



# Dynamics of global institutional collaboration in insect taxonomy reveal imbalance of taxonomic effort

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**Abstract.** 1. Institutional collaboration promotes development and technical advances in science. A social network analysis is often used to assess the evolutionary dynamics of institutional collaboration in many fields. However, there has been no social network analysis of the insect taxonomy field based on bibliometric data.

2. To explore the evolutionary pattern of institutional collaboration in this field, a total of 21 095 articles were collected from the Web of Science between 1997 and 2016. According to author affiliations data, we found increasingly closer collaboration has occurred in this network over time. Due to economic development, social attention, and policies supporting science and research, developing countries such as China and Brazil have shown a strong upward tendency towards collaboration since 2001.

3. However, the development of institutional collaboration reveals imbalance of taxonomic effort and requires careful attention to certain aspects. Several countries have published numerous research articles, whereas most countries have published a small number of papers. Most institutions have tended to collaborate with institutions from same country, neighbouring countries or continent. Some institutions in developing countries (e.g. China) have numerous collaborators, however these institutions only played a modest role in introducing new collaboration between their collaborators. More work needs to be done to improve intermediary ability and to reduce the influence of geographical distance.

4. This study offered a vision for understanding the evolutionary dynamics of institutional collaboration in the insect taxonomy field, and it also suggested further enhancement of institutional collaboration in some weak aspects.

**Key words.** Cluster analysis, insect taxonomy, institutional collaboration, social network analysis, taxonomic effort.

## Introduction

Insects are the most diverse and richest group of organisms, with about half of all species on Earth (Costello *et al.*, 2012, 2013). To understand and recognise such a complex group, insect taxonomy, as a branch of

entomology, has developed to focus on the classification of insects, particularly involving areas such as the discovery and description of new species. Since 1735, when Carl Linnaeus' first edition of the *Systema Naturae* was published, the number of described insects has increased to 827 165 species (Roskov *et al.*, 2017). Recent analyses of potential global species richness suggest that nearly one-third of insect species remain to be discovered (Costello *et al.*, 2012, 2013; Costello, 2015).

During the past several hundred years, insect taxonomists have provided a taxonomic information that helps understanding, conservation and management of

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insect diversity in the natural world. However, taxonomic effort has not been equal in different countries. Due to lack of access to library facilities and reliably identified collections, it has been difficult for many taxonomists from developing countries to classify unknown species (Wheeler *et al.*, 2004; Godfray *et al.*, 2007), despite most biodiversity hotspots being located in developing countries (Myers *et al.*, 2000; Grenyer *et al.*, 2006). Species richness in different regions exhibits significant differences, as there are higher numbers of herbivorous insects in tropical rainforests compared to temperate zones (Novotny *et al.*, 2006). For any country, it is impossible to have the taxonomic expertise covering all taxa, and international cooperation is considered an effective way to promote exploration, discovery, and new species description (Costello *et al.*, 2013). Recent studies have determined the average number of authors describing species each year has increased since the 1960s, indicating that increasing numbers of taxonomists have been discovering new species (Costello *et al.*, 2012, 2013).

However, to date, there has been little systematic assessment of the extent and patterns of these collaborations in the taxonomy based on sufficient bibliometric data. Co-authorship is considered the most formal indicator of academic collaboration in scientific research (Acedo *et al.*, 2006), providing a window into the patterns of collaboration within the academic community (Newman, 2004). There are 47000 professional taxonomists working on taxonomic research in the world (Costello *et al.*, 2013, 2014). Meanwhile, numerous amateurs describe many species (Brûlé & Touroult, 2014); for example, nearly half of all new species of European animals have been described by amateurs (Fontaine *et al.*, 2012; Costello *et al.*, 2013). Recent literature has indicated that institutional collaboration plays a very important role in academic research, providing additional access to resources for individual researchers (Jones *et al.*, 2008; Hottenrott & Lawson, 2017). Multi-institutional collaborations have become the fastest growing type of authorship structure, and these contribute to publishing broader-impact research (Jones *et al.*, 2008). Author's institutional affiliations are a practical way to evaluate academic collaboration.

Social network analysis of institutional collaboration has been applied to many fields, such as strategic management research (Koseoglu, 2016), tourism and hospitality research (Ye *et al.*, 2012), online services of scientific profiles (Ortega & Aguillo, 2013) and reproductive biology (González-Alcaide *et al.*, 2008). In the insect taxonomy field, few studies have focused on the evolution of the network of institutional collaboration to identify the dynamics of institutional collaboration on a wide scale via social network analysis (SNA). Therefore, we have evaluated the evolution of institutional collaboration in insect taxonomy research worldwide. Based on abundant literature, we identified the critical and main institutions in the network and explored the evolutionary model of the network of institutional collaboration over time. Finally, we evaluated the

drivers of institutional collaboration in insect taxonomy research.

## Methods

### *Data collection and extraction*

To determine the characteristics of the evolving institutional collaboration in the insect taxonomy field for the past 20 years between 1997 and 2016, we collected data from the Web of Science Core Collection. The data were searched using the search string '(new-speci\* OR new-tax\*) and (Archaeognatha OR Blattodea OR Coleoptera OR Dermaptera OR Diptera OR Embioptera OR Ephemeroptera OR Grylloblattodea OR Hemiptera OR Hymenoptera OR Isoptera OR Lepidoptera OR Mantodea OR Mantophasmatodea OR Mecoptera OR Megaloptera OR Neuroptera OR Odonata OR Orthoptera OR Phasmida OR Phthiraptera OR Plecoptera OR Psocodea OR Raphidioptera OR Siphonaptera OR Strepsiptera OR Thysanoptera OR Trichoptera OR Zoraptera OR Zygentoma)'. In the search, the names of insect orders followed the taxonomic tree used by Catalogue of Life (Roskov *et al.*, 2017). The complete records including titles, author information (author full names and research addresses), publication years, document types, accession numbers and others were downloaded. The records including valid author information were extracted.

We stipulated a rule that each author in an article represented only one institution. In other words, if an author was affiliated with multiple institutions, the first institution that appeared was identified as his/her affiliated institution (Koseoglu, 2016). Meanwhile, the same institutions represented by different names were found by sight. Consequently, a total of 5594 institutions, which published 21095 papers of insect taxonomy in the past 20 years, were identified.

