

Scientometric analysis of publications on tadpoles worldwide, with an emphasis on Brazil

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ABSTRACT

Approximately 41% of known amphibian species are at risk of extinction. Amphibians are even more vulnerable during their larval stages, as their skin is more permeable and more susceptible to absorbing environmental contaminants. There has been a significant increase in the number of studies on tadpoles in Brazil in recent years. Despite this increase, the number remains insufficient. Therefore, the objective of this research is to gather information about the current knowledge on tadpoles. To achieve this, a scientometric study was conducted, performing a non-automated systematic review of the available scientific literature. The research used the Web of Science and Google Scholar databases, with the descriptors “tadpoles” or “anuran larvae” covering publications from January 1960 to July 2024. Scientific articles, technical notes, and indexed books were included in this study. The analysis also aimed to identify Brazilian states with the highest number of publications and to analyze keywords using VOSviewer software. A total of 24,971 articles were found, of which 4,845 met the inclusion criteria. The USA had the highest number of publications (1,039), followed by Brazil (962), and China (291). Most worldwide articles mainly focus on specific families, such as Ranidae, Bufonidae, and Hylidae. In Brazil, 843 articles were valid, covering research on 17 families and 541 species, with Hylidae being the most studied (257 species; 46.9%), followed by Leptodactylidae (106 species; 19.3%), and Bufonidae (38 species; 6.9%). The families Alsodidae, Ceratophryidae, and Eleutherodactylidae were the least studied, with only one species each (0.01%). Most Brazilian studies are concentrated in the Southeast, especially in São Paulo, Minas Gerais, and Rio de Janeiro, while the North and Northeast regions have fewer publications. The analysis revealed patterns in research distribution, a growth in interest in tadpoles since 2010, and notable gaps in key areas that warrant further investigation.

Key words: Amphibians; Amphibian larvae; Anura; Caatinga; Tadpole ecology.

RESUMO

Aproximadamente 41% das espécies de anfíbios conhecidas estão em risco de extinção. Os anfíbios são ainda mais vulneráveis durante seus estágios larvais, pois sua pele é mais permeável e mais suscetível à absorção de contaminantes ambientais. Nos últimos anos, houve um aumento significativo no número de estudos sobre girinos no Brasil. Apesar desse aumento, o número ainda é insuficiente. Portanto, o objetivo desta pesquisa é reunir informações sobre o conhecimento atual a respeito de girinos. Para tanto, foi realizado um estudo cientométrico, conduzindo-se uma revisão sistemática não automatizada da literatura científica disponível. A pesquisa utilizou as bases de dados Web of Science e Google Scholar, com os descritores “girinos” ou “larvas de anuros”, abrangendo publicações de janeiro de 1960 a julho de 2024. Artigos científicos, notas técnicas e livros indexados foram incluídos neste estudo. A análise também visou identificar os estados brasileiros com o maior número de publicações e analisar palavras-chave utilizando o software VOSviewer. Foram encontrados 24.971 artigos, dos quais

4.845 atenderam aos critérios de inclusão. Os EUA apresentaram o maior número de publicações (1.039), seguidos pelo Brasil (962) e pela China (291). A maioria dos artigos internacionais concentra-se em famílias específicas, como Ranidae, Bufonidae e Hylidae. No Brasil, 843 artigos foram considerados válidos, abrangendo pesquisas sobre 17 famílias e 541 espécies, sendo Hylidae a família mais estudada (257 espécies; 46,9%), seguida por Leptodactylidae (106 espécies; 19,3%) e Bufonidae (38 espécies; 6,9%). As famílias Alsodidae, Ceratophryidae e Eleutherodactylidae foram as menos estudadas, com apenas uma espécie cada (0,1%). A maioria dos estudos brasileiros concentra-se na região Sudeste, principalmente em São Paulo, Minas Gerais e Rio de Janeiro, enquanto as regiões Norte e Nordeste apresentam menor número de publicações. A análise revelou padrões na distribuição da pesquisa, um aumento no interesse por girinos desde 2010 e lacunas notáveis em áreas-chave que justificam uma investigação mais aprofundada.

Palavras-chave: Anfíbios; Anura; Caatinga; Ecologia de girinos; Larvas de anfíbios.

Introduction

Most amphibians have a two-phase life cycle, characterized by distinct larval and adult stages (McDiarmid & Altig, 1999; Pough, 2008). In anuran amphibians, the larval stage is known as a tadpole, and represents one of the main characteristics of the group (McDiarmid & Altig, 1999).

Currently, approximately 41% of known amphibian species worldwide are at risk of extinction (Pimm *et al.*, 2014; Santos *et al.*, 2023), and population declines are associated with high levels of environmental degradation, such as habitat fragmentation, climate change, increased use of chemicals and soil contamination, and pollution of water bodies, all of which have harmful effects on amphibian species (White *et al.*, 1997; Díaz *et al.*, 2000; Driscoll, 2004; Goulart *et al.*, 2012; Deheuvels *et al.*, 2014). The vulnerability of amphibian larvae is even greater because during their metamorphosis, the skin of the individuals becomes more permeable and susceptible to absorbing environmental contaminants (Vitt *et al.*, 1990).

