific knowledges of the world's amphibian species, and identify the factors that are most strongly associated with high and low levels of knowledge production. We adopt a hurdle regression model to independently evaluate the factors that influence the scientific production on amphibians. Our findings demonstrate that generally the endangered species are less researched than those that are not at extinction risk. Because threatened species occur in small and fragmented habitats, and are endemics they may be less accessible to researchers. Meanwhile, more studied species have several uses for scientists and the general public. In addition, scientists tend targeting older described species, and species that occur in countries with higher scientific capacity, and in artificial habitats, with larval development, higher reproductive frequency and greater body size. This was observed in general and conservation scientific production on amphibians. Since that previously studies demonstrated that threatened species of mammalian and birds are more interesting to the public and to scientists, and have greater investments in conservation, conservationist programs could contribute to increase the visibility of endangered amphibian species.

Key words: Biodiversity, Conservation, Research effort, Scientific knowledge, Research trend.

SUMÁRIO

1. APRESENTAÇÃO

Os anfíbios compõem um grupo bastante diversificado, contando atualmente com 7.969 espécies conhecidas no mundo inteiro (FROST, 2019). Esses organismos são eficientes organismos-modelo em diversos estudos biológicos (LIU et al., 2016). Um importante motivo que tornam os anfíbios atrativos para a pesquisa é a sua sensibilidade às variações ambientais, por serem ectotérmicos, possuírem alta permeabilidade cutânea e tamanho reduzido. Assim, essa sensibilidade às variações do ambiente possibilita aos anfíbios serem indicadores das condições do meio (TEJEDO et al., 2010). Os anfíbios também são amplamente utilizados com finalidades medicinais e para o ensino (ROURKE, 2007). Entretanto, várias populações desse grupo vêm declinando em muitas regiões do mundo. Isto se deve a diversos fatores, dentre os quais se destacam a perda de hábitat e a sobre-exploração humana (BOWER et al., 2017; TURVEY et al., 2018).

Diante do atual cenário conhecido como “crise da biodiversidade”, é fundamental avaliar o progresso da pesquisa nesta área (STORK & ASTRIN, 2014). Esta é uma medida essencial para compreender aspectos sobre a produtividade por subárea e espécie, assim como nas diferentes regiões (LIU et al., 2011; ALI & KUMARI, 2018). Desta forma, torna-se possível explorar a produção científica sobre a biodiversidade e gerenciar medidas conservacionistas (STORK & ASTRIN, 2014).

Uma forma eficiente de se explorar o conhecimento científico sobre os seres vivos compreende o uso das técnicas cienciométricas. A cienciometria tem sido de grande utilidade para a quantificação de diferentes áreas da ciência. Este campo permite estudar tendências no conhecimento científico, além de fazer predições e investigar padrões temporais na pesquisa, dentre outros aspectos quantitativos (SPINAK, 1998). Um exemplo de aplicação da cienciometria é o seu uso no estudo da produção científica sobre a ecologia, biodiversidade e biologia da conservação (NOBIS & WOHLGEMUTH, 2004; ALI & KUMARI, 2018). Assim sendo, utilizar técnicas cienciométricas para medir o conhecimento científico sobre os anfíbios permite visualizar um panorama das tendências na pesquisa sobre o grupo. Consequentemente, este estudo pode demonstrar quais aspectos e espécies necessitam de maior foco, auxiliando desta forma as estratégias de conservação.

Esta dissertação inicia-se com um capítulo de revisão de literatura, onde serão abordados os principais aspectos teóricos da literatura científica sobre os temas deste trabalho. O capítulo a seguir é o principal deste trabalho, e contém um artigo formatado conforme as normas do periódico *Biological Conservation*, que se adequa aos objetivos e temáticas abordados neste estudo. Por fim, serão apresentadas as conclusões gerais resultantes desta dissertação.

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2. REVISÃO DE LITERATURA

2.1. Anfíbios e a pesquisa científica

Os organismos da classe Amphibia surgiram no período Devoniano, há aproximadamente 350 milhões de anos atrás, e foram os primeiros vertebrados terrestres (ZHANG, 2011). Atualmente, existe um total de 7.969 espécies descritas de anfíbios, que são classificadas em três ordens: Anura (sapos, rãs e pererecas), Caudata (salamandras) e Gymnophiona (cecílias) (FROST, 2019). Estes animais se distribuem em várias regiões do globo, e são encontrados numa grande variedade de hábitats, de modo que suas espécies podem ser arbóreas, fossoriais, terrestres, ou de ambientes aquáticos (MCDIARMID, 1994; BUCKLEY & JETZ, 2007; VASCONCELOS et al., 2012; KOO et al., 2013).

Muitas espécies de anfíbios destacam-se quanto à sua utilização pelos seres humanos. Um exemplo disto são aquelas espécies que representam modelos ideais tanto para estudos médicos, como para a investigação herpetológica (ROURKE, 2007). *Xenopus laevis*, por exemplo, que é popularmente conhecida como rã africana de unhas, é muito utilizada em experimentos na área médica (HARLAND & GRAINGER, 2011). Outro exemplo é *Bufo bufo* (sapo comum europeu), que é uma espécie visada para o ensino (HITCHINGS & BEEBEE, 1998). A exploração dos anfíbios pelos humanos também inclui o uso desses organismos como controle biológico de pragas, no comércio de animais domésticos, ou ainda como recurso alimentar humano (LEVER, 2001; KLEECK & HOLLAND, 2018). Assim, a sobre-exploração dos anfíbios é uma das causas de extinção de muitas espécies do grupo. Outros fatores que também contribuem para a extinção dessas espécies são a perda de hábitat, poluentes, espécies invasoras e doenças emergentes (WAKE & VREDENBURG, 2008). Há espécies que estão ameaçadas por serem removidas em grandes quantidades de seus hábitats naturais para o uso humano (BOWER et al., 2017; TURVEY et al., 2018). Esse foi o caso de *Rana draytonii*, uma espécie excessivamente consumida como alimento nos Estados Unidos, o que provocou um drástico declínio de suas populações. Esta espécie é atualmente considerada como vulnerável na Lista Vermelha da IUCN (JENSEN & CAMP, 2003; DUAN et al., 2015; BACKLIN et al., 2018).

