



Organic matter decomposition in subtropical South America aquatic environments: a systematic and scientometric review

Decomposição de detritos orgânicos em ambientes aquáticos continentais em clima subtropical da América do Sul: uma revisão sistemática e cientométrica

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Abstract: Aim: To evaluate the general situation of studies on the decomposition of organic matter in aquatic environments in the subtropical region of South America. **Methods:** We compiled publications (1990-2018) with a combination of words referring to decomposition, debris, aquatic environments and South American countries with subtropical climate. The characteristics of the publications were analysed over time. **Results:** A total of 1,042 publications were found, with 106 specifically addressing the purpose of this study. For subtropical climates in South America, this research topic is incipient. Most studies were carried out in streams (39.6%) and studied the decomposition process and associated invertebrates (42.5%). There is a great deficiency of studies in lentic environments (e.g. lakes, 10%). **Conclusion:** Studies on the decomposition of organic detritus in aquatic ecosystems in the subtropical region of South America are still emerging. While the knowledge about the role of shredders is more or less understood, the importance of microorganisms on the decomposition process still needs to be better evaluated. Finally, our study demonstrated that scientific collaboration boosted publication on the topic.

Keywords: leaf degradation; organic detritus; ecological processes; scientific production; aquatic metabolism.

Resumo: Objetivo: Avaliar a situação geral dos estudos sobre a decomposição da matéria orgânica vegetal em ambientes aquáticos continentais da região subtropical da América do Sul. **Métodos:** Utilizamos bancos de dados e compilamos publicações (1990-2018) utilizando combinações de palavras referentes à decomposição, detritos, ambientes aquáticos e países da América do Sul com clima subtropical. As características das publicações foram analisadas ao longo do tempo. **Resultados:** Um total de 1.042 publicações foram encontradas, com 106 tratando especificamente do objetivo deste estudo. Em clima subtropical na América do Sul este tópico de pesquisa é incipiente. A



maioria dos estudos foi realizada em riachos (39,6%) e avaliou o processo de decomposição e a associação de invertebrados (42,5%). Há uma grande deficiência em estudos realizados em ambientes lênticos (e.g. lagos, 10%). **Conclusão:** Os estudos sobre a decomposição de detritos orgânicos em ecossistemas aquáticos na região subtropical da América do Sul são ainda emergentes. Enquanto o conhecimento sobre o papel dos fragmentadores é razoável, poucos estudos têm avaliado a importância de microrganismos no processo de decomposição. Finalmente, nosso estudo demonstrou que as colaborações científicas impulsionaram as publicações sobre o tema.

Palavras-chave: degradação foliar; detritos orgânicos; processos ecológicos; produção científica; metabolismo aquático.

1. Introduction

The decomposition of organic matter in aquatic environments is an important ecological process (Graça et al., 2015). This process is directly linked to biogeochemical cycles, contributing to nutrient cycling and to the maintenance of trophic webs in aquatic environments (Vannote et al., 1980). Decomposition also provides important ecosystem services such as controlling diseases and maintaining water quality and biodiversity (Cole et al., 2020).

The decomposition of organic matter is influenced by physical, chemical, and biological factors and is essential for the cycling of nutrients and energy flow (Farjalla et al., 1999; Hoorens et al., 2003; Gessner et al., 2010). In aquatic ecosystems, decomposition is mediated by processes that occur simultaneously including leaching, microbial conditioning, and fragmentation (Gessner et al., 1999). The leaching phase consists of the release of water-soluble compounds such as carbohydrates, phenols, and amino acids (Bärlocher, 2005). Microbial conditioning represents the colonization of organic matter by microorganisms including fungi and bacteria (Gonçalves Junior et al., 2006a). The fragmentation occurs both through physical abrasion of the water and through the action of invertebrate shredders (Gessner et al., 1999).