Most tadpoles are adapted to an aquatic life cycle and dependent on water during their development (McDiarmid & Altig, 1999). Tadpoles are found in different microhabitats and present remarkable morphological diversity (McDiarmid & Altig, 1999; Melo *et al.*, 2018; Dubeux *et al.*, 2019, 2020). They play essential ecological roles as primary consumers, being prey for several species, and act as predators that regulate populations of macroinvertebrates (Mc-

Diarmid & Altig, 1999; Haddad *et al.*, 2013; Dubeux *et al.*, 2020). Additionally, tadpoles contribute to transferring energy within food webs (Capps *et al.*, 2015), function as environmental bioindicators, and play a role in bioturbation processes (Montaña *et al.*, 2019; Gonçalves *et al.*, 2024). Although research on tadpoles has increased steadily in recent decades, it remains limited to some specific scenarios, regions, and study areas (Provete *et al.*, 2012; Dubeux *et al.*, 2019, 2020; Vera Candiotti *et al.*, 2023).

There are currently approximately 8,933 species of amphibians worldwide, including about 230 caecilians (Gymnophiona), 828 salamanders (Urodela), and 7,875 anurans (frogs, treefrogs, and toads), distributed across 80 families (Frost, 2025). Brazil harbors the highest richness of amphibians in the world, with more than 1,188 species, including approximately 1,144 species of anuran distributed among 20 families and 107 genera (Segalla *et al.*, 2021). However, despite this diversity, studies focusing on tadpoles in Brazil remain insufficient when compared to those on other vertebrate groups or even adult anurans (Provete *et al.*, 2012; Dubeux *et al.*, 2019; Vera Candiotti *et al.*, 2023). It is estimated that around 40% of Brazilian anuran species still lack descriptions of their larval stages (Provete *et al.*, 2012; Dubeux *et al.*, 2019).

The scarcity of studies focusing on tadpoles has resulted in substantial gaps in knowledge regarding some aspects, such as geographic distribution, diet,

and morphology, thereby limiting the development of effective conservation strategies for amphibian populations (Vera Candiotti *et al.*, 2023). Given the ecological importance and high diversity of tadpoles, it is essential to assess the current state of knowledge. Accordingly, this study aims to quantify and synthesize available information on tadpoles in Brazil through a scientometric approach, complemented by updated data on the global scenario. Specifically, we aim to: (a) quantify the number of studies on tadpoles published over the last 60 years, corresponding to the period during which detailed studies on tadpoles became more widespread; (b) identify the regions with the highest number of studies; (c) determine which topics and species have been most frequently studied over time; (d) identify potential gaps in knowledge regarding tadpoles; and (e) assess the conservation status of the Brazilian species with described larval stages.

Materials y methods

Study characterization

A scientometric study employs both qualitative and quantitative approaches and aims to examine, in a cumulative and comparative manner, the characteristics and patterns of production, dissemination, and use of scientific information (Silva *et al.*, 2011). This type of study seeks to review the literature in order to identify and discuss possible gaps within a given subject or region (Galvão & Ricarte, 2019). Scientometric studies are also referred to as bibliometric analysis (Bornmann & Mutz, 2015) and can address a wide range of topics, such as citations, authorship, scientific productivity, research trends, publication patterns, and collaborative networks (Bornmann & Mutz, 2015).

Data gathering

A non-automated systematic review of the scientific literature available in the Web of Science (WoS) and Google Scholar (GS) databases was conducted, as these platforms present a large number of both international and national research (Singh *et al.*, 2021; da Costa Neto *et al.*, 2022). Topic searches were performed using the descriptors and Boolean operators “tadpoles” OR “anuran larvae”, considering all available fields. Searches were done in English in the WoS database and in Portuguese in the GS database in order to expand the scope of the search (Alves *et al.*, 2021).

The search for documents encompassed all ar-

ticles available in the aforementioned databases from January 1960 to July 2024, providing a comprehensive overview of approximately 60 years of research on tadpoles. As inclusion criteria, all scientific articles, short communications, and books published in indexed journals that addressed any aspect of tadpole were selected. As exclusion criteria, gray literature (undergraduate theses, master’s theses, and doctoral dissertations), paywalled or duplicated papers, conference proceedings, articles presenting only citations, and review articles were excluded. Subsequently, using the same inclusion and exclusion criteria, articles that focused exclusively on Brazil were selected to assess national contributions.

The taxonomic classification and scientific nomenclature of all species recorded during the review were updated following Amphibian Species of the World (Frost, 2025). Conservation status was verified using the Brazilian Red List of Threatened Species (ICMBIO/MMA, 2024) and the Red List of the International Union for Conservation of Nature (IUCN, 2025).

Data analysis

For each article, abstracts and methodologies were initially screened, and those that met the inclusion criteria were read in full. Information on authorship, geographic location of the study (countries and Brazilian states), year of publication, species and families studied, research objectives, and keywords were extracted. All collected information was compiled into a table (see Appendix 1).

Locations of the studies were added to identify the countries with the highest number of publications. The same approach was used to determine the Brazilian states with the highest number of published articles. Articles that did not provide information on study location were excluded from these analyses. Maps were generated using ArcGIS v.10.3 software (Santos *et al.*, 2024).

A correlation of Pearson was performed between the number of articles published in Brazil and the year of publication to assess temporal trends in publications (Mira *et al.*, 2022). To characterize and categorize the studies, both the specific objectives of each article and the thematic scope of the journals in which they were published were considered. Analyses of the number of families and species studied in Brazil was carried out using VOSviewer v.1.6.17 software (Leiden University, The Netherlands) (Bhoomaiah *et al.*, 2020). For species-level analyses,

the 20 most representative species were considered, whereas for family-level analyses, the 30 most representative families were included. Based on the results obtained in VOSviewer, clusters were generated and represented by different colors. Within these clusters, the size of the circles corresponds to the number of publications related to a given species or family, and the distance between circles indicates the degree of similarity among them (Zhao *et al.*, 2018).

