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Population biology and distribution of the portunid crab *Callinectes ornatus* (Decapoda: Brachyura) in an estuary-bay complex of southern Brazil

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ABSTRACT. Trawl fisheries are associated with catches of swimming crabs, which are an important economic resource for commercial as well for small-scale fisheries. This study evaluated the population biology and distribution of the swimming crab *Callinectes ornatus* (Ordway, 1863) in the Estuary-Bay of São Vicente, state of São Paulo, Brazil. Crabs were collected from a shrimp fishing boat equipped with a semi-balloon otter-trawl net, on eight transects (four in the estuary and four in the bay) from March 2007 through February 2008. Specimens caught were identified, sexed and measured. Samples of bottom water were collected and the temperature and salinity measured. A total of 618 crabs were captured (332 males, 267 females and 19 ovigerous females), with a sex ratio close to 1:1. A large number of juveniles were captured (77.67%). Crab spatial distributions were positively correlated with salinity (Rs = 0.73, p = 0.0395) and temperature (Rs = 0.71, p = 0.0092). Two peaks of recruitment occurred, in summer and autumn, and ovigerous females were mostly captured during summer, showing a seasonal reproductive pattern. The results showed that *C. ornatus* uses the bay as a nursery area for juvenile development. *Callinectes ornatus* is not yet a legally protected species, and the minimum allowed size of crabs caught in the area, although already restricted, should be carefully evaluated since the removal of large numbers of juveniles could negatively impact the local population.

KEY WORDS. Migration; population biology; seasonal distribution; swimming crab.

Species of *Callinectes* (Stimpson, 1860) are extensively investigated around the world (Turner *et al.* 2003, Fischer & Wolff 2006, Kennedy & Cronin 2007). These crabs are important as a valuable fishery resource (Hines *et al.* 1995, Secor *et al.* 2002), indicator of heavy metals (Sastre *et al.* 1999, Skaggs & Henry, 2002, Andrade *et al.* 2011) and ecologically (Branco *et al.* 2002, Lipcius & Stockhausen 2002).

In Brazil, most crustacean fisheries target shrimps, and crabs caught in the trawls have secondary economic importance (Costa & Negreiros-Fransozo 1998) or are mostly consumed by small fishing communities (Sforza *et al.* 2010). The most economically important crab worldwide is *Callinectes sapidus* (Rathbun, 1896), but *Callinectes danae* (Smith, 1869) and *Callinectes ornatus* (Ordway, 1863) are also caught on the Brazilian coast, which has motivated scientific studies (Santos & Bueno 2002, Keunecke *et al.* 2009, Sant'Anna *et al.* 2012a). In the Brazilian trawl fishery for the shrimp *Xiphopenaeus kroyeri* (Heller, 1862), *C. ornatus* is one of the most abundant brachyurans discarded in the bycatch (Carvalho *et al.* 2011).

Because of the economic importance of *C. ornatus,* several studies have examined its reproduction (Mantellato & Fransozo 1997, 1999, Carvalho *et al.* 2011, Keunecke *et al.* 2012,), feeding habits (Mantellato & Christofoletti 2001, Reigada & Negreiros-Fransozo 2001, Branco *et al.* 2002, Mantellato *et al.* 2002), growth (Haefner 1990, Keunecke *et al.* 2008), population structure (Buchanan & Stoner 1988, Branco & Lunardon-Branco 1993, Negreiros-Fransozo *et al.*1999, Branco & Fracasso 2004, Guerra-Castro *et al.* 2007, Tudesco *et al.* 2012) and physiology (Norse 1978, Freire *et al.* 2011, Garçon *et al.* 2013). However, no study has assessed its distribution in estuaries as well as along the coast, and these areas are important for its biology and life habits (Melo 1996). In addition, the population structure and other biological aspects such as distribution are less well understood, particularly in Santos-São Vicente Bay, the largest Latin American port (Zangrande *et al.* 2003, Sant'Anna *et al.* 2012b).

Callinectes ornatus is widely distributed in the western Atlantic, usually on sand or mud bottoms near rivers, and usually in brackish waters (Melo 1996). Most studies on *C. ornatus* were conducted along the coast with rivers nearby, but the distribution of this species on the coast as well as in the estuaries was not investigated. This study analyzed the population biology and the seasonal and spatial distribution in the Estuary-Bay Complex of São Vicente, São Paulo, Brazil.