### *Network evolution analysis*

The whole time period was split into four equal and consecutive 5-year sub-periods (1997–2001, 2002–2006, 2007–2011, and 2012–2016). Descriptive analyses were done to assess network evolution using article numbers, institution numbers, institution appearances and the proportion of single/multi-institutions. Five indicators (density, clustering coefficient, mean distance, connectedness and fragmentation) were calculated to compare institutional collaboration networks each period using the package 'igraph' (Csardi & Nepusz, 2006). Furthermore, the data collected in our study were imported into Sci2 Tool (Science of Science Tool v1.2 beta, <https://sci2.cns.iu.edu>) (Sci2 Team, 2009), and node values (the paper numbers of institutions) and edge values (the numbers of collaboration between two institutions) were obtained using extracting co-author network function. Considering the

time-consuming calculation of massive data and the difficulty visualising the whole network, the data for a node value >5 and edge value >1 were selected to create circular visualisations of networks for each period.

### Collaboration trend analysis

A heatmap of institutional collaboration was built to explore the collaborative preference using edge values among influential institutions (node value > 99). Min–Max normalisation was performed to scale the values by row, and a dendrogram of influential institutions was constructed based on hierarchical cluster analysis, using the package ‘lattice’ (Sarkar, 2008) and ‘pheatmap’ (Kolde, 2012). In the visualisation tool Gephi (Gephi v0.9.1, <http://gephi.org>) (Bastian *et al.*, 2009), a network of the largest institutional collaboration component was established (4634 members) to analyse a cooperative relationship on a country’s level. The node and edge values of countries were calculated based on the country information of institutions; then, a collaboration network (node value > 4) on the world map was constructed with the packages ‘RgoogleMaps’ (Loecher, 2014) and ‘geosphere’ (Hijmans *et al.*, 2012). Finally, the degree of centrality and betweenness centrality were determined to identify the institutions playing crucial roles in network using the package ‘reshape2’ (Wickham, 2007). All of the packages were utilised in the R language environment (R Core Team, 2017).

## Results

### Network evolution in the insect taxonomy field

There were 1628 articles and 769 institutions during the first period (1997–2001) in Table 1. Furthermore, the number of articles and institutions exhibited significant increases in subsequent periods, and the final articles and institutions were 9673 and 3564 respectively, during the last period. The percentage of single institutions (representing authors from the same institution) obviously

declined, from 0.796 (first period) to 0.457 (last period), whereas the percentage of collaboration among multiple institutions sharply increased. Fig. 1 shows the rate of change for different kinds of institutional collaboration each year. The proportion of co-institutions collaborating within one country increased leading up to 2006, then held relatively stable. The rate of institutional collaboration between two countries significantly increased over time. For co-institutions of three or more countries, a slight increase was identified during the past twenty years.

Five indicators were used to assess the co-institutional networks during each period. As a first indicator, density reflected the intensive degree of connection for each node (Scott, 1988; Fischbach *et al.*, 2011); in other words, density represented the proportion of existing links to the maximum possible number of distinct links in a network (Abbasi *et al.*, 2011). In our study, the density values were very low (0.002 to 0.001 in each period), and the density value for all periods was 0.001. The phenomenon of a low-density value existed widely for large co-authorship networks (Fischbach *et al.*, 2011; Koseoglu, 2016). The second indicator was a clustering coefficient, representing the probability that any two collaborators of an institute were willing to collaborate with each other (Barabási *et al.*, 2002; Abbasi *et al.*, 2011). The coefficient was 0.266 during the first period, which decreased in subsequent periods to a low value for the overall periods (0.078). The decline in clustering coefficients over time indicated that it was not common for institutions to broker new collaborations. The third indicator is the mean distance. The distance was 4.925, 4.525, 4.215, and 4.090 for each period respectively, and was 3.907 over the whole period. With the growth of the network size, the average distance among nodes decreased to approximately 4, indicating that only about four steps were necessary to reach another for one randomly chosen institution. The fourth and fifth indicators were connectedness and fragmentation, defined as the stability of network construction. Connectedness/fragmentation was 0.102/0.898 in the first period. In addition, in the next three periods, connectedness rose from 0.489 to 0.658, whereas fragmentation declined from 0.511 to 0.342. Similarly, high connectedness (0.645) and low fragmentation (0.355) existed in the

**Table 1.** Descriptive analyses of co-institutions in the insect taxonomy field for each period.

Period	1997–2001	2002–2006	2007–2011	2012–2016	1997–2016
Articles	1628	3325	6469	9673	21 095
Institutions	769	1457	2387	3564	5594
Institution appearances	2059	5310	10 614	17 274	35 257
Single-institution	0.796	0.569	0.528	0.457	0.523
Muti-institutions	0.204	0.431	0.472	0.543	0.477
Density	0.002	0.002	0.001	0.001	0.001
Clustering coefficient	0.266	0.131	0.110	0.101	0.078
Mean distance	4.925	4.525	4.215	4.090	3.907
Connectedness	0.102	0.489	0.571	0.658	0.645
Fragmentation	0.898	0.511	0.429	0.342	0.355

overall period. This suggested that the institutional collaboration network was becoming increasingly stable, particularly since 2001.

Visual circular networks are shown for each period in Fig. 2. In each period, the United States Department of Agriculture’s Agricultural Research Service (USDA ARS)

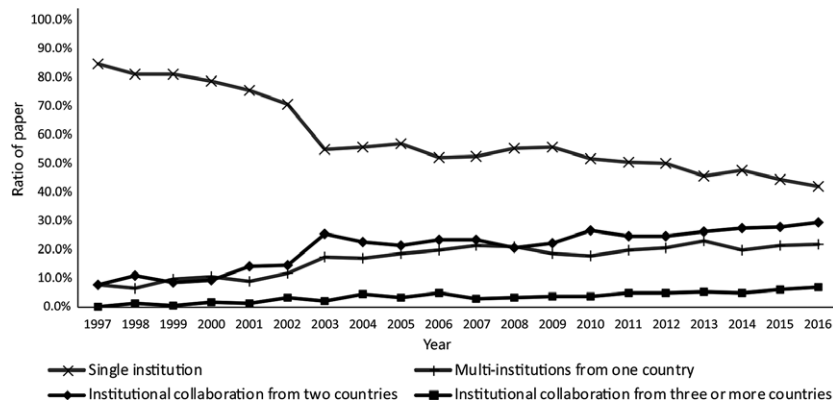


Fig. 1. The dynamics of different kinds of institutional collaboration by year.