O declínio de muitas espécies de anfíbios tem se acentuado nos últimos anos, sendo uma das principais causas as atividades antrópicas (ZIPPEL et al., 2011; ARNTZEN et al., 2017). Assim sendo, é fundamental tomar providências para conservar esses organismos. Tais medidas requerem a realização de pesquisas aplicadas à conservação (HADDAD, 2013). Neste contexto, é fundamental ressaltar que diversos fatores podem motivar pesquisas sobre estratégias de conservação de espécies. Dentre esses fatores, pode-se mencionar o tamanho corporal da espécie, assim como aspectos socioeconômicos (JARIĆ et al., 2019). DAVIES et al. (2018), por exemplo, demonstraram que o interesse público em determinadas espécies de aves e mamíferos tem motivado os investimentos conservacionistas. Entretanto, para as espécies de peixes, répteis e anfíbios que são menos conhecidas pelo público, existem menos investimentos de conservação. Deste modo, os investimentos em conservação também podem estar influenciando a pesquisa científica sobre as espécies.

Em síntese, diversos fatores podem influenciar a pesquisa sobre uma determinada espécie (FLEMING & BATEMAN, 2016). E uma forma eficiente de identificar os potenciais fatores que motivam a pesquisa científica é a utilização dos métodos cienciométricos. Deste modo, além de se investigar as tendências na pesquisa sobre a biodiversidade, é possível identificar as variáveis geradoras dos vieses e tomar as medidas propícias para conservação (LIU et al., 2011; STORK & ASTRIN, 2014).

2.2. Quantificando o conhecimento

Avaliar quantitativamente as mais diversas áreas do conhecimento é um esforço que remonta ao início do século XX. O primeiro trabalho de que se tem registro nesse campo é o de COLES & EALES (1917). Esses autores utilizaram informações de coleções bibliográficas sobre anatomia comparada contidas em bibliotecas europeias para investigar os táxons mais estudados ao longo do tempo. Além disso, eles também compararam a produção científica sobre esse tema entre diferentes países da Europa (FONSECA, 1986). Este trabalho foi o pioneiro numa área conhecida inicialmente como *bibliografia estatística*, onde se buscava informações de materiais bibliográficos para compreender quantitativamente um determinado tema. Em 1934, no livro *Traité de documentatión*, Paul Otlet se referiu a esse campo usando o termo *bibliometria*, que passou a ser amplamente empregado no final da década de 1960. A partir de então, os pesquisadores passaram a reconhecer cada vez mais a importância de estudos quantitativos para mensurar com eficiência o conhecimento contido em livros de bibliotecas (RAVICHANDRA, 1986). A *cienciometria* foi criada em 1965 pelo historiador Derek Price, e utiliza técnicas matemáticas e estatísticas para quantificar o conhecimento científico (PRICE, 1965; SPINAK, 1998).

Em 1979, Otto Nacke, na Alemanha, propôs um novo termo: *informetria*, um campo que avalia quantitativamente informações provenientes de qualquer tipo de fonte, como livros, artigos científicos, dentre outras. A primeira Conferência de Bibliometria, Cienciometria e Informetria foi realizada em 1989, na cidade de London (Canadá). Discussões sobre as características dessas três áreas resultaram na inclusão da bibliometria e da cienciometria como subáreas da informetria (TAGUE-SUTCKIFFE, 1994).

ALMIND & INGWERSEN (1997) destacaram a importância de se utilizar as técnicas bibliométricas para avaliar quantitativamente informações obtidas da internet, com o objetivo de se explorar dimensões sociais e culturais. Esta nova subárea da informetria, a *webometria*, surgiu numa época em que, mesmo a internet não sendo tão generalizada como seria alguns anos depois, era possível enxergá-la como uma potencial fonte para estudos das tendências sociais (ALMIND & INGWERSEN, 1997; BJÖRNEBORN, 2002).

O avanço das técnicas computacionais, além de ter sido fundamental para o desenvolvimento dos métodos webométricos, também tem garantido um notável progresso para a cienciometria (RAZERA, 2016). Estas ferramentas passaram a ganhar destaque no meio acadêmico após o *Institute for Scientific Information* (ISI), criado em 1960 nos Estados Unidos, ter vendido sua base de dados para várias instituições de ensino superior. Essa plataforma abrange diversos periódicos científicos, que atualmente podem ser acessados na plataforma online *Web of Science* (NOBIS & WOHLGEMUTH, 2004). Além da Web of Science, outras plataformas online, como *Scopus* e *Google Scholar*, também são muito utilizadas em estudos cienciométricos para o acesso e avaliação das publicações científicas (URBIZAGASTEGUI, 2016).

As técnicas computacionais tiveram um grande desenvolvimento ao longo dos anos 1970 e 1980. Nesse período, os cientistas passaram a usar cada vez mais computadores como ferramentas para o armazenamento e processamento de dados. Em 1981, esse avanço resultou no surgimento do primeiro computador pessoal. Nos anos seguintes, modelos cada vez mais elaborados de computadores pessoais foram lançados. Contudo, nessa época essas máquinas ainda não eram muito acessíveis (GILES, 2010). Nos anos 1990 e principalmente no início do século XXI, houve uma evolução notável nas tecnologias computacionais, envolvendo uma maior capacidade de processamento e armazenamento de dados. Esse avanço desencadeou no uso do computador como valiosa ferramenta em empresas, e também em universidades, nas quais o seu emprego na pesquisa tornou-se cada vez mais frequente (BRIGGS & BURKE, 2006). Deste modo, o uso dos computadores passou a ser cada vez mais abrangente, tornando maior a acessibilidade aos computadores pessoais domésticos. Todos esses avanços na informática foram marcantes para o amplo acesso à internet, e para sua decisiva incorporação na cultura humana (CASTELLS, 2003; GILES, 2010).

O desenvolvimento da internet ocorreu simultaneamente com os computadores (Figura 1). O primeiro computador foi criado durante a Guerra Fria, e nessa época a internet consistia num algoritmo com o papel de meio de comunicação entre as forças militares dos Estados Unidos (GILES, 2010). Entretanto, um avanço significativo da internet pôde ser observado a partir de 1992, quando o cientista da computação Tim Berners-Lee criou a *World Wide Web*, ou simplesmente web. A web é um sistema de documentos em hipertexto e multimídia que podem ser executados na internet usando-se um programa específico, conhecido como navegador (como o Firefox e o Google Chrome, por exemplos). O surgimento da web, aliado ao contínuo progresso computacional, tornou a internet cada vez mais visada para armazenar e compartilhar informações em nível global (BERNERS-LEE, 1999; CASTELLS, 2003; GILES, 2010).

