

Study of the mayfly order Ephemeroptera (Insecta) in Brazil: a scientiometric review

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ABSTRACT. Study of the mayfly order Ephemeroptera (Insecta) in Brazil: a scientiometric review. Despite an increase in the number of studies in recent years of the aquatic insect order Ephemeroptera (the mayflies) much still remains to be learnt. In order to identify the current state of knowledge of this group in Brazil, we performed a scientiometric analysis with the purpose of identifying the strong and weak points of Brazilian research into the group. Our research used the “Institute for Scientific Information – ISI” database and was based on the abstracts, titles and keywords of manuscripts published between 1992 and 2011. We selected the papers with the combination of the words “Ephemeroptera” and “Brazil*” based on a search in February 2012. We analyzed 92 articles, and noted a lack of studies in some Brazilian states, no specific studies about some families, and an absence of phylogenetic studies. To improve ecological studies, it is necessary to fine-tune taxonomic resolution. Moreover, there is a lack of studies investigating the environmental variables which influence the distribution of mayflies. Despite these gaps, if the rate of publication with mayflies proceeds at the same pace, we anticipate that many of these knowledge gaps will be closed.

KEYWORDS. Biogeographic database; citation analyses; knowledge gaps; knowledge states; sampling effort.

The interest in the study of aquatic insects started in the 1930s and 1940s because of studies with sport fishing interests (Merritt *et al.* 2008). Nowadays, these aquatic insects have become one of the groups most utilized in aquatic ecosystem and ecology research, often as water quality bio-indicators (*e.g.* Cummins 1973; Vison & Hawkins 1998; Voelz & McArthur 2000; Melo 2009; Dias-Silva *et al.* 2010; Juen & De Marco 2011; Couceiro *et al.* 2012; Monteiro-Júnior *et al.* 2013).

One of the most important insect orders in aquatic ecosystems is the Ephemeroptera—the mayflies. These insects spend most of their life as immatures in water and emerge only to copulate and disperse; living first as subimagos, then imagos for a brief period, just two or three days in most of the species (Edmunds *et al.* 1976). The order is notable for including members in all functional feeding groups, and by being abundant and inhabiting most aquatic freshwater regions (Barber-James *et al.* 2008). The interest in studying the potential of mayfly nymphs as biologic indicators has increased in recent years. Following the accumulation of organic pollutants in streams and lakes there are concurrent changes in their abundance, sometimes resulting in local extinction (Da-Silva & Salles 2012).

The first comprehensive study concerning mayflies in the Neotropical realm was published in 1924 (Needham & Murphy 1924). Almost 100 years have passed and the taxonomy of the group is still considered poorly-known in Brazil (Da-Silva & Salles 2012). According to Hubbard (1982), until the referred year, no general catalog of Ephemeroptera was published for

the region. Recently, however, it has been possible to observe a progress in the study of this order in Brazil following the growing number of publications (*e.g.* Brito *et al.* 2011; Gonçalves *et al.* 2011a; Gonçalves *et al.* 2011b; Lima *et al.* 2011; Mariano 2011; Molineri *et al.* 2011; Salles & Lima 2011; Souto *et al.* 2011; Boldrini *et al.* 2012; Couceiro *et al.* 2012).

Our goal was to carry out a scientiometric analysis of the order Ephemeroptera in Brazil. We aim to answer the following questions: (i) What is the rate of growth in scientific production with Ephemeroptera in recent years in Brazil? (ii) Are these papers being cited by others authors? (iii) In which regions and states of Brazil are these studies being carried out? (iv) In which journals are these studies being published? (v) Which are the most studied groups in Brazil? (vi) Which are the main characteristics and gaps in scientific production, taxonomic resolution, study type and life stage? Through this research it will be possible to identify the main knowledge gaps in the current literature of Brazilian mayflies once most part of knowledge will be summarize in this manuscript. By pointing the gaps, we hope to call attention to what remains to be done and studied within the order, encouraging new researches in poorly known areas.

MATERIAL AND METHODS

Our bibliographic research was carried out through the database of the “Institute for Scientific Information – ISI” (<http://portal.isiknowledge.com>). The research was based on

the abstracts, titles and keywords of papers published between 1992 and 2011. Papers presenting the combination of words “Ephemeroptera” and “Brazil*” were selected.