The source of organic matter in aquatic ecosystems can be of allochthonous or autochthonous origin (Webster & Benfield, 1986). The autochthonous sources are algae and other photosynthetic organisms, which are more common in environments where there is plenty of light incidence (Neres-Lima et al., 2016; Neres-Lima et al., 2017). Although algae are common in lentic environments, aquatic macrophytes can contribute significantly depending on the characteristics of the environment (Cunha-Santino et al., 2008). The allochthonous organic material may also be important in streams and small lakes, due to the interaction with the terrestrial environment (Webster & Benfield, 1986; Pieczyńska, 1986). In lower order lotic environments, such as those at the highest portions

of hydrographic basins, riparian vegetation is the main source of allochthonous organic matter (Vannote et al., 1980), and is composed mainly of tree leaves (~ 70%; Gonçalves Junior et al., 2006b; Gonçalves Junior & Callisto, 2013).

The decomposition of organic matter in aquatic ecosystems can vary according to the region's climate regime (Ward & Stanford, 1982), water temperature (Irons et al., 1994; Song et al., 2013), invertebrate richness (Krevš & Kučinskiene, 2017), and microbial dynamics (Suberkropp & Klug, 1976). In temperate environments, decomposition tends to be influenced mainly by the presence of shredder invertebrates (Graça, 2001; Hieber & Gessner, 2002; Boyero et al., 2011), as these organisms are adapted to cold environments (Cowan et al., 1983). In the tropics, the number of shredder invertebrates is decreased compared to temperate regions, with the decomposition being carried out mainly by microorganisms that decompose organic matter (Irons et al., 1994; Gonçalves Junior et al., 2007; Li et al., 2009). Important factors in the occurrence of shredders are altitudinal gradients, water temperature, characteristics of riparian vegetation, and water chemistry (Boyero et al., 2009; Yule et al., 2009).

Studies on organic matter decomposition have been carried out mainly in temperate and tropical zones (Abelho, 2001; Graça, 2001; Gonçalves Junior et al., 2007). On the other hand, in regions with a subtropical climate (especially in South America), studies on organic matter decomposition are incipient. In this sense, this systematic and scientometric review focuses on the survey of existing information, precisely, in the subtropical region of South America. South American regions with a subtropical climate have an average monthly air temperature over 10 °C for eight to twelve months of the year and in the coldest month the temperature is normally below 18 °C (Belda et al., 2014). The rainfall in these regions vary in amplitude depending on the meso- or micro-region, with dry summers, humid winters, or well-distributed rains throughout the year (Belda et al., 2014). In these

places, the vegetation includes different South American biomes, especially Atlantic Forest and Pampa biomes, with transition zones existing between these two biomes and tropical forests (Oliveira-Filho et al., 2015).

In this study, we did a systematic and scientometric review to assess studies on the decomposition of organic matter in continental aquatic environments in the subtropical region of South America. We evaluated the temporal patterns of scientific production, the relative contribution of the countries of South America, the existence of national and international scientific cooperation, and identified the main objectives of the studies.

2. Material and Methods

2.1 Selection of publications

We conducted the research using the Web of Science (Clarivate Analytics) and Scopus (Elsevier) databases in June 2019. We used these two bases to expand our research, given that some South American journals are not indexed in Web of Science. We searched for publications that contained the following combination of terms in the title, abstract, or keywords: (decomposition or degradation or decomposing) and (leaf* or macrophyte* or “aquatic plant*” or litter or “leaf breakdown” or “allochthonous material” or “autochthonous material” or “riparian vegetation”) and (river* or lake* or stream* or lentic* or lotic* or wetland* or reservoir* or pond* or floodplain* or lagoon* or mangrove* or estuary* or estuarine* or freshwater*) and (subtropical or Brazil* or Paraguay* or Uruguay* or Argentina* or Chile* or Venezuela* or Colombia* or Ecuador* or Peru* or Bolivia*). We used \$ and * to compile variations of the term, however, * represents any group of characters, including no characters, while \$ represents no characters or one character. In addition, we used the CU field label on the Web of Science and AFFILCOUNTRY on Scopus to define the authors' affiliation and indicate the countries (Brazil, Paraguay, Uruguay, Argentina, Chile, Venezuela, Colombia, Ecuador, Peru, or Bolivia) in South America. Our research considered publications from January 1990 to December 2018. As the Web of Science database abstracts are available only from 1991 onwards, we considered only the Scopus database from 1990, while the search on the Web of Science database started in 1991.

