The scientific literature on *Limnoperna fortunei* (Dunker 1857) from 1982 to 2012

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ABSTRACT

Limnoperna fortunei (golden mussel) is a freshwater bivalve native to Southeast Asia, but is becoming an invasive species in several aquatic ecosystems in the world. In this study, a scientometric analysis was performed to identify the patterns, trends and gaps of knowledge for this invasive species. A survey of the published literature was conducted using the database of the Thomson Institute for Scientific Information (ISI). A total of 107 papers were surveyed that were published between 1982 and 2012 in 60 journals. The number of papers on *L. fortunei* over the years has increased, especially within the last eight years of the study period. Argentina, Brazil, and Japan are the countries that contributed the most papers to the literature on invasive bivalve. The majority of papers were field-observational studies. Among some important gaps that need to be addressed are the relatively small number and/or lack of studies conducted in the native countries and in countries invaded by *L. fortunei*, the lack of internationally collaborative publications in these countries, as well as a low number of internationally collaborative studies.

Key words: biological invasions, golden mussel, scientific production, scientometric analysis.

INTRODUCTION

Invasive species are recognized as a major threat not only to biodiversity (Clavero and Garcia-Berthou 2005), but also to economic development (Pimentel et al. 2001, Pejchar and Mooney 2009). To mitigate this global problem, interest in invasive species has grown substantially, mainly in the last decades (Qiu and Chen 2009, Richardson and Pysek 2008, Lowry et al. 2013) and in invasive species in freshwater ecosystems (Strayer 2010).

Among the various taxonomic groups of invaders in freshwater ecosystems, the ecological and economic impact of bivalves is well-documented

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(see Karatayev et al. 2007a, b and Sousa et al. 2013 to review). Invasive bivalves are considered an aggressive species and a threat to both native diversity and ecosystem functioning (Karatayev et al. 2007b), and in addition to being a threat due to their biofouling activity in structures of industrial and power plants (e.g., hydroelectric power stations, pulp and paper mills, refineries, and water treatment and distribution facilities) (Magara et al. 2001, Elliott et al. 2005, Darrigran et al. 2007, Lucy et al. 2012). Several freshwater invasive bivalve species have been reported worldwide, especially *Corbicula fluminalis* (Müller 1774), *Corbiculla fluminea* (Müller 1774), *Dreissena bugensis*

(Andrusov 1857), *Dreissena polymorpha* (Pallas 1771) and *Limnoperna fortunei* (Dunker 1857) (Karatayev et al. 2007b).

Limnoperna fortunei (Bivalvia, Mytilidae), commonly known as golden mussel, is a freshwater bivalve native to estuaries, lakes, and rivers of southeastern Asia, including Cambodia, China, Indonesia, Korea, Laos, Thailand, and Vietnam (Ricciardi 1998). In 1965, *L. fortunei* invaded Hong Kong (Morton, 1977), Japan (Kimura 1994) and Taiwan (Ricciardi 1998) in the 1990s. In South America, it was first recorded in 1991 in Bagliardi Beach, Rio de la Plata estuary, Argentina, probably introduced by ballast water from Asian commercial ships (Pastorino et al. 1993). Currently, the distribution of *L. fortunei* in South America includes estuaries (Darrigran and Pastorino 1995, Brugnoli et al. 2005, Capítoli et al. 2008), lakes, streams, reservoirs, and rivers (Mansur et al. 2003, Oliveira et al. 2006, Boltovskoy et al. 2009) and it can be found in five countries: Argentina (in 1991), Uruguay (in 1994), Paraguay (in 1997), Brazil and Bolivia (in 1998) (Darrigran and Mansur 2006, 2009). This invasive bivalve has also caused serious environmental damage (see Karatayev et al. 2007a to review), as well as having a negative economic impact in South America (Darrigran and Damborenea 2005, Boltovskoy et al. 2006) and Japan (Magara et al. 2001, Matsui et al. 2002).

