Latin American Journal of Aquatic Research
E-ISSN: 0718-560X
lajar@ucv.cl
Pontificia Universidad Católica de Valparaíso
Chile

Stanski, Gilson; Mantelatto, Fernando L.; Leão-Castilho, Antonio
Hermit crab bycatch fauna (Decapoda, Anomura) off the coast of Santa Catarina State, Brazil: diversity and spatial-temporal distribution
Latin American Journal of Aquatic Research, vol. 44, núm. 3, julio, 2016, pp. 546-556
Pontificia Universidad Católica de Valparaíso
Valparaíso, Chile

Lat. Am. J. Aquat. Res., 44(3): 546-556, 2016
DOI: 10.3856/vol44-issue3-fulltext-13

Research Article

Hermit crab bycatch fauna (Decapoda, Anomura) off the coast of Santa Catarina State, Brazil: diversity and spatial-temporal distribution

Gilson Stanski[1], Fernando L. Mantelatto[2] & Antonio Leão-Castilho[1]
[1]NEBECC (Núcleo de Estudos de Biología, Ecología e Cultivo de Crustáceos)
Departamento de Zoología, Instituto de Biociências de Botucatu
Universidade Estadual Paulista, São Paulo, Brasil
[2]Laboratório de Bioecologia e Sistemática de Crustáceos (LBSC)
Departamento de Biologia, Faculdade de Filosofia, Ciências e Letras de RibeirãoPreto Universidade de São Paulo (USP), RibeirãoPreto, São Paulo, Brasil
Corresponding author: Gilson Stanski (stanski@ibb.unesp.br)

ABSTRACT. Biodiversity and spatial-temporal distribution of hermit crabs captured as bycatch in the non-selective fishery of shrimp were analyzed in this study from July 2010 through June 2011 off coast Santa Catarina State (southern Brazil). Ecological indexes and redundancy analyses were conducted to understand the hermit community and their relationship with environmental factors. In total, 644 specimens were collected, representing two families, five genera, and six species, demonstrating remarkable species richness in the study area, mainly because Santa Catarina is a subtropical region. *Isocheles sawayai* showed the highest abundance, followed by *Loxopagurus loxochelis*. Both species demonstrated correlation with temperature (positive) and sediment grain size (negative). The highest richness and evenness values were estimated at the deeper area (17 m). However, in 5 m deep area showed the lowest evenness because of the high dominance of *I. sawayai*, resulting in a lower estimated diversity. During a period of lower temperature and higher salinity (July), higher levels of diversity were registered, probably because of the lower dominance of tropical species (*I. sawayai*) and the presence of some species distributed in offshore regions (*Petrochirus diogenes*, *Dardanus insignis* and *Pagurus exilis*). Thus, we detected that the capture effort designated in the shrimp fishery activities had a strong influence in the diversity of hermit crabs and other associated fauna, especially because of catch specimens in expressive abundance at various stages of development, including juveniles. This profile makes us argue in favor of constant monitoring of bycatch resources in order to preserve the marine fauna.

Keywords: hermit crab, habitat selection, fishery, Babitonga Bay, Brasil.

Fauna de captura incidental de cangrejo ermitaño (Decapoda, Anomura) en la costa de Santa Catarina, Brasil: diversidad y distribución espacio-temporal

RESUMEN. Se analizó la biodiversidad y distribución espacio-temporal de los cangrejos ermitaños, como descartes en la pesca no selectiva de camarón, entre julio de 2010 y junio de 2011 en la costa del Estado de Santa Catarina. Los índices ecológicos y análisis de redundancia se analizaron para describir el desarrollo de la comunidad de ermitaños y su relación con los factores ambientales. Se encontró una notable riqueza específica en una región subtropical, como fue la de Santa Catarina, donde se obtuvieron 644 individuos pertenecientes a dos familias, cinco géneros y seis especies. *Isocheles sawayai* presentó la mayor abundancia, seguida de *Loxopagurus loxochelis*; ambas especies mostraron correlación con la temperatura y tamaño de las partículas del sedimento. Los mayores valores de riqueza y uniformidad se dieron en la zona más profunda estudiada (17 m). Sin embargo, a 5 m de profundidad se encontró la equirepartición más baja debido al predominio de *I. sawayai*. Durante un período de baja temperatura y mayor salinidad (julio) se registraron altos valores de diversidad, probablemente debido la baja dominancia de especies costeras tropicales (*I. sawayai*) y presencia de algunas especies de aguas oceánicas (*Petrochirus diogenes*, *Dardanos insignis* y *Pagurus exilis*). Se detectó que el esfuerzo de captura aplicado en las pesca del camarón tuvo una fuerte influencia en la diversidad de los can-

Corresponding editor: José A. Álvarez-Pérez

grejos ermitaños y fauna asociada, especialmente debido a que en las muestras se observaron diversas etapas de desarrollo de las especies, incluyendo juveniles. Estos resultados son argumentos a favor de una vigilancia constante de los descartes a fin de preservar la fauna marina.

Palabras clave: cangrejo ermitaño, selección del hábitat, pesquería, Bahía Babitonga, Brasil.

INTRODUCTION

The highest mortalities of marine species are associated with shrimp trawling, activity that possesses, as a main characteristic, low selectivity (Escobar-Toledo *et al*., 2014). Such activity causes indirect impacts on the physical environment, with changes in the marine substrate (Pilskaln *et al*., 1998), as well as direct impacts, with the extraction of species that are accidentally captured (bycatch) (Alverson *et al*., 1994). The biological impact is so significant, it is estimated that for every 1 kg of shrimp harvested, 11 kg of other species are caught and discarded (Connoly, 1986; Severino-Rodrigues *et al*., 2002).

However, little is known about the ecology and life cycle of bycatch species when compared to commercially profitable species. In the case of hermit crabs, crustaceans with a significant level of diversity of over 1,100 species (Mclaughlin *et al*., 2010), have an important role in the marine food web (McLaughlin *et al*., 2007; Fantucci *et al*., 2009), but are often captured in this type of activity.

In addition, for our knowledge about diversity of these animals, it is necessary to study and understand their interactions with the environment and its features. In this sense, it is known that some components have a large influence on the occurrence and distribution of benthic marine species. Among these the sediment, water temperature and salinity are cited as the most important factors for hermit crabs (Abele, 1974; Negreiros-Fransozo *et al*., 1991; Bertini *et al*., 2004; Mantelatto *et al*., 2004; Fantucci *et al*., 2009).