We reviewed the titles, abstracts and study areas to select the publications corresponding to the topic under analysis. Review articles were not

considered in this analysis. To define the study area of publications and selected only countries with a subtropical climate, we used group C of the Köppen-Trewartha climate classification (Belda et al., 2014; Figure 1). In addition, we collected the geographical coordinates of the study areas of publications and overlaid them on the climate classification map using the ArcGIS® software. From this overlap, we selected the publications that were used in the final analysis. After evaluating each publication individually, we considered only the publications that met the proposal of this study, that is, only those conducted in the subtropical climate of South America. We identified 1042 publications and, after applying the selection criteria and eliminating duplicate publications and/or studies in regions that were not of a subtropical climate in the two databases, we obtained 106 publications for our analysis.

In each selected publication we extracted general and specific information: year of publication, scientific journal where the study was published, nationality of the authors, country where the study was carried out, type of environment (i.e., wetland, river, lake, mangrove), organic matter source (i.e., autochthonous or allochthonous), experimental or field study, and objectives of the study. When evaluating the objectives of the studies, we considered whether the focus of the publication was on microorganisms, invertebrates, and loss of mass. In addition, we observed whether the objectives of the studies contemplated the entry of allochthonous material (i.e., litterfall), environmental effects on the decomposition process, or comparison of the decomposition of two or more plant species. To study the temporal trend of publications during the period of interest, we plotted the number of articles published over the years and examined the trend using a polynomial model. The type of scientific collaboration between countries was determined based on the country of the authors for each publication. The term Single Country Publication (SCP) was attributed to publications with corresponding author and co-authors belonging to the same country; Multiple Country Publication (MCP) was attributed to publications where the corresponding author and co-authors belonged to different countries (Liu et al., 2011). We analysed the data using the R environment (R Core Team, 2019) with the ‘bibliometrix’ package (Aria & Cuccurullo, 2017).

