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DISSERTAÇÃO DE MESTRADO

Biologia e ecologia de crustáceos decápodos (Caridea e Brachyura) do infralitoral não consolidado da costa sudeste do Brasil

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BOTUCATU – SP

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Palavras-chave: Biodiversidade; Crustacea (Decapoda); Distribuição ecológica; Estratégia reprodutiva; Estrutura populacional.

"Não são as espécies mais fortes que sobrevivem nem as mais inteligentes, e sim as mais suscetíveis a mudanças."

Charles Darwin

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CONSIDERAÇÕES INICIAIS

CONSIDERAÇÕES INICIAIS

O subfilo Crustacea é, entre todos os organismos atuais, o grupo que apresenta a maior diversidade morfológica (Martin & Davis 2001). Essa variação de formas permitiu a esses organismos habitar os mais diferenciados ambientes, adquirindo, portanto uma expressiva distribuição no mundo todo (Ng *et al*. 2008). A ordem Decapoda é a mais diversa, sendo constituída de cerca de 14756 espécies descritas (De Grave *et al*. 2009) Essa ordem agrega organismos abundantes, com importância ecológica e apreciados na alimentação humana, como os camarões, lagostas, siris e caranguejos.

A Infraordem Caridea é representada por aproximadamente 2500 espécies de camarões descritos. Estes são caracterizados por apresentarem filobrânquias, o primeiro ou os dois primeiros pares de pereópodos quelados e de tamanhos variados e a segunda pleura abdominal marcadamente mais expandida, recobrindo parcialmente a primeira e a terceira pleuras (Hendrickx 1995). Esta Infraordem é formada por 16 superfamílias e 36 famílias (Martin & Davis 2001). A Família Palaemonidae, inserida dentro da Superfamília Palaemonoidea, é grande e diversa, com pelo menos 118 gêneros e 887 espécies. Os camarões palaemonídeos são epibentônicos e ecologicamente importantes, atuando como detritívoros, predadores de pequenos invertebrados e presas para peixes (Bauer 2004).

O camarão palaemonídeo utilizado nesse estudo foi o camarão barriga branca *Nematopalaemon schmitti* (Holthuis, 1950) (Figura 1). Esta espécie apresenta uma ampla distribuição geográfica, desde a Venezuela até o Brasil (do Amapá até São Paulo) (Holthuis 1980, Ramos-Porto & Coelho 1998). Esta espécie habita águas marinhas e

estuarinas, onde o substrato é composto por cascalho, areia e/ou silt + argila, e em profundidades de até 75 m (Holthuis 1980).

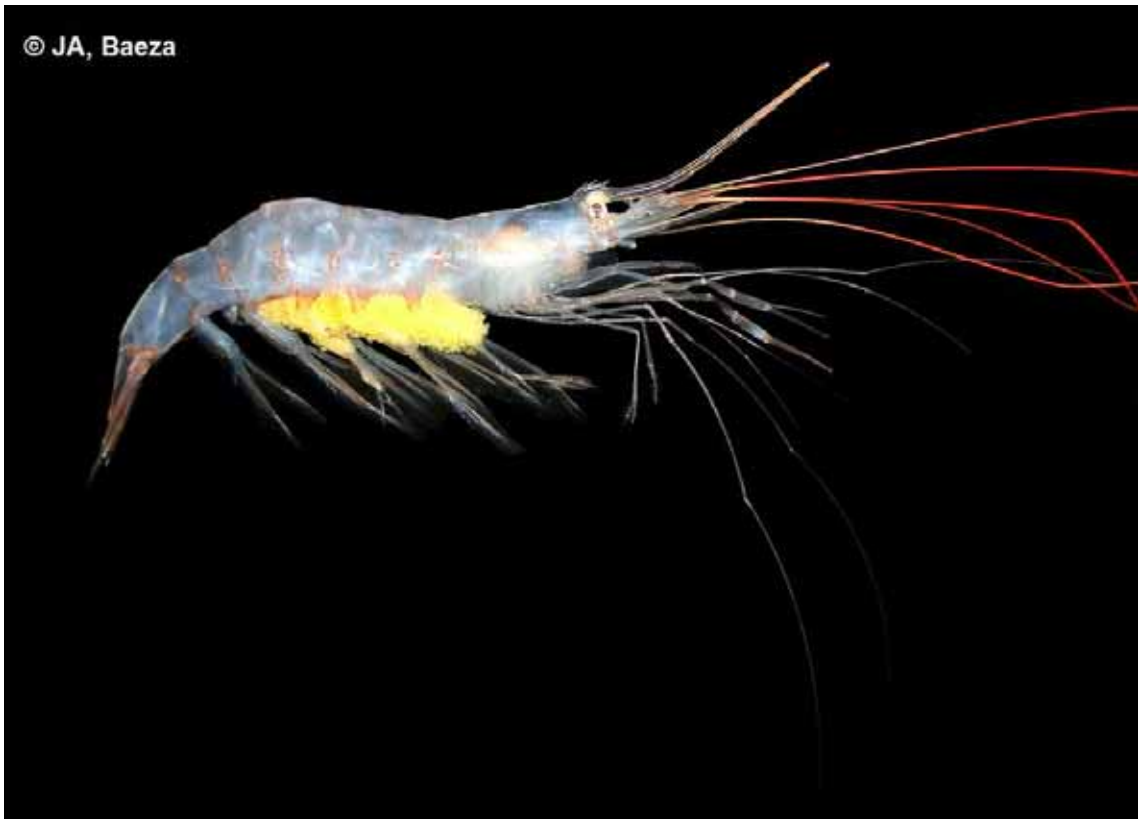

Figura 1 - *Nematopalaemon schmitti* (Holthuis, 1950). Foto de JA, Baeza.

Pertencente à subordem Pleocyemata, a Infraordem Brachyura é constituída por mais de 6700 espécies (Ng *et al*. 2008, De Grave *et al*. 2009), das quais mais de 300 são conhecidas na costa brasileira e 188 são descritas no litoral do Estado de São Paulo (Bertini *et al*. 2004). Esta Infraordem é composta por caranguejos e siris, os quais apresentam ampla distribuição, podendo ser encontrados em habitats diversificados (terrestre, marinho e dulcícola) (Ng *et al*. 2008).

As espécies de braquiúros utilizadas nesse estudo foram: *Persephona mediterranea* (Herbst, 1794), *Persephona punctata* (Linnaeus, 1758), *Persephona lichtensteinii* Leach, 1817 e *Callinectes danae* Smith, 1869.

Os caranguejos *P. mediterranea* (Figura 2), *P. punctata* (Figura 3), e *Persephona lichtensteinii* (Figura 4) apresentam ampla distribuição no Atlântico Ocidental, habitando zonas bentônicas, em substratos compostos por lodo, areia, conchas, algas calcárias e corais. No Brasil, *P. mediterranea* e *P. punctata* possuem distribuição mais ampla quando comparadas à *P. lichtensteinii*. As duas primeiras ocorrem desde o Amapá ao Rio Grande do Sul, enquanto a outra espécie se distribui do Amapá à São Paulo (Melo 1996).

Figura 2 - *Persephona mediterranea* (Herbst, 1794). Foto de A, Fransozo.

Figura 3 - *Persephona punctata* (Linnaeus, 1758). Foto de A, Fransozo.

Figura 4 - *Persephona lichtensteinii* Leach, 1817. Foto de A, Fransozo.

O siri *Callinectes danae* (Figura 5) tem distribuição registrada para o Atlântico Ocidental, sendo encontrado em Bermuda, Flórida, Golfo do México, Antilhas, Colômbia, Venezuela e Brasil (da Paraíba ao Rio Grande do Sul). Essa espécie habita, preferencialmente, regiões de águas salobras até hipersalinas, sendo encontrada em manguezais e estuários lamosos, em praias arenosas e mar aberto, e na região intertidal até os 75m de profundidade (Melo 1996).

Figura 5 - *Callinectes danae* Smith, 1869. Foto de A, Fransozo.

Conhecer a distribuição de organismos marinhos é de fundamental importância para inferir sobre preferência de habitat, seja espacial ou temporal. Além disso, pode-se prever com base nos fatores ambientais analisados, de que forma essa distribuição pode ser moldada por fatores ambientais. No entanto, é importante pensar que a distribuição não é regida apenas por relações entre os organismos e os agentes do ambiente, variações genéticas e até mesmo intra e interespecíficas podem alterar os padrões distribucionais de organismos marinhos (Haedrich *et al*. 1975, Hecker 1990, Pinheiro *et al*. 1996, Bertini *et al*. 2001, Bertini & Fransozo 2004). Compreender esses padrões de distribuição é importante para conhecermos a biologia e ecologia das populações, fornecendo resultados que sirvam de subsídio a futuros estudos e ainda informações que possam servir de fonte para que os órgãos competentes possam estabelecer medidas de mitigação de impacto sobre as espécies marinhas.

Ao se estudar uma população, a biologia reprodutiva e todos os seus aspectos deve ser estudada a fim de estabelecer padrões reprodutivos para espécies. Isso pode auxiliar a determinação de regiões de reprodução, as quais são de fundamental importância para a conservação e manutenção das populações. Aspectos como o tamanho ao atingir a maturidade sexual e o período reprodutivo da espécie são utilizados como ferramenta para definir períodos de defeso para espécies de interesse comercial. O tamanho ao atingir a maturidade sexual representa o tamanho a partir do qual os indivíduos tornam-se aptos a reprodução e, portanto, manter o equilíbrio da população (Hines 1982). Esse tamanho pode variar diante de uma série de fatores ambientais, gradiente latitudinal, relações intra e interespecíficas (Sastry 1983, Hartnoll 1982, 1985, 2006). Por isso, é importante conhecer o que, de fato, atua sobre a reprodução da população. Além disso, o período reprodutivo deve ser compreendido,

seja para dar suporte às inferências de regiões de reprodução, afirmando quando os organismos de uma população estão ativos reprodutivamente, ou então para dar suporte e informações básicas à biologia de espécies marinhas, podendo evidenciar padrões de reprodução contínua ou sazonal.

A fim de fornecer informações complementares de populações, são ainda realizados estudos da estrutura populacional. Esses são fundamentais para se conhecer de que forma esses animais se distribuem em grupos demográficos (Jovens, Machos, Fêmeas e Fêmeas ovígeras), e como esses grupos flutuam em decorrência de eventos de natalidade e mortalidade. Ainda, esse tipo de estudo pode fornecer informações quanto ao equilíbrio populacional, quando se considera a razão sexual entre machos e fêmeas. Por fim, nesse tipo de estudo, pode-se ainda verificar a entrada de jovens na população ao avaliar o recrutamento da mesma, e assim obter informações que auxiliam tanto na compreensão da estrutura, e dos aspectos reprodutivos desses organismos (Bertini *et al*. 2010, Almeida *et al*. 2013).

De modo geral, a presente dissertação tem como título "Biologia e ecologia de crustáceos decápodos (Caridea e Brachyura) do infralitoral não consolidado da costa sudeste do Brasil", sendo subdividida em duas seções, as quais estão subdivididas em capítulos. A primeira seção, Infraordem Caridea, é composta por um capítulo. A segunda seção, Infraordem Brachyura, é subdividida em três capítulos. O primeiro capítulo, "Reproductive strategy of the shrimp *Nematopalaemon schmitti* (Holthuis, 1950) (Decapoda, Caridea, Palaemonoidea) from the Southeastern Brazilian coast" aborda as estratégias reprodutivas do camarão carídeo *N. schmitti*, focando no investimento reprodutivo, fecundidade, perda de ovos, e sincronia no desenvolvimento de ovos e ovários dessa espécie. Os dados utilizados nesse capítulo são provenientes de

coletas entre os anos de 2008 e 2011 na Enseada de Ubatuba. O segundo capítulo, "Ecological distribution and population parameters of *Persephona mediterranea* (Herbst, 1794) (Brachyura, Leucosiidae) in a protected área on the southeastern Brazilian coast" revela a distribuição ecológica de *P. mediterranea*, em diferentes profundidades e estações do ano, a estrutura populacional, a razão sexual e o tamanho ao atingir a maturidade sexual. Os caranguejos desse estudo foram coletados durante o ano 2000 na região de Ubatuba, na qual está incluída uma área marinha de proteção ambiental (APA marinha – Setor Cunhambebe). O terceiro capítulo, "Environmental factors influencing the distribution of three Species within the genus *Persephona* Leach, 1817 (Crustacea, Decapoda, Leucosiidae) in two regions on the northern coast of São Paulo State, Brazil" aborda a influência dos fatores ambientais na distribuição batimétrica de três espécies do gênero *Persephona*, buscando padrões de distribuição para essas espécies. Neste capítulo, os dados utilizados são provenientes de coletas no período de julho/2001 a junho/2003 nas regiões de Ubatuba e Caraguatatuba. O quarto capítulo, "Environmental factors modulating the abundance and distribution of *Callinectes danae* Smith, 1869 (Decapoda, Portunidae) from two áreas of the Southeastern coast of Brazil" compreende a influência dos fatores ambientais sobre a abundância e distribuição do siri *Callinectes danae*, destacando a abundância e distribuição da espécie em escala espacial e temporal. Esses siris foram coletados durante o período de julho/2001 a junho/2003 nas regiões de Ubatuba e Caraguatatuba. Assim, esta dissertação pretende contribuir com informações relevantes sobre aspectos da biologia e ecologia de diferentes espécies de crustáceos que habitam a costa sudeste brasileira.

