

## Abundance and spatio-temporal distribution of the amphidromous shrimp *Macrobrachium olfersii* (Caridea: Palaemonidae) along the Ribeira de Iguape River (São Paulo, Brazil)

Crislene Cristo Ribeiro  [orcid.org/0000-0002-3877-6723](https://orcid.org/0000-0002-3877-6723)

Victor Hugo Polachini Lopes  [orcid.org/0000-0002-5009-8523](https://orcid.org/0000-0002-5009-8523)

Giovana Bertini  [orcid.org/0000-0003-4489-0351](https://orcid.org/0000-0003-4489-0351)

Laboratory of Biology and Culture of Crustaceans (LABCRUST), São Paulo State University (UNESP), Campus of Registro. Rua Nelson Brihi Badur, 430, 11900-000, Registro, São Paulo, Brazil.

CCR E-mail: [crislenebio@yahoo.com.br](mailto:crislenebio@yahoo.com.br)

VHPL E-mail: [bragga.bragga@hotmail.com](mailto:bragga.bragga@hotmail.com)

GB E-mail: [giovana.bertini@unesp.br](mailto:giovana.bertini@unesp.br)

ZOOBANK: <http://zoobank.org/urn:lsid:zoobank.org:pub:5F3C2019-E092-49EB-9F26-A044E7996034>

### ABSTRACT

In this study we investigated the distribution of *Macrobrachium olfersii* (Wiegmann, 1836) along ~150 km of the Ribeira de Iguape river, São Paulo, Brazil. We compared the abundance and spatio-temporal distribution, and checked for differences in size and proportion of each sex in the collections, using two sampling methods. Shrimps were collected monthly at four sites (Eldorado, Sete Barros, Registro, and Iguape), from January to December 2007, using traps and sieves. We obtained a total of 23,818 individuals. The abundance was significantly higher at the Iguape-site, which was the closest to the estuary. There was a positive cross-correlation between abundance and rainfall, indicating an increase in abundance with a decrease in rainfall. The body size increased significantly upstream, suggesting a juvenile upstream migration, controlled by the rainfall regime and the amphidromous behavior of *M. olfersii*. More than 95% of the individuals were captured by sieving through the marginal vegetation of the river. The average size and sex ratio of each sample varied depending on the capture method: traps captured more and larger males than the sieve. Therefore, we recommend the combined use of these methods to obtain a better coverage of the population biology of freshwater shrimps.

### KEYWORDS

Capture method, rainfall, sieve, trap, Vale do Ribeira

#### CORRESPONDING AUTHOR

Giovana Bertini  
[giovana.bertini@unesp.br](mailto:giovana.bertini@unesp.br)

SUBMITTED 16 December 2019

ACCEPTED 07 April 2020

PUBLISHED 15 June 2020

DOI 10.1590/2358-2936e2020017



All content of the journal, except where identified, is licensed under a Creative Commons attribution-type BY.

Nauplius, 28: e2020017

## INTRODUCTION

Shrimps of the genus *Macrobrachium* Spence Bate, 1868 can be separated into two groups, depending on the environment where they spend most of their life cycle. The first group is composed of freshwater species that have an abbreviated or direct larval development (Magalhães and Walker, 1988; Jalihal *et al.*, 1993; Hancock, 1998). The second group has amphidromous species that migrate twice during their life cycle: first as planktonic larvae that float passively towards an estuary, and later as juveniles that migrate upstream in rivers and creeks to live there as adults (Bauer and Delahoussaye, 2008; Bauer, 2011).

The Ribeira de Iguape river catchment area has a high species richness of decapod crustaceans, including five shrimp species of the genus *Macrobrachium* (see Rocha and Bueno, 2004). Four of them are amphidromous (*Macrobrachium acanthurus* (Wiegmann, 1836), *Macrobrachium carcinus* (Linnaeus, 1758), *Macrobrachium heterochirus* (Wiegmann, 1836), and *Macrobrachium olfersii* (Wiegmann, 1836), and the other one lives exclusively in freshwater (*Macrobrachium potiuna* (Müller, 1880)). *Macrobrachium olfersii*, popularly known as “Pitu”, “Bristled River Shrimp” or “Buchura River Prawn” (Rossi *et al.*, 2016), has a wide geographic distribution, occurring from the southeast of the United States to the south of Brazil (Holthuis and Provenzano, 1970; Melo, 2003; Rossi and Mantelatto, 2013). Due to the physiological need for brackish water, it is restricted to coastal basins and to the lower courses of rivers and streams that flow directly into the sea (Holthuis and Provenzano, 1970). In these environments, *M. olfersii* is found in the marginal vegetation and in crevices between trunks and rocks (Barros, 1995; Melo, 2003).

Amphidromous shrimps can undertake upstream migrations of hundreds of kilometers (Rome *et al.*, 2009). In many cases, the shrimp’s distribution is influenced by the degree of conservation of the environments found along the migration course (Snyder *et al.*, 2013). During the migration, they can be exposed to stressful conditions due to: 1) the suppression of riparian forest and siltation of rivers and streams, both which lead to loss of microhabitats (Iwata *et al.*, 2003; Teixeira and Couto, 2012); 2) fisheries, that can lead to declining populations (Hein

*et al.*, 2011; Snyder *et al.*, 2013); and 3) dams, that can change and/or disrupt species migration routes (March *et al.*, 2003; Greathouse *et al.*, 2006). Some of these anthropogenic impacts have been observed in the catchment area of Ribeira de Iguape river, namely fisheries (Bertini and Valenti, 2010), suppression of riparian vegetation (Leonardo *et al.*, 2008; Iori *et al.*, 2019) and contamination by pesticides, especially carbofuran, which is one of the most commonly used agrochemicals employed in the banana plantations in the region (Marques *et al.*, 2007a; 2007b).

The influence of environmental degradation in the abundance and distribution of *M. olfersii* has been recorded by several authors. In the Mangues river, south of Bahia (Brazil), Teixeira and Couto (2012) noticed that the shrimps were absent in places lacking the riparian vegetation and where the riverbed was altered. Pescinelli *et al.* (2016) also attributed the disappearance of *M. olfersii* from the Taquaral river (Ubatuba, Brazil), over a five-year interval, to anthropogenic impacts. In Sarapiquí (Costa Rica), Snyder *et al.* (2013) compared the relative abundance of *M. olfersii* over a 20-year gap between the pre-disturbance and post-disturbance and observed strong changes in the abundance in the places affected by the anthropogenic impacts.

The distribution of shrimps in freshwater environments is also driven by environmental factors. In the case of *M. olfersii* the main known factors driving the populations are temperature (Müller and Prazeres, 1992), conductivity, river flow, and substrate type (Snyder *et al.*, 2016). In addition, the distribution of shrimps in a water body is also related to resources such as organic detritus, phytoplankton and zooplankton, which are used by different species during their life cycles (Hobbs and Hart, 1982; Teixeira and Sá, 1998; Müller *et al.*, 1999; Almeida *et al.*, 2008).

Previous studies about the distribution patterns and ecology of *M. olfersii* addressed only populations from relatively small rivers (Müller and Prazeres, 1992; Ammar *et al.*, 2001; Mossolin and Bueno, 2002; Teixeira and Couto, 2012; Pescinelli *et al.*, 2016). Thus, in this study we investigated the distribution of *M. olfersii* in the Ribeira de Iguape river, covering four sites along an ~150 km transect from the estuary. We analyzed the abundance and spatio-temporal distribution using two capture methods. Due to

the high habitat heterogeneity found in freshwater environments, there are many different methods that can be used to capture shrimps, such as traps, sieves, nets, electrofishing, and manual capture (Abele and Blum, 1977; Fièvet *et al.*, 1996; Garcia *et al.*, 2003; Rocha and Bueno, 2004; Rocha, 2010; Copatti *et al.*, 2016). We also analyzed differences in the size and proportion of each sex in the samples, depending on the capture method. We expected to find a similar abundance across all sampling sites, since there are no physical barriers that could hamper the migration, and the degree of anthropogenic impact is similar along the whole river extension.