Scientometric studies can be used to measure scientific progress within a specific topic, country, field, or institution, based on the number of papers published in scientific journals (Van Raan 1997, Hood and Wilson 2001). In a recent scientometric study, Sousa et al. (2013) showed that scientific production on invasive bivalves in freshwater ecosystems has increased steeply in the last years. Therefore, an assessment of the publications on *L. fortunei* is essential to the scientific progress in the field of the invasive species. In this context, the purpose of this scientometric study was to analyze the literature on *Limnoperna fortunei* to identify the

patterns, trends and knowledge gaps for this invasive species. This present study differs from the study by Sousa et al. (2013) because here were evaluated various traditional scientometric components (e.g., author, citation and journal) and others more specific (e.g., approach employed) that were not evaluated by Sousa et al. (2013). Moreover, some standard indicators (e.g., collaborated publications and co-authorships) were adopted to analyze performance of countries, institutes and researchers (e.g., Liu et al. 2011). Additionally, the results presented here can help researchers manage and prioritize future studies that need to be developed to fill gaps in research on *L. fortunei*.

MATERIALS AND METHODS

The survey of the published literature was conducted using the database of the Thomson Institute for Scientific Information (ISI; www.isiknowledge.com) with the keywords "*Limnoperna fortunei*" or "golden mussel". The search was performed in March 2013 and all papers published until December 31st, 2012 were compiled.

Each paper was identified by: (i) the year of publication; (ii) the scientific journal of publication; (iii) the Web of Science subject category(ies) of the journal; (iv) the number of citations; (v) the approach employed (field-experimental, field-observational, laboratory-experimental or others, such as, modeling, review, theoretical); (vi) countries of publication; (vii) authors, and (viii) research institutions.

A regression tree (De'Ath and Fabricius 2000) was used to identify possible trends over time for the number of papers on *L. fortunei* (see Barbosa et al. 2012 for a similar use of this method). The number of papers on *L. fortunei* was standardized over time by dividing it by the total number of papers in the ISI database in a given year, and multiplying the result by 10,000. The analysis was conducted using the package rpart (Therneau et al. 2012) in the R environment (R Development Core Team 2013).

A Generalized Linear Model (family distribution = Poisson) (Crawley 2007) was applied to evaluate the temporal trend of the number of journals and the number of authors per paper. An ANOVA in blocks (Gotelli and Ellison 2012) was used to test the statistical difference between the number of citations among the type of papers (article paper, meeting abstract, proceeding paper, and review), considering the variations from year to year. If significance was detected, the Tukey test was used to determine the statistical differences among the approaches employed ($P < 0.05$). The t test for paired samples (per year; Sokal and Rohlf 1994) was used to test the significance of the difference between the number of articles published as a single country or as an internationally collaborative publication. The analyses were conducted in the R environment (R Development Core Team 2013).

Collaborations among authors, countries, or research institutions were determined based on the complete count strategy (i.e., each signatory on the papers was treated equally) (Liu et al. 2011). As is common in other scientometric studies (Liu et al. 2011, Cao et al. 2012) the term: (i) "collaborative publication" was assigned to papers with two or more authors, (ii) "single country publication" if the researchers were from the same country, (iii) "internationally collaborative publication" to those papers that were coauthored by researchers from multiple countries, (iv) " single institute publication" if the researchers were from the same institute, and (v) " inter-institutionally collaborative publication" if the authors were from different institutes.

RESULTS

A total of 107 papers on *L. fortunei* research were contained within the ISI web database between 1982 and 2012. From 1982 to 1998, few papers were published and for many years, no papers appeared on the subject. The regression tree analysis partitioned the predictor variable (i.e., year of publication) into two periods: before and after

2004.5. The period from 1982 to 2004 corresponds to the period with a low and relatively constant production of papers on *L. fortunei*. The second period (2005 to 2012) showed an increase in the number of papers published (Figure 1).

Papers on *L. fortunei* appeared in 60 journals, although 39.25% (N = 42) of these contained only one paper and 18.69% (N = 10) contained only two papers. The eight journals that published more than three papers on *L. fortunei* accounted for 42.06% (45 papers) of the total number (Figure 2). The journal *Hydrobiologia* published 10 papers, followed by *Biofouling* (seven papers) and the *Brazilian Journal of Biology* and the *Journal of Shellfish Research* (six papers, each). The number of journals considered, increased over the years ($z = 6.822$, $P < 0.001$, N = 20).