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INFRAORDEM CARIDEA

CAPÍTULO 1

REPRODUCTIVE STRATEGY OF THE SHRIMP *Nematopalaemon schmitti* (HOLTHUIS, 1950) (DECAPODA, CARIDEA, PALAEMONOIDEA) FROM THE SOUTHEASTERN BRAZILIAN COAST

ABSTRACT

The specimens of *Nematopalaemon schmitti* were captured in southeastern Brazil from 2008 to 2011, for reproductive output (RO) and fecundity analysis of species. Changes in the egg development associated to the ovary maturation of ovigerous female were also analyzed in order to verify possible synchronous relationship between them. Obtained ovigerous females were measured (carapace length [CL]) and analyzed as the stage of development of their ovaries and eggs. The RO was calculated based on dry weight of eggs and female masses. Fecundity was expressed by the equation obtained from regression between egg numbers and CL. A significant relationship was observed between the number of eggs and CL ($p<0.001$), showing that as higher is the female higher is its capacity to produce eggs. Comparing the mean number of eggs in stages I and II in *N. schmitti*, became evident a loss of 7% of eggs. Females with rudimentary ovaries showed, predominantly, eggs in stage I and females with developed ovaries showed only eggs in stage II, showing synchrony between the developing of both, thus supporting the hypothesis of a continuous reproductive cycle for *N. schmitti* in the study region. The RO and fecundity can be affected for biotic and abiotic factors, as parasites and variations in the latitudinal gradient. Informations of the reproductive output and its relations with the synchrony between the gonadal and embryonic development are rare for the palaemonoid shrimps, although they are crucial in understanding the reproductive biology of these animals, as well as other caridean shrimps.

Keywords: Egg loss, egg production, reproductive biology.

INTRODUCTION

Reproductive characteristics of crustaceans may vary according to the individual intrinsic aspects such as the size and age of females, and also environmental factors (Sastry 1983). These variations that can be the number and size of eggs and the reproductive investment of individuals may reflect adaptive mechanisms of species to environmental conditions. All these reproductive aspects play an important role in the biology and ecology of the species (Yoshino *et al*. 2002). Changes in volume of eggs of species of crustaceans were verified by Sastry (1983) in latitudinal gradients, depth, thermal and salinity. Furthermore, significant differences in reproductive investment of freshwater and marine caridean were verified by Anger & Moreira (1998). Thus, to study newly fertilized eggs can help show responses to selective pressures that these eggs were submitted, which affect the reproductive investment and larval development of crustaceans (Bauer 1991).

Among the several subjects addressed in the reproduction of caridean shrimp studies, the reproductive output (RO) and the fecundity have been considered as important quantifiable measures of the species reproductive effort (e.g., Clarke *et al*. 1991, Clarke 1993, Anger & Moreira 1998, Wehrtmann & Lardies 1999, Kim & Hong 2004, Oh & Hartnoll 2004, Chilari *et al*. 2005, Pavanelli *et al*. 2008, Echeverría-Sáenz & Wehrtmann 2011). Reproductive output is defined by the association between the dry weight of the brood and dry weight of the female (Hines 1982). In general, both fecundity and RO show a strong relationship with some body measures of each species, and its respective variations at spatial and temporal scales. While, the Fecundity is considered as the number of eggs released by a female during a single spawning event

or specific period of its life history, being frequently associated to the female width (Negreiros-Fransozo *et al*. 1992, Ramírez-Llodra 2002).

The population of whitebelly shrimp *Nematopalaemon schmitti* (Holthuis, 1950) has been heavily impacted due to the fishing activity, which can cause imbalances in the food chain in which it is, since it presents fundamental ecological importance in their habitat, serving as a food source for other species as an important item of marine trophic web (Fransozo *et al*. 2009, Almeida *et al*. 2012). Nevertheless, the publications related to this species are restricted to spatial and temporal variations in abundance and association with abiotic factors (Fransozo *et al*. 2009, Almeida *et al*. 2012), population structure and reproductive period (Almeida *et al*. 2011). In the southeast coast of Brazil, *N. schmitti* occurs at temperatures around 23°C (usually recorded during autumn and winter), in areas where the sediment is composed of fine and very fine sand and silt and clay, and presence of algae and plant fragments (Fransozo *et al*. 2009, Almeida *et al*. 2012). Concerning the population structure of the whitebelly shrimp, there is a sexual dimorphism in body size, with males attaining smaller sizes than females. In addition, the reproduction of *N. schmitti* is characterized by a continuous pattern along the northern coast of São Paulo State (Almeida *et al*. 2011).

Therefore, additional investigations that contribute to the knowledge of the *N. schmitti* life history and reproductive aspects on the southeastern coast of Brazil are needed for the purpose of maintaining and preserving the natural stocks.

The aim of this study is describing some features of the reproductive biology of *N. schmitti* on the Brazilian southeastern coast, such as reproductive output (RO),

fecundity (F) and possible synchronous relationship between ovary maturation and egg development.

MATERIAL AND METHODS

Shrimp samples were collected from Ubatuba Bay (23º 30' S, 45º 09' W), São Paulo, during November 2008, January 2009, July 2010 and July 2011 using a fishing boat carrying two otter-trawl nets (4.5 m wide; 20 mm and 15 mm mesh diameter at the body and cod end of the net, respectively).

Females carrying embryos at different stages of development were immediately placed in an ice chest filled with ice, transported to the laboratory and stored frozen until analysis. Next, the carapace length (CL, the distance from the orbital angle to the posterior margin of the carapace) of each female was measured with a caliper (precision = 0.1 mm). After that, each female was examined under a stereomicroscope to determine the degree of embryonic and ovarian development. Two stages of embryonic development were recognized: (1) embryos just spawned with no visible eyes, no visible blastoderm and uniformly distributed yolk and (2) embryos near hatching with large developed eyes and no yolk (Corey 1981, Jewett *et al*. 1985). Similarly, based on the color and volume of the ovary, three stages of ovarian development were recognized: (1) rudimentary ovaries filling less than half of the space in the cephalothorax having a translucent white coloration, (2) developing ovaries with light orange coloration filling most of space in the cephalothorax, and (3) developed ovaries (near spawning) with dark orange coloration filling all the space in the cephalothorax and the first abdominal segment (modified from Bauer & Abdalla 2000).

Females were measured and their embryos and ovarian development examined. The totality of the embryos attached to the pleopods of each female was carefully extracted using a dissecting needles and a fine brush. After that, they were counted

under the dissecting microscope. Each female and their embryo masses were dried for 48 h at 60°C and then weighed with an analytical balance (precision = 0.001 g). The differences between the number of eggs in different stages of development were tested using a Student t–test.

The RO and fecundity were analyzed based on measurements of weight and body size, respectively. In addition, the brood production of the whitebelly shrimp was characterized according to changes in the ovary maturation and egg development.

Differences in the RO of *N. schmitti* were analyzed by size classes with interval of 0.5 mm CL using analysis of variance (One-way ANOVA, $\alpha = 0.05$), followed by a multiple comparison test (Tukey, $\alpha = 0.05$).

The fecundity (F = n° embryos female−1) of each female were obtained from both stages 1 and 2 of embryonic development. Whereas the reproductive output (RO = brood dry weight / female body dry weight - Clarke *et al*. 1991) was analyzed based on females carrying initial embryos (Stage I). The isometry was tested for F vs. CL and brood dry weight (BDW) vs. female body dry weight (FBW). For this purpose, the relationship between F and CL, and brood weight and body weight of females was examined using the allometric model y = axb, converted to the linear form, lny = lna + blnx, by means of natural logarithm transformation (y = dependent variables [F or brood dry weight]; x = independent variable [CL or body dry weight]; a = intercept on the y-axis of the line relating y to x; and b = allometric coefficient - Hartnoll 1978, 1982). The slope b of the ln–ln least squares linear regression represents the rate of exponential change of each reproductive parameter with an increase in CL or body weight of female shrimps. The relationship between F and CL was considered isometric when b was = 3,

positively allometric when b > 3 and negatively allometric when b < 3 (Somers 1991). In turn, the relationships between brood dry weight and female body dry weight were considered isometric when b was = 1, positively allometric when b > 1 and negatively allometric when b < 1. Departures from isometry were tested using a Student t–test (Zar 2010).

We estimated embryo loss (%) during embryonic development and examined the hypothesis of successive spawning in *N. schmitti*. The hypothesis of no embryo loss during development was tested using a Student t-test (Zar 2010). In this test, embryo stage (I vs. II) was used as the factor to estimate differences between females carrying embryos in different stages of development in fecundity.

Lastly, the hypothesis of successive spawning was examined as in Bauer & Newman (2004) and Baeza (2006) by determining the association between embryonic and ovarian development. For this purpose, the association between embryonic and ovarian development categories was tested with the Goodman's test, which analyzes the contrasts between and within multinomial proportions (Goodman 1965, Curi & Moraes 1981). If females spawn successively after every molt, then the degree of embryonic development should be positively correlated with the degree of ovarian development.

In the different analyses above, tests for homocedasticity and normality of the contrasted data sets (after ln-ln transformation) were examined and found to be satisfactory (Zar 2010).

RESULTS

A total of 107 females carrying embryos at different stages of development were collected. Carapace length of ovigerous females varied between 10.2 and 13.7 mm, with mean (± standard deviation) of 11.6 ± 0.7 mm (Table I).

Table I – *Nematopalaemon schmitti* (Holthuis, 1950). Number of ovigerous females by size class (amplitude 0.5 mm CL), gonad development stage (Rudimentary, Developing, Developed), and embryo development stage (I = initial, II = final).

Gonad Stage		**Rudimentary**		**Developing**		**Developed**		
Embryonic stage		**I**	**II**	**I**	**II**	**I**	**II**	**Total**
Size classes	**CL (mm)**							
1	10.0 |-- 10.5	1	0	1	2	0	1	5
2	10.5 |-- 11.0	7	1	3	2	0	1	14
3	11.0 |-- 11.5	9	2	2	2	0	3	18
4	11.5 |-- 12.0	17	2	3	2	0	4	28
5	12.0 |-- 12.5	5	0	5	3	0	2	15
6	12.5 |-- 13.0	2	0	2	2	0	0	6
7	13.0 |-- 13.5	1	0	2	0	0	0	3
8	13.5 |-- 14.0	1	0	0	0	0	0	1
Total		43	5	18	13	0	11	90

CL = carapace length (mm); I = initial embryonic development; II = final embryonic development.

Differences between RO and size classes was not statistically detected (ANOVA: F= 0.59, df= 7, p = 0.76), while the ratio between the weight of female and the weight of the egg mass was positive statistically significant (linear regression: F= 27.67, df= 1.73, p< 0. 0001). Obtained an isometric relation to brood dry weight and female body dry weight. The average RO of *N. schmitti* was 0.123 ± 0.041, rangind from 0.055 to 0.248. The reproductive output total estimado was de 12.31% (Figure 1).

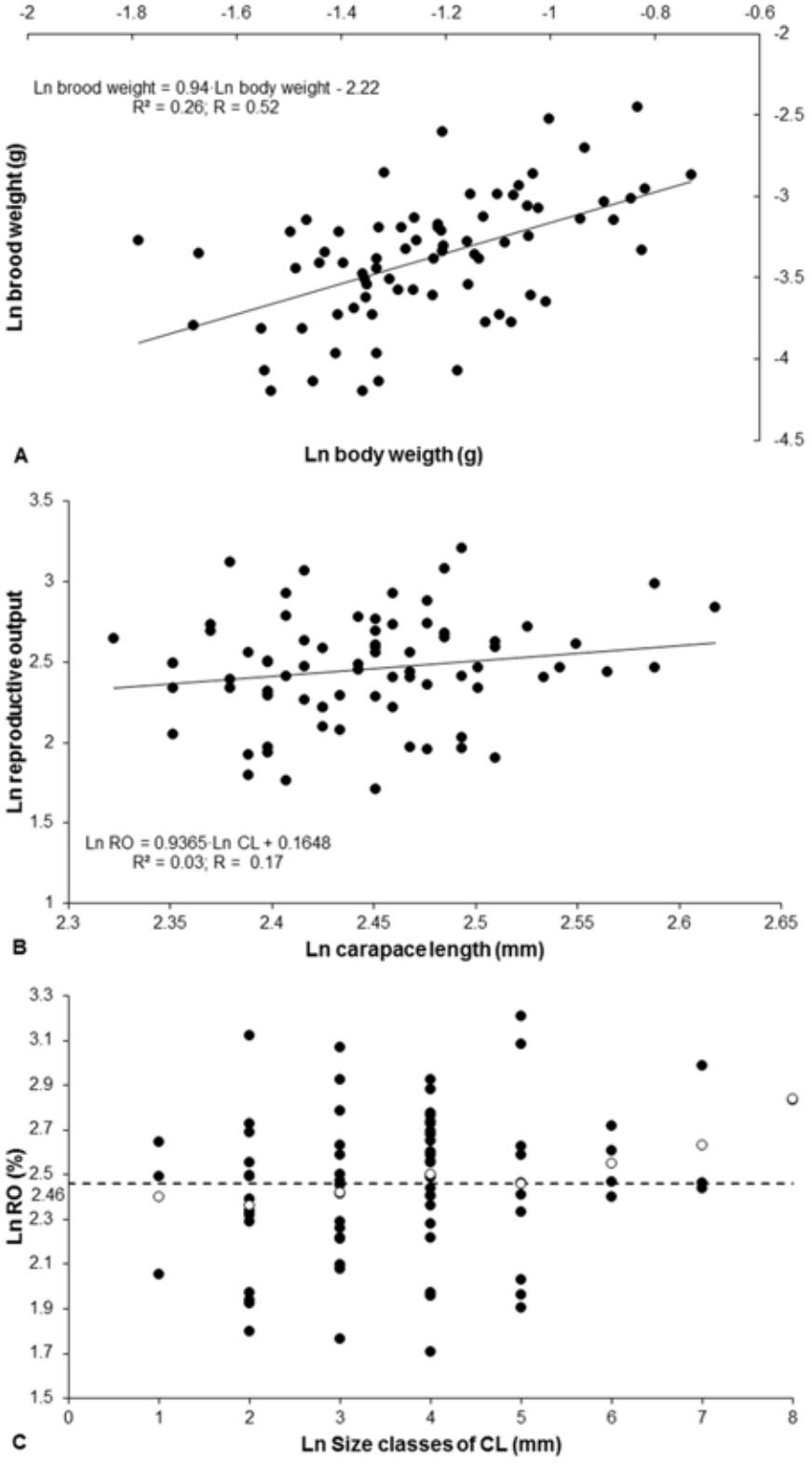

Figure 1 – *Nematopalaemon schmitti* (Holthuis, 1950). Reproductive output (RO) by carapace length (CL), size class and weight.