## MATERIAL AND METHODS

### Study Area

The region of Vale do Ribeira is located south of the state of São Paulo and east of the state of Paraná. This region harbors an important remnant of the Atlantic Forest. About 40% of the vegetation cover of this remnant belongs to São Paulo State and was appointed as the largest continuous reserve inside the national territory (Silva Matos and Bovi, 2002). The Ribeira de Iguape river catchment area (23°50'S 46°50'W; 25°30'S 50°00'W) is approximately 25,000 km<sup>2</sup> and is one of the largest on the Brazilian coast (Mahiques *et al.*, 2014). According to Köppen's climate classification, the climate is humid subtropical, and the average annual temperature is 21°C (Rolim *et al.*, 2007). The average rainfall is 2200 mm yr<sup>-1</sup> and there is a marked rainy season between November and February (Mahiques *et al.*, 2014). The river outflow, in its lower course, varies from ~300 to more than 1200 m<sup>3</sup> s<sup>-1</sup>, and this fluctuation is strongly influenced by the humid subtropical climate (Mahiques *et al.*, 2014).

The riverbed of Ribeira de Iguape is rocky along the rapids, and sandy/loamy in the backwaters. Depth varies with rainfall in the range of 1–8 meters (DAEE: <http://www.hidrologia.dae.sp.gov.br/>). The most conspicuous problem is that the riparian vegetation has been replaced by banana plantations and pastures along almost all the river's extension (Leonardo *et al.*, 2008). These land-use changes introduced agrochemicals into the water (Marques

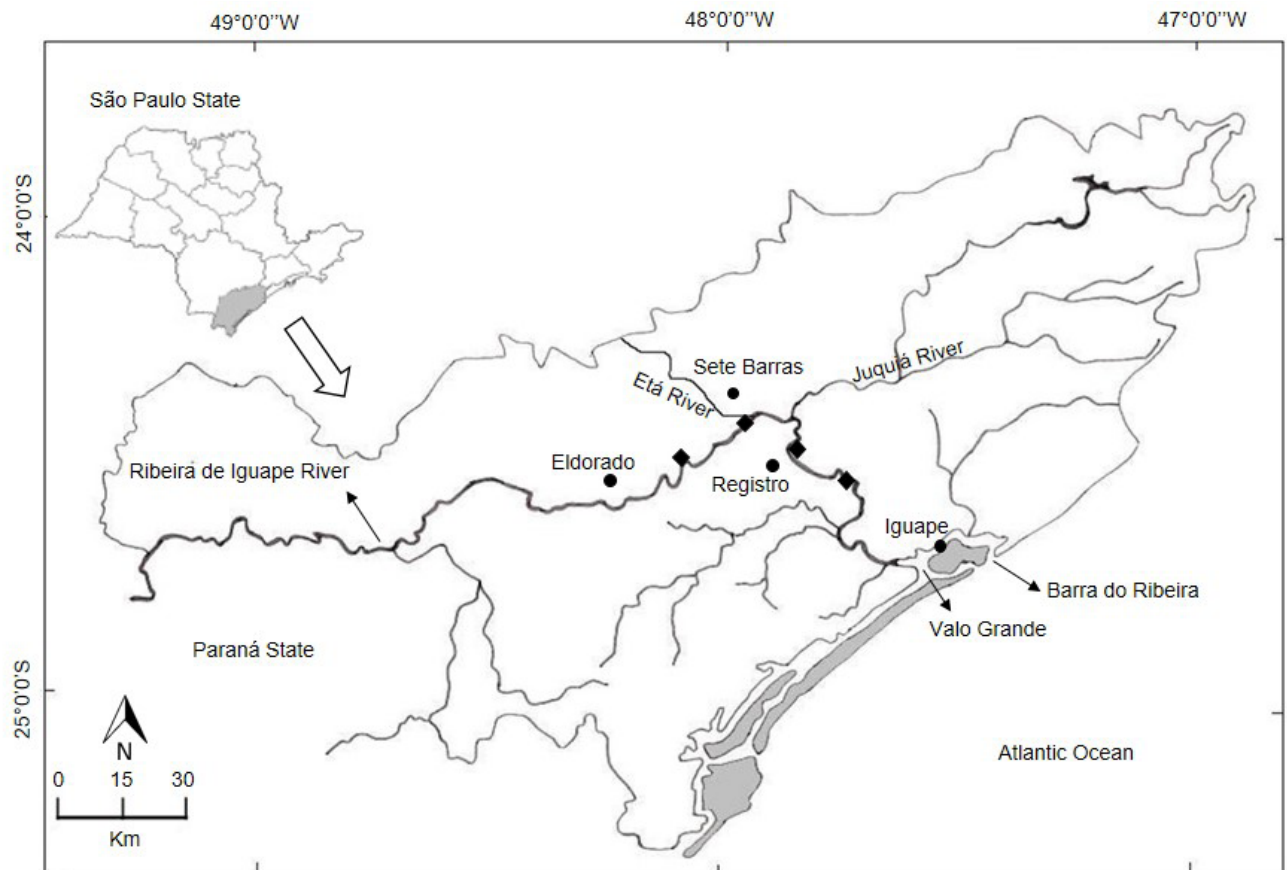
*et al.*, 2007b), and the suppression of vegetation plus the extraction of sand has led to siltation (Lelles *et al.*, 2005).

### Data Collection

Samples of *M. olfersii* were taken monthly, from January to December 2007, at four sites distributed along the river. These sites were selected to characterize the migration and abundance of *M. olfersii* along the river's extension. The site Iguape was located 72 km from the estuary, and the remaining sites were located upstream: Registro (114 km), Sete Barras (138 km) and Eldorado (155 km) (Fig. 1). The river margins were similar in these four sites, with pastures and banana plantations. In the river margins the presence of grasses was common (*Brachiaria subquadripa* (Trin.) Hitchc, *Brachiara platyphylla* Sukachev, and *Panicum dichotomiflorum* Michx) and in Iguape there was a high amount of aquatic plants (floating water hyacinth, *Eichhornia crassipes* (Mart.) Solms). Between Eldorado and Iguape, the river receives two tributaries, the Etá river, near Sete Barras, and Juquiá river, the main tributary, near Registro (Fig. 1).

In each site we took samples from two places, 2 km apart from each other, using a combination of minnow traps and a sieve (Fig. 2). Twelve minnow traps (1 m length, 30 cm diameter, and 8 mm mesh size) were baited with small banana pieces and/or cow bones and installed in each site. They were spread among the marginal vegetation (n = 6 traps) and in the river bottom (n = 6 traps) and retrieved after 24 h. In addition, two people sampled the river margin (against the current) for 20 min with a single sieve (0.5 m<sup>2</sup>, 5 mm mesh size), focusing on the semi-submerged vegetation where shrimps are known to shelter (Bertini *et al.*, 2014). The collected shrimps were placed in thermal boxes with crushed ice and transported to the laboratory, where they were kept frozen until the analysis. All specimens were identified according to Melo (2003).

In each site we measured the water temperature and salinity with a thermometer and a refractometer, respectively. Rainfall data for each region for 2007 were obtained from the Integrated Agrometeorological Information Center (CIIAGRO) of the Agronomic Institute (IAC).



**Figure 1.** Map of the Ribeira de Iguape river basin, São Paulo, Brazil, showing the sampling sites (Eldorado, Sete Barras, Registro, and Iguape).



**Figure 2.** Capture methods. (A) Trap baited with cow bones. (B) Sieve (0.5 m<sup>2</sup>, 5 mm mesh size). Photos: G. Bertini.

