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ECOSYSTEMS

Microcrustaceans in rice fields: A scientometric analysis from 1977 to 2019

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Abstract: We evaluated the worldwide trends in studies of the active and dormant forms of microcrustaceans in rice fields, and the potential of this environment as a stock of diversity through a scientometric analysis. Web of Science and Scopus databases were used to compile the 77 studies published before 2019. Publications were distributed over 35 years, with a positive correlation between the number of studies and the year of publication (rho = 0.34). The identified studies were from 18 countries, and 58.4% were conducted in Japan, Italy, the United States, and Spain. Most studies addressed more than two groups of microcrustaceans (37.6%), followed by those focused on Cladocera (27.2%) and Ostracoda (18.1%). We quantified 301 species from six groups of microcrustaceans, the majority of which were Cladocera (41.5%) and Ostracoda (39.8%). The greatest richness of microcrustaceans identified in studies were found in Italy, Thailand, Malaysia, Spain, France, Japan, and Brazil. Of the studies, 87% were centered on the active forms of microcrustaceans rather than dormant forms. We found that 15.5% of the countries that grow rice have identified the richness of microcrustaceans, and even though they are artificial environments, rice fields have high potential to store a high diversity of microcrustaceans.

Key words: Crustacea, paddy, scientific production, wetlands, zooplankton.

INTRODUCTION

Irrigated rice fields cover around 167.2 million hectares across the globe, spread across 116 countries (Shahbandeh 2019). Rice cultivation is concentrated in some regions, for example, United States, southern Europe, Mediterranean regions, the Nile Delta in Egypt, and some other regions of Africa (Lawler 2001), but, the largest rice production is concentrated in Asia, which comprises about 89% of all rice fields (Smith et al. 2018).

Rice fields provide basic food for 40% of the world population and it is one of the most important grains in terms of economic value (Lawler 2001). Since rice is the one of the most consumed foods in the world, it requires a large production area, providing habitat for the species (Smith et al. 2018). These environments represent 15% of the wetlands of the world and function as temporary aquatic systems (Lawler 2001). They are flooded in the spring for planting seeds, during the summer the water levels are kept high for rice growth, but after harvest in autumn/winter the water level depends mainly on rainfall and agricultural management, and they can remain without water during these seasons (Lawler 2001, Stenert et al. 2010).

Rice fields are replacing natural wetland habitats, which have been lost to drainage and decreased water levels due to their use for irrigation (Stenert et al. 2010, Natuhara 2013). It was estimated that 57% of rice fields occupy areas that were previously natural wetlands

(Lawler 2001). With the decline of natural wetlands, rice fields can serve as a refuge, especially during the hydroperiod, for birds (Lourenço & Piersma 2009, Herring et al. 2019), fish, crayfish (Clavero et al. 2015), amphibians (Groffen et al. 2018), and invertebrates (Maiphae et al. 2010, Savatenalinton 2017, Smith et al. 2018). Despite their function as a refuge, studies warn that it is not appropriate to convert natural wetlands into rice fields (Pires et al. 2016). The conversion of natural areas into rice fields results in many changes, such as the application of pesticides and maintenance activities (e. g. ploughing, planting, and harvesting) and can have a negative effect on their aquatic habitats, modifying the ecosystem physically and chemically, and making it difficult for animals to remain there (Sun & Yuan 2019).

Invertebrates can be sensitive to the use of pesticides and fertilizers, but even so, they are often recorded in rice fields (Reimche et al. 2014, Sun & Yuan 2019). Concerning invertebrates found in rice fields, microcrustaceans (Amphipoda, Anostraca, Cladocera, Conchostraca, Copepoda, and Ostracoda) have often been studied in these environments, as they are abundant and resistant to physical and chemical disturbances (Stenert et al. 2010, Ávila et al. 2015, Smith et al. 2018, 2019). These microorganisms are an important link in the trophic chains of these ecosystems, as they are the source of energy for various groups of organisms, such as fish larvae (Ali 1990, Cabral et al. 1998) and birds (Lourenço & Piersma 2009). The persistence of microcrustaceans in rice fields is due to behavioral and physiological adaptations, such as the production of a bank of dormant forms in the sediment in these environments (Stenert et al. 2010, Ávila et al. 2015).

The production of dormant forms is a common strategy for the survival and persistence of most microcrustaceans in different environments, and provides not only resistance from desiccation in temporary environments, but also a way to maintain the genetic and phenotypic diversity of species and the community during periods without water (Ávila et al. 2015). Some studies state that the dormant forms of microcrustaceans support the dry phase and cultivation system of rice fields, enabling the hatching and maintenance of the community when the environment becomes favorable again (Stenert et al. 2010, Ávila et al. 2015). It is unknown whether dormant forms are less studied than active forms in these environments; however, active and dormant forms can be complementary for assessing the diversity of microcrustaceans in specific environments (Stenert et al. 2010). Studies have shown that rice fields often have a high diversity of microcrustaceans (Rossi et al. 2003, Savatenalinton 2017, Smith et al. 2018) and often describe new species (Savatenalinton 2017, Fefilova & Alekseev 2018, Smith et al. 2019), but most studies in the rice fields focus on a specific location and/or group of animals and use more specific approaches, which is essential for surveying biodiversity and contributes to the realization of global studies (Rossi et al. 2003, Savatenalinton 2017, Fefilova & Alekseev 2018, Smith et al. 2018, 2019).