In the case of hermit crabs, in particular, another variable that plays a crucial role in the interaction with the environment is the existence of gastropod shells that modulate diversity, which is directly related with the lifestyle of these organisms. The empty shell of the gastropod has a structure that is essential to growth, reproduction and protection from predators and mechanical abrasion, which commonly occur in the natural environment competition during the intra or interspecific by this shelter (Bach *et al*., 1976; Elwood *et al*., 1995; Teoh *et al*., 2014).

Thus, the purpose of this study was to characterize the structure of temporal and spatial richness, and diversity of hermit crabs species obtained as bycatch in shrimp fishing, in the region adjacent to Babitonga Bay in Santa Catarina State. We also analyzed the distribution of the species related to abiotic factors, such as salinity, water temperature, organic matter and grain size of the sediment.

MATERIALS AND METHODS

The anomurans and environmental factors were sampled monthly from July 2010 through June 2011 at five sites (stations) parallel to the shoreline and at different depths (5, 8, 11, 14 and 17 m) in adjacent areas of Babitonga Bay (Fig. 1). This bay is located on the northern coast of Santa Catarina near the towns of Joinville, Itapoá and São Francisco do Sul (Fig. 1). In the southern hemisphere, the seasons are separated as follows: July, August and September (winter); October, November and December (spring); January, February and March (summer); April, May and June (autumn).

Biological collection

Biological sampling was conducted in 30 min trawls using a shrimp boat outfitted with double-rig nets (see Grabowski *et al*., 2014). Specimens were packed in an insulate box containing crushed ice for later analyses. In the laboratory, hermit crabs were carefully removed from their shells, identified according to Melo (1999) procedures, counted (numbers absolute) and number caught per standard trawl (catch per unit effort CPUE), *i.e*., hermit crabs collected for 60 min (2 nets 30 min) in each month. The animals were preserved in 80% ethyl alcohol and were deposited in the Crustacean Collection of the Department of Biology, Faculty of Philosophy, Sciences and Letters at Ribeirão Preto, University of São Paulo (CCDB/FFCLRP/USP).

Abiotic factors collection and analysis

In general, the methodology used for collection and analysis followed the protocols developed by Fransozo *et al*. (1992) and Santos *et al*. (1994). Bottom water samples were taken using a Van Dorn bottle to measure salinity and temperature, for which an optical refractometer and a mercury thermometer were used. An ecobathymeter coupled with a GPS was used to record depth (m) at sampling sites.

Sediment was obtained using a Petersen grab. The samples were packed individually and frozen to minimize loss of organic matter. At the laboratory, the sediment was dried in a 70ºC oven for 72 h. From each sample, a 100 g subsample was ash-weighed to deter-

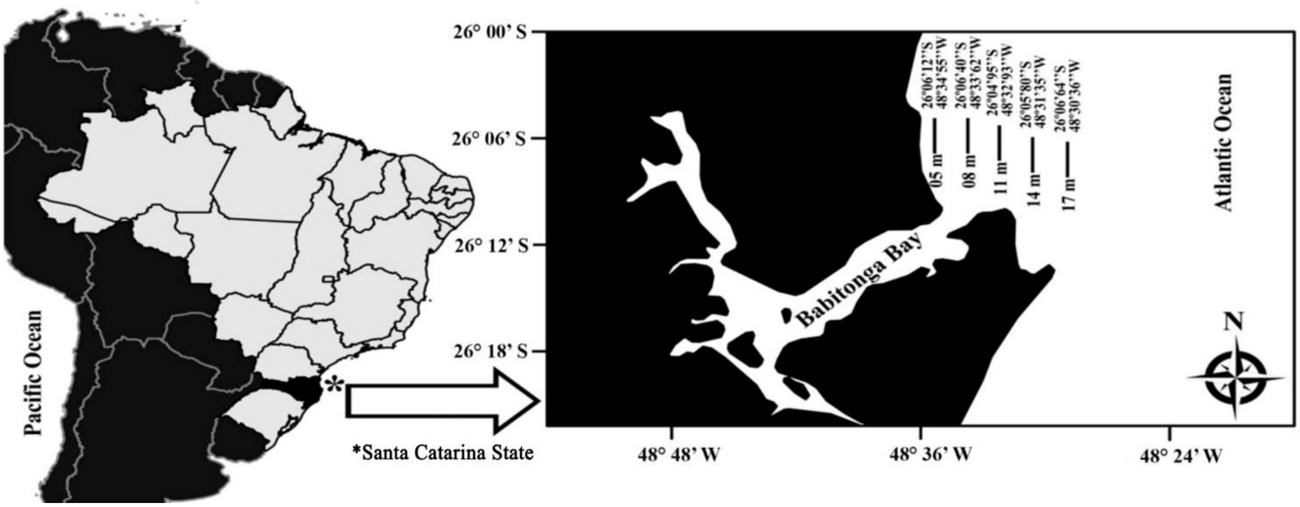

Figure 1. Map of the study area, highlighting the five sampled stations in an area adjacent to Babitonga Bay, Santa Catarina, Southern Brazil (source: Grabowski *et al*., 2014).

mine the grain-size distribution. Sediments were sieved through 2 mm (gravel), 2.0-1.01 mm (very coarse sand), 1.0-0.51 mm (coarse sand), 0.50-0.26 mm (medium sand), 0.25-0.126 mm (fine sand), and 0.125-0.063 mm (very fine sand); smaller particles were classified as silt-clay (Suguio, 1973; Hakanson & Jansson, 1983).

Grain size categories followed the American standard, and fractions were expressed on the phi (ϕ) scale, *i.e.*, using the formula $\phi = -\log_2 d$, where d = grain diameter (mm) (Tucker, 1988), *e.g.*, $-1 = \phi < 0$ (very coarse sand); $0 = \phi < 1$ (coarse sand); $1 = \phi < 2$ (intermediate sand); $2 = \phi < 3$ (fine sand); $3 = \phi < 4$ (very fine sand) and $\phi \geqslant 4$ (silt+clay). Finally, ϕ was calculated by cumulative particle-size curves were plotted on a computer using the ϕ scale, with values corresponding to 16^{th}, 50^{th}, 84^{th} percentiles being used to determine the mean diameter of the sediment using the formula $Md = (\phi_{16}+\phi_{50}+\phi_{84})/3$. The organic matter content (%) was obtained by ash-weighing: three aliquots of 10 g each per station were placed in porcelain crucibles, heated for 3 h at 500°C, and then weighed again (Tucker, 1988).

Environmental data on rainfall was obtained monthly from Epagri/Ciram/Inmet (Centro de Informações de Recursos Ambientais e de Hidrometereologia de Santa Catarina) using weather stations located near the study site (Itapoá City).