To analyze the shrimp size, we did a subsampling of the total amount of *M. olfersii* collected per site and month. In samples containing up to 80 shrimps, all individuals were analyzed. If samples had more than 80 shrimps, a subsample was randomly taken, by adapting the procedures of Wenner *et al.* (1991) and Bertini *et al.* (2014), as follows: 80 individuals were selected from samples containing 80–160 shrimps; 50% of the individuals were taken from samples with 160–320; 25% were taken from samples with 320–500, and 10% were taken from samples with more than 500 shrimps.

All individuals of *M. olfersii* from each subsample were sexed based on the examination of secondary sexual characters. Males were recognized by the presence of the appendix masculina on the endopodite of the second pair of pleopods, and females by the absence of it. The carapace length (CL) was taken as the distance between the orbital angle and the posterior margin of the carapace. In individuals > 10.0 mm the CL was measured with a caliper (to the nearest 0.1 mm). Individuals < 10.0 mm CL were measured to the nearest 0.025 mm under the stereomicroscope using a graduated ocular micrometer (Olympus, SZX7<sup>®</sup>). After evaluating all individuals, we concluded that the size of the smallest male bearing an appendix masculina was 4 mm. Thus, all shrimps smaller than 4 mm were considered as juveniles, following Pescinelli *et al.* (2016).

#### Statistical analysis

To analyze the distribution and abundance of *M. olfersii*, we recorded the total number of shrimps per site, month, and capture method (trap or sieve). The abundance was compared between seasons, as follows: Summer (January to March), Autumn (April to June), Winter (July to September) and Spring (October to December).

To verify the possible relationship between the variation in total abundance per month and the monthly average water temperature and rainfall in the region, a time series cross-correlation analysis was used. Six time-intervals were considered (-6 to 6), and the significant values in the correlogram were used to verify the magnitude and lag in the covariance between the time series (Chatfield, 2004).

To compare the total abundance of shrimps between sites and seasons a generalized linear model

(GLM) with gamma distribution and log-link function was fitted to the data (Venables and Ripley, 2002). This model was chosen among others because it had the lowest *Akaike Information Criterion* (AIC) (Akaike, 1974). The same GLM was used to check for differences in size between the sexes and capture methods (trap or sieve).

The body size of *M. olfersii* was compared between sites and months using the non-parametric Kruskal-Wallis test, followed by Dunn's multiple comparison test. In addition, the body size was also compared between the two capture methods using the Mann-Whitney test (Sokal and Rohlf, 2001). Pearson's chi-squared test with residue analysis was used to check for biases in the sex ratio, depending on the capture method (trap and sieve) (Sokal and Rohlf, 2001). All statistical analyses took into account a significance level of 95%.

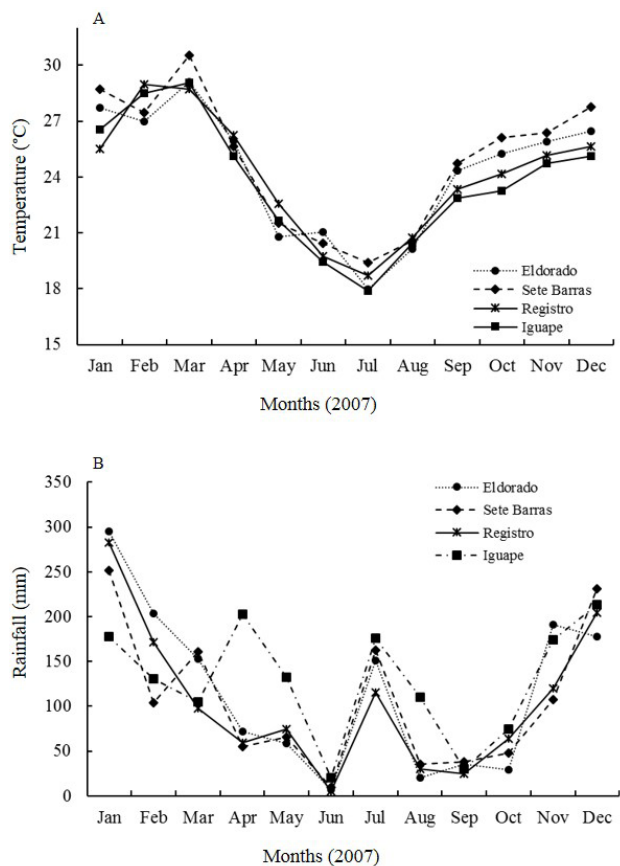
## RESULTS

### Environmental factors

Salinity was zero (0‰) at all sites and there was no tidal influence, even at Iguape, which was close to the estuary. Mean water temperature in the four sites ranged from  $17.9 \pm 0.18^\circ\text{C}$  (July; Iguape) to  $30.6 \pm 0.07^\circ\text{C}$  (March; Sete Barras) (Fig. 3A). The lowest rainfall ( $10.6 \pm 7.06$  mm) was recorded in June, and the highest, in January ( $251.9 \pm 52.59$  mm) (Fig. 3B). In July, a high volume of rainfall was observed, with a mean of  $151.2 \pm 25.83$  mm, which is considered atypical for the region (Fig. 3B).

### Spatial and temporal distribution

The total number of *M. olfersii* individuals captured in the four sites along the Ribeira de Iguape river was 23,818, corresponding to 1,594 specimens from Eldorado, 2,333 from Sete Barras, 2,201 from Registro, and 17,690 from Iguape. The GLM indicated a significant difference in the total abundance between sites and seasons ( $p < 0.05$ ), but there was no interaction between these factors (Fig. 4A, B). The abundance at Iguape (closest to the estuary) was statistically higher than in the other regions, farther from the river mouth (Eldorado, Sete Barras and Registro) (*Post hoc* LSD test;  $p < 0.05$ ) (Fig. 4A). The highest abundance was recorded in autumn (*Post hoc* LSD test;  $p < 0.05$ ) (Fig. 4B).

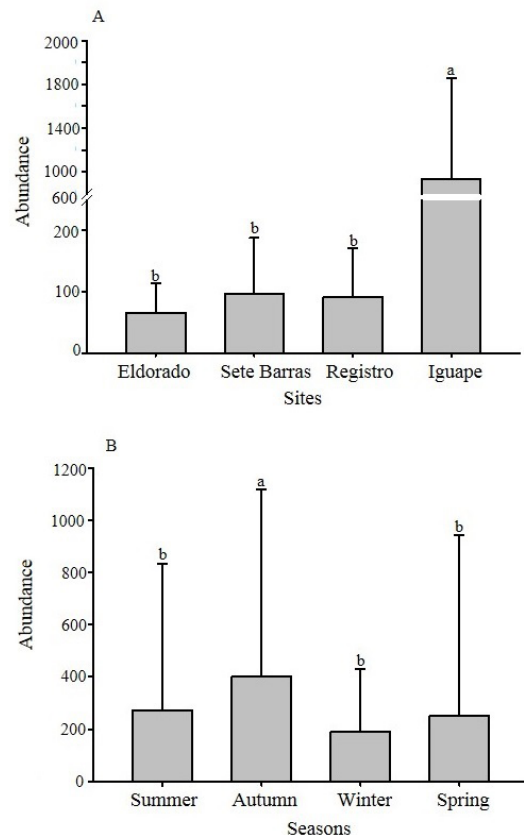


**Figure 3.** Mean water temperature (A) and rainfall (B) in Ribeira de Iguape river, São Paulo, Brazil, from January to December 2007.

Regarding the relationship between abundance, temperature and rainfall (Fig. 5A, B), the cross-correlation indicated a relationship with rainfall, demonstrating that, when rainfall decreases the number of individuals increased (3 lag time;  $r = 0.659$ ;  $p < 0.05$ ).

