

Research Article

Description of the scientific domain *Macrobrachium* through the analysis of the authors with higher productivity and higher H-index according to Scopus

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ABSTRACT. One of the most important domains in aquaculture is *Macrobrachium*, since it represents one of the most cultured crustacean genus worldwide. Description of the authors that study and publish on the subject constitutes a solid contribution to the knowledge of this genus. Indicators of productivity, visibility, relevance, sex and co-authorship of the authors were collected from the Scopus database for the period 1980-2016 to describe the *Macrobrachium* domain. Conceptual mapping techniques were used to visualize co-author relationships. The greatest amount of contributions to knowledge of the genus *Macrobrachium* was shown to come from researchers in China, Brazil, USA and India. Only seven women are among the most productive and relevant authors. Multiple co-author networks exist in which the most relevant researchers are the center. Many networks appear to be closed groups with little interaction between external groups or researchers.

Keywords: *Macrobrachium*, scientific production, co-author networks, functional principal components analysis.

INTRODUCTION

The *Macrobrachium* genus is considered one of the most important domains in aquaculture due to its characteristics favorable towards farm production and its potential to contribute to food security for a growing global population. This domain is linked to biology as a generic scenario and to aquaculture as a specific one. Freshwater prawns of the genus *Macrobrachium* are distributed around the world, mainly in tropical and subtropical regions. More than a hundred *Macrobrachium* spp. have been described, many of which demonstrate high culture potential (García-Guerrero *et al.*, 2013). Research related to the *Macrobrachium* genus consolidates during the late 2000s, but specialized journals have been collecting scientific articles on the subject since the mid-1980s (Chong-Carrillo *et al.*, 2015). This growing field of research still holds unexploited potential. Thus, a detailed description of the authors that research and

publish on the subject constitutes a solid contribution to the knowledge of the genus, as previously approached using a scientometric analysis (Chong-Carrillo *et al.*, 2015, 2016).

Interactions between researchers play a strong role in the development and advancement of science. Therefore, the analysis of the structure of scientific collaboration is a fundamental aspect in the creation of knowledge and the dissemination of its results within a certain scientific domain. A domain of knowledge is a system in which the components of the community (researchers), knowledge structures, information, disciplines or areas of knowledge interact as subsystems (Romero-Quesada, 2013).

Fernández-Molina & Moya-Anegón (2002) analyzed domains without considering how individuals affect the holistic understanding of these communities, basing their analysis on the idea that a scientific domain is constructed by the interactions between individual researchers, rather than a single researcher. Therefore,

the analysis must start on the individual level as the base of the communities that integrate scientific domains.

The objective of the present study was to analyze the researchers on the individual level who have generated knowledge related to the genus *Macrobrachium*, including co-authorship, to gain a broader understanding of the scenario in which they operate within this particular scientific domain. In addition to analyzing the behavior, in time, of the production of scientific articles, as evidence of the knowledge generated by the most productive authors who research the subject.

MATERIALS AND METHODS

All scientific papers published between 1980 and 2016 that included the term *Macrobrachium* in the title were selected from the Scopus® database (Elsevier, Netherlands). The complete records were transferred as a text file and then standardized with the EndNote 10® program, using the bibliographic references manager. Then, Bibexcel (Olle Persson, Umeå University, Umeå, Sweden) was used to analyze the data extracted from the Scopus database and Pajek (version 3.14, Batagelj and Mrvar, University of Ljubljana, Ljubljana, Slovenia) was used to create a mapped representation of the results that corresponded to the frequency of publication and the collaborative relationships between the authors. Data related to the H index (A scientist has index h if h of his or her N_p papers have at least h citations each and the other ($N_p - h$) papers have $\leq h$ citations each) (Hirsch, 2005), number of published articles and number of citations were obtained with the Citation Tracker tool from the Author Details page of Scopus.

In order to analyze the behavior over time of the production of scientific articles by the most productive authors, the method of Functional Principal Components Analysis (FPCA) was applied, considering the data set composed by the 28 most prolific authors about *Macrobrachium* in the period from 1995 to 2016. The *fd* package version 2.4.3 for R (Ramsay *et al.*, 2013) for was used to perform the calculations.

RESULTS

The number of registered articles that contained the term *Macrobrachium* in the title was 1926, with 2044 authors registered. Table 1 shows 28 authors with at less 17 articles published between 1980 and 2016, including the number of citations and the H index of each author.

W. Cheng of China was shown as the author with the most publications (40), followed by W.C. Valenti of Brazil (38) and J.H. Tidwell of the USA (35), respectively. For the number of citations obtained by each author, W.C. Valenti fell 15 positions with a total of 250 citations and J.H. Tidwell fell 10 positions with a total of 301 citations. J.C. Chen was in the 3 position, with 454 citations, and finally W. Cheng was in the first positions with 819 citations for the most cited manuscripts.

J.R. Bonami was second in this ranking with 574 citations despite having just 18 published papers. For the H index, W. Cheng, J.R. Bonami and J.C. McNamara, are in the first positions again with indices of 20, 14 and 13 respectively. W.C. Valenti and J.H. Tidwell gained a position, both with an H index of 12 and 10 respectively.

The 15 most relevant authors worldwide, based on their H index, and their affiliations based on Scopus are shown in Table 2. Forty percent of the most relevant authors are affiliated to universities located in China and India. The remaining authors are affiliated to universities located in Israel, USA and Brazil (13.3% each), and Japan, Belgium and France (6.6% each).

