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Bromeliad phytotelmata: the first scientometric study

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ABSTRACT

Bromeliad phytotelmata: the first scientometric study

Bromeliads are plants predominantly found in the Neotropical Region, with high diversity of species and wide distribution. Some representatives of this family have the ability to form phytotelma environments through the accumulation of water and organic matter, serving as substrate and food for a variety of organisms. Here, a scientometric analysis was carried out to show trends in scientific work on bromeliad phytotelmata and the importance of these microcosms for the maintenance of biodiversity. The papers were analyzed using the Thomson Reuters, Scopus and Scielo databases between the years 1970 and 2021. Information was sought on the years of publications, geographic regions, countries, article design (descriptive, predictive, experimental, review), focus (ecological, biological, molecular), and ecological level of study (organism, population, community and ecosystem). South America presented the highest number of works developed with the subject and also with researchers involved. Most studies presented predictive designs focusing on community ecology. Insecta, followed by Crustacea and Anura, were the most studied groups of organisms. The results contribute to a better understanding of biodiversity in bromeliad phytotelmata, pointing out gaps and trends in research directed at these natural microcosms.

Key words: water-filled plant cavity, aquatic ecosystems, biodiversity, Insecta, Crustacea

RESUMEN

Phytotelmata en bromelias: el primer estudio cienciométrico

Las bromelias son plantas que se encuentran predominantemente en el Neotrópico, con una alta diversidad de especies y una amplia distribución. Algunos representantes de esta familia tienen la capacidad de formar fitotelmas a través de la acumulación de agua y materia orgánica, sirviendo de sustrato y alimento para una variedad de organismos. En este trabajo, se llevó a cabo un análisis cienciométrico para mostrar las tendencias de los trabajos científicos sobre fitotelmas en bromelias y la importancia de estos microcosmos para el mantenimiento de la biodiversidad. Los artículos fueron analizados en las bases de datos de Thomson Reuters, Scopus y Scielo, entre los años 1970 y 2021. Se buscó información sobre los años de publicación, regiones geográficas, países, diseño del artículo (descriptivo, predictivo, experimental, revisión), enfoque (ecológico, biológico, molecular) y nivel ecológico de estudio (organismo, población, comunidad y ecosistema). América del Sur presentó el mayor número de trabajos, así como, de investigadores involucrados. La mayoría de los estudios presentaron diseños predictivos centrados en la ecología de la comunidad. Los insectos, seguido de los crustáceos y anuros fueron los grupos de organismos más estudiados. Los resultados contribuyen a una mejor comprensión de la biodiversidad en fitotelmas presentes en bromelias, señalando las lagunas y tendencias en la investigación dirigida a estos microcosmos naturales.

Palabras clave: *depósitos de agua en cavidades de plantas, ecosistemas acuáticos, biodiversidad, Insecta, Crustacea*

INTRODUCTION

Bromeliads (Bromeliaceae) are among the most diverse and dominant plant communities found in Neotropical regions, with about 3000 species distributed in 56 genera (Luther & Sieff, 1998). The high number of species may be the result of a broad evolutionary process, occurring in several biomes, from deserts to tropical forests, such as the Atlantic Forest and the Amazon Forest (Benavides et al., 2006; Almeida & Souza, 2020; Malfatti et al., 2020). These plants are widely known due to their morphological and ecological plasticity (Mercado-Salas et al., 2021). Several species are epiphytes and colonize from the soil to the forest canopy, as well as presenting wide altitudinal distribution, with occurrence from sea level to high Andean altitudes (Blum et al., 2011; Von May, 2016).

Some bromeliad species can form phytotelma environments through the imbrication of their leaves. These bromeliads with phytotelmata are thus small aquatic ecosystems, since they accumulate water in these leaf tanks and are capable of maintaining an associated biota (Tsuda & Castellani, 2016). These tanks can accumulate up to 50 liters of water per hectare in tropical forests (Romero et al., 2020). Furthermore, they can store decomposing organic matter, which serves as substrate and food for a variety of organisms using this type of environment for foraging, reproduction, and refuge against predators (Kitching, 2001; Migliorini et al., 2018; Cassiano-Lima et al., 2020; Srivastava et al., 2020).