#### Individual size and capture methods

A high disparity was observed in relation to the two capture methods: 3.1% of the total number of individuals was captured in traps (total = 741 individuals; Eldorado = 205; Sete Barras = 172; Registro = 200; and Iguape = 164), whereas 96.9% (23,077 shrimps) was obtained by sieving (Eldorado = 1,389 ind.; Sete Barras = 2,161 ind.; Registro = 2,001 ind.; and Iguape = 17,526 ind.). Due to the



**Figure 4.** Mean abundance of *Macrobrachium olfersii* in the four sites (A) along the Ribeira de Iguape river, São Paulo, Brazil, and per season (B). GLM with *a posteriori* LSD test; different letters indicate significant differences at  $p < 0.05$ .

subsampling, the size of 9,691 individuals from the four sites were measured and analyzed (8,962 captured by sieving and 729 captured by the traps) (Tab. 1). The overall size of *M. olfersii* differed statistically between sites and increased towards the farthest site (Kruskal-Wallis,  $H = 2,051$ ;  $p < 0.05$ ) (Fig. 6). Between November and February, *i.e.*, from the end of spring until the end of summer, individuals were statistically larger than in the other months (Kruskal-Wallis,  $H = 2,684$ ;  $p < 0.05$ ) (Fig. 7).

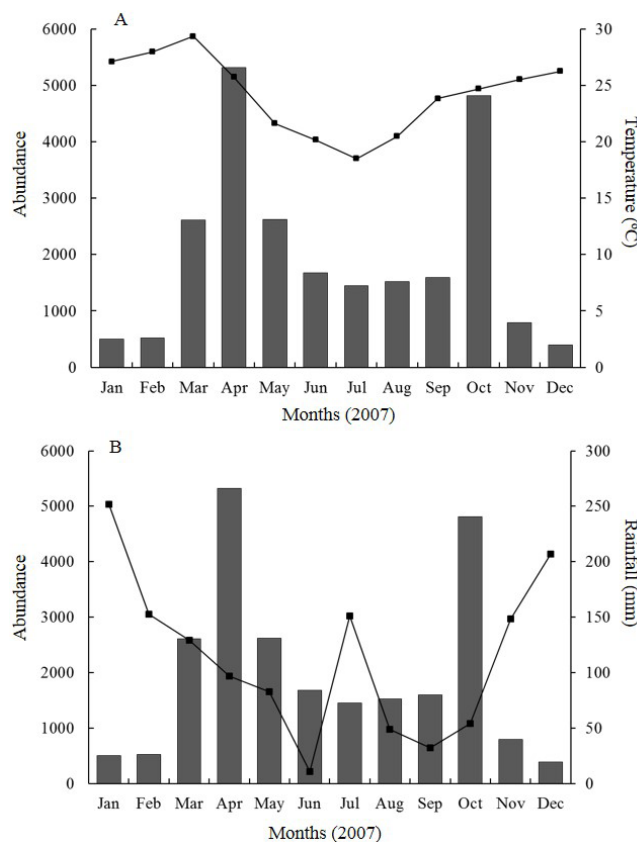
The GLM revealed that the shrimp size differed between the capture methods. Also, there was a significant interaction between the factors “capture methods” and “sex” ( $p < 0.05$ ). There were no differences in size when shrimps were captured by sieving (*Post hoc* Sidak test;  $p > 0.05$ ); in traps, however,

the males were larger than the females (*Post hoc* Sidak test;  $p < 0.05$ ). The between-sex comparison indicated that traps selected for largest individuals, irrespective of sex (*Post hoc* Sidak test;  $p < 0.05$ ) (Fig. 8). The overall size of individuals captured by the traps ( $16.4 \pm 2.69$  mm CL) was statistically higher than those from the sieve ( $4.2 \pm 2.36$  mm CL) (Mann-Whitney U = 37,530;  $p < 0.05$ ).

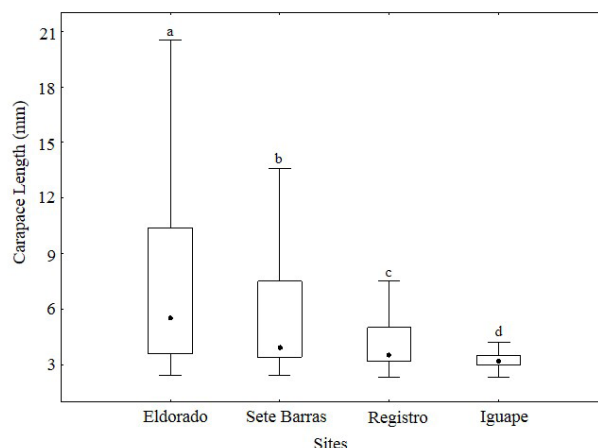
The statistical analysis of the contingency table indicated that the sex ratio depended on the capture method (Pearson Chi-Square = 45,817;  $p < 0.001$ ). In the traps, the number of males was higher than expected (observed: 498, expected: 419), and the opposite happened with the females (observed: 231; expected: 310). In the sieve, the number of males (1,248) was lower than expected (1,327), and the number of females (1,059) was higher than expected (980). Thus, the ratio of males:females was higher in the traps.

**Table 1.** Absolute abundance of *Macrobrachium olfersii* per site and capture method (NS= undifferentiated).

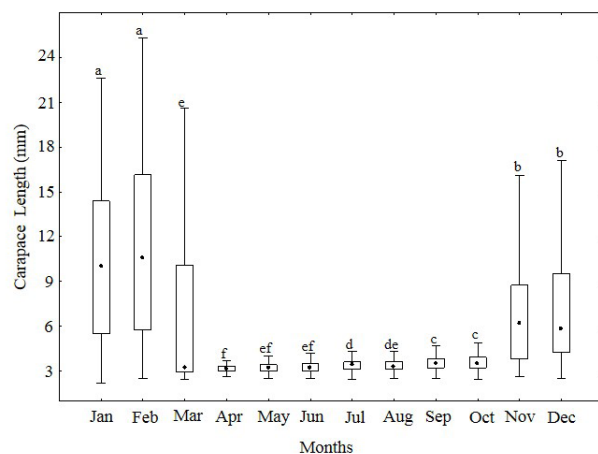
Sites	Capture methods	NS	Males	Females	Total
Eldorado	Traps	-	142	63	205
	Sieve	472	424	297	1,193
Sete Barras	Traps	-	96	76	172
	Sieve	855	331	308	1,494
Registro	Traps	-	123	65	188
	Sieve	1,135	231	160	1,526
Iguape	Traps	-	137	27	164
	Sieve	4,193	262	294	4,749
Total	Traps	-	498	231	729
	Sieve	6,655	1,248	1,059	8,962



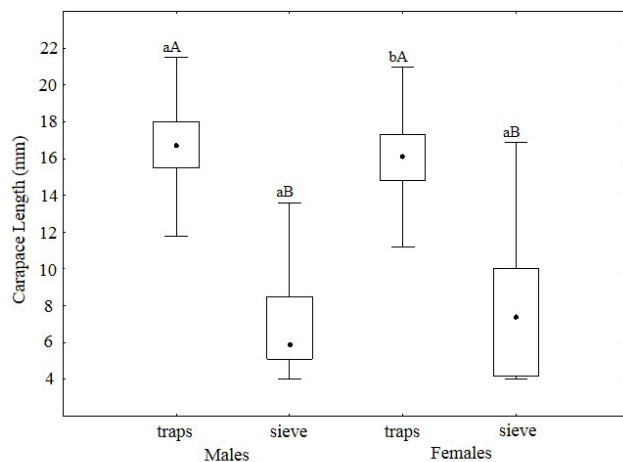
**Figure 5.** Relationship between the abundance of *Macrobrachium olfersii* with temperature (A) and rainfall (B), in Ribeira de Iguape river São Paulo, Brazil, from January to December 2007.



**Figure 6.** Median individual size of *Macrobrachium olfersii* per site, in Ribeira de Iguape river, São Paulo, Brazil. The boxplot shows the median: 75% and 25% quartiles; the whiskers indicate the non-outlier range; Kruskal-Wallis test: different letters indicate significant differences at  $p < 0.05$ .



