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Co-authorship networks (and other contextual factors) behind the growth of taxonomy of South American Ephemeroptera: A scientometric approach

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Abstract

Science carried out in South America has experienced a major rise in the levels of productivity and impact during the last decade. The continuity of this process depends upon strong policy decisions of personnel training and of increasing investments. We study the effects of a new regional paradigm, specifically, an increasing international visibility through knowledge support, using the particular case of taxonomy of an ancient group of insects (Ephemeroptera) in South America. We tracked the number of new species described in scholarly papers along a period of two centuries. We have also mined patterns of connections from the respective co-authorship network. A quantitative framework to analyze historical sequences of scientific output is also proposed. Our results point out three stages of taxonomic development: (i) a pioneering stage (1800's–1970's) where foreign authors coming from Europe and North America account for almost the totality of described species, (ii) a transitional stage (1980's–1990's) where new species are described by both foreign and regional authors, and (iii) an autonomous stage (1999–present) where the bulk of scientific output is performed by regional authors. Remarkably, the transitional stage coincides with the advent of democracy in the region. We hypothesize that conjunction of funding and interactions between researchers act synergistically to foster an autochthonous taxonomy in South America.

Key words: network analysis, research and development, systematics, funding

Introduction

Taxonomy is the science concerned with the exploration, description and analysis of species and their phylogenetic relationships (Anonymous 1994a, 1994b). This discipline plays a central role in all branches of biological sciences because it delivers the basic and indispensable knowledge of the life on Earth. Since we still depend on our knowledge on the living world around us for increasing our chances of survival and welfare, the importance of taxonomy also radiates to different human activities. Taxonomy, although fundamental, is the hidden service behind activities ranging from biodiversity conservation to food security, human welfare, new industrial products, and eco-tourism (Smith *et al.* 2011). Despite its significance, taxonomy is often perceived as relevant only to specialists working at natural history museums and universities. Because there may be no clear economic benefit in the short to medium term, taxonomy has long suffered funding shortages. According to Wheeler (2004:571) “Taxonomy, already weakened by decades of neglect, now suffers the loss of positions and funding to studies that reconstruct phylogeny that improve neither formal classifications nor the application of scientific names”. Besides these problems, the formation of taxonomists requires long periods of training before they become productive. For this reason, the interruption of funding for even short periods affects severely this long term preparation because specialists must shift their activities and rarely return to taxonomy. Nevertheless, it appears that in South America there is a significant growth in taxonomic output in recent times. Then, a natural question arises: is this trend coupled with a process of monetary injection into the scientific system?

In Latin American countries, Science and Technology (S&T) research depends primarily on public funding (Hansen *et al.* 2002). Therefore, it is subjected to the economic fluctuations and political inconstancy that

undermine the necessary continuity of taxonomic research. As a case study, we will focus on Ephemeroptera, a small order of aquatic insects. We used this group because, although a conspicuous element in the freshwater ecosystem, it has no relevance on economic or sanitary matters, being a good candidate to reflect neutrally the impact of research investment. Here we will study the development of taxonomic knowledge in South America and its associations to funding resources and origin of authors and their interaction. With regards to funding, it is impossible to know the exact percentage of S&T resources that is dedicated to taxonomy in the region, and even more complicated to determine which part of this is applied to Ephemeroptera. This situation is mainly due to the fact that grants that use part of its funding for these studies are requested by other disciplines, such as "Limnology", "Water Monitoring", or "Ecology" for example. For this, we made the assumption that the same percentage of the total annual S&T resources is dedicated to systematics of Ephemeroptera throughout the years. The S&T investment has been increasing in Latin American countries, since the return of democracy starting in the 80's. Before that time, the bulk of taxonomic publications were produced by authors from outside the region (North America and Europe), shifting later the leading role towards regional (South American) authors.

Peer-reviewed publications portray valuable information for evaluation of scientific productivity such as number of publications per period of time, number and nationality of authors and year of publication. A scientific paper reveals the cultural context of its authors and the nature of the scientific discipline from which it draws and to which it contributes (Gupta & Kumar 2001). A careful evaluation of periodical literature delivers valuable information about the discipline, the profession it represents and anything related to it (Davaranah & Aslekia 2008). The bibliometric approach to S&T is based on quantitative characteristics, attributes or objects of documentary flows. A principal assumption underlying the use of bibliometric indicators is that scholars publish their research findings in the publicly available literature and that one may obtain snapshots of scholarly activities from a quantitative analysis of scholarly documents (Garfield 1979). We will focus here on the publications referring to the description of species that are still considered as valid entities. With these data, we ask the following questions:

- a) How has the knowledge of South American Ephemeroptera improved through time?
- b) Is there any pattern in the collaborative efforts for the descriptions of new species?
- c) Is there any kind of correlation between funding and leading role of regional authors in taxonomic outputs?

Material and methods

The scientific data were obtained from published taxonomic works on South American Ephemeroptera up to December 2012. Most of the information was gathered from two on-line specialized catalogs (Dominguez *et al.* 2012; Kluge 2012) and a specialized on-line Ephemeroptera library (Ephemeroptera Galactica: www.ephemeroptera-galactica.com). These catalogs are based on all the bibliographic sources relevant to Ephemeroptera systematics. Additional data were obtained through searches using the Electronic Library of Science and Technology, Argentine Ministry of Science and Technology (www.biblioteca.mincyt.gov.ar), and Google Scholar web service. Appendix 1 includes the resulting list of valid species with their authors and year of publication. Taxonomic research involves several different types of studies and publications (taxon description, revisions, phylogenetic studies, etc.). Here, we will consider only valid species descriptions to evaluate taxonomic production. The advance of taxonomic knowledge must be measured not by the mere number of species described, but for the species that remain valid after the scrutiny performed by other specialists. Synonymy is a common artifact (species described more than once) that misrepresents productivity and if neglected could distort the actual advancement of the discipline. Furthermore, species descriptions are more standardized activities than other taxonomic tasks (revisions, phylogenetic studies, etc.) that can be much more variable in breath, reach and degree of elaboration, and therefore more complicated to compare.

The data about investment for S&T were taken from the web site of the *Red de Indicadores de Ciencia y Tecnología* (RICYT, <http://www.ricyt.org>) and contrasted with data provided by the World Bank (<http://data.worldbank.org>). Participants of RICYT include the national agencies for S&T of all Ibero-American countries, as well as universities, national institutes for statistics and Non-Governmental Organizations from all over the world. The general objective of RICYT is to promote the development of instruments for measuring and analyzing S&T in Ibero-America.

Data from scientific publications (number and origin of the involved authors, number of species described and year of publication) were tabulated. We also considered the current status of the described species (i.e. valid/invalid) by cross-checking its validity status with the latest publications. We separated the pool of authors into two sets in function of their provenance, namely South American authors (SA) and Non-South American ones (Non-SA). We took into account that this characterization was not only in agreement with the birthplace of the authors but also with the place where they have achieved their main academic background. We modeled the growth in the number of valid species described along the time using least-squares regressions. We adjusted separate curves for SA and Non-SA authors and compared their trends.

We studied the structure of co-authorship under two analytical strategies: 1) using boxplots for the number of co-authors detected at certain time intervals, and 2) constructing a network of scientific collaboration. The first approach enables us to understand better the social tendencies for collaborative work in Ephemeroptera systematics. The second approach highlights the flow of information in the system under study. The different authors are the actors or nodes of the network, whereas its edges or links represent co-authorship. Given a pair of authors indexed through i and j , we calculate the strength or weight of the link between them as follows:

$$c_{ij} = c_{ji} = \sum_k (\delta_{ijk} N_k) / (A_k)^2$$

where $\delta_{ijk} = 1$, when i and j are authors in publication k , otherwise $\delta_{ijk} = 0$. N_k and A_k represent the number of valid species described in publication k and the number of authors included in the publication k respectively. The advantage of this quantitative procedure is that the final symmetric matrix C yields a grand total equal to the total number of described species in the area under consideration. The values of the diagonal are also calculated, representing the unique contribution of single authors, in addition to the partial contribution derived from shared author papers.

We explored the modular nature of the network via label propagation algorithm (Raghavan *et al.* 2007). This is a fast, nearly linear time algorithm for detecting community structure in networks. It works by labeling the vertices with unique labels and then updating the labels by majority voting in the neighborhood of the vertex. A second property of the network investigated was the association between the productivity of authors and their centrality in the topology of the simple underlying co-authorship network. Productivity was estimated from the marginal totals of the previous matrix C and corresponds to the effort for describing species apportioned among co-authors. Thus, the productivity of an author corresponds to the overall sum of authorship credits. For each described species, authorship credit is allocated by dividing this credit equally among all coauthors. Centrality measures were used to estimate the topological location of the authors in the network. For each node, we calculated the following measures of centrality: degree (number of direct connections), betweenness (frequency of occurrence in the shortest paths connecting pairs of nodes), closeness (inverse of the sum of geodesic distances to all other nodes) and eigenvector centrality (derived from the respective value in the principal eigenvector of the adjacency matrix defining the network). By using a Kruskal-Wallis rank sum test, we search for statistical differences in the scores of centrality between the subset of most prolific (greater than the median of productivity) and less prolific (lower than then median of productivity) authors. In Appendix 2 we provide the basics of network analysis and a more detailed explanation of these centrality measures using a worked example.

To define an optimal period of critical contributions from SA authors, we designed an index based on the product of two parameters: *Prevalence* and *Representativeness*. Prevalence is the proportion of contributions performed by SA authors against the total production recorded in a given period. Representativeness is the proportion of contributions of SA authors in a given period against the whole SA authors' production. Let $[T_o, T_f]$ be our target time interval; let R be the contribution of SA authors restricted to the target interval; let W_t be the total production in the target interval (SA + Non-SA authors), and let W_s be the total production of SA authors. Then, our index ζ (Greek lowercase final *Sigma*), or *Characteristic fraction of production* is defined as:

$$\zeta = (R/W_t) (R/W_s) = R^2 / (W_t W_s)$$

We focus here on all possible time intervals ending in 2012, searching for the lower end of the target interval that maximizes the coefficient ζ . Once the characteristic time interval is identified, we studied the evolution of funding in this period. All statistical analyses were performed through the R platform (R Development Core Team 2012).

Results

Bibliographic production

The first South American mayfly species was described by Weber (1801), followed by 211 years of contribution reaching at present a total of 565 valid species, involving 107 authors. Partitioning the production of this period into time intervals, it is possible to recognize a trend going from Non-SA (foreign) to SA (regional) prevailing authorship (Fig. 1). Additionally, the increase of SA authors is accompanied by a collaboration process with the Non SA authors. The last decade is clearly dominated by regional authors.

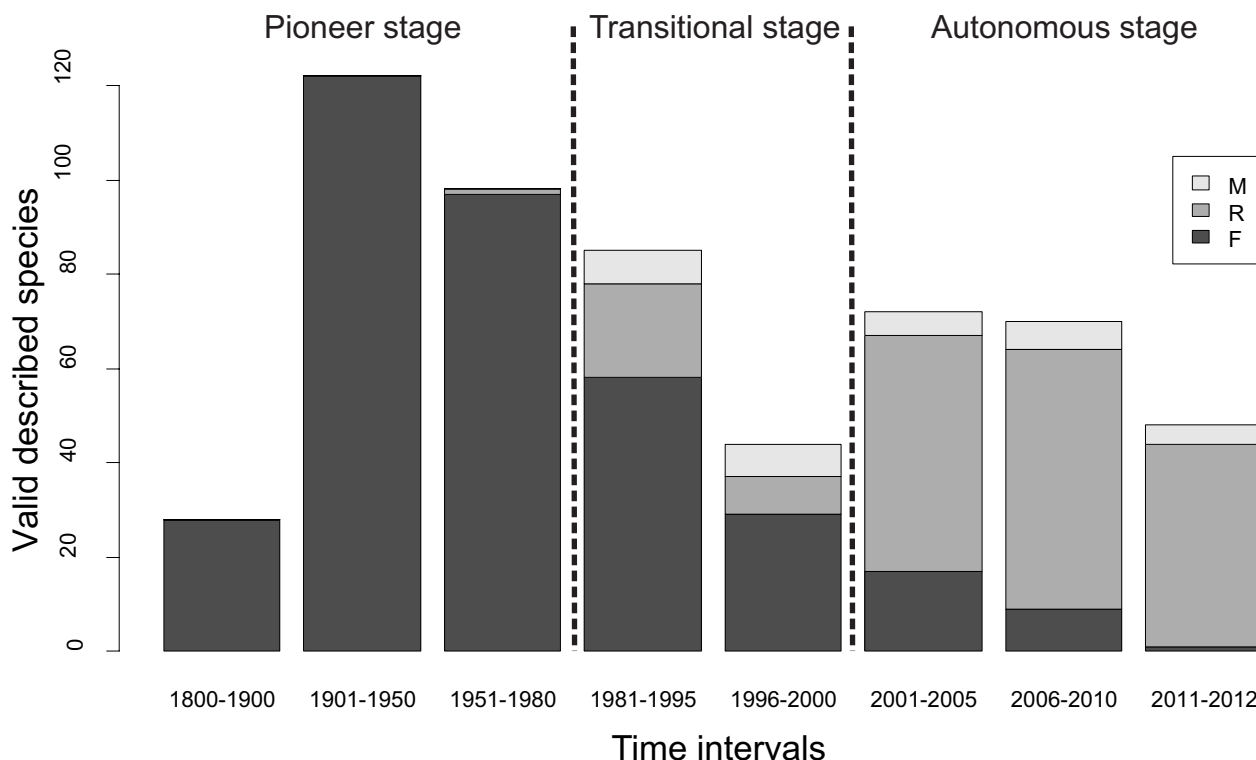


FIGURE 1. Number of valid species described by period. Species described by foreign (F), regional (R) and mixed (M) authors are represented by different tones. Note that binned time intervals do not represent equal periods.