Research on biodiversity and species conservation studies focuses on natural environments, such as lakes, river systems, and wetlands (Bandeira et al. 2019, Herring et al. 2019), and as rice fields are artificial environments, they may be incorrectly seen as less significant in terms of biodiversity (Kimura 2005, Maiphae et al. 2010, Smith et al. 2018). Quantifying the richness of microcrustaceans in rice fields means it is possible to inform rice producers and researchers on the importance of management in cultivation, since management intensity affects diversity on rice field banks

(Giuliano et al. 2018). We can also identify where the richness of microcrustaceans is being studied across the world, which could offer sustainable management solutions for meeting biodiversity requirements in these agroecosystems (Giuliano et al. 2018, Herring et al. 2019). Considering the global distribution of rice fields and the potential for these environments to store a high diversity of microcrustaceans, mainly because these organisms produce dormant forms that remain in the sediment, our objective was to use scientometric analysis to evaluate the global trend in studies of microcrustaceans in rice fields, and the potential of this environment as a stock of diversity. We evaluated: i) the temporal trend of studies related to microcrustaceans in rice fields from 1977 to 2019; ii) which countries have studied microcrustaceans; iii) which microcrustaceans groups are most studied in rice fields and their respective richness by groups and by countries; iv) whether the studies focus more on active or dormant forms of microcrustaceans; and v) whether there are differences in the faunal composition found in active or dormant forms.

MATERIALS AND METHODS

The Web of Science (WoS, Clarivate Analytics) and Scopus (Elsevier) databases were used to compile studies with microcrustaceans in rice fields published since the start of the databases (WOS in 1945 and Scopus in 1960) until 2019. We started the survey in September 2019 and updated it in January 2020, and searched in the two databases for studies that contained, in the title, abstract, and keywords, a combination of the names of the main groups of microcrustaceans and the environment of interest: (*Crustacea* OR Cladocera* OR Copepoda* OR Ostracoda* OR Anostraca* OR Conchostraca* OR Amphipoda*) AND (Rice*). We accessed the databases using the "Periódicos CAPES" (https://www.periodicos.capes.gov.br/) that is a Portal of the "Coordenação de Aperfeiçoamento de Pessoal de Nível Superior" (CAPES) in Brazil.

In the two databases, 691 studies were found. The Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA protocol, Moher et al. 2009) were used to screen those studies carried out in rice fields involving microcrustaceans (Figure 1). We excluded 614 studies with the following criteria: i) studies that were replicated in the databases; ii) studies that were not available in its totality in the databases, was requested to the authors but was not received by the time of the analysis; iii) studies that were carried out in rice fields, but did not report microcrustaceans; and iv) studies that reported microcrustaceans, but were not carried out in rice fields (Figure 1). The initial compilation included a total of 193 studies in the WoS database, and 498 studies in the Scopus database (Figure 1). We removed 147 studies from the WoS database and 327 studies from Scopus after screening.

After filtering, 77 studies (46 studies from WoS and 31 from Scopus), involving microcrustaceans in rice fields, were considered suitable for scientometric analysis (see Table SI – Supplementary Material). We obtained the following information for each study: i) year of publication; ii) groups of microcrustaceans; iii) species of microcrustaceans (when available, n= 70 studies); iv) country where the study was developed; and v) whether the focus was on active or dormant forms of microcrustaceans (see Table SII).

To verify the temporal trend of studies with microcrustaceans, we performed a Spearman correlation (Best & Roberts 1975) because the range of publications over the years was low and the data did not show a normal distribution. The data were presented using

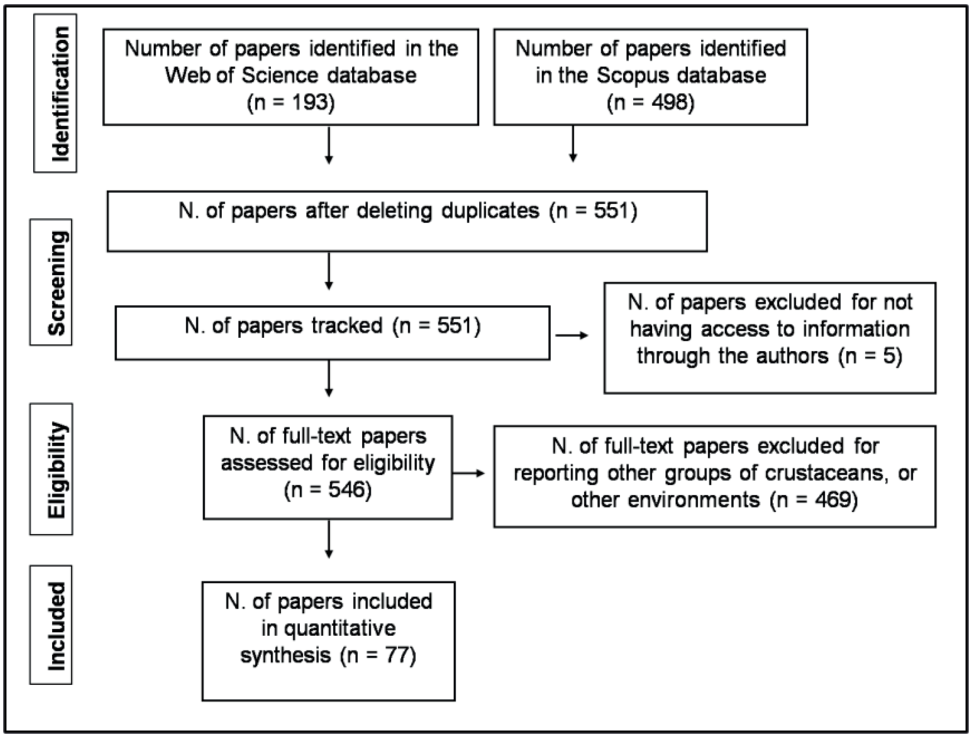

Figure 1. **PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analysis) protocol with the criteria for identification, selection, eligibility, and inclusion of studies with microcrustaceans in rice fields from the Web of Science and Scopus databases (adapted from Moher et al. 2009).**