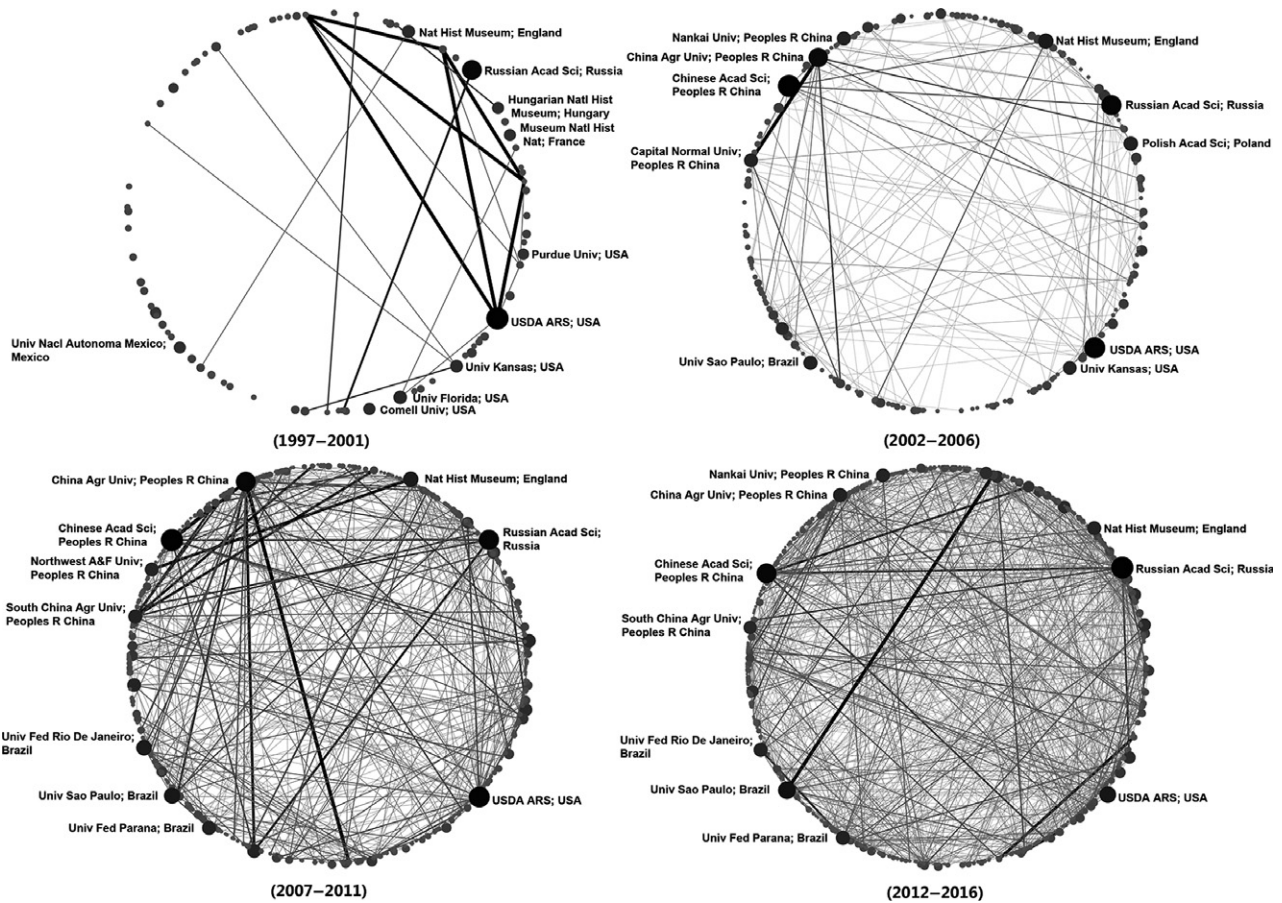


Fig. 2. Circular visualisation of institutional collaboration networks by period. The nodes represent institutions, whereas the lines between nodes represent their collaborative relationships. The institutions with more article numbers have larger sized nodes. Thick and dark coloured lines indicate stronger collaboration. The ten largest institutions are highlighted with their names. The node values >5 and edge values >1 are shown.

and the Russian Academy of Sciences (Russian Acad Sci) published a large number of articles. In the list of top 10 institutions, there were five institutions from the USA, one from Mexico and four from Europe during the first period (1997–2001). A big change occurred in the second period (2002–2006), with an increase in institutional collaboration. Half of the institutions on the list were replaced by institutions from China and Brazil, and the Chinese Academy of Science (Chinese Acad Sci) published the most papers. During the third period (2007–2011), institutions from China and Brazil occupied seven positions in the top 10 list. Kansas University (USA) and the Polish Academy of Sciences (Poland) were excluded from the list. The top 10 list of the last period (2012–2016) was similar as that of the third period, but Nankai University (China) displaced Northwest A&F University (China).

### *The tendency for Institutional Collaboration*

A heatmap based on the data for 45 institutions (node value > 99) is shown in Fig. 3a. According to the different rankings of publication numbers, an institution was considered to be relatively high or low influential. Most of the dark grey grids distributed in the upper-left corner of the figure, indicating that institutions with higher influence (publishing larger paper numbers) tend to cooperate with other higher influential institutions, and collaboration was less likely to occur among institutions with less influence. A dendrogram was constructed to further analyse the preferences of institutional collaboration (Fig. 3b). Based on a hierarchical cluster analysis, 45 institutions were clustered into five groups (after trying to divide 1–10 groups, five groups were thought to be the most meaningful for showing the preference of institutional collaboration). Group A, including institutions mostly from South America, and nearly all institutions in group B were from North America, except for one institution from Argentina. Two institutions from Poland and the Czech Republic were clustered together (group C). Chinese institutions were gathered with institutions from France, Hungary, Turkey, and Poland in group D. In addition, in group E, most Chinese institutions were clustered into one group. Our results show that institutions from the same country or the same continent had similar collaborative preferences.