The results obtained from the analysis of 42 of the most relevant authors worldwide, each having an H index >6 (seven articles with at least seven citations) are showed (Table 3). Asia (including the Far East, India and Southeast Asia) holds the largest number of researchers 18 (42.8%), most of which reside in China and India. The People's Republic of China and the Republic of China (Taiwan) are included in "China", since the latter is not recognized by the United Nations due to a dispute related to the legal territory of the People's Republic of China. The Americas hold eight researchers 13 (30.9%) from the USA, Mexico, Brazil and Argentina. European researchers account for only four (9.5%). Finally, Israel and Australia represent the Middle East and Oceania, respectively, with six (14.2%) and one (2.3%) respectively.

Table 4 shows the distribution of the most productive authors by sex. Only 7 of 21 of the most productive authors with the largest number of published manuscripts are women (from China, Japan, India, Malaysia and Thailand), representing just the 33.3% of the total authors.

The data set chosen for the principal components analysis was composed of the number of articles per year of the 28 most productive authors only in the period 1995-2016, for the analysis the square root of the original data was considered. A first approximation to the description of the behavior of the variable production of articles in the studied period was made when estimating the functional media. As shown in Figure 1, there is a tendency to increase production with a fall around 2008 and the peak production in 2012. The

Table 1. The most relevant authors according to their productivity (Ndoc = number of *Macrobrachium* published documents), influence (Ncit = number of cites of *Macrobrachium* published documents) and performance (H-index based in *Macrobrachium* published documents), based on Scopus data.

Author	Ndoc	Author	Ncit	Author	H-Index
Cheng, W.	40	Cheng, W.	819	Cheng, W.	20
Valenti, W.C.	38	Bonami, J.R.	574	Bonami, J.R.	14
Tidwell, J.H.	35	Chen, J.C.	454	McNamara, J.C.	13
McNamara, J.C.	30	Sahul-Hameed, A.S.	408	Sagi, A.	13
Bhassu, S.	28	Liu, C.H.	356	Cohen, D.	13
Geraldine, P.	26	Sagi, A.	344	Tidwell, J.H.	12
D´Abramo, L.R.	24	Yang, W.J.	337	Chen, J.C.	12
Fu, H.	23	D´Abramo, L.R.	330	D´Abramo, L.R.	12
Wang, W.	22	McNamara, J.C.	304	Liu, C.H.	12
Sahul-Hameed, A.S.	22	Tidwell, J.H.	301	Sahul-Hameed, A.S.	11
Sobhon, P.	22	Wilder, M.N.	293	Yang, W.J.	11
Sagi, A.	22	Sorgeloos, P.	282	Sorgeloos, P.	11
Qiao, H.	21	Cohen, D.	266	Valenti, W.C.	10
Ren, Q.	21	Geraldine, P.	262	Wilder, M.N.	10
Pillai, B.R.	20	Valenti, W.C.	250	Geraldine, P.	9
Yang, W.J.	20	Mather, P.B.	230	Wahab, M.A.	8
Cohen, D.	20	Wahab, M.A.	151	Mather, P.B.	8
Saravana-Bhavan, P.	19	Sobhon, P.	132	Sobhon, P.	7
Sorgeloos, P.	18	Pillai, B.R.	116	Bhassu, S.	6
Bonami, J.R.	18	Damrongphol, P.	99	Qiao, H.	6
Wilder, M.N.	18	Saravana-Bhavan, P.	98	Fu, H.	6
Sun, S.	17	Bhassu, S.	74	Pillai, B.R.	6
Arockiaraj, J.	17	Fu, H.	71	Wang, W.	5
Damrongphol, P.	17	Wang, W.	68	Ren, Q.	5
Liu, C.H.	17	Ren, Q.	63	Saravana-Bhavan, P.	5
Mather, P.B.	17	Arockiaraj, J.	59	Arockiaraj, J.	5
Chen, J.C.	17	Qiao, H.	48	Damrongphol, P.	5
Wahab, M.A.	17	Sun, S.	42	Sun, S.	4

effect of adding and subtracting a suitable multiple of the first harmonic to the functional media is shown in Figure 2.

This type of variation describes a trend towards a change in production around 2011. If a detailed analysis of the coefficients of each of the individuals for this component is realized, the high positive values correspond to authors whose production is concentrated in the years prior to 2011. The production of J.C. Chen exponent of these characteristics is included (Fig. 3).

Contrary to this trend (negative coefficients) are the authors for whom the bulk of publications is after 2011. See for example the W. Wang production shown in Figure 4. The second component (Fig. 5) represents a form of variation that polarizes two types of production one concentrated in the years prior to 2004 and another in the later years.

The above corresponds with the case of J.C. Chen (Fig. 3), and the opposite is observed with B.R. Pillai (Fig. 6).

In Figure 7 the individuals are represented in the space of the first two components. Taking into account the effects of the first two harmonics, we can consider that the authors located around the origin of coordinates (W.C. Valenti, J.C. McNamara, A. Sagi) have a relatively stable production of articles throughout the studied period. The third functional component (Fig. 8), represents a form of variation in which individuals with a high positive coefficient are authors with a stable production over the period, and that around 2000 had a fall in the number of publications.

