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Spatial and temporal distribution of brachyuran crab larvae in Ibiraquera Lagoon, southern Brazil

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Abstract. This study investigated the abundance and composition of brachyuran crab larvae in the four subsystems of Ibiraquera Lagoon throughout the year. A colder and drier period was detected, contrasting with warm months during which salinity varied depending on rainfall and whether the sand bar was open or closed. The mean density of brachyuran zoeae was 540 ± 96 (SE) larvae · 100 m^{-3}. Mean density was significantly ($p<0.05$) higher in three subsystems during April. Saco Lagoon (the outer subsystem) exhibited significantly higher ($p<0.05$) mean density in July, August, October, November and December 2004. Larvae from the families Portunidae, Menippidae, Panopeidae, Ocypodidae and Varunidae were found in Ibiraquera Lagoon. *Neohelice granulata* Dana, 1851 was the most abundant species. The high abundance of initial stage larvae showed the importance of Ibiraquera Lagoon as a nursery ground for crab species.

Key Words: Decapoda larvae, Brachyura, zoea, estuary

Resumo. Distribuição espacial e temporal de larvas de caranguejos braquiúros na Lagoa de Ibiraquera, sul do Brasil. Este estudo investigou a abundância e composição de larvas de Brachyura nos quatro subsistemas da Lagoa de Ibiraquera ao longo de um ano. Foi detectado um período frio e seco em contraste aos meses quentes, quando houve variação na salinidade em função das chuvas e da barra estar aberta ou fechada. A densidade média de zoés de Brachyura foi de 540 ± 96 (EP) larvas · 100 m^{-3}. Abril apresentou densidade média significativamente ($p<0,05$) superior em três subsistemas. A Lagoa do Saco (o subsistema mais externo) apresentou densidade média significativamente ($p<0,05$) superior em julho, agosto, outubro, novembro e dezembro de 2004. Larvas pertencentes às famílias Portunidae, Menippidae, Panopeidae, Ocypodidae e Varunidae foram encontradas na Lagoa de Ibiraquera. *Neohelice granulata* Dana, 1851 foi a espécie mais abundante. A alta abundância de larvas em estágio inicial mostrou a importância da Lagoa de Ibiraquera como um berçário para espécies de caranguejos.

Palavras chave: larvas de Decapoda, Brachyura, zoé, estuário

Introduction

Coastal lagoons are shallow bodies of water, separated from the ocean by a barrier and linked at least sporadically to the ocean by one or more channels (Kjerfve 1994). In South America these ecosystems occupy more than 12% of the coastal areas (Enrich-Prast *et al*. 2004). They exhibit high levels of productivity and are considered one of the most productive types of ecosystem in the world (Knoppers 1994). Consequently, they are of great importance to the production of fish and crustaceans of high economic value (Esteves 1998).

The southern Brazilian continental shelf is one of the most productive fishing areas of Brazil's 8,500 km coast, and the life cycles of many commercial species are related to the estuaries (e.g. Baptista-Metri *et al*. 2005, Rosa & Bemvenuti 2005, Barcelos *et al*. 2007, Gregati & Negreiros-Fransozo 2007, Silva-Falcão *et al*. 2007). Along the 350 km of Santa Catarina coast there are 19 lagoons where artisanal fishery has declined sharply in the last fifty years (Seixas & Berkes 2003).

Anthropic impacts on coastal and estuarine areas may cause deficient larval recruitment, resulting in low organism densities (Silva *et al*. 2004). These reduced densities can result in considerable decreases in fishery resources and also in ecological imbalances in the estuary and in the adjacent coast, to where an important fraction of animal biomass and mangrove detritus is carried (Schwamborn *et al*. 1999, 2001).

Many fish, shrimp and crab species produce larvae which are part of the estuarine zooplankton (Negreiros-Fransozo *et al*. 2002). Brachyuran larvae are the most abundant decapod larvae in coastal lagoons and estuarine areas, and their abundance increases during summer (e.g. Schwamborn *et al*. 2001, González-Gordillo & Rodríguez 2003, Yannicelli *et al*. 2006). Their life cycles include transport of larvae from the lagoon to the continental shelf where larval development occurs. Larvae then re-invade the lagoon as megalopae looking for food and a safe place for recruitment (Anger 2001). Studies of the distribution of larval stages of several estuarine species indicate a spatial distribution pattern in which first zoeae and megalopae are found in the estuaries whereas intermediate stages are found offshore (Paula *et al*. 2004).