**Figure 7.** Monthly median size variation of *Macrobrachium olfersii* in Ribeira de Iguape river, São Paulo, Brazil, from January to December 2007. The boxplot shows the median: 75% and 25% quartiles; the whiskers indicate the non-outlier range; Kruskal-Wallis test: different letters indicate significant differences between months at  $p < 0.05$ .



**Figure 8.** Median size of *Macrobrachium olfersii* males and females captured by traps or sieves in the sampling area, São Paulo, Brazil. The boxplots show the median: 75% and 25% quartiles; the whiskers indicate the non-outlier range; GLM with *a posteriori* Sidak test: capital letters compare the sexes by capture method, whereas small caps indicate the comparison of capture methods by sex at  $p < 0.05$ .

## DISCUSSION

*Macrobrachium olfersii* was extremely abundant in the Ribeira de Iguape river. It was found throughout all the studied sites, including Eldorado, which is ~155 km upstream the river mouth. Within the Vale do Ribeira, *M. olfersii* was also found in small rivers of the Juréia-Itatins Ecological Station, Campina do Encantado State Park, Cardoso Island State Park, Cananéia, and in Comprida Island, all located within the state of São Paulo (Rocha and Bueno, 2004). Furthermore, Rocha and Bueno (2004) reported the existence of *M. olfersii* specimens from Eldorado (MZUSP 13568) and from Iporanga (MZUSP 13549) (which is a city located ~80 km upstream of Eldorado), and deposited in the “Museu de Zoologia da Universidade de São Paulo” (MZUSP). They concluded that these populations established there through the migration of adults, but that their larvae are unlikely to contribute to the recruitment process due to the long distance to the estuary, which is needed to complete the life cycle.

Our results on the spatial distribution of *M. olfersii* indicate that they are more abundant in Iguape, near the river mouth. In Eldorado we found juveniles and adults, suggesting that *M. olfersii* individuals are capable of migrating upstream and reaching this region as juveniles, after going through the long passive

migration towards the estuary during the larval phase. Bertini *et al.* (2014) observed the same migration pattern in the sympatric species *M. acanthurus* (in the same study area), indicating that these species are capable to undertake a long migration and establish far away from the estuary. The larval migration back to the estuary is possible because the reproductive peak of *M. acanthurus* takes place in summer, when rainfall is abundant and increases the current's speed. Under these conditions, the larvae from Eldorado can reach the estuary in the region of Iguape within ~37 h of passive transport.

The temporal fluctuation observed in the abundance of *M. olfersii* can also be explained by its amphidromous behavior. In summer, when the precipitation was high, there was a decrease in abundance and the population was composed of large individuals. During the low precipitation recorded in autumn, there was a peak in abundance, and the population was composed of smaller individuals, indicating an upstream migration of juveniles. This relationship between reproduction and recruitment and the rainy period was also observed in the northern coast of São Paulo, in *M. olfersii* (cf. Mossolin and Bueno, 2002; Pescinelli *et al.*, 2016) and in *M. acanthurus* (cf. Bertini *et al.*, 2014). The migration of *M. olfersii* during the early juvenile stages was previously observed in Tacarigua, a coastal lagoon in eastern Venezuela, where it occurred year-round but was more intense in January–February (Gamba and Rodríguez, 1987). There, late post larvae or early juveniles of *M. olfersii* form visible parallel bands at the margins of the canal during migration (Gamba and Rodríguez, 1987). In Brazil, Pompeu *et al.* (2006) observed the mass migration of juvenile *M. carcinus* at dams of the Mucuri river (Minas Gerais state) using the mechanisms built for fish transposition. This mass migration is related to the reproductive strategy of this species. Since reproduction occurs in the upper river and adults do not need to reach the coast, downstream larval drift and upstream migration of juveniles are the only migratory movements necessary for the maintenance of this species in this basin (Pompeu *et al.*, 2006). Upstream migrations of juvenile amphidromous shrimps were also observed in many other locations around the world, such as India (Ibrahim, 1962), Caribbean and other tropical islands (Holmquist



*et al.*, 1998; March *et al.*, 2003; Covich *et al.*, 2006), Japan (Hamano and Hayashi, 1992), Australia (Lee and Fielder, 1979; Novak *et al.*, 2017a; 2017b), United States (Bauer and Delahoussaye, 2008), Mexican Pacific coast (Rodríguez-Uribe *et al.*, 2014), and Costa Rica (Snyder *et al.*, 2016).

Despite the intense anthropogenic impacts observed along the Ribeira de Iguape river (Marques *et al.*, 2007a; 2007b; Leonardo *et al.*, 2008), which included water contamination and suppression of the riparian vegetation, the upstream migration of *M. olfersii* still occurred. This statement is based on observations made during other collection campaigns performed at the same study sites from 2017 to 2019. In other localities of Brazil and Costa Rica, however, the occurrence and abundance of *M. olfersii* have been negatively affected by the lack of riparian vegetation, morphological changes in the riverbed, contamination by pesticides, and shrimp fisheries (Teixeira and Couto, 2012; Snyder *et al.*, 2013; Pescinelli *et al.*, 2016). In these localities, the rivers studied were small. The Ribeira de Iguape river, on the other hand, is large and has a higher carrying capacity. Its large dimensions may have contributed to minimize the negative effects of the anthropogenic impacts on the shrimps, allowing the maintenance of the population along the river course.

Changes in the riparian vegetation can increase the erosion of stream banks, sedimentation, and water flow, which in turn decrease the habitat heterogeneity and affect the abundance and diversity of decapods (Pérez-Reyes *et al.*, 2016). Nonetheless, we can infer that the studied population of *M. olfersii* is relatively resistant and/or resilient to the disturbances that affect the Ribeira de Iguape river, which are constant and have occurred for a long time in the region. The same can be said about *M. acanthurus*, which is also abundant in the studied region (Bertini and Baeza, 2014; Bertini *et al.*, 2014). When a species is resistant its abundance stays relatively stable upon disturbances, whereas in a resilient species the abundance decreases but can recover fast to the original, pre-disturbance levels (Holling, 1973). The resistance and/or resilience of the *M. olfersii* population and its upstream migration along the 155 km of the Ribeira de Iguape river may be explained by the presence of grasses and macrophytes

along the river margins, which are used as shelters by the juveniles, during the upstream migration.

The marginal vegetation and macrophytes can help to minimize the anthropogenic impacts, since they are important resources to many vertebrate and invertebrate species, including freshwater shrimps. This vegetation constitutes refuge against predators (West and Williams, 1986; Rozas and Odum, 1988; Castellanos and Rozas, 2001; Almeida *et al.*, 2008; Beatty *et al.*, 2011; Soares *et al.*, 2015) and places for reproduction and feeding (Montoya, 2003). Species of the genus *Macrobrachium* are omnivores (Abele and Blum, 1977; Odinetz-Collard, 1988) and can feed directly on the roots of water hyacinths (Green *et al.*, 1976). The periphytic algae (mainly diatoms and Cyanophyceae) attached to the roots likely enhance the quality of this nutritional resource (Montoya, 2003). Thus, *M. olfersii* may benefit from the presence of this marginal vegetation and use it as shelter and food along its upstream migration.

According to Snyder *et al.* (2016), the long-distance (>100 km) upstream migratory behavior of freshwater shrimps like *M. olfersii* has a great influence on their distribution and abundance patterns. It is driven by factors that operate at local (substrate and discharge) and landscape (conductivity) scales. Thus, depending on the characteristics of the region and river from which the samples are taken, abiotic factors and/or anthropogenic impacts may have a great influence on the abundance and distribution. However, the reproductive strategy (amphidromous behavior), the rainfall regime, and the presence of marginal and submerged vegetation can also be considered as key factors. In this context, Cantrell (1985) and Montoya (2003) mentioned also the important role of drifting or windblown vegetation in spreading invertebrates and shrimps from one part of a water body to another.