The curve of cumulative number of species (Fig. 2A) follows a growing trend, with no sign of reaching a plateau. When disaggregated in its regional and foreign components, two different behaviors can be recognized. While foreign contributions adjust to a direct linear relationship with time (Fig. 2B), the regional ones accommodate to an exponential growth function (Fig. 2C). The characteristic period of regional production as revealed by the ζ coefficient spans from 1999 to 2012 (Fig. 3).

In South American, Brazil and Argentina are responsible for the majority of publications on mayfly systematics (Fig. 4). Interestingly, Argentina is always present in regional collaborative papers.

Co-authorship patterns

The proportion of descriptions portrayed by different numbers of authors points out an opposite profile of publication behavior regarding origin of authors (foreign, regional and mixed; Table 1). While the majority of descriptions performed by foreign authors were produced by a single author (66%), in the case of the regional descriptions, the collaboration is more common (59%). In the case of mixed collaboration (foreign - regional) the bulk was done by only two authors (65%). There is a clear tendency for collaboration towards the present time (Fig. 5). In this regard, most of the publications of single or double authorship are found below the critical threshold of 1999. On the contrary, most of the publications of multiple authorships are above this year.

TABLE 1. Cross-tabulation for the totality of valid Ephemeroptera species, all of them recorded at South America, according to the number and origin of the authors involved in their description. The column Foreign accounts for the descriptions performed by Non-South American authors, whereas the column Regional corresponds to descriptions performed by South American authors. The third column (called Mixed) counts the descriptions performed by regional and foreign authors in collaboration. Note that collaboration is more frequent in regional production than in foreign descriptions, being the latter characterized by the prevalence of single authorship.

| Number of authors | Foreign | Regional | Mixed |
|-------------------|---------|----------|-------|
| 1 | 238 | 72 | --- |
| 2 | 114 | 56 | 19 |
| 3 | 7 | 41 | 8 |
| 4 | 0 | 5 | 1 |
| 5 | 0 | 3 | 1 |

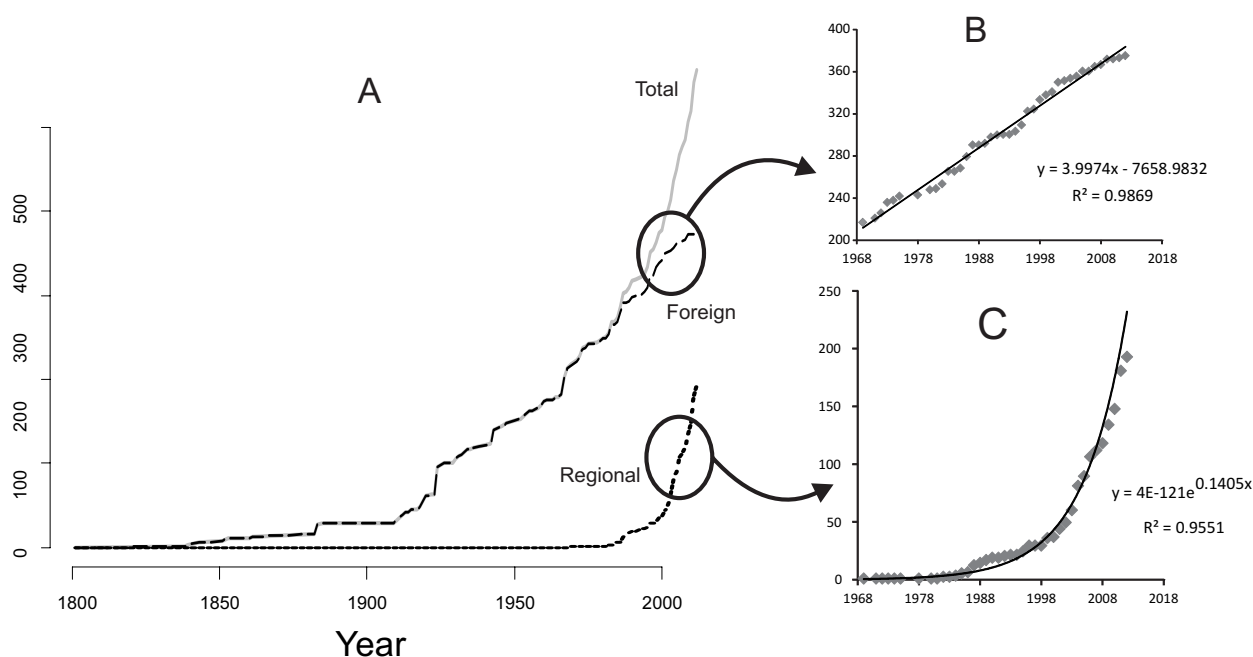


FIGURE 2. (A) Cumulative number of valid species described in South America since the first description in 1801 (in grey), total number disaggregated in contributions by foreign (dashed line) and regional (dotted line) authors. (B) and (C) Detail of respective cumulative curves from 1968 to 2012. Least-squares regression lines with their equations and goodness of fit coefficient shown.

Figure 6 displays the resultant co-authorship network. Sixty-six out of the universe of 108 authors are connected to the major component (the largest group of connected authors). The remaining authors are either isolated, or distributed in minor components of sizes two, three and seven. The minor component of size seven has the distinct characteristic that all its members share the French nationality, and that the study area was French Guiana. Table 2 lists the authors and their attributes. The foreign authors represent a disaggregated pool of elements. Several of them are disconnected from the major component while others are connected to it but only peripherally (see empty squares in Fig. 6A). When considering the mixing patterns, the regional authors can be differentiated by their homophily/heterophily profile of connections (here, homophily and heterophily mean a tendency to connect with authors of the same or different nationalities respectively). The Brazilian authors present a mainly homophylic pattern. The rest of regional authors (Argentinean, Colombian and Venezuelan) on the other hand, present a heterophilic behavior. As a consequence of this, Brazilian authors are mainly concentrated in communities M and N (green circle and red triangle respectively, Figure 6B). On the other hand, community F is more promiscuous as their members belong to all the nationality categories here considered.

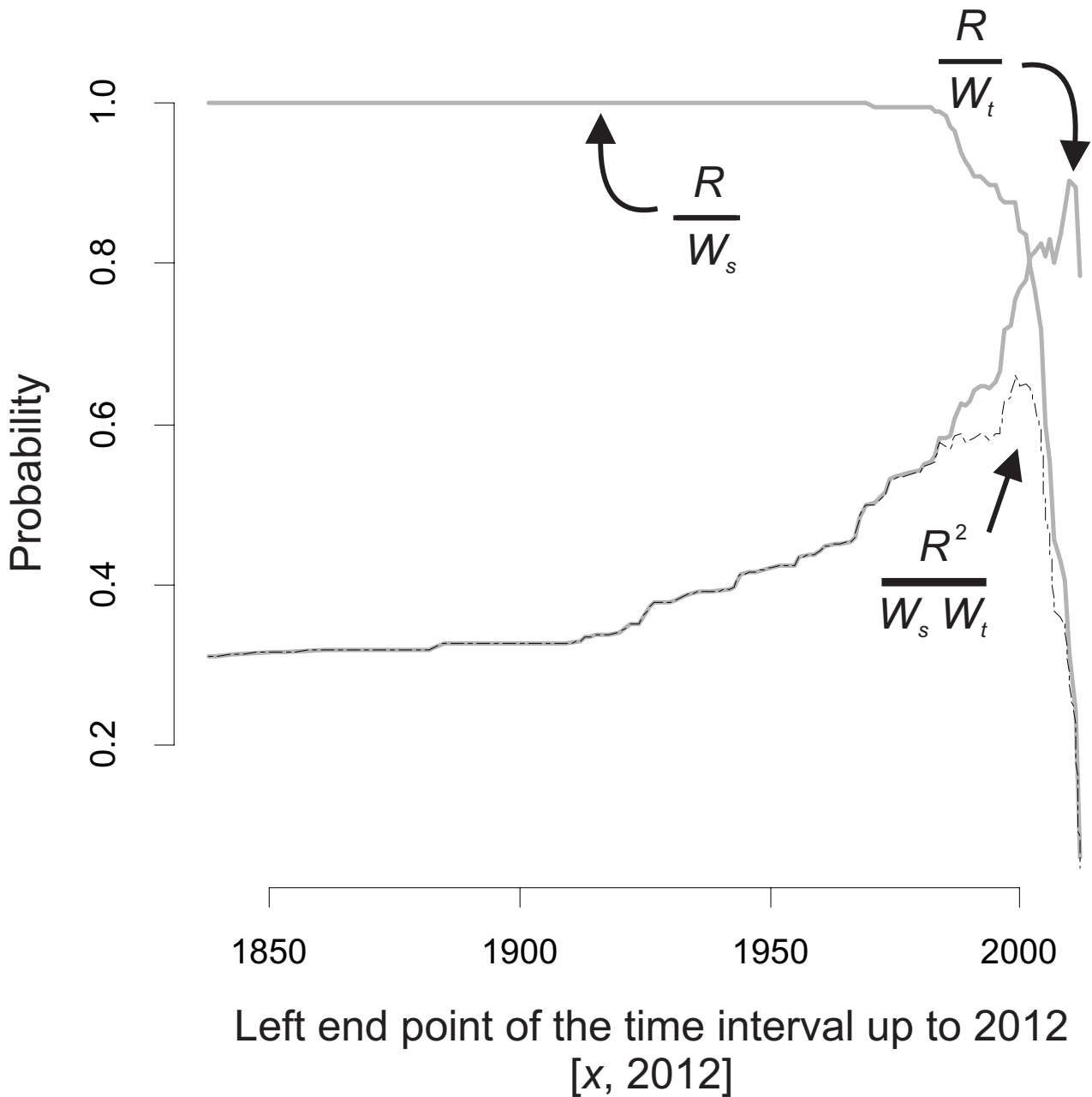


FIGURE 3. Characteristic fraction of author production measured for different intervals. The fractions R/W_t and R/W_s represent the prevalence and representativeness of regional author production respectively. R = Number of valid species described by regional authors within the target time interval; W_t = Total number of valid species described within the target time interval; W_s = Total number of valid species described solely by regional authors. Dashed line corresponds to coefficient ζ and its maximum corresponds to the period [1999, 2012]. In this period: (i) the overall production is dominated by South American authors, and (ii) the bulk of South American production is included.

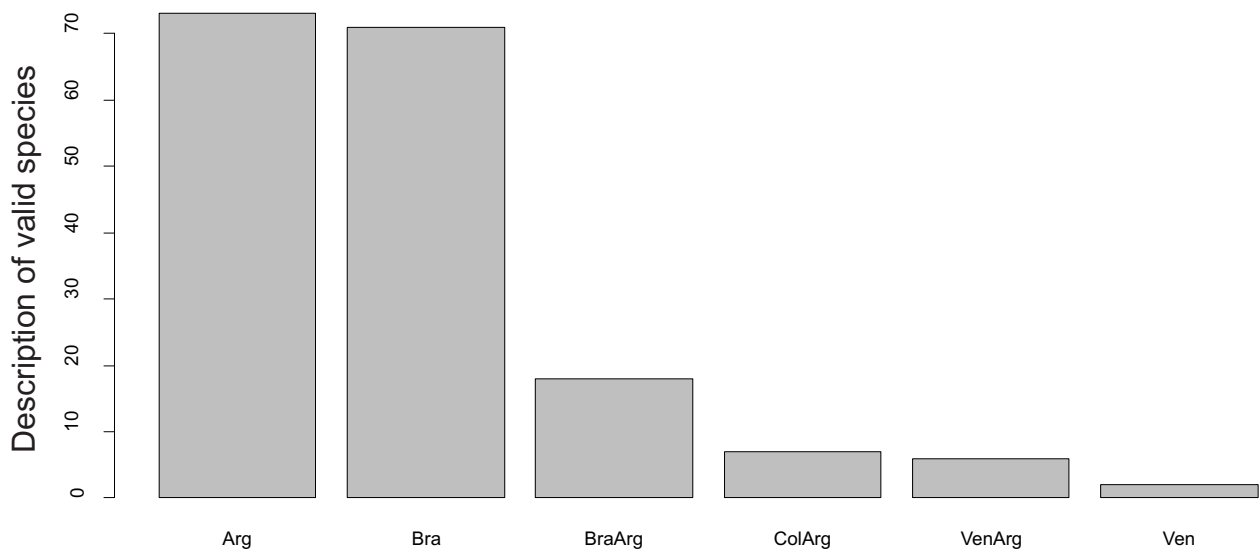


FIGURE 4. Barplot showing the production of South American authors, including collaborative works. Production measured as number of valid species described.