The brachyuran crab *Neohelice granulata* (e.g. Rosa & Bemvenuti 2005, Barcelos *et al*. 2007, Gregati & Negreiros-Fransozo 2007) and the Portunidae family of blue crabs (e.g. Branco & Masunari 2000, Weber & Levy 2000, Baptista-Metri *et al*. 2005) are commonly found in Brazilian coastal lagoons and estuarine systems. In the states of Santa Catarina and Rio Grande do Sul, artisanal fishermen catch both portunids *Callinectes danae* Smith, 1869 and *Callinectes sapidus* Rathbun, 1896 (Weber & Levy 2000). In Ibiraquera Lagoon, this activity involves the whole family, including the fishermen, their wives and their children (Seixas & Berkes 2003). Despite its natural characteristics and importance for tourism, Ibiraquera Lagoon has been little studied and so there is no biological data specific to the area that could be used as the foundation for management planning (Bonetti *et al*. 2005). Recently egg and fish larvae (Macedo-Soares *et al*. 2009) and shrimps (Ferreira & Freire 2009) were surveyed in the same sampling program of the present work.

The aim of this study was to describe the variability in density and composition of brachyuran crab larvae, especially blue crab species, throughout the year and in a spatial gradient across Ibiraquera Lagoon.

Material and Methods

Study area

The Ibiraquera Lagoon is located on the southern Brazilian coast from 28°06`18`` to 28°10`16``S and from 48°37`44`` to 48°41`53`` W (Fig. 1). It is about 9 km long with a total area of 8,700 km^2, and is connected to the sea by a semi-permanent mouth that is 150 m wide and is opened artificially twice a year. The local depth ranges from 0.2 m to 2.0 m with a sandy bottom (Seixas & Berkes 2003). According to Kjerfve (1994) it is a “shallow choked” lagoon, with a high surface/volume ratio and restricted water exchange with the adjacent ocean. It is geomorphologically segmented into four subsystems known locally as Cima Lagoon, Meio Lagoon, Baixo Lagoon and Saco Lagoon (Bonetti *et al*. 2005). These four subsystems are interconnected by small channels and the largest of them (Cima Lagoon) has an area of 4,000 km^2.

Freshwater input is restricted to small streams in Baixo and Saco Lagoons, and conditioned mainly by rainfall. The input of salty water and the reduction of the water level during the opening of the sand bar, combined with the local wind, improve the water mixture and therefore the distribution of nutrients and oxygen in the lagoon (Bonetti *et al*. 2005). The area is located within an intermediary subtropical zone (humid mesothermic group), with rains equally distributed throughout the year. There are eight communities, including 600 professional fishermen living around the lagoon.

Sampling methods

Monthly zooplankton samples were collected from December 2003 to December 2004, except for May and September 2004. The sand bar was opened from December 2003 to February 2004, and from June to August. Three replicates were taken at each subsystem, with the exception of the January and February samples at Saco Lagoon, where no samples were taken, and the June and July samples at Cima Lagoon, where only two replicates were taken, due to shallow depth, comprising a total of 124 samples. Samples were collected with a 200 µm mesh net equipped with a General Oceanics flowmeter, during surface horizontal hauls lasting 5 minutes each.