Results

Worldwide production

A total of 24,971 articles were published worldwide between 1960 and 2024. After applying the inclusion and exclusion criteria, 4,845 articles were considered valid for global analysis. Studies were published in nearly every country worldwide. The United States of America had the highest number of publications (1,039 articles; 21,4%), followed by Brazil (962; 19,8%) and China (291; 6%) (Fig. 1). Most articles focused on specific families, such as Ranidae, Bu-

fonidae, and Hylidae, and their respective genera *Aquarana*, *Rhinella*, and *Scinax*, demonstrating a clear pattern of taxonomic interest among researchers.

Tadpoles in Brazil

In Brazil, an increase in research interest on tadpoles has been evident since 2000, with a continuous growth in the number of publications and no peak moments (Fig. 2). A total of 962 articles were selected, covering 541 species belonging to 17 families. Hylidae was the most represented family, with 257 species studied, which represents 47.5% of the articles. Leptodactylidae and Bufonidae followed, with 106 (19.5%) and 38 (7.0%) species studied, respectively. Other families with notable representation were Odontophrynidae (28 species; 5.2%), Hylodidae (26 species; 4.8%), Aromobatidae (25 species; 4.6%), Microhylidae (18 species; 3.3%), Cycloramphidae (12 species; 2.2%), and Dendrobatidae (15 species; 2.8%). Families with fewer species studied were Centrolenidae (six species; 1.1%), Pipidae (five species; 0.9%), Hemiphractidae (four species; 0.7%),

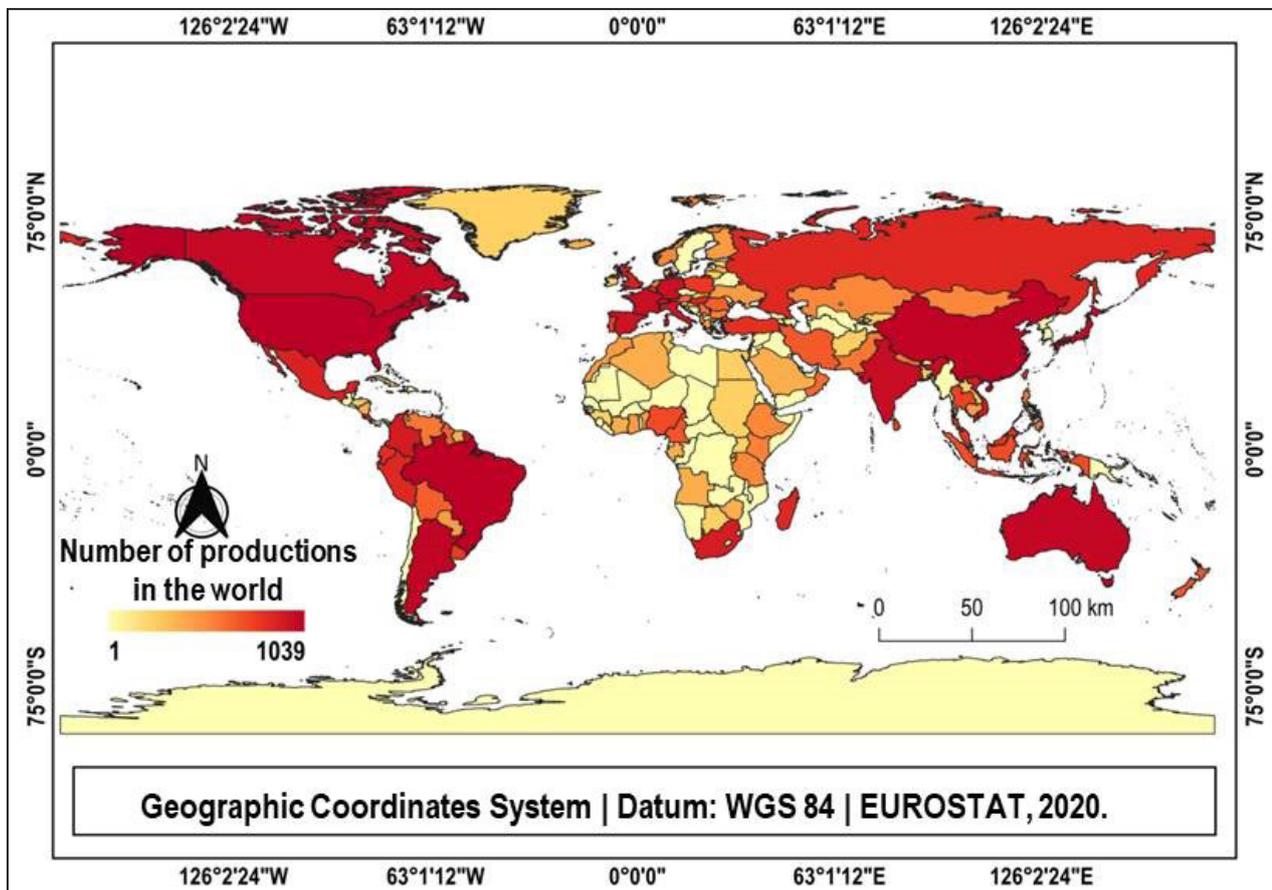


Figure 1. World map showing the distribution of scientific production on tadpoles in all countries over the last 60 years. The intensity of the red color represents the number of studies carried out by the country. Juliana Delfino, 2024.

Ranidae (three species; 0.5%), and Strabomantidae (two species; 0.4%). Alsodidae, Ceratophryidae, and Eleutherodactylidae were each represented by only one species (0.2%).

