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Environmental variables influencing the *Callinectes* (Crustacea: Brachyura: Portunidae) species distribution in a tropical estuary—Cachoeira River (Bahia, Brazil)

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The genus Callinectes *comprises seven species of blue crab found on the Brazilian coast, almost all are recorded in Cachoeira River estuary. The objective of this study is to analyse distribution of* Callinectes *species in the estuary of Cachoeira River (Ilhéus, Bahia). Monthly collections were conducted in the low tide of neap tide for a year and in five stations distributed according to the estuary salinity gradient. Six traps were assembled and submerged at each station for two hours. Sediment samples were collected for granulometric characterization and measuring of organic matter content. Temperature, salinity and pH were also measured in the bottom water, as well as water transparency at the start of each collection. Five species were collected:* Callinectes danae, C. ornatus, C. exasperatus, C. larvatus *and* C. bocourti. *The species presented different distribution patterns based on the salinity gradient and transversal profile of the estuary. Only* C. danae *was found in all collection points, and was the most abundant species throughout the study period.* Callinectes ornatus *was restricted to external estuarine areas, which presented higher salinity and transparency values.* Callinectes larvatus *predominantly occurred in the external station and estuary partitions, mainly in the margin. In spite of the occurrence of* C. exasperatus *throughout the entire estuary, this species was restricted to the margin. This study supports the assumption that species distribution patterns of this genus are the result of both variable influence, namely salinity, and complex intraspecific and interspecific relations between the congeneric species.*

Keywords: habitat sharing, segregation, migration, swimming-crabs

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INTRODUCTION

The swimming crabs are members of the Portunidae Rafinesque, 1815 family, which is represented in Brazil by nine genera and 22 species, including the exotic species *Charybdis hellerii* (Milne-Edwards, 1867). Most of these species are restricted to west Atlantic regions from eastern United States to Argentina, although they also occur in other regions (Fausto-Filho, 1980; Melo, 1996; Mantelatto & Dias, 1999).

Portunid crabs of the genus *Callinectes* Stimpson (1860) show extensive distribution and can be found in lagoons, mangroves, estuaries and shelves at depths of up to 90 m (Melo, 1996). Along the Brazilian coastline, this genus comprises seven species: *Callinectes bocourti* Milne-Edwards, 1879; *C. danae* Smith, 1869; *C. exasperates* (Gerstaecker, 1856); *C. larvatus* Ordway, 1863; *C. ornatus* Ordway, 1863; *C. sapidus* Rathbun, 1895; and *C. affinis* Fausto-Filho, 1980, of which only the latter cannot be found in Ilhéus (Almeida *et al.*, 2006). An additional species, *C. maracaiboensis* (Taissoun, 1972), was cited on the Brazilian coastline, although it was later considered a junior synonym of *C. bocourti* by Robles *et al.* (2006).

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On the Brazilian coastline studies conducted in the continental shelf have shown that *Callinectes danae* and *C. ornatus* are the most abundant species in these areas (Lunardon-Branco & Branco, 1993; Severino-Rodrigues *et al.*, 2002). In estuarine areas, however, segregation of species distribution was observed, with prevailing species changing along the estuary (Pita *et al.*, 1985; Teixeira & Sá, 1998; Severino-Rodrigues *et al.*, 2001; Carmona-Suárez, 2009). Some studies have shown that a variety of factors can influence *Callinectes* species distribution in an estuary. Attrill *et al.* (1999) showed the importance of temperature as a controlling variable for some species of Portunidae and other groups. Norse (1978) noticed that distribution of Portunidae in estuarine areas reflects low saline tolerance variations among species, as all species have shown tolerance to higher saline levels. However, Buchanan & Stoner (1988) suggest that *Callinectes* spp. distribution patterns can also be the result of complex intraspecific and interspecific interactions between the congeneric species.