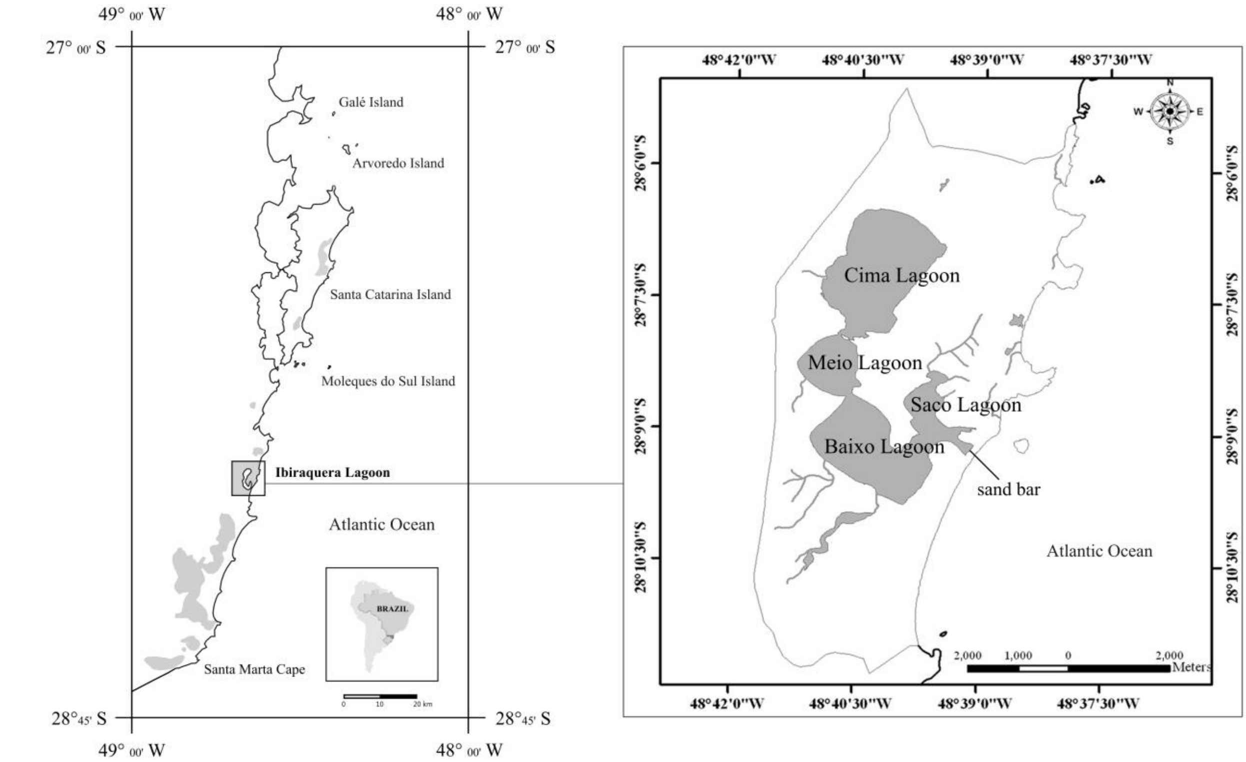

Figure 1. The location of Ibiraquera Lagoon (28°06`18``S, 48°37`44`` W) on the southern Brazilian coast with its four subsystems in detail (Saco Lagoon, Baixo Lagoon, Meio Lagoon and Cima Lagoon).

The mean volume of water filtered was 46.79 m³. Samples were fixed in 4% buffered formaldehyde and brachyuran larvae were sorted from the entire sample or from sub-samples divided with a Folsom splitter into 1/2, 1/4 or 1/8, depending on larval abundance and considering a minimum of 100 larvae counted per subsample. Larva counting was performed using Olympus SZ40 and Carl Zeiss ® Stemi DV4 stereomicroscopes. Larval densities were standardized according to individuals per 100 m³ of water filtered. Brachyuran larvae were counted in all samples and further identification was carried only in the Saco and Baixo Lagoons samples that contained the highest numbers of larvae. Brachyuran larvae showing a lateral spine were dissected using a Carl Zeiss Stemi DV4 stereomicroscope and a Studar[Lab] microscope to ascertain whether they belonged to the Portunidae family. Larvae were identified according to Costlow & Bookhout (1959, 1966), Boschi *et al*. (1967), Diaz & Costlow (1972), Bookhout & Costlow (1974), Scotto (1979), Montú *et al*. (1988), Pohle *et al*. (1999) and Sankarankutty *et al*. (1999). Only larvae from the dominant species (*Neohelice granulata*) and individuals from the genus *Callinectes* Stimpson, 1860 were quantified separately, due to their importance to the ecology and fisheries. Although other species were identified, they were pooled together with non-identified larvae into a single group termed “brachyuran larvae”. The larval stage was recorded for all individuals. Larvae were identified in only one sample of each month at Saco and Baixo Lagoons.

Water temperature was measured using a thermometer (accurate to 0.5 ºC) and salinity (in 0.5 increments) was measured with a refractometer at the surface, at the same time as the plankton was sampled. In months when no plankton samples were taken, temperature and salinity were obtained from the team conducting the main project in the area. Data on local rainfall were obtained from the EPAGRI (Empresa de Pesquisa Agropecuária e Extensão Rural de Santa Catarina S.A) scientific station, located in Urussanga (28º31’S, 49º19’W), Santa Catarina state.

Data analysis

Two-way ANOVA was used to determine whether there were any significant differences in temperature, salinity or brachyuran larvae density for different months and subsystems. Brachyuran data were log (x+1) transformed. The Bartlett test was applied in order to verify the homogeneity of variances before each analysis and Tukey's multiple comparison test was used whenever significant differences were detected (Zar 1996). The tests were performed on Statistica© 5.0 (Statsoft Inc. 1984-1995).

Pearson's correlation was used to verify possible associations between brachyuran larvae density from each subsystem with temperature and salinity, and from each month with rainfall.

Results

Hydrographic conditions

The water temperature characterized two periods during the year (Fig. 2a): warm months, with mean temperatures greater than 25 °C (January, February, March, November and December 2004), and cold months with mean temperatures below 20 °C (June and July). The interaction between months and subsystems (Table I) can be explained by the significantly higher ($p<0.01$) mean temperature at Saco Lagoon in October, November and December 2004, and at Cima Lagoon in June and July.

When the sand bar was opened in December 2003, the salinity increased at all stations until March (Fig. 2b). After September, when the bar was closed, the salinity decreased as the months passed. In April, July and August the salinity was significantly higher ($p<0.01$) at Baixo Lagoon, while in May and June the salinity was significantly higher at Saco Lagoon, explaining the significant interaction between months and subsystems (Table I).

The variation of rainfall, during the study period, characterized months with rainfall above 200 mm (December 2003, May and September), and months with rainfall less than 100 mm (February, June, July, August and October) (Fig. 2c).

Analysis of the hydrographic conditions characterized a cold and dry period (June to August), with high salinity at stations near the sand bar. During the warm months, salinity varied depending on rainfall and whether the sand bar was open or closed.

Table I. Results of two-way ANOVA performed to test the effects of month, subsystem and their interaction on water temperature and salinity in Ibiraquera Lagoon.