Srivastava et al. (2004) explored the idea that bromeliads serve as natural microcosms, where the aquatic-terrestrial interface acts as a physical barrier and consequently imposes some level of natural restriction on the dispersion of the associated biota. However, some authors claim that bromeliad phytotelma environments are not totally closed structures and constant changes occur in communities by certain processes such as the emergence of insect larvae and colonization by microorganisms (Srivastava, 2006; Buosi et al., 2014a; Cardoso et al., 2015).

These environments are excellent for the study of ecological processes (Almeida & Souza, 2020; Céréghino et al., 2020; Srivastava et al., 2020), presenting replicates in the same habitat and easy manipulation. Therefore, they may be used to answer questions of population dynamics in ecosystem communities and processes (Kneitel & Miller, 2003; Trzcinski et al., 2016; Simão et al., 2017). According to Kitching (2001), these environments can be framed as ecotones, having unique conditions that are not observed in any other complex ecosystem, hosting fauna with a high degree of endemism and contributing to an increase in local and regional biodiversity. In addition, it is known that within these environments there are possible interactions between numerous species and they may interfere with internal processes of communities (Jocqué & Field, 2014).

The taxonomic groups that can live within these phytotelma environments are predominantly viruses, bacteria, protists, algae, fungi, invertebrates, and vertebrates (Simão et al., 2017; Giongo et al., 2019; Céréghino et al., 2020; Sachertt-Mendes et al., 2020; Srivastava et al., 2020). However, most publications are geared towards the insects, with a lower number of studies aimed at other taxonomic groups (Lichtwardt, 1994; Jocque et al., 2013; Buosi et al., 2014b; Neretina et al., 2019; Sachertt- Mendes et al., 2020).

Understanding the variety of organisms that inhabit phytotelma environments is essential to develop conservation and environmental protection measures, both on local and regional scales. For this, scientometric studies are of high importance, since they synthesize knowledge about a certain area of research, evaluate trends, gaps and contributions and consequently add to scientific and technological advancement on the subject. Therefore, the study aimed to carry out a scientometric analysis, emphasizing the importance of the phytotelmata of bromeliads in support for the biodiversity of aquatic organisms. We analyzed the temporal and spatial trend in publications in terms of the design employed in the studies (descriptive, predictive, experimental and review), the focus of papers (ecological, biological and molecular), and the level of ecological organization considered (population, community and ecosystem).

MATERIALS AND METHODS

We performed a scientometric analysis in May 2022 based on publications indexed in Thompson Reuters (www.isiwebofknowledge.com) based on the search terms bromeliad* AND "(phytotelm* OR tank* OR water-filled OR aquatic OR freshwater) and the period from 1970 to 2021. We cataloged bibliographic production used as an indicator of the results. Among the selected papers, we recorded: i) genus of bromeliads; ii) year of publication; iii) the continent (region) where the research originated and the origin of the researcher; iv) the design used in the studies; descriptive (comparative studies); predictive (ecological predictive models); experimental (studies carried out in the field or laboratory under controlled conditions); and review (literary reviews); v) the approach addressed in the works, namely: ecological, biological and molecular studies ; vi) ecological level of study (population, community, ecosystem); and vii) taxa (Kingdom, Phylum, Class) found in the studies. We emphasize that some publications do not present information how many others are counted more than once when they meet various criteria.

We found 549 papers in the Thompson Reuters database. However, of these, we kept only 501 papers for scientometric analysis, since the others referred to botanical studies and physical and chemical analyses, without any relationship to the biota associated with phytotelmata. We grouped the years of publications into four-year intervals, starting in 1970 (first publication included in the analysis) and ending in December 2021. For better visualization of some categories, we created nine time intervals: 1970-1975, 1976-1981, 1982-1987, 1988-1993, 1994-1999, 2000-2005, 2006-2011, 2012-2017, 2018-2021. To verify whether there was an effective change in the characteristics of studies on phytotelmata from bromeliads in the scientometric survey between the years 1970 and 2021, we performed a regression tree (MRT) (De'Ath & Fabricius, 2002).