A good example of this behavior is the case of W.C. Valenti, (Fig. 9). The individuals that in this component correspond to a high negative coefficient in terms of absolute value are authors with rather sporadic publications but were productive around the year 2000.

Figure 10 shows the co-author network of 123 authors with the highest H-index in the *Macrobrachium* domain. The authors with outstanding H index are pre-

Table 2. The 15 more relevant authors (H index) and their affiliations based on Scopus.

Author	Affiliation
Cheng, W.	Department of Aquaculture, National Pingtung University of Science and Technology, Taiwan, China
Bonami, J.R.	ECOLAG, UMR 5119, CNRS/UM2, cc 093. Université Montpellier 2, France
McNamara, J.C.	Universidade de São Paulo - USP, Department of Biology, São Paulo, Brazil
Sagi, A.	Ben-Gurion University of the Negev, Department of Life Science, Beer Sheba, Israel
Cohen, D.	Hebrew University of Jerusalem, Center for Rationality and Interactive Decision Theory, Silberman Institute of Life Sciences, Dept. of Ecology, Evolution, and Behaviour, Jerusalem, Israel
Tidwell, J.H.	Kentucky State University, Aquaculture Research Center, Frankfort, United States
Chen, J.C.	National Taiwan Ocean University, Department of Aquaculture, Keelung, Taiwan, China
D'Abramo L.R.	University of Alabama at Birmingham, Department of Biology, Birmingham, United States
Liu, C.H.	National Pingtung University of Science and Technology, Department of Aquaculture, Pingtung, Taiwan, China
Sahul Hameed, A.S.	C. Abdul Hakeem College of Engineering and Technology, Department of Zoology, Vellore, India
Yang, W.J.	Bharathiar University, Department of Zoology, Coimbatore, India
Sorgeloos, P.	Universiteit Gent, Laboratory of Aquaculture and Artemia Reference Center, Ghent, Belgium
Valenti, W.C.	UNESP-Universidade Estadual Paulista, São Paulo, Brazil
Wilder, M.N.	Japan International Research Center for Agricultural Science, Tsukuba, Japan
Geraldine, P.	Bharathidasan University, Department of Animal Science, Tiruchirapalli, India

sented with circles whose color represents a lower or higher index H, in this way: white color < lila < pale blue < deep blue (deep blue color = highest H index). The circle size is proportional to the number of citations, and the intensity of its co-author relationships is visualized as the thickness of the lines that bind the authors. This figure demonstrated that the Chinese authors W. Cheng, J.C. Chen and C.H. Liu lead the *Macrobrachium* domain with the highest number of citations, high H indices and an intense co-author relationship.

The Brazilians W.C. Valenti and J.C. McNamara and the Americans J.H. Tidwell and S.D. Coyle also hold wide networks of co-authorship, less intense in the case of W.C. Valenti and slightly more intense for J.C. McNamara. The Americans show a very intense co-author relationship between them and moderately intense relationships with other authors. W.J. Yang from China shows a scarce and moderately intense co-authorship network, while P. Geraldine from India only shows an intense co-author relationship.

DISCUSSION

Chong-Carrillo *et al.* (2015) found 2165 scientific manuscripts on the topic *Macrobrachium* from 1980 to

2013, while the present study found 1926 articles from 1980 to 2016. The difference is relatively low considering that Chong-Carrillo *et al.* (2015) included a wider period and used several databases (Biological Abstracts, ISI Web of Science, SciELO Citation Index, BioOne, Science Direct, Scopus and Redalyc), the title of the article, abstract and the keywords, while the present work was based only on the Scopus database and the title of the paper. The search was carried out in Scopus using only the title to make the search process more relevant to the subject at hand.

Due to the differing search methods between Chong-Carrillo *et al.* (2015) and the present study, some of the authors shown in the present study hold lesser positions for productivity (quantity of published manuscripts) than in the previous study. For example, J.C. McNamara of Brazil has 70 publications in the previous study and 30 in this study. Nonetheless, these authors were found among the most relevant authors for both studies. W. Cheng (China), appears as the most productive author with 40 publications, followed by W.C. Valenti, with 38 publications. However the scientists W. Cheng, and J.R. Bonami, hold 819 and 574 citations, respectively, while W.C. Valenti, registers 250 citations. This anomaly may be related to the themes approached by these scientists. Studies by W.C. Valenti focus primarily on aspects of biology and the

Table 3. Distribution by country of the most visible authors (H index > 6) based on Scopus.

Country	Number of authors
Asia	
China	10
India	3
Malaysia	1
Bangladesh	1
Japan	2
Thailand	1
18 (42.8%)	
America	
USA	5
Brazil	3
Argentina	2
Mexico	2
Canada	1
13 (30.9%)	
Europe	
Belgium	2
France	1
United Kingdom	1
4 (9.5%)	
Middle East	
Israel	6
6 (14.2%)	
Oceania	
Australia	1
1 (2.3%)	
Total	n = 42 (100%)

culture of native species in Brazil (e.g., *M. amazonicum*), while the others authors have focused on aspects of immunology and pathophysiology of *M. rosenbergii*, which are of major interest to the international scientific community.