Statistical analysis

Ecological indexes were applied to measure the dynamics of studied species, including richness, dominance, diversity and evenness, using the software PAST, version 2.06 (Hammer *et al*., 2001). The richness (S') was represented by the number of species present in the community (Mcintosh, 1967). Dominance (d) was determined using the Berger & Parker Index (1970), which considered the major proportion of the species with the best individual abundance, expressed by the formula $d = N_{max}/N_{total}$, where: N_{max} is the number of specimens of the more abundant species and N_{total} is the total number of specimens in the sample.

Diversity and species richness were quantified using the Shannon-Wiener (1949) diversity index and Pielou's evenness index (1966). Diversity (H') was expressed as $H' = -\sum p_i(\log p_i)$, taking into account the richness and the relative abundance of the species, where p_i is the result of the number of specimens of species *i* in the sample, divided by the total number of specimens (S). Pi is the importance value and log = base 2 (bits). Evenness (J') was estimated by the equation: $J' = H'/\log_2 S$.

A redundancy analysis (RDA) was used to test the relationship of species abundance with environmental factors (Legendre & Legendre, 1998). However, *Petrochirus diogenes* (Linnaeus, 1758), *Dardanus insignis* (Saussure, 1858), *Pagurus exilis* (Benedict, 1892), and *Pagurus leptonyx* (Forest & Saint Laurent, 1968) were not incorporated into the RDA because they were present in less than 10% of the monthly samples.

Previous analysis of the main species showed a linear response in their abundance in relation to the environmental variables used, and the use of the RDA offers a greater percentage of the variance explained in comparison with the canonical correspondence analysis (CCA), which is more suitable when there is a unimodal response (Gotelli & Elison, 2011). The set of environmental variables used in RDA calculations comprised bottom salinity and bottom temperature, organic matter content and grain size of sediments. The routine Vegan was used, embedded in the software R (R Development Core Team, 2009). Tests for homoscedasticity (Levene tests) and normality (Shapiro-Wilk tests) were first performed as prerequisites for the statistical test. Data were log-transformed prior to analysis (Zar, 1999). All of the data sets were normally distributed with homogeneous variances.

RESULTS

Ecological indexes and spatial-temporal distribution

Throughout of the year, 644 animals were collected (11 animals by trawl hour), of which 352 (54.7%) were males, 188 (29.2%) females without embryos, and 104 (16.1%) females with embryos, belonging to two families (Paguridae and Diogenidae), five genera, and six species. *Isocheles sawayai* had the greatest number of specimens (575), followed by *Loxopagurus loxochelis* (56), *Petrochirus diogenes* (9), *Dardanus insignis* (2), *Pagurus exilis* (1), and *Pagurus leptonyx* (1) (Table 1).

The stations at depths of 5 and 17 m presented the lowest and highest rates of diversity, respectively. In depths where the dominance increased, the evenness decreased, resulting in low diversity (Fig. 2).

Temporally, July presented highest diversity index (H' = 1.4 bits) and high evenness (E = 0.9). November recorded the greatest number of specimens and the highest index of dominance during the study (D = 0.9). The number of specimens increased during the spring and summer seasons, which are periods with higher temperatures. On the other hand, the species richness was higher in seasons with lower temperatures (Tables 1-2).

The majority of *I. sawayai* was found at 5 m deep, while *L. loxochelis* showed larger plasticity in the occupation of sampled stations (Fig. 3). On the other hand, *P. diogenes* and *P. leptonyx* were found only at depths of 14 and 17 m, *D. insignis* and *P. exilis* in depth of 17 m, where the highest salinity values and lower values bottom water temperature were recorded (Fig. 4). The last two mentioned species were found only in the winter and *P. exilis* only in autumn (Table 1).

The rainy season began in October, with highest average rainfall during the spring seasons (185 ± 31 mm) and during summer (451 ± 27 mm), coinciding with the greatest amount of dominant individual species, *I. sawayai* and *L. loxochelis* (Tables 1-2).

Redundancy analysis-*Isocheles sawayai* and *Loxopagurus loxochelis*

The species with the greatest number of specimens, *I. sawayai* and *L. loxochelis*, were found during the whole year and with greater occurrence during spring and summer, especially in months with temperatures between 21-23°C, and in sites with sediment composed of high silt+clay concentration (Fig. 5).

Both *I. sawayai* (96%) and *L. loxochelis* (57%) presented the greatest occurrences in depths of 5 m. Therefore, the Redundancy Analysis (RDA) was performed temporarily only at this depth. The RDA analysis demonstrated the relationship between species and environmental variables. Variations of the data were mainly explained by the first axis (*i.e.*, 62% of the variance), representing primarily the bottom temperature and Phi (Fig. 6, Table 3).

DISCUSSION

Bycatch

Considering that Santa Catarina is subtropical region, and therefore, trends naturally towards the present pattern with lower species richness in comparison with tropical regions, because is influenced by the presence of larger amplitudes in the environmental parameters, mainly water temperature (Thorson, 1950; Gray, 2007), the region of the Babitonga Bay presented a significant richness of hermit crabs higher than the five found by Branco *et al*. (2015) along the coast of the State of Santa Catarina.

Table 1. Composition and absolute number of individuals collected and catch per unit effort (CPUE) by season during July 2010 to June 2011 in the region adjacent to the Babitonga Bay, Santa Catarina. Winter: July-September, and subsequently to other seasons.

Species	Winter 2010 (CPUE)		Spring		Summer 2011		Autumn		Total (CPUE)	
Isocheles sawayai	34	(0.57)	422	(7.0)	107	(1.8)	12	(0.2)	575	(9.5)
Loxopagurus loxochelis	6	(0.1)	26	(0.4)	20	(0.3)	4	(0.06)	56	(0.9)
Petrochirus diogenes	3	(0.05)	1	(0.01)	4	(0.06)	1	(0.01)	9	(0.15)
Dardanus insignis	2	(0.03)	0	(0)	0	(0)	0	(0)	2	(0.03)
Pagurus exilis	1	(0.01)	0	(0)	0	(0)	0	(0)	1	(0.01)
Pagurus leptonyx	0	(0)	0	(0)	0	(0)	1	(0.01)	1	(0.01)
Total	46	(0.8)	449	(7.4)	131	(2.2)	18	(10.7)	644	(10.7)