descriptive statistics to verify which countries studied microcrustaceans, which groups of microcrustaceans were the most studied, and the richness of each group.

To identify possible variables that explain the number of studies carried out in different countries and the total richness of microcrustaceans found in the studies, generalized linear models (GLMs; family = Poisson; Crawley 2007) were used. Five explanatory variables were selected: i) cultivation area (in ha; FAOSTAT: http://www.fao.org/faostat/en/#data/QC); ii) rice production in countries (in tons; FAOSTAT: http://www.fao.org/faostat/en/#data/QC); iii) gross domestic product (GDP) of each country (US$ millions; World Bank: https://data.worldbank.org/indicator/NY.GDP.MKTP.CD?view=chart); iv) Human Development Index (HDI: varies between 0–1; UNDP: http://hdr.undp.org/en/composite/HDI); and v) research and development expenditure (% of GDP; World Bank: https://data.worldbank.org/indicator/GB.XPD.RSDV.GD.ZS?view=chart). Initially, Spearman's correlation was used to determine whether there was collinearity between the explanatory variables (Dormann et al. 2013). When two variables showed a high correlation (rho> 0.80), one was excluded; in this case, the cultivation area was excluded because of the high correlation with rice production in countries (rho> 0.95). The GLMs were compared with the Akaike Information Criterion (AIC; Burnham & Anderson 2002), using the '*MASS*' package (Venables & Ripley 2002), and considered the models that had the lowest AIC value. After selecting models, the relative importance of each variable in the models was checked using the '*relaimpo*' package (Grömping 2006). Two explanatory variables from the 70 studies with microcrustaceans were selected to explain the total richness of microcrustaceans in the countries studied: i) use of pesticides (dummy variable, where 1 indicated presence and 0, absence); and ii) whether the study used the active or dormant form of microcrustaceans (dummy variable, where 1 indicated an active form and 0, a dormant form).

Spearman correlation was used to verify whether the total microcrustacean richness was related to the number of studies per country (Best & Roberts 1975). A Venn diagram was built to illustrate the number of studies with active and dormant forms of microcrustaceans (Archer 1950). The *'VennDiagram'* package (Chen 2018) was used. A non-metric multidimensional scaling (NMDS) using a Jaccard index of species (presence/absence) was used to see if species composition differs between active or dormant forms. Next, we apply a Similarity Analysis (ANOSIM) to make sure that the groups formed at NMDS are similar. All analyses were performed in the R environment (R Core Team 2019).

RESULTS

Studies with microcrustaceans in rice fields had accumulated for over 35 years, with the inclusion of the first study in 1977 in the databases (Figure 2a). There was a positive correlation (rho = 0.34; p = 0.041) between the number of studies and the years of publication, although, the number of studies in the years studied was low (Figure 2b). In the 77 studies considered, 18 countries (Figure 3a) studied microcrustaceans in rice