Hylidae and Leptodactylidae not only consisted of the highest number of studied species, but also showed the highest frequency of occurrence in studies, representing 41% and 27% of the total studies, respectively. Ranidae (23%) and Bufonidae (15%) were also strongly represented, largely due to studies on the genera *Aquarana* and *Rhinella*, respectively. The most frequently studied species were *Aquarana catesbeiana* (Ranidae), *Boana faber* (Hylidae), *Rhinella marina* (Bufonidae), *Physalasmus cuvieri* (Leptodactylidae), and *Leptodactylus latrans* (Leptodactylidae).

VOSviewer analyses revealed clear patterns of co-occurrence and strong links among the families Leptodactylidae, Hylidae, and Bufonidae, indicating that research focusing on one of these groups often includes the other (Fig. 3). In contrast, families such as Pipidae, Aromobatidae, Dendrobatidae, Eleutherodactylidae, and Hemiphractidae showed fewer publications and weaker associations among

them (Fig. 3).

These results demonstrated that Leptodactylidae, Hylidae, and Bufonidae dominate the research output. A distinct pattern was observed for the families Microhylidae, Centrolenidae, Dendrobatidae, and Aromobatidae, which, despite being represented by fewer publications, are often studied in combination. In contrast, Ranidae, although frequently reported, showed limited association with other families, suggesting a more isolated research approach (Fig. 3).

At the species level, analyses included the 45 most frequently reported taxa. Species of Hylidae exhibited higher frequencies and stronger associations with species of Leptodactylidae and Bufonidae (Figure 4). Interestingly, a consistent association with Microhylidae species was also detected, as these groups are often examined together (Figure 4). *Aquarana catesbeiana* (Ranidae) was the most frequently reported species but showed little evidence of co-occurrence with other taxa (Fig. 4).

Based on study locations, 843 out of the 962 selected articles presented well-defined geographic information. The Southeast region accounted for the

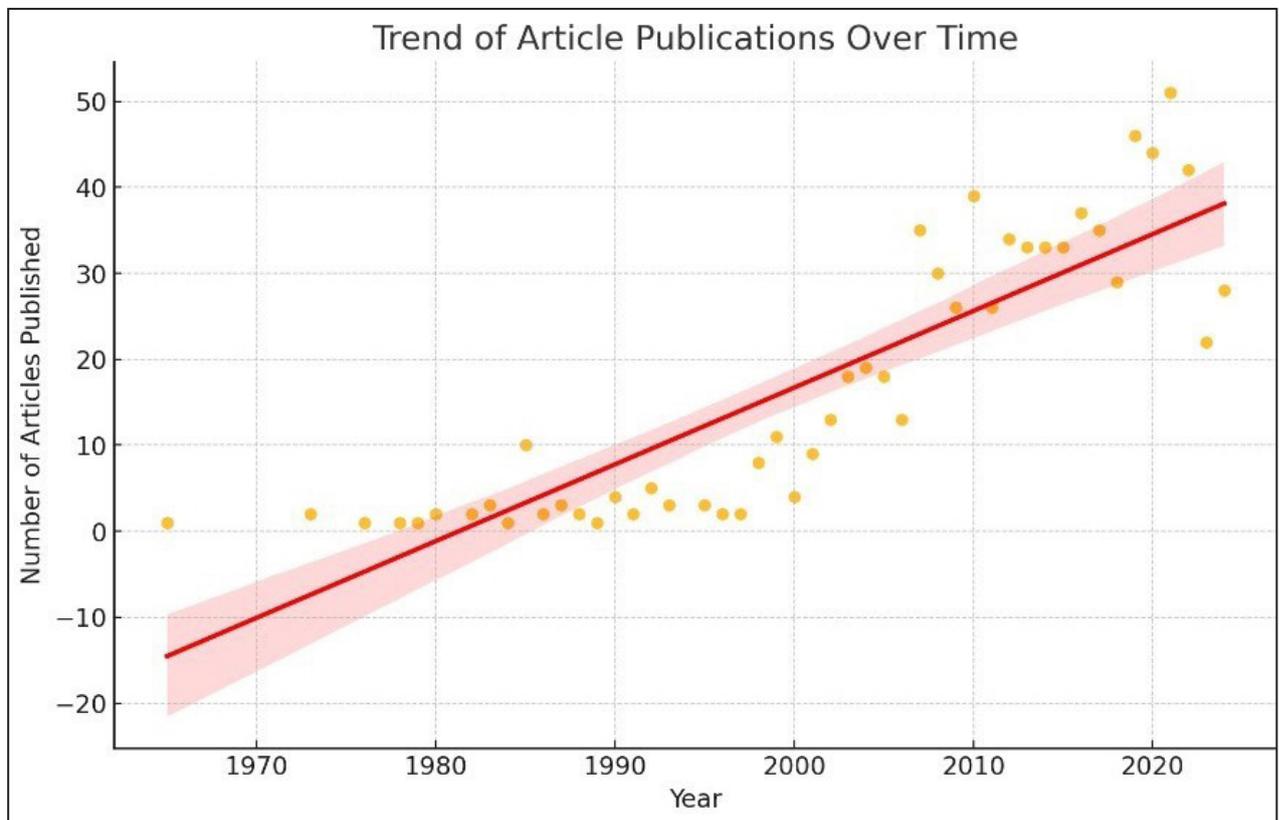


Figure 2. World map showing the distribution of scientific production on tadpoles in all countries over the last 60 years. The intensity of the red color represents the number of studies carried out by the country.

highest number of studies (407 articles), with São Paulo (N = 222), Minas Gerais (N = 94), and Rio de Janeiro (N = 91) being the most represented states. The South region followed with 94 studies, from Rio Grande do Sul (N = 59) and Santa Catarina (N = 35). The Center-West region contributed with 84 articles, including Goiás (N = 63), Mato Grosso (N = 13), and Mato Grosso do Sul (N = 8). The North (63 studies; Amazonas: N = 44 and Pará: N = 19) and Northeast regions (93 studies; Bahia: N = 52, Alagoas: N = 20, Pernambuco: N = 12, and Paraíba: N = 9) represented the lowest number of studies (Fig. 5). In the North region, Tocantins and Rondônia were the least studied states, with two and one publications, respectively.