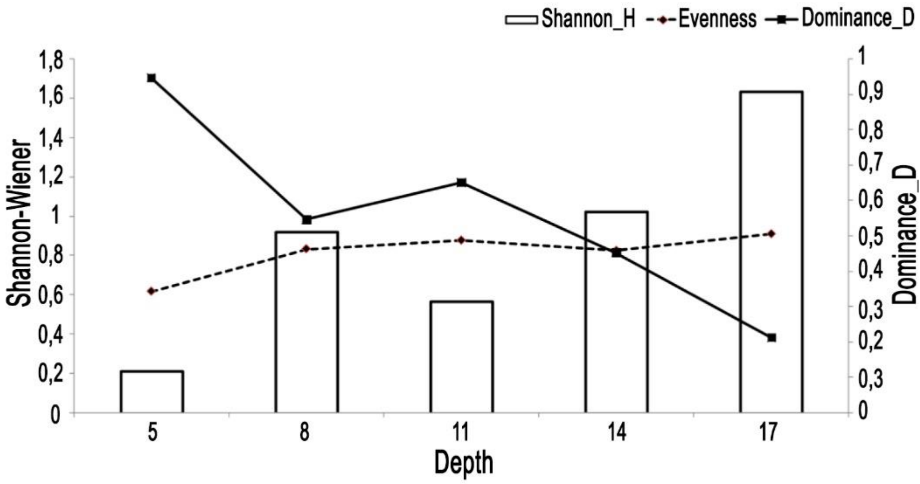

Figure 2. Shannon-Wiener, evenness and dominance Berger-Parker indexes, in the five depths studied during the period from July/2010 to June/2011.

Table 2. Mean and standard deviation (mean ± SD) by season, of bottom water temperature, bottom salinity, dissolved organic matter in the substrate, and rainfall for the period from July 2010 to June 2011, in the region adjacent to Babitonga Bay, Santa Catarina.

Season	Temp. (°C)	Salinity	M.O. (%)	Rainfall (mm)
Winter	19.0 ± 0.7	33.1 ± 1.6	3.2 ± 3.0	101.3 ± 37
Spring	22.4 ± 2.4	32.3 ± 0.1	5.9 ± 1.8	185.5 ± 31
Summer	25.5 ± 0.8	32.9 ± 0.8	2.7 ± 0.9	451.9 ± 27
Autumn	21.2 ± 1.1	35.2 ± 0.4	2.2 ± 0.2	79.2 ± 19

On the other hand, the observation of expressive amounts of hermits crabs caught by fishing equipment assumes alarming proportions because Santa Catarina is the greatest producer of national fishery (Sedrez *et al*., 2013). Therefore, if significant diversity and abundance were observed in 30 min of sampling (this study), it would be assumed that the amount that has been captured by bycatch in the commercial trawl by boat lasting up to 4 h consecutive (Haimovici & Mendonça, 1996) and for longer periods, must be much higher with repetitions made throughout the day, removing significant concentrations of these organisms and causing habitat modification of benthic species.

A constant extraction pressure impacting recruitment, reproduction and growth of specimens, can damage the maintenance of the population, as well as the perpetuation over time (Severino-Rodrigues *et al*., 2002). Small animals (many juveniles) and females with embryos were captured in the sampling conducted for this study, during shrimp fishing process, demonstrating that shrimp fishing captures individuals in various stages of development given the unselective fishing methods, negatively affecting abundance of benthic populations.

Some trawling characteristics are crucial to generating large amounts of bycatch, such as the type of beam-trawl, that are made exclusively targeting the highest yield of shrimp catches without any concern regarding the escape of other species that share the same habitat (Sá Paiva *et al*., 2009). The fishing effort carried out on stocks of profitable species is beyond the tolerable maximum, causing exploitation of bycatch species (small or big individuals), as *Artemesia longinaris* (Spence Bate, 1888) and *Pleoticus muelleri* (Spence Bate, 1888) shrimps (Costa *et al*., 2004; Castilho *et al*., 2007).

In addition, loss of biological diversity, disturbance or elimination of local species cause direct changes in predator-prey relationships and impair the delicate balance of the marine ecosystem, causing harmful effects on its structure and functioning (Alverson *et al*., 1994). So, minimizing bycatch catches during fishing activity becomes vital to the socioeconomic development of the region in which fishing is carried out; otherwise, the frequent bycatch capture and changes in the coastal ecosystem structure will endanger the sustainability of the target species and the entire associated biological community (Wallace *et al*., 2013).

Biological environmental framework

Variations in the abundance and diversity of hermit crabs throughout the year is a consequence of heterogeneous environmental conditions from a wide variety of microenvironments related to environmental complexity (Wenner *et al*., 1983; Abelló *et al*., 1988), and during seasonal changes in the environment, diffe-

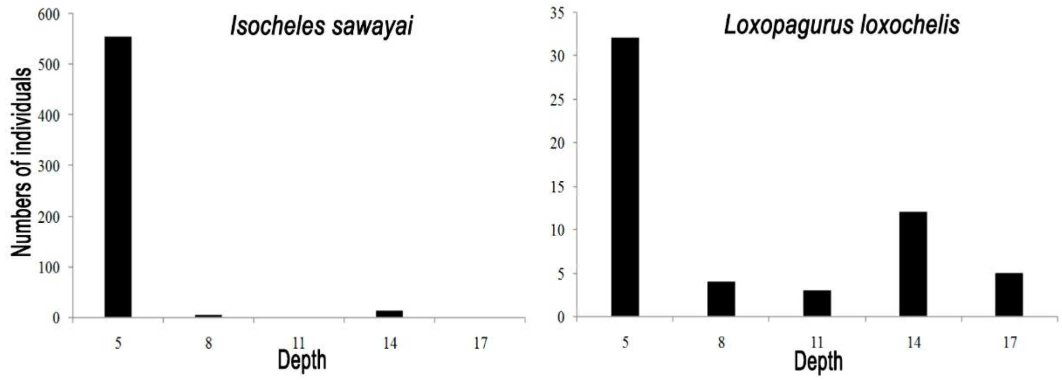

Figure 3. Spatial distribution of the most abundant species collected during the period from July 2010 to June 2011, in the region adjacent to the Babitonga Bay, Santa Catarina.