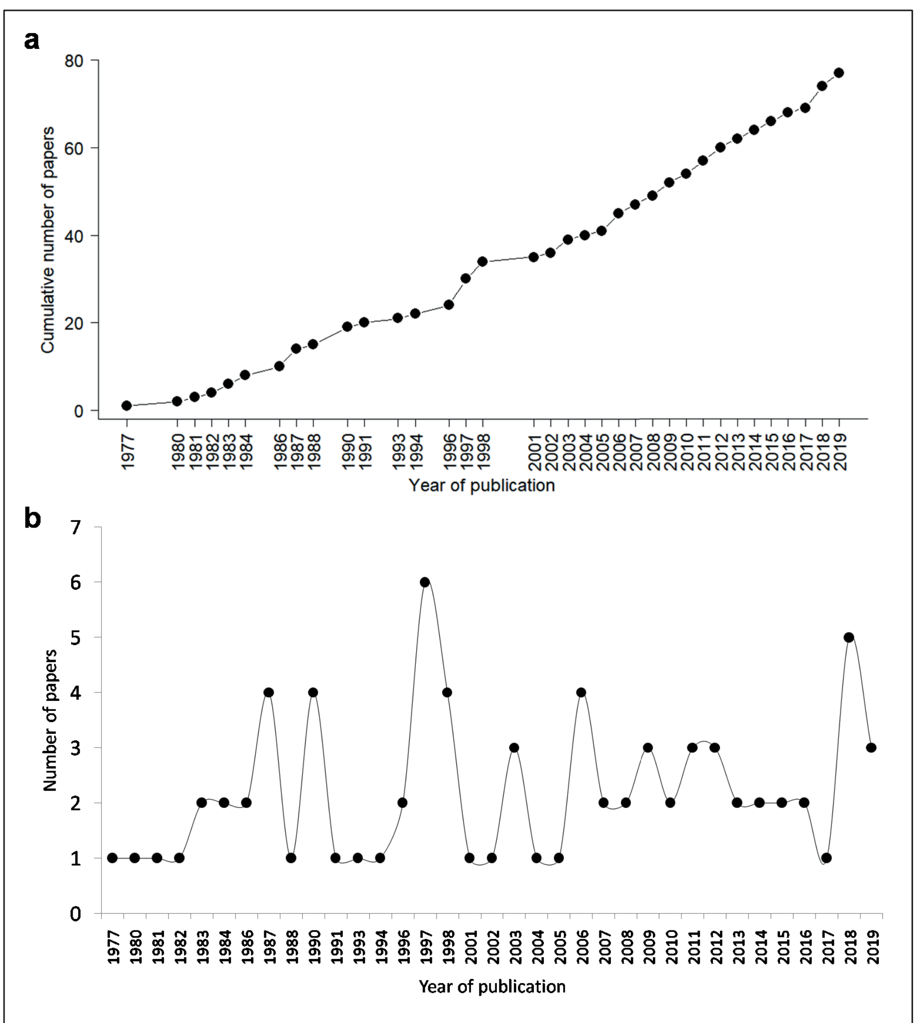

Figure 2. Temporal distribution of studies involving microcrustaceans in rice fields in the Web of Science and Scopus databases between 1977 and 2019: (a) Cumulative number of papers and (b) Total number of papers.

fields. The largest number of studies (58.4% of studies) was produced in Japan, followed by Italy, the USA, and Spain. The remaining 14 countries had fewer than six studies (Figure 3a). The best model explaining the number of studies with microcrustaceans (AIC = 101.5; see Table SIII to GLM results) included the most important explanatory variables, HDI (relative importance = 0.51) and GDP (relative importance = 0.48). Most studies addressed more than two groups of microcrustaceans (37.7% of the studies), followed by those that addressed only Cladocera (27.2%) and Ostracoda (18.1%). Other groups had less than 10 studies (Figure 3b).

The studies recorded a total richness of 301 species of microcrustaceans in 70 studies (seven studies cited only the groups) in rice fields of the 18 countries. In our study, the highest richness of microcrustaceans in rice fields was reported in Italy (29.5% of the species), followed by Thailand (24.9%), Malaysia (19.2%), Spain (15.2%), France (13.6%), Japan (12.2%), Brazil (11.9%), USA (3.6%), Vietnam (2.3%), and India (1.9%). The remaining eight countries registered fewer than five species (Figure 4a). The model that best explained the richness of microcrustaceans found in these countries (AIC = 591.9; see Table SIII to GLM results) included the use of pesticides in the studies as an explanatory variable, although, it did not have a significant effect (p= 0.09). A positive correlation (rho = 0.68; p = 0.001) was also found between total microcrustacean richness and the number of studies found in these countries. Within groups, the greatest richness was Cladocera (41.5% of species), followed by Ostracoda (39.8%), and less than 20 species for Conchostraca, Anostraca, and Amphipoda (Figure 4b).

In the 77 studies, the majority involved microcrustaceans in an active form (87%), a minority in dormant forms (11.6%), and only one study used both active and dormant forms (1.2%;