To answer our questions, we analyzed information about the year of publication, the number of citations per year, journal, region and state where mayflies were sampled and the taxa studied in each paper. Papers involving more than one geographic region were counted once only for each region or state. Taxonomic groups were divided into three classes: Ephemeroptera (papers dealing with just one taxon inside the order), other groups (papers with groups cited like “macroinvertebrates”, “benthos”, “Insecta”, “aquatic insects” or “aquatic invertebrates”) and EPTs (papers dealing with the entire local community of Ephemeroptera, or Ephemeroptera and Trichoptera, or Ephemeroptera, Plecoptera and Trichoptera).

For information about taxonomic resolution, type of study and life stage, the following categories were used: (1) Taxonomic resolution. “Species”, “morphospecies”, “genus” or “family”. When this information was not found in the abstract, we consulted the main body of the paper. When more than one resolution was used in the same article, we considered resolution applied for more than 50% of the identified taxa. (2) Study type. “Ecological with field approach”, “ecological with experimental/observational approach”, “taxonomical”, “phylogenetic” or “species lists”. We considered field approaches when the paper utilized a systematic methodology resulting in standardized and independent samples. We considered differences in experimental/observational approaches where results were either conducted in the laboratory or by direct observation (field or laboratory). “Taxonomical” were those papers that present species description or redescription, taxonomic recombination or identification keys. “Phylogenetic” were ones that presented character matrices and phylogenetic analyses. Finally, “species lists” were considered when the paper presented species lists or when only new records were reported. Papers that encompassed more than one category counted for more than one category (example: papers of species description accompanied by a phylogenetic analysis). (3) Life stage. “Nymph”, “imago” or “both”.

RESULTS AND DISCUSSION

We found 114 papers concerning the Ephemeroptera in Brazil. Five of them, however, were carried out by Brazilian authors, but not in Brazil, three did not focus on Ephemeroptera as the study group, and 14 dealt with stomach contents of fish (of which mayflies were found in their diet). These papers were removed from the analysis, and 92 papers remained to be analyzed. Although recognizing that our research method left out non-indexed papers, we believe that the standardization of the research is valid for our aim. In case of adopting a manual search to add information, we could inadvertently insert gaps in our results by adding non-indexed papers or by inserting papers that have not been reviewed by

qualified referees. Using only papers within the ISI database, we ensure that all papers analyzed have been carefully reviewed. There are many examples of previous papers using only data from the ISI database (*e.g.* Melo *et al.* 2006; Carneiro *et al.* 2008; Padial *et al.* 2010; Thomaz *et al.* 2010).

Between 1992 and 2011, in four different years in the decade of the 1990s (1993, 1994, 1995 and 1998) there were no papers published on mayflies in Brazil (Fig. 1). After 2008, there was a rapid increase in the number of publications, and 2011 was the most productive year, with 23 published papers. More than one third of the papers were published in the last two years (36 papers). This tendency is concurrent with the increase of scientific papers of aquatic macrophytes in the Neotropics (Padial *et al.* 2008) and with international journals on limnology (Melo *et al.* 2006). A reason for the ascendant interest in aquatic insects can be related to the use of these orders as water bioindicators, as argued by Rosenberg & Resh (1993), Hynes (1984), Merritt *et al.* (1984) and Resh & Rosenberg (1984), as well as an increased interest in stream ecology (Allan 1995).

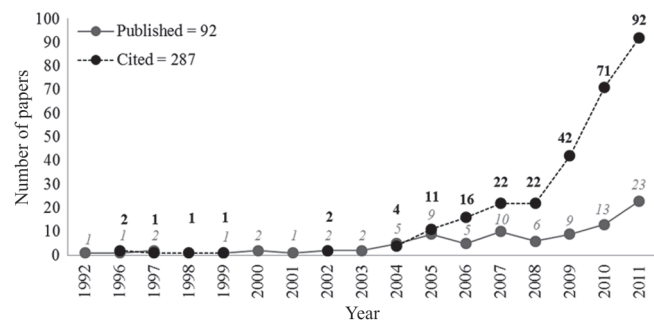


Fig. 1. Number of papers with the order Ephemeroptera (Insecta) published and cited in Brazil, between 1992 and 2011. Bold numbers above represent cited papers and italic numbers below represent published ones.