Fecundity of females carrying initial (stage I – N = 75) and final (stage II – N = 32) embryos varied, respectively, between 740 and 3293 (1542.03 ± 480.00 eggs) and between 708 and 2310 (1433.34 ± 406.26 eggs). No statistical difference was observed between the number of eggs at different stages of development (Student t-test, p = 0:30) with a loss of only 7% of embryos during development. Obtained an isometric relation to F and CL ratio. A positive statistically significant correlation between fecundity and CL was detected for females carrying both initial and final stage embryos (linear regression; stage I: R = 0.61, df = 1, p < 0.001; stage II: R =0.54, df = 1, p = 0.001) (Figure 2).

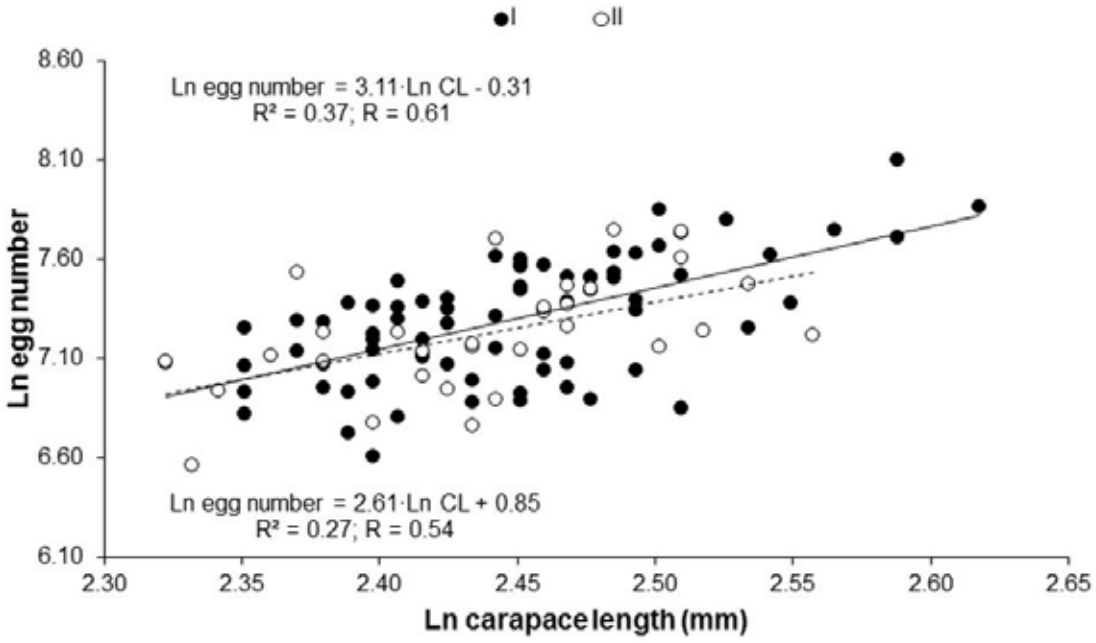

Figure 2 – *Nematopalaemon schmitti* (Holthuis, 1950). Allometric relationship between ln number of eggs and ln carapace length (I = initial embryonic development, II = final embryonic development).

Lastly, the association between ovarian and embryonic development was statistically significant (Goodman's test: $p < 0.05$). It is possible to observe changes in the egg development associated to the ovary maturation of females analyzed in the present study (Figure 3). Considering the developmental stages of eggs, there was a predominance of eggs in stage I (67.80%), followed by stage II (32.20%). In relation to gonadal development, it was observed that most females had rudimentary ovaries (53.33%). While females with developing and developed ovaries accounted for 34.44% and 12.22% of the total abundance, respectively. Females with rudimentary ovaries exhibited predominantly eggs at stage I, and females with developed ovaries showed only eggs in stage II. However, females with developing ovaries showed eggs in both stage I and II.

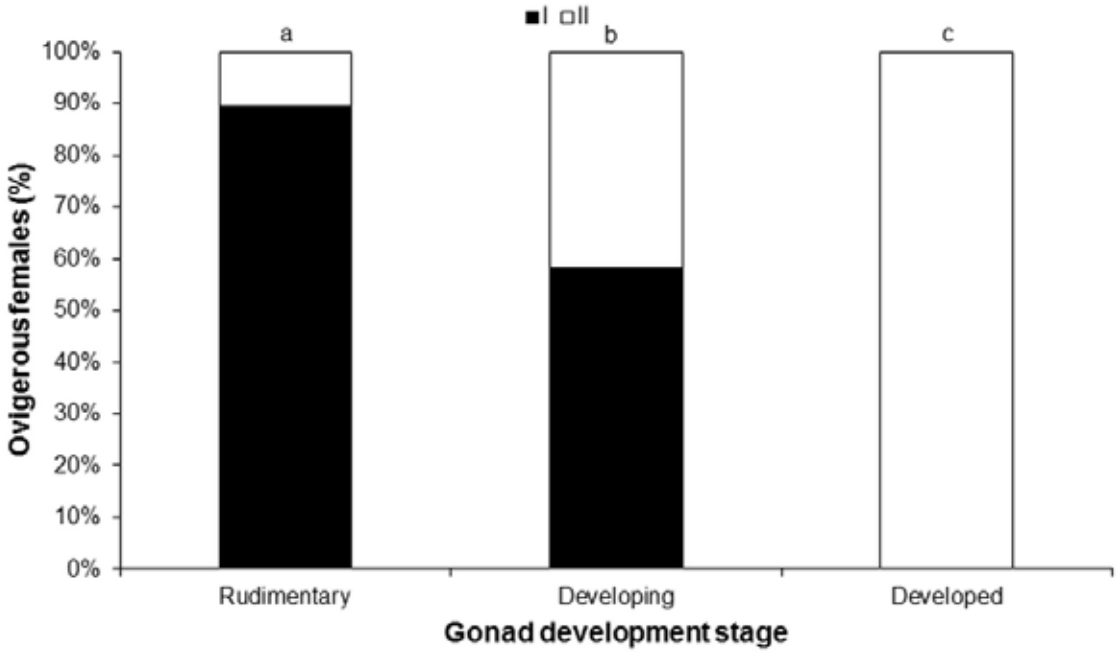

Figure 3 – *Nematopalaemon schmitti* (Holthuis, 1950). Frequency of ovigerous females (N = 100) in each embryo development stage (I = initial, II = final) related to each gonad development stage (Rudimentary, Developing, Developed).

DISCUSSION

No association was observed between reproductive output and the carapace lenght for *N. schmitti* in this study. Echeverría-Sáenz & Wehrtmann (2011) obtained similar results for *Heterocarpus vicarius* Fazon, 1893, attributing the lack of association between the RO and CL to variations in egg size of species. According Wehrtmann & Lardies (1999), as observed for fertility, the RO would also be related to latitudinal differences. These authors compared the RO of *Austropandalus grayi* (Cunningham, 1871) (collected in the Magellan Region, South America) with other species, and observed that *A. grayi* present lower values of RO compared to *Pandalus borealis* Kroyer, 1838 (collected in Western Bering Sea) and *Pandalus montagui* Leach, 1814 (collected in Northumberland coast, England), but high value when compared to *Heterocarpus reedi* Bahamonde, 1955 (collected in Northern Chile), indicating RO increased by increasing latitude. Thus, the production of eggs in caridean can be associated to the latitude of the area in which the species is distributed, there is a tendency to reduce the number of eggs and increase in eggs volume for the species that inhabit regions of high latitudes (Clarke *et al*. 1991, Echeverría-Sáenz & Wehrtmann 2011). It is possible that in southeastern Brazil the RO of *N. schmitti* is under latitudinal influence (23° 26’ S to 45° 02’ W), as observed by Clarke *et al*. (1991), Wehrtmann & Lardies (1999) and Echeverría-Sáenz & Wehrtmann (2011) for *P. borealis* species, *A. grayi* and *H. vicarius*, respectively, at different latitudes, for example 79° 10' N, 10° 40' E, 58° 47' N, 10° 55' E (Clarke *et al*. 1991.); 53° 42' 8" S, 70° 57' 4" N, 55° 09' 2" S, 67° 01' 6" W (Wehrtmann & Lardies 1999). How different latitudes imply different environmental conditions, specimens of *N. schmitti* obtained in this study in a tropical region have higher RO compared to species of polar areas, probably due to high

temperature, food availability, among other factors. Thus, species of tropical regions may have higher RO and consequent increased production of eggs to ensure the survival of their offspring by abiotic and biotic conditions favorable to their establishment in these regions.

Assuming that female size is closely linked to reproductive strategies (Hines 1982), the positive relationship between carapace length and number of eggs observed in *N. schmitti* is corroborated with previous studies for other caridean shrimp as *P. borealis* (Clarke *et al*. 1991), *Hippolyte zostericola* (Smith, 1873) (Negreiros-Fransozo *et al*. 1996), *A. grayi* (Wehrtmann & Lardies 1999) *Exhippolysmata oplophoroides* (Holthuis, 1948) (Chacur & Negreiros-Fransozo 1999), *Hippolyte obliquimanus* Dana, 1852 (Mantelatto *et al*. 1999) and *Palaemon gravieri* (Yu, 1930) (Kim & Hong 2004). This positive relationship suggests that larger females produce more eggs because they are more energy resource and ability to use it (Baeza 2006), and more space in the abdomen to accommodate them (Clarke 1993, Chacur & Negreiros-Fransozo 1999, Mantelatto *et al*. 1999). According to Calado & Dinis (2007), in some cases after the seeding of puberty the growth rate of individuals of *Lysmata seticaudata* (Risso, 1816) decreases and energy resources are directed to gonad maturation. In the present study we observed that smaller females produce fewer eggs than larger females. Probably due to the larger females have higher abdominal cavity to accommodate the embryos and greater available energy resource, investing more in reproduction than smaller females. Although it is clear that the number of eggs is larger in larger females, the reproductive output does not vary significantly. The variation is much greater within each class than between the averages of the different classes.

Studies show that the number of eggs tends to be higher in areas of low latitude, not associated only to the size of females (Clarke *et al*. 1991, Wehrtmann & Lardies 1999), which may vary with the number of consecutive spawns in a same reproductive cycle (Sainte-Marie 1993) and by the loss of eggs during embryonic development (Mantelatto *et al*. 1999).

The egg loss that occurs during the development of embryos was reported by different authors (Wehrtmann & Lardies 1999, Nazari *et al*. 2003, Kim & Hong 2004, Oh & Hartnoll 2004, Echeverría-Sáenz & Wehrtmann 2011), among them Nazari *et al*. (2003) emphasize that this loss may be favorable for the eggs which remain adhered to the female pleopods, since they will have more space to accommodate in the abdominal cavity, allowing a greater circulation of water between them and the consequent increase rate of oxygen around them. Some authors mention the loss of eggs can be influenced by specimens sampling, increased volume eggs, parasite action or mechanical stress (Wehrtmann & Lardies 1999, Kim & Hong 2004, Oh & Hartnoll 2004, Echeverría-Sáenz & Wehrtmann 2011). In study conducted with the caridean *A. grayi* (Wehrtmann & Lardies 1999), it was verified the species loses 51.1% of the initially exteriorized eggs, being this loss related to the capture process and abrasions between embryos as for the caridean *H. vicarius*, a loss of 46.9% was observed (Echeverría-Sáenz & Wehrtmann 2011), which is associated with the end of embryonic development, when the incorporation of a large quantity of water occurs, which facilitates the larvae hatching. With the incorporation of large amounts of water, the eggs are larger and the space between them is reduced, which facilitates the abrasion between the embryos and the consequent loss to the environment. To *N. schmitti* a loss of less than the eggs of other species, with only 7% was observed. It was observed that

the loss of eggs in *N. schmitti* and other caridean, *Exopalaemon modestus* (Heller, 1862) (Oh *et al*. 2002) were similar, both around 7%. However, *E. modestus* inhabits freshwater environment and is subject to different conditions of temperature and salinity compared to the species of the marine environment. Moreover, the collection methodology can influence this loss, varying according to the time and type of network used in the sampling of specimens. For *E. modestus* used a hand net, while for *N. schmitti* made use of trawl nets. It is believed that the drag is more stressful for the animals, since they require longer collection time.