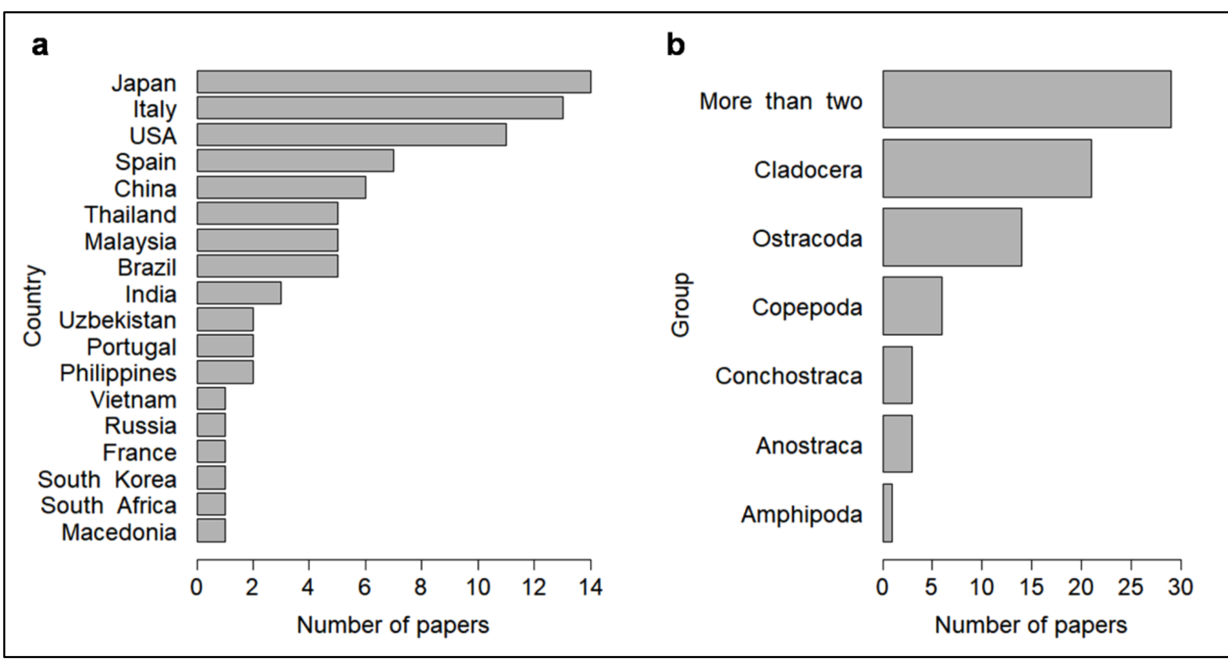

Figure 3. Number of studies with microcrustaceans in rice fields in the Web of Science and Scopus databases between 1977 and 2019: (a) countries studied and (b) groups of microcrustaceans. USA = United States of America. More than two = more than two groups of microcrustaceans studied (e. g. Cladocera, Copepoda and Ostracoda in the same study).

Figure 5a). When comparing the composition of species found in the active and dormant forms of microcrustaceans, we found no difference in composition, although ANOSIM was significant (ANOSIM: Global R = 0.18; p = 0.002), there was no representative segregation between the life forms (Figure 5b).

We found studies with the active forms of microcrustaceans in all 18 countries, with the dormant forms in Brazil, Spain, India, Italy, Japan, and Thailand, and with both forms only in Italy.

DISCUSSION

Temporal trend of studies with microcrustaceans

Our results showed that there was an increase in the number of studies with microcrustaceans over 35 years in the rice fields; however, the number of studies was low compared to a previous scientometric study involving a general analysis of rice fields (Liu et al. 2017). This reduced number of studies may be due to the use of a specific group in our study in contrast to the general analysis of the other studies (Morooka et al. 2014, Liu et al. 2017). Moreover, it may be related to less incentive for ecological research on these groups in rice fields, since general scientific research involving rice has grown by about 6.9% per year (Liu et al. 2017). These studies involving rice fields are focused on several themes that have been summarized in scientometric studies and reviews, such as the development of cultivation technologies in Japan (Morooka et al. 2014), the importance of co-cultures with aquatic animals (Bashir et al. 2019), the effect of climate change on crops in China (Liu et al. 2019), and of fertilizers (Sun & Yuan 2019). These themes are important for understanding the practical applications of rice fields, but we realize that there is still a need for more basic ecological research, especially involving microcrustaceans, as they can help us to understand the functions of these very unstable environments. Morooka et al. (2014), Liu et al. (2017, 2019), Bashir et al. (2019), and Sun and Yuan (2019) reported an increase in the number of studies, but used criteria different

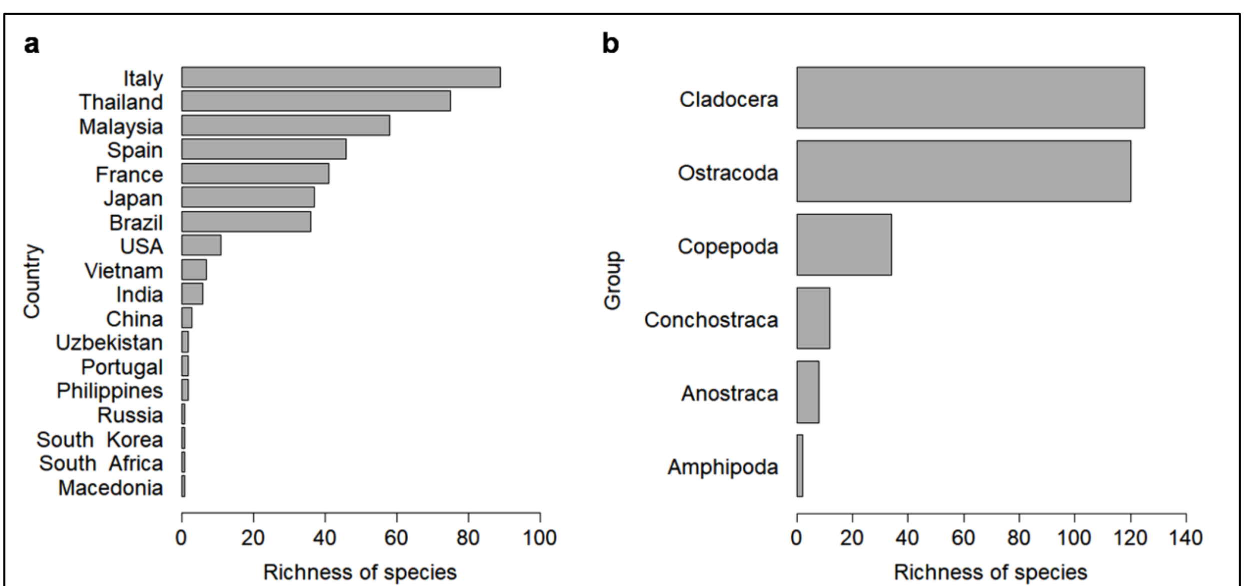

Figure 4. Richness of microcrustaceans found in studies in rice fields indexed in the Web of Science and Scopus databases between the years 1977 and 2019: **(a)** richness in countries and **(b)** richness by group. USA = United States of America.

from ours to compile and filter the studies to be analyzed. We emphasize the importance of using protocols, such as PRISMA, as well as analyzing all the studies compiled to select only those that address the studied subject. This can reduce the bias of the results and enable the correct estimation of time trends for the studies, since the studies with the topic addressed are selected specifically and transparently.