The 92 published papers were cited 287 times (Fig. 1), of which the most cited was Buss *et al.* (2002), cited 35 times, followed by Melo (2005) (cited 23 times) and Moulton *et al.* (2004) (cited 22 times). These three papers have an ecological approach. The first one investigated the influence of environmental factors on the macroinvertebrate fauna, the second one, on the impact of changes in taxonomic resolution on spatial patterns of macroinvertebrates and the third one investigated the relation between mayfly and shrimp communities and periphyton and sediment. It is clear that ecological papers are most cited than others. Thirty of the 92 studied papers were not cited at all, and the remaining papers were cited one (18 papers), two (11 papers), three (nine papers), four (seven papers), five (two papers), six (four papers), seven (three papers), eight (two papers) and 12, 14, 15, 22, 23 and 35 times (one paper each of them). This is the general pattern of the distribution of citations for scientific papers as proposed by Padial *et al.* (2010), in which few papers receive a high number of citations, whereas most articles receive few or no citations at all.

When we analyzed the regions in which the studies were conducted (Fig. 2), southeastern Brazil was the most studied, with more than 50% of the Brazilian publications (48) and Rio de Janeiro was the most-studied state, largely the result of the researchers J. Nessimian and E. Da-Silva. In the northern region, the laboratory coordinated by N. Hamada in Amazonas state occupied the second place in the publication rank. The high number of publications in Amazonas is also a result of the partnership accomplished by research groups led by N. Hamada and F. F. Salles. Ten of the 15 published papers incorporating data from the Amazon basin were made in association with these specialists. The large amount of work performed in the other northern states is reflective of the new researchers' formation by the *Instituto de Pesquisa da Amazônia* – INPA, that is currently working in Roraima and Amazonas.



Fig. 2. Number of papers published with the order Ephemeroptera (Insecta) in Brazilian regions (below left) and in the Brazilian States, between 1992 and 2011. White states do not have published papers.

The northeast region is the least studied. Less than 10% of the papers published in Brazil were with mayflies sampled in this region, and three of the nine states still did not have any work up to the date of our search (Rio Grande do Norte, Paraíba and Sergipe). We also found a lack of knowledge in the northern region, with three states without published papers (Acre, Amapá and Tocantins), despite being the region with the second highest number of papers, as noted by Salles *et al.* (2004). In the midwest region we could not find studies carried out in the Distrito Federal.

The 92 papers were published in 23 journals. The most used journals were *Zootaxa*, *Aquatic Insects* and *Annales de Limnologie* (all non-Brazilian journals, Fig. 3). The first one

focus on systematics papers, the second one, on systematics and ecology papers with aquatic insects, and the last one, only on ecology papers. Among the Brazilian journals, the most frequently used were *Revista Brasileira de Zoologia* (currently *Zoologia*), *Revista Brasileira de Entomologia* and *Iheringia Série Zoologia*. All of them publish in both systematics and ecology.

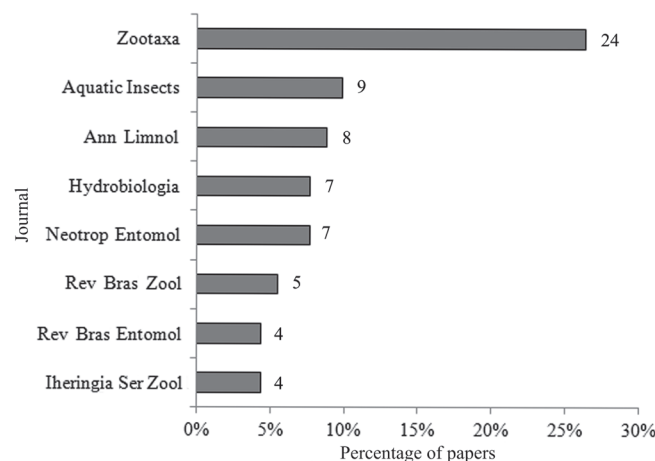


Fig. 3. Percentage and number of published papers in each of the most popular periodicals with the order Ephemeroptera (Insecta) in Brazil, between 1992 and 2011.