MATERIAL AND METHODS

The swimming crabs were collected monthly in the São Vicente Estuary-Bay Complex, state of São Paulo, Brazil, from March 2007 through February 2008. A shrimp fishing boat equipped with an otter-trawl net 4.0 m wide, 2.0 m high and 9.5 long with a 15 mm-mesh body and 10 mm-mesh cod liner was used to capture the crabs during a 20-min sampling on eight transects, four in the estuary and four in the bay (Fig. 1). On each transect, after the trawl, the bottom water was collected with a Nansen bottle and the temperature (°C) and salinity (‰) were measured.

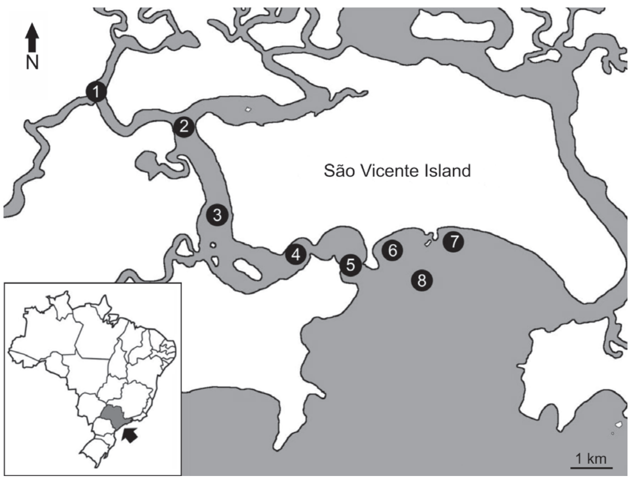


Figure 1. Estuary-Bay Complex of São Vicente, showing the sampling locations in the estuary (transects 1, 2, 3 and 4) and in the bay (transects 5, 6, 7 and 8). Conic projection, WGS84. Source: Timoteo T. Watanabe.

The crabs were sorted and identified according to MELO (1996), the sex was determined by inspection of abdominal morphology, and the sexual maturity was determined through inspection of the abdomen: adhered for juveniles or loose for adults. The carapace width (CW, measured between the bases of the last and penultimate lateral spines) was recorded using a caliper (0.01 mm). For the size-frequency distribution analysis, size-class intervals of 6 mm of carapace width were used. The size intervals for each class were determined according to the mathematical formula of STURGES (1926). The Kolmogorov–Smirnov (KS) was used to test the normality of the size–frequency distribution for each population category (sex). The size was compared between the sexes with the Kruskal–Wallis test. The monthly and overall sex ratios (M:F) were tested with the Chi-square test (χ^2) and the data for abiotic factors (temperature and salinity) and number of individuals were analyzed by the Spearman's rank correlation coefficient. A significance level of $p < 0.05$ was adopted for all statistical analyses (SOKAL & ROHLF 1995). The reproductive period was determined by the monthly incidence of ovigerous females during the course of the sampling period.

RESULTS

A total of 618 crabs (332 males, 267 females and 19 ovigerous females) were caught; juvenile crabs comprised 77.67% (480 individuals) of this total. Most of the crabs were caught in the bay (84.30%, 521 individuals) (Table I). The spatial distribution of the number of individuals (Fig. 2) was positively correlated with salinity (Table II); most individuals occurred in locations with higher salinity. There was also a significant positive correlation with temperature, where more crabs were found in the warmer months (Table II, Fig. 3).

Table I. Number of individuals of *Callinectes ornatus* caught in the bay and estuary of São Vicente. (AM) Adult male, (JM) juvenile male, (AF) adult female, (JF) juvenile female, (OF) ovigerous female.