Our initial compilation of the studies in the databases revealed that the first study involving rice fields was by Rosenberg in 1947, describing the life cycle of shrimp in crops (Rosenberg 1947). Thirty years later, in 1977, Pont published the first study with microcrustaceans in these environments that was indexed in the databases we used. However, Pont (1977) had cited previous articles involving microcrustaceans in rice fields (e. g. Schachter & Conat 1951), showing that this area of research began well before 1977. This suggests that there may be a bias in our research, since there are more studies involving microcrustaceans in rice fields, but not all are indexed in the databases WoS and Scopus. We emphasize the importance of publishing studies in international databases, since the global scientific community does not always have access to regional/local journals and/or grey literature, causing language bias, since the English language is not always used and peer reviewed. Morooka et al. (2014) used different databases to compile the studies carried out only in Japan, and the smallest number of studies was found in WoS, which reinforces the idea that there may be biases in language and peer review in the databases, causing a reduction in the number of studies identified, which may not reflect the true situation. We found a positive correlation over 35 years, however, we emphasize that there is a need for more studies focused on microcrustaceans, as they are an important component in the function of the trophic chain of rice fields (Reimche et al. 2014).

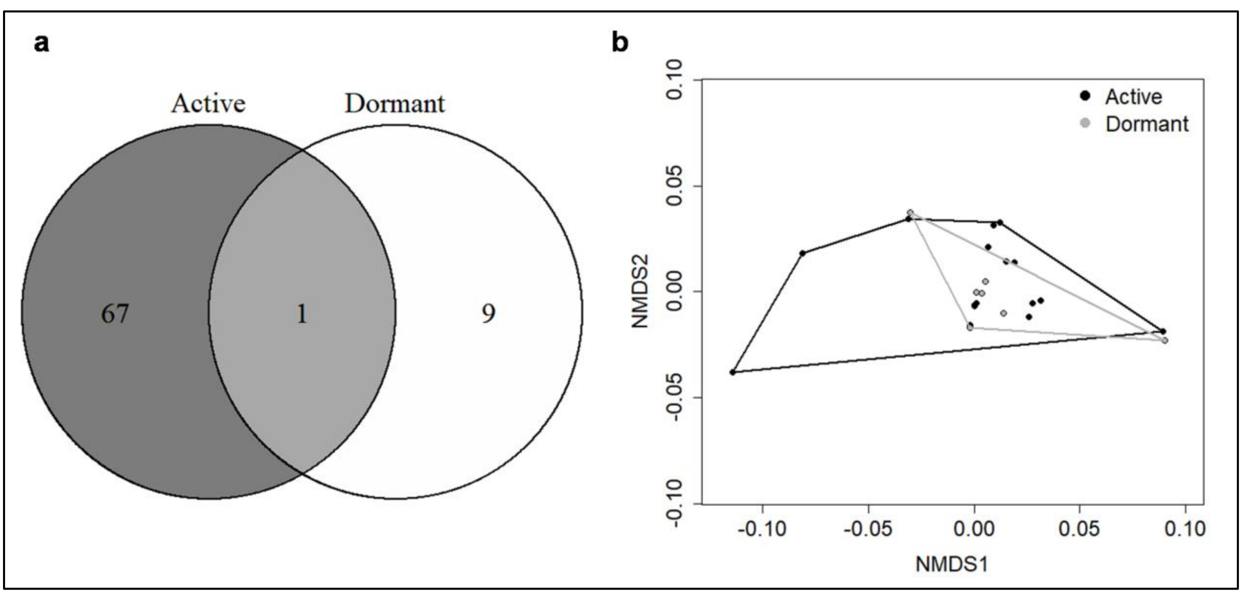

Figure 5. Distribution of the number of studies and species composition of the active and dormant forms of microcrustaceans: (a) Venn diagram with the number of studies showing the active (dark gray), dormant (white), and the two (light gray) forms of microcrustaceans in the rice fields and (b) NMDS with the composition of species of the active (black) and dormant (gray) forms of microcrustaceans.

Studies with microcrustaceans in rice fields

We found that 18 countries are studying microcrustaceans in rice fields, this represents 15.5% of the 116 countries that grow rice (Shahbandeh 2019), indicates that few countries know about the microcrustacean fauna in their fields. Of the 18 countries, eight (i.e. Japan, USA, China, Thailand, Brazil, India, Philippines, and South Korea) have already been identified as very productive in relation to the number of scientific studies on rice (Liu et al. 2017), mainly related to fertilizers in rice fields (Sun & Yuan 2019). Our results showed a different pattern, in which, most of the countries we registered had not previously stood out as conducting a high number of studies (e. g. Italy, Spain, and Malaysia), and this means that the amount of studies in these countries may vary according to the approach used in the studies (Sun & Yuan 2019).

We perceived a division between the countries that have contributed the most and those that have contributed the least regarding the number of studies with microcrustaceans. We found that 58.4% of the studies were carried out in Japan, Italy, the USA, and Spain. At the level of discussion, we compared the ranking of the ten largest rice producers in the world and found that the countries that produce the most rice are not the ones that study microcrustacean fauna the most, since the USA, Japan, Italy, and Spain occupy the 11^{th}, 13^{th}, 31^{st}, and 39^{th} positions, respectively. We found that the world's largest rice producers were China, India, Vietnam, Thailand, Philippines, and Brazil, and these countries contributed only 28.5% of the studies. This does not follow the pattern found in other studies, and is the opposite of that found by Liu et al. (2017) and Sun & Yuan (2019), where the countries that produce the most rice were also those that carried out the most studies, confirming that the number of studies in countries may vary according to the approach used to define it.