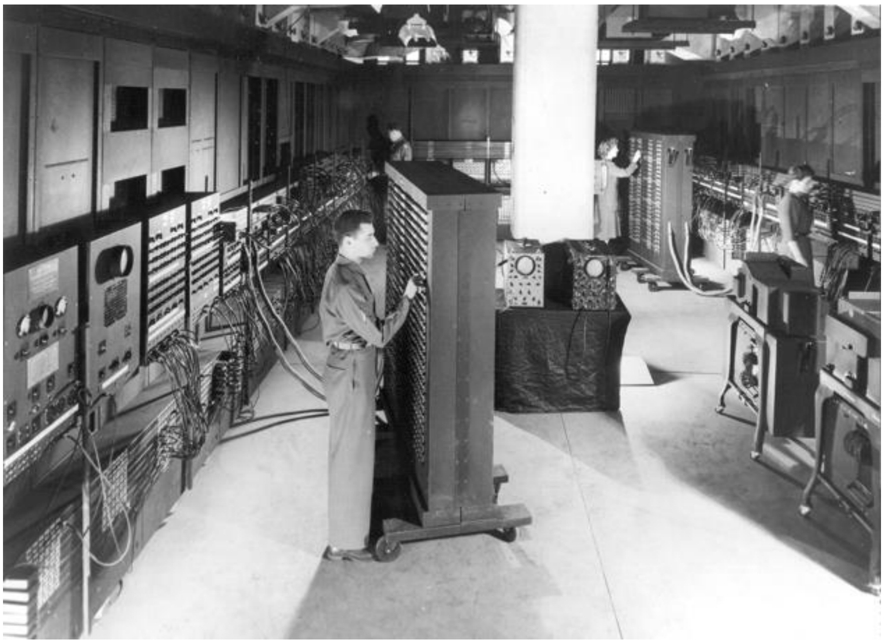

Figura 1 - Sala de operações militares dos EUA ocupada pelo ENIAC (*Eletronic Numerical Integrator and Computer*), o primeiro computador da História, que foi criado em 1946. No final da década de 1960, o ENIAC já estava obsoleto, mas suas técnicas serviram de inspiração para modelos de computadores posteriores e para o desenvolvimento da internet. Fonte da imagem: *Wikimedia Commons*.

Na primeira década do século XXI ocorreu uma verdadeira revolução digital, propiciada pela generalização dos computadores pessoais e pelo desenvolvimento da internet. A acessibilidade aos computadores domésticos e sua ampla utilização motivaram o mercado tecnológico a desenvolver continuamente dispositivos que pudessem ser ainda mais acessíveis ao público. Modelos portáteis, como *notebooks* e *netbooks*, passaram então a ser cada vez mais visados devido à sua praticidade no cotidiano (CASTELLS, 2003). Consequentemente, a facilidade no acesso à internet tornou-se uma variável impulsionadora para o exponencial crescimento tecnológico das ferramentas computacionais. Deste modo, o acesso às diversas mídias da web alcança atualmente bilhões de dispositivos manuais em todo o mundo, como *smartphones* e *tablets* (STAMFORD, 2013).

A generalização a nível global dos dispositivos com acesso à internet foi acompanhada pelo advento e popularização das diversas mídias sociais (BARGH & MCKENNA, 2004; ATZORI et al., 2012). As mídias sociais têm permitido aos usuários da internet o compartilhamento de suas ideias e emoções, que geralmente são expressas em postagens (e reações a essas postagens), e termos de buscas (COLACE et al., 2015). Este fato tem gerado uma grande quantidade de informações armazenadas na internet, as quais refletem as percepções públicas sobre diversos temas (KITCHIN, 2014; GANDOMI & HAIDER, 2015; LEUNG et al., 2018; SCHROEDER, 2018). Este enorme volume de dados provenientes da internet é conhecido como *big data*, um termo que foi mencionado pela primeira vez no trabalho de COX & ELLSWORTH (1997). Desde então, a quantidade de informações geradas na web aumentou exponencialmente (ULARU et al., 2012). Devido a esse crescimento gigantesco de dados, trabalhar com *big data* constitui-se um verdadeiro desafio. Porém, a criação e o contínuo aprimoramento de vários métodos analíticos têm permitido avaliar quantitativamente e qualitativamente esses dados para se investigar diversos padrões. Em outras palavras, é possível utilizar abordagens eficazes para compreender tendências no interesse científico e público (MICHEL et al., 2011; CORREIA et al., 2016).

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3. What is our interest on amphibians? A scientometric approach

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Abstract: Anthropic activities contribute increasingly to the decline and extinction of many species around the globe. Thus, to conserve threatened species, it is essential to have sufficient biological, ecological and cultural knowledge to support the choice, design and implementation of appropriate conservation interventions. However, research effort expended on different species is extremely patchy due several intrinsic, populational and socio-economic factors of the species. Here, we quantify the general and conservation scientific knowledge of the world's amphibian species, and identify the factors that are most strongly associated with high and low levels of knowledge production. We adopt a multi-model inference approach with a hurdle regression model to independently evaluate the factors that influence the scientific production on amphibians. Our findings demonstrate that generally the endangered species are less well researched than those that are not at risk of extinction. Because they present fragmentation, endemism and smaller areas, threatened species may be less accessible to researchers. Meanwhile, more studied species have several uses for scientists and the general public. In addition, scientists tend targeting older described species, and species that occur in countries with higher scientific capacity, and in artificial habitats, with larval development, higher reproductive frequency and greater body size. This was observed in general and conservation scientific production on amphibians. Since that previously studies demonstrated that threatened species of mammalian and birds are more interesting to the public and to scientists, and have greater investments in conservation, conservationist programs could contribute to greater visibility of endangered amphibian species.

Key words: Biodiversity, Conservation, Research effort, Scientific knowledge, Research trend.

Este capítulo está no formato de um artigo científico do periódico *Biological Conservation*.

3.1. Introduction

Natural catastrophes on Earth have destroyed ecosystems and caused mass extinctions (Monjeau et al., 2017). Despite this, several records suggest humans as the cause for the extinction of hundreds of species already in prehistoric times (Ceballos et al., 2015). Currently, anthropic activities continue to contribute to the decline and extinction of many species around the globe (Crooks et al., 2017). In fact, evidence indicates that current species extinction rates are higher than those in the pre-human period (Dirzo et al., 2014). In the last decades, anthropic factors that have been strongly associated with species extinctions have spurred conservation action to avoid extinctions as much as possible (Adams, 2013). Achieving this objective typically requires the fulfillment of three interlinked criteria: (i) the species needs to be identified as being at risk of extinction, which is normally achieved through standardized expert assessments such IUCN’s Red List (Rodrigues et al., 2006); a species can be recognized as threatened if it has a very restricted distribution, or reduced and declining populations; according to Beissinger and McCullough (2002), an efficient way to determine species’ status is to utilize Population Viability Analyzes (PVA). This metric uses computational techniques that may help predict species extinction probability. The results of these analyses allow us to understand the species threat level, and the elaboration of efficient conservation actions (Brook, 2002); (ii) Conservation groups (governmental, NGO or private) with the technical capacity, financial resources and willingness to intervene. As Ladle and Jepson (2008) pointed out, these groups have been successful in addressing the extinction of species to attract the attention on the inter-state polity; and (iii) there should be sufficient biological, ecological and cultural knowledge to support/inform the choice, design and implementation of appropriate conservation interventions. In this context, datasets that include biological, ecological and geographic information about species are essential for the planning of conservation actions (Sutherland et al., 2004, Cooke et al., 2017). Another important measure is to understand what factors determine scientific research on species (Murray et al., 2015). That away, scientific knowledge is clearly central to all three criteria.