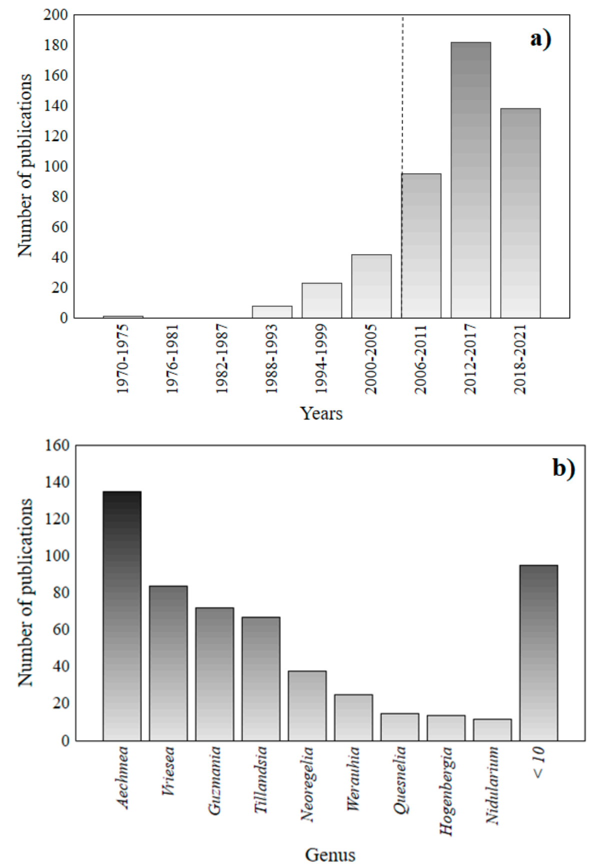

Figure 1. Temporal trend in the number of publications on phytotelmata indexed in the Thomson Reuters and Scopus databases between 1991 and 2020 (a) genus of bromeliads (b). *Tendencia temporal en el número de publicaciones sobre fitotelmas indexadas en las bases de datos de Thomson Reuters y Scopus entre 1991 y 2020 (a) género de bromelias (b).*

RESULTS

The results showed an increase in scientific production on phytotelmata in 2006, as suggested by the MRT. The threshold was observed in 2007 and, from that year on, there was an increase in the number of publications over time, with a peak in the 2012-2017 interval (n = 182) (Fig. 1a). Among the bromeliad genera found through-out the study, *Aechmea* (n = 138) had the highest number of records, followed by *Vriesea* (n = 84) (Fig. 1b).

Considering the research origin, South America was the continent with the highest number of scientific publications (n = 296), followed by Central America (n = 94) and North America (n = 75). The smallest number of publications was found in Asia (n = 4), followed by Oceania (n = 3), and no studies were found in Africa. It was also observed that South America, Central America and North America were the pioneers in studies on phytotelmata from bromeliads. (Fig. 2a). According to the origin of the researcher, South America (n = 210) had the highest number of studies, followed by Europe (n = 161) and North America (n = 129) (Fig. 2b).

Regarding the design used in the published papers, descriptive (n = 214) and predictive (n = 129) works were the pioneers and constituted the majority of publications. Papers with a predictive design were registered in most time intervals, with the highest number of studies in the 2018-2021 range, when the number of published papers also increased. Experimental studies (n = 138) had their first publication in 2009 and were included in all subsequent intervals until 2020. The We found review works (n = 3) only in the periods from 2000-2002, 2012-2014 and 2018-2020, and these also presented a lower number of publications than the other designs used during the period (Fig. 3).