Our comparison of sampling methods revealed that sieves were more effective and captured more than 95% of the total individuals. Moreover, the body size varied with the method as sieves captured smaller individuals compared to traps. Thus, the use of a single method would affect the estimation of mean and maximum size of the individuals. Although comparative studies like ours with freshwater shrimps are scarce, previous studies reported similar patterns. For example, Rocha

(2010) mentioned this issue when studying *M. olfersii* and *M. acanthurus* in a river within the Juréia-Itatins Ecological Station (in the same basin of Ribeira de Iguape). Differences in body size depending on the sampling methods have also been observed in other decapods, such as aeglids (Dalosto *et al.*, 2014; Copatti *et al.*, 2016).

Our results indicated that the capture method is also biased regarding the sex, since traps captured more and larger *M. olfersii* males compared to the sieve. Traps captured 315 males larger than 16 mm CL, whereas the sieve captured only five. Large *M. olfersii* males inhabit the bottom of the river, and are known to be territorialists and have well-documented aggressive behavior (see Karplus and Barki, 2019), and seem to be attracted by the baited traps more efficiently. They live in deeper places, among rocks and large tree trunks and come out at night to feed, and then are caught in the traps. On the other hand, females and juveniles inhabit the marginal vegetation where they find shelter and food (Pyron *et al.*, 1999; Montoya, 2003; Almeida *et al.*, 2008), and are more likely to be caught by sieving. Similar behaviors that can lead to a higher capture of males by traps, have also been demonstrated in the mud shrimp *Neotrypaea uncinata* (H. Milne Edwards, 1837) (Garcia *et al.*, 2003), in the crayfish *Cherax cainii* (Beatty *et al.*, 2011) and many aeglids (Bueno *et al.*, 2007; Teodósio and Masunari, 2009; Grabowski *et al.*, 2013; Dalosto *et al.*, 2014; Copatti *et al.*, 2016).

According to Rocha (2010), the sex ratio of *M. acanthurus* changed depending on the sampling method: sieves captured more females, while traps captured more males, as demonstrated with *M. olfersii* in the present study. Therefore, the sampling method influences the composition of the collected shrimps, because if the biased sex ratio was a true characteristic of the population, it would have been detected by both methods (Rocha, 2010). Thus, the combined use of both methods helps to cover all microhabitats occupied by the different demographic groups, as discussed by Copatti *et al.* (2016) for *Aegla georginae* Santos and Jara, 2013.

In conclusion, *M. olfersii* shrimps are very abundant in Ribeira de Iguape river, where they undertake a long-distance upstream migration. This species can be considered resistant and/or resilient to the

anthropogenic impacts that have been affecting the region. The long-distance upstream migration can be accomplished due to the amphidromous behavior, rainfall regime of the region, and presence of grasses and macrophytes by the river margins. The two sampling methods are selective and lead to samples with different sex ratio and body size. Thus, the best way of studying the population biology of freshwater shrimps is to combine both methods (trap and sieve). The combination of methods can provide a more accurate overview of the population structure of these shrimps.

## ACKNOWLEDGEMENTS

We are grateful to the FAPESP (Fundação de Amparo à Pesquisa do Estado de São Paulo) for providing financial support (05/56131-0). We are also thankful to students and technicians for their help during fieldwork and Dr. Luis Carlos Ferreira de Almeida for his help with the statistical analysis. Sampling was conducted according to the São Paulo state and Brazilian federal laws.

## REFERENCES

- Abele, L.G. and Blum, N. 1977. Ecological aspects of the freshwater decapod crustaceans of the Perlas archipelago, Panamá. *Biotropica*, 9: 239–252.
- Akaike, H. 1974. A New Look at the Statistical Model Identification. *IEEE Transactions Automatic on Control*, 9: 716–723.
- Almeida, A.O.; Coelho, P.A.; Luz, J.R.; Santos, J.T.A. and Ferraz, N.R. 2008. Decapod crustaceans in fresh waters of southeastern Bahia, Brazil. *Revista de Biología Tropical*, 56: 1225–1254.
- Ammar, D.; Müller, Y.M.R. and Nazari, E.M. 2001. Reproductive biology of *Macrobrachium olfersii* (Wiegman) (Crustacea, Decapoda, Palaemonidae) collected at Santa Catarina's Island, Brazil. *Revista brasileira de Zoologia*, 18: 529–537.
- Barros, M.P. 1995. Dados biológicos sobre *Macrobrachium olfersii* (Wiegmann, 1836) (Decapoda, Palaemonidae) da Praia da Vigia, Garopaba, Santa Catarina, Brasil. *Biociências*, 3: 239–252.
- Bauer, R.T. 2011. Amphidromy and migrations of freshwater shrimps. I. Costs, benefits, evolutionary origins, and an unusual case of amphidromy. p. 145–156. In: A. Asakura (ed), *New frontiers in crustacean biology*. Leiden, The Netherlands, Koninklijke Brill NV.
- Bauer, R.T. and Delahoussaye, J. 2008. Life history migrations of the amphidromous river shrimp *Macrobrachium ohione* from a continental large river system. *Journal of Crustacean Biology*, 28: 622–632.