Despite the central role of scientific knowledge in species conservation, the research effort expended on different species is extremely patchy (Clark and

May, 2002, Murray et al., 2015, Fleming and Bateman, 2016). This patchiness is due to several factors, which can be classified into three categories: (i) intrinsic factors of the species, such as body size and phylogenetic aspects; (ii) population-level or spatial factors, such as abundance, extinction risk and range size; and (iii) socio-economic factors such as the cultural, economic and ecological value of the species (Jarić et al., 2019). Knowledge deficits of species can be extreme, and may significantly limit our ability to recognize that a species is at risk, prioritize conservation action and design appropriate conservation interventions. An essential step in addressing this scientific knowledge unbalance is to: (i) identify which species are poorly/well studied, and (ii) identify the factors (cultural, ecological, geographical) that generate the observed biases in scientific knowledge production. In other words, we need to understand why some species have been more researched than others.

In this article, we quantify scientific knowledge of the world's amphibian species and identify the factors that are most strongly associated with high and low levels of knowledge production. We use amphibians because they are widely distributed (Duellman, 1999), highly visible in human environment and highly sensitive to environmental degradation and have undergone dramatic global declines that, in some cases, have led to extinction (Bacigalupe et al., 2017). Moreover, the literature on amphibians is extensive, allowing the application of scientometric techniques to assess trends in scientific production related to individual species (c.f. Liu et al., 2011, Stork and Astrin, 2014).

3.2. Methods

3.2.1. Global list of amphibian species

We compiled a list with the names of all known amphibian species using the online platform Amphibian Species of the World (http://research.amnh.org/vz/herpetology/amphibia/), which is maintained by the researcher Darrel Frost and the *American Museum of Natural History*. We have used this taxonomic list due to its extensive use in amphibian research, having been cited in more than 5000 papers according to Google Scholar metrics. Our list was obtained in February 2018 and included 7,668 species, distributed over the three Orders (Anura: 6,752 species, Gymnophiona: 205 species and

Caudata: 711 species). From that list, we also retrieved for each species its currently accepted scientific name, as well as its respective synonyms (which may have been used in older scientific publications). We used *defrostR* package, within the R platform, to retrieve and collate the data on this list.

3.2.2. Scientific Production

Our metric of scientific knowledge production was the number of published articles (indexed on Clarivate Analytics' Web of Science platform – www.webofknowledge.com) that mention each species. Clearly, this does not represent all scientific knowledge about a species, but was considered a good proxy under the assumption that a well-known species will also be the subject of many scientific studies, some of which will be published in the academic literature.

We estimated the number of scientific articles that contained information about each species by searching Web of Science using the following search terms: the species currently accepted scientific name and any synonyms (e.g. "*Hylodes gryllus*" OR "*Rana dorsalis*"). We have included in each search both the current scientific name of the species and its synonyms, since we wanted to retrieve as much information as possible for each species: analyses for species that cover long periods of time or include species described long ago have a great tendency to present synonyms, since they accumulate over time (Tessaloro et al., 2017). Therefore, considering a single scientific name recognized for a species does not guarantee complete scientific information for it, and the more synonyms are considered in the search, the greater the number of results obtained (Correia et al., 2018, Guala, 2016). We searched titles, abstracts and key words on the assumption that, if the species was important to the scientific research reported in the article, then it is likely that it would be mentioned in these sections. This is a conservative strategy that will exclude articles that, for example, only mention the common name of a species in these sections. Nevertheless, it should produce a broadly representative and unbiased sample.

We conducted manually the searches between March and May 2018, using the general search engine, that considers all databases indexed in the Web of Science. We included the number of documents registered between 1945 and 2018. We also performed filtering searches, limiting results to the thematic area

“Biodiversity & Conservation”. We considered the results of these filtered searches as a measure of scientific knowledge specifically related to the conservation of amphibians. We used both general research production (i.e. total number of articles) and conservation research production (i.e. articles in the Biodiversity and Conservation research area) as response variables in our explanatory model of researcher behavior.

3.2.3. Explanatory Variables

We considered a range of explanatory variables that may influence a scientist’s choice of study species:

(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, the most threatened species have small populations and restricted distributions, so may also be less studied. Threat status of each species was derived 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. Then, we worked with three categories: ‘LC’ (*least concern*), ‘NT’ (*near threatened*), and threatened, which englobed ‘VU’ (*vulnerable*), ‘EN’ (*endangered*) and ‘CR’ (*critically endangered*);

(ii) Years since the 1st work about each species was recorded in Web of Science platform (based on the year of the first publication for each species in our database). This variable was included because we theorized that, due to the iterative nature of scientific research, earlier publications would form the basis for future research;

(iii) Scientific capacity of countries where the species occurs. Our index of scientific capacity was based on the percentage of global environmental sciences publications (1996-2017) attributed to countries where the species is present (data from: www.scimago.com). Our prediction was that species that occur in countries with higher environmental science capacity will, *ceteris* *paribus*, be more studied, due to geographic convenience. To obtain these values, we first created a binary matrix containing species presences and absences in countries. Then we multiplied the value of each cell in that matrix (i.e. each occurrence value) by the percentages of environmental science publications of each country;

(iv) Presence in anthropic environments. We obtained from the IUCN Red List website information on amphibian species that occur in artificial regions, both aquatic and terrestrial. Our prediction was that species occurring in anthropogenic regions tend to be more researched because they are more easily found and/or more familiar to people;

(v) Breeding strategy, which has three classes: larval, direct and viviparous. Our prediction is that species with larval development will be more studied because they are easier to locate and sample (during mating aggregations and while still in the larval phase). We obtained the data this variable from the online platform AmphiBIO (Oliveira et al., 2017);

(vi) Body size. There is a large body of literature that suggests that larger species of vertebrates generate more public interest (e.g. Frynta et al. 2013, Roll et al., 2016) and may therefore have more intrinsic appeal to researchers. Larger species may also be easier to locate and sample in the field. We retrieved amphibians' body size information (in millimeter) from AmphiBIO database;

(vii) Number of reproductive events per year, whose data we collect from the AmphiBIO platform. We theorized that species with more reproductive events provide more opportunity for study.