In addition to differences between species regarding spatial distribution, species individuals can present different distributions according to development stages. Branco & Masunari (2000) and Mantelatto (2000) showed that *Callinectes* females migrate to external estuarine areas during the spawning seasons. Such behaviour can cause sex proportion differences during specific times of the year. This sexual proportion disparity, expected to be a ratio of 1:1, is

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common in crustaceans and can be related to both migration and other aspects of species reproductive strategies, such as dispersion patterns, mortality and differential growth rates between sexes (Mantelatto & Fransozo, 1999). Moreover, Pita *et al.* (1985) observed that age groups show different distributions throughout the estuarine area.

Most studies on population aspects of *Callinectes* occurring in Brazil were conducted on *Callinectes ornatus*, *C. danae* and *C. sapidus* and are mainly restricted to the subtropical zone of Brazil (Branco & Lunardon-Branco, 1993; Negreiros-Fransozo & Fransozo, 1995; Mantelatto & Fransozo, 1996, 1999; Branco & Masunari, 2000; Baptista *et al.*, 2003; Branco & Fracasso, 2004; Oliveira *et al.*, 2006; Pereira *et al.*, 2009). The published studies on population aspects of *Callinectes* in the tropical zone and studies on the biology of other species found on the Brazilian coastline are still incipient.

The objective of this study is to analyse spatial and temporal distribution of the *Callinectes* species in the tropical Cachoeira River estuary (Ilhéus, Bahia, Brazil), observing environmental variables that influence the distribution of these organisms.

MATERIALS AND METHODS

The estuarine portion of the Cachoeira River comprises around 1.272 ha of mangroves (Projeto Mata Atlântica Nordeste, 1994). Climate is type Af (hot and humid, without defined dry season), according to the Köppen climate classification system. High rainfall periods are in May and August (namely between June and August), with mean annual rainfall of 2.179 mm; 2.628 mm maximum and 1.737 mm minimum (BAHIA, 1993).

Fluvial systems can be characterized as torrent with very abrupt outflow fluctuations and sediment input in coastal areas (Souza, 2005).

Monthly collections were conducted between October 2007 and September 2008 in five stations distributed according to estuary salinity gradient during low tide of neap tide.

Due the characteristics of the environment, with some areas of rocky bottom, traps were used (trapdoor-type devices locally known as *manzuá*) built in metal and polyethylene netting. A coating net container was installed inside the device to hold the bait (Figure 1). Each trap contained approximately 100 g of bait, composed of meat and sardines (10:1). Six traps were submerged in each station for around two hours; three at the river margin and three in the channel (Figure 2).

Collected crabs were stored in containers with ice and later frozen. In the laboratory, individuals were identified according to species and sex. Morphological maturity was determined through form and adherence of abdominal somites to thoracic sternites. Adults were considered as being those without abdominal somites adhered to sternites (Taissoun, 1969; Williams, 1974).

Sediment samples were collected with Van Veen-type grabs in each collection station for granulometric characterization and organic matter content levels according to Dean (1974). In addition, temperature, salinity and pH of bottom water at margins and channels were also recorded with a portable meter, and transparency with a Secchi disc at the start of each collection. Depth of each collection point was measured

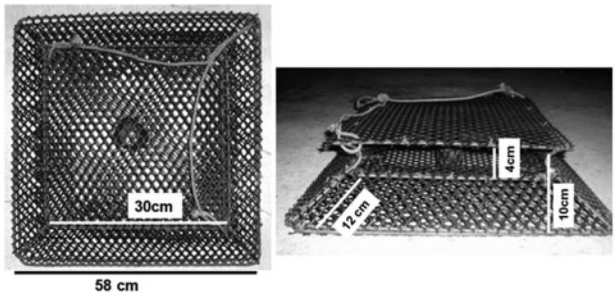

Fig. 1. *Manzuá*-type trap used in collections.

with a portable probe (HawkEye® with 0.03 m precision) during low tide of neap tide (height of 0.7 m).

The Student's *t*-test for dependent samples was used to verify possible differences in species capture between channel and margin of each station.