- Beatty, S.; de Graaf, M.; Molony, B.; Nguyen, V. and Pollock, K. 2011. Plasticity in population biology of *Cherax cainii* Austin and Ryan, 2002 (Decapoda: Parastacidae) inhabiting lentic and lotic environments in south-western Australia: Implications for the sustainable management of the recreational fishery. *Fisheries Research*, 110: 312–324.
- Bertini, G. and Valenti, W.C. 2010. Importância dos camarões-de-agua-doce. p. 155–170. In: R.B. Silva and L.M. Ming (eds), Polo de Biotecnologia da Mata Atlântica (PBMA): “Relatos de pesquisas e outras experiências vividas no Vale do Ribeira”. Jaboticabal, Maria de Lourdes Brandel - ME.
- Bertini, G. and Baeza, J.A. 2014. Fecundity and fertility in a freshwater population of the neotropical amphidromous shrimp *Macrobrachium acanthurus* from the southeastern Atlantic. *Invertebrate Reproduction & Development*, 58: 207–217.
- Bertini, G.; Baeza, J.A. and Perez, E. 2014. A test of large-scale reproductive migration in females of the amphidromous shrimp *Macrobrachium acanthurus* (Caridea: Palaemonidae) from south-eastern Brazil. *Marine and Freshwater Research*, 65: 81–93.
- Bueno, S.L.D.S.; Shimizu, R.M. and Rocha, S.S.D. 2007. Estimating the population size of *Aegla franca* (Decapoda: Anomura: Aegliidae) by mark-recapture technique from an isolated section of Barro Preto stream, county of Claraval, state of Minas Gerais, southeastern Brazil. *Journal of Crustacean Biology*, 27: 553–559.
- Cantrell, M.A. 1985. Dissemination of aquatic invertebrates on windblown vegetation mats in Lake Chilwa, Malawi. *Journal of the Limnological Society of Southern Africa*, 11: 1–4.
- Castellanos, D.L. and Rozas, L.P. 2001. Nekton use of submerged aquatic vegetation, marsh, and shallow unvegetated bottom in the Atchafalaya River Delta, a Louisiana tidal freshwater ecosystem. *Estuaries*, 24: 184–197.
- Chatfield, C. 2004. The analysis of time series, an introduction. New York, USA, Chapman & Hall/CRC, 333p.
- Copatti, C.E.; Legramanti, R.P.; Trevisan, A. and Santos, S. 2016. Method of capture and population structure of *Aegla georginae* Santos and Jara, 2013 (Decapoda: Anomura: Aegliidae) in a tributary of the Ibicuí River in southern Brazil. *Brazilian Journal of Biology*, 76: 1035–1042.
- Covich, A.P.; Crowl, T.A. and Heartsill-Scalley, T. 2006. Effects of drought and hurricane disturbances on headwater distributions of palaemonid river shrimp (*Macrobrachium* spp.) in the Luquillo Mountains, Puerto Rico. *Journal of the North American Benthological Society*, 25: 99–107.
- Dalosto, M.M.; Palaoro, A.V.; Oliveira, D.D.; Samuelsson, É. and Santos, S. 2014. Population biology of *Aegla platensis* (Decapoda: Anomura: Aegliidae) in a tributary of the Uruguay River, state of Rio Grande do Sul, Brazil. *Zoologia*, 31: 215–222.
- Fièvet, E.; De Morais, L.T. and De Morais, A.T. 1996. Quantitative sampling of freshwater shrimps: comparison of two electrofishing procedures in a Caribbean stream. *Archiv für Hydrobiologie*, 138: 273–287.
- Gamba, A.L. and Rodríguez, G. 1987. Migratory behavior of postlarval white, *Penaeus schmitti*, and river shrimps, *Macrobrachium olfersii* and *Macrobrachium acanthurus*, in their zone of overlap in a tropical lagoon. *Bulletin of Marine Science*, 40: 454–463.
- Garcia, K.E.; Embry, S.J.; Grossblat, D.; Holbrook, A.M.; McLaren, W.M.; Reed, S.K.; Wildey, H.C. and Shuster, S.M. 2003. A comparison of two methods for sampling the Gulf of California mud shrimp, *Neotrypaea uncinata* (Crustacea: Thalassinidea). *Journal of Natural History*, 37: 1847–1854.
- Grabowski, R.C.; Santos, S. and Castilho, A.L. 2013. Reproductive ecology and size of sexual maturity in the anomuran crab *Aegla parana* (Decapoda: Aegliidae). *Journal of Crustacean Biology*, 33: 332–338.
- Greathouse, E.A.; Pringle, C.M. and Holmquist, J.G. 2006. Conservation and management of migratory fauna: dams in tropical streams of Puerto Rico. *Aquatic Conservation: Marine and Freshwater Ecosystems*, 16: 695–712.
- Green, J.; Corbet, S.A.; Watts, E (née Betney) and Lan, O.B. 1976. Ecological studies on Indonesian lakes. Overturn and restratification of Ranu Lamongan. *Journal of Zoology*, 180: 315–354.
- Hamano, T. and Hayashi, K.I. 1992. Ecology of an atyid shrimp *Caridina japonica* (De Man, 1892) migrating to upstream habitats in the Shiwagi Rivulet, Tokushima Prefecture. *Research Crustacean Cacinological Society Japan*, 21: 1–13.
- Hancock, M.A. 1998. The relationship between egg size and embryonic and larval development in the freshwater shrimp *Paratya australiensis* Kemp (Decapoda: Atyidae). *Freshwater Biology*, 39: 715–723.
- Hein, C.L.; Pike, A.S.; Blanco, J.F.; Covich, A.P.; Scatena, F.N.; Hawkins, C.P. and Crowl, T.A. 2011. Effects of coupled natural and anthropogenic factors on the community structure of diadromous fish and shrimp species in tropical island streams. *Freshwater Biology*, 56: 1002–1015.
- Hobbs, H.H. Jr. and Hart, C.W. Jr. 1982. The shrimp genus *Atya* (Decapoda: Atyidae). *Smithsonian Contributions to Zoology*, 364: 1–143.
- Holling, C.S. 1973. Resilience and stability of ecological systems. *Annual Review of Ecology and Systematics*, 4: 1–23.
- Holmquist, J.G.; Schmidt-Gengenbach, J. and Buchanan-Yoshioka, B. 1998. High dams and marine-freshwater linkages: effects on native and introduced fauna in the Caribbean. *Conservation Biology*, 12: 621–630.
- Holthuis, L.B. and Provenzano, A.J. 1970. New distribution records for species of *Macrobrachium* with notes on the distribution of the genus in Florida (Decapoda, Palaemonidae). *Crustaceana*, 19: 211–213.
- Ibrahim, K.H. 1962. Observations on the fishery and biology of the freshwater prawn *Macrobrachium malcolmsonii* Milne Edwards of River Godavari. *Indian Journal of Fisheries*, 9: 433–467.
- Iori, P.; Silva, R.B.; Junior, M.D.S.D.; Nakamura, R. and Almeida, L.C.F. 2019. Soil quality analysis in riparian areas for soil and water resource management. *Archives of Agronomy and Soil Science*, 66: 572–585.
- Iwata, T.; Inoue, M.; Nakano, S.; Miyasaka, H.; Doi, A. and Covich, A.P. 2003. Shrimp abundance and habitat relationships in tropical rain-forest streams, Sarawak, Borneo. *Journal of Tropical Ecology*, 19: 387–395.
- Jalihal, D.R.; Sankolli, K.N. and Shenoy, S. 1993. Evolution of larval developmental patterns and the process of freshwaterization in the prawn genus *Macrobrachium* Bate, 1868 (Decapoda, Palaemonidae). *Crustaceana*, 65: 365–376.