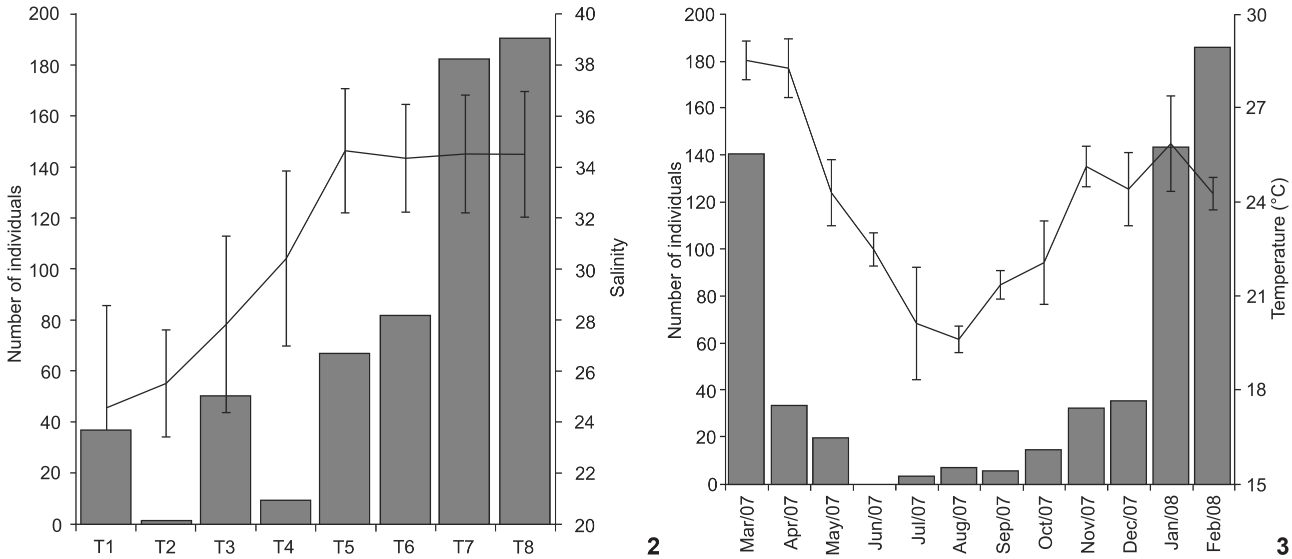
Location	AM	JM	AF	JF	OF	Total
Bay	62	215	32	197	15	521
Estuary	18	37	7	31	4	97
Total	80	252	39	228	19	618

Table II. Spearman's Rank test for salinity vs. number of individuals per transect and temperature (°C) vs. number of individuals per month. *p < 0.05.

	Salinity x Transect	Temperature (°C) x Months
Rs	0.7306	0.7133
Number of pairs	8	12
t	2.6206	3.2183
p	0.0395*	0.0092*

The high proportion of juveniles decreased the overall mean size, and therefore the ovigerous females were significantly larger than males and non-ovigerous females (Tables III and IV). The overall size-frequency distribution of *C. ornatus* (Fig. 4) showed a bimodal distribution for males and a unimodal distribution for females, with the distribution differing from normality for males (KS = 0.1306, $p < 0.01$), and normal distributions for females and ovigerous females (KS = 0.0701, p = 0.08; KS = 0.1587, p = 0.30, respectively). The seasonal size-frequency distribution indicated a relationship to the seasons (Fig. 5), with crabs present in larger numbers in the summer and autumn.

The sex ratio of the *C. ornatus* population did not differ significantly from the expected 1:1 (χ^2 = 3.576, p = 0.06). This pattern was the same in all months, except in March 2007, when males were more abundant than females (Table V). Ovigerous females were recorded in higher percentages in the warmer seasons, probably related to seasonal reproduction (Fig. 6).



Figures 2-3. (2) Number of individuals (bars) and the mean salinity (lines) of each transect collected through the year. (3) Monthly distribution of *Callinectes ornatus* (bars), with the mean water temperature (line) through the months.

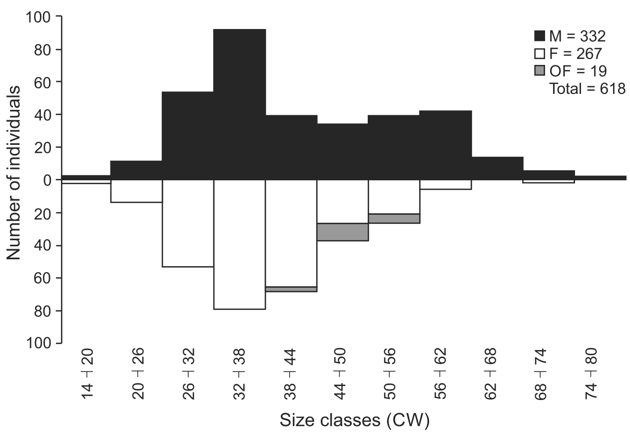


Figure 4. Size-frequency distribution of individuals (juveniles included) of *Callinectes ornatus* caught in the Estuary-Bay Complex of São Vicente. (OF) Ovigerous females, (F) females, (M) males, (CW) carapace width (mm).