Most papers presented an ecological focus (n = 302), followed by those with biological (n = 115) and molecular (n = 45) studies. Studies with a biological focus were recorded at almost

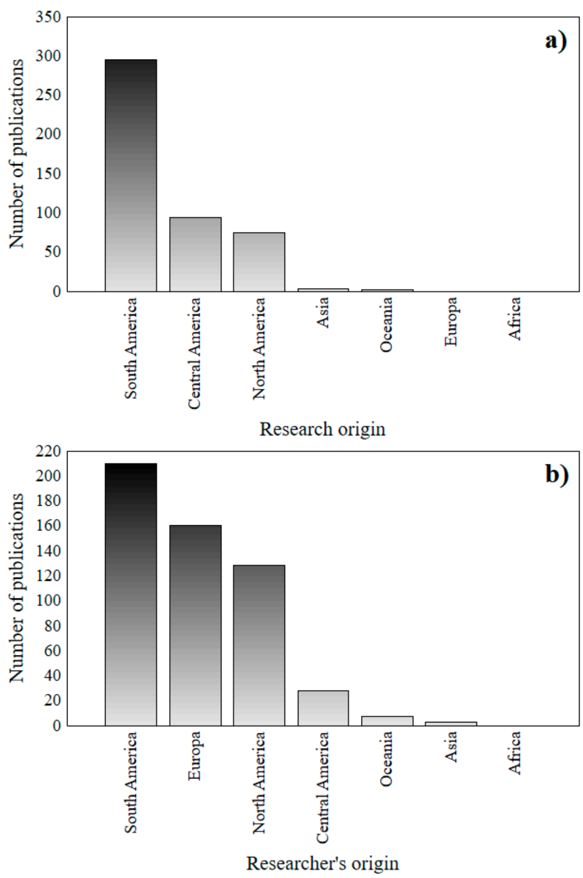

Figure 2. Number of publications on phytotelmata recorded on each continent during the period covered in the scientometric study. * some publications do not present information how many others are counted more than once when they meet various criteria. *Número de publicaciones sobre fitotelmas registradas en cada continente durante el período que abarca el estudio cienciométrico. * algunas publicaciones no presentan información de cuantas otras se cuentan más de una vez cuando cumplen varios criterios.*

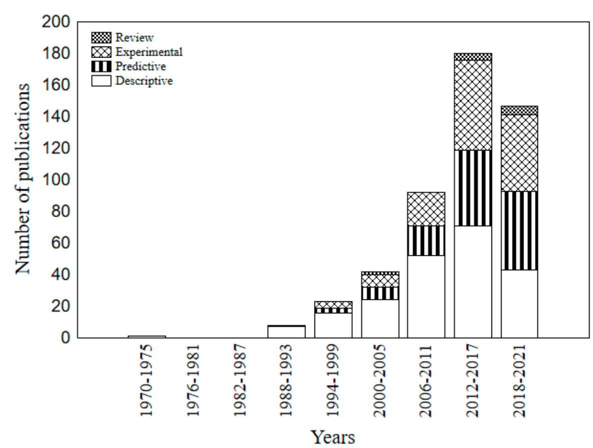

Figure 3. Number of publications on phytotelmata classified according to the design used during the period of the scientometric survey. * Some publications do not present information how many others are counted more than once when they meet various criteria. *Número de publicaciones sobre fitotelmas clasificadas según el diseño utilizado durante el período de la revisión cienciométrica. * Algunas publicaciones no presentan información de cuantas otras se cuentan más de una vez cuando cumplen varios criterios.*