Canonical correlation analysis (ACC) was conducted on abundance data of each intraspecific group, divided according to species, sex and morphological maturity stage (juvenile, adult and ovigerous) for ordering in accordance with variables of salinity, temperature, transparency, pH, depth, margin distance, organic matter content and granulometric composition. Intraspecific classes with very low abundance (less than eight individuals) were discarded. ACC was conducted on software R (version 2.7) using the vegan package (Oksanen *et al.*, 2009). The Monte Carlo test with 1000 permutations was used to verify significant variables in species ordering. A significance level of 0.05 was assumed in all analyses.

RESULTS

Salinity presented an upstream reduction pattern due to mixture of seawater with continental drainage. There were no expressive variations throughout the study period. However, collections from October to December 2007 and from July to September 2008 showed slightly higher values in most stations, with the exception of Station 5. All stations except Station 3 showed a clear difference between channel and margin caused by a salt wedge (Figure 3). This could have been caused by bathymetric characteristics and circulation of this station, which allow salt wedge passage near the margin.

The pH values did not present a gradient along the estuary, without expressive differences between channel and margin of stations. Highest pH values were recorded in Station 5, which constantly receives nutrients from the nearby sewage treatment station (ETE), possibly increasing primary production with a corresponding dissolved CO_2 consumption and consequent elevation of pH values in the area (Table 1).

Depth and transparency showed an upstream tendency to reduction, with higher values in channels. Temperature presented an inverse tendency, with higher values recorded in margins.

Organic matter content clearly increased upstream. This gradient was most expressive when recording margin values, which were higher than those observed in their corresponding channels (Figure 4).

A total of 1051 individuals were collected pertaining to five species of the genus *Callinectes* (793 *Callinectes danae*, 133

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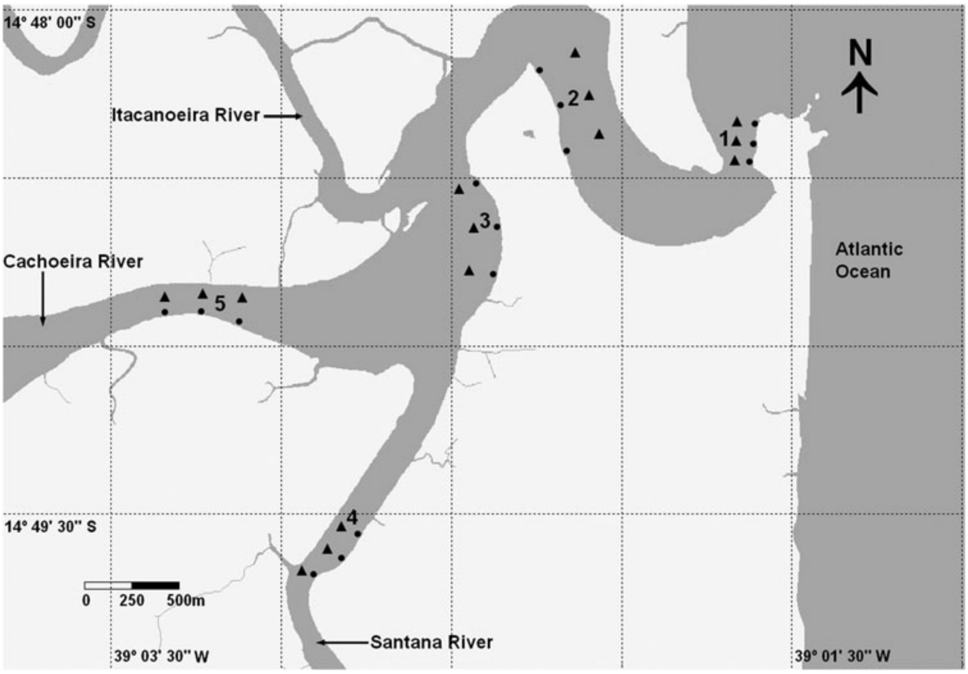

Fig. 2. Study area and layout of traps in each collection station (1 to 5). ▲, channel; •, margin.