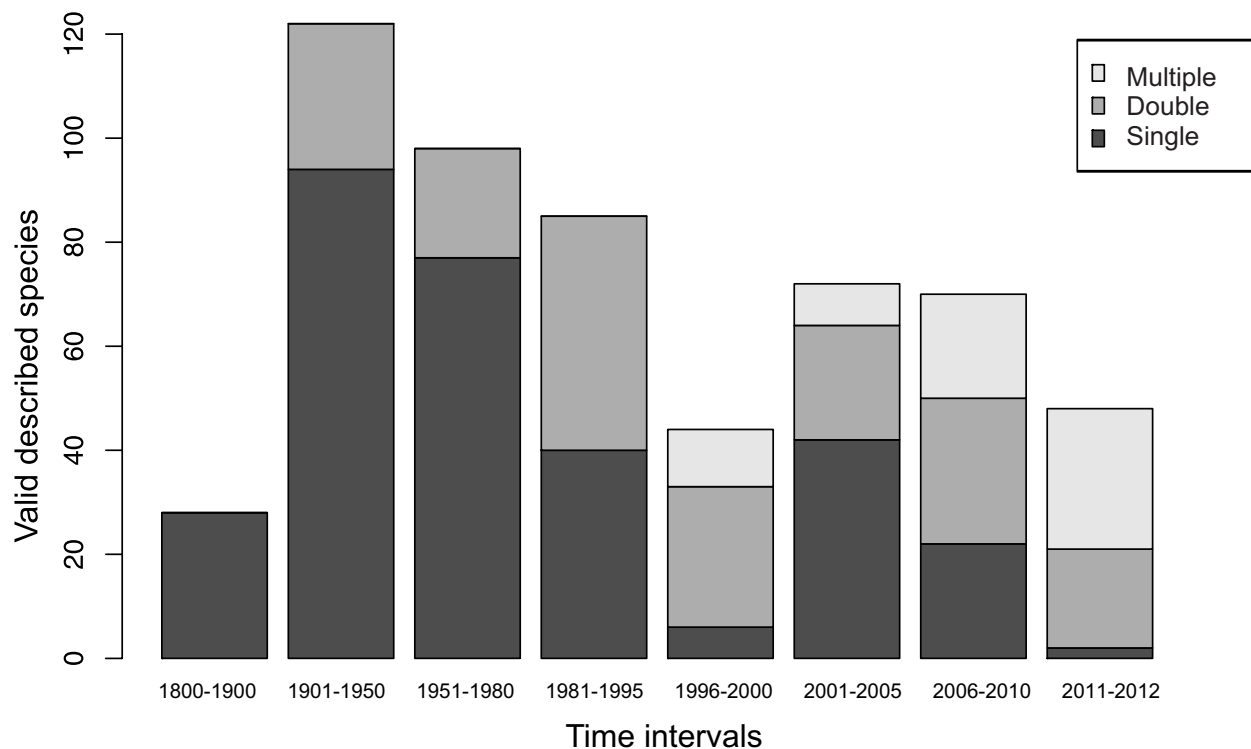


FIGURE 5. Number of valid species described by different number of authors across time. Time interval match those of Figure 1.

The authors of the largest component contribute differently to the total number of valid species. Kruskal-Wallis rank sum test revealed significant differences ($P < 0.01$) for the centrality measures of node degree and betweenness when the set of most prolific authors is compared with the set of less prolific ones. In other words, the most productive authors are those that attract many connections and act as bridges between pairs of unconnected authors. Null hypothesis of no difference between these set of authors could not be rejected using Eigenvector and closeness centrality measures. Figure 7 shows the distribution of the different centrality measures for both productivity sets.

TABLE 2. Detailed information about the different authors involved in species description of South American Ephemeroptera. Node labels used in Figure 5 are in column *ID*. The *Community membership* column corresponds to the classification of authors into research communities as inferred by the label propagation algorithm implemented on the co-authorship network. Authors of ambiguous membership are indicated through an underscore. Isolated are unconnected authors. Foreign authors are consigned as Non-SA in the *Origin* column, whereas regional authors are discriminated by their nationality: Arg, Argentinean; Bra, Brazilian; Col, Colombian; Ven, Venezuelan. Topological measures of centrality associated with the co-authorship network as well as the scores of productivity for each author are reported in the last five columns (see text).

| ID | Author | Community membership | Origin | Degree Centrality | Betweenness Centrality | Closeness Centrality | Eigenvector Centrality | Productivity |
|----|----------------|----------------------|--------|-------------------|------------------------|----------------------|------------------------|--------------|
| 1 | Alba-Tercedor | A | Non-SA | 1 | 0.000 | 1.000 | 0.000 | 0.500 |
| 2 | Allen | B | Non-SA | 1 | 0.000 | 1.000 | 0.000 | 24.500 |
| 3 | Andrade | M/N | Bra | 2 | 0.000 | 0.006 | 0.015 | 0.333 |
| 4 | Bacca | M | Col | 4 | 0.333 | 0.006 | 0.021 | 1.083 |
| 5 | Banks | Isolated | Non-SA | 0 | 0.000 | 0.000 | 0.000 | 6.000 |
| 6 | Barcelos | M | Bra | 2 | 0.000 | 0.006 | 0.014 | 0.333 |
| 7 | Batista | M | Bra | 2 | 0.000 | 0.006 | 0.014 | 1.500 |
| 8 | Belmont | M | Bra | 2 | 0.000 | 0.006 | 0.014 | 1.333 |
| 9 | Berner | K | Non-SA | 1 | 0.000 | 1.000 | 0.000 | 0.500 |
| 10 | Blanchard | Isolated | Non-SA | 0 | 0.000 | 0.000 | 0.000 | 1.000 |
| 11 | Boldrini | M | Bra | 5 | 3.250 | 0.006 | 0.024 | 2.500 |
| 12 | Boutonnet | L | Non-SA | 1 | 0.000 | 0.091 | 0.000 | 0.500 |
| 13 | Burmeister | Isolated | Non-SA | 0 | 0.000 | 0.000 | 0.000 | 1.000 |
| 14 | Cabette | M | Bra | 2 | 0.000 | 0.004 | 0.004 | 0.333 |
| 15 | Castillo | I | Ven | 1 | 0.000 | 0.333 | 0.000 | 0.500 |
| 16 | Chacon | C | Ven | 3 | 0.000 | 0.005 | 0.010 | 1.333 |
| 17 | Cockerell | Isolated | Non-SA | 0 | 0.000 | 0.000 | 0.000 | 1.000 |
| 18 | Cruz | M | Bra | 7 | 33.836 | 0.006 | 0.032 | 1.667 |
| 19 | Currea | F | Col | 2 | 0.000 | 0.005 | 0.009 | 0.333 |
| 20 | Da Silva | N | Bra | 9 | 164.962 | 0.006 | 0.026 | 4.583 |
| 21 | De-Souza | M/N | Bra | 3 | 3.810 | 0.006 | 0.021 | 1.500 |
| 22 | Demoulin | Isolated | Non-SA | 0 | 0.000 | 0.000 | 0.000 | 15.000 |
| 23 | Derka | H | Non-SA | 3 | 124.000 | 0.005 | 0.005 | 2.833 |
| 24 | Dias | M | Bra | 7 | 125.617 | 0.006 | 0.025 | 4.417 |
| 25 | Dominguez | F | Arg | 18 | 724.100 | 0.008 | 0.054 | 28.633 |
| 26 | Dominique | L | Non-SA | 3 | 0.500 | 0.111 | 0.000 | 4.000 |
| 27 | Eaton | Isolated | Non-SA | 0 | 0.000 | 0.000 | 0.000 | 9.000 |
| 28 | Edmunds | D | Non-SA | 3 | 125.000 | 0.004 | 0.002 | 9.000 |
| 29 | Emmerich | H | Arg | 3 | 1.667 | 0.005 | 0.016 | 5.833 |
| 30 | Esben-Petersen | Isolated | Non-SA | 0 | 0.000 | 0.000 | 0.000 | 7.000 |
| 31 | Ferreira | M | Bra | 4 | 0.533 | 0.006 | 0.022 | 1.333 |
| 32 | Flowers | F | Non-SA | 5 | 5.000 | 0.005 | 0.017 | 8.700 |

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TABLE 2. (Continued)

| ID | Author | Community membership | Origin | Degree Centrality | Betweenness Centrality | Closeness Centrality | Eigenvector Centrality | Productivity |
|----|---------------|----------------------|--------|-------------------|------------------------|----------------------|------------------------|--------------|
| 33 | Francischetti | M | Bra | 6 | 15.000 | 0.006 | 0.026 | 1.583 |
| 34 | Froehlich | F | Bra | 3 | 13.217 | 0.005 | 0.007 | 2.833 |
| 35 | Gillies | Isolated | Non-SA | 0 | 0.000 | 0.000 | 0.000 | 2.000 |
| 36 | Giordano | F | Arg | 1 | 0.000 | 0.005 | 0.007 | 0.500 |
| 37 | Gonçalves | N | Bra | 2 | 0.000 | 0.005 | 0.006 | 2.167 |
| 38 | Grillet | F | Ven | 4 | 0.000 | 0.006 | 0.021 | 0.600 |
| 39 | Guerrero | F | Ven | 4 | 0.000 | 0.006 | 0.021 | 0.600 |
| 40 | Hagen | Isolated | Non-SA | 0 | 0.000 | 0.000 | 0.000 | 2.000 |
| 41 | Hamada | M | Bra | 3 | 0.750 | 0.006 | 0.018 | 2.000 |
| 42 | Horeau | L | Non-SA | 2 | 0.000 | 0.100 | 0.000 | 0.333 |
| 43 | Hubbard | F | Non-SA | 4 | 0.000 | 0.005 | 0.014 | 3.200 |
| 44 | Kluge | Isolated | Non-SA | 0 | 0.000 | 0.000 | 0.000 | 7.000 |
| 45 | Lestage | Isolated | Non-SA | 0 | 0.000 | 0.000 | 0.000 | 3.000 |
| 46 | Lima | M | Bra | 3 | 0.500 | 0.006 | 0.016 | 2.000 |
| 47 | Lopes | F | Bra | 3 | 41.517 | 0.006 | 0.011 | 0.833 |
| 48 | Lugo-Ortiz | E | Non-SA | 4 | 240.000 | 0.006 | 0.019 | 15.750 |
| 49 | Malzacher | F | Non-SA | 1 | 0.000 | 0.005 | 0.006 | 16.500 |
| 50 | Mariano | F | Bra | 6 | 83.750 | 0.007 | 0.031 | 7.333 |
| 51 | Massariol | M | Bra | 1 | 0.000 | 0.006 | 0.012 | 1.000 |
| 52 | Mathuriau | L | Non-SA | 2 | 0.000 | 0.100 | 0.000 | 0.667 |
| 53 | Mayo | Isolated | Non-SA | 0 | 0.000 | 0.000 | 0.000 | 12.000 |
| 54 | McCafferty | E | Non-SA | 4 | 185.000 | 0.005 | 0.003 | 16.167 |
| 55 | Medina | I | Ven | 1 | 0.000 | 0.333 | 0.000 | 0.500 |
| 56 | Molineri | F | Arg | 12 | 191.462 | 0.007 | 0.048 | 34.933 |
| 57 | Moll | Isolated | Non-SA | 0 | 0.000 | 0.000 | 0.000 | 1.000 |
| 58 | Morihara | D | Non-SA | 1 | 0.000 | 0.003 | 0.000 | 0.500 |
| 59 | Mosquera | A | Col | 1 | 0.000 | 1.000 | 0.000 | 0.500 |
| 60 | Murphy | G | Non-SA | 1 | 0.000 | 1.000 | 0.000 | 14.000 |
| 61 | Nascimento | M | Bra | 4 | 2.833 | 0.006 | 0.020 | 1.000 |
| 62 | Navas | Isolated | Non-SA | 0 | 0.000 | 0.000 | 0.000 | 32.000 |
| 63 | Needham | G | Non-SA | 1 | 0.000 | 1.000 | 0.000 | 15.000 |
| 64 | Nessimian | N | Bra | 4 | 26.055 | 0.006 | 0.019 | 2.667 |
| 65 | Nieto | H | Arg | 8 | 279.352 | 0.007 | 0.035 | 31.100 |
| 66 | Orth | L | Non-SA | 2 | 0.000 | 0.100 | 0.000 | 0.833 |
| 67 | Percheron | Isolated | Non-SA | 0 | 0.000 | 0.000 | 0.000 | 1.000 |
| 68 | Pereira | N | Bra | 1 | 0.000 | 0.005 | 0.003 | 3.500 |
| 69 | Perez | I | Ven | 2 | 1.000 | 0.500 | 0.000 | 1.000 |