Trends and knowledge gaps about tadpoles in Brazil

Of the 962 articles analyzed, 789 presented clearly defined objectives and were classified into 13 research categories: systematics and taxonomy (species description and phylogeny; N = 172), population and community ecology (population structure, species richness, and diversity; N = 118), natural history

(reproductive strategies, behavior, predation, and diet; N = 96), toxicology (N = 79), physiology (N = 77), morphology (descriptive morphological and anatomical studies; N = 68), frog farming (commercial breeding; N = 55), geographic distribution (occurrence records and spatial distribution; N = 51), ontogeny (developmental studies; N = 23), parasitology (N = 16), microbiology (N = 11), genetics (cytogenetic studies; N = 9), and other areas, including statistics, histology, and pathology (N = 14).

Gaps remain regarding the number of studied species. Despite Brazil harboring more than 1,000 amphibian species, only 541 species from 17 families have been studied, based on 843 national articles analyzed.

Among species assessed, those classified as threatened according to the Brazilian Ministry of the Environment (ME) and the International Union for Conservation of Nature (IUCN) include Critically Endangered species (*Melanophryniscus cambaraensis* and *M. admirabilis* [Bufonidae]; *Phrynomedusa marginata*, *Pithecopus rusticus* [Hylidae]; and *Physalaemus soaresi* [Leptodactylidae]), Vulnerable species (*Cycloramphus faustoi* [Cyclo-

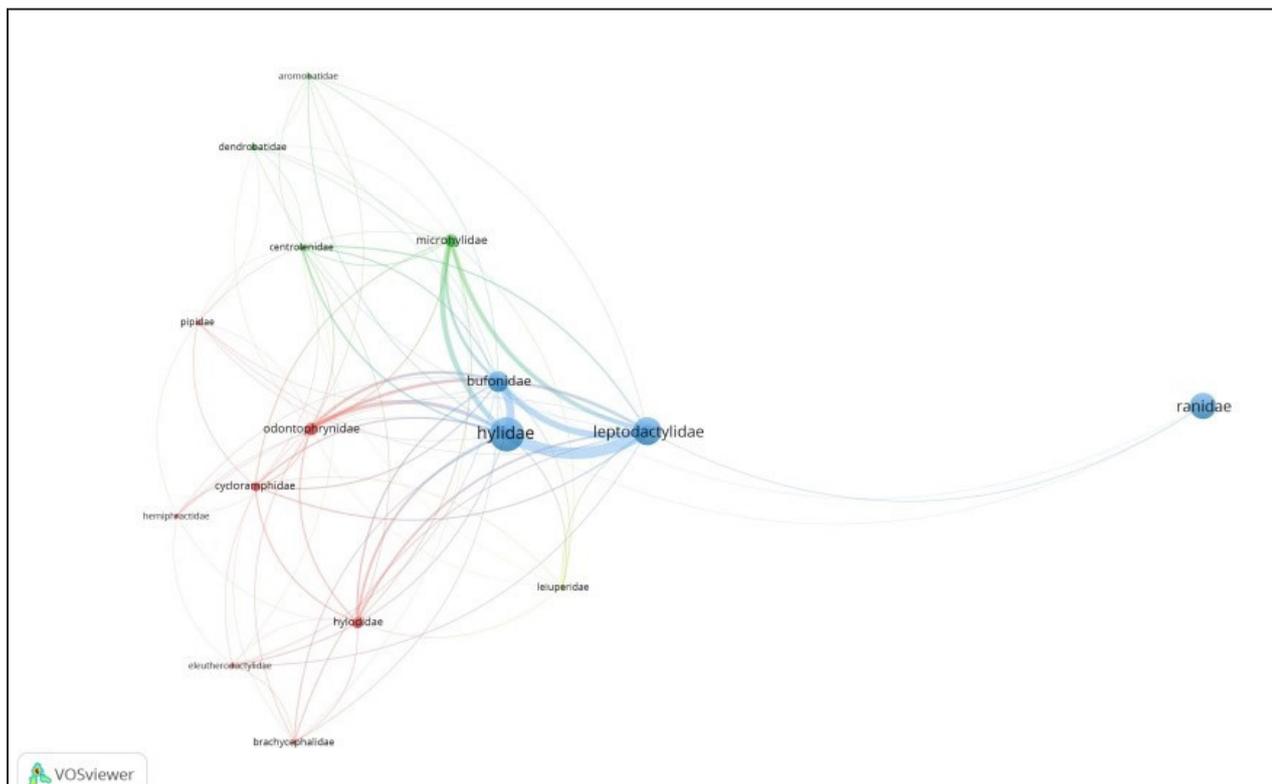


Figure 3. Brazilian trends in the number of scientific publications and tadpole families studied. The size of the circle indicates the number of articles published on each family. The distance between one family and another indicates the extent to which one family is associated with another in studies. The colors indicate groups formed according to the families that were related in the studies found.

ramphidae]), and species listed as Least Concern (*Melanophryniscus dorsalis* [Bufonidae]).

Discussion

Number of articles worldwide

There is a considerably high number of studies related to tadpoles; nevertheless, it is clearly possible to observe that some countries have a substantially higher number of publications compared to others, resulting in a considerable disparity in the scientific knowledge about tadpoles. A clear, visible pattern emerges, with the United States of America, Brazil, and China showing the highest concentrations of scientific studies; a trend that may be related to multiple factors.