C. ornatus, 66 *C. exasperatus*, 58 *C. larvatus* and 1 *C. bocourti*). Species *C. danae*, *C. exasperatus* and *C. larvatus* presented individuals of both sexes and all stages of maturity in the study area. *Callinectes ornatus* did not present juvenile females and *C. bocourti* was represented by a single adult female in the study area (Table 2).

The dominant species during most of the study period was *Callinectes danae*, showing lesser abundance from October to November 2007 and September 2008. Highest abundance was recorded in December 2007 (Figure 5).

Callinectes ornatus reached highest abundance levels in November 2007, March, July and September 2008, a period in which higher salinity values were observed. This species did not occur or recordings of frequency were very low in other months.

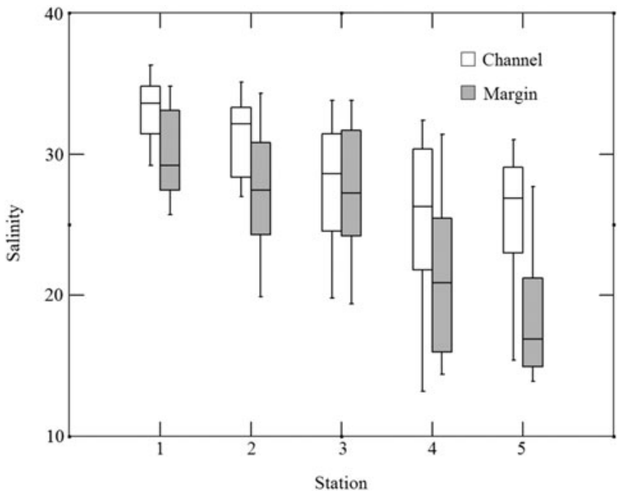

Fig. 3. Salinity values (median and quartile) for channels and margin of each collection station in the estuary of Cachoeira River between October 2007 and September 2008.

Frequency of other species was low during the entire study period. *Callinectes larvatus* was not captured from October 2007 to January 2008, and *C. exasperatus* was not recorded in October 2007 and April 2008, being that highest abundance levels were recorded between July and August 2008.

Only one *Callinectes bocourti* individual was captured during the entire study period and recorded in the month of August 2008.

Callinectes danae and *C. exasperatus* were the only species captured in all stations (Figure 6). There was a restricted occurrence of *Callinectes ornatus* in outer estuarine areas, with collection in Stations 1 and 2. *Callinectes larvatus* was predominant in the outer and intermediary zones (Stations 1, 2 and 3) with collection of only one individual in Station 5, whereas *C. bocourti* was only recorded in Station 1.

In addition to species distribution differences along the estuary, species also presented different distributions in relation to the transversal estuarine profile. This behaviour was observed through differences in species capture between channel and margin of each station ($P < 0.01$), with the exception of *Callinectes ornatus* ($P = 0.13$). *Callinectes danae* was the only species found both in channel and margin of all stations (Figure 6). Despite the occurrence of *C. exasperatus* in all stations, this species was restricted to margins. Similar behaviour was observed for species *C. larvatus*, which occurred mainly in the margins of Stations 1, 2 and 3, being that only one individual was collected in the channel of Stations 1 and 3 and the margin of Station 5. *Callinectes ornatus* occurred both in the channel and margin of Station 1, and was recorded in the channel of Station 2.

Callinectes danae was the dominant species in most salinity levels, with the exception of zones with salinity levels between 33 and 37, in which *C. ornatus* was predominant.

Callinectes larvatus was not recorded to salinity levels 13 to 17, while *C. exasperatus* showed lesser participation as salinity increased (Figure 7).

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Table 1. Mean and standard deviation of temperature, pH, transparency and depth values recorded for channel and margin of each station.