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TABLE 2. (Continued)

| ID | Author | Community membership | Origin | Degree Centrality | Betweenness Centrality | Closeness Centrality | Eigenvector Centrality | Productivity |
|-----|------------|----------------------|--------|-------------------|------------------------|----------------------|------------------------|--------------|
| 70 | Peru | L | Non-SA | 2 | 0.000 | 0.100 | 0.000 | 1.333 |
| 71 | Pes | M | Bra | 3 | 0.000 | 0.006 | 0.018 | 0.500 |
| 72 | Pescador | J | Non-SA | 5 | 184.000 | 0.006 | 0.013 | 9.833 |
| 73 | Peters | J | Non-SA | 4 | 12.000 | 0.006 | 0.018 | 17.500 |
| 74 | PetersJ | F | Non-SA | 5 | 1.500 | 0.005 | 0.015 | 0.533 |
| 75 | Pictet | Isolated | Non-SA | 0 | 0.000 | 0.000 | 0.000 | 4.000 |
| 76 | Pinheiro | M | Bra | 2 | 0.000 | 0.006 | 0.014 | 0.667 |
| 77 | Polegatto | M | Bra | 4 | 67.533 | 0.006 | 0.015 | 1.833 |
| 78 | Puthz | Isolated | Non-SA | 0 | 0.000 | 0.000 | 0.000 | 2.000 |
| 79 | Py-Daniel | F/N | Bra | 2 | 0.000 | 0.005 | 0.005 | 0.333 |
| 80 | Raimundi | M | Bra | 1 | 0.000 | 0.006 | 0.012 | 0.500 |
| 81 | Richards | H | Non-SA | 1 | 0.000 | 0.005 | 0.005 | 1.500 |
| 82 | Roback | B | Non-SA | 1 | 0.000 | 1.000 | 0.000 | 1.500 |
| 83 | Salinas | M | Col | 3 | 0.000 | 0.006 | 0.018 | 0.750 |
| 84 | Salles | M | Bra | 30 | 1374.924 | 0.009 | 0.087 | 26.000 |
| 85 | Sartori | Isolated | Non-SA | 0 | 0.000 | 0.000 | 0.000 | 1.000 |
| 86 | Savage | J | Non-SA | 5 | 1.500 | 0.005 | 0.016 | 12.700 |
| 87 | Schloegel | H | Non-SA | 2 | 0.000 | 0.004 | 0.001 | 0.333 |
| 88 | Segnini | C | Ven | 3 | 0.000 | 0.005 | 0.010 | 1.333 |
| 89 | Serrao | M | Bra | 1 | 0.000 | 0.006 | 0.012 | 1.500 |
| 90 | Shimano | M | Bra | 2 | 0.000 | 0.006 | 0.015 | 0.667 |
| 91 | Siegloch | F/M | Bra | 2 | 0.000 | 0.004 | 0.003 | 0.333 |
| 92 | Sites | E | Non-SA | 2 | 0.000 | 0.004 | 0.000 | 0.667 |
| 93 | Soares | M | Bra | 2 | 0.000 | 0.006 | 0.015 | 0.333 |
| 94 | Soldan | Isolated | Non-SA | 0 | 0.000 | 0.000 | 0.000 | 2.000 |
| 95 | Sousa | M | Bra | 2 | 0.000 | 0.004 | 0.004 | 0.333 |
| 96 | Spieth | Isolated | Non-SA | 0 | 0.000 | 0.000 | 0.000 | 7.000 |
| 97 | Svitok | H | Non-SA | 2 | 0.000 | 0.004 | 0.001 | 0.333 |
| 98 | Thew | K | Non-SA | 1 | 0.000 | 1.000 | 0.000 | 4.500 |
| 99 | Thomas | L | Non-SA | 6 | 11.500 | 0.167 | 0.000 | 6.333 |
| 100 | Traver | D | Non-SA | 1 | 0.000 | 0.003 | 0.000 | 36.500 |
| 101 | Ulmer | Isolated | Non-SA | 0 | 0.000 | 0.000 | 0.000 | 17.000 |
| 102 | Walker | Isolated | Non-SA | 0 | 0.000 | 0.000 | 0.000 | 4.000 |
| 103 | Waltz | E | Non-SA | 1 | 0.000 | 0.004 | 0.000 | 1.500 |
| 104 | Wang | E | Non-SA | 2 | 0.000 | 0.004 | 0.000 | 0.667 |
| 105 | Weber | Isolated | Non-SA | 0 | 0.000 | 0.000 | 0.000 | 0.000 |
| 106 | Weyenbergh | Isolated | Non-SA | 0 | 0.000 | 0.000 | 0.000 | 6.000 |
| 107 | Zuñiga | F | Col | 2 | 0.000 | 0.005 | 0.014 | 3.500 |

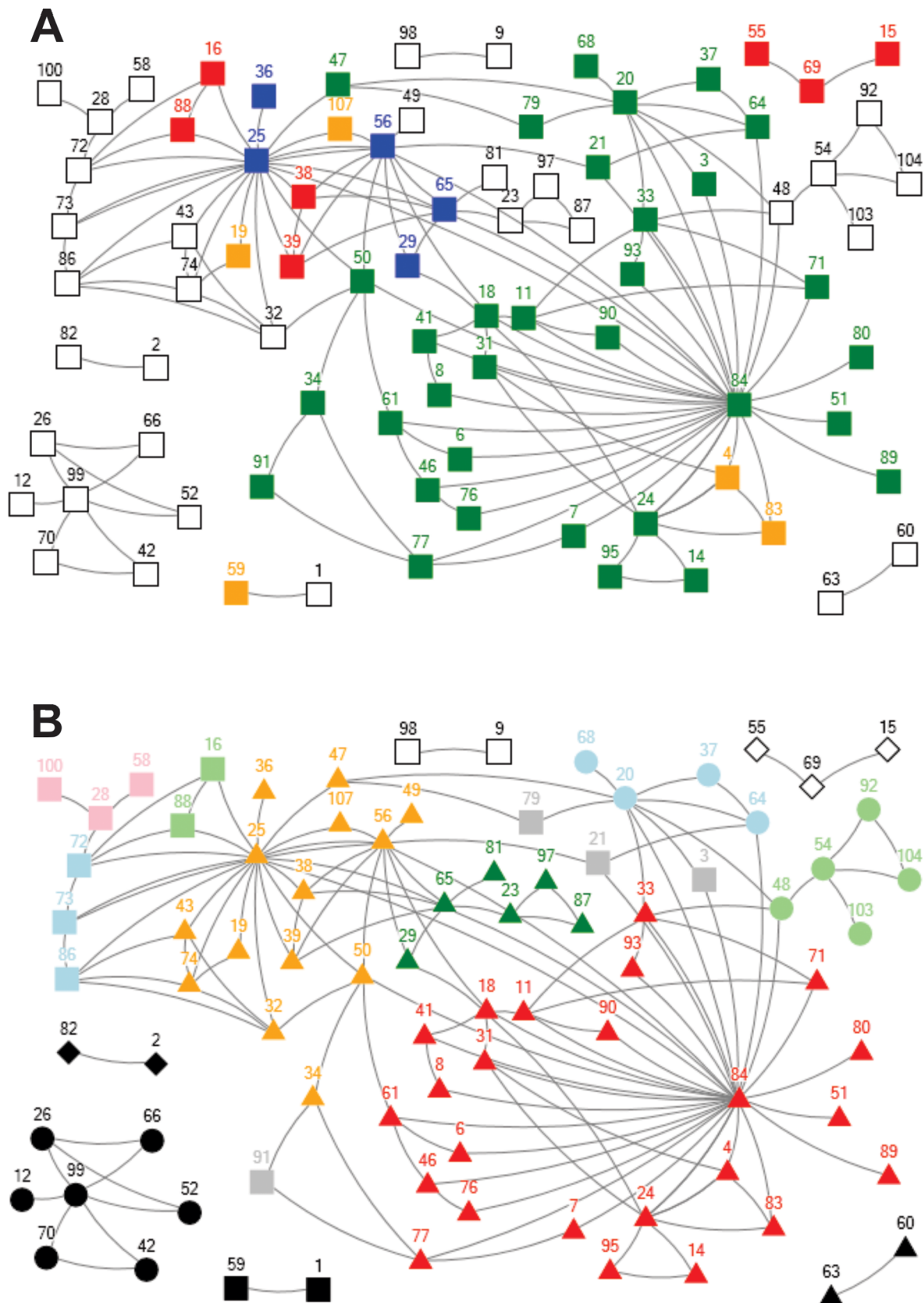


FIGURE 6. Co-authorship network. Each author is linked to others whenever they share credits in the South American Ephemeroptera valid species description. The same layout is used in A and B. A, Origin, same colored nodes represent same nationality or geographical category: Argentinean, blue; Brazilian, green; Colombian, orange; Venezuelan, red; NSA, empty squares. B: Community, same colored and shaped nodes represent group membership. Isolated nodes (i.e. single authors without links) have been omitted. For the label of nodes (authors), see Table 2.

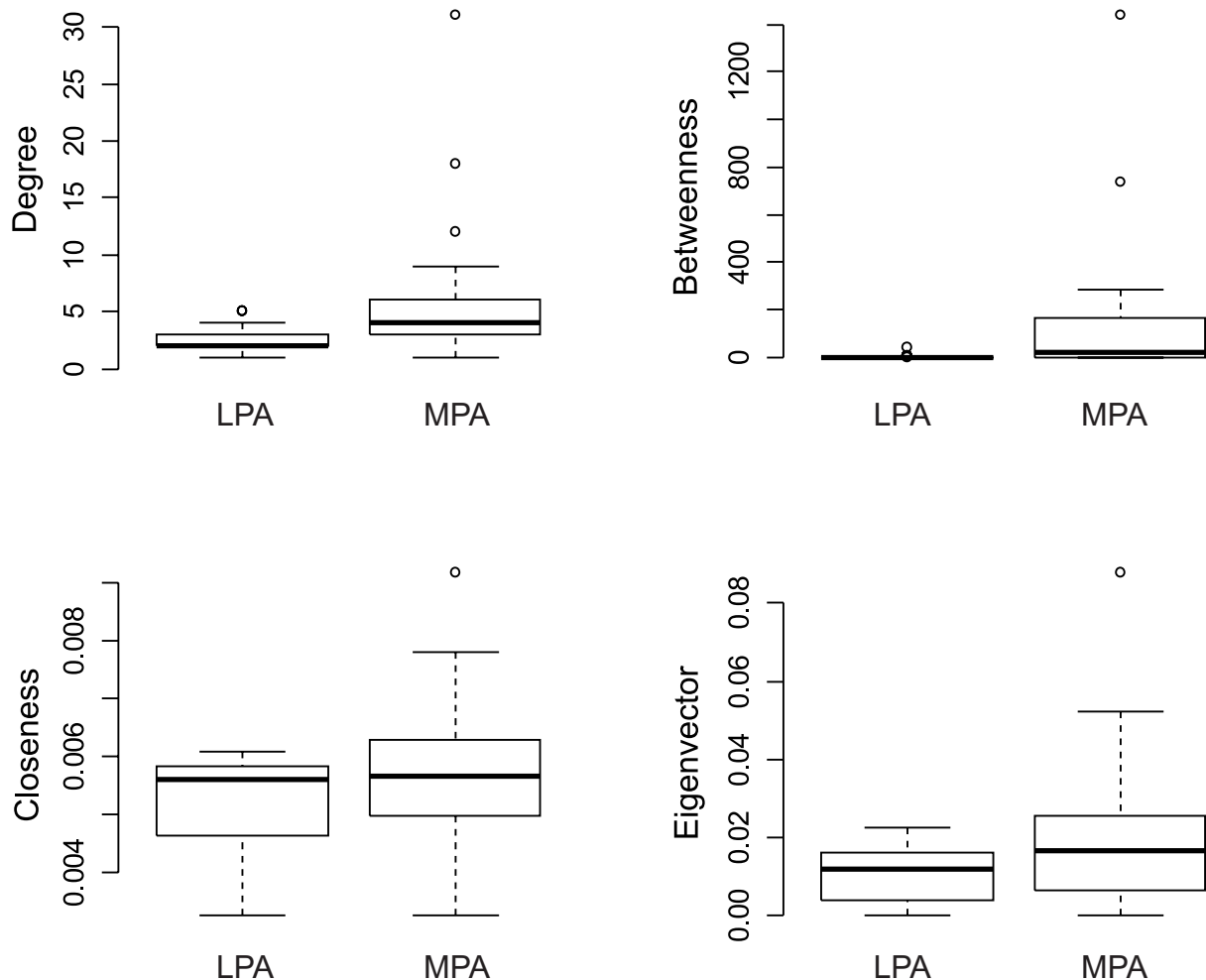


FIGURE 7. Centrality measures in function of author productivity. LPA= Least Productive Authors; MPA= Most Productive Authors.

Evolution of funding in the region

The main volume of species described by South American authors is due to Argentinean and Brazilian authors, with some participation from Colombian and Venezuelan ones. Table 3 shows the budgets for S&T for these countries from 2000 to 2010. As a general rule, an increment in the investment in this period can be observed for all these countries. Furthermore, the investments exhibit a high correlation between countries ($r > 0.94$ for all pairwise comparisons) that in the case of Argentina and Brazil is even higher ($r > 0.98$). Exponential functions adjust very well the investment rates of Argentina and Brazil ($R^2 > 0.89$). The case of Venezuela is remarkable because of the sharp increase in its investment in S&T starting in 2006.