Although our taxonomic list had shown 7,668 species of amphibians, our final dataset, which recorded information of each variable for the species, included a total of 3,129 species. This is due to the fact that not all the species on the list presented data for all the explanatory variables studied. Thus, those species that did not have information for one or more explanatory variables were excluded from our study.

3.2.4. Data Analysis

Because many species were not associated with even a single record in Web of Science, our data set had many zeros. To account for this fact, we used a Hurdle Model to evaluate the relations between the explanatory variables and our metrics of scientific knowledge. 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 test, we used the *pscl* R package. The variable 'year of the first paper' was not included in the models of zero hurdle. Since several variables in our study may influence scientific research for certain species of amphibians, 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, considering the most appropriate hypothesis that explains the research motivations (Burnham and Anderson 2004, Burnham et al., 2011). Then, we evaluated all probable model combinations taking into consideration the explanatory variables, and verified the set of most adequate models according to AIC corrected for small sample size (AICc). We considered all models with a ΔAICc ≤ 10 in relation to the best model by a model averaging process. All continuous explanatory variables were standardized before inclusion in the models. This way, we considered the relative effect size of variables as a metric of its relative importance, considering the scientific visibility to the species level.

3.3. Results

From 3,129 amphibians from our dataset, 299 species (283 anurans, 15 salamanders and one caecilian) had no article retrieved in the Web of Science platform from 1945 to February 2018. A total of 2,830 amphibian species and 206,576 articles were recovered. For 2,455 anuran species, 175,516 articles were found. For 350 salamander species, 30,501 articles and for 25 caecilians, 559 records were obtained. We evaluated the 10 most researched species, considering the area in the Web of Science and the species' status in the IUCN Red List (Figure 1). In relation to all areas, he 10 most studied species are classified as Least Concern in IUCN. African clawed frog (*Xenopus laevis*) presented the highest number of articles (46,021 papers), considering all IUCN categories (Figure 1A). Among the 10 endangered and most studied species for all areas, axolotl (*Ambystoma mexicanum*) was the most studied, presenting 2,228 articles (Figure 1B). The hellbender (*Cryptobranchus alleganiensis*), presented 86 articles, and was the most aimed by researchers in the conservation area among species classified in the IUCN as Near Threatened. Among the species in this same category, considering all areas, the iberian ribbed newt (*Pleurodeles waltl*) was the most studied (1,515 articles).

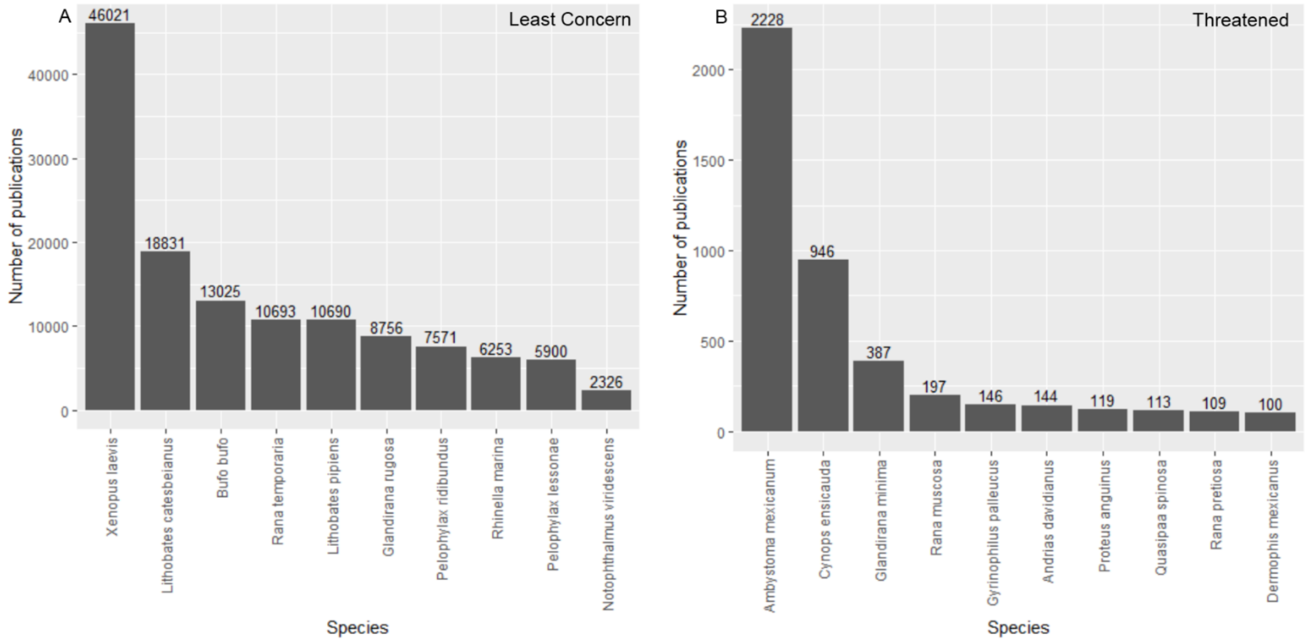

Figure 1. Number of publications in the Web of Science for the 10 most studied amphibian species, considering all thematic area in Web of Science.

To the multi-model inference approach considering all themes presented 4 most parsimonious models (Table S1). For all areas of Web of Science, scientific capacity, species that use artificial habitats and larger species had a positive effect on the Hurdle Zero Model. In this model, the number of reproductions per year, species with larval and viviparous development and species near threatened had no effect. Conversely, threatened species had a negative effect. In the Hurdle Count Model, older species in the platform, scientific capacity, species present in artificial habitats, number of reproductions per year, body size, larval and viviparous development have a positive effect on the number of articles. However, threatened and near threatened species negatively impact the research (Figure 2).