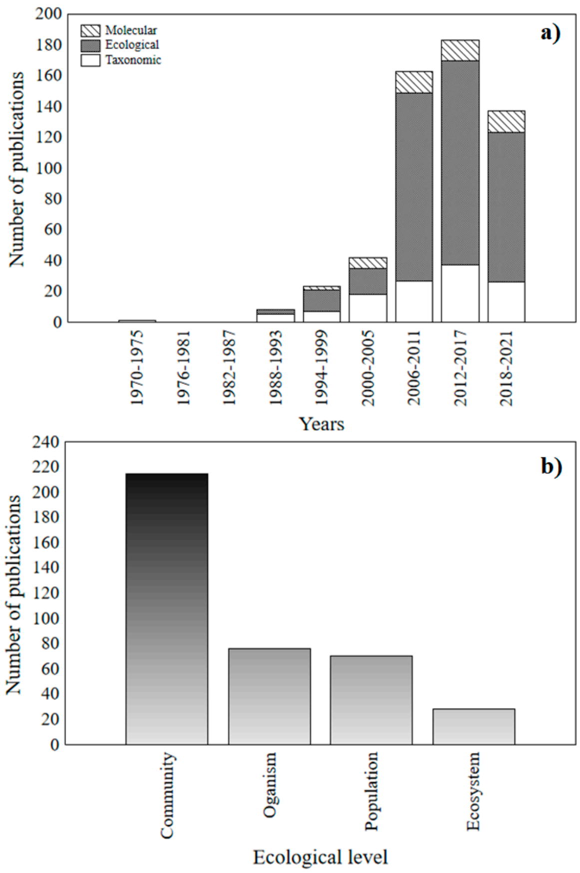

Figure 4. Number of publications on phytotelmata classified according to the approach addressed in the article during the period of the scientometric survey. * Some publications do not present information how many others are counted more than once when they meet various criteria. *Número de publicaciones sobre fitotelmas clasificadas según el enfoque abordado en el artículo durante el período de la revisión cienciométrica. * Algunas publicaciones no presentan información de cuantas otras se cuentan más de una vez cuando cumplen varios criterios.*

all time intervals, with the exception of the 1976-1981 and 1982-1987 intervals. From this interval, the records of publications with an ecological focus began to increase, remaining with high numbers in all subsequent intervals. Molecular studies started to be published after the year 1993 (Fig. 4a). When verifying the level of ecological organization, it was possible to observe that most of the studies were carried out at the community level (n = 215), followed by those at the organism level (n = 76). The smallest number of studies had an ecosystem approach (n = 28) (Fig. 4b).

According to the types of organisms found in the study, insects (n = 173) were present in the greatest number of studies. Protozoa (n = 67) were the second most recorded group in the studies, followed by Amphibia (n = 58). On the other hand, the organisms that were present in the smallest number of studies were Virus and Mollusca, grouped as other organisms, both totaling two articles each (Fig. 5).

DISCUSSION

Bromeliads are plants native to the Neotropical region, distributed latitudinally from South Florida to the Patagonia region, with peaks of diversity and abundance in tropical forests (Blum et al., 2011; Breviglieri & Romero, 2017; Fernandez Barrancos et al., 2017). However, some species have been introduced to other continents (Kolicka et al., 2016; Wilke et al., 2018 Poniewozik et al., 2020). Some of these introductions generated further problems, such as that of *Billbergia pyramidalis* (Sims). Lindl. in South Florida, which through ecological facilitation processes allowed the colonization and establishment of viable populations of non-native *Aedes albopictus* mosquitoes (Skuse,1894) (Lounibos et al., 2003; Wilke et al., 2018).