When we analyzed the taxonomic groups, 64 papers (more than 70%) dealt exclusively with a single family of Ephemeroptera, 17 papers comprised Ephemeroptera, Plecoptera and Trichoptera (EPT) and 11 papers dealt with others groups too. The papers dealing with more than one family, in general, were ecology papers or species lists. Only five of the ten families found in Brazil had at least one paper dedicated to them (Fig. 4A). Our results show that Caenidae, Coryphoridae, Euthyplociidae, Ephemeridae and Melanemerellidae did not have a single paper dealing specifically with them, being only mentioned in species checklists. However, we are aware of a paper that cover one of these families in Brazil, Molineri & Domínguez (2003), that were not included in the ISI results. It must be also pointed that Coryphoridae and Melanemerellidae are monotypic, minimizing the possibility of taxonomic papers being carried out. Euthyplociidae and Ephemeridae, in spite of being non-monotypic, have a low diversity in South America (Domínguez *et al.* 2006). Euthyplociidae has four recorded species to Brazil and Ephemeridae just one (Salles *et al.* 2012). Finally, Caenidae is little studied in Brazil with respect to taxonomy as well as to ecology. In Brazil, 12 of the 19 recorded species have been cited only in the paper containing their respective original description (see <http://ephemeroptera.com.br>).

Baetidae, on the other hand, was the most studied family, with almost 45% of the papers (27). Probably, the available resources allowing for identification at the larval stage of this family have contributed to this result once the knowl-

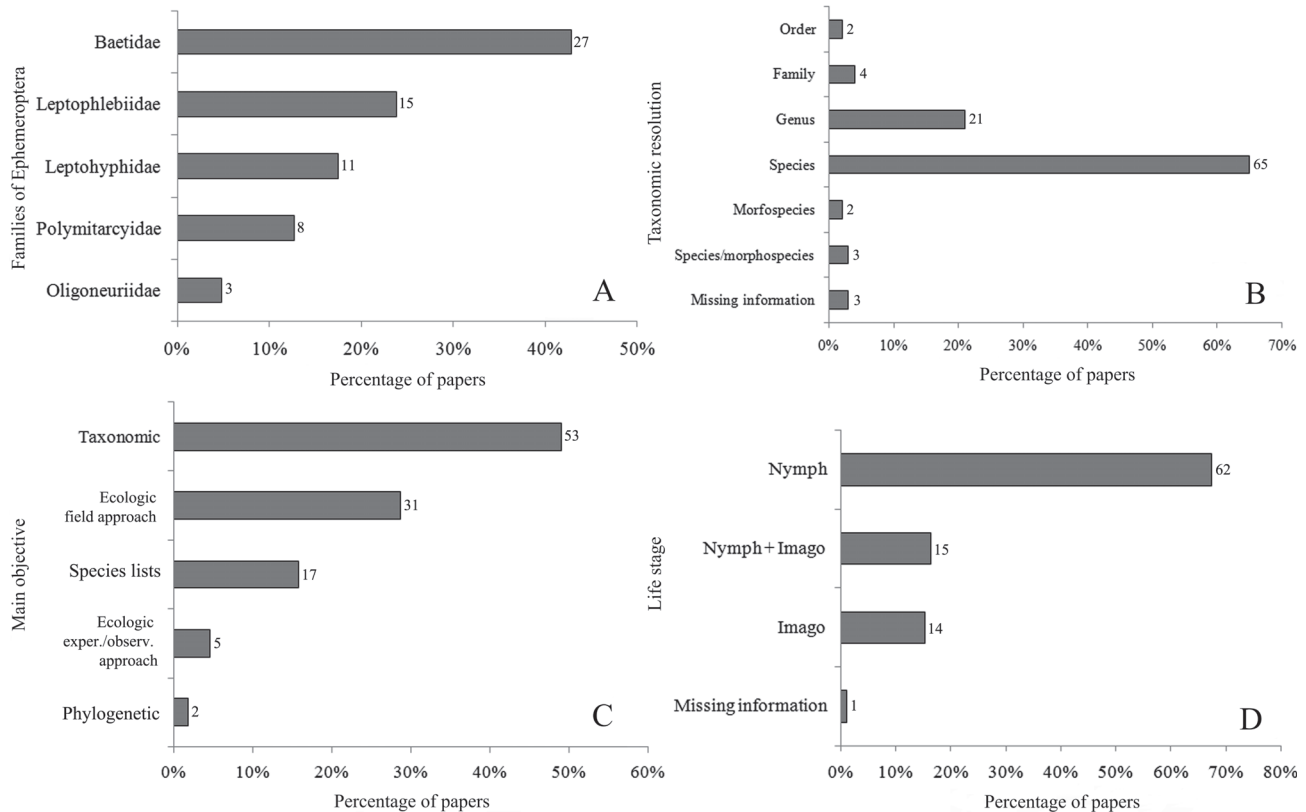


Fig. 4. Percentage and number of published papers according to: Ephemeroptera families (A); taxonomic resolution (B); main objective (C) and life stage of mayflies (D), between the years 1992 and 2011.

edge regarding nymphal stage characters useful for identifying genera and species of Baetidae has increased substantially (Waltz & Burian, 2008). Also, the high diversity of the taxon (83 species recorded from Brazil in Salles *et al.* 2012) may have contributed almost 50% of papers about Ephemeroptera. Another important factor is the high quantity of specialist researchers working on Baetidae, at least five nowadays (employed specialists plus doctoral students).