Thirty-three papers (30.84%) received only between one and four citations, whereas 23 papers (21.50%) were never cited (Figure 3a). The most-cited article was by Ricciardi (1998), which received 45 citations. Other heavily cited papers were by Villela et al. (2006), Boltovskoy et al. (2006) (39 citations, each), Darrigran et al. (1998) (38 citations), and Karatayev et al. (2007b) (37 citations). The paper by Karatayev et al. (2007a) figured among the most cited after standardizing the number of citations by the year of publication (i.e., the number of citations divided by the number of years since their publication) (Figure 3b). There was a difference in citation between types of papers ($F = 14.68$, $P < 0.001$, N = 107); reviews received more citations than other types of papers.

Field-observational studies were the most often conducted, appearing in 43 papers (40.18%), followed by laboratory-experimental studies (30 papers, or 28.03%), field-experimental studies (21 papers, or 19.62%), and others (13 papers, or 12.14%).

Ten countries published papers on *L. fortunei* (Table I). The greatest number of articles was published from Argentina (56.07% or 60 out of 107 papers), followed by Brazil (30 papers, or
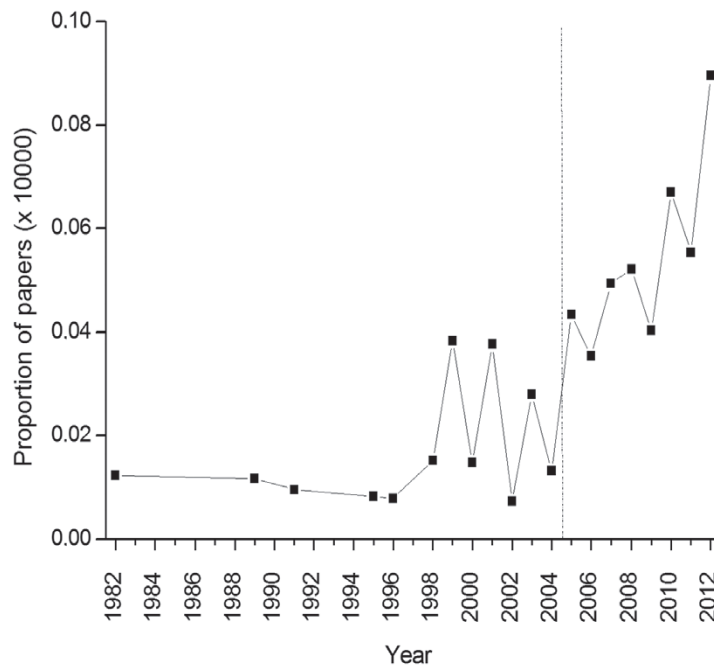
Fig. 1 - Proportion of papers (x 10000) on *Limnoperna fortunei* research in relation to the total number of papers published from 1982 to 2012, indexed by the Institute for Scientific Information (ISI). The dashed line indicates the year (2004.5) in which the regression tree partitioned the data in two segments.
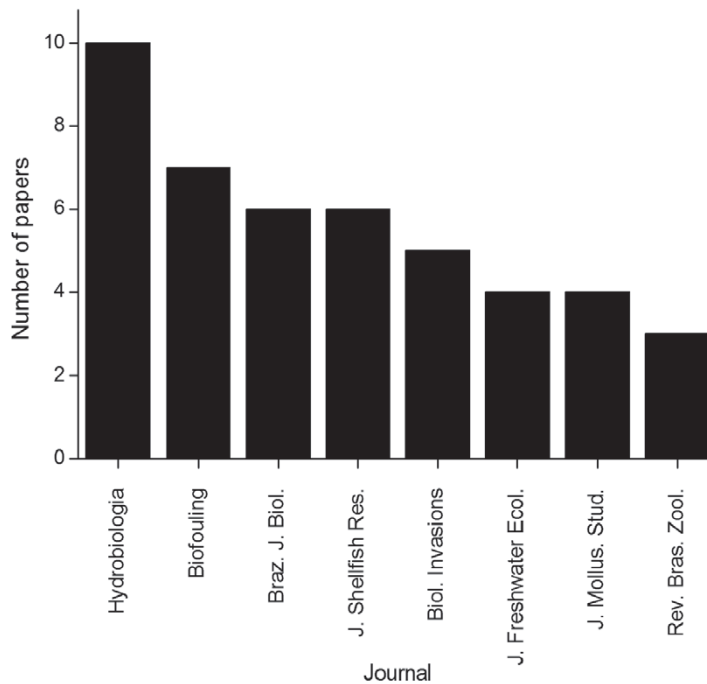
Fig. 2 - Journals that published more than three papers on *Limnoperna fortunei* indexed by the ISI from 1882 to 2012. Braz. J. Biol. = Brazilian Journal of Biology, J. Shellfish Res. = Journal of Shellfish Research, Biol. Invasions = Biological Invasions, J. Freshwater Ecol. = Journal of Freshwater Ecology, J. Mollus. Stud. = Journal of Molluscan Studies, and Rev. Bras. Zool. = Revista Brasileira de Zoologia (currently, Zoologia).
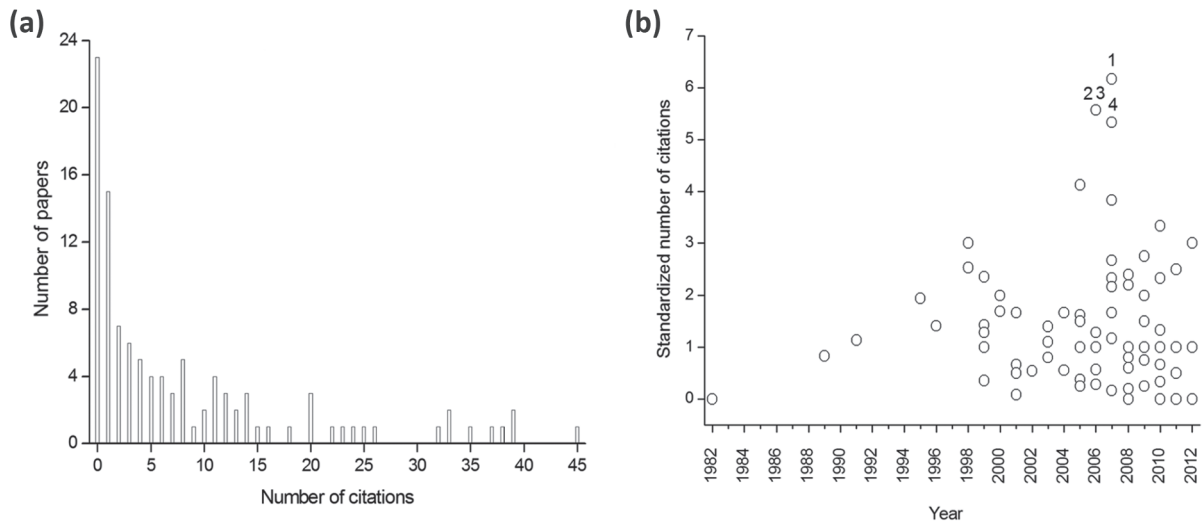
Fig. 3 - Number of papers in relation to the number of citations received (a) and temporal variation in the standardized (number of citations divided by the number of years since the papers was published) number of citations received by each paper (b). Number in (b) are: 1 = Karatayev et al. (2007b); 2 = Villela et al. (2006); 3 = Boltovskoy et al. (2006); 4 = Karatayev et al. (2007a).