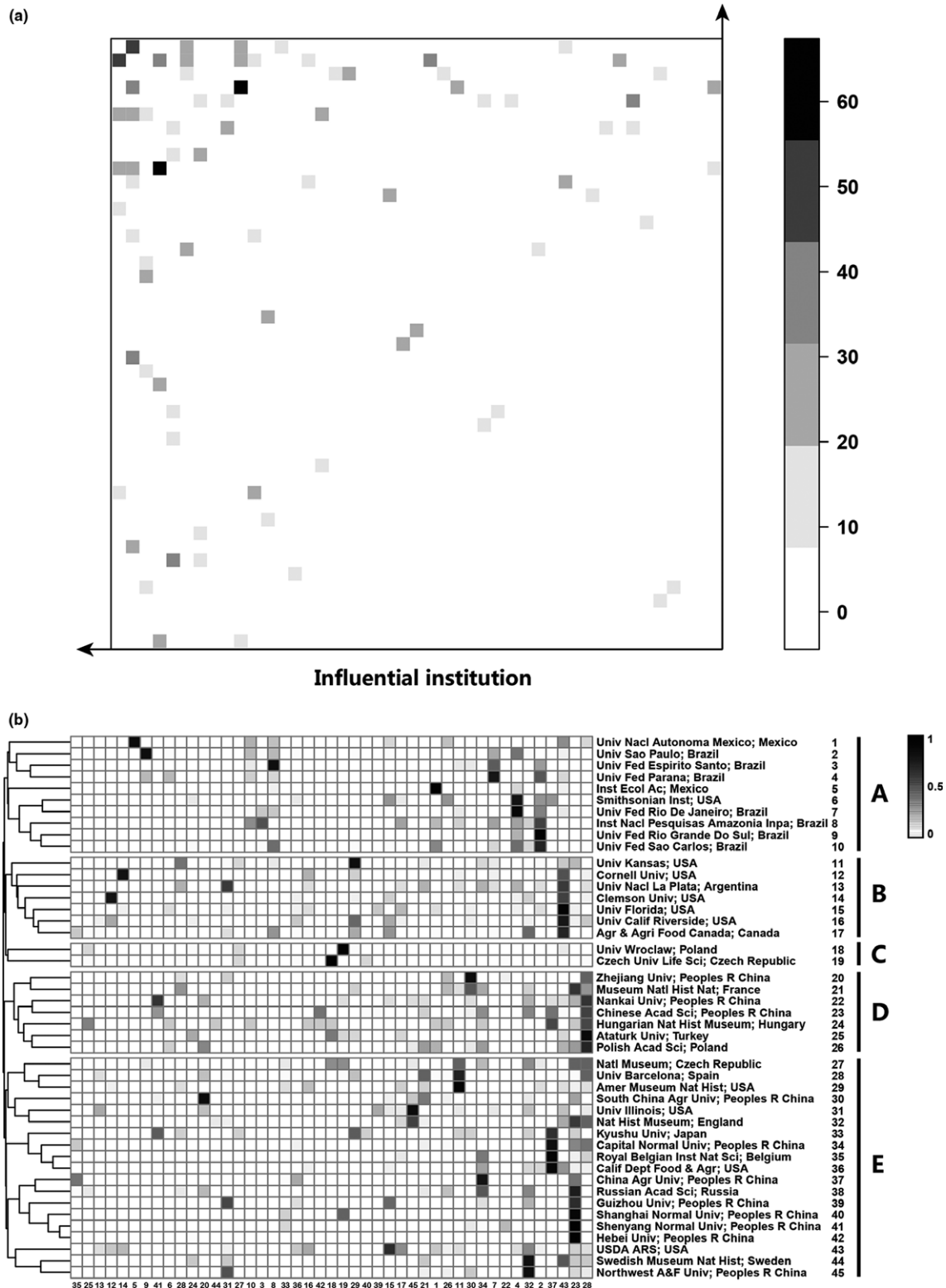
A visualisation of the network at a country level was constructed based on the largest component consisting of connected institutions (4634) (Fig. 4). In general, institutions were gathered with institutions from the same country. Compared to China and the USA, Brazil had a more centralised distribution in the network. According to the country information for each institution, the countries (node value > 4) were selected to build a collaborative network on a world map (Fig. 5). The USA had the highest node value (4647), followed by China (3748) and Brazil (2345). The values for European countries were not high (<1200), whereas the values for African countries

were lower (<300). Considering the European Union (EU-28) as an entirety, EU-28 had the highest value (6287). The links in the map represent collaboration among different countries. The USA had more collaborations with China, Brazil, and Canada, whereas China collaborated more frequently with Russia, the USA, and Japan. In Oceania, Australia collaborated more closely with the USA (approximately 100 times). There were few institutions distributed in Africa, and these institutions seldom collaborated with each other. The most international collaborations were found between South Africa and the USA (36 times).

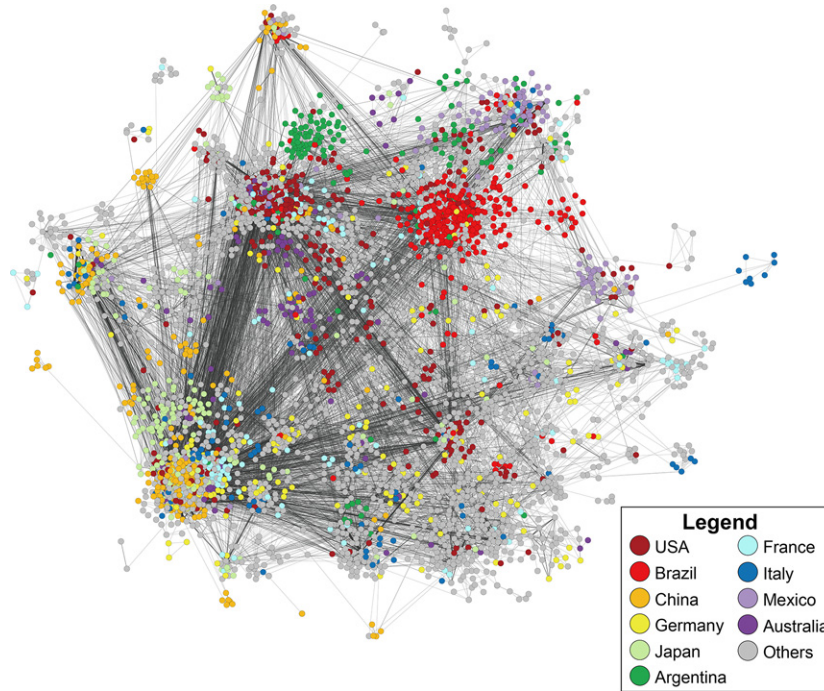
Degree centrality and betweenness centrality were used to provide available information about the rankings of the top institutions in the network (Table 2). The degree of centrality represented the number of links in a node, which indicated the number of collaborative institutions (Estrada & Bodin, 2008; Abbasi *et al.*, 2011). USDA ARS (USA) had the highest degree of collaboration, followed by the Russian Acad Sci (Russia) and the Chinese Acad Sci (China). There were four institutions from the US and four from China in the list. Betweenness centrality was defined as an institution's capacity to connect with other institutions within the network (Acedo *et al.*, 2006). This measure showed which nodes (institutions) acted as 'bridges' between other nodes in a network, and a high betweenness value could indicate that the 'bridge' institutions played important roles to foster collaboration. In the overall period, the top three institutions with the highest betweenness values were Nat Hist Museum (England), USDA ARS (USA) and the Univ Kansas (USA). Furthermore, the betweenness values of these three institutions were much higher than others. No institutions from China or Russia appeared in the betweenness list. Meanwhile, some institutions from Spain, the Czech Republic, Poland, and Colombia were not included in the degree list, but emerged in the betweenness list.