		Degrees of freedom	MS	F	p
Temperature	Month	10	0.0485	426.0	0.000000
	Subsystem	3	0.0007	6.0	0.000630
	Month x subsystem	30	0.0008	7.0	0.000000
	Error	88	0.0001		
Salinity	Month	10	0.1215	158.0	0.000000
	Subsystem	3	0.0124	16.1	0.000000
	Month x subsystem	30	0.0067	8.7	0.000000
	Error	88	0.0008		

Temporal and spatial distribution of brachyuran larvae

The mean density of brachyuran zoeae in Ibiraquera Lagoon was 540 ± 96 (SE) larvae · 100 m^{-3}, with the highest density (10,308 larvae · 100 m^{-3}) observed in November at Saco Lagoon.

The ANOVA test detected a significant interaction ($p<0.05$) (Table II) between month and subsystem due to higher mean density at Baixo, Meio and Cima Lagoons in April, contrasting with July, August, October, November and December 2004 when mean density was significantly greater in Saco Lagoon (Fig. 3).

Table II. Results of two-way ANOVA performed to test the effects of month, subsystem and their interaction on brachyuran crab larvae densities (larvae · 100 m^{-3}) in Ibiraquera Lagoon.

	Degrees of freedom	MS	F	p
Month	10	1.3026	5.8	0.000001
Subsystem	3	5.1837	23.0	0.000000
Month x subsystem	30	0.3665	1.6	0.043301
Error	88	0.2263		

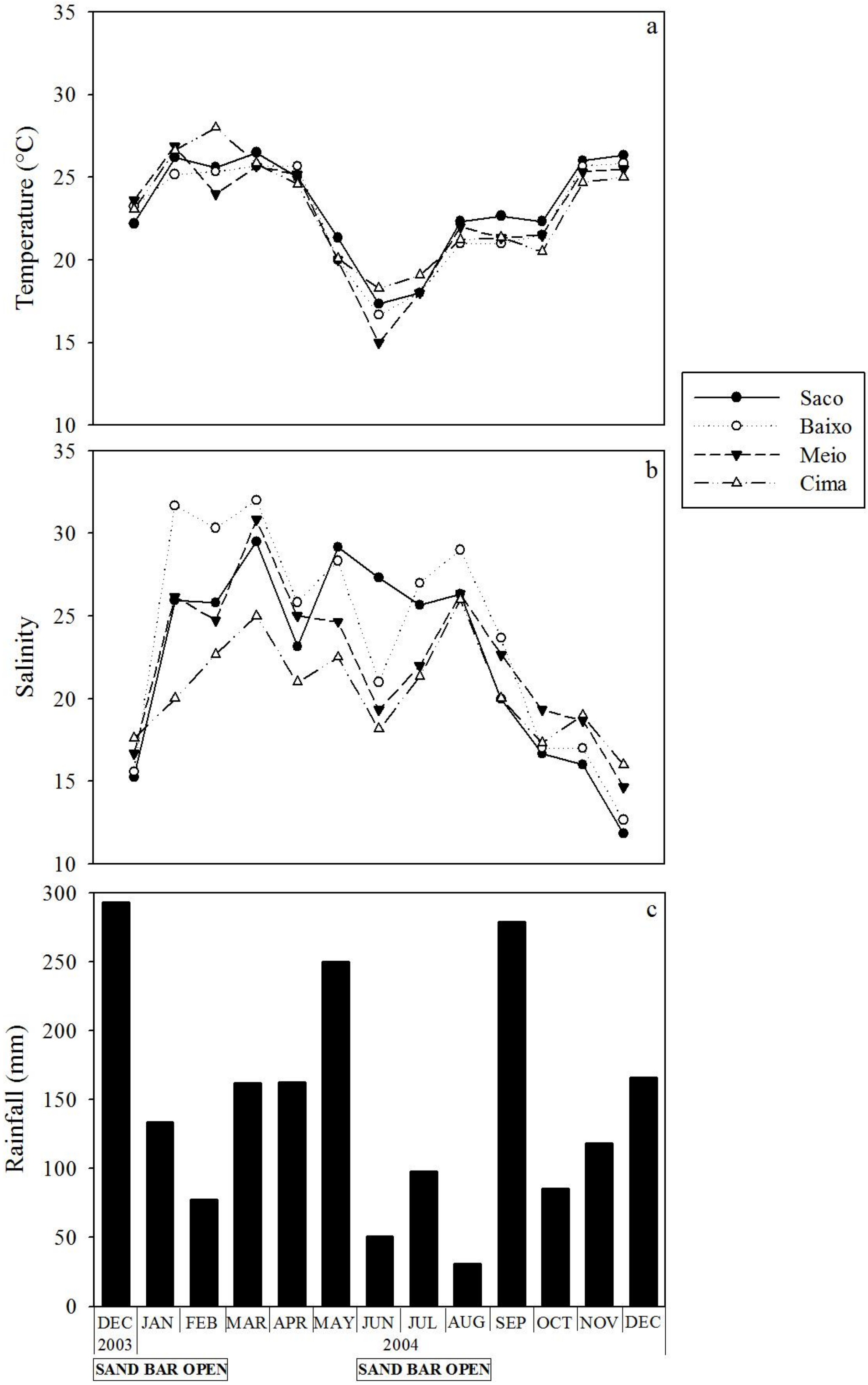

Figure 2. Hydrographic conditions in Ibiraquera Lagoon from December 2003 to December 2004. (a) Water temperature (°C), (b) variations in mean salinity and (c) total rainfall per month (mm).