TABLE I
Countries that published on *Limnoperna fortunei* with the number of papers, single country publication, and internationally collaborative publication during the period of 1982-2012.

Country	TP	SP	CP
Argentina	60	46	14
Brazil	30	21	9
Japan	14	14	0
United States	11	1	10
Canada	4	1	3
Germany	3	0	3
Hong Kong	2	1	1
United Kingdom	2	1	1
Uruguay	2	2	0
Ireland	1	0	1

TP, total papers; SP, single country publication; CP, internationally collaborative publication.

28.03% of the total 107 papers), and Japan (14 papers, or 13.08% of the total 107 papers). The number of single country publications was higher than that of internationally collaborative publications ($t = 4.1474$, $P = 0.0005472$, N = 20). Argentina was the single country responsible for the most papers (46, or 42.98% of the total 107 papers) and for internationally collaborative papers (14, or 13.08% of the total 107 papers). Japan had no internationally collaborative papers and the United States of America (USA) was the country with the second highest number of internationally collaborative papers (Table I) and its major collaborators were Argentina and Brazil.

A total of 207 authors contributed to studies on *L. fortunei*, although from 146 authors who (co) authored at least one *L. fortunei* paper, 58 or 28.02% contributed to fewer than eight papers, whereas the top three or 3.86% authors produced 61 or 57% of the total papers. The most productive authors in *L. fortunei* research were Boltovskoy and Darrigran with 22 papers each, followed by Cataldo

with 17 papers (Table II). The six most productive authors tended to cooperate with a relatively small group of co-authors. For example, Mansur and Sylvester had a mean of 2.42 and 2.37 co-authors on their papers, respectively (Table II). The mean number of authors per paper for all *L. fortunei* papers ± S.E. was 3.85 ± 0.37 and the number of authors per paper did not increase during the period studied ($z = 0.597$, $P = 0.550$, N = 107).

TABLE II
The six most productive authors that published on *Limnoperna fortunei* with the number of papers, collaborated publications, co-authorships during the period of 1982-2012.

Author	TP	CP	CO
Boltovskoy, D	22	22	25
Darrigran, G	22	22	35
Cataldo, DH	17	17	23
Damborenea, MC	8	8	11
Sylvester, F	8	8	19
Mansur, MCD	7	7	17

TP, total papers; CP, collaborated publications; CO, co-authorships.

Limnoperna fortunei studies were performed in 70 research institutions, 38 or 54.28% of which published only one paper and 23 or 32.85% published fewer than four papers. The nine

research institutions that published more than five papers on *L. fortunei* accounted for 12.85% of the total (Table III). The *Consejo Nacional de Investigaciones Científicas y Tecnicas* led institutional productivity with 46 papers, followed by the *Museo Argentino de Ciencias Naturales "Bernardino Rivadavia"* with 28 papers, the *Universidad de Buenos Aires* with 24 papers, and the *Universidad Nacional de La Plata* with 18 papers. The number of inter-institutional collaborations was higher than that of single institute publications ($t = -2.8613$, $P = 0.0099$, N = 20).

DISCUSSION

This scientometric study showed an increase in the number of papers on *L. fortunei* over time, especially in the eight years from 2005–2012, probably due to increasing interest in invasive species in recent decades (Lowry et al. 2013). Additionally, the serious ecological and economic impact caused by the species (Boltovskoy et al. 2006, Karatayev et al. 2007a) has certainly contributed to the growth of studies, because, according to Pysek et al. (2008), the impact of an invasive species determines whether it is studied. However, the number of studies on *L. fortunei*

TABLE III
The nine most productive research institutions that published on *Limnoperna fortunei* with the number of papers, single institute publication, and inter-institutional collaborative publication during the period of 1982-2012.

Institute	TP	SP	CP
Consejo Nacional de Investigaciones Científicas y Tecnicas, Argentina	46	2	44
Museo Argentino de Ciencias Naturales "Bernardino Rivadavia", Argentina	25		25
Universidad de Buenos Aires, Argentina	24		24
Universidad Nacional de La Plata, Argentina	18	2	16
Universidade Federal do Rio Grande do Sul, Brazil	7		7
Universidade Federal do Paraná, Brazil	7	2	5
Gifu University, Japan	6		6
Shinshu University, Japan	6	1	5
Embrapa Pantanal, Brazil	5		5

TP, total papers; SP, single institute publication; CP, inter-institutional collaborative publication.

has increased much less than that on other freshwater invasive bivalves. For instance, Sousa et al. (2013) conducted a scientometric study on freshwater invasive bivalves using publications of the period 1980–2010 and found more studies with *D. polymorpha*, *C. fluminea*, and *D. bugensis* than for *L. fortunei*.

The papers on *L. fortunei* were published in many journals and this number increased throughout the studied period. This pattern suggests that studies on *L. fortunei* have been performed in several research areas, beyond biology or ecology. For instance, some papers were published in journals of engineering and water resources (e.g., Environmental Science and Technology and the Journal of the American Water Works Association), since the species had an economic impact to man-made structures (Mansur et al. 2003). The journal that published the most papers on golden mussel was *Hydrobiologia* and this journal was also the favorite for studies on macrophytes in the Neotropics (Padial et al. 2008), following the general pattern noted by Hendriks and Duarte (2008) and Melo et al. (2006). This pattern is probably related to the fact that *Hydrobiologia* publishes papers in all sub-fields of Limnology, with no bias regarding organism (Melo et al. 2006).