This same scenario is observed in the positions taking as central axis the H index. The authors W. Cheng and J.R. Bonami have H index of 20 and 14 respectively and are in the first two positions, while W.C. Valenti is ranked in position 13 with an H index of 10. Again, the rankings can be explained by the type of subject that is addressed in the studies of these scientists. In general, the most productive authors are shown as those that hold a larger number of citations and, consequently, a higher H index. This is not accepted as a rule, however, because there are authors who do not appear among the most productive, yet are among the most cited and with a higher H index. Such is the case for two of the most relevant scientists in the *Macrobrachium* domain worldwide, J.R. Bonami with 18 publications with H index of 14, and S. Bhassu with 28 publications an H index of 11.

Table 4. Sex of the most productive authors (number of published papers) based on Scopus.

Author	Sex		Country
	Male	Female	
Cheng, W.	♂		China
Valenti, W.C.	♂		Brazil
Tidwell, J.H.	♂		USA
McNamara, J.C.	♂		Brazil
Bhassu, S.		♀	Malaysia
Geraldine, P.		♀	India
D'Abramo, L.R.	♂		USA
Fu, H.	♂		China
Wang, W.		♀	China
Sahul-Hameed, A.S.	♂		India
Sobhon, P.		♀	Thailand
Sagi, A.	♂		Israel
Qiao, H.		♀	China
Ren, Q.	♂		China
Pillai, B.R.		♀	India
Yang, W.J.	♂		China
Cohen, D.	♂		Israel
Saravana-Bhavan, P.	♂		India
Sorgeloos, P.	♂		Belgium
Bonami, J.R.	♂		France
Wilder, M.N.		♀	Japan
Total	14 (66.7%)	7 (33.3%)	

Chinese and Indian universities are 40% (20% each) of the institutions affiliated with six of the most relevant authors. The study published by Chong-Carrillo *et al.* (2015) found that 25% of higher institutions belong to China, and Chinese institutions account for 70% of the total patents around the world (Chong-Carrillo *et al.*, 2016). The results obtained with Scopus alone demonstrate that the Chinese and Indian institutions play a significant role in the generation of knowledge related to this genus. From Latin America, the São Paulo University (USP) and Universidade Estadual Paulista (UNESP) holds two of the most relevant authors, affirming Chong-Carrillo *et al.* (2015), while the Kentucky State University (KSU) and University of Alabama at Birmingham (UAB) represents the higher institutions of the USA for holding two of the most prestigious authors. In the same sense, the countries in Asia (including East Asia, South Asia and Southeast Asia) account for almost the 43% of the highest number of researchers with an H index greater than >6, while the Americas, Europe, Middle East and Oceania account for the remaining 57%. The relationship Asia>Americas>Europe>Middle East>Oceania is similar to the order found by Chong-Carrillo *et al.* (2015) for authors in general, without considering the H index. Notable is the fact that only Israel has six of the most productive researchers worldwide. This fact places it as

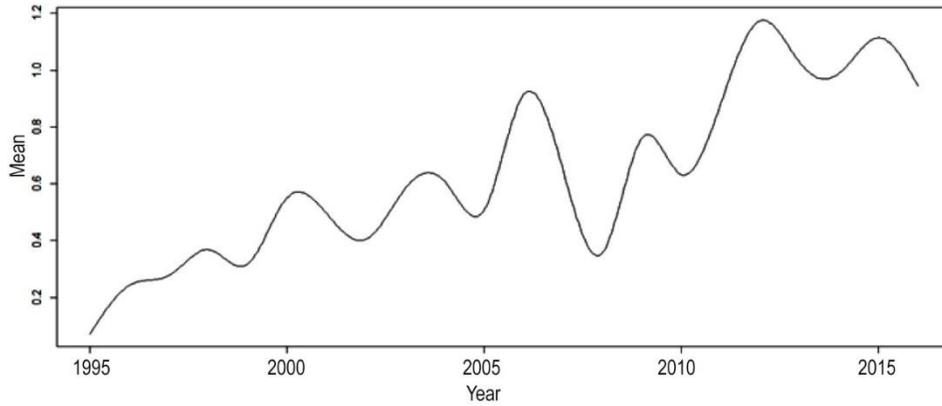


Figure 1. The sample mean function of the article production functional data.

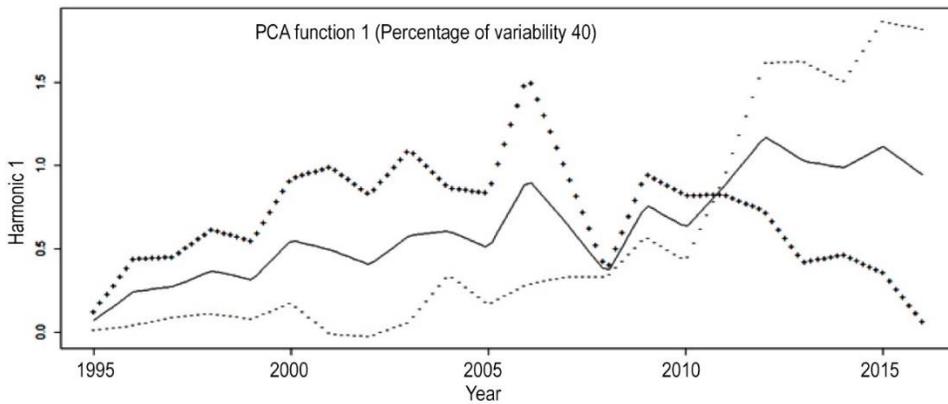


Figure 2. The effect of the first principal component of the article production functional data. The solid curve is the overall mean, the dashed curves are the mean \pm a suitable multiple of the relevant principal component weight function.