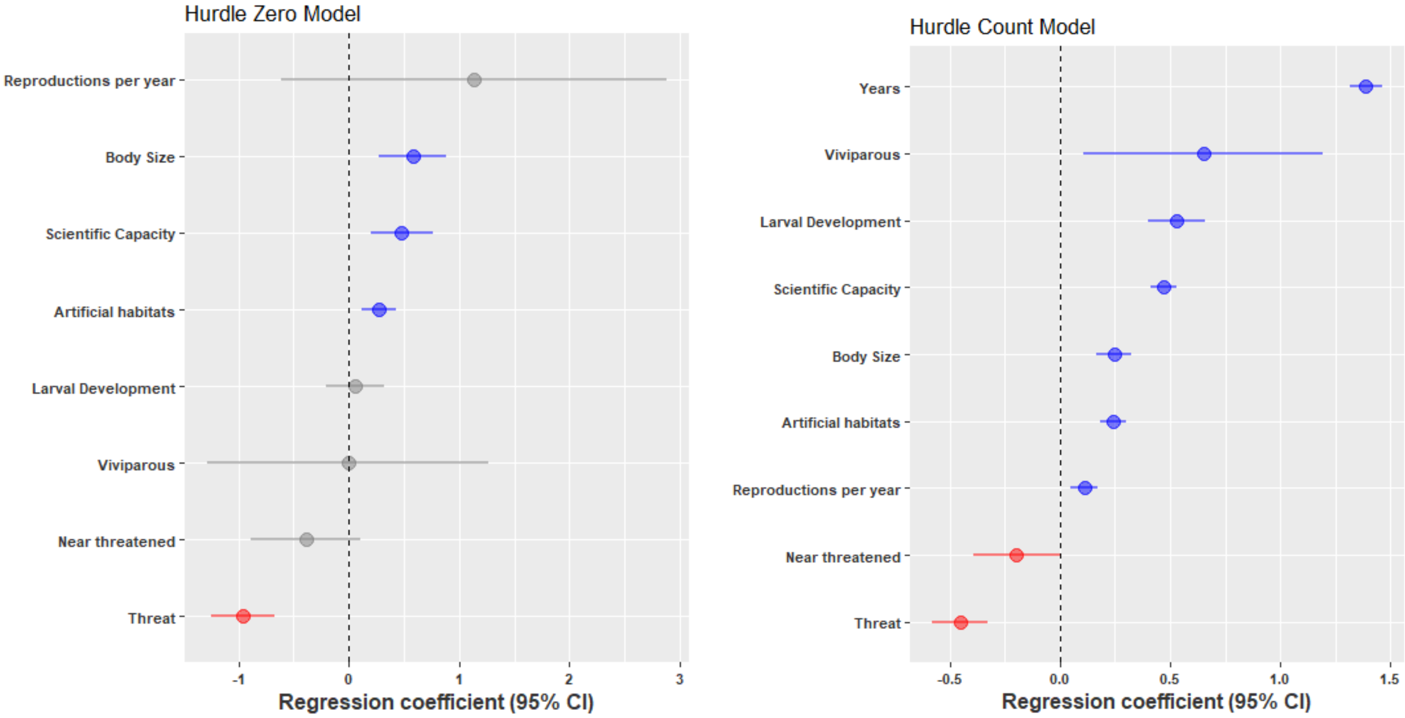

Figure 2. Coefficient estimates (± 95% confidence intervals), showing direction and magnitude of effects of variables on number of articles for amphibians, for zero (left) and count (right) Hurdle models (blue and red symbols represent positive and negative effects, respectively; grey represents no effect).

By filtering to “Biodiversity & Conservation” thematic area, 2,064 amphibian species and 18,210 articles were retrieved from the Web of Science platform. One thousand sixty-five species (948 anurans, 107 salamanders and 10 caecilians) were not reclaimed when we used this filter. A total of 1,790 species of Anura and 14,370 articles were recovered when our search was constrained to conservation theme. For Caudata, 258 species had a total of 3,795 articles and for Gymnophiona 16 species were cited in 45 articles. The 10 most studied species for conservation also are classified as Least Concern in IUCN. Common toad (*Bufo bufo*) was the most studied species, with 1,395 articles (Figure 3A). Among threatened species, mountain yellow-legged frog (*Rana muscosa*) had the greatest number of articles on conservation, totaling 90 articles (Figure 3B).

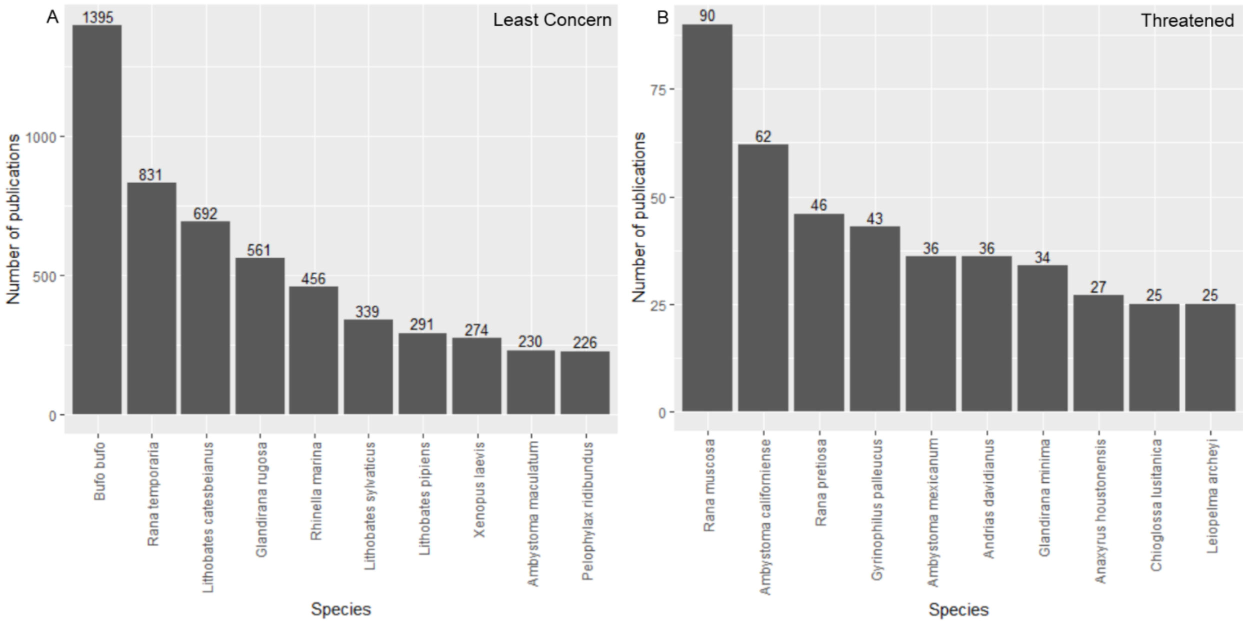

Figure 3. Number of publications in the Web of Science for the 10 most studied amphibian species, considering “Biodiversity & Conservation” thematic area in Web of Science.