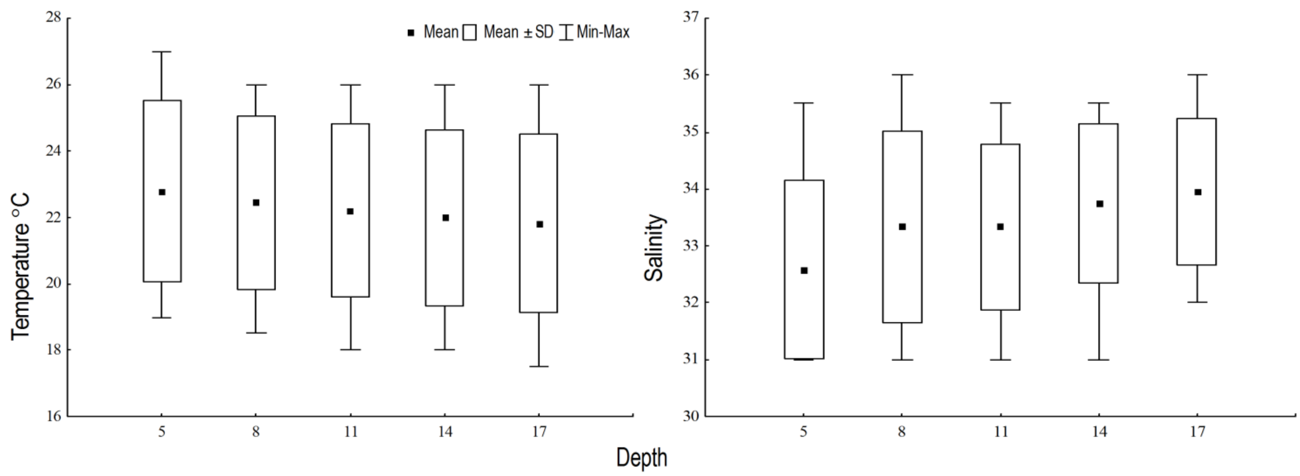

Figure 4. Variation of the temperature and bottom salinity in the five sampled depths during the period of July 2010 to June 2011, in the region adjacent to the Babitonga Bay, Santa Catarina.

rent species can adapt to the conditions in different seasons. Thus, it is expected that more species may coexist in environments that show seasonal changes than in those that are at a constant ambient condition (Begon *et al*., 2006).

The greatest diversity of species recorded in July (winter) was intimately related to water temperature and organic matter decrease, and the increased salinity. It is proposed that variation of these environmental factors may have caused a decrease in the abundance of dominant species, such as *I. sawayai*, directly influencing the Shannon-Wiener diversity index, which takes into account not only species richness, but also their abundance (Magurran, 2004). Linked to this, it is proposed that reduction in temperature values in the sampled sites promotes migration to coastal regions (shallower) of species inhabiting preferable places offshore (deep), such as *P. exilis*, *D. insignis*, and *P. diogenes*. Fransozo *et al*. (1998) found similar results on the coast of São Paulo (23ºS, 45ºW), under similar environmental conditions, with a greater diversity index during winter, proposing that decreases in water temperature benefit species that are adapted to this environment, providing them with abiotic conditions near the coast. Consequently, during warmer periods, such as summer, cold stenothermal species return to the deepest sites, reducing diversity and increasing the presence of dominant species.

Spatially, higher rates of evenness and richness were recorded in the 17 m by the low dominance of species and representativeness of those usually found at greater depths, such as *P. exilis*, *D. insignis*, and *P. diogenes*, which are hermit crabs that occur mainly in regions that present low water temperature and sediment with lower prevalence of silt+clay (Fransozo *et al*., 2008). On the other hand, at 5 m, lower values of equitability and high dominance of *I. sawayai* were recorded because high abundance of a species leads to low diversity, and consequently, to low local evenness (Magurran, 2004). The fitness of dominant species is higher or not according to the abiotic features and potential competitors that exist or not in their habitat

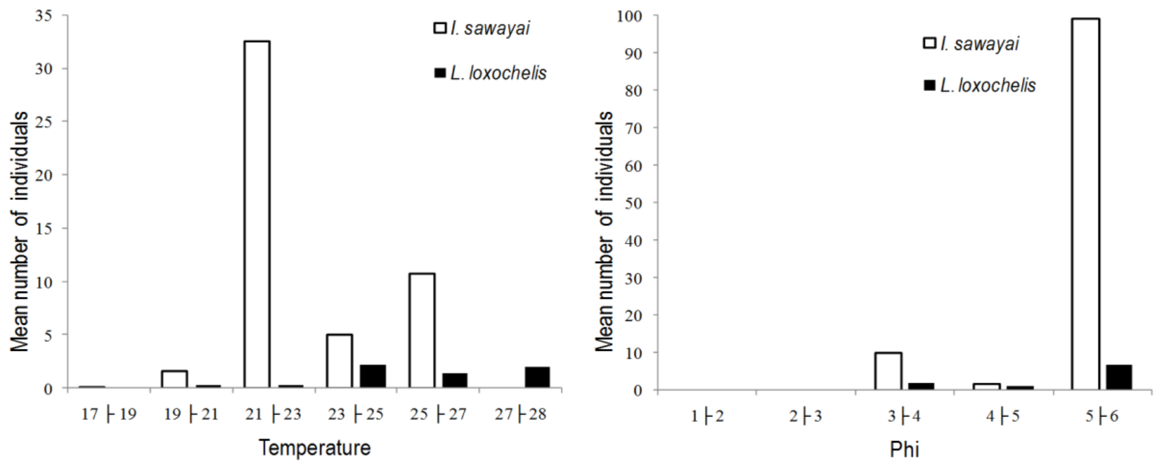

Figure 5. Average number of *Isocheles sawayai* and *Loxopagurus loxochelis* individuals, for each Phi classes collected by trawling from July 2010 to June 2011, in the region adjacent to the Babitonga Bay, Santa Catarina.

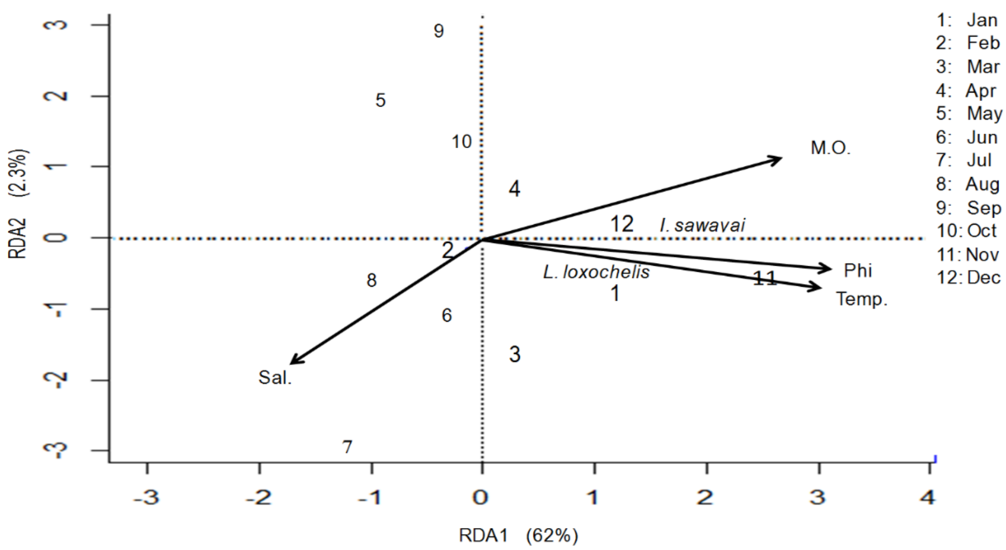

Figure 6. Redundancy Analysis (RDA). Spatial variation axes biplot of observations regarding data of species and environment variables during the period from July 2010 to June 2011 in an area adjacent to Babitonga Bay, Santa Catarina. The arrows indicate strength of the relationship between axes and environmental factors.