Table III. Number of individuals and size range (carapace width) of *Callinectes ornatus*. (n) Number of individuals, (Min) minimum, (Max) maximum, (X) mean, (SD) standard deviation, (M) males, (F) non-ovigerous females, (OF) ovigerous females (OF). Means followed by the same lower-case letter did not show significant differences (p > 0.05).

Sex	n	Min	Max	X ± SD
M	332	14.90	79.00	42.29 ± 12.30 a
F	267	18.10	73.45	37.45 ± 8.41 b
OF	19	43.08	59.08	47.78 ± 4.04 c
Total	618	14..90	79.00	40.37 ± 10.93

Table IV. Kruskal-Wallis test results followed by Dunn test for size of males, females and ovigerous females of *Callinectes ornatus*.

	H	DF	p
Kruskal-Wallis	34.67	2	0
	Frequency	Rank sum	Mean rank
Males	332	110748	333.58
Females	267	71677	268.45
Ovigerous females	19	8846	465.58
Total	618		
Dunn method	Rank diff.	Z	p
Males x Females	65.12	4.43	<0.05
Males x Ovigerous females	132.00	3.13	<0.05
Females x Ovigerous females	197.12	4.64	<0.05

DISCUSSION

Callinectes ornatus is more euryhaline than other seawater portunids such as *Arenaeus cribrarius* (Lamarck, 1818) or species of *Portunus* (Weber, 1795), but less euryhaline than other members of *Callinectes* such as *C. sapidus*, *C. bocourti* or *C. danae* (Norse 1978). However, this may not in itself explain the low number of adults of *C. ornatus* in the bay area, where salinities are higher. This species is usually smaller than *C. sapidus* or *C. danae* (Buchanan & Stoner 1988), and the large number of adults of *C. danae* in the region (Sant'Anna *et al*. 2012a) may lead to agonistic relationships with *C. ornatus*. Norse (1978) found that *C. ornatus* living in areas without other, larger species of *Callinectes* are more tolerant to hyposaline conditions than are