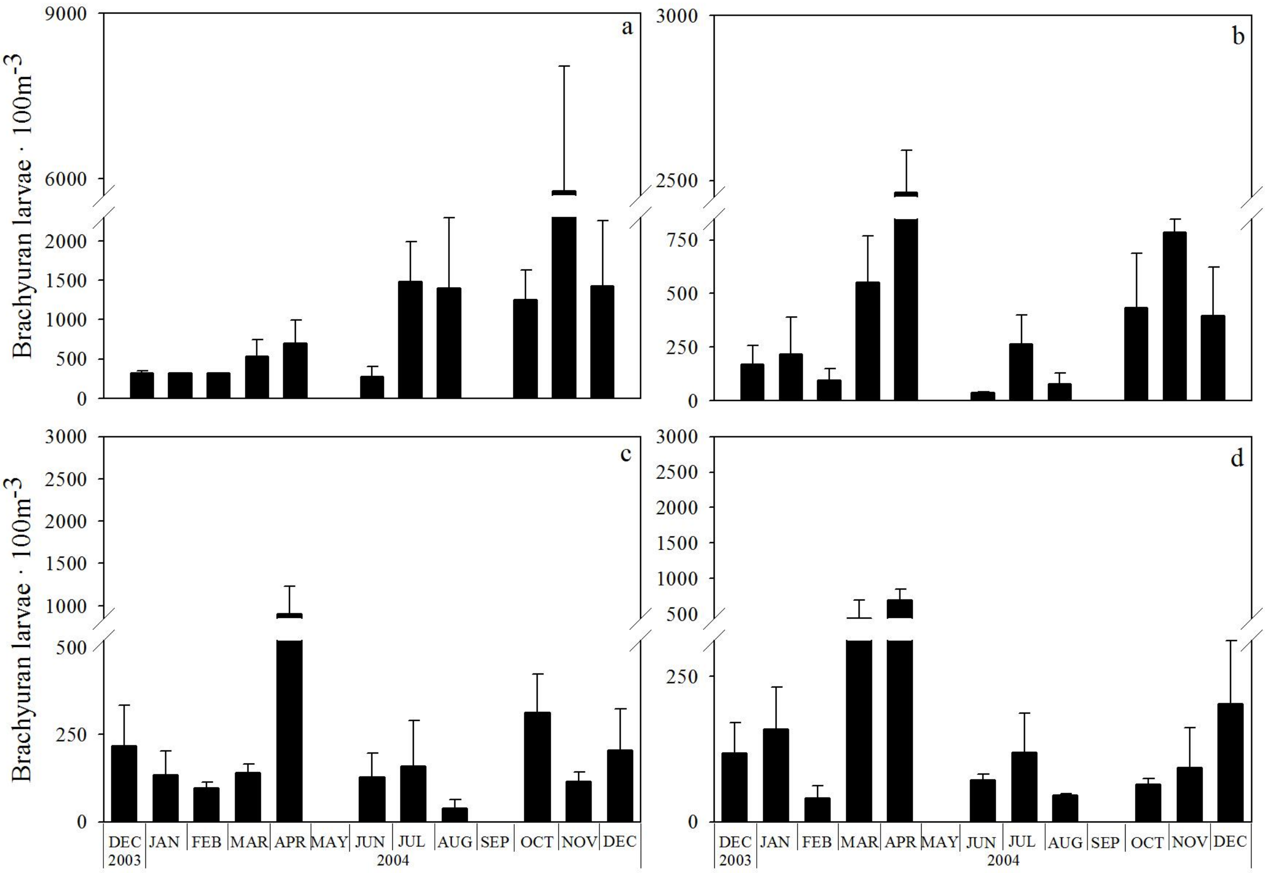

Figure 3. Densities (mean ± SE) of brachyuran larvae in the four Ibiraquera subsystems: (a) Saco Lagoon, (b) Baixo Lagoon, (c) Meio Lagoon and (d) Cima Lagoon.

A positive and significant correlation was found at Baixo Lagoon between larvae density and temperature ($r = 0.3863$, $p = 0.026$, $N = 33$). No significant correlation was found between larvae density, temperature and salinity at the other lagoons, as no significant correlation was found between larval density and rainfall.