Discussion

The development of taxonomic studies of Ephemeroptera in South America can be divided in three main periods, according to the origin of the leading authors through time. The first period or pioneer stage is dominated by foreign authors, and expands from the 1800's up to the 1970's. The second period, or transitional stage, recognizes the incorporation of regional authors to the description of new species process, mainly in collaboration with foreign specialists, and extends from the 1980's to the 1990's. In the third period, or autonomous stage, going from 1999 to the present, there is a strong and distinctive incidence of regional authors, with an increasing trend of collaboration among them. Curiously, 1999 was also identified as a critical year by Melo *et al.* (2006) in assessing the

contribution of Brazilian limnologists in international journals. In that work they divided the period 1970–2004 into three phases of production: scarce between 1970 and 1983; steeply increased between 1983 and 1999; notably increased after 1999, with no sign of stabilization.

TABLE 3. Investment in S&T, years 2000–2010, millions of US dollars expressed in PPP (Purchasing Power Parity). The Venezuelan Organic Law of Science, Technology and Innovation (LOCTI) explains the substantial increase of investment in S&T for Venezuela since its starting in 2006.

| Year | Argentina | Brazil | Colombia | Venezuela |
|------|-----------|----------|----------|-----------|
| 2000 | 1694.60 | 15890.23 | 726.90 | 775.49 |
| 2001 | 1583.11 | 16863.42 | 680.48 | 1082.18 |
| 2002 | 1328.01 | 17323.53 | 786.71 | 861.55 |
| 2003 | 1540.21 | 17286.72 | 952.27 | 589.99 |
| 2004 | 1826.36 | 18490.93 | 1151.84 | 571.88 |
| 2005 | 2202.94 | 20104.84 | 1327.44 | 905.89 |
| 2006 | 2698.65 | 21964.49 | 1311.72 | 5344.24 |
| 2007 | 3178.81 | 26418.47 | 1409.63 | 8908.21 |
| 2008 | 3479.98 | 30233.91 | 1868.03 | 9115.31 |
| 2009 | 3892.81 | 33236.43 | 2107.16 | 8249.43 |
| 2010 | 4525.43 | 36101.39 | 2233.62 | ----- |

The historical structure of academic autonomy, which changes according to a set of factors –mainly the role of the state in the higher education system, explains the particular features of the process of professionalization in Latin American scientific fields (Beigel 2012). One consequence of the political difficulties endured by several Latin America countries between the 1940's and 1970's has been the exodus of thousands of qualified researchers (Latorre 2001; Hermes-Lima & Navas 2006). However, during the 1980's and 1990's, Latin America was characterized by increased political stability and greater investments in science, technology and education. Latin America has experienced a vigorous growth in scientific production since the 1990's. This appears to be a consequence of increasing investment in tertiary education, especially at the doctoral level (Hermes-Lima & Navas 2006). From 2000 to 2010, the region has seen a high growth of more than 9% per year in scholarly output, becoming a visible actor in global research through increases in both article share and relative citation impact (Huggett 2012). The increasing contribution to the world's annual output of scholarly papers cannot be decoupled from investment. For instance, Walz (2010) observed a direct relationship between scientific limnological production and gross expenditure for research and development. Another factor pivotal to the growth in publications is the education of new scientists. In this sense, the governmental educational policies oriented to promote inclusion of graduates students into the scientific system, has played a central role in increasing the critical mass of authors. These circumstantial sociological processes of science and education outlined as a general phenomenon for the region, illuminates the patterns of scientific achievements in our particular case of study.

Co-authorship networks are an important type of social network. We have used it to obtain a snapshot of the sociological structure associated with the generation and interchange of taxonomic knowledge in South America. In network theory, the concept of homophily refers to the tendency of nodes with similar characteristics to be connected, with the opposite effect being heterophily (Newman 2003; Park & Barabási 2007). Both aspects of mixing patterns in connections can be recognized in the research communities detected in our co-authorship network. Regarding the provenance of authors, homophily is verified in (a) communities B, D, E, G, J, K, L which are integrated exclusively by foreign authors; and groups constituted by regional authors: (b) communities M and N almost exclusively represented by Brazilian authors, and (c) communities C and I formed by Venezuelan authors. On the other hand, heterophily occurs in the structure of communities A, F and H. The eclecticism of the F group is remarkable since it includes foreign, Argentinean, Brazilian, Colombian and Venezuelan authors. Communities F and M are the largest ones and epitomize the collaborative behavior of the main regional authors: Brazilians are prone to collaborate with each other whereas Argentineans exhibit a more diverse profile of interactions. Academic author ranking is another common application of patterns mined from a co-authorship network. Interestingly, we

have found that some of the classic centrality measures (i.e. degree and betweenness) could discriminate between most and least productive authors from the population of authors associated with the largest component. Productivity is thus intimately related to the role a given author plays in the concert of colleagues mainly as attractor of newly connections (popularity) and strategic position in the flow of information (intermediacy).

Within the South American countries here considered, Brazil and Argentina are responsible for the majority of publications on mayfly taxonomy, and noticeably concentrated among a few authors. Although at present the total production of authors of both countries is balanced, it should be stressed that Argentinean authors started publishing earlier. In fact, the later irruption of Brazil in the taxonomic scene explains the accelerated rate of scientific output detected in the autonomous stage ranging from 1999 to present. The recent growth of Brazil's scientific production is impressive. In the last decade, the number of Brazilian publications in the main international databases has increased considerably (Leta 2012). In a paper published in the prestigious journal *Science*, Regalado (2010) has exalted Brazilian performance within the world mainstream science and calls attention to the positive effects of the current expansion of the economy on Brazilian science. Brazil has invested roughly nine times more than Argentina on S&T on average during the last decade. Nevertheless, at this point we can see another interesting pattern: a much more moderated but steady increase in funding resulted in roughly the same number of publications by a reduced number of Argentinean authors in a longer time period. It would be very interesting to follow the description of species trend from now on. If the Brazilian funding continues, will the publications keep rising, or will they soon reach a plateau? Also, how will the collaboration among different groups continue? Melo *et al.* (2006) found that articles published by solely Brazilian authors tended to be less cited than those co-authored with international researchers. We did not delve into that particular issue, but would be interested to investigate whether homophily represents a handicap for South American authors, and international collaboration is not only desirable but also more efficient.

Brazilian and Argentinean authors accumulate the bulk of the species authorship. This correlates with the fact that Brazil and Argentina are the only two South American countries with more than 0.5% of the total world scholarly papers in 2010 (Huggett 2012). Clearly, the emergence of the autonomous stage parallels the increase in resource allocation for S&T in the region. However, is this increase in investment responsible for the consolidation of the third period, or are there other underlying factors necessary for this achievement? According to Latorre (2001) tradition is essential for the development of Science, and tradition needs stability. Latin American countries have lacked stability since their independence. This lack of continuity in their institutions has tremendously affected the development of science in these countries. Coincidentally, the transitional stage coincides with the advent of the democratization in the region, which coupled with the increase in funding would result later in the more prolific autonomous stage. In this sense, the "tradition" component can be derived from the co-authorship network, by the linkage from "old" to "young" authors. For example, in the same component there is a path that connects the late Traver (1894–1974; node 101) with the young researcher Mariano (1979– ; node 51), through the following sequence of authors: Edmunds (1920–2006; node 28), Pescador (1951– ; node 73), Peters (1939–2000; node 74), Domínguez (1958– ; node 25) and Molineri (1974– ; node 57). There are other cases in which this linkage is not present, not contributing to the main "tradition" component (see for example the separate French component, community L).

According to our analysis, not only is adequate funding necessary, but its continuity along time also is crucial to ensure the survival of tradition. The interruption of funding can act instantaneously in a negative way on production, but more importantly can also have a long term effect in disrupting the formation of qualified human resources that constitutes tradition. Alternatively, the intensification of scientific collaboration could soften the effects of a reduction in the resources for science (Meneghini 1996). Certainly, higher funding and sustainability of tradition through a robust network of collaborative effort foster the development of science, and these are probably the underlying reasons why Brazil in particular and South America in general looks at a promising future for the science of systematics, as exemplified by the case of Ephemeroptera.

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APPENDIX 1. List of valid species (updated 2012).

FAMILY AMELETOPSIDAE

- *Chaquihua bullocki* (Navás, 1930)
- *Chiloporter eatoni* Lestage, 1931

FAMILY BAETIDAE

- *Adebrotus amazonicus* Lugo-Ortiz & McCafferty, 1995
- *Adebrotus lugo* Salles, 2010
- *Americabaetis alphas* Lugo-Ortiz & McCafferty, 1996
- *Americabaetis bridarolli* (Navas, 1932)
- *Americabaetis jorgenseni* (Esben-Petersen, 1909)
- *Americabaetis labiosus* Lugo-Ortiz & McCafferty, 1996
- *Americabaetis longetron* Lugo-Ortiz & McCafferty, 1996
- *Americabaetis maxifolium* Lugo-Ortiz & McCafferty, 1996
- *Americabaetis mecistognathus* Salles & Raimundi, 2010
- *Americabaetis oldendorffi* (Weyenbergh, 1883)
- *Americabaetis peterseni* (Hubbard, 1974)
- *Americabaetis robacki* (Lugo-Ortiz & McCafferty, 1994)
- *Americabaetis titthion* Lugo-Ortiz & McCafferty, 1996
- *Americabaetis weiseri* (Navas, 1926)
- *Andesiops angolinus* (Navás, 1933)
- *Andesiops ardua* (Lugo-Ortiz & McCafferty, 1999)
- *Andesiops peruvianus* (Ulmer, 1920)
- *Andesiops torrens* (Lugo-Ortiz & McCafferty, 1999)
- *Apobaetis fuzai* Salles & Lugo-Ortiz 2002
- *Apobaetis hamadae* Cruz, Boldrini & Salles 2011
- *Apobaetis insolitus* Nieto, 2006
- *Apobaetis kallawaya* Nieto, 2006
- *Apobaetis niger* Nieto, 2006
- *Apobaetis signifer* Lugo-Ortiz & McCafferty, 1997
- *Aturbina beatrixae* Gillies, 2001
- *Aturbina georgei* Lugo-Ortiz & McCafferty, 1996
- *Aturbina maculata* Salles, Boldrini & Shimano, 2010
- *Aturbina nigra* Salles, Boldrini & Shimano, 2010
- *Baetodes andamagensis* Mayo, 1972
- *Baetodes arawak* (Traver, 1943)
- *Baetodes awa* Salinas, Dias, Salles & Bacca, 2011
- *Baetodes capixaba* de-Souza, Salles & Nessimian, 2011
- *Baetodes chilloni* Mayo, 1972
- *Baetodes cochunaensis* Nieto, 2004
- *Baetodes copiosus* Nieto, 2004
- *Baetodes diasae* Salinas, Dias, Salles & Bacca, 2011
- *Baetodes gibbus* Nieto, 2004
- *Baetodes huaico* Nieto, 2004
- *Baetodes itatiyanus* Demoulin, 1955
- *Baetodes iuaquita* de-Souza, Salles & Nessimian, 2011
- *Baetodes levis* Mayo, 1968
- *Baetodes liviae* Salles & Polegatto, 2008
- *Baetodes peniculus* Mayo, 1973
- *Baetodes pehuenche* Nieto, 2004
- *Baetodes proiectus* Mayo, 1973
- *Baetodes proscolus* de-Souza, Salles & Nessimian, 2011