The United States and China have large research institutions that invest in herpetology and ecology (De Negri & Squeff, 2014; Segalla *et al.*, 2021; Demartin *et al.*, 2024). In addition, they have more robust infrastructure and funding for field and laboratory research, which facilitates the execution of systematic and long-term studies (Ficetola *et al.*, 2008; Demartin *et al.*, 2024).

In tropical countries such as Brazil, where

biodiversity is high and anthropogenic pressures on habitats are intense (e.g. deforestation, urbanization, and water pollution), understanding ecological processes becomes fundamental for conservation strategies (Haddad & Prado, 2005; Rohr *et al.*, 2008). In Brazil, specifically, the high diversity of amphibians (Segalla *et al.*, 2021), especially anurans, makes the country a privileged setting for investigations on tadpoles. Environmental heterogeneity and marked seasonality in tropical regions further expand research opportunities, particularly regarding tadpole ecology and their breeding sites (Haddad & Prado, 2005; Nunes-de-Almeida *et al.*, 2021). On the other hand, in temperate-climate countries or regions with lower amphibian diversity, the reduced availability of suitable aquatic habitats may explain the scarcity of studies. In these contexts, tadpoles may not be considered such relevant models for ecological studies, or herpetological research may focus on other animal groups (Rohr *et al.*, 2008).

The families Hylidae, Leptodactylidae, and Bufonidae exhibit the highest species diversity and the greatest number of published studies. According to Haddad and Prado (2005), the high diversity within these families is explained by their wide range of be-

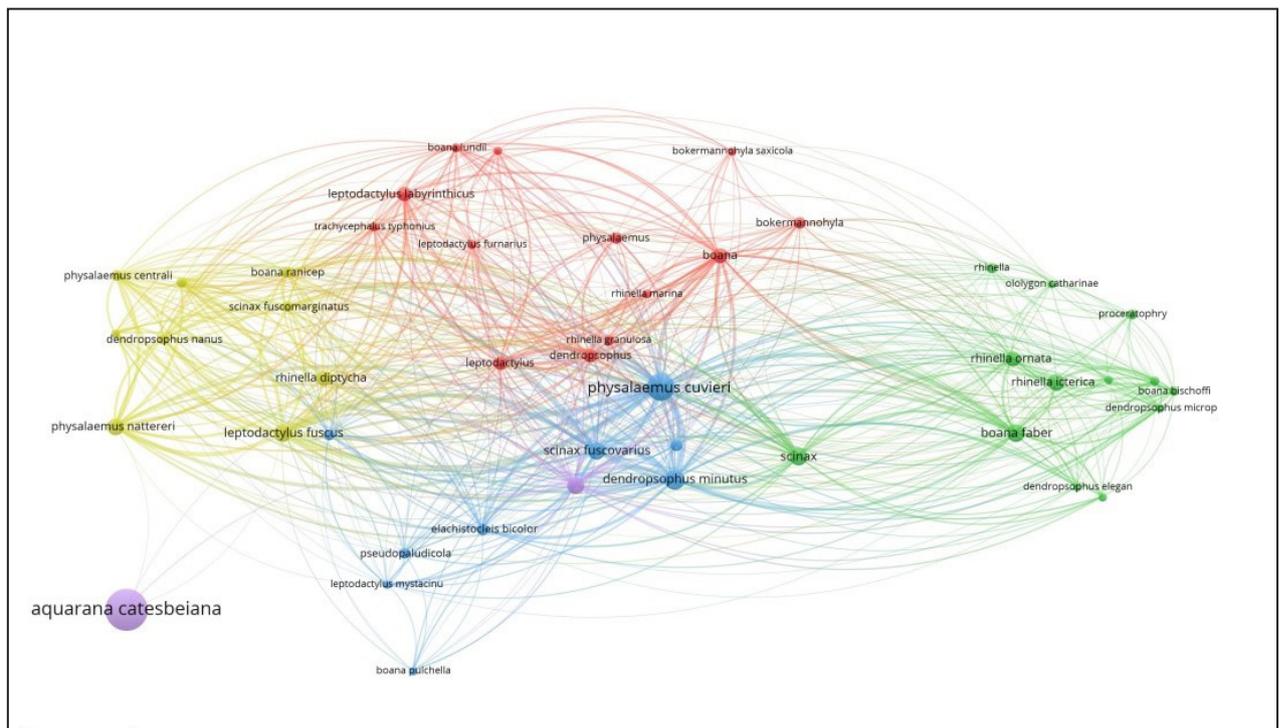


Figure 4. Brazilian trends in the number of scientific publications and tadpole species studied. The size of the circle indicates the number of articles published on each species. The distance between species indicates the extent to which one is associated with another in studies. The colors indicate groups formed according to the species that were related in the studies found.

haviors, habitats, and reproductive strategies, which increase species survival, including their ability to adapt to modified environments. Haddad and Prado (2005) and Nunes-de-Almeida *et al.* (2021) also note that the diversity of reproductive strategies and oviposition site choices within these families increases the occurrence of tadpoles across different aquatic microhabitats, from temporary pools to permanent water bodies, making their study feasible in multiple environmental contexts. The broad ecological plasticity and adaptability of tadpoles from these families facilitate the observation of responses to environmental factors such as resource availability, predators, and seasonal variations (Rossa-Feres *et al.*, 2015). Furthermore, their high species richness enables comparative analyses of reproductive modes and larval development strategies, which are essential for understanding evolutionary patterns and anuran ecology (Rossa-Feres *et al.*, 2015). Therefore, the higher number of studies on tadpoles of Hylidae, Leptodactylidae, and Bufonidae can be attributed both to their abundance in nature and to the diversity of larval life forms within these families.