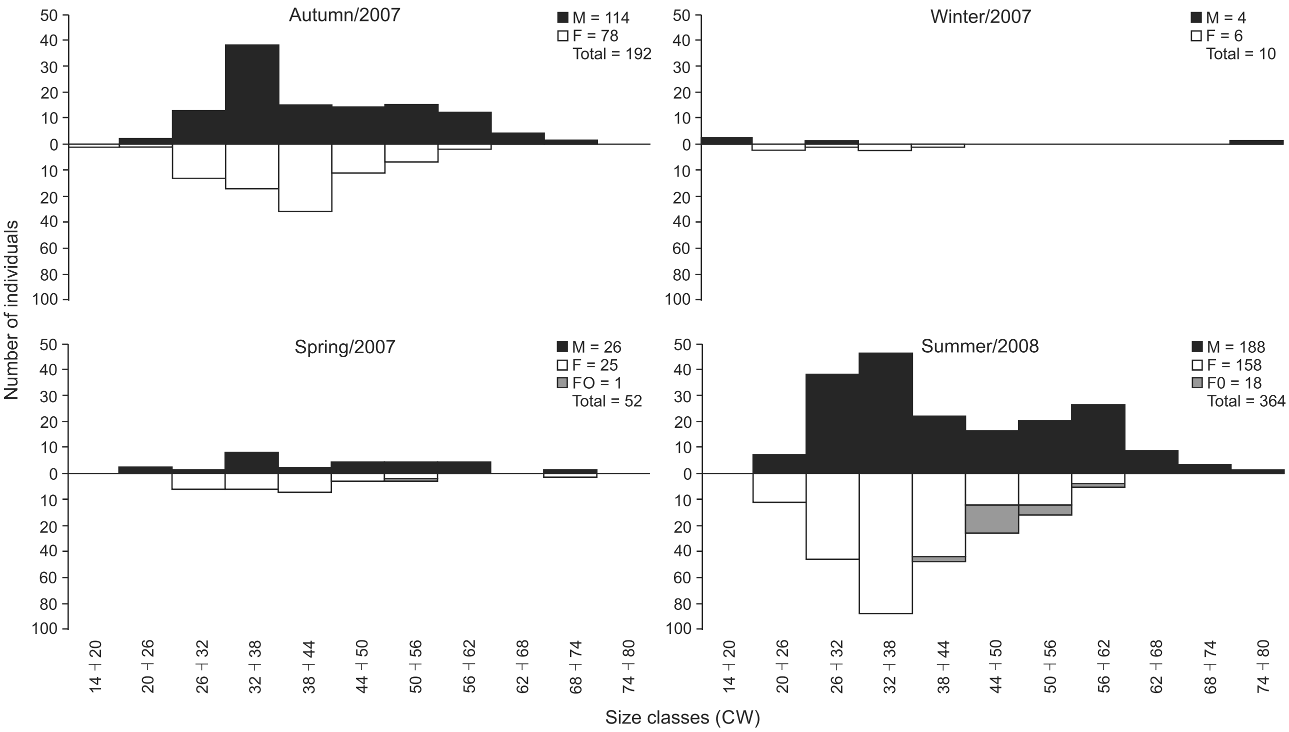


Figure 5. Size-frequency distribution of *Callinectes ornatus* caught monthly in the Estuary-Bay Complex of São Vicente (juveniles included), by season (Autumn: March-May, Winter: June-August, Spring: September-November, Summer: December-February). (OF) Ovigerous females, (F) females, (M) males. Measurements in millimeters.

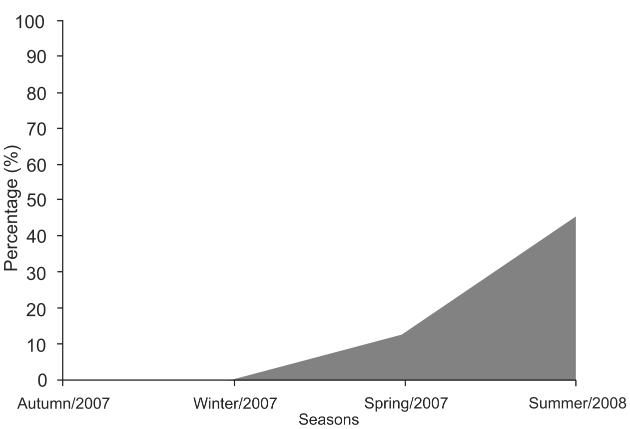


Figure 6. Percentage of ovigerous females of *Callinectes ornatus* caught during the study period in the Estuary-Bay Complex of São Vicente, by season.

Table V. Sex ratio by month obtained for the population of *Callinectes ornatus* in the Estuary-Bay Complex of São Vicente.

Months	Males	Females	Total	Sex ratio (M/F)	χ^2	p
March/07	87	53	140	1.64	7.779	0.0053*
April/07	17	16	33	1.06	0	1.0000
May/07	10	9	19	1.11	0	1.0000
June/07	0	0	0	0.00	0	0.0000
July/07	2	1	3	2.00	0	1.0000
August/07	2	5	7	0.40	0.571	0.4497
September/07	3	2	5	1.50	0	1.0000
October/07	7	8	15	0.88	0	1.0000
November/07	16	16	32	1.00	0	1.0000
December/07	18	17	35	1.06	0	1.0000
January/08	72	71	143	1.01	0	1.0000
February/08	98	88	186	1.11	0.435	0.5093
Total	332	286	618	1.16	3.277	0.0703

individuals found in the presence of other large species of the same genus, although the salinity stress alters the metabolisms of *C. ornatus* and *C. danae* metabolisms similarly (Freire *et al.* 2011). Larger blue crabs behave aggressively toward conspecifics (Clark *et al.* 1999, Reichmuth *et al.* 2011), and might also be aggressive toward other species. We speculate that the presence of the other, larger *Callinectes* species such as *C. danae* (Sant'Anna *et al.* 2012a) in the estuary-bay complex may influence the distribution of *C. ornatus*, combined with the euryhalinity characteristic of the species. Further studies on competition for resources such as territory use or food are needed to test this hypothesis. However, one clue supporting this hypothesis is that the distribution and salinity were positively correlated, indicating that competition with other species could also explain the low number of the adults in both the estuary and bay. For instance, Pinheiro *et al*. (1997) found that different swimming crabs can show niche overlap, but that the number of individuals of *C. ornatus* was lower when in the presence of greater numbers of larger crabs such as *C. danae* or *A. cribrarius*.