### **Discussion**

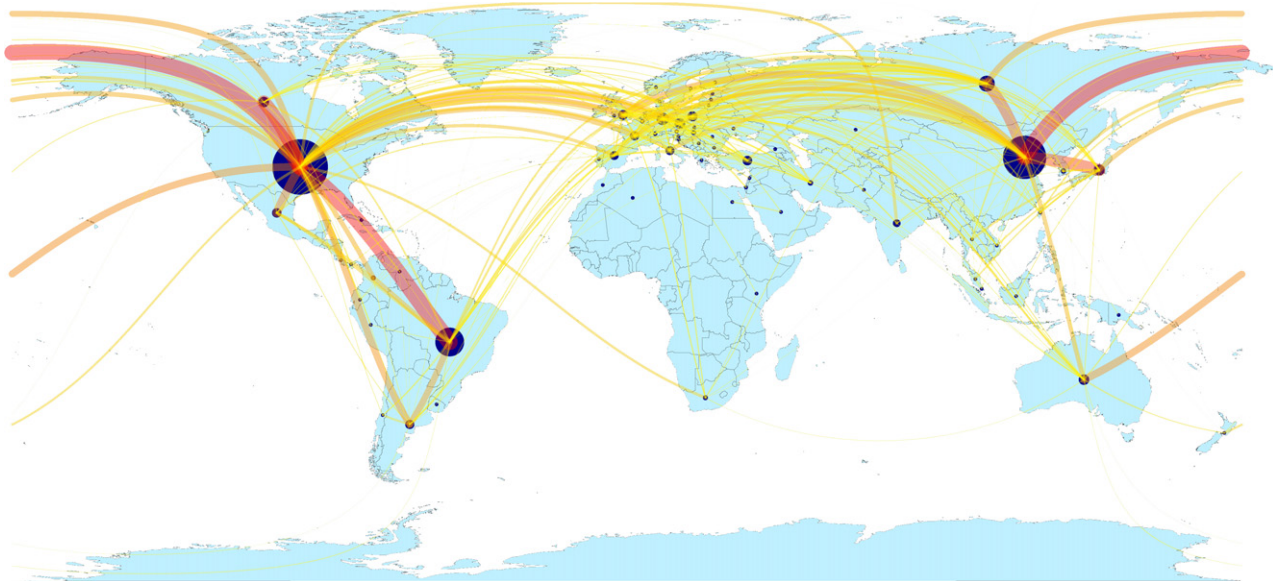
As in Fig. 1, the collaboration among multiple institutions has been a common phenomenon for most researchers. A remarkable decreasing tendency occurred in the proportion of articles that single institutions produced independently. Relying on collaboration among multiple institutions, insect researchers desire to obtain more resources, such as sufficient specimens, accurate species identification and robust analytical methods for species delimitation. Intraspecific and geographical variation is widespread in many insect groups (Ben-Dov & Hodgson, 1997; Aspetsberger *et al.*, 2003; Dujardin & Le Pont, 2004). This requirement of obtaining more specimens encourages insect researchers to seek collaborators in other regions to decrease the spatial distance and gain more specimens. Meanwhile, increasingly more identification demands have arisen in ecology, evolution, molecular phylogeny, and conservation and contribute to close ties



**Fig. 3.** (a) The heatmap of institutional collaboration among 45 influential institutions with paper number higher than 99. The frequency of institutional collaboration is shown in different shades of grey. (b) A dendrogram of cluster analysis based on the heatmap. The grids with dark grey represent more robust collaborative relationships.



**Fig. 4.** The institutional network of the largest component visualised at a country level. Nodes with different colours represent institutions from different countries. [Colour figure can be viewed at [wileyonlinelibrary.com](http://wileyonlinelibrary.com)]



**Fig. 5.** A national collaboration map in the insect taxonomy field. The circles represent corresponding countries (node value > 4) on the map, and the sizes of the circles illustrate the number of publications. The thick and dark coloured lines indicate stronger collaborative relationships. [Colour figure can be viewed at [wileyonlinelibrary.com](http://wileyonlinelibrary.com)]

among insect researchers and other field researchers. In addition, new identification techniques for species delimitation based on molecular data, such as DNA Barcoding (Hebert *et al.*, 2003, 2004), General Mixed Yule

Coalescent (Pons *et al.*, 2006), Poisson Tree Process (Zhang *et al.*, 2013) and Automatic Barcode Gap Discovery (Puillandre *et al.*, 2012) also impel more researchers to participate in insect taxonomy initiatives and to cooperate

**Table 2.** The top 15 influential institutions, as measured by the degree of centrality and betweenness centrality in the insect taxonomy field.