In the present study, comparing the abundance of females according to each stage of development of eggs and ovaries, it was possible to see, in general, synchrony between the development of both. Females with rudimentary ovaries showed mostly eggs in stage I, and females with developed ovaries showed only eggs in stage II. According to the results obtained in this study, along with the standard continuous reproduction of *N. schmitti* in the study region (Almeida *et al*. 2011), it is assumed that the reproductive cycle of females occurs as follows: females with ovaries in advanced stages of development suffer molt, called "parturial molt" are copulated and then externalize their eggs. After extrusion, the ovaries of these females are rudimentary, and eggs in early stages of development. During the incubation period, both the eggs as the ovaries develop almost in synchrony, and at larvae hatching, the ovaries of these females are at an advanced stage of development, beginning again with the reproductive cycle. With these results, we argue in support of the hypothesis of successive spawning as in Bauer & Newman (2004) and Baeza (2006). It was noted in this study that the number of eggs exteriorized by *N. schmitti* is correlated to carapace length, showing that larger specimens have higher space available to accommodate the eggs in the abdomen

and greater potential as energy resources for production of the eggs. The loss of 7% in the number of eggs initially externalized can be linked to factors such as the increase in egg volume and the action of parasites, for example, may also have some influence on the loss. Although larger females have shown a greater number of eggs, the RO was not significantly associated to the size of females. Therefore, research on the reproductive biology of species that are widely distributed among different latitudes, help in understanding the influence of these species on the production of eggs. Through the wide geographic distribution of caridean *N. schmitti*, studies that address the RO along the Atlantic became critical for a better understanding of the reproductive biology of this species. The synchrony observed between the development of eggs and ovaries supports the standard cycle of continuous reproduction of *N. schmitti* in the study region. These results allow us a better understanding not only of the reproductive biology of *N. schmitti*, as well as other caridean which occur in the region of this study. Researches of this nature are essential for us to be able to propose effective conservation strategies, such as mitigation of impact on natural communities and important suggestion for conservation, and provide support for new research that addresses the biology and ecology of decapod crustaceans.

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INFRAORDEM BRACHYURA

CAPÍTULO 2

ECOLOGICAL DISTRIBUTION AND POPULATION PARAMETERS OF *Persephona mediterranea* (HERBST, 1794) (BRACHYURA, LEUCOSIIDAE) IN A PROTECTED AREA ON THE SOUTHEASTERN BRAZILIAN COAST

ABSTRACT

The crab *Persephona mediterranea* is an abundant species in trawl fisheries in the Brazilian coast. As with other by catch species, it is subjected to similar impact as target species. In order to ascertain the life history of by catch species, investigations on their distribution and population parameters are needed. Such information becomes even more strategic when obtained from priority areas for conservation, for instance marine protected areas. In this study we aimed to describe the patterns of ecological distribution of *P. mediterranea* at different depths and seasons in the Ubatuba region, which is included in a marine protected area off the southeastern coast of Brazil (APA Navy - Sector Cunhambebe). According to our results, *P. mediterranea* is more abundant during the winter and at depths of 10 to 15 m. The type of sediment, salinity variations at the bottom of the water column and depth strongly affect the demographics of this species. With respect to the population parameters, the recruitment pattern and continuous reproduction are highlighted. Our results on population structure, sex ratio and sexual maturity are similar to literature records for the southeastern region of the continental shelf, suggesting that the distributional, structural and reproductive characterization of *P. mediterranea* seems to be conservative among species of the genus *Persephona*. Results of studies such as ours, therefore, are indispensable for future comparisons and to make decisions concerning the species in a newly established Marine Protected Area on the southeastern coast of Brazil.

Keywords: Bathymetry, Brazilian littoral, purse crab, size at sexual maturity.

INTRODUCTION

The zonation of the soft-bottom marine fauna is probably the result of the interaction among complex physical and biological factors, and the relative importance of each factor varies among the different areas (Hecker 1990). What exactly determines zonation in benthic marine communities is insufficiently understood. The traditional perception has been that changes in the fauna correspond with variables in the physical environment, for example temperature, sediment type, intensity of currents, and topography (Haedrich *et al*. 1975).

As noted by Bertini & Fransozo (2004), the bathymetric distribution pattern of crabs is visible and, according to Pinheiro *et al.* (1996), it derives from the direct influence of environmental and biotic factors, which act on the benthic community. The distribution of decapods has been studied and associated with environmental factors such as bottom temperature, surface salinity, organic matter content, grain size and depth. The following publications on the subject are noteworthy: Santos *et al*. (1994), Negreiros-Fansozo & Fransozo (1995), Pinheiro *et al*. (1996), Atrill *et al*. (1999), Bertini *et al*. (2001), Martínez *et al*. (2009), Carvalho *et al*. (2010), Carvalho & Couto (2010). Environmental and biotic factors vary in space and time, and are especially influential in coastal areas when it comes to the population dynamics of crustaceans (Warwick & Uncles 1980, Bertini *et al*. 2001).

The reproductive cycles observed in decapods are continuous or seasonal (Sastry 1983, Choy 1988, Emmerson 1994, Pinheiro & Fransozo 2002). Several authors have studied the reproductive cycle of brachyurans with respect to the presence reproductively mature individuals (with developed gonads) and presence of ovigerous females (Batoy *et al*. 1987; Mantelatto & Fransozo 1999, Reigada &

Negreiros-Fransozo 1999, Mantelatto 2000, Pinheiro & Fransozo 2002, Bertini *et al*. 2010). Factors such as latitude, temperature and food availability can influence the reproductive season of brachyuran (Emmerson 1994).

The crab *Persephona mediterranea* (Herbst, 1794) is widely distributed in the western Atlantic, with records of occurrence at the intertidal zone down to 60 m deep (Melo 1996). Although the species is not considered of economic importance, Bertini *et al*. (2010) pointed out that populations of this crab are subject to similar impacts as commercially harvested crabs and prawns in the southeastern coast of Brazil. Furthermore, the species plays an important ecological role as part of the trophic web (Martínez *et al*. 2009, Almeida *et al*. 2013).

MATERIAL AND METHODS

1. Study area and sampling

The Ubatuba region was established as a MPA (Marine Protected Area from north coast: Sector Cunhambebe) by Proclamation No. 53525, on 8 October 2008 by the Brazilian Ministry of Environment, which aimed to prioritize the conservation, preservation and sustainable use of marine resources in the region. Under this MPA, fishing is only permitted in two circumstances: when it is necessary for the subsistence of traditional human communities, or for sports. Commercial fishing is not allowed. The idea is to protect, ensure and discipline the rational use of resources in the region, promoting sustainable development.

This region is characterized by innumerable spurs of the Serra do Mar mountain chain that form an extremely indented coastline (Ab`Saber 1955). The exchange of water and sediments between the coastal region and the adjacent shelf is very limited (Mahiques 1995). This region is influenced by three water masses: coastal water (CW: temperature > 20^{o}C, salinity < 36 PSU), tropical water (TW: > 20^{o}C, > 36 PSU) and South Atlantic central water (SACW: < 18^{o}C, < 36 PSU) (Castro-Filho *et al*. 1987, Odebrecht & Castello 2001). During summer months, the SACW penetrates into the bottom layer of the coastal region and forms a thermocline over the inner shelf, which is located at depths of 10 to 15 m. In the winter, the SACW retreats to the shelf break and is replaced by the CW. As a result, no stratification is present over the inner shelf (Pires 1992, Pires-Vanin & Matsuura 1993). The sediment is composed mainly of silt, clay, and fine and very fine sand, a result of the limited water movement within the bay and between the bay and the adjacent continental shelf (Mahiques *et al*. 1998).

Specimens of *P. mediterranea* were collected monthly in Ubatuba, São Paulo, from January to December 2000. Samples were taken with a commercial fishing boat equipped with "double rig" type nets (mesh size 20 mm, 15 mm in the cod end). Trawling was conducted at six different depths (10 m, 15 m, 20 m, 25 m, 30 m and 35 m) in the Ubatuba region (Figure 1).

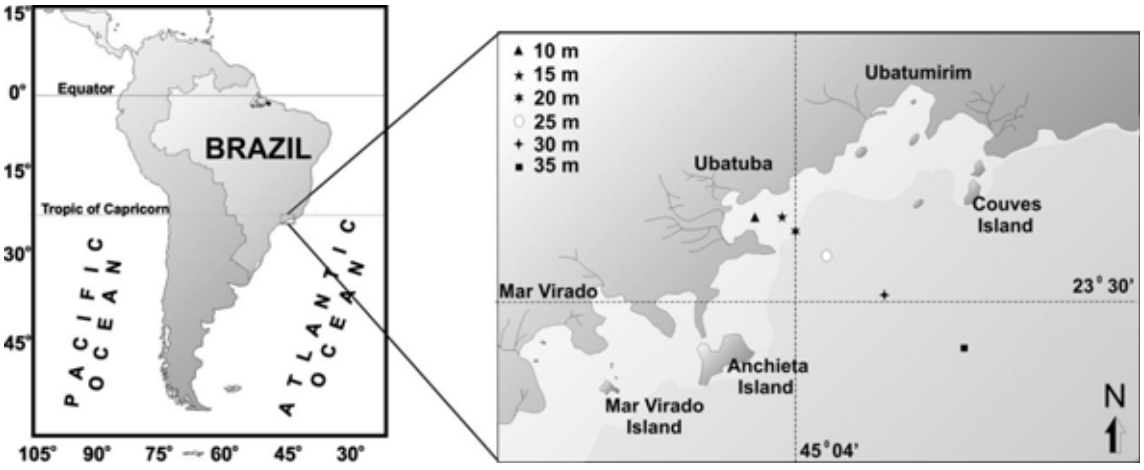

Figure 1 - Study area and transect sampling in Ubatuba, north coast of São Paulo, Brazil.

In each transect sampled we recorded bottom (BT) and surface (ST) temperatures, bottom (BS) and surface (SS) salinity, organic matter (OM) and sediment grain size (Phi).

Salinity (PSU) and temperature (^{o}C) were measured in samples of the bottom-water, obtained each month from each transect, using a Nansen bottle. Temperature was measured with a mercury thermometer and salinity was measured with an optic refractor.

Sediment samples were collected seasonally with a 0.06 m^2 Van Veen grab. In the laboratory, the sediment was oven-dried at 70^{o}C for 72h. For analysis of

grain size composition, two 50 g sub-samples were separated, treated with 250 ml of a 0.2 N NaOH solution and stirred for 5min to release silt and clay particles. Sub-samples were then rinsed on a 0.063 mm sieve. Sediments were sieved through 2 mm (gravel); 2.0-1.0 mm (very coarse sand); 1.0-0.5 mm (coarse sand); 0.5-0.25 mm (medium sand); 0.25-0.125 mm (fine sand); 0.125-0.063 mm (very fine sand); smaller particles were classified as silt-clay. Cumulative particle size curves were computer-plotted using the phi scale and phi values, corresponding to the 16^{th}, 50^{th} and 84^{th} percentiles read from the curves to determine the mean diameter of the sediment. This was calculated using the formula $Md = (\varphi_{15} + \varphi_{50} + \varphi_{84})/3$. The value of phi was calculated using the formula $\varphi = -\log_2 d$, where d = grain diameter (mm). The organic matter content of the sediment was calculated by the difference between the ash-free dry weights of three 10 g substrate subsamples incinerated in porcelain crucibles at 500^oC for 3h.

The three quantitatively most important sediments were defined according to Magliocca & Kutner (1965): class A corresponds to sediments in which medium sand (MS), coarse sand (CS), very coarse sand (VCS) and gravel (G) account for > 70% of the total weight; in class B, fine sand (FS) and very fine sand (VFS) make up > 70% of total weight of sediment. More than 70% of sediments in class C are silt and clay (S+C). From these three categories, groups were established according to the combination of granulometric fractions in several proportions: PA = (MS+CS+VCS+G) > 70%; PAB = prevalence of A over B (FS+VFS); PAC = prevalence of A over C (S+C); PB = (FS+VFS) > 70%; PBA = prevalence of B over A; PBC = prevalence of B over C; PC = (S+C) > 70%; PCA = prevalence of C over A; PCB = prevalence of C over B. All procedures for sediment analysis followed Hakanson & Jansson (1983) and Tucker (1988).

Species identification was based on Melo (1996). The gender of the crabs was identified and specimens were dissected for the macroscopic observation of gonad development. The sex of the crabs was determined by scanning the shape of the abdomen and number of pleopods in each individual (abdomen of females approximately oval with four pairs of pleopods; males with abdomen elongated in a "T" with two pairs of pleopods). The gonads were classified into four stages of development according to their volume and color: immature (IM), rudimentary (RU), developing (DE) and advanced (AD) (adapted from Johnson 1980 and Bertini *et al.* 2010). From the classification of gonad groups the population structure (demographics) was defined for statistical analysis as IMM, IMF, RUM, RUF, DEM, DEF, ADM, ADF and OF (ovigerous females). The following abbreviation acronyms of gonad development were used, followed by M for male and F for female. Gonads were measured with a precision caliper (0.01mm), and the largest width of the carapace (CW) was measured.

2. Statistical analyses

Initially, we tested the data for univariate and multivariate analysis normality, respectively, sing the Shapiro-Wilk test (Shapiro & Wilk 1965) and symmetry and multivariate kurtosis (Mardia 1970, 1980) (with modifications proposed by Doornik & Hansen 2008 - omnibus test). In order to test for univariate and multivariate homogeneity (equivalence of covariance matrices) we used the Levene test (Levene 1960) and the M Box test (Anderson 1958), respectively.

We analyzed crab size (CW) and population structure temporally (seasons) and spatially (depth) through the SDF, considering the demographic groups (males, females and ovigerous females). The number of size classes was estimated by the

rule of (1926): K = 1+3.322 x logN, where K = number of classes, N = number of individuals captured. The range class was obtained by the equation A/K, where A=difference of the largest individual collected minus the smallest individual collected. As for the sex ratio, the subjects were analyzed for each sex, month and season using the multinomial proportions test proposed by Goodman (Goodman 1964). This analysis compares the binomial proportion between and within multinomial populations (Curi & Moraes 1981).