Tadpoles in Brazil

The analysis of tadpole data in Brazil revealed patterns in research distribution, as well as significant gaps in key areas that deserve future attention. The families Leptodactylidae, Hylidae, and Bufonidae were also those with the highest numerical representation of published articles, whereas Centrolenidae was the least represented family. Centrolenidae is considered poorly studied, especially in relation to

its tadpoles, as only about 25% of its diversity has been described (Dias *et al.*, 2020).

During the analysis of the articles, it was observed that seven studied species mentioned the family Brachycephalidae in association with the tadpole stage, although this group exhibits direct development, characterized by the absence of a larval stage (Pombal Jr, 1999; Pombal Jr & Izecksohn, 2011). This finding demonstrates the potential for inappropriate and incorrect interpretations of reproductive aspects. Furthermore, inconsistencies in how life history characteristics are reported can hide the compilation of reliable ecological information. Ranidae was an immensely representative family in terms of the number of studies, particularly in the early years of tadpole research (Cruz, 1973; Fontanello *et al.*, 1982; Soares *et al.*, 1983) and during the period when frog farming expanded as a commercial activity (Hayashi *et al.*, 2004; Barbosa *et al.*, 2005; Cribb, 2013; Seixas Filho *et al.*, 2016).

Research on tadpoles has grown exponentially in recent decades, particularly since 2010, as demonstrated in the present study. However, there is a stronger concentration of studies conducted in the Southeastern region of Brazil, a pattern consistent with previous findings (Provete *et al.* 2012; Sidone *et al.* 2016). This region hosts the largest number of studies, likely due to the high density of research institutions and graduate programs in the region (Guerra *et al.*, 2020; Pezzuti *et al.*, 2021; Santos *et al.*, 2023d). In contrast, the Northern and Northeastern regions exhibit the lowest number of studies on tadpoles (Guerra *et al.*, 2020; Santos *et al.*, 2023c). Although research in the Center-West increased, many species remain uninvestigated (Santos *et al.*, 2023b). This scenario is concerning, as it demonstrates that despite the expansion of scientific production over the past six decades, knowledge generation remains geographically concentrated, potentially compromising a comprehensive understanding of tadpole ecology and biogeography in Brazil.

Amphibians are currently the most threatened group of vertebrates (IUCN, 2025), and many species may become extinct before their larvae are even known (Rossa-Feres *et al.*, 2015; Vera Candiotti *et al.*, 2023). Knowledge gaps related to tadpoles, such as information on distribution, genetics, and adaptations to environmental factors, further complicate conservation efforts (De Almeida *et al.*, 2015; Almeida *et al.*, 2016; Vera Candiotti *et al.*, 2023). Filling these gaps is essential to expand our unders-

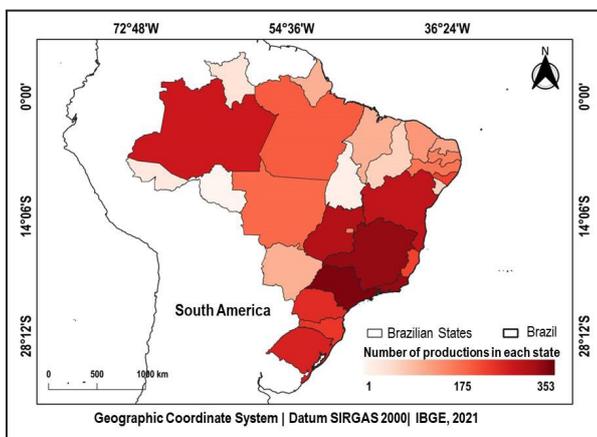


Figure 5. Map of the distribution of scientific production on tadpoles in Brazil showing the distribution of studies published in each state over the last 60 years. The intensity of the red color represents the number of studies carried out per country. Source: Juliana Delfino, 2024.

tanding of the group, particularly for species whose ecology remains undescribed, complementing data on species richness (Silva, 2010; Magalhães *et al.*, 2013; Mascarenhas *et al.*, 2016; Dubeux *et al.*, 2019; Vera Candiotti *et al.*, 2023) and biodiversity surveys (Rossa-Feres; Nomura, 2006; Nori & Loyola, 2015; Jordani *et al.*, 2017; Fatorelli *et al.*, 2018; Alves-Ferreira *et al.*, 2021). Additionally, information on tadpoles can contribute to taxonomy and phylogenetic studies (Haas, 2003; Frost *et al.*, 2006; Fouquet *et al.*, 2019), as well ecology and conservation, especially in understanding which environmental factors influence species composition (Marques & Nomura, 2015; Nori & Loyola, 2015; Marques *et al.*, 2018; Annibale *et al.*, 2020), and in ecotoxicological and ecophysiological studies (Simon *et al.*, 2015; Gutiérrez-Pesquera *et al.*, 2016; Macagnan *et al.*, 2017; Da Silva *et al.*, 2021; Malafaia *et al.*, 2022; Dos Santos *et al.*, 2024).

These knowledge gaps hinder identification of other types of threats to tadpole populations beyond environmental changes, complicating the development of effective conservation strategies. This issue becomes particularly critical for species already considered threatened, such as the eight species recorded in this study.