Station	Temperature (°C)		Ph		Transparency (m)		Depth (m)	
	Channel	Margin	Channel	Margin	Channel	Margin	Channel	Margin
1	27.5 ± 1.0	28.36 ± 1.0	7.9 ± 0.3	7.9 ± 0.4	1.2 ± 0.4	1.2 ± 0.4	10.2 ± 3.0	1.5 ± 0.3
2	28.0 ± 0.9	28.6 ± 1.1	7.9 ± 0.3	7.9 ± 0.3	1.2 ± 0.5	1.0 ± 0.3	4.5 ± 0.9	1.3 ± 0.3
3	27.9 ± 0.7	28.2 ± 0.7	7.9 ± 0.3	7.8 ± 0.3	1.0 ± 0.4	0.9 ± 0.4	3.5 ± 0.5	1.3 ± 0.3
4	28.4 ± 1.1	28.5 ± 0.8	7.7 ± 0.4	7.6 ± 0.4	1.0 ± 0.3	0.8 ± 0.3	2.5 ± 0.4	0.7 ± 0.3
5	28.5 ± 0.8	29.1 ± 1.0	8.0 ± 0.3	8.1 ± 0.6	0.9 ± 0.5	0.6 ± 0.5	3.1 ± 0.9	0.8 ± 0.8

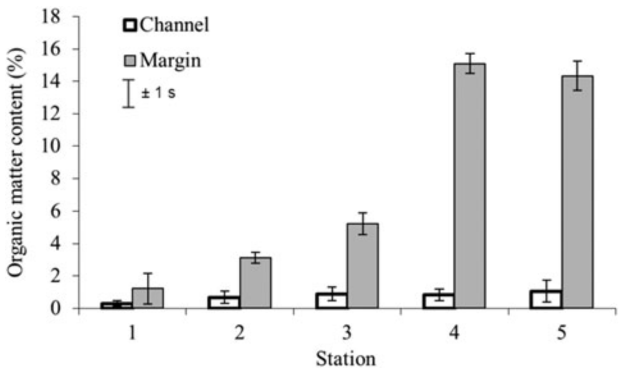

Fig. 4. Organic matter content in channel and margin of collection stations in the Cachoeira River estuary. S, standard deviation.

The Monte Carlo test with ACC data showed the importance of salinity variables, transparency, depth, margin distance, organic components and granulometric fractions (grains, very course sand, course sand, medium sand, fine sand, very fine sand and silt + clay) in intraspecific and species ordering. Grain fractions presented a value of $P = 0.02$, whereas all variables presented $P < 0.01$. The pH ($P = 0.45$) and temperature ($P = 0.15$) did not show significant correlations in species ordering (Figure 8).

Analysis showed that *Callinectes ornatus* occurred mainly in areas of higher salinity, depth, transparency and proportion of medium to fine sand, corresponding to areas of higher marine influence (Stations 1 and 2). *Callinectes danae*, with occurrence in all stations, was grouped close to the central vector variable regions. *Callinectes larvatus* was most frequent in areas with intermediary values of salinity, depth and transparency and higher fine fraction sediment and organic matter values. This species also presented a clear negative relation with margin distance. *Callinectes exasperatus* showed a positive relation with fine fractions of sediment and organic matter content, occurring in areas with lesser salinity, transparency and depth. As in the case of *C. larvatus, C. exasperatus* was recorded in regions closer to the margin.

Canonical correlation analysis also showed that sex and morphological maturity stage (intraspecific groups) of each species can present a different distribution pattern. Adult females of C. *danae*, *C. exasperatus* and *C. larvatus* tended to occur in outer estuarine areas, with higher values of salinity, transparency and depth. Ovigerous and non-ovigerous females of *C. ornatus* also present slightly different distribution with ovigerous females occurring in outer estuarine areas.

Juvenile individuals of *Callinectes danae* and *C. larvatus* showed different ordering of adult species, which were mainly recorded in inner estuarine areas and near the margin.

Table 2. Abundance of intraspecific classes of *Callinectes* in the Cachoeira River estuary.