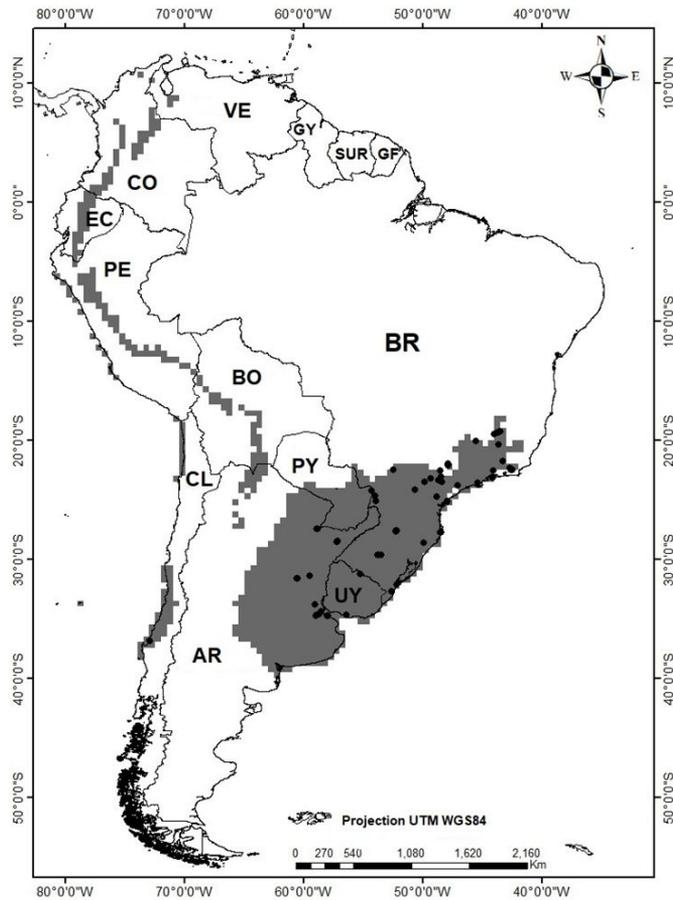


Figure 1. Map of the regions with subtropical climate in South America, based on the Köppen-Trewartha climate classification. Gray area = subtropical regions. Points: origin of the publications. AR: Argentina; UY: Uruguay; BR: Brazil; PY: Paraguay; CL: Chile; BO: Bolivia; PE: Peru; CO: Colombia; VE: Venezuela; EC: Ecuador; GY: Guyana; SUR: Suriname; GF: French Guiana.

3. Results

After our bibliographic survey, we identified a total of 1,042 publications on the proposed topic. From the reading of the study area, we selected the studies conducted in the in the subtropical region of South America, resulting in 129 publications. We subsequently performed a new screening for works focusing on aquatic ecosystems, ending with a total of 106 publications (10.1% of the original set). We observed an increase in the number of publications from 1990 to 2018 (Figure 2).

The studies were published in 61 scientific journals. The scientific journal “Brazilian Journal of Biology” published the largest number of articles (9.4%; Table 1). Of the total scientific journals, 19.8% are from South American countries, while 80.2% of the scientific journals are from North America, Europe, and Oceania.

Among the 10 countries in South America that have regions with a subtropical climate, we observed

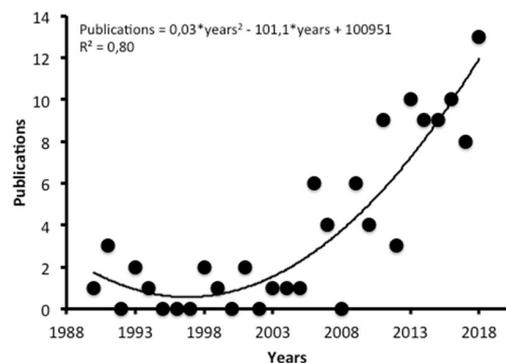


Figure 2. Number of publications on decomposition in subtropical South American aquatic environments (1990-2018).

studies carried out in Brazil (72.6% of publications), Argentina (21.5%), Ecuador (3.7%), Uruguay (3.7%), Chile (1.9%), and Colombia (1.9%). The sum of these publications exceeds 100% because studies carried out in more than one country were

Table 1. Journals with more than one publication on decomposition in subtropical South American aquatic environments, during the period between 1990 and 2018, using the Scopus and the Web of Science databases.

Journal	JIF	Number of publications	Country
Brazilian Journal of Biology	0.98	10	Brazil
Limnologica	2.05	5	Netherlands
Hidrobiológica	0.23	4	Mexico
Marine and Freshwater Research	1.85	4	Australia
Acta Limnologica Brasiliensia	0.35*	4	Brazil
Hydrobiologia	2.32	4	Netherlands
International Review of Hydrobiology	2.53	4	UK
Aquatic Botany	2.14	3	Netherlands
Ecologia Austral	0.20*	3	Argentina
Journal of Limnology	1.60	3	Italy
Wetlands	1.85	3	Netherlands
Annales de Limnologie – Int. J. of Limnology	0.82	2	France
Brazilian Journal of Microbiology	2.85	2	Brazil
Ecological Indicators	4.49	2	Netherlands
Freshwater Biology	3.40	2	UK
Fundamental and Applied Limnology	0.98	2	Germany
Interciencia	0.26	2	Venezuela
Journal of Insect Science	1.44	2	USA
Limnetica	0.57	2	Spain
River Research and Applications	1.95	2	USA
Other journals (only one publication)		41	

JIF= Journal impact factor (2018). *Scimago Journal & Country Rank is shown for journals without JIF.

Table 2. Countries (first author) that published studies about decomposition in subtropical South American aquatic environments during the period between 1990 and 2018.