We found that HDI and GDP were the main variables affecting the number of studies involving microcrustaceans in the countries found in our study. As Japan, Italy, the USA, and Spain contributed most to the number of studies, this means that more developed countries are the ones that most study microcrustaceans in rice fields. This result is not restricted to studies involving microcrustaceans in rice fields, as other scientometric studies suggest socioeconomic parameters as the main variables in the increase in the number of studies, such as the study by Coelho et al. (2014) with macroalgae as a source of raw material for biofuels, and Pereira et al. (2019) with the effect of the construction of dams on fish. With the corroboration of these studies, our results indicate that the largest number of studies are in more economically developed countries, which as Coelho et al. (2014) pointed out, have a high level of infrastructure for the development of scientific research, which has a positive effect on their high scientific productivity. May (1997), studying the scientific wealth of nations, also found that countries with the largest economies invest the most in research and development, and are consequently those with the greatest scientific production.

Most studies in our research were conducted with more than two groups of microcrustaceans. In these studies, the authors addressed topics, such as diversity, composition, and dynamics in ecological communities in rice fields (e. g., Pont 1977, Ali 1990, Martinoy et al. 2006, Chittapun et al. 2009), the effects of environmental factors on microcrustaceans (e. g., Stenert et al. 2010, Chittapun 2011), the effects of crop systems (e. g., Yamazaki et al. 2003, Reimch et al. 2014, Ávila et al. 2015), and the importance of these environments for the dissemination of invasive species and dispersal of these organisms (e. g., Lovas-Kiss et al. 2018). We observed an evolution in the approaches used in these studies, where, initially, the interest was in which species were present in the rice fields, since lists of species were made. Research questions evolved towards the behavioral attributes of microcrustaceans, trying to understand how these organisms react to the constant changes in environmental variables and in the cultivation process, until reaching ecological issues that have recently become more worrying, such as the effect of invasive species and the potential of these environments for the dispersal of organisms (Lovas-Kiss et al. 2018). This evolution has allowed us to note that despite finding a small number of studies, the approaches used are very relevant and are constantly updated, mainly to reflect the importance of microcrustaceans in the development and relevance of rice fields as an ecologically productive environment, although artificial (Smith et al. 2018).

We found that Cladocera and Ostracoda were the most commonly studied groups of microcrustaceans in rice fields. Studies of Cladocera focused on diversity (e. g., Maiphae et al. 2010, Sinev & Korovchinsky 2013), ecological succession throughout the cultivation cycle (e. g., Ferrari et al. 1991, Leoni et al. 1998), effect of water reuse irrigation (Grippo et al. 2016), and more widely on the effects of pesticides and fertilizers (e. g., Zhang et al. 2016, Chen et al. 2018, Jiang et al. 2018, Içoğlu 2019, Subrero et al. 2019). For Ostracoda, the studies were focused on diversity (e. g., Rossi et al. 2003, Savatenalinton 2017, Smith et al. 2019), the effects of pesticides (e. g., Perez & Aspiras 1982, Lim & Wong 1986), species dispersal (e. g., Mckenzie & Moroni 1986), bioremediation (e. g., Grant et al. 1983, Hamdi et al. 2007), population genetics (e. g., Rossi et al. 1996, 2006), and invasive species (e. g., Mesquita-Joanes et al. 2012, Valls et al. 2014). However, we found that a large contribution to the number of studies with Cladocera and Ostracoda were the result of the species *Daphnia magna* Straus, 1820 (Cladocera) and *Heterocypris incongruens* (Ramdohr), 1808 (Ostracoda), which mainly addressed the effects of pesticides and fertilizers. Diversity surveys also made a high contribution to the number of studies and, consequently, Cladocera and Ostracoda also show the greatest richness in rice fields. This may be an effect of the type of studies performed, since most studies made with these two groups were inventories, while research on other groups mostly focused on experiments or other topics.

The least studied groups were Copepoda, Anostraca, Conchostraca, and Amphipoda. The studies for these groups addressed diversity (e. g., Petkovski 1997, Fefilova & Alekseev 2018), life history (e. g., Tinti & Scanabissi 1996, Plodsomboon et al. 2012), population genetics (e. g., Montoliu et al. 2015), and the effect of pesticides (e. g., Dieng et al. 2003, Chandler et al. 2004, Moore et al. 2009). Less than 20% of the studies were carried out with these four groups, and the approaches were focused on reproductive aspects and few on the survey of diversity. This suggests that these groups may be underestimated in rice crops, or that they are less present in these environments, since we also found lower richness for these groups.