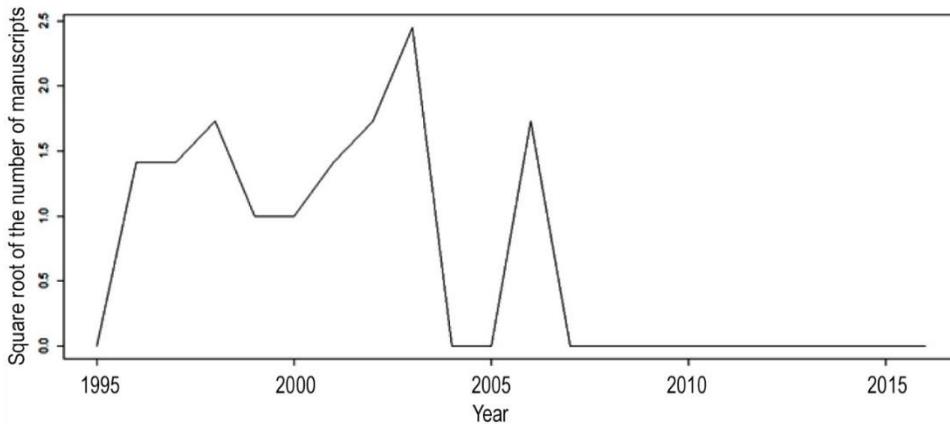


Figure 3. Scientific manuscript production of J.C. Chen from 1995 to 2016.

the second country that more authors with high H index owns, and only surpassed by China.

In relation to the sex of the most productive authors (number of papers registered in Scopus), a significant difference was shown between the number of male and female authors. Only 33.3% (seven records) of 21 of the authors with the largest number of publications are

women. Remarkable is the fact that no high productive researcher woman, is original from the Americas neither Europe. Despite holding the largest number of relevant researchers, China only holds two prominent woman researchers. This anomaly is not unique to the *Macrobrachium* domain, as it is common for most areas of science. In the March 7, 2013 editorial of Nature, the

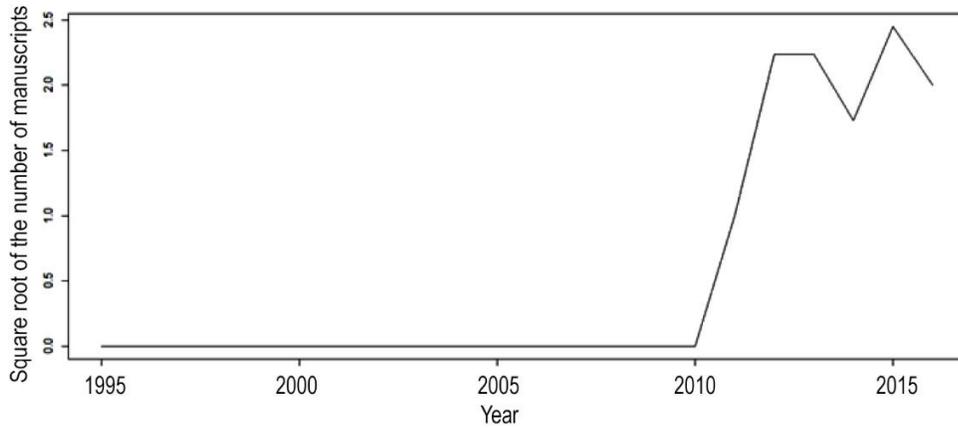


Figure 4. Scientific manuscript production of W. Wang from 1995 to 2016.

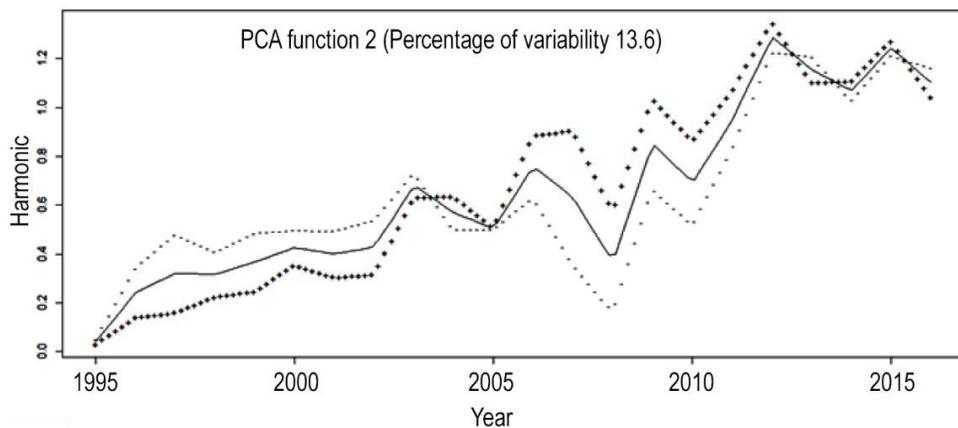


Figure 5. The effect of the second principal component of the article production functional data. The solid curve is the overall mean, the dashed curves are the mean \pm a suitable multiple of the relevant principal component weight function.