The increase in the number of papers on phytotelmata in bromeliads over time is indicative of the increase in the number of researchers and institutions working in different locations with these organisms. As phytotelma bromeliads are native to the Neotropics, it is to be expected that the largest number of publications would be concentrated in South and Central America (Janetzky et al., 1996; de Araújo et al., 2020; Cassiano-Lima et al., 2020). From 2003 onwards, there was significant growth in South American publications and a progressive increase in papers published, making this region, especially Brazil, the largest producer of scientific publications on phytotelmata in bromeliads in the world. This reflects the fact that South America is the region with the greatest distribution of bromeliad species in the Neotropical region, mainly in the Atlantic and Amazon forests (Blum et al., 2011; Ferreira-Keppler, 2017; Giongo et al., 2019). Another important point that may have influenced the increase in the number of publications was the creation and expansion of ecological research centers in South America. In Brazil, the expansion of these research centers began precisely in 2003, with the expansion of university campuses to the interior of the states (Buosi et al., 2015; Ramos et al., 2019; Trombini et al., 2020), in a period when the Brazilian economy was growing rapidly (2002-2011). This financial contribution provided researchers with better working conditions and diversification of research systems, such as bromeliad phytotelmata. Additionally, the increase in the number of publications may be associated with the creation of the Bromeliad Working Group (BWG) in 2011. The BWG is an organization that comprises approximately 60 researchers around the world who work on the aquatic organisms in bromeliads from a community and ecosystem ecology perspective. This organization reports survey data (1993- present) of the aquatic invertebrate communities recorded in > 1600 bromeliads sampled in 26 field sites, developing traits and feeding relationships among the more than 600 invertebrate taxa (Srivastava, 2018). Africa was the continent that did not present any record of occurrence, because despite having a record of a native bromeliad, this is not a phytotelma species (Porembski & Barthlott). In Asia and Oceania only one appeared. Asia's one reference was an inventory of cyanobacteria in exotic bromeliads used as botanical ornaments (Poniewozik et al., 2020). As it does not have bromeliads in its natural environment, phytotelma research on this continent has been aimed at other plant taxa (Ling-Chua & Mim Lim, 2012; Shelomi & Lin, 2020).

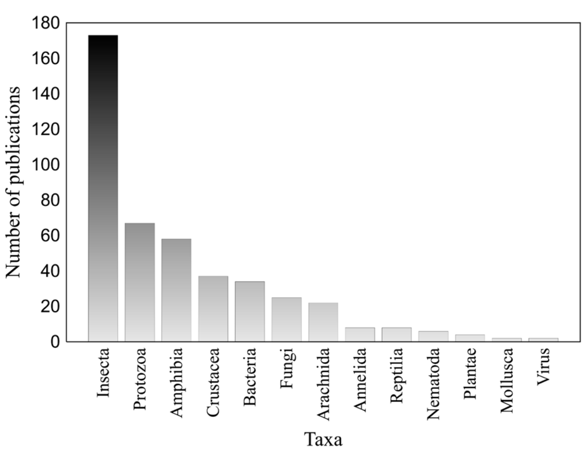

Figure 5. Number of publications on phytotelmata classified according to the ecological level during the period analyzed. * Some publications do not present information how many others are counted more than once when they meet various criteria. *Número de publicaciones sobre fitotelmas clasificadas según el nivel ecológico durante el período analizado. * Algunas publicaciones no presentan información de cuantas otras se cuentan más de una vez cuando cumplen varios criterios.*

Considering the retained publications, it was observed that Aechmea and Vriesea are of the most species-rich genera in formations, especially in Brazil (Kersten & Silva, 2001; Mestre et al., 2001). The large number of species of this genus is indicative of the ecological importance of epiphytic species due to their interaction with other organisms, in addition to serving as food for birds and as nurseries for insect and tadpole larvae and also as a shelter for several groups of invertebrates (Reitz, 1983; Mestre, 2001).

In the database, the first studies registered largely addressed taxonomical aspects (identification of new species) and ecological aspects related to the occurrence of species in bromeliads. The ensuing increase in ecological studies is related to the recognition that phytotelmata are particularly well suited to the study of ecological processes, especially those related to dispersion, colonization, and interaction between species (Maguire, 1971).

Most studies on bromeliad phytotelmata presented a trend in descriptive and predictive designs (Ramos et al., 2017; Tonini et al., 2020). Descriptive articles are closely related to the search for basic knowledge, i.e., that which allows the researcher to carry out observations confirmed through descriptive design, and consequently make inferences that may indicate probable casual routes (predictive design) for further performance of experimental and review studies.