The Northeastern states are largely located within the Caatinga biome, which is rich in biodiversity but remains undersampled for several groups, including amphibians and especially tadpoles (Marques *et al.*, 2023). Paraíba stands out as one of the states with the lowest number of tadpole-related studies, with only nine publications. Of these, three focused on species descriptions (*Physalaemus cicada*, *Leptodactylus vastus*, and *Phyllodytes brevirostris*; Vieira *et al.*, 2007; Vieira & Arzabe, 2008; Vieira *et al.*, 2009), one pursued to characterize the reproductive modes of Caatinga anurans (Vieira *et al.*, 2009), another described the reproductive behavior of a specific species (Hödl, 1992), and one described an adult specimen, while mentioning some characteristics of tadpoles (Caramaschi, 2006).

The low number of studies in the North and Northeast raises concerns about the underestimation of regional biodiversity in Brazilian research. Although the Caatinga has approximately 15 priority areas for conservation (Camardelli & Napoli, 2012), nearly 40% of the biome remains insufficiently studied (Tabarelli & Silva, 2003; Tabarelli & Vicente, 2004), which is consistent with the low number of studies on tadpoles in this biome.

The Caatinga has been recognized as one of the least known biomes in relation to amphibians, a pattern first noted by Heyer (1988) and later corroborated by other studies (Tabarelli & Silva, 2003; Tabarelli & Vicente, 2004). This suggests that knowledge about amphibian ecology, especially tadpoles, remains limited in this region (Garda *et al.*, 2017). The unique ecological conditions of the Caatinga may influence the behavior, development, and adaptations of tadpoles in ways that are still poorly understood (Garda *et al.*, 2017).

The lack of basic information about the species hampers conservation strategies, such as the scarcity of studies on genetics and tadpole development. Although taxonomy was the category with the highest number of studies, it remains insufficient when considering Brazil's amphibian richness. Another critical gap is the lack of studies directly addressing the impact of climate change on tadpoles (Guerra *et al.*, 2020). While studies on geographic distribution exist, few examine how global warming, altered by changes in precipitation patterns and aquatic habitat degradation, affects the tadpole life cycle and population dynamics (Nori & Loyola, 2015; Guerra *et al.*, 2020). In the context of fast global change, this gap is particularly concerning.

Article categories

Overall, a large number of articles related to the search terms were found in the databases. However, some studies were not freely available, which negatively impacts the global dissemination of information by limiting both the submission of new articles in this format and access to published work. This limitation occurs because the cost of accessing a given article is often unaffordable for many researchers (Gomes *et al.*, 2018), thereby restricting the availability of data on the group. Despite the high proportion of non-open-access publications, the number of studies on tadpoles worldwide has shown continuous growth, especially from 2000 to the present.

The limited attention given to “genetics and microbiology” may indicate a significant gap in our understanding of the evolutionary dynamics and health of tadpoles. Population genetics studies are crucial for assessing genetic variability, gene flow among populations, and the capacity of species to adapt to environmental changes such as pollution and global warming (Allentoft & O'Brien, 2010; Tavares-Junior *et al.*, 2020). The scarcity of genetic data hinders predictions of resilience under increasing

selective pressures. Given the crucial role of tadpoles in aquatic ecosystems, especially as bioindicators, expanding studies in these areas is fundamental for evaluating anthropogenic impacts on ecosystems (Thomson *et al.*, 2018; Tavares-Junior *et al.*, 2020).

Another critical concern is “microbiology”. Recent studies have shown that the microbiota of tadpoles can influence health and resistance to pathogens, such as *Batrachochytrium dendrobatidis*, the fungal agent responsible for chytridiomycosis, a disease that has devastated amphibian populations worldwide (Bletz *et al.*, 2013; Ujszegi *et al.*, 2023). The lack of in-depth research on this topic represents a major gap for amphibian conservation. The diversity of research areas covered also reflects the complexity of tadpole ecology. While studies on physiology and morphology have provided a basic understanding of how these organisms adapt to their environment, fields such as parasitology and microbiology are emerging as important areas for revealing new ecological interactions and challenges for conservation.

Another point worth highlighting is the scarcity of studies that address the impact of climate change on the distribution and ecology of tadpoles. Although 51 studies focused on the geographic distribution of species, few explore how global warming and altered precipitation patterns affect aquatic habitats and, consequently, larval survival (Catenazzi, 2015).

Conclusion

Among the 789 studies analyzed regarding the defined objectives and the thematic scope, “systematics and taxonomy” was the most explored research area. This result is considerably expected, as taxonomy is fundamental to biology and provides the basis for the identification and classification of species (Padiál *et al.*, 2010). The second most frequently studied area was “population and community ecology”, reflecting a strong interest in understanding the structure and dynamics of tadpole populations in natural habitats. Such studies are important because intraspecific and interspecific interactions are naturally present and play an important role in maintaining biodiversity (Parris, 2006). Studies of tadpole community composition are also crucial for assessing the impacts of environmental changes, including habitat loss and forest fragmentation, which threaten the survival of many species (Kopp & Eterovick, 2006).

Overall, the analysis of tadpole-related publi-

cations in Brazil reveals a concentration of research in well-established areas such as taxonomy and ecology, with important gaps in emerging fields, such as microbiology and genetics. The pronounced geographic imbalance in research efforts, with an underrepresentation of the North and Northeast regions, highlights the need for greater investment in scientific studies in these areas. Moreover, global issues such as climate change and environmental degradation must be more widely integrated into research on tadpoles, given the vulnerability of amphibians and their importance for the health of aquatic ecosystems.

To address these challenges, it is crucial to increase financial and logistical support for research in underexplored regions, promote interdisciplinary approaches, and prioritize emerging topics such as tadpole health and environmental change. Filling these gaps will make it possible to develop more effective conservation strategies for tadpoles and the ecosystems on which they depend. Furthermore, in light of increasing global threats to aquatic ecosystems, expanding research in toxicology and ontogeny will be essential for predicting how tadpole populations respond to environmental factors.

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Apendice

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