(Negreiros-Fransozo *et al.*, 1997; Sant'Anna *et al.*, 2006). For example, *I. sawayai* showed dominance (great abundance) in places with temperatures around 22°C, low salinity and the prevalence of thin substrate, which are favorable condition for its development (Fantucci *et al.*, 2009).

Isocheles sawayai is adapted to low salinity and elevated water temperatures, which may explain their abundance during the warmer seasons of the year (Negreiros-Fransozo & Hebling, 1983; Fantucci *et al.*, 2009). In addition, it is proposed that increases of organic materials in suspension in the regions near the coast favored the presence of suspension-feeder species (Bertness, 1981), such as *I. sawayai*, especially during the spring and summer periods, which presented high rainfall indexes (1,700 mm year) (data from National Institute of Meteorology, 1939-1983; Hardt, 2005). This can lead to increased material in suspension. Rainfall elevates the river discharge to the coastal region, mediated by the estuary, providing the entrainment of organic suspended matter or associated with the substrate for marine regions (Abreu, 1980; Schettini, 2002).

On the other hand, *L. loxochelis* have occurred in colder waters with geographical distribution to Argentina (38°S), where the species has significant abun-

Table 3. Redundancy Analysis (RDA). Summary results of hermit crabs and environmental variables collected, during the period from July/2010 to June/2011, in the region adjacent Babitonga Bay, Santa Catarina. Phi: mean grain size. Significance was inferred using α ($P < 0.05$): 0*** 0.001**, 0.01* 0.05, 0.1 P value based on 9999 permutations.

Axes	RDA1	RDA2	R^2	P
Proportion explained	0.6223	0.2331		
% organic matter	0.6612	0.2764	0.3270	0.1667
Bottom temperature	0.7081	-0.1326	0.5526	0.0228*
Phi	0.7539	-0.2539	0.3956	0.0594
Bottom salinity	-0.4914	-0.4981	0.2319	0.3104

dance during periods when the water temperature is lower (Mantelatto *et al*., 2004; Ayres-Peres & Mantelatto, 2008). Bertini *et al*. (2004) and Mantelatto *et al*. (2004) found larger amounts of *L. loxochelis* at temperature ranges of 16-22°C and 17-23°C, respectively. These authors stated that low water temperature and locations that do not have much of an influence on freshwater, especially above 15 m deep in the Ubatuba Region, are mainly modulators in the distribution of species.

However, in the present study, the species was the only one that showed spatial distribution at all depths sampled, with a significant number of specimens at 5 m, even during periods of the year with temperatures above 23°C. Although there are previous records of *L. loxochelis* in places with cold waters and high salinity (Bertini *et al*., 2004; Ayres-Peres & Mantelatto, 2008), it is proposed that the species possesses plasticity in ambient occupation when food conditions benefit their development because the species has suspension-feeder habits (Melo, 1999). These include sites with substrate consisting mainly of finer sediments, such as those found at five meters and have a higher organic matter content (Burone *et al*., 2003), favoring feeding. The granulometry and level of organic matter in the sediment have been postulated as the most relevant factors in the distribution of Anomura (Negreiros-Fransozo *et al*., 1997; Fransozo *et al*., 1998).

Moreover, areas with predominance of medium sand would be unfavorable for the behaviour of burying hermit crabs, as *L. loxochelis* which is frequently captured in areas compound by fine sediment and favourable for its behavior (Mantelatto *et al*., 2004). In addition, it is proposed that with increased rainfall during the spring and summer months, there is an increase in the entry of food particles in places near the coast, benefiting the development of suspension-feeder species. According to Melo (1985), decapod species alter their limits of bathymetric distribution, depending on environmental conditions and their physiological needs.

The constant impact of fishing equipment on species of no commercial value, such as hermit crabs, is harmful to the ecosystem and, over time, this situation tends to worsen irreversibly, negatively affecting the balance of the marine biological community as a whole. As shrimp fishing is essential to the survival of hundreds of fishermen in the northern region of the Santa Catarina State, since the activity contributes to reducing poverty and promoting food security (Béné, 2003; Branco & Verani, 2006; Ye *et al*., 2012), it is fundamental that substantial changes should be implemented in the fishing pattern currently used. Shorter bottom trawling and adjustments to the networks allowing for the escape of tiny animals are some strategies that may favor the survival of the target species or bycatch, benefiting the biotic balance as a whole. Particularly for hermits, the bycatch impact is certainly minimized by the presence of shells that act as protection and allows for greater survival until discard. Thus, it is essential to study the role of this variable in the more abundant species in areas of bycatch.

ACKNOWLEDGEMENTS

The authors are indebted to foundations that provide financial support during field collections, visiting activities and scholarships: Fundação de Amparo à Pesquisa do Estado de São Paulo-FAPESP (2010/50188-8), CAPES CIMAR II (23038.004310/2014-85 and 23038.004308/2014-14), CAPES (post-graduation scholarships), CNPq (Research Scholarships PQ 304 968/2014-5 and PQ 308653/2014-9), Fundação para o Desenvolvimento da Unesp-FUNDUNESP (1214/2010-DFP), and the Pró-Reitoria de Pesquisa (PROPE). We thank many colleagues from the NEBECC group who helped with sampling and laboratory analyses; and the "Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis" (IBAMA) for granting permission to collect the shrimp.

REFERENCES

Abele, L.G. 1974. Species diversity of decapods crustaceans in marine habitats. Ecology, 55(1): 156-161.

Abelló, P., F.J. Valladares & A. Castellón. 1988. Analysis of the structure of decapod crustacean assemblages off the Catalan coast (North-West Mediterranean). Mar. Biol., 98: 39-49.