Regarding the approach of studies referring to publications, biological papers had the greatest number of records in the first intervals, such as descriptions of new species of harpacticoid copepods (Reid & Janetzky, 1996) and dipterous insects (Lounibos & Machado, 1993; Epler & Janetzky, 1998). Generally, studies in new environments begin with descriptions of the organisms found (Greeney, 2001; Jocque et al., 2013), and this profile was also seen in this paper. However, the same upward trend in the number of publications has not continued over the periods analyzed. This could be an indication that knowledge was accumulated by biological approaches in the early periods, and this was crucial and served to support new ecological research, which increased the number of articles in this area. The prevalence of studies with ecological foci may be justified by the fact that phytotelmata in bromeliads constitute a rich environment for testing ecological theories like species coexistence, neutral theory, metacommunities and evolution (Buosi et al., 2014a; Buosi et al., 2014b; Carrias et al., 2014; LeCraw et al., 2014; McCracken & Forstner, 2014).

The publication of research papers on bromeliads with molecular emphasis only started in 1994. This area of knowledge is still considered recent, since it became possible only after the discovery of DNA structure and further popularization of knowledge about it. Advances in metagenomics and next-generation sequencing have revolutionized the molecular field, and these methods are important tools for biodiversity studies, decreasing the time, expense and resources spent on traditional survey methods (Klymus et al., 2017). Studies using eDNA allow researchers to identify species of amphibians not sampled by traditional sampling methods, for example, in bromeliads (Lopes et al., 2021). From this type of study, new possibilities for molecular research have emerged, which have been even more widely applied to studies of organisms.

These trends in the area of study, design and ecological level of publications, associated with the increase in papers from 2007 onwards, directly influenced the increase in knowledge about the diversity of organisms found. This progressive increase led to the peak in groups of organisms found between the years 2015 and 2018, precisely the period with the highest number of publications reported in the analysis. One of the reasons for the increase in knowledge about biodiversity in this period may be the greater number of publications at an ecosystem level, with predictive analyses and experimental studies of complex food webs, with the inclusion of organisms from primary producers like bacteria and algae (Salinas et al., 2018; Cereghino et al., 2019; Cereghino et al., 2020). Another important factor was that there was an increase in the diversity of the studied organisms, such as a description of new species of desmids of the genus *Cosmarium* (Ramos et al., 2018; Ramos et al., 2019) and new records of little-studied groups in phytotelmata, such as viruses, cyanobacteria, tecameba and fungi, expanding the knowledge of their spatial distribution (Trzcinski et al., 2016; Kratina et al., 2017; Mendes et al., 2019).

The organism group that presented the largest number of studies was insects. Within the Arthropoda phylum, the Insecta group is the most diverse, abundant and dominant (Triplehorn & Johnson 2005), distributed in numerous communities (aquatic or terrestrial). Dominant terrestrial arthropods with aquatic larvae inhabiting phytotelmata bromeliads are typically insect larvae, especially of the order Diptera, of which at least 16 families have been reported (Frank & Lounibos, 2009). In a study carried out in bromeliads, 852 taxa were found, of which 46 families were insects and 11 non-insect taxa (Céréghino et al., 2018). Among the works developed with insects, those involving the genera *Aedes*, *Sabethes* and *Haemagogus* are vectors of tropical diseases, such as dengue, chikungunya and yellow fever, sparking great interest in academic and public health studies' (Etienne et al., 2017; Faria et al., 2017; Wilke et al., 2018).

CONCLUSION

The results showed a progressive increase in the number of publications on bromeliad phytotelmata, mainly in South America, possibly as a result of greater investments in ecological and zoological research centers in this region of the Americas and the creation of the BWG, a very efficient publication-producing organization. An increase in the number of publications with predictive and experimental designs was also noted, which allowed the application of ecosystem concepts, contributing to boosting scientific knowledge about these small environments.

A great diversity of organisms was found referenced in publications, especially higher taxa. These small microcosms are able to answer modern ecological questions, generating support for environmental and conservation measures. However, phytotelmata are still an understudied ecosystem when compared to large water bodies, such as lakes and rivers, and some of the limnological environments are also still poorly explored in terms of scientific research. It is intended that this scientometric article should broaden the perception of the biodiversity present in these limnic microcosms, to encourage closer attention from researchers.

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