Country	TP	SCP	MCP	Country
Brazil	74	66	8	Argentina, Australia, Canada, Portugal, Spain, Scotland, USA
Argentina	22	20	2	Brazil, Australia
Ecuador	2	1	1	Argentina
Portugal	2	0	2	Germany
Uruguay	2	1	1	Brazil
USA	1	0	1	Argentina
Canada	1	0	1	Chile, Portugal
Colombia	1	1	0	
Spain	1	0	1	Brazil
Total	106	89	17	

TP = Total publications; SCP = Single Country Publications: Publications with authors from a single country; MCP = Multiple Country Publications: Publications with authors from different countries.

assigned to each one separately in the analysis. When considering scientific collaboration, only 16% of the articles has international collaboration, of which 47% involve Brazilian authors (Table 2). During the period considered in this study, Brazilian authors have collaborated with authors from countries in South and North America, Oceania and Europe (Table 2).

Most of the studies were carried out in lotic systems (50.9% of publications) (Table 3). However, we observed studies carried out on lentic systems (29.2%), laboratory experiments (16.9%), and phytotelma (2.8%). Among the lotic systems, streams were the most studied ecosystems (77.7%),

Table 3. Systems and ecosystems where decomposition studies were carried out in subtropical South American aquatic environments.

System	Ecosystem	Number of publications
Lotic	Stream	42
	River	9
	Estuary	3
Lentic	Wetland	10
	Lake	11
	Reservoir	9
	Mangrove	1
Laboratory	Mesocosm	18
Phytohelmata	Bromeliaceae	3
Total		106

Table 4. Description of the objectives and number of publications about decomposition in aquatic environments at the subtropical region of South America.

Objectives	Number of publications (frequency, %)
Studies that evaluated only the litterfall	1 (0.9%)
Studies that evaluated litterfall and leaf decomposition rates	3 (2.8%)
Studies that evaluated litterfall and invertebrate fauna associated with the decomposition process	2 (1.9%)
Studies that evaluated litterfall, invertebrate fauna and microorganisms associated with the decomposition process	7 (6.6%)
Studies that described the decomposition of debris over time	11 (10.4%)
Studies comparing the decomposition rates of different plant species	11 (10.4%)
Studies that assessed the effects of environmental variables on decomposition rates	12 (11.3%)
Studies that evaluated the decomposition rates and invertebrate fauna associated with the process	45 (42.5%)
Studies that evaluated the decomposition rates and the microorganisms associated with the process	9 (8.5%)
Studies that evaluated decomposition rates, invertebrate fauna and microorganisms associated with the process	5 (4.7%)

while wetlands (32%), lakes (34%), and reservoirs (29%) where the most studied lentic ecosystems (Table 3). The leaves of aquatic macrophytes were the most frequently used source of organic matter in laboratory studies and in lentic environments. In phytohelmetata and lotic environments, leaf detritus from tree species (allochthonous origin) were the most studied substrates.

When analysing the objectives of the publications, we observed that the majority (42.5%) sought to evaluate the rates of decomposition and associated invertebrates (Table 4). In addition, 10.4% of publications aimed to describe the decomposition process, 10.4% compared the decomposition rate of two or more species, and 11.3% sought to describe environmental effects on the rates of decomposition. Only 6.6% of the publications contemplated organic matter input (i.e., litterfall) in the aquatic environments and the participation of invertebrates and microorganisms. Only one publication had the exclusive objective of describing the litterfall of tree species (Table 4). We observed that most of the publications (68.8%) evaluated the participation of biological components on the decomposition process (i.e., microorganisms or invertebrates). Of these, 45.2% of publications considered only invertebrates, 9.4% evaluated only microorganisms, and another 14.1% evaluated the participation of both biological components. Among the publications that evaluated the participation of invertebrates, 81% considered all groups and 19% evaluated only one specific group in the decomposition process (e.g., Chironomidae, Aeglididae, Plecoptera, or Trichoptera). Among the publications that evaluated the microbial component,

48% evaluated the total microbial biomass, 40% exclusively evaluated fungi, and 12% exclusively evaluated bacteria. The publications that did not evaluate the biological component (31.1%) focused on studying the leaching process, decay rates, the effect of the “litter quality” or chemical composition of organic matter, and the limnological characteristics of water on the decomposition process.