Abreu, J. 1980. Distribuição e ecologia dos Decapoda numa área estuarina de Ubatuba (SP). Bolm. Inst. Oceanogr., 29(2): 1-3.

Alverson, D.L., M.H. Freeberg, J.G. Pope & S.A. Murawski. 1994. A global assessment of fisheries bycatch and discards. FAO Fish.Tech. Pap., 339: 233 pp.

Ayres-Peres, L. & F.L. Mantelatto. 2008. Análise comparativa da estrutura populacional do ermitão endêmico do Atlântico Ocidental *Loxopagurus loxochelis* (Decapoda, Anomura) em duas regiões do Estado de São Paulo, Brasil. Iheringia, Sér. Zool., 98(1): 28-35.

Bach, C.B., B. Hazlett & D. Rittschof. 1976. Effects of interspecific competition on fitness of the hermit crab *Clibanarius tricolor*. Ecology, 57: 579-586.

Begon, M., C.R. Townsend & J.L. Harper. 2006. Ecology from individuals to ecosystems. Blackwell Publishing, London, 700 pp.

Béné, C. 2003. When fishery rhymes with poverty: a first step beyond the old paradigm on poverty in small-scale fisheries. World Develop., 31(6): 949-975.

Berger, W.H. & F.L. Parker. 1970. Diversity of planktonic foraminifera in deep sea sediments. Science, 68: 1345-1347.

Bertini, G., A. Fransozo & A.A. Braga. 2004. Ecological distribution and reproductive period of the hermit crab *Loxopagurus loxochelis* (Anomura, Diogenidae) on the northern coast of São Paulo State, Brazil. J. Nat. Hist., 38(18): 2331-2344.

Bertness, M.D. 1981. The influence of shell-type on hermit crab growth rate and clutch size (Decapoda, Anomura). Crustaceana, 40(2): 197-205.

Burone, L., P. Muniz, A.M.S. Pires-Vanin & M. Rodrigues. 2003. Spatial distribution of organic matter in the surface sediments of Ubatuba Bay (Southeastern Brazil). An. Acad. Bras. Ciênc., 75(1): 77-90.

Branco, J.O. & J.R. Verani. 2006. Análise quali-quantitativa da ictiofauna acompanhantena pesca do camarão sete-barbas, na Armação do Itapocoroy, Penha, Santa Catarina. Rev. Bras. Zool., 23(2): 381-391.

Branco, J.O., F. Freitas Júnior & M.L. Christoffersen. 2015. Bycatch fauna of seabob shrimp trawl fisheries from Santa Catarina State, southern Brazil. Biota Neotrop., 15(2): 1-14.

Castilho, A.L., M.A. Gavio, R.C. Costa, E.E. Boschi, R.T. Bauer & A. Fransozo. 2007. Latitudinal variation in population structure and reproductive pattern of the endemic South American shrimp *Artemesia longinaris* (Decapoda: Penaeoidea). J. Crustacean Biol., 27: 548-552.

Costa, R.C., A. Fransozo & A.P. Pinheiro. 2004. Ecological distribution of the shrimp *Pleoticus muelleri* Bate, 1888 (Decapoda: Penaeoidea) in southeastern Brazil. Hydrobiologia, 529: 195-203.

Connoly, P.C. 1986. Status of the Brazilian shrimp fishing operations and results of related research. FAO General Contribution, 3: 1-28.

Elwood, R.W., N. Marks & J.T.A. Dick. 1995. Consequences of shell-species preferences for female reproductive success in the hermit crab *Pagurus bernhardus*. Mar. Biol., 123(3): 431-434.

Escobar-Toledo, F., M.J. Zetina-Rejón & L.O. Duarte. 2014. Measuring the spatial and seasonal variability of community structure and diversity of fish by-catch from tropical shrimp trawling in the Colombian Caribbean Sea. Mar. Biol. Res., 11(5): 528-539.

Fantucci, M.Z., R. Biagi, A.L. Meireles & F.L. Mantelatto. 2009. Influence of biological and environmental factors on the spatial and temporal distribution of the hermit crab *Isocheles sawayai* Forest & Saint-Laurent, 1968 (Anomura, Diogenidae). Nauplius, 17(1): 37-47.

Fransozo, A., G. Bertini, A.A. Braga & M.L. Negreiros-Fransozo. 2008. Ecological aspects of hermit crabs (Crustacea, Anomura, Paguroidea) off the northern coast of São Paulo State, Brazil. Aquat. Ecol., 42: 437-448.

Fransozo, A., F.L. Mantelatto, G. Bertini, L.C. Fernandez-Góes & J.M. Martinelli. 1998. Distribution and assemblages of anomuran crustaceans in Ubatuba Bay, north coast of São Paulo State, Brazil. Acta Biol. Venez., 18(4): 17-25.

Fransozo, A., M.L. Negreiros-Fransozo, F.L. Mantelatto, M.A.A. Pinheiro & S. Santos. 1992. Composição e distribuição dos Brachyura (Crustacea, Decapoda) do sublitoral não consolidado na enseada da Fortaleza, Ubatuba (SP). Rev. Bras. Biol., 52(4): 667-675.

Gotelli, N.J & A.M. Ellison. 2011. Princípios de estatística em ecologia. Artmed, Porto Alegre, 528 pp.

Grabowski, R.C., S.M. Simões & A.L. Castilho. 2014. Population structure, sex ratio and growth of the seabob shrimp *Xiphopenaeus kroyeri* (Decapoda, Penaeidae) from coastal waters of southern Brazil. ZooKeys, 457: 253-269.

Gray, J.S. 2007. Marine biodiversity: patterns, threats and conservation needs. Biodivers. Conserv. 6: 153-175.

Hammer, Ø., D.A.T. Harper & P.D. Ryan. 2001. PAST: Paleontological statistics software package for education and data analysis. Palaeontol. Electron., 4(1): 1-9.

Haimovici, M. & J.T. Mendonca. 1996. Descartes da fauna acompanhantena pesca de arrasto de tangones dirigida a linguados e camarões na plataforma continental do sul do Brasil. Atlântica, 18: 161-177.

Hakanson, L. & M. Jansson. 1983. Principles of lake sedimentology. Springer-Verlag, Berlin, 316 pp.

Hardt, F.A.S. 2005. Padrões de residência do golfinho *Sotalia guianensis*, na Baía da Babitonga, litoral norte de Santa Catarina. Brasil. Dissertação Mestrado em Ciências Biológicas, AC: Zoologia, Universidade Federal do Paraná, Paraná, 120 pp.

Legendre, P. & L. Legendre. 1998. Numerical ecology, Elsevier Science, Amsterdam, 853 pp.