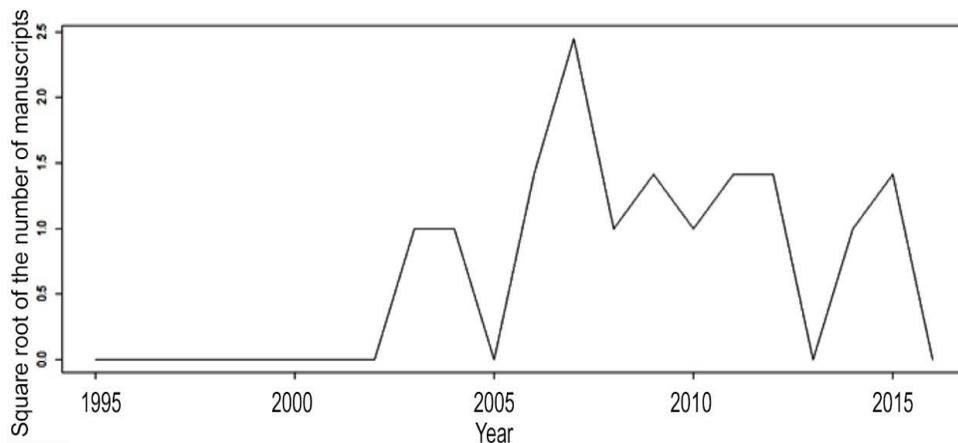


Figure 6. Scientific manuscript production of B.R. Pillai from 1995 to 2016.

journal self-criticizes its editorial processes by reporting that only 14% of reviewers and 19% of invited authors are female. Statistics conducted by the National Science Foundation (USA) report that the percentage of women with academic positions in biology, agriculture, and environmental sciences (with

a work age greater than 10 years) is only 30% compared to the academic positions held by men (Catalyst, 2013). It is also evident that the percentage of university faculties with women who have scientific doctorates and work as teachers is only 22% (Catalyst, 2013). The results obtained in the present study and the examples

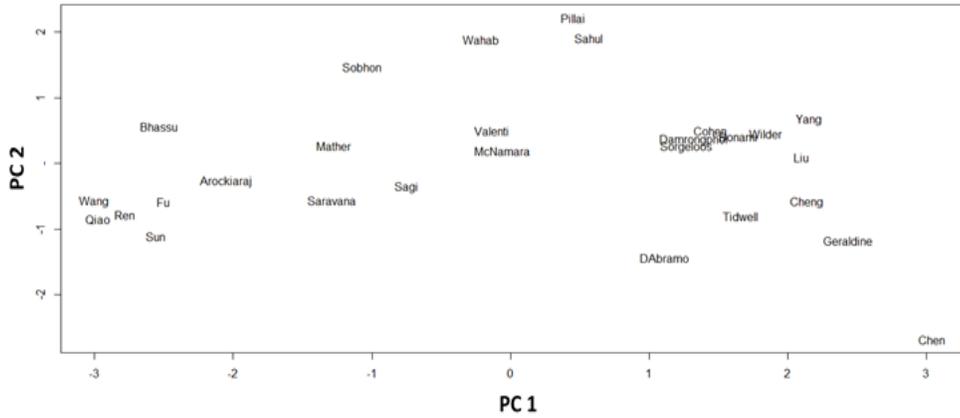


Figure 7. Plot of the first two principal components scores of the scientific article production functional data.

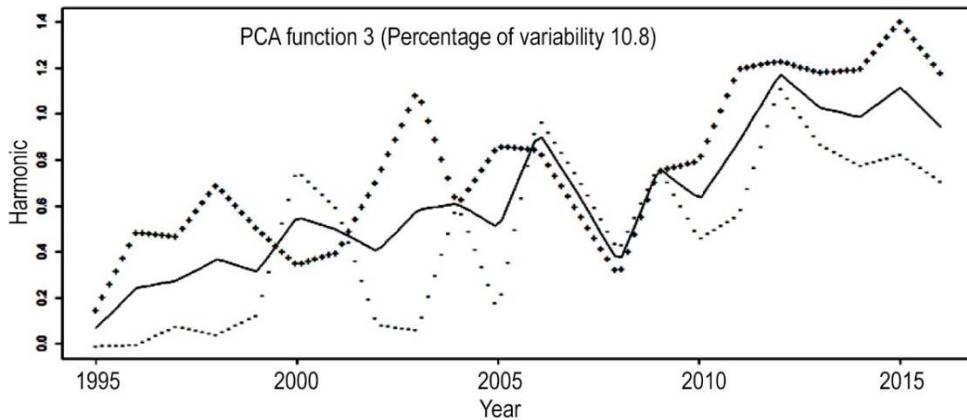


Figure 8. The effect of the third principal component of the article production functional data. The solid curve is the overall mean, the dashed curves are the mean \pm a suitable multiple of the relevant principal component weight function.