- *Baetodes pseudogibbus* Nieto, 2004
- *Baetodes pseudospinae* Salinas, Dias, Salles & Bacca, 2011
- *Baetodes rutilus* Nieto, 2004
- *Baetodes sancticatarinae* Mayo, 1972
- *Baetodes santateresa* Salles & Polegatto, 2008
- *Baetodes serratus* Needham & Murphy, 1924
- *Baetodes solus* Mayo, 1972
- *Baetodes spinae* Mayo, 1968
- *Baetodes spinifer* Traver, 1943
- *Baetodes traversae* Mayo, 1972
- *Baetodes uruguai* Nieto, 2004
- *Baetodes yuracare* Nieto, 2004
- *Callibaetis alegre* Traver, 1944
- *Callibaetis camposi* Navás, 1930
- *Callibaetis capixaba* Cruz, Salles & Hamada, 2009
- *Callibaetis dominguezi* Gillies, 1990
- *Callibaetis fasciatus* (Pictet, 1843)
- *Callibaetis fluminensis* Cruz, Salles & Hamada, 2009
- *Callibaetis gonzalezi* (Navás, 1934)
- *Callibaetis gregarius* Navás, 1930
- *Callibaetis guttatus* Navás, 1915
- *Callibaetis jocosus* Navás, 1912
- *Callibaetis nigrivenosus* Banks, 1918
- *Callibaetis pollens* Needham & Murphy, 1924
- *Callibaetis radiatus* Navás, 1920
- *Callibaetis sellacki* (Weyenbergh, 1883)
- *Callibaetis viviparus* Needham & Murphy, 1924
- *Callibaetis willineri* Navás, 1932
- *Callibaetis zonalis* Navás, 1915
- *Camelobaetidius alcyoneus* (Traver, 1943)
- *Camelobaetidius anubis* (Traver & Edmunds, 1968)
- *Camelobaetidius apis* Nieto, 2003
- *Camelobaetidius billi* Thomas & Dominique, 2000
- *Camelobaetidius cayumba* (Traver & Edmunds, 1968)
- *Camelobaetidius dryops* (Needham & Murphy, 1924)
- *Camelobaetidius edmundsi* Dominique, Mathuriau & Thomas, 2001
- *Camelobaetidius francischetti* Salles, Andrade & Da-Silva, 2005
- *Camelobaetidius hamadae* Salles & Serrão, 2005
- *Camelobaetidius huarpe* Nieto, 2003
- *Camelobaetidius ipaye* Nieto, 2003
- *Camelobaetidius janae* Thomas & Dominique, 2000
- *Camelobaetidius juparana* Boldrini, Pes, Francischetti & Salles, 2012
- *Camelobaetidius lassance* Salles & Serrão, 2005
- *Camelobaetidius leentvaari* Demoulin, 1966
- *Camelobaetidius mantis* Traver & Edmunds, 1968
- *Camelobaetidius maranhensis* Salles & Serrão, 2005
- *Camelobaetidius mathuriae* Dominique & Thomas, 2001
- *Camelobaetidius matilei* Thomas, Peru & Horeau, 2003
- *Camelobaetidius ortizi* Dominique & Thomas, 2001
- *Camelobaetidius patricki* Dominique, Mathuriau & Thomas, 2001
- *Camelobaetidius penai* (Traver & Edmunds, 1968)
- *Camelobaetidius rufiventris* Boldrini & Salles, 2009
- *Camelobaetidius phaedruss* (Traver & Edmunds, 1968)
- *Camelobaetidius serapis* (Traver & Edmunds, 1968)
- *Camelobaetidius spinosus* Boldrini, Pes, Francischetti & Salles, 2012
- *Camelobaetidius suapi* Nieto, 2002
- *Camelobaetidius tantillus* (Needham & Murphy, 1924)
- *Camelobaetidius tuberosus* Lugo-Ortiz & McCafferty, 1999
- *Camelobaetidius yacutinga* Nieto 2003
- *Chane baure* Nieto, 2003
- *Cloeodes anduzei* (Traver, 1943)

- *Cloeodes auwe* Salles & Batista, 2004
- *Cloeodes aymara* (Traver, 1971)
- *Cloeodes aymore* Massariol & Salles, 2011
- *Cloeodes barituensis* Nieto & Richard, 2008
- *Cloeodes binocularis* (Needham & Murphy, 1924)
- *Cloeodes dialutoi* Nieto & Emmerich, 2011
- *Cloeodes espinillo* Nieto & Richard, 2008
- *Cloeodes guenoa* Nieto & Emmerich, 2011
- *Cloeodes hydation* McCafferty & Lugo-Ortiz, 1995
- *Cloeodes incus* (Waltz & McCafferty, 1987)
- *Cloeodes irvingi* Waltz & McCafferty, 1987
- *Cloeodes itajara* Massariol & Salles, 2011
- *Cloeodes jaragua* Salles & Lugo-Ortiz, 2003
- *Cloeodes opacus* Nieto & Richard, 2008
- *Cloeodes penai* (Moriyama & Edmunds, 1980)
- *Cloeodes redactus* Waltz & McCafferty, 1987
- *Cloeodes stelzneri* (Weyenbergh, 1883)
- *Cloeodes turbinops* (Needham & Murhpy, 1924)
- *Cloeodes vaimaca* Nieto & Emmerich, 2011
- *Corinnella eximia* Thomas & Dominique, 2006
- *Cryptonympha copiosa* Lugo-Ortiz & McCafferty, 1998
- *Cryptonympha dasilvai* Salles & Francischetti, 2004
- *Fallceon murphyae* (Hubbard, 1974)
- *Fallceon yaro* (Traver, 1971)
- *Guajiroilus ektrapeloglossa* Flowers, 1985
- *Guajiroilus flowersi* Thomas & Dominique, 2005
- *Guajiroilus queremba* Nieto, 2003
- *Guajiroilus rondoni* Salles, 2007
- *Harpagobaetis gulosus* Mol, 1986
- *Mayobaetis ellenae* (Mayo, 1973)
- *Moribaetis aneto* (Traver, 1971)
- *Moribaetis comes* (Navas, 1912)
- *Nanomis galera* Lugo-Ortiz & McCafferty, 1999
- *Paracloeodes assu* Nieto & Salles, 2006
- *Paracloeodes atroari* Nieto & Salles, 2006
- *Paracloeodes binodulus* Lugo-Ortiz & McCafferty, 1996
- *Paracloeodes charrua* Emmerich & Nieto, 2009
- *Paracloeodes eurybranchus* Lugo-Ortiz & McCafferty, 1996
- *Paracloeodes ibicui* Lugo-Ortiz & McCafferty, 1996
- *Paracloeodes leptobanchus* Lugo-Ortiz & McCafferty, 1996
- *Paracloeodes morelli* Emmerich & Nieto, 2009
- *Paracloeodes pacawara* Nieto & Salles, 2006
- *Paracloeodes peri* Nieto & Salles, 2006
- *Paracloeodes poranga* (Salles & Lugo-Ortiz, 2003)
- *Paracloeodes quadridentatus* Lima & Salles, 2010
- *Paracloeodes waimiri* Nieto & Salles, 2006
- *Paracloeodes yuto* Nieto & Salles, 2006
- *Parakari auyanensis* Nieto & Derka, 2011
- *Parakari churiensis* Nieto & Derka, 2011
- *Prebaetodes meridinensis* Chacón, Pescador & Segnini, 2010
- *Prebaetodes sitesi* Lugo-Ortiz & McCafferty, 1996
- *Rivudiva coveloae* (Traver, 1971)
- *Rivudiva minantenna* Lugo-Ortiz & McCafferty, 1998
- *Rivudiva trichobasis* Lugo-Ortiz & McCafferty, 1998
- *Rivudiva venezuelensis* (Traver, 1943)
- *Spiritiops silvudus* Lugo-Ortiz & McCafferty, 1998
- *Spiritiops tepuiensis* Nieto & Derka, 2012
- *Tomodontus primus* Lugo-Ortiz & McCafferty, 1995
- *Tupiara ibirapitanga* Salles, Lugo-Ortiz, Da-Silva & Francischetti, 2003
- *Varipes cajuato* Nieto, 2004
- *Varipes helenae* Salles & Batista, 2004

- *Varipes lasiobranchius* Lugo-Ortiz & McCafferty, 1998
- *Varipes minutus* Nieto, 2004
- *Varipes sancarlos* Castillo & Perez, 2011
- *Varipes singuil* Nieto, 2004
- *Waltzoyphius fasciatus* Lugo-Ortiz & McCafferty, 1995
- *Waltzoyphius roberti* Thomas & Peru, 2003
- *Zelus principalis* Lugo-Ortiz & McCafferty, 1998

FAMILY CAENIDAE

- *Alloretochus peruanicus* (Soldán, 1986)
- *Brasilocaenis intermedia* Malzacher, 1986
- *Brasilocaenis irmleri* Puthz, 1975
- *Brasilocaenis mendesi* Malzacher, 1998
- *Brasilocaenis puthzi* Malzacher, 1975
- *Brasilocaenis renata* Malzacher, 1975
- *Brasilocaenis septentrionalis* Malzacher, 1990
- *Caenis argentina* Navás, 1915
- *Caenis burmeisteri* Malzacher, 1990
- *Caenis candelata* Malzacher, 1986
- *Caenis chamie* Alba-Tercedor & Mosquera, 1999
- *Caenis cigana* Pereira & da Silva, 1990
- *Caenis cuniana* Froehlich, 1969
- *Caenis dominguezii* Malzacher, 2001
- *Caenis fittkai* Malzacher, 1986
- *Caenis gonseri* Malzacher, 2001
- *Caenis ludicra* Navás, 1920
- *Caenis nemoralis* Navás, 1922
- *Caenis pflugfelderi* Malzacher, 1990
- *Caenis plaumanni* Malzacher, 2001
- *Caenis pseudamica* Malzacher, 1990
- *Caenis quatipuruica* Malzacher, 1986
- *Caenis reissi* Malzacher, 1986
- *Caenis sigillata* Malzacher, 1986
- *Caenis tarapoto* Molineri, 2009
- *Caenis teipunensis* Molineri, Grillet, Nieto, Domínguez & Guerrero, 2010
- *Caenis tenella* (Navás, 1912)
- *Caenis uruzu* Molineri & Malzacher, 2007
- *Latineosus colombianus* (Soldán, 1986)

FAMILY COLOBURISCIDAE

- *Murphyella needhami* Lestage, 1930

FAMILY CORYPHORIDAE

- *Coryphorus aquilus* Peters, 1981

FAMILY EPHEMERIDAE

- *Hexagenia (Pseudeatonica) albivitta* (Walker, 1853)
- *Hexagenia (Pseudeatonica) callineura* Banks, 1914
- *Hexagenia (Pseudeatonica) mexicana* Eaton, 1883

FAMILY EUTHYPLOCIIDAE

- *Campylocia anceps* (Eaton, 1883)
- *Campylocia bocainensis* Pereira & da Silva, 1990
- *Campylocia dochmia* Berner & Thew, 1961
- *Euthyplocia haenschi* Ulmer, 1942
- *Euthyplocia hecuba* (Hagen, 1861)
- *Mesoplocia intermedia* Demoulin, 1952

FAMILY LEPTOHYPHIDAE

- *Allenhyphes? asperulus* (Allen, 1967)
- *Allenhyphes flinti* (Allen, 1973)

- *Allenhyphes? spinosus* (Allen & Roback, 1969)
- *Amanahyphes saguassu* Salles & Molineri, 2006
- *Haplohyphes aquilonius* Lugo-Ortiz & McCafferty, 1995
- *Haplohyphes baritu* Domínguez, 1984
- *Haplohyphes dominguezi* Molineri, 2000
- *Haplohyphes huallaga* Allen, 1966
- *Haplohyphes mithras* (Traver, 1958)
- *Haplohyphes yanahuicsa* Molineri, 2003
- *Leptohyphes albipennis* Molineri & Zúñiga 2006
- *Leptohyphes carinus* Allen, 1973
- *Leptohyphes coconuco* Molineri & Zúñiga 2006
- *Leptohyphes cornutus* Allen, 1967
- *Leptohyphes ecuador* Mayo, 1968
- *Leptohyphes eximius* Eaton, 1882
- *Leptohyphes hirsutus* Allen & Roback, 1969
- *Leptohyphes illiesi* Allen, 1967
- *Leptohyphes invictus* Allen, 1973
- *Leptohyphes jodiannae* Allen, 1967
- *Leptohyphes liniti* Wang, Sites & McCafferty, 1998
- *Leptohyphes maculatus* Allen, 1967
- *Leptohyphes mollipes* Needham & Murphy, 1924
- *Leptohyphes nigripennis* Molineri & Zúñiga 2006
- *Leptohyphes nigripunctum* Traver, 1943
- *Leptohyphes peterseni* Ulmer, 1920
- *Leptohyphes petersi* Allen, 1967
- *Leptohyphes plaumanni* Allen, 1967
- *Leptohyphes populus* Allen, 1973
- *Leptohyphes setosus* Allen, 1967
- *Leptohyphes tacajalo* Mayo, 1968
- *Leptohyphes tuberculatus* Allen, 1967
- *Leptohyphodes inanis* (Pictet, 1843)
- *Lumahyphes guacra* Molineri (Molineri & Zúñiga, 2004)
- *Lumahyphes yagua* Molineri & Zúñiga, 2004
- *Lumahyphes pijcha* Molineri, 2004
- *Macunahyphes australis* (Banks, 1913)
- *Macunahyphes incognitus* Molineri, Grillet, Nieto, Domínguez & Guerrero, 2010
- *Macunahyphes pemonensis* Molineri, Grillet, Nieto, Domínguez & Guerrero, 2010
- *Traverhyphes (Traverhyphes) chiquitano* Molineri, 2004
- *Traverhyphes (T.) frevo* Lima, Salles & Pinheiro, 2011
- *Traverhyphes (T.) indicator* (Needham & Murphy, 1924)
- *Traverhyphes (T.) pirai* Molineri, 2001
- *Traverhyphes (Byrsahyphes) nanus* (Allen, 1967)
- *Traverhyphes (B.) yuqui* Molineri, 2004
- *Traverhyphes (Mocoihyphes) edmundsi* (Allen, 1973)
- *Traverhyphes (M.) yuati* Molineri, 2004
- *Tricorythodes arequita* Traver, 1959
- *Tricorythodes barbatus* Allen, 1967
- *Tricorythodes bullus* Allen, 1967
- *Tricorythodes capuccinorum* Emmerich, 2007
- *Tricorythodes caunapi* Dias, Bacca, Ferreira, 2011
- *Tricorythodes cristatus* Allen, 1967
- *Tricorythodes chalaza* Gonçalves, Da Silva & Nessimian, 2010
- *Tricorythodes diasae* Gonçalves, Da Silva & Nessimian, 2010
- *Tricorythodes faeculopsis* Belmont, Salles & Hamada, 2011
- *Tricorythodes hiemalis* Molineri, 2001
- *Tricorythodes lichyi* Traver, 1943
- *Tricorythodes mirca* Molineri, 2002
- *Tricorythodes molinerii* Dias & Salles, 2006
- *Tricorythodes nicholsae* (Wang et al, 1998)
- *Tricorythodes ocellus* Allen & Roback, 1969
- *Tricorythodes popayanicus* Domínguez 1982