Composition of brachyuran species

The brachyuran larvae Portunidae (*Callinectes danae*, *C. sapidus*, *Portunus spinicarpus* (Stimpson, 1871)), Menippidae (*Menippe nodifrons* Stimpson, 1859), Panopeidae (*Hexapanopeus angustifrons* (Benedict and Rathbun, 1891), *Panopeus austrobesus* Williams, 1983), Ocypodidae (*Ocypode quadrata* (Fabricius, 1787)) and Varunidae (*Neohelice granulata*) were present in Ibiraquera Lagoon. *Neohelice granulata* accounted for 46% of the brachyuran larvae identified.

Neohelice granulata were present at the highest density, with a mean of 463 ± 222 larvae (SE) · 100 m^{-3}. The mean density of the set of all Portunidae larvae was 104 ± 33 larvae (SE) · 100 m^{-3}, and occurred during all months except June. The mean densities of *C. danae* and *C. sapidus* were 53 ± 29 larvae (SE) · 100 m^{-3} and 20 ± 8 larvae (SE) · 100 m^{-3}, respectively. Portunids accounted for more than 10% of brachyuran larvae in January, February, April and November. More than 65% of brachyuran larvae were *N. granulata* in June, July, August and October (Fig. 4).

Brachyuran larvae were observed from zoeae stage I to zoeae stage IV, with the first larval stage predominating in all months. In August, October, November and December 2004 at least 10% of the larvae were in zoeae II or later stages (Fig. 5). *Callinectes danae* was found up to zoeae III; only zoeae I and II of *C. sapidus* were observed. Other Portunidae (including *P. spinicarpus*) were observed up to zoeae stage III. *Neohelice granulata* were observed up to zoeae stage III. Some Panopeidae larvae were found up to zoeae stage IV.

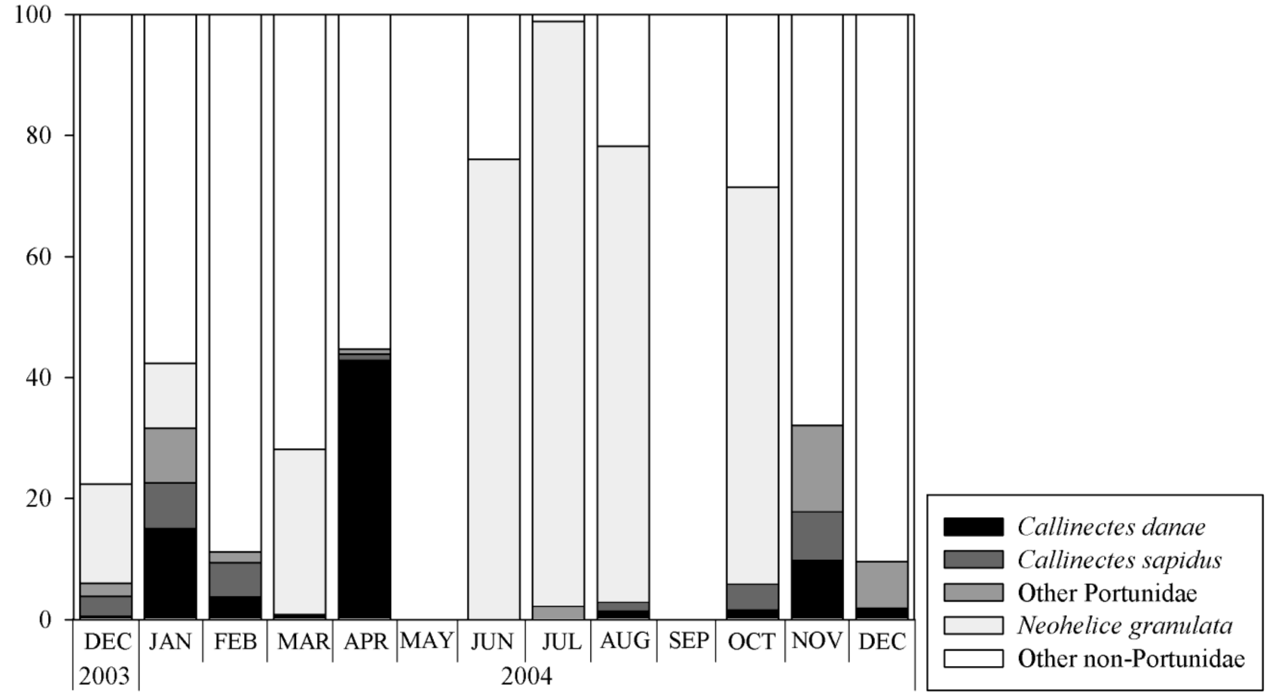

Figure 4. Composition of brachyuran larvae (%) in identified samples from Saco and Baixo Lagoons for the different months.

Discussion

Temperature, salinity and rainfall data characterize Ibiraquera Lagoon as a mixohaline lagoon (Bonetti *et al*. 2005), with salinity strongly influenced by rainfall and dynamics of the sand bar. Temperature variation follows the pattern found in subtropical latitudes (Muelbert & Weiss 1991; Lüchmann *et al*. 2008), and the rainfall pattern is similar to that recorded at Conceição Lagoon (Lüchmann *et al*. 2008). Freshwater input was mainly influenced by rainfall, since Ibiraquera Lagoon has few small freshwater sources (Bonetti *et al*. 2005).