	Male		Female		
	Juvenile	Adult	Juvenile	Adult	Ovigerous
C. bocourti				1	
C. danae	169	226	76	276	46
C. exasperatus	2	8	9	46	1
C. larvatus	8	28	8	13	1
C. ornatus	2	42		80	9

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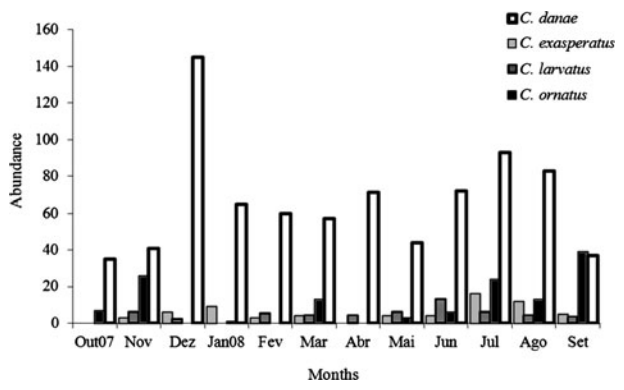

Fig. 5. Number of *Callinectes* individuals captured in each collection. *Callinectes bocourti* was not included as only one individual was collected.

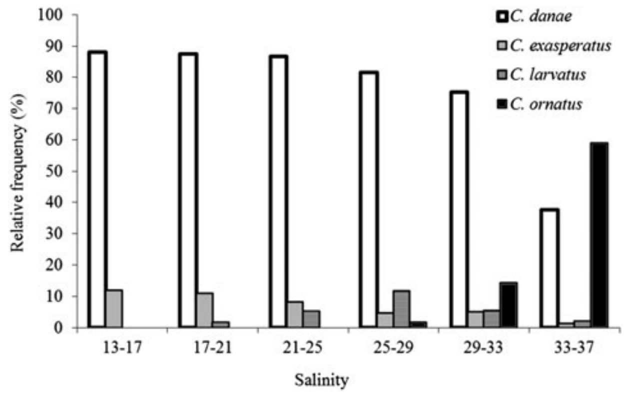

Fig. 7. Relative frequency of *Callinectes* species in each salinity level. *Calinectes bocourti* was not included as only one individual was captured.

DISCUSSION

Considering the environmental variables measured in the estuary of Cachoeira River in conditions of neap tide, species responded to two main gradients. In the first, variables reflect strongly areas of lesser and greater marine influence, while in the second, variables represent variations of water and sediment characteristics found between channel and margin of each estuarine region.

Callinectes danae is shown as the dominant species in most station collections during the study period, supporting significant salinity variation. Due to the ammonia site responsible for osmotic equilibrium, this species can tolerate high salinity variations (Masui *et al.*, 2002, 2003), which was not observed with *C. ornatus* (Garçon *et al.*, 2007). However, despite the physiological capability of *C. danae* to occur in high saline areas, *C. ornatus* was more abundant in areas of higher marine influence, possibly indicating higher efficiency of *C. ornatus* in these conditions.

Among other factors, expressive differences in the capture of individuals between margin and channel of stations may be caused by the difference in salinity observed in this study caused by the saline wedge and characteristic sediment differences, considering that margins tend to present higher participation of fine fractions and higher organic matter content