- *Tricorythodes quizeri* Molineri, 2002
- *Tricorythodes rondoniensis* Dias, Cruz & Ferreira, 2009
- *Tricorythodes sallesi* Dias, Cabette & Souza, 2009
- *Tricorythodes santarita* Traver, 1959
- *Tricorythodes trifasciatus* Molineri & Zúñiga, 2006
- *Tricorythodes uniandinus* Emmerich, 2007
- *Tricorythodes yapekuna* Belmont, Salles & Hamada, 2012
- *Tricorythodes yura* Molineri, 2002
- *Tricorythodes zunigae* Molineri, 2002
- *Tricorythopsis acara* Belmont, Salles & Hamada, 2011
- *Tricorythopsis araponga* Dias & Salles, 2005
- *Tricorythopsis artigas* Traver, 1958
- *Tricorythopsis bahiensis* Dias, Salles & Ferreira, 2008
- *Tricorythopsis baptistai* Dias & Salles, 2005
- *Tricorythopsis chiriguano* Molineri, 2001
- *Tricorythopsis gibbus* (Allen, 1967)
- *Tricorythopsis intercalatus* Belmont, Salles & Hamada, 2011
- *Tricorythopsis minimus* (Allen, 1973)
- *Tricorythopsis pseudogibbus* Dias & Salles, 2005
- *Tricorythopsis sigillatus* Molineri, 1999
- *Tricorythopsis spongicola* Lima, Salles & Pinheiro, 2011
- *Tricorythopsis ticuna* Molineri & Zúñiga 2006
- *Tricorythopsis undulatus* (Allen, 1967)
- *Tricorythopsis volsellus* Molineri, 1999
- *Tricorythopsis yacutinga* Molineri, 2001
- *Tricorythopsis yucupe* Dias, Salles & Ferreira, 2008
- *Yaurina mota* Molineri, 2001
- *Yaurina ralla* (Allen, 1967)
- *Yaurina yapa* Molineri, 2001
- *Yaurina yuta* Molineri, 2001

FAMILY LEPTOPHLEBIIDAE

- *Askola cipoensis* Domínguez, Molineri & Mariano, 2009
- *Askola emmerichi* Domínguez, Molineri & Mariano, 2009
- *Askola froehlichii* Peters, 1969
- *Askola paprockii* Domínguez, Molineri & Mariano, 2009
- *Askola yanoman* Cavalante, Barcelos & Salles, 2011
- *Atopophlebia flowersi* Domínguez & Molineri, 1996
- *Atopophlebia fortunensis* Flowers, 1987
- *Atopophlebia obrienorum* Flowers, 1987
- *Atopophlebia pitculya* Flowers, 2012
- *Atopophlebia yarinacocha* Flowers, 1987
- *Bessierus doloris* Thomas & Orth, 2000
- *Dactylophlebia carnulenta* Pescador & Peters, 1980
- *Demoulinellus coloratus* Pescador & Peters, 1982
- *Ecuaphlebia rumignai* Domínguez, 1988
- *Farrodes caribbianus* (Traver, 1943)
- *Farrodes carioca* Domínguez, Molineri & Peters, 1996
- *Farrodes iguazuanus* Domínguez & Savage, 1987
- *Farrodes longispinus* Domínguez, Molineri & Peters, 1996
- *Farrodes maculatus* (Needham & Murhpy, 1924)
- *Farrodes ochraceous* Domínguez, Molineri & Peters, 1996
- *Farrodes pakitza* Domínguez, Molineri & Peters, 1996
- *Farrodes roundsi* (Traver, 1947)
- *Farrodes savagei* Domínguez, 1999
- *Farrodes tepui* Domínguez, Molineri & Peters, 1996
- *Farrodes xingu* Domínguez, Molineri & Peters, 1996
- *Farrodes yungaensis* Domínguez & Savage, 1987
- *Fittkaulus amazonicus* Kluge, 2009
- *Fittkaulus cuiabae* Savage, 1986
- *Fittkaulus cururuensis* Savage, 1986

- *Fittkaulus maculatus* Savage & Peters, 1978
- *Gonserellus atopus* Pescador, 1997
- *Hagenulopsis diptera* Ulmer, 1920
- *Hagenulopsis esmeralda* Domínguez, Molineri & Mariano, 2009
- *Hagenulopsis lipo* Domínguez, Molineri & Mariano, 2009
- *Hagenulopsis minuta* Spieth, 1943
- *Hagenulopsis zunigae* Domínguez, Molineri & Mariano, 2009
- *Hagenulus marshalli* J Peters, Flowers, Hubbard, Domínguez & Savage, 2005
- *Hapsiphlebia anastomosis* (Demoulin, 1955)
- *Hermanella costalis* (Navás, 1934)
- *Hermanella froehlichii* Ferreira & Domínguez, 1992
- *Hermanella grandis* Domínguez & Flowers, 1989
- *Hermanella guttata* Domínguez & Flowers, 1989
- *Hermanella maculipennis* (Ulmer, 1920)
- *Hermanella (Hermanella) thelma* Needham & Murphy, 1924
- *Hermanellopsis arsia* Savage & Peters, 1983
- *Hermanellopsis incertans* (Spieth, 1943)
- *Homothraulus larensis* (Navás, 1926)
- *Homothraulus lucretiae* Traver, 1960
- *Homothraulus misionensis* (Esben-Petersen, 1912)
- *Hydromastodon mikei* (Thomas & Boutonnet, 2004)
- *Hydromastodon sallesi* Polegatto & Batista, 2007
- *Hydrosmilodon gilliesae* Thomas & Péru, 2004
- *Hydrosmilodon plagatus* Lima, Nascimento & Salles, 2012
- *Hydrosmilodon saltensis* Flowers & Domínguez, 1992
- *Hylister chimaera* Kluge, 2008
- *Hylister plaumanni* Domínguez & Flowers, 1989
- *Leentvaaria palpalis* Demoulin, 1966
- *Lisetta ernsti* Thomas, Dominique & Orth, 2005
- *Magallanella flinti* Pescador & Peters, 1980
- *Massartella alegrettae* Ulmer, 1943
- *Massartella brieni* (Lestage, 1924)
- *Massartella devani* Derka, 2002
- *Massartella hirsuta* Derka, Svitok & Schlögl, 2009
- *Massartella venezuelensis* Pescador & Peters, 1990
- *Massartellopsis irarrazavali* Demoulin, 1955
- *Meridialaris biobionica* (Ulmer, 1938)
- *Meridialaris chiloeensis* (Demoulin, 1955)
- *Meridialaris diguillina* (Demoulin, 1955)
- *Meridialaris inflata* Pescador & Peters, 1987
- *Meridialaris laminata* (Ulmer, 1920)
- *Meridialaris lestagei* (Ulmer, 1938)
- *Meridialaris spina* Pescador & Peters, 1987
- *Meridialaris tintinnabula* Pescador and Peters, 1987
- *Microphlebia pallida* Savage & Peters, 1983
- *Microphlebia surinamensis* Savage & Peters, 1983
- *Miroculis (Atroari) amazonicus* Savage & Peters, 1983
- *Miroculis (Atroari) colombiensis* Savage & Peters, 1983
- *Miroculis (Atroari) duckensis* Savage & Peters, 1983
- *Miroculis (Miroculis) bicoloratus* Savage, 1987
- *Miroculis (Miroculis) brasiliaensis* Savage & Peters, 1983
- *Miroculis (Miroculis) caparaoensis* Salles & Lima 2011
- *Miroculis (Miroculis) chiribiquete* J Peters, Domínguez & Currea, 2008
- *Miroculis (Miroculis) fittkai* Savage & Peters, 1983
- *Miroculis (Miroculis) marauiae* Savage & Peters, 1983
- *Miroculis (Miroculis) nebulosus* Savage, 1987
- *Miroculis (Miroculis) rossi* Edmunds, 1963
- *Miroculis (Ommaethus) froehlichii* Savage & Peters, 1983
- *Miroculis (Ommaethus) misionensis* Domínguez, 2007
- *Miroculis (Ommaethus) mourei* Savage & Peters, 1983
- *Miroculis (Yaruma) wandae* Savage & Peters, 1983

- *Miroculitus emersoni* (Needham & Murphy, 1924)
- *Needhamella ehrhardti* (Ulmer, 1920)
- *Needhamella mazama* Nascimento, Mariano & Salles, 2012
- *Nousia bella* Pescador & Peters, 1985
- *Nousia crena* Pescador & Peters, 1985
- *Nousia delicata* Navás, 1918
- *Nousia grandis* (Demoulin, 1955)
- *Nousia maculata* (Demoulin, 1955)
- *Nousia minor* (Demoulin, 1955)
- *Paramaka antonii* Sartori, 2005
- *Paramaka convexa* (Spieth, 1943)
- *Paramaka pearljam* Mariano, 2011
- *Penaphlebia (Megalophlebia) vinosa* (Demoulin, 1955)
- *Penaphlebia (Penaphlebia) barriai* Pescador & Peters, 1991
- *Penaphlebia (s.s.) chilensis* (Eaton, 1883)
- *Penaphlebia (s.s.) exigua* Domínguez & Pescador, 1982
- *Penaphlebia (s.s.) flavidula* Pescador & Peters, 1991
- *Penaphlebia (s.s.) fulvipes* (Needham & Murphy, 1924)
- *Perissophlebiodes flinti* (Savage, 1982)
- *Poranga nessimiani* Gonçalves & Da-Silva, 2011
- *Rhigotopus andinensis* Pescador & Peters, 1982
- *Secochela illiesi* Pescador & Peters, 1982
- *Segesta riograndensis* Siegloch, Polegatto & Froehlich, 2006
- *Simothraulopsis demerara* (Traver, 1947)
- *Simothraulopsis diamantiensis* Mariano, 2010
- *Simothraulopsis janae* Mariano, 2010
- *Simothraulopsis plesius* Kluge, 2008
- *Simothraulopsis sabalo* Kluge, 2008
- *Terpides guyanensis* Demoulin, 1966
- *Terpides sooretamae* Boldrini & Salles, 2009
- *Thraulodes amanda* Mariano & Froehlich, 2012
- *Thraulodes basimaculatus* Giordano & Domínguez, 2005
- *Thraulodes bolivianus* Domínguez, 1986
- *Thraulodes bomplandi* (Esben Petersen, 1912)
- *Thraulodes cochunaensis* Domínguez, 1987
- *Thraulodes colombiae* (Walker, 1853)
- *Thraulodes consortis* Domínguez, 1987
- *Thraulodes daidaleus* Thew, 1960
- *Thraulodes eduardorum* Medina & Pérez, 2011
- *Thraulodes flinti* Domínguez, 1987
- *Thraulodes furficulus* Traver, 1946
- *Thraulodes guanare* Chacón, Segnini & Domínguez, 1999
- *Thraulodes itatiajanus* Traver & Edmunds, 1967
- *Thraulodes jones* Gonçalves, Da-Silva & Nessimian, 2010
- *Thraulodes laetus* (Eaton, 1883)
- *Thraulodes limbatus* Navás, 1936
- *Thraulodes liminaris* Domínguez, 1987
- *Thraulodes marreroi* Chacón, Segnini & Domínguez, 1999
- *Thraulodes mucuy* Chacón, Segnini & Domínguez, 1999
- *Thraulodes osiris* Traver & Edmunds, 1967
- *Thraulodes papilionis* Traver & Edmunds, 1967
- *Thraulodes paysandensis* Traver, 1964
- *Thraulodes pelicanus* Mariano & Froehlich, 2012
- *Thraulodes quevedoensis* Flowers, 2009
- *Thraulodes regulus* Traver & Edmunds, 1967
- *Thraulodes schlingeri* Traver & Edmunds, 1967
- *Thraulodes sinuosus* Mariano & Flowers, 2012
- *Thraulodes subfasciatus* Navás, 1924
- *Thraulodes telegraphicus* Needham & Murphy, 1924
- *Thraulodes traverae* Thew, 1960
- *Thraulodes trijunctus* (Banks, 1918)