In the multi-model inference approach considering publications related to conservation, we obtained 14 most parsimonious models, which we used in the model-averaging of Hurdle Model (Table S2). In the Hurdle Zero Model output for amphibian conservation, threatened species had a negative impact. Conversely, the scientific capacity, as well as species of artificial habitats, with more reproductive frequency per year and with larger body size had a positive effect in the Hurdle Zero Model. Species with viviparous and larval development and those near threatened had no effect in this part of the model. The Hurdle Count Model output on the scientific production on amphibian conservation has shown that threatened and near threatened species have a negative effect on the number of works. In this model, scientific capacity, oldest species on the platform, larval development, species present in artificial habitats, species with larger sizes and species with more annual number of reproductions positively influenced the research. However, species with viviparous development had no effect in this part of the model (Figure 4).

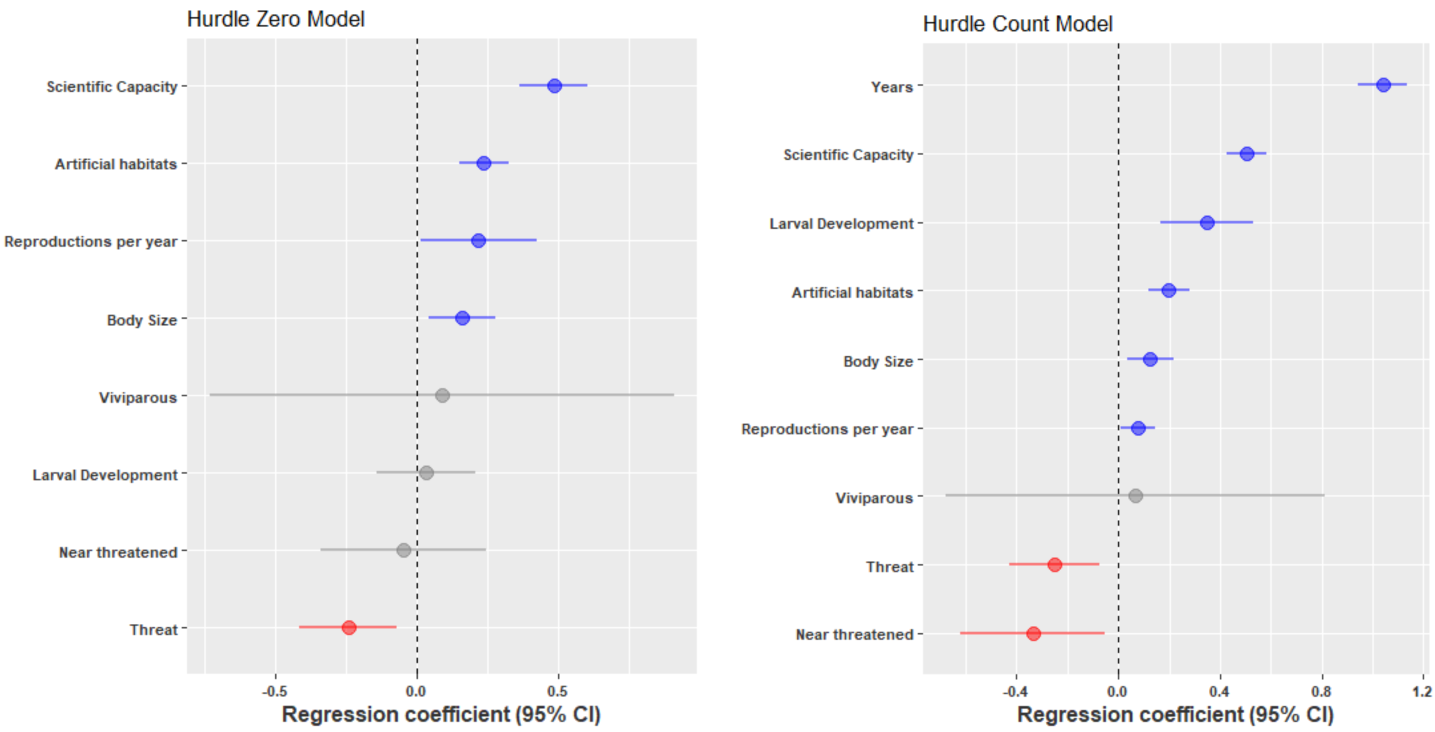

Figure 4. Coefficient estimates (± 95% confidence intervals), showing direction and magnitude of effects of variables on number of articles of conservation for amphibians, for zero (left) and count (right) Hurdle models (blue and red symbols represent positive and negative effects, respectively; grey represents no effect).

3.4. Discussion

The African clawed frog (*Xenopus laevis*) was the most studied species for all areas. The genus *Xenopus* has been widely used as a model in studies of biochemistry, cell, molecular and development biology, always providing satisfactory results (Wallingford et al., 2010, Harland and Grainger, 2011). It is important to note that the African clawed frog, besides being widely used in research, is also very much used in pet trade (Measey et al., 2012). The American bullfrog (*Lithobates catesbeianus*) also stood out in the number of articles for all areas. This species may influence the research's choice due to the fact that it is fairly used for human consumption as a meat source, entertainment and agent to control pests (Lever, 2003). *Lithobates catesbeianus* also is an invasive species around the globe, and a very competitive animal (Silva et al., 2009, Mikula, 2015).

In general, the result of our study of scientific production on amphibians for all areas in Web of Science was very similar to the result constrained for conservation-related areas. Nevertheless, there were some differences, as in the quantity of species without articles, which in this part of the study was much smaller, corresponding to approximately 9% of the total species. Of the total of

299 species with no records for all areas, 190 of these are threatened. As in the scientific production on conservation, here the majority the threatened species presented either no or low number articles compared to those non-threatened species. The Axolotl (*Ambystoma mexicanum*) was the threatened species with the highest number of articles for all themes, with 2,228 works. This species is very interesting due to its highly regenerative capacity, being therefore a laboratory subject in many laboratories (McCusker et al., 2016) and hence an important model organism in genetic studies (Nowoshilow et al., 2018). However, despite its important research value, this species is undergoing an increasing decline due to anthropic activities (Ayala et al., 2018).

There is a bias in conservation investments, which are usually directed toward endangered species that are most charismatic to people. In fact, the public interest in species of birds and mammals is much higher than in other vertebrate groups such as amphibians, fishes and reptiles (Davies et al., 2018). Moreover, species with less public interest, such as amphibians, even if threatened, receive less investment for their conservation. According to the results of Hurdle Zero and Hurdle Count analyses for scientific production on conservation, endangered species either have no articles or have fewer articles than no-threatened species. This goes against the argument that the risk of extinction of a species is one of the important attributes for scientific visibility (Zhang et al., 2015, Jarić et al., 2019). Other factors may be acting for these threatened amphibians not attracting researchers' attention. For example, the risk of extinction of a species is directly proportional to its decline, fragmentation and rarity in the environment (Hartley and Kunin, 2003). In addition, endangered species have areas of smaller sizes and/or are endemic, not easily found in/near urban areas (Howard et al., 2015, Xing et al., 2015). These factors may make these species less accessible to researchers and, consequently, less or not studied.