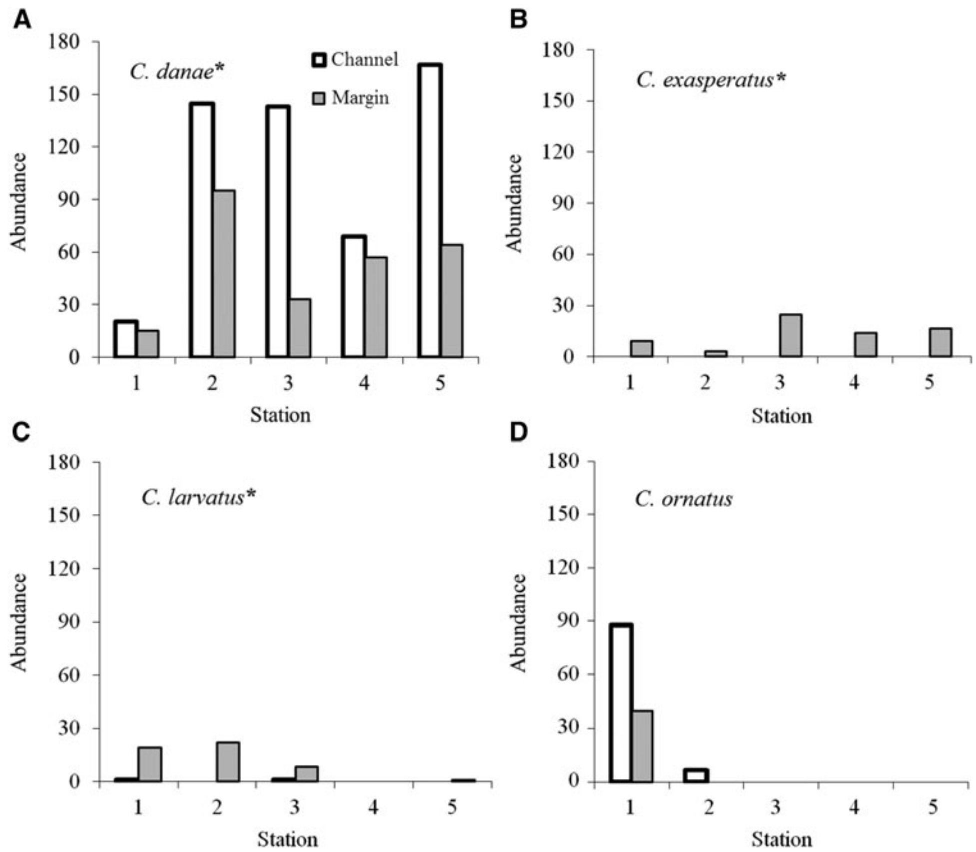

Fig. 6. Abundance of *Callinectes* species in channel and margin of each collection station of Cachoeira River estuary. *, significant difference in monthly specimens captured between channel and margin of each station ($P < 0.01$).

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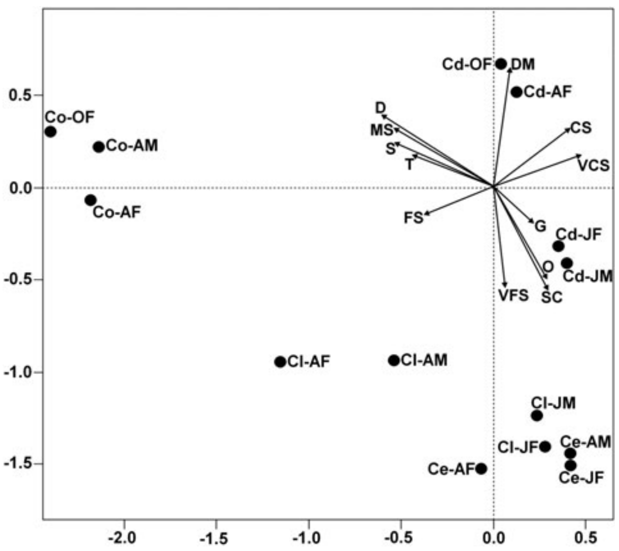

Fig. 8. Canonical ordering diagram based on abundance data by sex and morphological development stage of each species and environmental variable of the Rio Cachoeira estuary. Cd, *Callinectes danae*; Ce, *Callinectes exasperatus*; Cl, *Callinectes larvatus*; Co, *Callinectes ornatus*; JF, juvenile female; AF, adult female; OF, ovigerous female; JM, juvenile male; AM, adult male; S, salinity; D, depth; T, transparency; DM, distance of margin; O, organic matter content; SC, silt + clay; VFS, very fine sand; FS, fine sand; MS, medium sand; CS, course sand; VCS, very course sand; G, grains.

than corresponding channels. In addition to salinity influence, Mansur (1997) observed a negative relation of *Callinectes ornatus* with very course, course and medium sand fractions and a positive relation between the species and very fine sand and silt + clay fractions. This behaviour differed from findings in this study in that the species also presented a negative relation with very course and course sand but responded negatively to silt + clay and medium and fine sand areas.