- *Thraulodes ulmeri* Edmunds, 1950
- *Thraulodes venezuelana* Ulmer, 1943
- *Thraulodes vitripennis* (Blanchard in Gay, 1851)
- *Thraulodes xavantinensis* Mariano & Froehlich, 2012
- *Tikuna bilineata* (Needham & Murphy, 1924)
- *Tikuna fusconotum* Kluge, 2009
- *Tikuna nigrobulla* Kluge, 2009
- *Traverella (Traverella) bradleyi* (Needham & Murphy, 1924)
- *Traverella (Traverella) montium* (Ulmer, 1924)
- *Traverella (Traverella) valdemari* (Esben Petersen, 1912)
- *Traverella (Zonda) calingastensis* Domínguez, 1995
- *Ulmeritoides araponga* Salles & Domínguez, 2012
- *Ulmeritoides flavopedes* (Spieth, 1943)
- *Ulmeritoides haarupi* (Esben-Petersen, 1912)
- *Ulmeritoides huitoto* Domínguez & Zúñiga 2003
- *Ulmeritoides luteotinctus* (Traver, 1959)
- *Ulmeritoides misionensis* Domínguez, 1995
- *Ulmeritoides nigribullae* Salles & Domínguez, 2012
- *Ulmeritoides oepa* Lopes, Da Silva & Py-Daniel, 2003
- *Ulmeritoides patagiatus* (Thew, 1960)
- *Ulmeritoides spinulipenis* Domínguez, 1995
- *Ulmeritoides uruguayensis* (Traver, 1959)
- *Ulmeritus balteatus* Thew, 1960
- *Ulmeritus carbonelli* Traver, 1956
- *Ulmeritus saopaulensis* (Traver, 1946)

FAMILY MELANEMERELLIDAE

- *Melanemerella brasiliana* Ulmer, 1920

FAMILY NESAMELETIDAE

- *Metamonius anceps* (Eaton, 1885)

FAMILY OLIGONEURIIDAE

- *Fittkaunearia adusta* Pescador & Edmunds 1994
- *Fittkaunearia carina* Pescador & Edmunds, 1994
- *Homoeoneuria (Notachora) fittkai* Pescador & Peters, 1980
- *Homoeoneuria watu* Salles, Francischetti & Soares, 2009
- *Lachlania boanovae* Da Silva & Pereira, 1993
- *Lachlania cacautana* (Needham, 1932)
- *Lachlania dominguezi* Pereira, 1989
- *Lachlania garciai* (Navás, 1912)
- *Lachlania pallipes* (Eaton, 1883)
- *Lachlania radai* (Navás, 1926)
- *Lachlania santosi* Pereira, 1987
- *Oligoneuria anomala* Pictet, 1843
- *Oligoneuria itayana* Kluge, 2007
- *Oligoneuria macabaiba* Gonçalves & Da-Silva & Nessimian, 2011
- *Oligoneurioides amazonicus* Demoulin, 1955
- *Spaniophlebia assimilis* Banks, 1913
- *Spaniophlebia escomeli* Cockerell, 1926
- *Spaniophlebia trailiae* Eaton, 1881

FAMILY ONISCIGASTRIDAE

- *Siphonella guttata* (Pictet, 1843)
- *Siphonella ventilans* Needham & Murphy, 1924
-

FAMILY POLYMITARCYIDAE

- *Asthenopus angelae* de Souza & Molineri, 2011
- *Asthenopus crenulatus* Molineri, Cruz & Emmerich, 2011
- *Asthenopus curtus* (Hagen, 1861)
- *Asthenopus gilliesi* Domínguez, 1988

- *Asthenopus picteti* (Hubbard, 1975)
- *Campsurus albicans* (Percheron in Guerin & Percheron, 1838)
- *Campsurus albifilum* (Walker, 1853)
- *Campsurus amapaensis* Molineri & Emmerich 2010
- *Campsurus argentinus* Esben - Petersen, 1912
- *Campsurus assimilis* Traver, 1944
- *Campsurus burmeisteri* Ulmer, 1942
- *Campsurus claudus* Needham & Murphy, 1964
- *Campsurus corumbanus* Needham & Murphy, 1924
- *Campsurus cuyuniensis* Traver, 1947
- *Campsurus dallasi* Navás, 1927
- *Campsurus dorsalis* (Burmeister, 1839)
- *Campsurus duplicatus* Spieth, 1943
- *Campsurus essequibo* Traver, 1947
- *Campsurus evanidus* Needham & Murphy, 1924
- *Campsurus holmbergii* (Weyenbergh, 1883)
- *Campsurus indivisus* Ulmer, 1942
- *Campsurus jorgenseni* Esben - Petersen, 1912
- *Campsurus latipennis* (Walker, 1853)
- *Campsurus litaninensis* Spieth, 1943
- *Campsurus longicauda* Navás, 1931
- *Campsurus lucidus* Needham & Murphy, 1924
- *Campsurus mahunkai* Puthz, 1973
- *Campsurus major* Needham & Murphy, 1924
- *Campsurus meyeri* Navás, 1934
- *Campsurus mutilus* Needham & Murphy, 1924
- *Campsurus nappii* (Weyenbergh, 1883)
- *Campsurus notatus* Needham & Murphy, 1924
- *Campsurus paranensis* Navás, 1932
- *Campsurus paraquarius* Navás, 1920
- *Campsurus pedicellarius* Spieth, 1943
- *Campsurus pfeifferi* Navás, 1931
- *Campsurus quadridentatus* Eaton, 1871
- *Campsurus segnis* Needham & Murphy, 1924
- *Campsurus striatus* Needham & Murphy, 1924
- *Campsurus truncatus* Ulmer, 1920
- *Campsurus ulmeri* Traver, 1950
- *Campsurus violaceus* Needham & Murphy, 1924
- *Campsurus vulturorum* Emmerich & Molineri, 2011
- *Campsurus wappaei* (Weyenbergh, 1883)
- *Campsurus zikani* Navás, 1934
- *Tortopsis bruchianus* (Navás, 1926)
- *Tortopsis canum* Gonçalves, Da Silva & Nessimian, 2011
- *Tortopsis limoncocha* Molineri, 2010
- *Tortopsis obscuripennis* Domínguez, 1985
- *Tortopsis parishi* (Banks, 1918)
- *Tortopsis sarae* Domínguez, 1985
- *Tortopsis spatula* Molineri, 2010
- *Tortopsis unguiculatus* (Ulmer, 1920)
- *Tortopus arenales* Molineri, 2010
- *Tortopus harrisi* Traver, 1950
- *Tortopus igaranus* Needham & Murphy, 1924
- *Tortopus zottai* (Navás, 1920)

APPENDIX 2. Brief explanation of network concepts and centrality measures.

Whenever our object of study can be abstracted as a set of elements connected among them, we can use a network representation for studying its pattern of connections. A network is a collection of nodes (or vertices) and links (or edges) that models the elements and their relationships, respectively. In the context of social networks, centrality measures are commonly used as indices of prestige, prominence, importance, and power of actors (Borgatti 1995). There are different approaches to

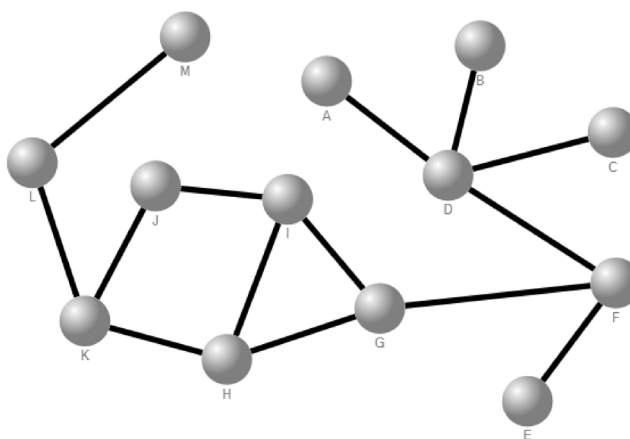
describe the locations of individuals in terms of how close they are to the nucleus of the action in a network: degree, closeness, betweenness, and eigenvector centrality. The first three were described in modern form by Freeman (1978) while the last was proposed by Bonacich (1972).

To illustrate the basics on centrality measurement, we adopt here the (now classical) artificial network posted by Martin Everett to a webmail list of network scientists in 1996. It consists of 13 vertices (or nodes) and 14 edges (or links). At our best knowledge, it is the smallest known network in which the most central actors in terms of degree, closeness, betweenness and eigenvector were all different. Mathematically, networks are formalized using concepts of graph theory. Simple networks (i.e. undirected, unweighted and without self-loops graphs) are numerically expressed with a symmetric binary adjacency matrix where entries valued 1 denote pair of vertices directly connected between them, otherwise 0. Graphically, networks are represented through punctual symbols with lines between them if a direct connection exists.

Everett's network. Matrix representation.

| | A | B | C | D | E | F | G | H | I | J | K | L | M |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| B | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| C | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| D | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| E | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| F | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| G | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 |
| H | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 0 |
| I | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 0 |
| J | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 |
| K | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 1 | 0 |
| L | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 |
| M | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |

Everett's network. Graphical representation.



In dealing with technical aspects of networks, two terms are frequently used: path and geodesic distance. A path from one node i to another j is an alternating sequence of nodes and edges, beginning with i and ending with j , such that each edge connects its preceding node with its succeeding node. In simple networks, the path length is the sum of traversed edges. The minimum length of any path connecting a pair of nodes is called geodesic distance. Next, we offer a short description for each measure of centrality. We also describe details about its calculation using the vertex K as the focal one.

Betweenness

OPERATIVE DEFINITION: It considers the frequency a given vertex occurs in the shortest paths between any pair of

vertices in the network. **MEANING:** It reflects a bridging role in the flow of information throughout the structure of the network. **WORKED EXAMPLE:** Vertex K occurs always in the shortest paths connecting the following pairs of nodes: {A, L}; {A, M}; {B, L}; {B, M}; {C, L}; {C, M}; {D, L}; {D, M}; {E, L}; {E, M}; {F, L}; {F, M}; {G, L}; {G, M}; {H, L}; {H, M}; {I, L}; {I, M}; {J, L} and {J, M}. Then, 20 shortest paths pass necessarily through vertex K. However, note that K is also intermediary in one of the two shortest paths there exist from H to J (or vice versa). Here, we consider the fraction of shortest paths our target vertex K belongs to (that is, 1/2). So, the resulting betweenness score for K equals 20.5 (= 20 + 0.5).

Closeness

OPERATIVE DEFINITION: It may be defined as the total geodesic distance (along the shortest path) between the focal vertex and all other vertices reachable from it. We know three procedures for quantifying it: 1) to take the mean distance, 2) to take the reciprocal of the mean distance and 3) to take the reciprocal of the total. Softwares such as NodeXL use the latter procedure. **MEANING:** It indicates proximity to all other vertices, so it is correlated with a central location in the network. **WORKED EXAMPLE:** The geodesic distances between K and the rest of vertices of the network are: 5 (with A, B and C), 4 (with D and E), 3 (with F), 2 (with I, G and M) and 1 (with J, H and L). The overall sum is 35, so closeness (its reciprocal) equals to 0.029.

Eigenvector

OPERATIVE DEFINITION: It assigns relative scores to all nodes in the network based on the principle that connections to high scoring nodes contribute more to the score of the node in question than equal connections to low scoring nodes. For computing it, we firstly obtain the eigenvector solution (normalized to unit length) for the greatest eigenvalue resulting from the spectral decomposition of the adjacency matrix. The *i-th* component of the related eigenvector then gives the centrality score of the *i-th* node in the network. It is a common practice to report the eigenvector centralities as the relative loading of each component with regards to the overall sum of loadings. **MEANING:** It measures the importance of a node as a function of the propinquity to well-connected vertices. **WORKED EXAMPLE:** The requested eigenvector for the present adjacency matrix has the following components (normalized to unit length): [0.06651184, 0.06651184, 0.06651184, 0.17744310, 0.10265024, 0.27385464, 0.45050760, 0.47006557, 0.45796294, 0.30119965, 0.34559018, 0.15071482, 0.05649315]. The 11-*th* component (=0.34559018) corresponds to the loading of our focal node K, and the respective eigenvector centrality is expressed as its fraction to the overall sum of the components, namely 0.1157362 (= 0.34559018/2.986017).

Degree

DEFINITION: Number of neighbors (or direct connections) of a focal vertex. **MEANING:** It indicates the potential accessibility and popularity of a given node in the network. **WORKED EXAMPLE:** Node K has degree 3 because there are three links incident on it: K-J, K-H and K-L.

In the following table, vertices are ordered from the most central to the most peripheral in function of the scores of centrality which are in turn enclosed between brackets.

| Degree | Betweenness | Closeness | Eigenvector |
|--------|-------------|-----------|-------------|
| D (4) | F (39) | G (0.037) | H (0.157) |
| F (3) | G (36) | F (0.036) | I (0.153) |
| G (3) | D (30) | H (0.033) | G (0.151) |
| H (3) | H (22.5) | I (0.031) | K (0.116) |
| I (3) | K (20.5) | D (0.030) | J (0.101) |
| K (3) | L (11) | K (0.029) | F (0.092) |
| J (2) | I (7.5) | J (0.027) | D (0.059) |
| L (2) | J (1.5) | E (0.026) | L (0.050) |
| A (1) | A (0) | A (0.023) | E (0.034) |
| B (1) | B (0) | B (0.023) | A (0.022) |
| C (1) | C (0) | C (0.023) | B (0.022) |
| E (1) | E (0) | L (0.023) | C (0.022) |
| M (1) | M (0) | M (0.018) | M (0.019) |