Magurran, A.E. 2004. Measuring biological diversity. Blackwell Science, Oxford, 256 pp.

Mantelatto, F.L., J.M. Martinelli & A. Fransozo. 2004. Temporal-spatial distribution of the hermit crab *Loxopagurus loxochelis* (Decapoda, Anomura, Diogenidae) from Ubatuba Bay, São Paulo State, Brazil. Rev. Biol. Trop., 52(1): 47-55.

McIntosh, R.P. 1967. An index of diversity and the relation of certain concepts to diversity. Ecology, 48(3): 392-404.

McLaughlin, P.A., R. Lemaitre & U. Sorhannus. 2007. Hermit crab phylogeny: a reappraisal and its "fall-out". J. Crustacean Biol., 27(1): 97-115.

McLaughlin, P.A., T. Komai, R. Lemaitre & D.L. Rahayu. 2010. Annotated checklist of anomuran decapod crustaceans of the world (exclusive of the Kiwaoidea and families Chirostylidae and Galatheidae of the Galatheoidea) Part 1. Lithodoidea, Lomisoidea and Paguroidea. Raff. Bull. Zool., 23: 5-107.

Melo, G.A.S. 1985. Taxonomia e padres distribucionais e ecológicos dos Brachyura (Crustacea: Decapoda) do litoral sudeste do Brasil. Ph.D. Thesis. Universidade de São Paulo, São Paulo, 215 pp.

Melo, G.A.S. 1999. Manual de identificação dos Crustacea Decapoda do litoral brasileiro: Anomura, Thalassinidea, Palinuridea e Astacidea. Editora Plêiade, São Paulo, 551 pp.

Negreiros-Fransozo, M.L. & N.J. Hebling. 1983. Desenvolvimento pós-embrionário de *Isocheles sawayai* Forest e Saint Laurent, 1968 (Decapoda, Diogenidae), em laboratório. Pap. Avul. Zool., 35(4): 41-53.

Negreiros-Fransozo, M.L., A. Fransozo, M.A.A. Pinheiro, F.L. Mantelatto & S. Santos. 1991. Caracterização física e química da Enseada da Fortaleza, Ubatuba, SP. Rev. Bras. Geociê., 21(2): 114-120.

Negreiros-Fransozo, M.L., A. Fransozo, F.L. Mantelatto, M.A.A. Pinheiro & S. Santos. 1997. Anomuran species (Crustacea, Decapoda) in their ecological distribution at Fortaleza Bay sublittoral, Ubatuba, São Paulo, Brazil. Iheringia, Sér. Zool., 83: 187-194.

Pielou, E.C. 1966. The measurement of diversity in different types of biological collections J. Theor. Biol., 13: 131-144.

Pilskaln, C.H., J.H. Churchill & L.M. Mayer. 1998. Resuspension of sediment by bottom trawling in the Gulf of Maine and potential geochemical consequences. Conserv. Biol., 12(6): 1223-1229.

R Development Core Team. 2009. R: a language and enviroment for statistical computing. R Foudation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0. http://www.R-Project.org.

Sá Paiva, K., J.A.N. Aragão, K.C.A. Silva & I.H.A. Cintra. 2009. Fauna acompanhante da pesca industrial do camarão-rosa na plataforma continental norte brasileira. Bol. Téc. Cient. Cepno. Belém, 9: 25-42.

Sant'Anna, B.S., C.M. Zangrande, A.L.D. Reigada & E. Severino-Rodrigues. 2006. Spatial distribution and shell utilization in three sympatric hermit crabs at non-consolidated sublittoral of estuarine-bay complex in São Vicente, São Paulo, Brazil. Rev. Biol. Mar. Oceanogr., 41(2): 141-146.

Santos, S., M.L. Negreiros-Fransozo & A. Fransozo. 1994. The distribution of the swimming crab *Portunus spinimanus* Latreille, 1819 (Crustacea: Brachyura: Portunidae) in Fortaleza Bay, Ubatuba, SP, Brazil. Atlântica, 16: 125-141.

Sedrez, M.C., J.O. Branco, F. Freitas Junior, H.S. Monteiro & E. Barbieri. 2013. Ictiofauna acompanhante na pesca artesanal do camarão sete barbas (*Xiphopenaeus kroyeri*) no litoral sul do Brasil. Biota Neotrop., 13(1): 1:11.

Severino-Rodrigues, E., D.S.F. Guerra & R. Graça-Lopes. 2002. Carcinofauna acompanhante da pesca dirigida ao camarão-sete-barbas (*Xiphopenaeus kroyeri*) desembarcada na Praia do Perequê, Estado de São Paulo, Brasil. Bol. Inst. Pesca, 28(1): 33-48.

Shannon, C.E. & W. Weaver. 1949. The mathematical theory of communication. University Illinois Press, Urbana, 117 pp.

Schettini, A.C. 2002. Caracterização física do estuário do Rio Itajaí-Açu, SC. Rev. Bras. Recur. Hídr., 7: 123-142.

Suguio, K. 1973. Introdução à sedimentologia. Editora da Universidade de São Paulo, São Paulo, 317 pp.

Teoh, H.W., M.S.H. Hussein & V.C. Chong. 2014. Influence of habitat heterogeneity on the assemblages and shell use of hermit crabs (Anomura: Diogenidae). Zool. Stud., 53(67): 1-9.

Thorson, G. 1950. Reproductive and larval ecology of marine invertebrates. Biol. Rev. Camb. Philos. Soc., 25: 1-45.

Tucker, M. 1988. Techniques in sedimentology. Blackwell Scientific Publications, Oxford, 394 pp.

Wallace, B.P., C.Y. Kot, A.D. Di Matteo, T. Lee, L.B. Crowder & R.L. Lewison. 2013. Impacts of fisheries bycatch on marine turtle populations worldwide:

toward conservation and research priorities. Ecosphere, 4(3): 40.

Wenner, E.L., D.M. Knott, R.F. Van Dolah & V.G. Jr. Burrell. 1983. Invertebrate communities associated with hard bottom habitats in the South Atlantic Bight. Estuar. Coast. Shelf Sci., 17: 143-158.

Received: 15 July 2015; Accepted: 22 April 2016

Ye, Y., K.L. Cochrane, G. Bianchi, R. Willmann, J. Majkowski & M.T.F. Carocci. 2012. Rebuilding global fisheries: the world summit goal, costs and benefits. Fish. Fish., 14(2): 174-185.

Zar, J.H. 1999. Biostatistical analysis. Prentice-Hall, New Yersey, 663 pp.