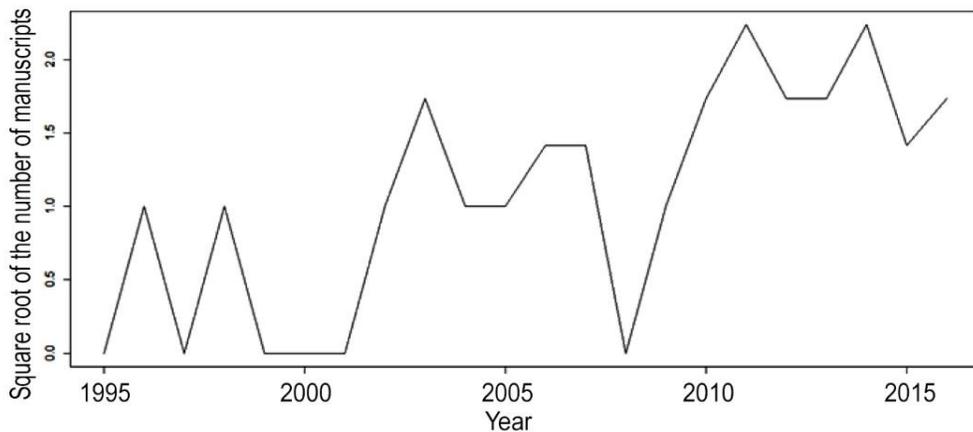


Figure 9. Scientific manuscript production of W.C. Valenti from 1995 to 2016.

cited above show that men still occupy the most advantageous work positions in most scientific and academic fields.

Ramsay & Dalzell (1991) were the pioneers in the use of the term functional data analysis (FDA). This discipline encompasses a series of statistical techniques

and numerical methods for working with data of a functional nature. One of the most used tools for the exploration of a functional data set is the functional principal components analysis. In the present study, the analysis of the behavior in time of the production of scientific articles, by the most productive authors, in a

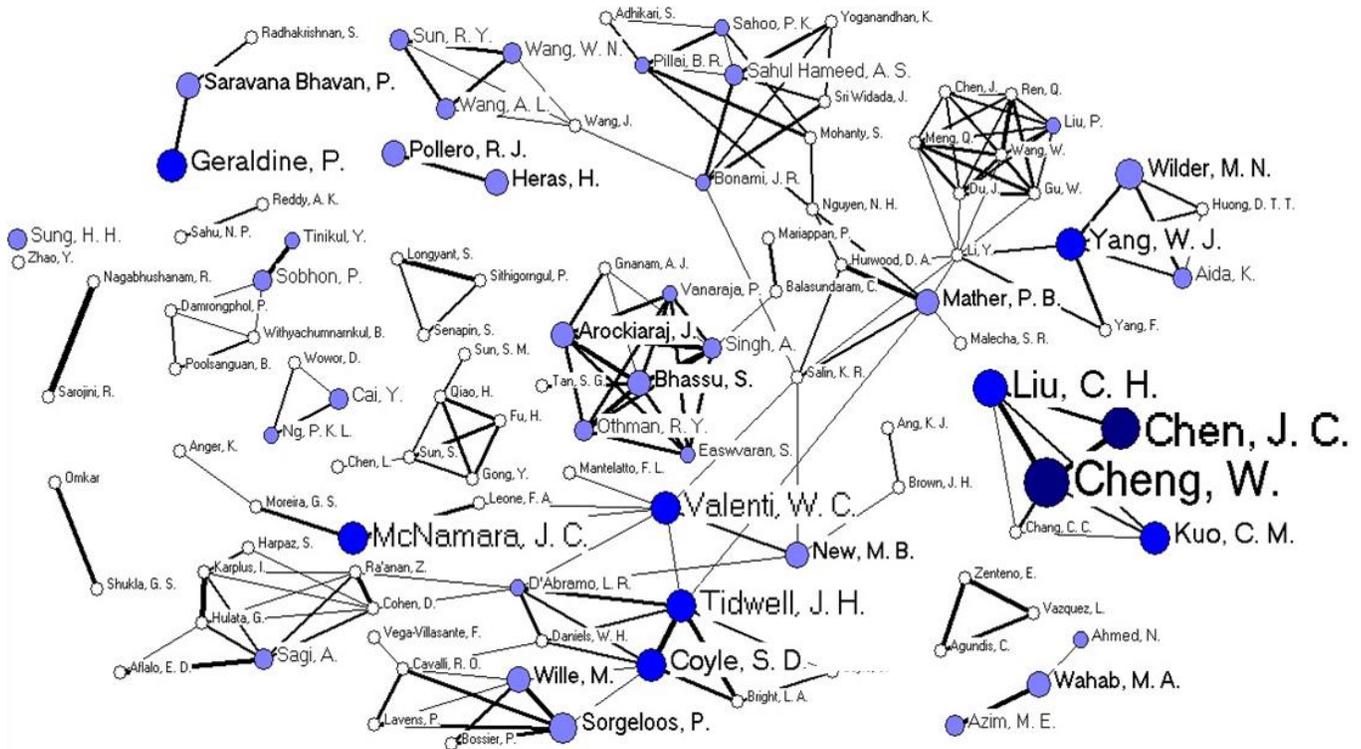


Figure 10. Coauthorship network of the 123 most relevant authors according to their H index and number of cites (Scopus). Circles color represents a lower or higher H index, in this way: white color < lila < pale blue < deep blue (deep blue color = highest H index). The circle and letter size is proportional to the number of citations (larger circles = higher cites number). Intensity of co-author relationships is visualized as the thickness of the lines that bind the authors (thicker lines = high intensity of relationship).

first component, marks an important turning around 2011, in which a group of Asian researchers bursts into the scenario of *Macrobrachium* study, while another group of researchers concentrate their production before 2011. The second component describes similar behavior but around 2004-2005. The third component shows authors who have maintained a stable production of scientific articles throughout the studied period, which classifies them as gnoseological referents within the production of knowledge about the genus, as is the case of W.C. Valenti, P. Sorgeloos and A. Sagi.