Rank	Institution (abbreviated)	Country	Degree centrality	Institution (abbreviated)	Country	Betweenness centrality
1	<b>USDA ARS</b>	<b>USA</b>	667	<b>Nat Hist Museum</b>	<b>England</b>	108354.2632
2	Russian Acad Sci	Russia	638	<b>USDA ARS</b>	<b>USA</b>	99704.02471
3	Chinese Acad Sci	Peoples R China	614	<b>Univ Kansas</b>	<b>USA</b>	87814.37573
4	<b>Nat Hist Museum</b>	<b>England</b>	552	<b>Polish Acad Sci</b>	<b>Poland</b>	43146.96995
5	China Agr Univ	Peoples R China	511	<b>Univ Sao Paulo</b>	<b>Brazil</b>	39364.21522
6	<b>Univ Sao Paulo</b>	<b>Brazil</b>	463	Calif Dept Food & Agr	USA	38691.31505
7	Museum Natl Hist Nat	France	284	Univ Barcelona	Spain	36553.59131
8	<b>Univ Florida</b>	<b>USA</b>	269	<b>Univ Florida</b>	<b>USA</b>	34575.20676
9	Capital Normal Univ	Peoples R China	267	Natl Museum	Czech Republic	34252.19678
10	Univ Fed Parana	Brazil	265	Univ Nacl Colombia	Colombia	33704.08289
11	<b>Univ Kansas</b>	<b>USA</b>	264	Amer Museum Nat Hist	USA	31636.93032
12	South China Agr Univ	Peoples R China	261	Texas A&M Univ	USA	30453.00833
13	Agr & Agri Food Canada	Canada	241	Clemson Univ	USA	27924.10732
14	<b>Polish Acad Sci</b>	<b>Poland</b>	233	Acad Sci Czech Republic	Czech Republic	27804.52337
15	Univ Nacl Autonoma Mexico	Mexico	203	Kyushu Univ	Japan	27649.78055

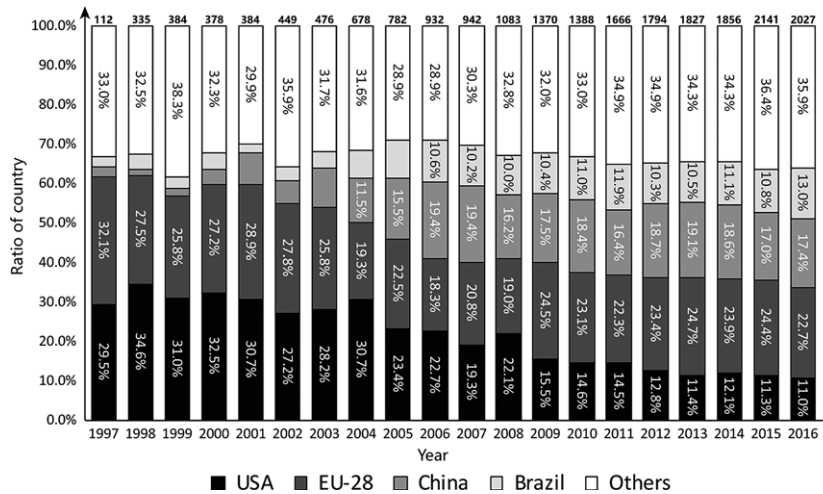
The institutions appear in two lists of measured centrality with bold text.

with researchers from different institutions. In fact, a similar upward tendency of collaboration is also observed among other research fields, indicating that increasingly closer collaboration over time has occurred in various fields (Larivière *et al.*, 2006; Schneider *et al.*, 2014; Koseoglu, 2016).

Policies of government agencies and/or institutions might become more influential in motivating researchers to increase mutual cooperation and science production. It is clear that large funding expenditures have accelerated research in China (Zhou & Leydesdorff, 2006). Research funding from the Chinese government has increased continuously from 0.6% of GDP in 1996 to 1.5% of GDP by 2007 (Fu *et al.*, 2011). China still occupies four places in the top 10 institutions of insect publications from 2002 to 2016 (Fig. 2). Our results are consistent with China being the second largest scientific producer since 2006 (Leydesdorff & Wagner, 2009). Brazil, another developing country, has followed a similar process during the past twenty years. The institutions from Brazil are not included in the list of the top 10 collaborative institutions during the first period (Fig. 2). As one of the world's prime megadiverse countries (Lewinsohn *et al.*, 2005), Brazil has high diversity of insects, providing rich resources to discover new species for insect taxonomists. Barreto (2006) reported that Brazil increased scientific production considerably since 2005 due to economic development, social attention, and policies supporting science and research (Schneider *et al.*, 2014). In the subsequent periods (2007–2016), there were still three of Brazil's institutions in the top 10 (Fig. 2). Previous studies also showed the increase in species descriptions from Asia and South America may result from the increasing number of researchers describing new species, which is likely due to the growth of new scientific positions in Asia and South America in recent past years (Costello *et al.*, 2012, 2013, 2015). Developing countries

have maintained a good upward trend in the insect taxonomy field, but some developed countries are still ahead in certain areas. The United States demonstrates the most extensive collaboration with other countries (Fig. 5), although the percentage of publications each year is decreasing relative to the percentage increases from China and Brazil (Fig. 6). Meanwhile, the USA also has a remarkable advantage in highly cited papers and citation/publication ratios (Leydesdorff & Wagner, 2009).

Geographical proximity plays a significant role in scientific collaboration (Katz, 1994). Some institutions from the same country or continent are clustered together (Fig. 3b), reflecting that they have a similar composition of cooperation partners. Geographical factors influence the selection of cooperating institutions. As Fig. 4 shows, the collaborative practices of institutions correspond more closely to institutions from the same country than those from other countries (Fig. 4). Researchers tend to seek adjacent collaborators; for example, widespread cooperation occurs in China–Japan, China–Russia, the USA–Mexico, and the USA–Canada (Fig. 5). Geographical proximity facilitates frequency of contact and enhances the likelihood of cooperative relationships (Gray, 1985). For most insect taxonomists, it is common to select cooperators from neighbouring countries because of the similar insect fauna in neighbouring regions. Examining a type specimen is an important way to identify a species, especially to distinguish closely related species. It is easier for adjacent researchers to have this opportunity because of low-cost travel, which contributes to more effective face-to-face interactions. Considering the significant influence on the insect taxonomy field and similar latitude ranges, cooperation between China and the USA is not limited due to geographical distance. However, the cooperation between China and Brazil is obviously weak compared to that between the USA and Brazil (Fig. 5). As described in



**Fig. 6.** The proportion of paper numbers from different countries based on addresses of the first corresponding authors by year. The proportion values <10% are hidden. The paper numbers are shown on the top of bars.

Gazni *et al.* (2012), language, culture, politics and some other elements (including geographical distance) can also affect collaborative behaviour. For example, Australian and American taxonomists share the English language and similar culture, they usually tend to collaborate more with each other in spite of the geographical distance.