- Karplus, I. and Barki, A. 2019. Male morphotypes and alternative mating tactics in freshwater prawns of the genus *Macrobrachium*: a review. *Reviews in Aquaculture*, 11: 925–940.
- Lee, C.L. and Fielder, D.R. 1979. A mass migration of the freshwater prawn, *Macrobrachium australiense* Holthuis, 1950 (Decapoda, Palaemonidae). *Crustaceana*, 37: 219–222.
- Lelles, L.C.D.; Silva, E.; Griffith, J.J. and Martins, S.V. 2005. Perfil ambiental qualitativo da extração de areia em cursos d'água. *Revista Árvore*, 29: 439–444.
- Leonardo, A.F.G.; Tachibana, L.; Corrêa, C.F.; Koki, M.R.; Neto, A.L. and Baccarin, A.E. 2008. Qualidade da água do Rio Ribeira de Iguape da área de extração de areia no município de Registro, SP. *Revista Acadêmica Ciência Animal*, 6: 483–492.
- Magalhães, C. and Walker, I. 1988. Larval development and ecological distribution of central Amazonian palaemonid shrimps (Decapoda, Caridea). *Crustaceana*, 55: 279–292.
- Mahiques, M.M.; Figueira, R.C.; Alves, D.P.; Italiani, D.M.; Martins, C.C. and Dias, J. 2014. Coastline changes and sedimentation related with the opening of an artificial channel: the Valo Grande Delta, SE Brazil. *Anais da Academia Brasileira de Ciências*, 86: 1597–1607.
- March, J.G.; Benstead, J.P.; Pringle, C.M. and Scatena, F.N. 2003. Damming tropical island streams: problems, solutions, and alternatives. *BioScience*, 53: 1069–1078.
- Marques, M.N.; Badiru, A.I.; Beltrame, O. and Pires, M.A.F. 2007a. Pesticide leaching and run-off hazard in the Ribeira de Iguape River Basin in São Paulo State, Brazil. *Journal of the Brazilian Society of Ecotoxicology*, 2: 179–185.
- Marques, M.N.; Cotrim, M.B.; Pires, M.A.F. and Beltrame Filho, O. 2007b. Avaliação do impacto da agricultura em áreas de proteção ambiental, pertencentes à bacia hidrográfica do rio Ribeira de Iguape, São Paulo. *Química Nova*, 30: 1171–1178.
- Melo, G.A.S. 2003. Manual de identificação dos Crustacea Decapoda de água doce do Brasil. São Paulo, Ed. Loyola, 429p.
- Montoya, J.V. 2003. Freshwater shrimps of the genus *Macrobrachium* associated with roots of *Eichhornia crassipes* (Water Hyacinth) in the Orinoco Delta (Venezuela). *Caribbean Journal of Science*, 39: 155–159.
- Mossolin, E.C. and Bueno, S.L. 2002. Reproductive biology of *Macrobrachium olfersi* (Decapoda, Palaemonidae) in São Sebastião, Brazil. *Journal of Crustacean Biology*, 22: 367–376.
- Müller, Y.M.R. and Prazeres, A.C. 1992. Influência da salinidade e temperatura da água sobre a captura de *Macrobrachium olfersii* (Wiegmann, 1836) coletados no canal da Lagoa do Peri. *Acta Limnologica Brasiliensis*, 4: 175–183.
- Müller, Y.M.R.; Nazari, E.M.; Ammar, D.; Ferreira, E.C.; Beltrame, I.T. and Pacheco, C. 1999. Biologia dos Palaemonidae (Crustacea, Decapoda) da bacia hidrográfica de Ratoões, Florianópolis, Santa Catarina, Brasil. *Revista brasileira de Zoologia*, 16: 629–636.
- Novak, P.A.; Bayliss, P.; Crook, D.A.; Garcia, E.A.; Pusey, B.J. and Douglas, M.M. 2017a. Do upstream migrating, juvenile amphidromous shrimps, provide a marine subsidy to river ecosystems? *Freshwater Biology*, 62: 880–893.
- Novak, P.A.; Bayliss, P.; Garcia, E.A.; Pusey, B.J. and Douglas, M.M. 2017b. Ontogenetic shifts in habitat use during the dry season by an amphidromous shrimp in a tropical lowland river. *Marine and Freshwater Research*, 68: 2275–2288.
- Odinetz-Collard, O. 1988. Aspectos ecológicos do camarão *Macrobrachium amazonicum* (Heller, 1862) no baixo Tocantins (Pa-Brasil). *Memoria de la Sociedad de Ciencias Naturales La Salle*, 48 (Suplemento): 341–353.
- Pérez-Reyes, O.; Crawl, T.A. and Covich, A.P. 2016. Comparison of decapod communities across an urban-forest land use gradient in Puerto Rican streams. *Urban Ecosystems*, 19: 181–203.
- Pescinelli, R.A.; Carosia, M.F.; Pantaleão, J.A.F.; Simões, S.M. and Costa, R.C. 2016. Population biology and size at the onset of sexual maturity of the amphidromous prawn *Macrobrachium olfersii* (Decapoda, Palaemonidae) in an urban river in southeastern Brazil. *Invertebrate Reproduction & Development*, 60: 254–262.
- Pompeu, P.D.S.; Vieira, F. and Martinez, C.B. 2006. Use of Santa Clara Power Plant fish lift by Palaemonidae shrimps, Mucuri River basin, Minas Gerais, Brazil. *Revista Brasileira de Zoologia*, 23: 293–297.
- Pyron, M.; Covich, A.P. and Black, R.W. 1999. On the relative importance of pool morphology and woody debris to distributions of shrimp in a Puerto Rican headwater stream. *Hydrobiologia*, 405: 207–215.
- Rocha, S.S.D. 2010. Diferença entre dois métodos de coleta utilizados na captura de crustáceos decápodes em um rio da Estação Ecológica Juréia-Itatins, São Paulo. *Iheringia, Série Zoologia*, 100: 116–122.
- Rocha, S.S.D. and Bueno, S.L.D.S. 2004. Freshwater decapod crustaceans from Ribeira de Iguape river basin and adjacent coastal areas, São Paulo Brazil. *Revista Brasileira de Zoologia*, 21: 1001–1010.
- Rodríguez-Uribe, M.C.; Vega-Villasante, F.; Guzmán-Arroyo, M. and Espinosa-Chaurand, L.D. 2014. Efectos de una barrera antrópica sobre la migración río arriba del langostino anfidromo *Macrobrachium tenellum* (Smith 1871) (Decapoda: Palaemonidae) en la costa del Pacífico mexicano. *Gayana*, 78: 1–9.
- Rolim, G.S.; Camargo, M.B.P.; Lania, D.G. and Moraes, J.F.L. 2007. Classificação climática de Köppen e de Thornthwaite e sua aplicabilidade na determinação de zonas agroclimáticas para o estado de São Paulo. *Bragantia*, 66: 711–720.
- Rome, N.E.; Conner, S.L. and Bauer, R.T. 2009. Delivery of hatching larvae to estuaries by an amphidromous river shrimp: tests of hypotheses based on larval moulting and distribution. *Freshwater Biology*, 54: 1924–1932.
- Rossi, N. and Mantelatto, F.L. 2013. Molecular analysis of the freshwater prawn *Macrobrachium olfersii* (Decapoda, Palaemonidae) supports the existence of a single species throughout its distribution. *PLoS One*, 8(1): e54698.
- Rossi, N.; De Grave, S. and Mantelatto, F.L. 2016. A note on the correct spelling of the name of the freshwater shrimp *Macrobrachium olfersii* (Wiegmann, 1836) (Decapoda, Palaemonidae). *Zootaxa*, 4114: 587–589.
- Rozas, L.P. and Odum, W.E. 1988. Occupation of submerged aquatic vegetation by fishes: testing the roles of food and refuge. *Oecologia*, 77: 101–106.
- Silva Matos, D.M. and Bovi, M.L. 2002. Understanding the threats to biological diversity in southeastern Brazil. *Biodiversity & Conservation*, 11: 1747–1758.

- Snyder, M.N.; Pringle, C.M. and Tiffer-Sotomayor, R. 2013. Landscape-scale disturbance and protected areas: long-term dynamics of populations of the shrimp, *Macrobrachium olfersii* in lowland Neotropical streams, Costa Rica. *Journal of Tropical Ecology*, 29: 81–85.
- Snyder, M.N.; Freeman, M.C.; Purucker, S.T. and Pringle, C.M. 2016. Using occupancy modeling and logistic regression to assess the distribution of shrimp species in lowland streams, Costa Rica: does regional groundwater create favorable habitat? *Freshwater Science*, 35: 80–90.
- Soares, M.R.; Oshiro, L.M.Y. and Toledo, J.C. 2015. Biologia reprodutiva de *Macrobrachium jelskii* (Crustacea, Decapoda, Palemonidae) no rio São Francisco, Minas Gerais, Brasil. *Iheringia, Série Zoologia*, 105: 307–315.
- Sokal, R.R. and Rohlf, F.J. 2001. Biometry: the principles and practice of statistics in biological research. New York, USA, WH Freeman, 887p.
- Teixeira, R.L. and Sa, H.S. 1998. Abundância de macrocrustáceos decápodos nas áreas rasas do complexo lagunar Mundaú/Manguaba, AL. *Revista Brasileira de Biologia*, 58: 393–404.
- Teixeira, R.R. and Couto, E.D.C.G. 2012. Crustacea Decapoda capturados através de coleta passiva em um trecho do Rio dos Mangues (Porto Seguro-BA). *Biotemas*, 25: 149–156.
- Teodósio, E.A.O. and Masunari, S. 2009. Estrutura populacional de *Aegla schmitti* (Crustacea: Anomura: Aeglididae) nos reservatórios dos Mananciais da Serra, Piraquara, Paraná, Brasil. *Zoologia*, 26: 19–24.
- Venables, W.N. and Dichmont, C.M. 2004. GLMs, GAMs and GLMMs: an overview of theory for applications in fisheries research. *Fisheries Research*, 70: 319–337.
- Wenner, E.L.; Coon, W.P.; Sandifer, P.A. and Shealy, M.H.Jr. 1991. A comparison of species composition and abundance of decapod crustaceans and fishes from the North and South Edisto Rivers in South Carolina. *Marine Resources Center, Technical Report*, 78: 1–48.
- West, D.L. and Williams, A.H. 1986. Predation by *Callinectes sapidus* (Rathbun) within *Spartina alterniflora* (Loisel) marshes. *Journal of Experimental Marine Biology and Ecology*, 100: 75–95.