The gonad sexual maturity was evaluated by plotting a logistic curve for each sex. The relative frequency (%) of subjects considered from the standpoint of mature gonads was plotted on a graph with the respective data size classes (Vazzoler 1996). The data were fitted by the logistics equation curve: $Y=1/1 + e^{r(LC-LC_{50})}$ with r = slope of the line, and LC_{50} = width of shell in which 50% of individuals are mature. The fit of the logistic function was determined by the method of least squares using the routine "Solver" program Microsoft Excel (Microsoft 2010) and by the GRG2 algorithm (Fylstra 1998). We considered individuals to be mature when their gonads could be classified as RU, DE and AD.

The relative abundance of crabs in groups of population structure (gonad stages) with respect to the environmental factors examined in each transect was assessed using redundancy analysis (RDA). Subsequently, we performed an adjustment of the RDA environmental vectors, a routine that draws the maximum correlation of environmental variables with the correlation data. The evaluation of the significance of the vectors adjustment was conducted through permutations (n = 9999) using the goodness of fit statistics of the squared (r^2) correlation coefficient. According to Oksanen *et al*. (2012), for the environmental variables it is defined as

$r^2 = 1 – SSw/ SSt$, where: SSw - sum of squares within groups and; SSt - total sum of squares.

All analyzes were performed using the software R (R Development Core Team 2012), considering $\alpha = 0:05$ (Zar 2010). The RDA and the adjustment of the environmental vectors were made with the package "vegan" (Oksanen *et al*. 2012). Each analysis was conducted separately, in order to avoid computational conflicts.

RESULTS

1. Population parameters

We obtained a total of 194 specimens of *P. mediterranea*: 96 males, 24 non-ovigerous and 74 ovigerous females. Males were more abundant in 15 m and 20 m depths; females, 15 m and 25 m (Table I). The abundance of individuals of both sexes was low in the 10 m and 35 m depths. The largest amount of ovigerous females was found in the 15 m transects and the smallest numbers in the 10 m, 20 m and 25 m depths. Ovigerous females did not occur at depths of 30 m and 35 m (Figure 2). The smallest mature male measured 23 mm CW, the smallest non-ovigerous female, 20.3 mm and the smallest ovigerous female, 25.7 mm CW.

Table I - *Persephona mediterranea* (Herbst 1794). Abundance of demographic groups in Ubatuba during the sampling period, for bathymetry. M – Males, F – Non ovigerous females, OF – Ovigerous females.

Depth	M	F	OF	Total
10	2	0	4	6
15	36	8	29	73
20	30	4	25	59
25	22	8	16	46
30	2	1	0	3
35	4	3	0	7
Total per sex	96	24	74	194
Percentage	49%	12%	38%	100%

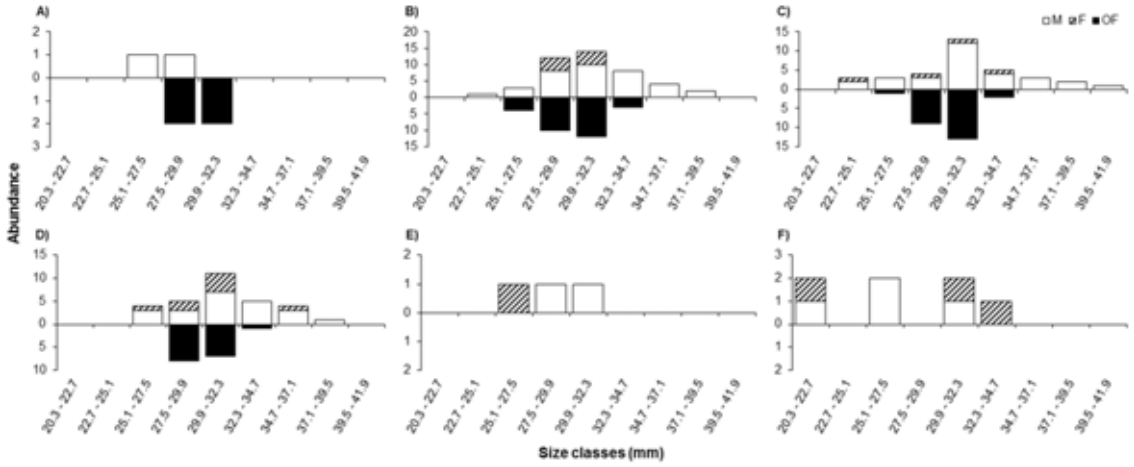

Figure 2 - Bathymetric distribution of demographic groups in Ubatuba during the sampling period. M – Males, F – Non ovigerous females, OF – Ovigerous female. A – 10 meters; B – 15 m; C – 20 m; D – 25 m; E – 30 m; F – 35 m.

Ovigerous females occurred in all seasons; they were not very abundant in the spring and summer. The largest size class crabs were more abundant in autumn and winter, whereas summer and spring were characterized by the presence of crabs in the lower class sizes (Figure 3).

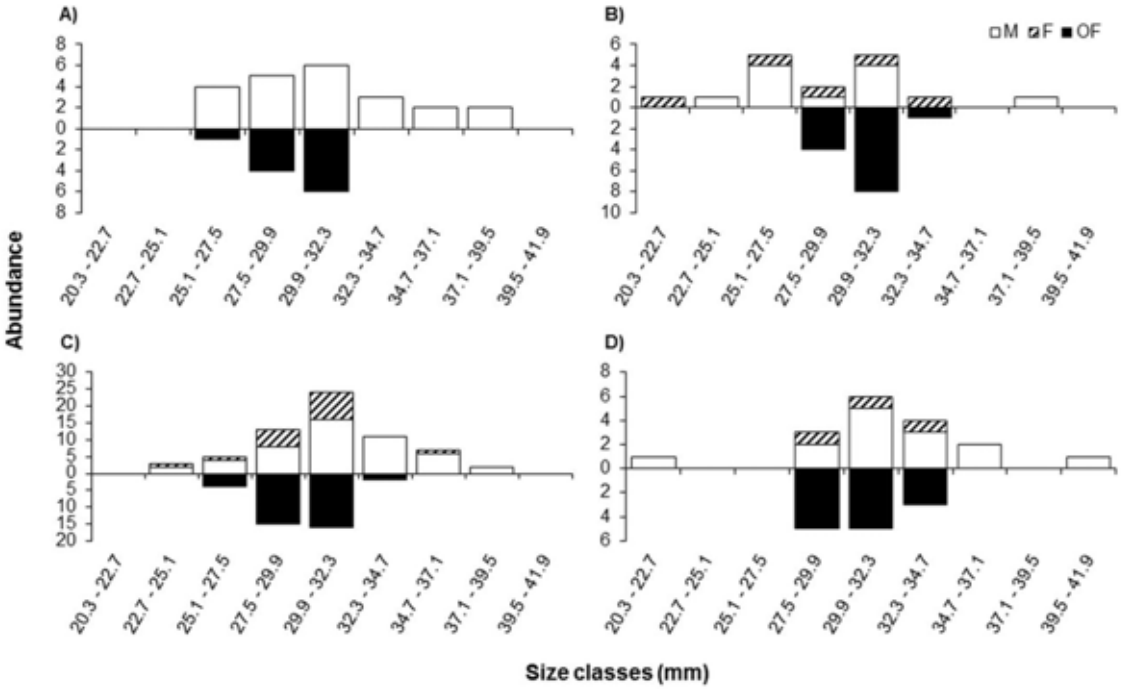

Figure 3 - Seasonal distribution of demographic groups in Ubatuba during the sampling period. See Figure 2 for acronyms. A – Summer; B – Autumn; C – Winter; D – Spring.

The multinomial analysis of Goodman indicated that there were seasonal (summer) and monthly (February) differences in the male/female ratio (Table II). When considering the variation in monthly multinomial proportions of each sex, we found different proportions of males in March, April, September, November and December and of females in January, March, April, June, August, September, November and December (Table II). Secondarily, with regards to the variation in seasonal multinomial proportions of each sex, differences were found between the summer and the other seasons for males, and between the summer and the winter for females (Table II). The size (CW) at which 50% of the crabs reached gonad maturity (CW_{50}) was 29.98 mm for males and 28.80 mm for females (Figure 4). Of the 194 individuals collected, only 3 (1.55%) were immature (Table III).

Table II – Results from Goodman multinomial proportion analysis for sex, by monthly and by season.

	Total N		Proportion			Total N		Proportion	
Months	Males	Females	Males	Females	Season	Males	Females	Males	Females
Jan	11	7	**A** 0.61	**B** 0.39					
Feb	9	3	**A** 0.75 **a**	**A** 0.25 **b**					
Mar	2	1	**B** 0.7	**BC** 0.3	Summer	22	11	**B** 0.67 **a**	**BC** 0.33 **b**
Apr	4	8	**B** 0.3	**B** 0.7					
May	7	9	**A** 0.4	**A** 0.6					
Jun	0	1	0	**BC** 1	Autumn	11	18	**BC** 0.44	**BC** 0.56
Jul	23	20	**A** 0.5	**A** 0.5					
Aug	22	29	**A** 0.4	**B** 0.6					
Sep	4	4	**B** 0.5	**BC** 0.5	Winter	49	53	**A** 0.48	**A** 0.51
Oct	11	14	**A** 0.4	**A** 0.6					
Nov	1	1	**B** 0.5	**BC** 0.5					
Dec	2	1	**B** 0.67	**BC** 0.33	Spring	14	16	**BC** 0.47	**BC** 0.53

Obs.: Similar uppercase letters in the same column indicate that there was no statistical difference between the months / seasons within each demographic group analyzed (males, females) ($p < 0.05$). Similar lowercase letters in the same line indicate that there was no statistical difference between each demographic group within each month / season ($p < 0.05$).

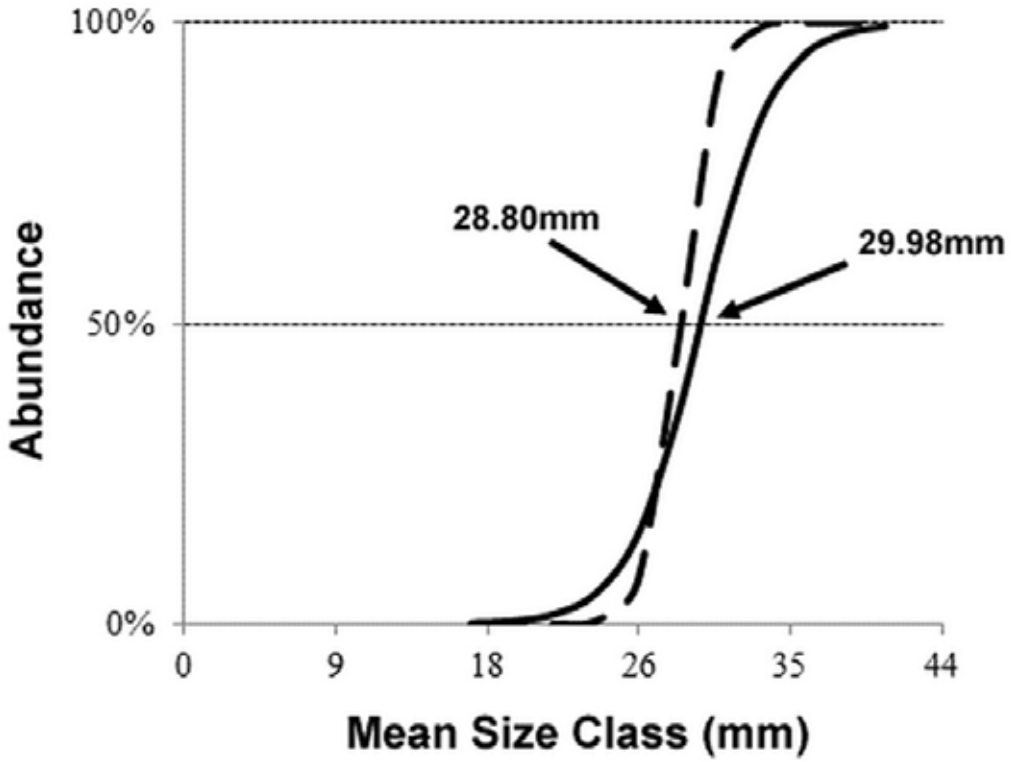

Figure 4 - Gonad size at maturity (CW_{50}) of males (full line) and females (dot line) of *P. mediterranea* from Ubatuba.

Table III - *Persephona mediterranea* (Herbst 1794). Abundance of immature and mature groups in Ubatuba during sampling period, by month.

Month	Absolute frequency of immatures	Relative frequency of immature (%)	Absolute frequency of mature forms	Relative frequency of mature forms (%)
Jan	0	0	18	9.28
Feb	0	0	12	6.19
Mar	0	0	3	1.55
Apr	0	0	12	6.19
May	2	1.03	14	7.22
Jun	0	0	1	0.52
Jul	0	0	43	22.16
Aug	0	0	51	26.29
Sep	0	0	8	4.12
Oct	0	0	25	12.89
Nov	0	0	2	1.03
Dec	1	0.52	2	1.03
Total	3	1.55	191	98.45

2. Bathymetric distribution

Redundancy Analysis (RDA) indicated that, in the first two axes generated, there was variation in the proportion of data in 95.18% (= 88.02% Axis 1 and Axis 2 = 7.16%) (Figure 5). The adjustment algorithm of the environmental vectors of the RDA proved that the groups of population structure are associated with the three environmental variables (salinity in the bottom - BS, Depth and Phi) (Table IV). Of the three environmental variables with significant correlation, according to the adjustment vectors, the observed order of influence in structuring the community were Phi, BS and depth. The population structure groups in the early stages of gonad development (IMM, IMF, RUF, RUM) were in the center of origin

of the RDA graph, indicating that these groups are the ones that are less associated with specific abiotic variables, whereas a gradient of gonad maturation for both sexes was observed in the negative direction of the axis 1 of the RDA. A direct association between the environmental variables Phi and BS with the gonad development gradient was observed, whereas depth was negatively associated with this gradient (Figure 5). The highest abundance was obtained in transects at 15 m and 20 m. The environmental factors checked in each transect were represented by their mean value and standard deviation (Figures 6, 7).