4. Discussion

Our study demonstrated that the number of publications on decomposition in subtropical South American aquatic ecosystems has increased, especially in the last 13 years. Since the beginning of the 20th century, several countries in South America have created scientific laboratories and institutions where local groups began to carry out original experimental studies recognized by the international scientific community with important contributions to knowledge (Canizares-Esguerra & Cueto, 2002). However, we note that the majority of publications in this review were concentrated in Brazil and Argentina. According to May (1997), this high scientific production may be associated with economic development. In fact, Argentina and Brazil are the two countries with the largest economies in South America (World Bank, 2021). Additionally, previous systematic reviews on aquatic ecology in South America or Neotropics showed that Argentina and Brazil were the most productive countries (Padial et al., 2008; Barbosa 2014; Dominguez & Santos, 2014; Kandus et al., 2017). The increase in publications across the years can be associated with investments in education,

science, and technology in Latin America and the increase in scientific collaboration. Since the 2000s, Brazil has expanded its scientific production (Huggett, 2012), and this has been reflected in the publication of studies in Aquatic Ecology (Dias et al., 2016; Silva & Perbiche-Neves, 2017; Junqueira et al., 2020; Tourinho et al., 2020). This expansion can be linked to the intensification of the networks of scientific collaboration between Brazilian researchers (Leta & Chaimovich, 2002) and, according to Sidone et al. (2016), geographical proximity plays an important role in collaboration networks in Brazil. For example, the first “Seminário sobre Estudos Limnológicos em Clima Subtropical” organized at the Universidade Federal do Rio Grande in 2008 had the participation of researchers and students from the three southern states of Brazil and sought to promote an approximation between research groups interested in subtropical limnology. The increase in publications in recent years coincides with the holding of these biannual scientific meetings. Public financial support and the holding of scientific meetings boosted scientific production on subtropical limnology. Despite the delay between the execution and publication of a scientific work, we suggest that the financial support and the promotion of scientific meetings favoured an increase on the number of studies about decomposition processes in subtropical aquatic environments.

We found that Brazil is the main contributor on publications about decomposition. In addition to the expansion of inter-institutional research groups, the increase in Brazilian scientific production is related to incentive policies established in the last decade (Regalado, 2010). The government's scientific development agencies (e.g., Coordenação de Aperfeiçoamento de Pessoal de Nível Superior, Conselho Nacional de Desenvolvimento Científico e Tecnológico, and State Foundations for Research) have invested significant amounts in scientific and technological development, as well as in the qualification of personnel, at various levels of academia (Borges, 2008; Dudziak, 2018). This is reflected in the increase in Brazilian scientific production in different areas, including Limnology (Melo et al., 2006; Walz, 2010). Although our research focused on South American publications, we found that the publications were not restricted to scientific journals from countries in South America. There are articles published in journals from North America and Europe, demonstrating the interest of the global scientific community for the knowledge

generated in South America, following the general pattern noted by Tourinho et al. (2020) regarding threatened freshwater fish species in Brazil.

Among the South American countries, only Brazil, Argentina, Ecuador and Uruguay published works in collaboration with researchers from other countries. The low percentage of collaboration (16%) suggests that academic research communities are still poorly connected with international collaborators. This gap has been mentioned by other authors who have carried out scientific studies on Brazilian Limnology (Melo et al., 2006), aquatic macrophytes (Padial et al., 2008), and invasive species (Barbosa, 2014). The low international collaboration in the production of articles reflects past difficulties in carrying out joint work. This pattern may be related to the fact that the realization of international collaboration, generally, results of the global view of the researcher (Neves et al., 2019). In addition, the existence of linguistic and cultural barriers and the geographical distance between countries makes it difficult to interact with foreign partners. On the other hand, these facts may favour partnerships between researchers from the same country (Sidone et al., 2016).