The maximum brachyuran larvae density found in Ibiraquera Lagoon (10,308 larvae · 100 m^{-3}) was greater than in the Itamaracá estuarine system (PE) (3,911 larvae · 100 m^{-3}) (Schwamborn *et al*. 2001) and than in Jaguaribe River Estuary (PE) (2,891 larvae · 100 m^{-3}) (Silva-Falcão *et al*. 2007). On the other hand, the maximum density in Ibiraquera Lagoon was lower than in the Guaraú River estuary (São Paulo state) (500,000 larvae · 100 m^{-3}) (Lopes 1994), than Suape bay (PE) (253,200 larvae · 100 m^{-3}) (Silva *et al*. 2004), than in the Chacahua - La Pastoría lagoon system (Mexico) (123,344 larvae · 100 m^{-3}) (Pantaleón-Lópes *et al*. 2005) and than at the entrance of Guanabara Bay (Rio de Janeiro state) (70,000 larvae · 100 m^{-3}) (Fernandes *et al*. 2002). There are many obstacles to compare data obtained with different methods. However the abundance of brachyuran larvae in Ibiraquera Lagoon was considered high, considering that, when compared to the systems cited above, it is small and shallow and has a semipermanent bar. Furthermore, all of those systems are surrounded by highly productive mangrove ecosystems.

The presence of zoeae I indicates that reproduction occurs inside the lagoon (Anger 2001). The occurrence of later-stage larvae while the sand bar was closed for three months indicates that they were also developing there. While the sand bar was open later larvae could remain or re-ingress in the lagoon.

As the ANOVA results showed, two reproductive periods were identified. The first was in the entire lagoon in April, with 40% of brachyuran larvae being portunids, and the second period was in November in Saco Lagoon, with 70% of the brachyuran larvae being non-Portunidae. During both these months the sand bar was closed, so the crab species that were reproducing had either entered the lagoon at least two months before, while the sand bar was open, or were resident species. Temperature is a stimulus to reproduction (Sastry

1983) and the reproductive peak of the different and unidentified crab species was in the warm temperatures of November, while in the cold months their abundance was low. This high density of brachyuran larvae in warm months in Ibiraquera Lagoon is comparable to decapod larvae in Guanabara Bay (Fernandes *et al*. 2002) and Delaware Bay (Dittel & Epifanio 1982) and also with fish larvae in the same lagoon (Macedo-Soares *et al*. 2009).

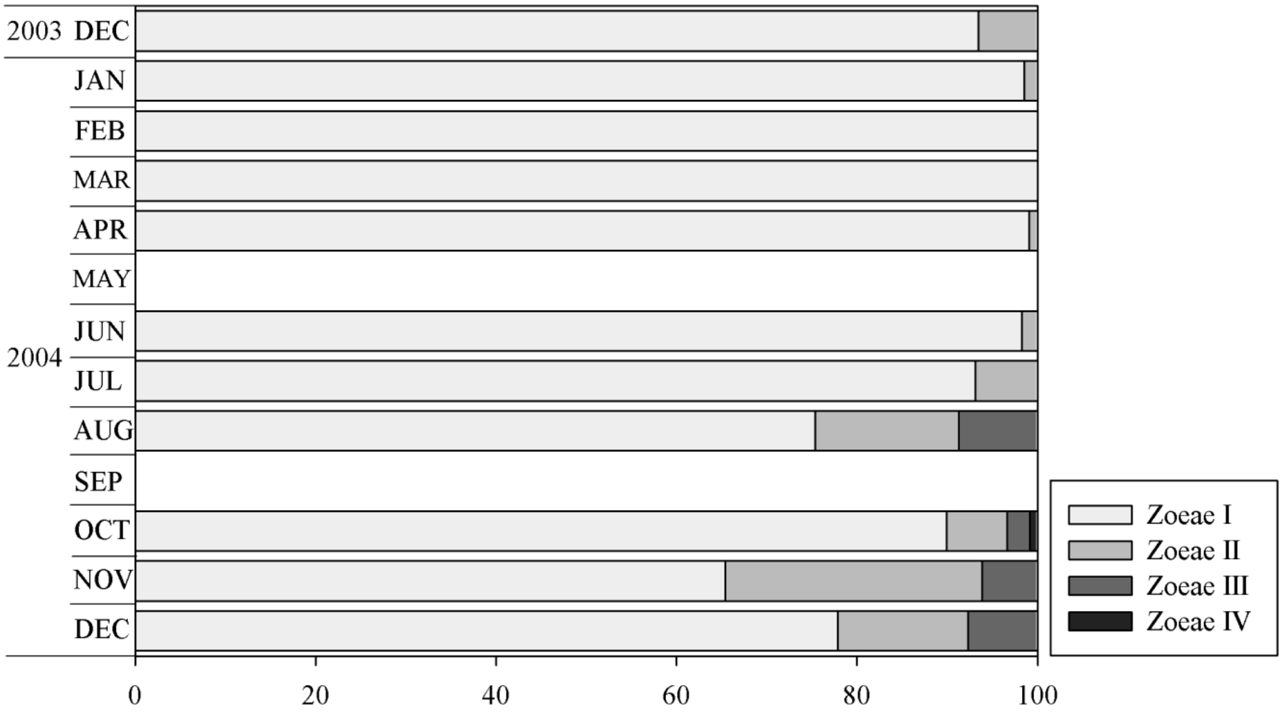

Figure 5. Percentage of each brachyuran larval stage in Ibiraquera Lagoon.