The top 10 most studied species in the conservation area has Least Concern status. Among these, common toad (*Bufo bufo*) and common frog (*Rana temporaria*) are the most targeted by scientists. These two species present features that may well explain their salience in conservation research. Despite being a fairly abundant species on the European continent, common toad populations have been suffering some decline due to pollution, agricultural activities and road mortalities, in addition to chytridiomycosis infection (Hitchings and Beebee, 1998, Santos et al., 2007, Origgi et al., 2018). The common frog is also abundant in Europe, but although it is classified as Least Concern, this species is susceptible to *Ranavirus* and *Batrachochytrium dendrobatidis*, responsible for the extinction of several amphibians (Bayley et al., 2013, Price et al., 2015). Their large sizes and their presence in anthropic environments (artificial ponds) may facilitate scientists to study these two species. They are easy to be found due to its large size and the proximity with urban areas may contribute the choice of these species by scientists. In the other words, visible and close species of urban environments are more familiar and charismatic to scientists and to study these species may be convenient for European herpetologists.

Regarding others variables of our study, important factors direct the conservation research on amphibians. The species presence in countries with high scientific capacity is an essential factor to the research on conservation, with species occurring in regions with high scientific capacity having a higher research effort. European and North American anuran species were the most studied species with conservation-related focus, with the exception of the Japanese wrinkled frog (*Glandirana rugosa*) from Asia, which was introduced in Hawaii in the late nineteen century. These continents have a historical investment of scientific research and it is not surprising that they lead scientific outputs. On the other side, countries with low scientific capacity had a negative influence on number of articles.

Species described first (older species) had more citations than younger species when all scientific areas were considered, as well as conservation papers alone. Perhaps pioneer studies (baseline data) provide a framework for more complex questions and may encourage future researches on species conservation (Engemann et al., 2015). The frequency of reproduction and the presence of a larval stage also positively influenced scientific production and conservation related articles, respectively. Amphibians are ectothermics and spend long time retreated in burrows and are active mostly in the reproductive season. If the species is a continuous breeder and has a larval stage, this increases the chance to be found in the environment and may contribute for studying these species.

The only non-anuran species retrieved in the Web of Science in our research when included all areas was *Ambystoma maculatum* and for conservation related articles was the red spotted newt (*Nothophthalmus viridescens*), both are salamanders from United States and Canada. In fact, salamanders are distributed mostly in the Northern Hemisphere and *A. maculatum* is one of the most studied species of United States and *N. viridescens* has been used in regeneration studies.

When we evaluated the top 10 most-studied endangered species for conservation related area, the number of articles was very reduced. Mountain yellow-legged frog (*Rana muscosa*), for example, is the most studied threatened species and has only 90 results. In contrast, the least concern common toad (*Bufo bufo*) has 1,395 conservation-related articles. Some factors may explain the fact that *R. muscosa* has a reduced amount of works, although it is the most studied threatened species: it is a small size anuran, endemic to California and its populations have already suffered many declines (Rachowicz and Briggs, 2007, Poorten et al., 2017). In general, these declines have occurred due to the predation by introduced fish species, as well as pesticides and chytridiomycosis infection (Rachowicz and Briggs, 2007, Sparling et al., 2015, Poorten et al., 2017). Despite this, this species can play the role of important model for the study of its genetic structure, which certainly contributes to the management of conservation actions (Poorten et al., 2017).

In relation to biological variables, larger sizes and more frequently reproducing species of amphibians are also more attractive to researchers. This may be related to scientific convenience, and also to attractiveness, since they are more familiar species. Regarding the type of development, we noticed that the researchers prefer to work with species that present larval development. Already viviparous development has not directed the conservation research effort. Using amphibian species that present larval development may be advantageous, since the larval stage can present a greater sensitivity to the changes in the environment, thus making it possible to measure the medium quality (Berven, 1990). Viviparous species, on the other hand, although not preferred to work in conservation. It is also important to consider that viviparity is not a predominant characteristic for most species of amphibians (Buckley, 2011), which may explain that this type of development is not related so much to a larger number of works.

Since threatened species are more interesting to the public and to scientists (Jarić et al., 2019), and have greater investments in conservation (Davies et al., 2018), conservationist programs could contribute to greater visibility of endangered amphibian species. These initiatives certainly would contribute for conservation of the most-threatened group of terrestrial vertebrates.

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Supplementary Material

Table S1. Summary result of the model averaging of Hurdle Model, presenting scientific effort general for amphibians, with the explanatory variables.

	Zero Model		Count Model	
Explanatory variables	Parsimonious models	Relative importance	Parsimonious models	Relative importance
Red List Status	4	1	4	1
Development	2	0.13	4	1
Scientific Capacity	4	1	4	1
Artificial habitats	4	1	4	1
Years to first paper	-	-	4	1
Reproductions per year	2	0.89	4	1
Body size	4	1	4	1

Table S2. Summary result of the model averaging of Hurdle Model, presenting scientific effort about conservation for amphibians, with the explanatory variables.

	Zero Model		Count Model	
Explanatory variables	Parsimonious models	Relative importance	Parsimonious models	Relative importance
Red List Status	10	0.88	12	0.97
Development	4	0.12	13	1
Scientific Capacity	14	1	14	1
Artificial habitats	14	1	14	1
Years to first paper	-	-	14	1
Reproductions per year	13	0.97	11	0.95
Body size	12	0.97	13	0.99

4. CONCLUSÕES

Em nosso estudo, nós apresentamos os possíveis fatores que podem motivar a produção científica sobre os anfíbios do mundo inteiro. Nós avaliamos o interesse científico pelos anfíbios tanto para a conservação, quanto para outros temas em geral, e para cada situação medimos quais espécies são menos estudadas, quais são mais estudadas, e as causas inerentes na pesquisa que podem gerar cada cenário. De modo geral, descobrimos que as espécies mais estudadas não estão em risco de extinção, enquanto as espécies ameaçadas possuem uma quantidade bem menor de estudos. Além disso, espécies que ocorrem em hábitats artificiais e em países com maior capacidade científica, assim como espécies maiores, descritas há mais tempo, com maior frequência reprodutiva e desenvolvimento larval são mais visadas pelos cientistas.

Nossa pesquisa demonstra a importância de se focar naquelas espécies de anfíbios menos pesquisadas, o que pode ser fundamental para a sua conservação. Em estudos futuros, pode ser interessante avaliar como as mesmas variáveis explanatórias impactam o interesse público sobre os anfíbios, e como isto pode estar relacionado com o interesse científico.