We believe that the five most studied families provide representative ecological data for the order since all functional feeding groups are found in these families (Shimano *et al.* 2012). Gathering-collectors are represented by Baetidae, Euthyplociidae and Leptohyphidae, filtering-collectors by Oligoneuriidae and Leptophlebiidae, predators by Baetidae, scrapers by Baetidae and Leptophlebiidae, and finally, shredders by Leptophlebiidae.

Most papers (65%) provided identifications at species level (Fig. 4B). The increase of studies with species-level identification is probably a consequence of the publication of an identification key for the Brazilian mayflies (Salles 2006) and of the book "Ephemeroptera of South America" (Domínguez *et al.* 2006). Salles' (2006) identification key has images of relevant body structures, allowing for reliable genus-level identification, and therefore making species identification possible. Domínguez *et al.* (2006), in turn, offers species keys for most South American taxa. Furthermore, there has been more papers dealing with taxonomy, there-

fore reflecting in more papers with species level identifications. According to Merritt *et al.* (2008), identification at the species level is important in ecological studies as congeneric species do not necessarily have the same ecological requirements or identical water quality tolerance.

Considering the type of study, almost 50% of the papers are species descriptions or identification keys (Fig. 4C). There is also a considerable amount of papers dealing with the ecology of Ephemeroptera (31; 30%), but most were conducted together with others orders (Trichoptera and Plecoptera), aquatic insects or even with macroinvertebrates in general. Only one ecological paper evaluated the environmental influence on the Ephemeroptera community (Buss *et al.* 2002). According to Buss *et al.* (2002), Riparian Channel Environment index, dissolved oxygen and dissolved chloride were acting on Ephemeroptera communities together with those of other macroinvertebrates.

The review papers, those including species lists and new or additional records, also represent a considerable percentage of studies (17%). The first list of Brazilian mayfly species (Salles *et al.* 2004) reported 10 families, 63 genera and 166 species. Today, 10 families, 68 genera and 233 species have been recorded (Salles *et al.* 2012). Even so, according to Da-Silva & Salles (2012) it is assumed that twice as many species still remain to be described or recorded in Brazil. A large current gap is found in the study of Ephemeroptera systematics (only 2% of the papers), with only two papers

published in the studied period (Nieto & Salles 2006; Salles *et al.* 2009).

The majority of the papers (almost 70%) studied nymphs (Fig. 4D). According to Waltz & Burian (2008), the major part of taxonomical and ecological papers with Ephemeroptera is focused on nymphs because of the brief adult life and their limited activity. Moreover, in ecological cases, nymphs are much more important due their role in aquatic nutrient cycle (Cummins *et al.* 2008). Only one ecological paper dealt with imagoes, but, mayflies were identified at the order level (Silva *et al.* 2011). The high number of taxonomic papers dealing with nymphs is probably due to the paucity of information in old descriptions (sometimes only a single paragraph). One way to solve part of the taxonomic uncertainties for aquatic insects is through the association between nymphs and imagoes (Merritt *et al.* 2008), what is reflected in the higher percentage of studies dealing with nymph-imago associations (16.3%) compared to the percentage of studies involving only imagoes (15.2%). In addition, apparently, nymphs are easier to sample than imagoes, and require less financial resources.

Concluding, the main gaps found with research on Ephemeroptera in Brazil are: (1) a lack of mayflies studies in some Brazilian states (Rio Grande do Norte, Paraíba, Sergipe, Acre, Amapá, Tocantins and the Distrito Federal), (2) absence of specific studies with some families in Brazil, such as: Caenidae, Coryphoridae, Euthyplociidae, Ephemeridae and Melanemerellidae, (3) absence of studies dealing with phylogenetic relationships, (4) need for improvement of the taxonomic resolution in ecological studies, especially when considering future conservation actions, and (5) lack of knowledge about the environmental variables which may be affecting the distribution of these organisms.

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