The high proportion of juveniles caught indicates that this species uses the bay for the early part of its life cycle. Our data, which revealed the presence of large numbers of juveniles, mostly in the bay (Table I), indicate that *C. ornatus* uses the bay as a nursery for the development of the juveniles. These data differ from the findings of Tudesco *et al.* (2012), of lower numbers of juveniles on the coast near the estuary of Guanabara Bay, Rio de Janeiro, Brazil compared to the number of adults; although the presence of *C. ornatus* in the estuary was not checked. However, Baptista *et al.* (2003) also found large numbers of juveniles during the summer near Paranaguá Bay in southern Brazil, outside the estuary, similarly to our data. Another factor that could explain the high proportion of juveniles is the calmer water in the bay; since the juveniles of *Callinectes* spp. usually prefer calm, shallow waters with more organic matter (Negreiros-Fransozo & Fransozo 1995, Tudesco *et al.* 2012), it is possible that the conditions in the bay also favor the presence of juveniles. During the larval period, some crustaceans do not have a large capacity for osmoregulation and cannot tolerate sudden changes of salinity, which explains why the juveniles use these areas (Hartnoll 1982).

Species of *Callinectes* have low tolerance for extreme temperature changes (Leffler 1972, Rome *et al.* 2005), and *C. ornatus* is usually found in tropical seas ranging from 18 to 31°C (Williams 1984). The low temperatures during colder seasons in São Vicente Bay could explain the low occurrence of *C. ornatus* during the study period. The migration pattern of this population showed that the swimming crabs were more abundant during warmer periods; according to Colton *et al.* (2014), winter temperatures could influence the number of individuals and impact the fluctuation and dynamic synchronization of a population of the blue crab *C. sapidus*. Some species of *Callinectes* migrate, which is more evident when correlating their presence with the reproductive period (Millikin & Williams 1984, Hines *et al.* 1987, Sant'Anna *et al.* 2012).

During the sampling period, there were high numbers of juveniles during the summer and autumn months, indicating a possible seasonal recruitment. Smaller recruitment peaks were not observed in the other seasons, although *C. ornatus* has multiple and continuous spawning with peaks in the autumn at Ubatuba (Mantellato & Fransozo 1997), and reproduction was more active during autumn and summer, similar to the present study. The differences between our study and others could be explained by the specific conditions in the different locations, the environment (Schaffner & Diaz 1988, Fernandes *et al.* 2006), or the differences in sampling effort in each study.

Few crustacean species maintain a sex ratio of 1:1 (Wenner 1972), and *C. ornatus* shows a segregated distribution according to the local environmental features (Negreiros-Fransozo *et al.* 1999, Tudesco *et al.* 2012). Thus, males and females showed different population concentrations as well as varying ratios in different size classes; this is also true for *C. ornatus*, where the habitats of adults and juveniles differ (Negreiros-Fransozo *et al.* 1999). In the present study, the data suggest that the São Vicente estuary-bay complex is the main habitat of juveniles, which explains the deviation toward lower individual sizes as well as the trend toward a bimodal distribution for males. The high proportion of juveniles helps to explain the 1:1 sex ratio, since most of the population was sexually immature, and females do not migrate as described for other *Callinectes* species (Aguilar *et al.* 2005, Sant'Anna *et al.* 2012a).

Usually, portunids reproduce throughout the year with peaks in certain seasons, generally winter and summer (Pita *et al.* 1985, Baptista-Metri *et al.* 2005). The local population of *C. ornatus* showed a peak of reproduction only in summer, with the presence of ovigerous females indicating a seasonal rather than a continuous reproduction pattern. Ovigerous females of some *Callinectes* species prefer higher-salinity waters, which could help the larvae to float and maintain osmotic pressure (Pita *et al.* 1985, Mantellato 2000). This could explain the low number of females in the study area, which receives a large freshwater inflow from the estuary.

The results of this study revealed that juveniles of *C. ornatus* use the bay area intensively; and also indicated a regional plasticity in reproduction, since *C. ornatus* shows different reproductive patterns along the Brazilian southern coast. Although the minimum catch size for *C. sapidus* and *C. danae* is regulated (Brazil 1983), the minimum catch size for *C. ornatus* is not. Despite the similarities in external morphology of these species, *C. ornatus* is not yet legally protected. The management of *C. ornatus* should be carefully evaluated, since it is also an economically important species, and trawling in the area, although highly restricted (IBAMA 1994), could still affect the population since most of the individuals were juveniles and this is likely to be an important nursery ground for their development.

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