The spawning of portunids in lagoons has not yet been recorded in the literature. Many portunids migrate to shelf waters adjacent to estuaries to spawn (e.g. Van Engel 1958, Dittel & Epifanio 1982, Anger 2001, Bilton *et al*. 2002), but since the sand bar was closed, spawning could only occur inside the lagoon. The female migration to the coast is associated with the lower exposure to predation, stability of salinity and temperature, steady food supply, increased species dispersal and genetic exchange between isolated habitats (Bilton *et al*. 2002). Since we found larvae up to zoeae stage IV in Ibiraquera Lagoon and considering that the sand bar is closed for half of the year, their entire development might be taking place in the lagoon. Crab populations would therefore be maintained by larvae that develop in the lagoon combined with recruitment from offshore larvae.

Saco Lagoon, which is the nearest to the sea, exhibited significantly higher mean densities in July, August, October, November and December of 2004. Larvae abundance was higher at Saco Lagoon even in cold months. During July and August the sand bar was open and larvae might have entered the lagoon. *Neohelice granulata* inhabits the lagoon, so it reproduces in these months, independent on the sand bar situation. In the other months, the considerable amount of larvae in this lagoon is probably the consequence of adults spawning in the lagoon. Barutot *et al*. (2009) suggest that *N. granulata* hatches eggs year-round, although the smallest percentages of ovigerous females are observed in April and May. Reproductive studies with portunid crabs have shown that reproduction is mainly constant, with peaks in summer and autumn (Lunardon-Branco & Branco 1993, Mantellato & Fransozo 1998).

Abundance of brachyuran larvae varied across all subsystems as was the case for fish larvae (Macedo-Soares *et al*. 2009). Since Saco and Baixo

Lagoons are the closest subsystems to the sea and have the highest salinity, brachyuran larvae could be arriving from the sea while the sand bar is open.

In common with Ibiraquera Lagoon, the brachyuran zoeae composition of other estuarine systems and bays included the genus *Menippe* De Haan, 1833 and *Panopeus* Milne Edwards, 1834 (Schwamborn *et al*. 1999); Ocypodidae and Portunidae (Negreiros-Fransozo *et al*. 2002); *Hexapanopeus angustifrons* and *Callinectes sapidus* (Steppe & Epifanio 2006); and *Callinectes* spp. (Silva-Falcão *et al*. 2007).

In Ibiraquera Lagoon, the maximum larval density of *C. sapidus* (84 larvae · 100 m^{-3}) was higher than in the mouth of Delaware Bay (55 larvae · 100 m^{-3}) (Dittel & Epifanio 1982). High frequency of occurrence of zoeae in the first larval stages was found, as was the case in the Jaguaribe River estuary (PE) (Silva-Falcão *et al*. 2007) and in the Gulf of Arauco (Chile) (Yannicelli *et al*. 2006). As is the case of the bulk of brachyuran larvae, these comparisons show the importance of Ibiraquera Lagoon for the reproduction of blue crab species. Ibiraquera Lagoon was also considered a nursery area for coastal fish, since economically and ecologically important families spawn in the lagoon (Macedo-Soares *et al*. 2009).

Zooplanktonic organisms represent the main source of food for larvae and juvenile marine pelagic fish. Morgan (1990) determined that estuarine fish had a preference for crab larvae. Morgan & Christy (1997) also showed that fish prefer crab larvae without many spines, which were abundant in Ibiraquera Lagoon. The highest brachyuran zoeae densities were found in the subsystems that also had the highest densities of fish eggs (Macedo-Soares *et al*. 2009). According to Freitas & Muelbert (2004), a partial overlap between zooplankton and fish egg distribution suggests a synchrony between spawning and the availability of food for the future larvae. These results indicated that the brachyuran larvae may also play a role as food for the larvae and juveniles of fishes that are important resources for the local community.

In conclusion, this study showed that brachyuran crab reproduction occurs in Ibiraquera Lagoon within well-defined periods (April and November) and that larvae also develop there. The human impact is concurrent with the main reproductive period (summer) and is also concentrated at Saco Lagoon, which presents higher larval density, as it receives larvae from the sea when the sand bar is open. With closure of the sand bar, *Callinectes* spp., which usually have a reproductive strategy based on migration to the adjacent coast to spawn, spawn in the lagoon. Crab populations of Ibiraquera Lagoon are maintained by larvae that develop in the lagoon combined with recruitment from offshore larvae.

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