Lotic ecosystems (especially streams) presented the largest number of publications about decomposition. This is probably because the relevance of allochthonous organic material as energy source to streams (Vannote et al., 1980; Trevisan & Hepp, 2007; Tonin et al., 2018). Also, the high level of anthropization that streams undergo, especially due to the degradation of riparian vegetation (Hepp et al., 2016; Biasi et al., 2020), may be another reason for the great interest in conducting studies at these ecosystems. Lentic environments were studied in approximately 30% of the analysed publications. The lowest percentage of studies on decomposition in lentic environments may be related to the greatest interest in carrying out studies on primary productivity and fish communities at these environments (e.g., Quiros, 1990; Pereira et al., 2012; Guimarães et al., 2013; Albertoni et al., 2014).

As for the organisms involved in the decomposition process, our results showed that almost half of the publications considered the participation of invertebrates in the decomposition process. Despite the low percentage of shredders in the functional composition of aquatic invertebrates (Tonin et al., 2014), this group plays a fundamental role in the transformation of coarse particulate organic matter into fine particulate organic

matter (Tonello et al., 2016). We also found that studies describing the decomposition process of aquatic macrophytes or allochthonous organic matter were common. Considering that studies on decomposition in the subtropical region of South America are recent, the description of the process is a basic and fundamental objective for advancing more applied research. The percentage of studies analysing microorganisms is low due to the difficulty of studying bacteria and aquatic fungi, in addition to the small number of researchers in this area (Gulis & Bärlocher, 2017; Raja et al., 2018). The choice of organic material used in the decomposition experiments was based on the frequency of this material in the areas adjacent to the studied environments (Fontana et al., 2020; Biasi et al., 2020).

We observed a great number of investigations on invertebrates associated with leaf detritus. The use of detritus as a food resource or substrate for invertebrates is widely discussed in the literature (Graça, 2001; Telöken et al., 2014; Albertoni et al., 2018). However, a low percentage of the invertebrate community is directly related to the process of transforming organic matter (i.e., shredders) (Ligeiro et al., 2010; Telöken et al., 2011; Carvalho et al., 2015; Albertoni et al., 2018). The larvae of the *Phylloicus* genus (Calamoceratidae, Trichoptera) are the shredder invertebrates that are widely found in aquatic environments in subtropical South America (Holzenthal et al., 2007) and we found that it is the most-studied genus because of its wide distribution.

Our analysis did not detect decomposition studies within broader topics, such as climate change, diversity loss, or relationships between diversity of resources and diversity of detritivores. Considering that even basic studies on decomposition in subtropical aquatic environments in South America are still scarce, studies aiming to answer broader questions are practically non-existent. Alternatively, projects on a global scale (e.g., Boyero et al., 2011; Tiegs et al., 2019) may inhibit the interest in carrying out more local studies, such as those in South America. Despite recent financial investments in science in some South American countries such as Brazil, increased financial resources in technology are necessary to set up and maintain research groups. This would facilitate the conduction of studies aiming to answer broader questions, such as the effects of climate change or other anthropogenic influences.

Although the decomposition process is complex (Gessner et al., 1999), few studies considered all stages (i.e., leaching, microbiological conditioning, and fragmentation) of the decomposition process. We also found that the understanding of the decomposition process mediated by microorganisms is still underdeveloped in the South American region, probably due to the low number of researchers specializing in the identification of fungi, as well as the analytical complexity of bacterial studies (Gulis & Bärlocher, 2017).

We observed a low number of studies that focused on decomposition processes in aquatic environments at the subtropical regions of South America. However, it is clear that the number of publications is increasing, indicating the growing interest of the scientific community on this subject. Our analysis highlighted some important directions for future studies, such as the need to expand international collaboration, the need to advance studies focusing on microorganisms and on lentic ecosystems, as well as studies on gut content or isotopic analysis of detritivores to better understand their food preferences.

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