Richness of microcrustaceans in rice fields

In the six groups of microcrustaceans that we studied, 7,697 species have been described in different natural freshwater environments, such as rivers, lakes, and wetlands (Brendonck et al. 2008, Boxshall & Defaye 2008, Forró et al. 2008, Martens et al. 2008, Väinölä et al. 2008). The global diversity of microcrustaceans includes 2,814 species of Copepoda (Boxshall & Defaye 2008), 1,936 species of Ostracoda (Martens et al. 2008), 1,870 of Amphipoda (Väinölä et al. 2008), 620 species of Cladocera (Forró et al. 2008), 307 species of Anostraca (Brendonck et al. 2008), and 150 species of Conchostraca (Brendonck et al. 2008). Our survey quantified a total of 301 species in rice fields in 18 countries, which represents around 4% of the global known diversity of microcrustaceans. Our results showed that 63.8% of the species were registered in the rice fields of Asian countries, 59.5% in European countries, 15.6% in America, and 0.3% in Africa. Thus, we suggest that there is still high potential for recording microcrustacean biodiversity in rice fields on all continents; as mentioned previously, the countries with the largest areas and productivity are those with the lowest records of studies with microcrustaceans. Considering that only 15.5% of the countries that cultivate rice have a survey of the richness of microcrustaceans, we can assume that, despite being artificial environments, rice fields have high potential to store such diversity.

We found that many studies have investigated the use of pesticides on the richness and abundance of microcrustaceans in rice fields, mainly studies with the effect of insecticides (for example, Reimche et al. 2014, Jiang et al. 2018) and fertilizers (for example, Barceló et al. 1991, Maiphae et al. 2010). This possibly influenced the richness of microcrustaceans in the countries studied. We observed that richness decreases with the use of pesticides in rice fields. This has been commonly noted in the literature, where Reimche et al. (2014) found that pesticides negatively affect the density of microcrustaceans in rice fields. Jiang et al. (2018) reported that pesticides negatively affect the viability of eggs, morphology of organisms, and growth and reproduction of microcrustaceans. The number of studies on fertilizer use (such as nitrogen, phosphorus, and potassium) in rice fields has continued to increase over the years (Sun & Yuan 2019). These fertilizers affect the proliferation of phytoplankton in rice fields, which serves as food for many microcrustaceans. Although high concentrations of phosphate in water can be lethal for microcrustaceans (Barceló et al. 1991), a positive correlation with phosphate and the abundance of microcrustaceans in rice fields has also been recorded (Maiphae et al. 2010).

We found that richness was positively correlated with the number of studies. This is also a consequence of a greatest sampling effort in the countries, indicating that the more studies that are carried out, the greater the probability of knowing the diversity of microcrustaceans in rice fields. Basic ecological studies are still needed, and we suggest that these should be mainly diversity surveys because we noted that this approach made a high contribution to the estimation of microcrustacean richness in our study, mainly for Cladocera and Ostracoda, which were the groups that presented the greatest microcrustacean richness in rice fields.

Studies with active and dormant forms of microcrustaceans

Our results showed that only 11.7% of the studies and few countries have considered the dormant forms of the groups analyzed, and 87% of the studies analyzed only the active forms of these organisms. As research has already shown, dormant form banks are the main source of active forms for the restructuring of communities in rice fields (Stenert et al. 2010, Chittapun 2011, Ávila et al. 2015, Lovas-Kiss et al. 2018). Failure to include this assessment may underestimate the potential to stock a diversity of microcrustaceans in aquatic environments formed temporarily in rice fields around the world. Thus, we suggest that the richness of dormant form banks should also be evaluated in future studies. This approach can assist in estimating the diversity of microcrustaceans in rice fields, since the dormancy structures are viable in the sediment for up to two years under desiccation, without compromising the emergence of microcrustaceans (Stenert et al. 2010). Recent research has also shown that microcrustaceans hatch at different intervals in temporary environments (Bandeira et al. 2019), which can also underestimate biodiversity in studies considering only the active communities. Another factor that reinforces the need for further studies of dormant forms in irrigated rice fields is that the existence of viable dormant forms in the sediment of rice fields can help in the restoration of natural wetlands, since the diversity and the abundance of dormant form banks are also essential for the ecological success of created or restored wetlands (Stenert et al. 2010, Ávila et al. 2015).

CONCLUSIONS

Our study showed the potential of rice fields as a stronghold for the biodiversity of microcrustaceans. We also reported that there are still gaps in our knowledge that must be explored to define robust actions for the management of agricultural and natural systems (i.e. agroecosystems) inserted in natural/anthropogenic landscapes. In addition, we found that there was an increasing trend in the number of studies and an evolution in approaches over time that assessed the diversity and behavioral and physiological responses of microcrustaceans in rice fields. The most commonly studied groups were Cladocera and Ostracoda, and the countries that produce the most rice are not the ones that most study microcrustacean fauna. Due to the low number of studies in the countries that produce the most rice, our results suggest a great underestimation of microcrustacean biodiversity. Because of this, we found a low percentage in relation to the global richness of the groups of these organisms.

We suggest that the diversity of microcrustaceans in rice fields should continue to be widely studied, especially the dormant forms. This has high potential to increase the rich knowledge of microcrustaceans in these environments and allow better understanding of communities and, consequently, the behavior of the trophic chain in rice fields. Rice fields, in conjunction with natural environments, can favor the conservation of microcrustaceans, especially in crops with less aggressive management, and this would possibly be favorable for the management of these agroecosystems.

We saw that rice fields have high potential to store a diversity of microcrustaceans, however, this study does not justify transforming natural environments into rice fields. Rice fields can hold a great diversity of microcrustaceans, and such knowledge can serve as a basis for integrated natural wetland management programs, as a source of species that help maintain the structure and function of rice-based ecosystems.

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SUPPLEMENTARY MATERIAL

Tables SI, SII, SIII.

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