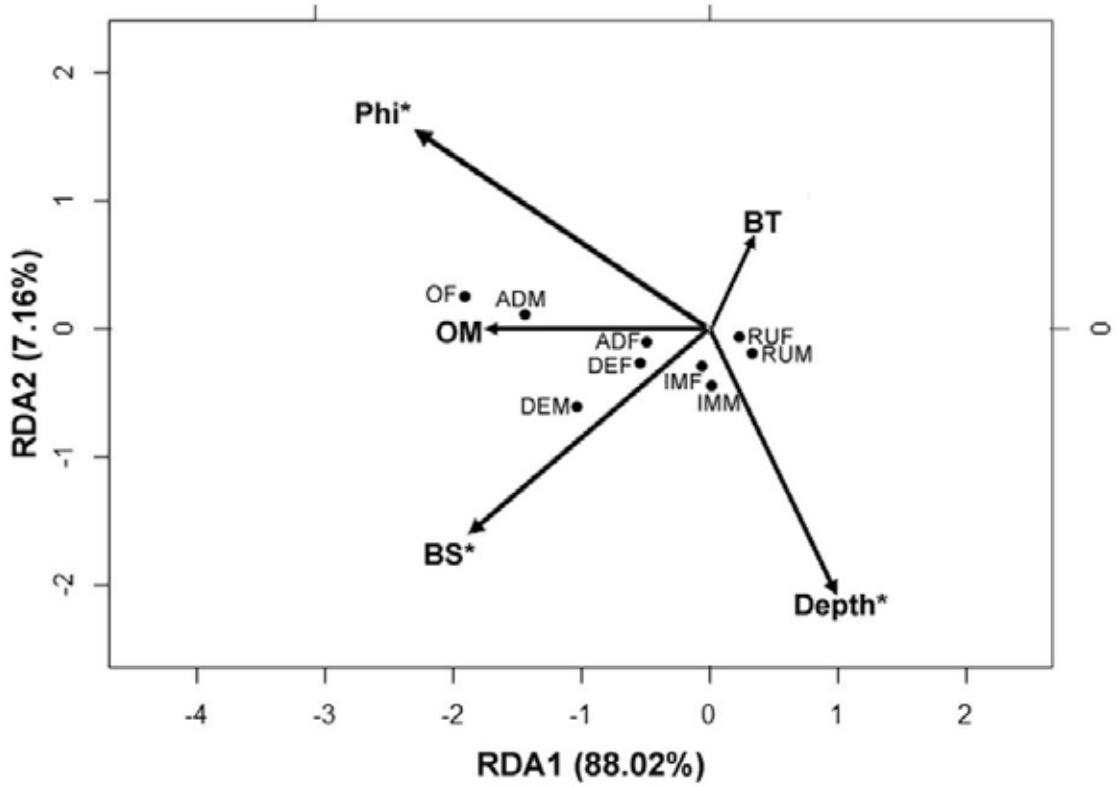

Figure 5 - Redundancy Analysis (RDA) for *P. mediterranea* in the Ubatuba region. *See Material & Methods for variables and population structure acronyms.* *significant variables under the environmental fitting algorithm.

Table IV - Environmental fitting from analysis of redundancy (RDA) showing significant correlated variables. R^2 – determination coefficient. *See Material & Methods for variables acronyms.*

	Axis 1	Axis 2	R^2	p-value
BT	0.45	0.9	0.04	0.591
BS	-0.67	-0.74	0.39	0.002
Depth	0.2	-0.98	0.25	0.029
Phi	-0.8	0.6	0.34	0.008
OM	-0.97	-0.23	0.15	0.126

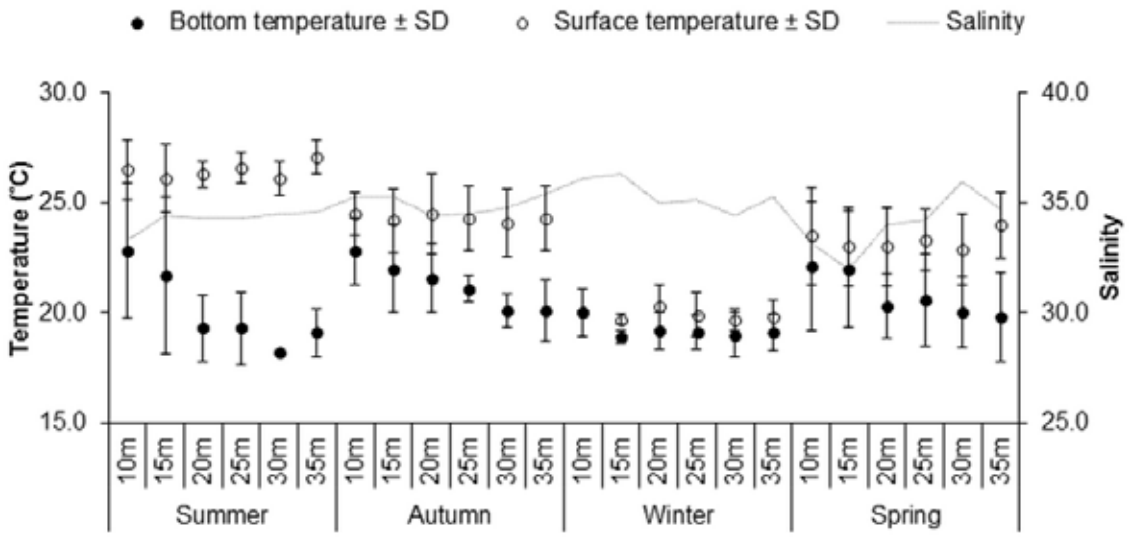

Figure 6 - Mean salinity, surface and bottom temperature variation of six transects from Ubatuba during 2000, by season.

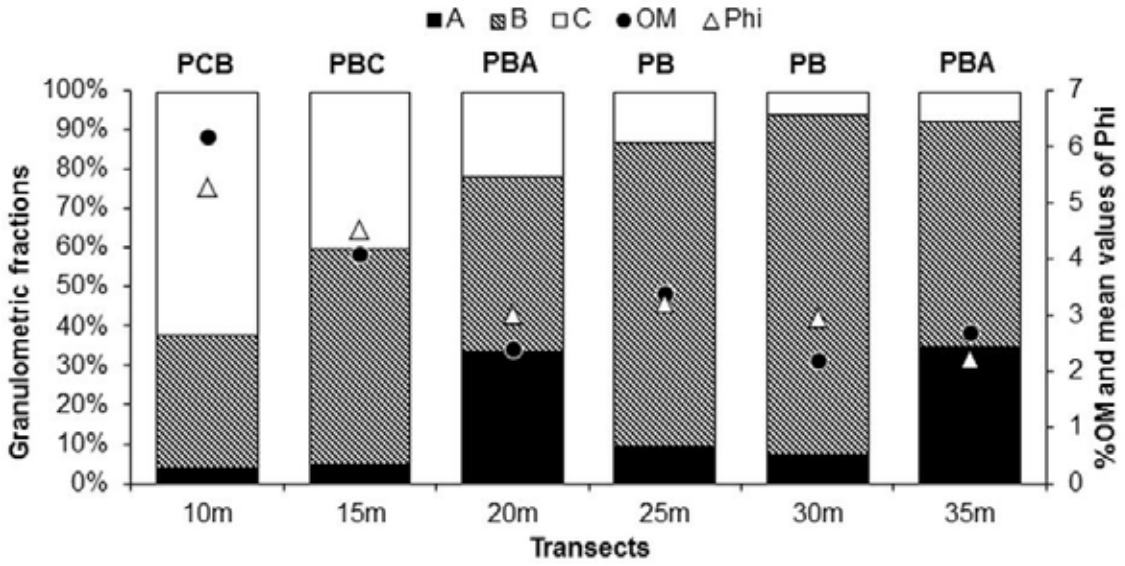

Figure 7 - Granulometric fractions, Organic-matter content (% OM), and phi of each transect. Grain-size classes (%): Black = Class A; Striped = Class B; White = Class C (*see Materials and methods for details*).

DISCUSSION

Persephona mediterranea was most abundant in the 15 m and 20 m transects, where 68 % of the individuals were captured. This result is consistent with the findings of Bertini & Fransozo (2004) and Bertini *et al.* (2010), who also collected more exemplars from transects at 15 m at 25 m. The preference for transects with similar sediment characteristics reflects the behavior of leucosids, which often get buried in fine sediment (Bertini *et al.* 2001, Carvalho *et al.* 2010).

The seasonal distribution indicated that *P. mediterranea* was most abundant in the winter. Bertini *et al*. (2001) found that *Persephona lichtensteinii* Leach, 1817 was more abundant in winter, whereas *Persephona punctata* (Linnaeus, 1758) was most abundant in the spring. Other authors observed a greater abundance of *P. punctata* and *P. lichtensteinii* in the autumn (Carvalho *et al.* 2010). Thus, we suggest that there is a reasonable variation in the abundance of species of the genus *Persephona* with respect to temporal variations.

The CW_{50} was slightly greater in males (29.98 mm) than in females (28.80 mm) in a manner similar to that found in the work Bertini *et al.* (2010), who studied the reproductive period and size of *P. mediterranea* at sexual maturity. Almeida *et al.* (2013) studied the relative growth, sexual maturity and reproductive period of three species of the genus *Persephona* Leach, 1817, including *P. mediterranea*. The same pattern was observed in other species of *Persephona* (Carvalho *et al*. 2010, Almeida *et al*. 2013), indicating that this is a conservative character in the genus. However, we emphasize that sexual maturity in decapods is subjected to spatial and latitudinal variations according to the different growth rates of individuals and changes in environmental factors that affect the organisms (Annala *et al.* 1980,

Hines 1982, 1989, Sampedro *et al*. 1999, Lestang *et al*. 2003). Significant differences in the size at which organisms reach sexual maturity may occur between sexes and congeneric species that have different reproductive strategies (Hartnoll 1985, Ramírez-Llodra 2002).

The sexual dimorphism found in our data, by which males had larger carapace compared to females, is a common pattern for Brachyura. After reaching sexual maturity, females grow slower, probably due to the energy requirements for egg production (Hartnoll 1982, 2006, Diaz & Conde 1989, Haefner & Spaargaren 1993, Mantelatto & Martinelli 1999, Bertini *et al*. 2010). When studying sexual maturity, the trade-off between growth and reproduction, processes that compete for energy resources, must be considered (Hartnoll 1985, Haefner & Spaargen 1993, Ramírez-Llodra 2002). Thus, in order for individuals to achieve reproductive success, resources must be properly allocated for it.

The reproductive pattern of *P. mediterranea* is continuous, which can be verified by the presence of individuals in reproductive age and ovigerous females throughout the year. However, in certain months, the reproductive activity is reduced. A similar pattern was observed by Bertini *et al*. (2010) for *P. mediterranea* and Almeida *et al*. (2013) for *P. mediterranea* and *P. punctata*, which suggests that the reproductive activity is conservative for the genus *Persephona*.

The pattern of continuous reproduction was also observed in other species on the northern coast of São Paulo, a subtropical region, for instance *Callinectes danae* Smith, 1869 studied by Costa & Negreiros-Fransozo (1998), *Callinectes ornatus* Ordway, 1863 by Mantelatto & Fransozo (1999) and *Hepatus pudibundus* (Herbst, 1785) by Reigada & Negreiros-Fransozo (1999). Subtropical and tropical regions provide favorable conditions for this pattern of continuous reproduction,

gonad and larval development and nutrition of individuals. However, temperate regions end up restricting the reproductive period of the species, which becomes seasonal following the availability seasonal of resources and variations in temperature (Sastry 1983).

The presence of developed female gonads and ovigerous females throughout the year may be an indication that the study area is a region where reproduction takes place and should be protected. Two pieces of evidence support the hypothesis of continuous reproduction in the region: the benefits of the organic matter content of the substrate for the crustaceans, which results in the enrichment of the pelagic trophic system, impacting the benthic system (González-Gurriarán & Olaso 1987), and the position of the ovigerous females in areas under the influence of the dynamics of water bodies, which acts on larval dispersal, directing the larvae to locals that favor the development (Mantelatto 2000).

The continuous recruitment pattern is characteristic of individuals with continuous reproduction. However, in this study we observed few numbers of immature individuals (1.55 %). The same was found by Almeida *et al*. (2013), and Bertini *et al*. (2010), who attributed the shortage of juveniles to the cryptic habits of *P. mediterranea*, recruitment in other areas, or ecological distribution.

The results presented here may be similar for other species of the genus *Persephona* along the Brazilian coast, since distributional, structural and reproductive characterization seems conservative. Thus, this study provides practical data for future comparisons of the life history and distribution patterns of *P. mediterranea* in a newly established marine protected area.

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CAPÍTULO 3

ENVIRONMENTAL FACTORS INFLUENCING THE DISTRIBUTION OF THREE SPECIES WITHIN THE GENUS *Persephona* LEACH, 1817 (CRUSTACEA, DECAPODA, LEUCOSIIDAE) IN TWO REGIONS ON THE NORTHERN COAST OF SÃO PAULO STATE, BRAZIL

ABSTRACT

Patterns of spatiotemporal distribution of Brachyura are determined by the interaction among life history traits, inter- and intraspecific relationships, as well as by the variation of abiotic factors. This study aimed to characterize patterns of spatiotemporal distribution of *Persephona lichtensteinii*, *Persephona mediterranea* e *Persephona punctata* in two regions of the northern coast of São Paulo State, southeastern region of Brazil. Collections were done monthly from July 2001 to June 2003 in Caraguatatuba and Ubatuba, using a shrimp fishery boat equipped with double-rig nets. The patterns of species distribution were tested by means of redundancy analysis (RDA) and generalized linear mixed models (GLMM) in relation to the recorded environmental factors (BT: bottom temperature, BS: bottom salinity, OM: organic matter and granulometry (Phi)). The most influent environmental factor over the species distribution was the Phi, and the ascendant order of influence was *P. lichtensteinii, P. punctata* and *P. mediterranea.* The greater abundance of *P. mediterranea* showed a conservative pattern of distribution for the genus in the sampled region. The greater occurrence of *P. punctata* and *P. lichtensteinii*, in distinct transects than those occupied by *P. mediterranea*, seems to be a strategy to avoid competition among congeneric species, which is related to the substratum specificity.