Percentage of organic matter in sediment is considered an important distribution factor of benthic organisms. In this study, *Callinectes exasperaus* and *C. larvatus* showed a positive relation with this variable, while *C. ornatus* occurred in areas of lesser organic matter content. This relation, however, was not observed for species of *Callinectes* by Mansur (1997), who only found a significant relation between organic matter content present in the water and abundance of *C. sapidus*.

The tendency of females, mainly ovigerous females, to occur in outer estuarine areas may be related to migration of these females in the search for more saline waters with better conditions for spawning and subsequent development of larvae stages (Branco & Masunari, 2000; Mantelatto, 2000). This can explain the occurrence of a *Callinectes bocourti* female in Station 1, as this species predominantly occurs in low salinity (Norse, 1978).

Juveniles of *C. danae* and *C. larvatus* present different distribution patterns to that of the adults of these species. Similar results were observed by Mansur (1997), who recorded a majority of juvenile individuals in areas of lower salinity with mean size of individuals increasing towards the sea. In Baia de Ubatuba, Chacur & Negreiros-Fransozo (2001) also observed that most juveniles of *C. danae* were found near the mouth of Rio Grande.

Although the study by Attrill *et al.* (1999) in the Thames estuary, UK, has demonstrated the importance of temperature on the abundance of some species of Portunidae, this relationship was not found in our study. This difference may be due to the regions where the studies were conducted. The Thames estuary is located in a temperate region, with high variation in temperature throughout the year, while the Cachoeira River estuary is located in a tropical region, without major changes (Table 1). On the other hand, internal areas, which tend to present higher temperatures, may contribute to higher growth rates of young individuals, albeit the absence of a significant relation between temperature and abundance of intraspecific groups. Moreover, internal estuarine zones may provide shelter against predators to which adult individuals are more vulnerable.

Adult and juvenile distribution difference may also be caused by different foraging strategies that possibly diminish intraspecific competition, as intraspecific and interspecific interference competition is easily observed in the field. In addition to the scope of this study, aggressive interaction between the *Callinectes* species and individuals of the same species in the presence of food was observed.

In general terms, the observed distribution pattern agrees with previous group study results (Mansur, 1997; Pita *et al.*, 1985; Buchaman & Stoner, 1988; Branco & Lunardon-Branco, 1993; Negreiros-Fransozo & Fransozo, 1995; Pereira *et al.*, 2009). However, Teixeira & Sá (1998) recorded in Lagoa de Mundaú (AL) that despite the predominance of *Callinectes ornatus* in high salinity areas, peak abundance occurred between 20 and 25. The result was significantly different from that found in this study, where the predominant species was found in salinity above 33 and was not recorded in salinity levels below 25. Such stenohaline behaviour corroborates the previous assumption of Mantelatto & Fransozo (1999) that this species' entire life cycle is lived out in marine areas and adult individuals may eventually enter the estuary in search of food resources.

Callinectes bocourti and *C. sapidus* are the most tolerant to low salinity (Norse, 1978) and are generally found in inner estuarine area, which was not sampled in the present study. *Callinectes sapidus*, recorded in a previous study in the Cachoeira River estuary (Almeida *et al.*, 2006), was not captured in this work. Occurrence of *C. bocourti*—a female captured in August in Station 1 and two individuals in an additional collection in December 2007 after abundant rainfall—suggest that, with the reduction of salinity in greater rainfall periods, or during the stage in which females search for more saline waters for spawning, these species may occur in outer estuarine areas.

In addition to the strong influence of environmental variables, the distribution pattern presented by species in this study apparently supports the proposal of Buchanan & Stoner (1988), who observed the complex intraspecific and interspecific interactions between congeneric species. However, studies on physiology, distribution of prey and predators, behavioural interaction between species of *Callinectes* and their corresponding age groups are required for a better understanding of factors that favour the observed habitat sharing of this group.

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