With the growth of network size, connectedness increased to the highest value in 2012–2016, whereas the mean distance and fragmentation values in the networks decreased over time. These indicators demonstrate that insect taxonomists have noticed a significance of collaboration research, and the institutions in the network have become increasingly close to each other. However, taxonomic effort is unbalanced in different countries. Several countries have published numerous research articles, whereas most countries have published a small number of papers (Fig. 6). The development of the institutions themselves also appears unbalanced. Active and influential institutions had high scores in both degree and betweenness values (Ye *et al.*, 2012). Although Chinese institutions have many collaborators (high degree of centrality), they do not play a critical role as ‘bridges’ in brokering and connecting isolated institutions to the main academic community, exhibiting low betweenness values (Table 2). The low clustering coefficient values also reflect this characteristic, where two randomly chosen institutes with a third common collaborator are less likely to collaborate with each other. The process of scientists introducing their collaborators to one another is a critical factor in the development of scientific communities (Abbasi *et al.*, 2011), and more work needs to be done to improve the intermediary ability of institutions in the insect taxonomy field.

Using publication data and co-institutional relationships, we illustrated an overview of collaborative networks in the insect taxonomy field. However, our data were collected from the Web of Science Core Collection (WOSCC) and do not represent the complete world of research on

insect taxonomy; numerous articles are published in other journals and languages. However, this significant bias was impossible to eliminate, due to the impracticality of collecting publications throughout the world. In other research areas, using representative journals or databases is very common in network analysis (Zhou & Leydesdorff, 2006; Abbasi *et al.*, 2011; Koseoglu, 2016). Moreover, the main purpose of our study was to explore the evolutionary tendency of institutional collaboration networks and to illuminate possible reasons for collaboration. Increasingly more researchers are trying to publish high-quality articles. WOSCC, representing the world’s leading scholarly literature database of scientific research, provides an available and convenient platform to research collaboration networks. In conclusion, our study constructed a relatively accurate network of collaborators in insect taxonomy and illustrated the collaboration tendencies in this field.

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## References

Abbasi, A., Hossain, L., Uddin, S. & Rasmussen, K.J.R. (2011) Evolutionary dynamics of scientific collaboration networks:

- multi-levels and cross time analysis. *Scientometrics*, **89**, 687–710.
- Acedo, F.J., Barroso, C., Casanueva, C. & Galán, J.L. (2006) Co-authorship in management and organizational studies: an empirical and network analysis. *Journal of Management Studies*, **43**, 957–983.
- Aspetsberger, F., Brandsen, D. & Jacobs, D.S. (2003) Geographic variation in the morphology, echolocation and diet of the little free-tailed bat, *Chaerephon pumilus* (Molossidae). *African Zoology*, **38**, 245–254.
- Barabási, A.L., Jeong, H., Néda, Z., Ravasz, E., Schubert, A. & Vicsek, T. (2002) Evolution of the social network of scientific collaborations. *Physica A Statistical Mechanics & Its Applications*, **311**, 590–614.
- Barreto, M.L. (2006) Growth and trends in scientific production in epidemiology in Brazil. *Revista de Saude Pública*, **40**, 79–85.
- Bastian, M., Heymann, S. & Jacomy, M.G. (2009) An open source software for exploring and manipulating networks. *International AAAI Conference on Weblogs and Social Media*, **8**, 361–362.
- Ben-Dov, Y. & Hodgson, C.J. (1997) Soft scale insects their biology, natural enemies and control. *World Crop Pests* (ed. by Y. Ben-Dov and C.J. Hodgson), Vol. **7A**, pp. 452. Elsevier, Amsterdam, The Netherlands.
- Brûlé, S. & Tourout, J. (2014) Insects of French Guiana: a baseline for diversity and taxonomic effort. *ZooKeys*, **434**, 111.
- Costello, M.J. (2015) Biodiversity: the known, unknown and rates of extinction. *Current Biology*, **25**, R368–R371.
- Costello, M.J., Houlding, B. & Wilson, S. (2014) As in other taxa, relatively fewer beetles are being described by an increasing number of authors: response to Löbl and Leschen. *Systematic Entomology*, **39**, 395–399.
- Costello, M.J., Lane, M., Wilson, S. & Houlding, B. (2015) Factors influencing when species are first named and estimating global species richness. *Global Ecology and Conservation*, **4**, 243–254.
- Costello, M.J., May, R.M. & Stork, N.E. (2013) Can we name Earth's species before they go extinct? *Science*, **339**, 413–416.
- Costello, M.J., Wilson, S. & Houlding, B. (2012) Predicting total global species richness using rates of species description and estimates of taxonomic effort. *Systematic Biology*, **61**, 871–883.
- Csardi, G. & Nepusz, T. (2006) The igraph software package for complex network research. *InterJournal Complex Systems*, **1695**, 1–9.
- Dujardin, J.P. & Le Pont, F. (2004) Geographic variation of metric properties within the neotropical sandflies. *Infection, Genetics and Evolution*, **4**, 353–359.
- Estrada, E. & Bodin, Ö. (2008) Using network centrality measures to manage landscape connectivity. *Ecological Applications*, **18**, 1810–1825.
- Fischbach, K., Putzke, J. & Schoder, D. (2011) Co-authorship networks in electronic markets research. *Electronic Markets*, **21**, 19–40.
- Fontaine, B., van Achterberg, K., Alonso-Zarazaga, M.A., Araujo, R., Asche, M., Aspöck, H., Aspöck, U., Audisio, P., Aukema, B., Bailly, N., Balsamo, M., Bank, R.A., Belfiore, C., Bogdanowicz, W., Boxshall, G., Burckhardt, D., Chylarecki, P., Deharveng, L., Dubois, A. & Enghoff, H. (2012) New species in the Old World: Europe as a frontier in biodiversity exploration, a test bed for 21st century taxonomy. *PLoS ONE*, **7**, e36881.
- Fu, H.Z., Chuang, K.Y., Wang, M.H. & Ho, Y.S. (2011) Characteristics of research in China assessed with Essential Science Indicators. *Scientometrics*, **88**, 841–862.
- Gazni, A., Sugimoto, C.R. & Didegah, F. (2012) Mapping world scientific collaboration: authors, institutions, and countries. *Journal of the Association for Information Science and Technology*, **63**, 323–335.
- Godfray, H.C.J., Clark, B.R., Kitching, I.J., Mayo, S.J. & Scoble, M.J. (2007) The web and the structure of taxonomy. *Systematic Biology*, **56**, 943–955.
- González-Alcaide, G., Alexandre-Benavent, R., Navarro-Molina, C. & Valderrama-Zurián, J.C. (2008) Coauthorship networks and institutional collaboration patterns in reproductive biology. *Fertility and Sterility*, **90**, 941–956.
- Gray, B. (1985) Conditions facilitating interorganizational collaboration. *Human Relations*, **38**, 911–936.
- Grenyer, R., Orme, C.D., Jackson, S.F., Thomas, G.H., Davies, R.G., Davies, T.J., Jones, K.E., Olson, V.A., Ridgely, R.S., Rasmussen, P.C., Ding, T.S., Bennett, P.M., Blackburn, T.M., Gaston, K.J., Gittleman, J.L. & Owens, I.P. (2006) Global distribution and conservation of rare and threatened vertebrates. *Nature*, **444**, 93–96.
- Hebert, P.D.N., Cywinska, A., Ball, S.L. & de Waard, J.R. (2003) Biological identifications through DNA barcodes. *Proceedings of the Royal Society B: Biological Sciences*, **270**, 313–321.
- Hebert, P., Stoeckle, M., Zemlak, T. & Francis, C. (2004) Identification of birds through DNA barcodes. *Plos Biology*, **2**, E312.
- Hijmans, R.J., Williams, E. & Vennes, C. (2012) *Geosphere: spherical trigonometry*. R package version, **1**, 2–28.
- Hottenrott, H. & Lawson, C. (2017) A first look at multiple institutional affiliations: a study of authors in Germany, Japan and the UK. *Scientometrics*, **111**, 285–295.
- Jones, B.F., Wuchty, S. & Uzzi, B. (2008) Multi-university research teams: shifting impact, geography, and stratification in science. *Science*, **322**, 1259–1262.
- Katz, J.S. (1994) Geographical proximity and scientific collaboration. *Scientometrics*, **31**, 31–43.
- Kolde, R. (2012) *Pheatmap: pretty heatmaps*. R package version, **0.7.7**.
- Koseoglu, M.A. (2016) Mapping the institutional collaboration network of strategic management research: 1980–2014. *Scientometrics*, **109**, 203–226.
- Larivière, V., Gingras, Y. & Archambault, É. (2006) Canadian collaboration networks: a comparative analysis of the natural sciences, social sciences and the humanities. *Scientometrics*, **68**, 519–533.
- Lewinsohn, T.M., Freitas, A.V.L. & Prado, P.I. (2005) Conservation of terrestrial invertebrates and their habitats in Brazil. *Conservation Biology*, **19**, 640–645.
- Leydesdorff, L. & Wagner, C. (2009) Is the United States losing ground in science? A global perspective on the world science system. *Scientometrics*, **78**, 23–36.
- Loecher, M. (2014) *RgoogleMaps: overlays on Google Map Tiles in R*. R package version, **1.2.0.6**.
- Myers, N., Mittermeier, R.A., Mittermeier, C.G., Fonseca, G.A.B.D. & Kent, J. (2000) Biodiversity hotspots for conservation priorities. *Nature*, **403**, 853–858.
- Newman, M.E. (2004) Coauthorship networks and patterns of scientific collaboration. *Proceedings of the National Academy of Sciences of the United States of America*, **101**, 5200–5205.
- Novotny, V., Drozd, P., Miller, S.E., Kulfan, M., Janda, M., Basset, Y. & Weiblen, G.D. (2006) Why are there so many species of herbivorous insects in tropical rainforests? *Science*, **313**, 1115–1118.