Although the information retrieval was made since 1980, it is clear that the most productive authors are concentrated since 1996. This beginning of the bulk of the publications could have some relation with the white spot syndrome virus (WSSV) epidemic. This is a double stranded DNA virus, which belongs to the Filoviridae family, *Whispovirus* genus (Flegel *et al.*, 2008). It appeared in 1992 in northwest Asia and spread rapidly to most shrimp farms in Asia and the Indo Pacific. The first confirmed case of WSSV in the West occurred in 1995, Texas (USA). In 1999 there were

reports of the WSSV in countries of Central America, North America and South America. The species affected can be *Penaeus monodon*, *Marsupenaeus japonicus*, *Fenneropenaeus chinensis*, *F. indicus*, *F. merguensis*, *Penaeus setiferus*, *P. stylirostris* and *P. vannamei* (Cuéllar-Anjel, 2012). However, apparently *Macrobrachium* species such as *M. rosenbergii* are more tolerant to infection (Yoganandhan & Hameed, 2007). Estimated world economic losses associated to WSSV approach one billion US\$ per year since its first report in 1992 (Flegel *et al.*, 2008), so that probably an alternative was the *Macrobrachium* species culture, which brought the takeoff in research on this genus, making it a line of research in continuous growth.

Knowledge maps are graphical representations that show the state of a given question (García-García *et al.*, 2015). Visual representations allow users to understand abstract information in an intuitive way. Among the most common visual representations are maps (Pino-Díaz *et al.* 2012). The representation of a social network by using a graph with nodes (individuals) connected by lines (relations), manifests concepts as

the one of centrality, determined by the degree of connections of a node with others (Del Fresno-García, 2014). In the analysis of the co-authorship ratio of the 123 most relevant researchers (according to their H index), authors with a high H index are represented graphically in a map of co-authorships with colored circles and size variations (a greater number of citations = greater size), qualities that are directly proportional to their influence (citations) and relevance (H-index) (color intensity).

Generally, these authors are the center of a particular collaborative group or co-author network. The intensity of this relationship of co-authorship is represented by the thickness of the lines that link authors. The most relevant authors appear to be those who have intense co-author relationships. These relationships are not necessarily diverse. When reviewing only the authors with an intense blue circle, the Chinese authors W. Cheng, J.C. Chen, C.H. Liu and C.M. Kuo, who have high H indexes, are shown to collaborate intensively among each other, but they do not demonstrate collaboration with other researchers or external groups. The opposite case is shown with the co-author network established between J.C. McNamara, W.C. Valenti, J.H. Tidwell and S.D. Coyle; W.C. Valenti (Brazil) and J.H. Tidwell (USA) appear as the centers of a vast co-author network. W.C. Valenti shows a more intense collaboration with M.B. New, whereas this intensity is not registered in all of his other co-author relations, suggesting that such collaborations have contributed to one or a few manuscripts. In addition to his research relationships with other Brazilian scientists (J.C. McNamara, F.A. Leone, F.L. Mantelatto), W.C. Valenti collaborates with the Americans J.H. Tidwell and L.R. D'Abramo and K.R. Salin of India. The situation of J.H. Tidwell is different because his co-authorship shows high intensity with other American authors (S.D. Coyle, L.R. D'Abramo, L.A. Bright and W.H. Daniels), but a low intensity with only one Brazilian scientist (W.C. Valenti) and one Australian, (P.B. Mather). J.C. McNamara is shown with a high H index, yet his network of collaboration according to Scopus has just a high intensity with G.S. Moreira and F.A. Leone and a little relation with W.C. Valenti. P. Geraldine, from India is the only female author to appear on the chart with a high H index. Her co-author network is limited to P. Saravana Bhavan with a high intensity. Finally, W.J. Yang from China is the center of a co-author network conducted intensely with M.N. Wilder and K. Aida from Japan and D.T.T. Huong, F. Yang and Y. Li from China.

Networks formed as a star or polyhedrons are apparent in several of the other co-author networks. These formations show a pattern of being a group of scientists who interact intensely, often having a

researcher with a high H index in the center or in one of the vertices of the group. This phenomenon is evident in the networks of P. Sorgeloos, S. Bhassu, P. Liu and A.S. Sahul Hameed, among others. These networks are very closed by showing interactions only among a limited number of authors, having little relation with external groups or researchers. These co-author networks were formed using only the 123 most relevant authors based on their H index. The interactions of the remaining authors with lower H-indexes registered in Scopus would increase the breadth of these networks.

The results obtained in the present study allow us to conclude that the most productive authors according to the number of articles published and their H index are from different regions of Asia, in particular China, followed by researchers the Americas. Thus, the distribution of authors from the different world regions is shown as Asia>Americas>Europe>Middle East>Oceania. Asian institutions hold the most productive authors, particularly Chinese and Indian universities. For the Americas, only four universities hold relevant scientists, two in Brazil and the same in the USA. Only six women are among the most productive and relevant authors. All of them work in Asian universities. The most relevant researchers appear as the center of their respective co-author networks. There are multiple networks, many of which are closed with little interaction between external groups or researchers.

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