Keywords: Brachyura, ecological distribution, sediment.

INTRODUCTION

Aspects of life history traits and intra- and interspecific interactions may be related to the distribution of different species of Brachyura. Furthermore, several physical and chemical characteristics of environment and available resources may influence the distribution of brachyuran crab communities, leading to a broad or restricted distribution (Carvalho *et al*. 2010, Hiroki *et al*. 2011).

Persephona lichtensteinii Leach, 1817, *P. mediterranea* (Herbst, 1794) and *P. punctata* (Linnaeus, 1758) are widely distributed in the Western Atlantic in benthic zones, in substrates composed of mud, sand, shells, calcareous algae and corals. In Brazil, *P. mediterranea* and *P. punctata* have wider distribution compared to *P. lichtensteinii*. The first is distributed from Amapá to Rio Grande do Sul States, while *P. lichtensteinii* is distributed from Amapá to São Paulo (Melo 1996).

There are few studies on the biology of leucosiid species, including *P. lichtensteinii*, *P. mediterranea* and *P. punctata*. The early larval development of *P. mediterranea* was described by Negreiros-Fransozo *et al*. (1989). The spatial and temporal distribution of *Persephona* spp., reproductive period and the sexual maturity of *P. mediterranea* was reported by Bertini *et al*. (2001, 2010) in Ubatuba region. A comparative analysis of the distribution and sexual maturity of *P. lichtensteinii* and *P. punctata* in Ilhéus, Bahia State, was performed by Carvalho *et al*. (2010). And relative growth, sexual maturity, and breeding season of three species of the genus *Persephona* were compared by Almeida *et al*. (2013) in Ubatuba bay.

Crabs of the genus *Persephona* are commonly caught as by catch fauna of marine shrimp fisheries in trawls (Branco & Fracasso 2004), although they are not commercially exploited. *Persephona lichtensteinii*, *P. mediterranea* and *P. punctata*

might play an essential ecological role within the trophic web of benthic environments in which they are inserted (Almeida *et al*. 2013), the study of the species is fundamental to understand the species population dynamics and evaluate possible impacts of trawl fisheries on the communities of Brachyura, and thus establish mitigation activities for the species conservation. These actions are necessary, especially in areas such as Southeastern coast of Brazil, where marine ecosystems are affected by intense and uncontrolled expansion of tourism (Mantelatto *et al*. 1995), which provides higher fishery exploration in order to feed the demand of organisms that serve as food to the human population.

The aim of the present study was to characterize the spatio-temporal distribution patterns of three species of the genus *Persephona* in Ubatuba and Caraguatatuba, on the Southeastern Brazilian coast. These patterns of distribution were correlated with the main environmental factors and bathymetry.

MATERIAL AND METHODS

Sampling and data collection

Crabs were monthly collected from July 2001 to June 2003 in Ubatuba (UBA) and Caraguatatuba (CA) regions on the Northern coast of São Paulo State (UBA = 23°26'27"S – 45°03'18"W; CA = 23°36'09"S – 45°20'25"W, Figure 1). In each region, seven transects were sampled, located at mean depths of 5, 10, 15, 20, 25, 30 and 35 m (Table I). A shrimp fishery boat equipped with double-rig nets (mesh size 20 mm, 15 mm in the cod end) was used for trawling. Transects were trawled during 30 min, covering 18,000 m². Captured specimens were labeled and stored frozen until analysis. In laboratory, the crabs were identified according to Melo (1996).

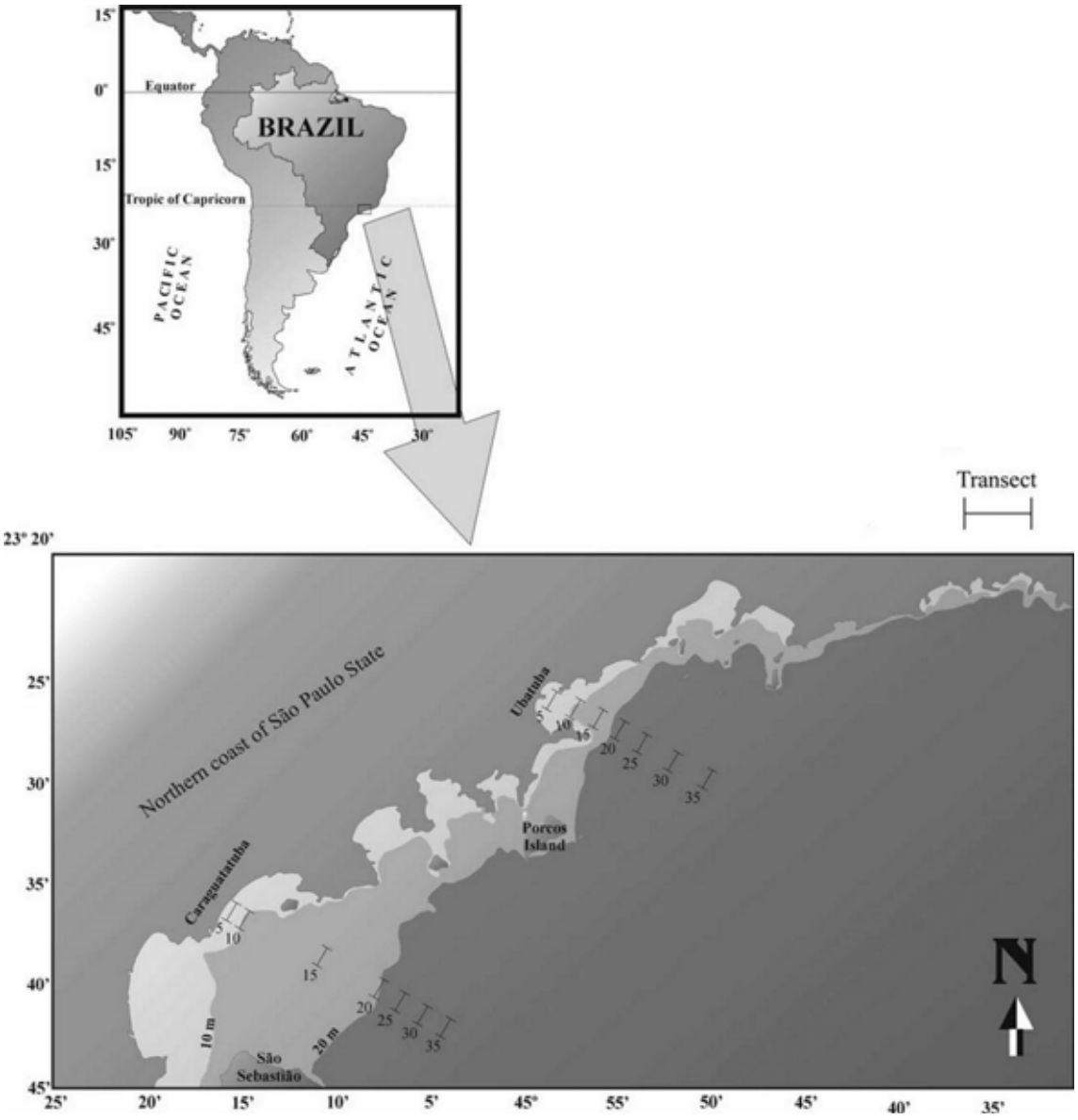

Figure 1 - Study area. Locality of Ubatuba and Caraguatatuba regions, northern littoral of São Paulo State, Brazil, indicating the transects of collection.

Table I - Geographic coordinates of each transects in the studied regions in the period from July 2001 to June 2003.

Transects (m)	Ubatuba		Caraguatatuba	
	Latitude	Longitude	Latitude	Longitude
5	23°26'27"S	45°03'18"W	23°36'09"S	45°20'25"W
10	23°26'08"S	45°02'11"W	23°36'47"S	45°25'35"W
15	23°26'49"S	45°00'41"W	23°39'52"S	45°14'23"W
20	23°28'03"S	44°59'39"W	23°40'07"S	45°11'41"W
25	23°28'51"S	44°58'55"W	23°40'12"S	45°09'50"W
30	23°30'14"S	44°58'06"W	23°42'04"S	45°07'16"W
35	23°31'57"S	44°55'28"W	23°43'07"S	45°00'42"W

The main differential on Northern coast of São Paulo (São Paulo Bight; Zembruscki 1979) is its geomorphological aspect, historically related to the presence of the ledge of Serra do Mar, thus forming an extremely irregular littoral with many bays with peculiar internal relief (Ab'Saber 1955, Mahiques *et al.* 2004), with semi-confined characteristics, suggesting a restrict interchange of water and sedimentary material between the coastal region and shallow continental shelf (Mahiques 1995).

At each transect salinity and temperature (bottom: BS, BT and surface water: SS, ST), depth, organic matter content (OM %), and mean grain-size (Phi) were measured. Bottom water was sampled using a Nansen bottle. Salinity (SU) was measured with an Atago S/1000 optic refractometer and temperature (°C) using a thermometer attached to the bottle. An ecobathymeter coupled with GPS (Global Positioning System) was used to record depth (m) at transects. Sediment samples were collected seasonally with a 0.06 m² Van Veen grab. In the laboratory, the sediment was dried at 70°C during 72 h in an oven. Two 50 g subsamples were separated, treated with 250 ml of a 0.2 N NaOH solution, and stirred for five minutes to release silt and clay particles. Subsamples were then sieved on a 0.063 mm mesh in order to analyze the

grain size composition. Sediments were sieved and the cumulative particle size curves were plotted using the Phi scale (see details in Tucker 1988).

The organic matter content (%) was obtained by ash weighting: three aliquots each one containing 10 g were placed in porcelain crucibles and incinerated for 3 hours at 500°C. The samples were then re-weighted (Mantelatto & Fransozo 1999).

The sediment texture was represented graphically by histogram using the three most important granulometric classes, as in Magliocca & Kutner (1965). Granulometric class A corresponds to sediments in which mean sand (MS), coarse sand (CS), very coarse sand (VCS), and gravel (G > 0.25 mm) account for more than 70% by weight. In class B, fine sand (FS) and very fine sand (VFS) make up more than 70% by weight of sediment samples. More than 70% of sediments in class C are silt and clay (S + C). These three categories were further combined to form different groups: PA = (MS +CS + VCS + G) > 70%; PAB = prevalence of A over B; PAC = prevalence of A over C; PB (FS + VFS)> 70%; PBA = prevalence of B over A; PBC = prevalence of B over C; PC (S + C) > 70%; PCA = prevalence of C over A; PCB = prevalence of C over B.

Statistical analysis

Initially, data were tested in relation to the univariate and multivariate normality, through Shapiro-Wilk test (Shapiro & Wilk 1965) and symmetry and multivariate kurtosis tests (Mardia 1970, 1980) (with modifications proposed by Doornik & Hansen 2008 – omnibus test), respectively. In order to test the homogeneity of variances the Levene test was used (Levene 1960). In addition, Box's M test (Anderson 1958) was performed to evaluate the equivalence (multivariate homogeneity) among covariance matrices with permutations of Monte Carlo for the significance value of the test. A correlation matrix of environmental

variables Depth, BT, ST, BS, SS, OM and Phi was created to observe the existence of collinearity among them. The Spearman correlation was preferred for this matrix because it disregards linear relations among variables. High collinearity was considered for modular correlation values higher than 0.7. Environmental variables that presented collinearity were removed from the following analysis. Data was complementary evaluated by the Variance Inflation Factor (VIF). Collinearity was considered for values higher than 10 for VIF.

To verify the influence of environmental factors on the species abundance a principal component analysis (PCA) was conducted followed by a redundancy analysis (RDA) and Generalized Linear Model (GLM) for each *Persephona* species. Initially PCA was performed with the aim to investigate and determine which environmental variables were capable to explain data variation, considering as significant those loadings higher than 0.7 and the main components that assigned for a cumulative variance from 70%. Environmental variables that satisfied such previous evaluation were separated for a posterior RDA used to assess the relation of abundance of *P. lichtensteinii*, *P. mediterranea* and *P. punctata* and environmental factors on each analyzed transect. In addition, environmental vectors were fitted on RDA through the function "envfit", a routine that traces the maximum correlation of environmental variables with data from an ordination. The evaluation of vectors value significance occurred by permutations (n = 999) using the goodness of fit of the square correlation coefficient (r^2). According to Oksanen *et al.* (2012) for environmental variables this is defined as $r^2 = 1 – SSw/ SSt$, being SSw – sum of squares within the group and SSt – sum of total squares.

Generalized Linear Models (GLM) were used to model each studied species by environmental factors. Independent variables were those abiotic variables

indicated by the fit of environmental vectors on RDA and categorical variables (region and season), using the distribution of Poisson with function logarithmic-type. For the categorical variable "Region", the "CA" level (region of Caraguatatuba) was fixed because the highest abundance of species was verified in this region. For the categorical variable "Season", the "Winter" level was fixed also because of the greater amount of individuals found in this season.