Citation frequency is usually used to quantify the relative importance of a paper (Garfield 1972). In this study, 51 papers were cited more than five times, which does not support the pattern suggested by Garfield (2006), in which most published papers are never cited or cited only a few times. Similarly, in a recent scientometric study, Barbosa et al. (2012) showed that 60% of the papers on the use of ecological niche models to predict the distribution of invasive species were cited more than five times. Among the most-cited papers, that by Ricciardi (1998), which is a review of the biology and invasion history of *L. fortunei* in Asia (Hong Kong, Japan, and Taiwan) and South America (Argentina and Uruguay), evaluates its potential range of expansion into North America. The other highly cited papers include three reviews (Karatayev et al. 2007a, b, Boltovskoy et al. 2006), which were published years after the growing interest in studies on *L. fortunei* as well as papers that evaluated the potential of *L. fortunei* as a biomonitor organism for the detection of genotoxicity in polluted water (Villela et al. 2006) and the impact caused by the species on the composition of the native fauna in Rio de la Plata, Argentina (Darrigran et al. 1998). According to Ruiz et al. (2009), reviews are usually more cited than original papers, which was the case here, following the general pattern noted by Sainte-Marie (2010).

Field-observational studies were the preferable approach in studies on *L. fortunei*. Similarly, in a recent systematic review on biological invasions, Lowry et al. (2013) showed that almost half of the papers were field-observational studies. However, other types of studies were important, especially those using modeling techniques. Modeling studies have been applied to predict the potential distribution of invasive species (Jiménez-Valverde et al. 2011) and therefore, are also essential for future preventative actions against *L. fortunei* (Barbosa and Melo 2009, Oliveira et al. 2010a), since once the species is present in the environment, it is extremely difficult to eradicate (Oliveira et al. 2006).

Argentina, Brazil and Japan were the countries that published the most papers. This is probably due to the problems caused by *L. fortunei* in man-made structures in Argentina (Darrigran and Damborenea 2005, Boltovskoy et al. 2006), Brazil (Mansur et al. 2003), and Japan (Magara et al. 2001, Matsui et al. 2002). Moreover, Qiu and Chen (2009) used publications from the period of 1991–2007 to perform a bibliometric study of all biological invasion-related publications and showed that Argentina, Brazil, and Japan were among the 15 countries that published papers on biological invasions with the highest frequency. According to May (1997), this high scientific production is

associated with economic development. In South America, Argentina and Brazil are among the countries with the largest economies (World Bank 2013). Additionally, Speziale et al. (2012) conducted a study to analyze the temporal trends of scientific research on non-native species in South America using publications of the period of 1961–2010, and Argentina and Brazil were the most productive countries. The low representation and/or lack of studies in countries invaded by *L. fortunei* might have several explanations, such as fewer resources for scientific studies and language barriers in countries in South America (see Speziale et al. 2012 for more explanations). The lack of studies within the native region of *L. fortunei* is notable, because this knowledge is essential to identify ways to mitigate the main problems caused by the species (Sousa et al. 2013).

Increasing international collaboration over time is a general trend across all countries and scientific fields (Abt 2007). In this study, the frequency of single country publications was higher than that of international collaborations. This suggests that academic communities of *L. fortunei* research are not internationally connected. For instance, Japan has no international collaborative papers, the same pattern noted by Qiu and Chen (2009) in biological invasion research. Moreover, the observed level of international cooperation on *L. fortunei* is much lower than that for the general field of biological invasions (57% across countries; Qiu and Chen 2009).

L. fortunei is not present in the USA, which had the second highest number of international collaborative papers, mainly together with Argentina and Brazil, both countries which are invaded by *L. fortunei*. This might be attributable to the high scientific production of the USA worldwide (Fazey et al. 2005). Furthermore, the USA is on the same continent as its main collaborators (some countries essentially collaborate only with countries that are close geographically) (Katz 1994), which probably facilitates cooperation (Leta and Chaimovich

2002). Padial et al. (2008) also showed that the USA cooperated the most in studies of aquatic macrophytes published by Neotropics. In parallel, using modeling techniques, Oliveira et al. (2010a) demonstrated the forecasts of the potential distribution of *L. fortunei* in three major North American river systems (Mississippi, Colorado, and Rio Grande).