- Ortega, J.L. & Aguillo, I.F. (2013) Institutional and country collaboration in an online service of scientific profiles: Google Scholar Citations. *Journal of Informetrics*, **7**, 394–403.
- Pons, J., Barraclough, T.G., Gomez-Zurita, J., Cardoso, A., Duran, D.P., Hazell, S., Kamoun, S., Sumlin, W.D. & Vogler, A.P. (2006) Sequencebased species delimitation for the DNA taxonomy of undescribed insects. *Systematic Biology*, **55**, 595–609.
- Puillandre, N., Lambert, A., Brouillet, S. & Achaz, G. (2012) ABGD, Automatic Barcode Gap Discovery for primary species delimitation. *Molecular Ecology*, **21**, 1864–1877.
- R Core Team (2017) *R: A Language and Environment for Statistical Computing*. R Foundation for Statistical Computing, Vienna, Austria. <<http://www.R-project.org/>>
- Roskov, Y., Abucay, L., Orrell, T., Nicolson, D., Bailly, N., Kirk, P.M., Bourgoin, T., DeWalt, R.E., Decock, W., De Wever, A., van Nieukerken, E., Zarucchi, J. & Penev, L. (eds.) (2017) Species 2000 and ITIS Catalogue of Life, 2017 Annual Checklist, Reading, UK: Species 2000. Available at [www.catalogueoflife.org/annual-checklist/2017/](http://www.catalogueoflife.org/annual-checklist/2017/).
- Sarkar, D. (2008) *Lattice: Multivariate Data Visualization with R*, pp. 268. Springer Science & Business Media, New York, New York.
- Schneider, D.R., Vidal-Infer, A., Bolaños-Pizarro, M., Alexandre-Benavent, R., Cañigral, F.J.B. & Valderrama-Zurián, J.C. (2014) Scientific collaboration between Latin America and the European Union (2001–2010) on drug abuse from the ISI Web of Science. *Salud Mental*, **37**, 199–210.
- Sci2 Team (2009) Science of Science (Sci2) Tool. Indiana University and SciTech Strategies. <<https://sci2.cns.iu.edu/user/index.php>>.
- Scott, J. (1988) Social network analysis. *Sociology*, **22**, 109–127.
- Wheeler, G.D., Raven, P.H. & Wilson, E.O. (2004) Taxonomy: impediment or expedient? *Science*, **303**, 285.
- Wickham, H. (2007) Reshaping data with the reshape package. *Journal of Statistical Software*, **21**, 1–20.
- Ye, Q., Song, H. & Li, T. (2012) Cross-institutional collaboration networks in tourism and hospitality research. *Tourism Management Perspectives*, **2**, 55–64.
- Zhang, J., Kapli, P., Pavlidis, P. & Stamatakis, A. (2013) A general species delimitation method with applications to phylogenetic placements. *Bioinformatics*, **29**, 2869–2876.
- Zhou, P. & Leydesdorff, L. (2006) The emergence of China as a leading nation in science. *Research Policy*, **35**, 83–104.

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