A small group of authors has contributed a substantial amount of papers on *L. fortunei*. This trend is not unique to studies of *L. fortunei*. Liu et al. (2011) showed that the most productive authors published 50.1% of the total papers on biodiversity. The most productive authors and research institutions on *L. fortunei* were from Argentina, Brazil and Japan. This domination of publication is not surprising, since these were the countries that published the most on this species.

In this study, the most productive authors tended to cooperate with a relatively small group of co-authors, the number of author per paper did not increase over the studied years and inter-institutional collaborations were more prevalent than single institute publications. These results suggest that *L. fortunei* has been studied by research teams composed of different research institutions within a single country. One possible explanation for this is the pressure from funding agencies and institutions of each country to increase research via inter-institutional collaborations and institutes might be developing into larger centers and labs, with greater investment. Additionally, previous scientometric studies showed that several authors tend to cooperate with a small group of collaborators (Qiu and Chen 2009, Liu et al. 2011) and that inter-institutional collaborations are more prevalent than international collaborations (Liu et al. 2011). The increase in the number of authors per paper over time is a global trend in science (Porter and Rafols 2009), however, this was not observed in this study, although, the mean number of authors per paper was higher

than for the field of invasive species research in general (3.2; Qiu and Chen 2009).

In summary, this scientometric analysis showed an increase in the number of papers on *L. fortunei* over time, especially in the last eight years of the studied period. However, some important gaps need to be addressed, such as the relatively small number and/or lack of studies conducted in the native countries or those invaded by *L. fortunei*, such as Bolivia, Hong Kong, Uruguay, Paraguay, and Taiwan, and the low number of internationally collaborative publications, as well as the lack of studies from international cooperation between native countries and those invaded by *L. fortunei*. However, it is notable that the low representation of studies from countries invaded by *L. fortunei* in this study does not necessarily represent a total absence of studies, but might mean that such studies are only available in other small or regional databases. *L. fortunei* is one of the worst aquatic invasive species due to its serious ecological and economic impact (Mansur et al. 2003). In addition, models based on the ecological niche have been used to predict the spread of *L. fortunei* (Kluza and McNyset 2005, Oliveira et al. 2010a, b). For instance, the global model created by Kluza and McNyset (2005) has shown that *L. fortunei* can potentially colonize regions of Africa, Asia, Europe, North America, South America, and Central America. Whereas eradication of the species is extremely difficult (Oliveira et al. 2006), measures to control its spread are important. Thus, future studies via international collaboration, together with cooperative studies between native countries and those invaded by the species, are of considerable importance to mitigate the main problems caused by *L. fortunei*.

ACKNOWLEDGMENTS

RESUMO

Limnoperna fortunei (golden mussel) é um bivalve de água doce nativo do sudeste da Ásia, mas está se tornando uma espécie invasora em diversos ecossistemas aquáticos do mundo. Neste estudo, uma análise cienciométrica foi realizada para identificar padrões, tendências e lacunas do conhecimento para esta espécie invasora. Uma pesquisa da literatura publicada foi realizada utilizando a base de dados Thomson Institute for Scientific Information (ISI). Foram encontrados 107 artigos publicados entre 1982 e 2012, em 60 periódicos. O número de artigos sobre *L. fortunei* tem aumentado ao longo dos anos, especialmente nos últimos oito anos do período de estudo. Argentina, Brasil e Japão são os países que mais publicaram artigos sobre o bivalve invasor. A maioria dos artigos foi estudos de campo-observacional. Entre algumas lacunas importantes que precisam ser abordadas são o número relativamente pequeno e/ou falta de estudos realizados em países nativos e invadidos por *L. fortunei*, a falta de publicações colaborativas internacionais entre estes países, bem como um número baixo de estudos colaborativos internacionais.

Palavras-chave: invasões biológicas, mexilhão dourado, produção científica, análise cienciométrica.

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