Due to the great number of zeros recorded in the abundance of each species (dependent variables), a Generalized Linear Mixed-Models Zero-Inflated was chosen. When executing such models, data were treated in two ways, the first one grouped all data in which there were abundance values and performed a GLM Poisson (Count part), and in the second data were transformed in presence/absence followed by a GLM Binomial (Occurrence part), it means, in mixed models the influence of independent variables on the variation of abundance and occurrence were evaluated (Zuur *et al.* 2009) for the *Persephona* species:

Y ~ Count part | Occurrence part. Equal to:

Y ~ X1 + X2 + X3 + X4 + Xi | X1 + X2 + X3 + X4 + Xi

where, Y is the dependent variable (species of *Persephona*), Xi are the independent variables (categorical or quantitative).

The occurrence of overdispersion (ϕ) of data was tested through the likelihood ratio (L/R), which was applied with the same data of each species between a GLMM Zero-Inflated by Poisson distribution (GLMM ZIP) and a GLMM Zero-Inflated by Negative Binomial distribution (GLMM ZINB),

indicating overdispersion through the significant difference ($p<0.05$) between the models. Overdispersion of data refers to the ratio of residual deviation in function of degrees of freedom, surpassing the unitary equality ($\phi \neq 1$), it means, when the obtained values of variance are significant higher than the mean.

Only reduced models of GLMM were considered for the better interpretation among *Persephona* species. In addition, the reduced models were developed by manual technique of variable removed step by step. All adopted proceedings for GLMM were based on Zuur *et al.* (2009).

All statistical analyses were made using the software R (R Development Core Team 2012), considering $\alpha = 0.05$ (Zar 1999). The following packages were used: "vegan" (RDA, envifit, Oksanen *et al.* 2012), 'pscl' (GLMM Zero-Inflated, Jackman, 2012), 'lmtest' (Likelihood Ratio Test, Zeileis & Hothorn 2002).

RESULTS

Salinity presented the more homogeneous values in Ubatuba, ranging from 32.0 to 37.0. In Caraguatatuba values ranging from 30.0 to 37.0 were observed, constant values were observed during the first year and in autumn such values decreased. In the second year the lowest values were observed in winter. Among the transects, the lowest salinity values were found in shallower waters (5 m and 10 m) in both regions.

Considering the bottom temperature, the lowest mean values were recorded in October and November (spring) of the first year in both regions. However, the highest mean values occurred in February (summer) of the first year in Ubatuba, and in April (autumn) of the second year in Caraguatatuba. In both sampled regions the decrease of temperature was directly related to the increase of depth of transects. In greater depths it was possible to observe a decrease of bottom temperature during spring and summer in the two regions, but variations of bottom temperature were more pronounced in Ubatuba (Figure 2).

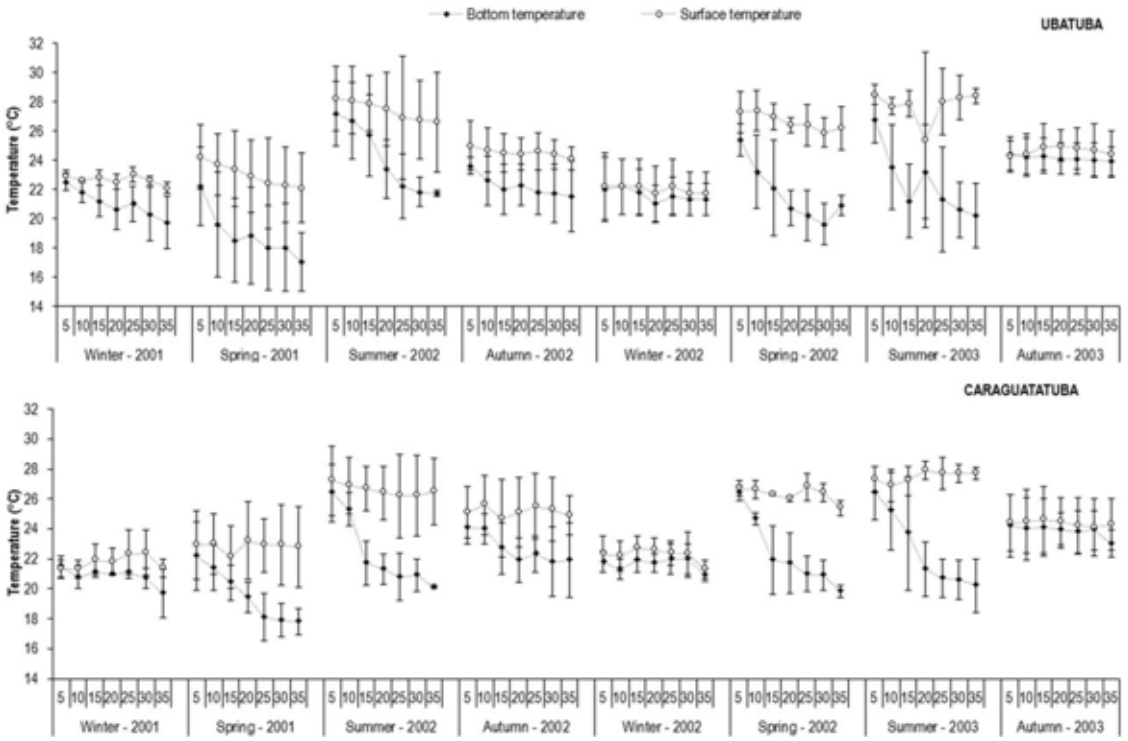

Figure 2 - Variations in the means of bottom and surface temperatures (± standard deviation) by transects, during the sampling period (July 2001 to June 2003).

Variations in the proportion of granulometric classes of the sediment mean values of Phi and the organic matter content are represented in Figure 3. In the region of Ubatuba a predominance of class C was observed in shallower transects, 5 and 10m, and of classes A and B in deeper transects, 30 and 35m. In the same region the tendency of reduction of Phi and percentage of organic matter are higher as depth increases. In Caraguatatuba the class C predominated in intermediate transects, mainly in 15 and 20 m, and the lowest values of Phi and percentage of organic matter tended to be located in shallower and deeper transects, it means, those with predominance of larger granulometric sediments.

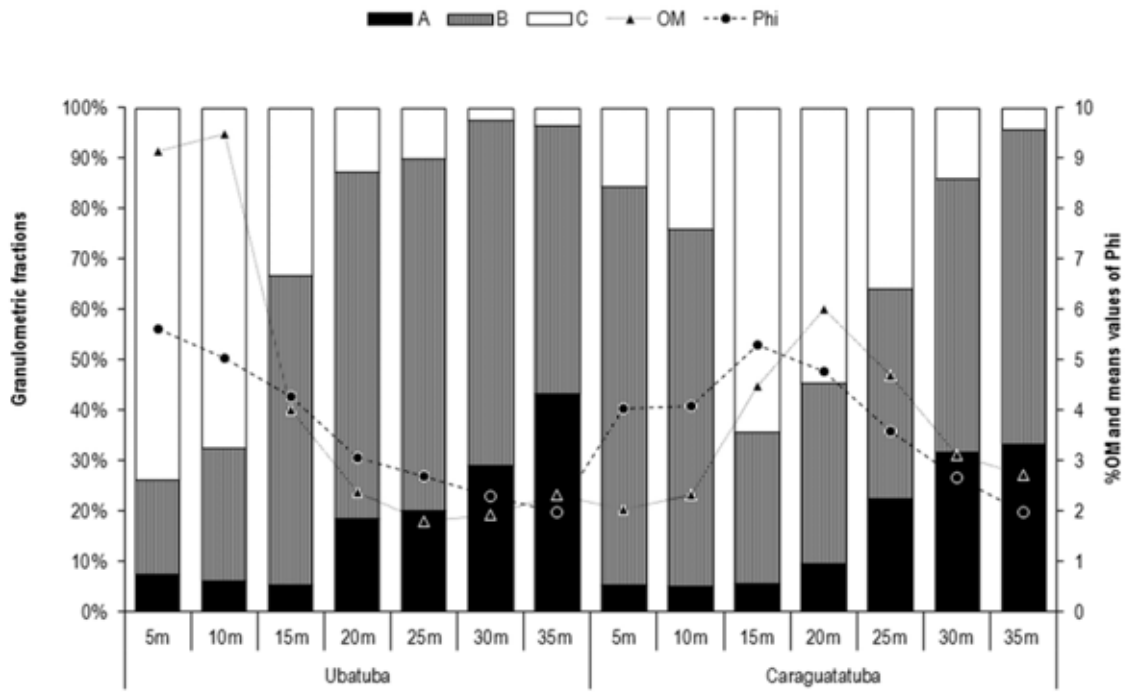

Figure 3 - Proportions of grain size classes, central tendency of bottom sediments (Phi), and mean organic matter content (%) for each transect. *See Material and Methods for granulometric class classifications*.

Overall, 1492 individuals were collected. In Ubatuba, 433 *P. mediterranea*, 47 *P. punctata* and 18 *P. lichtensteinii* were recorded, while in Caraguatatuba 814 *P. mediterranea*, 140 *P. punctata* and 40 *P. lichtensteinii* were captured (Figure 4, Table II).

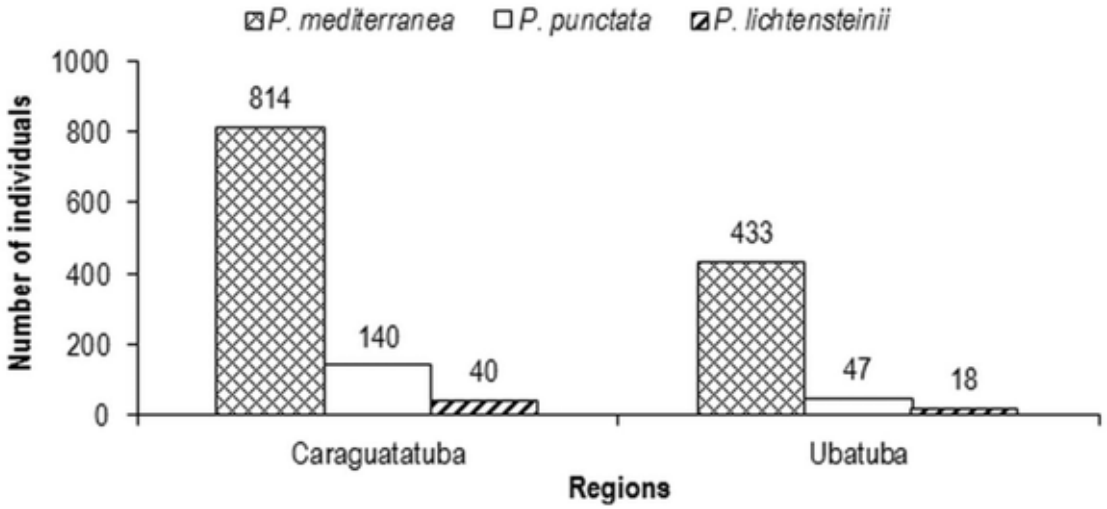

Figure 4 - Abundance of thespecies of genus *Persephona* in Ubatuba and Caraguatatuba regions, northern littoral of São Paulo State, Brazil.

Table II - Monthly collections of *Persephona* species in each region (1st = July 2001 to June 2002; 2nd = July 2002 to June 2003), and total for each season, in the northern littoral of São Paulo State, Brazil. UBA – Ubatuba, CA – Caraguatatuba.

Month	*Persephona mediterranea*							*Persephona punctata*							*Persephona lichtensteinii*						
	UBA		CA		Total		Season Total	UBA		CA		Total		Season Total	UBA		CA		Total		Season Total
	1st	2nd	1st	2nd	1st	2nd		1st	2nd	1st	2nd	1st	2nd		1st	2nd	1st	2nd	1st	2nd	
July	66	65	125	58	191	123		2	9	7	1	9	10		0	1	9	1	9	2	
August	18	9	95	46	113	55	Winter = 580	1	2	78	2	79	4	Winter = 109	0	4	12	0	12	4	Winter = 28
September	2	20	6	70	8	90		0	5	2	0	2	5		0	1	0	0	0	1	
October	3	10	16	10	19	20		1	0	6	1	7	1		0	0	0	0	0	0	
November	3	8	0	2	3	10	Spring = 82	0	0	0	0	0	0	Spring = 9	0	0	0	0	0	0	Spring = 1
December	2	23	2	3	4	26		0	0	0	1	0	1		0	1	0	0	0	1	
January	27	32	100	68	127	100		0	1	4	4	4	5		0	0	0	0	0	0	
February	22	7	0	4	22	11	Summer = 312	2	9	0	0	2	9	Summer = 26	0	2	0	0	0	2	Summer = 2
March	0	36	0	16	0	52		0	4	0	2	0	6		0	0	0	0	0	0	
April	0	30	0	42	0	72		0	1	0	5	0	6		0	1	0	1	0	2	
May	5	22	15	65	20	87	Autumn = 273	0	10	0	3	0	13	Autumn = 43	0	6	0	7	0	13	Autumn = 27
June	18	5	30	41	48	46		0	0	13	11	13	11		0	2	1	9	1	11	
Total	166	267	389	425	555	692	1247	6	41	110	30	116	71	187	0	18	22	18	22	36	58

The crab *P. mediterranea* was collected in greater abundance in winter months and in lower amounts in spring months (Figure 5). In the region of Ubatuba peaks were observed in July of both years and the lowest number of individuals was recorded in the months with lower bottom temperatures. In Caraguatatuba peaks of abundance were observed in July and January of the first year and in September, January and May of the second year. The greater abundance of *P. punctata* was recorded in winter months (Figure 5), both in Ubatuba and Caraguatatuba. The crab *P. lichtensteinii* was captured predominantly in autumn and winter months in the two regions (Figure 5), coinciding with higher bottom temperatures.

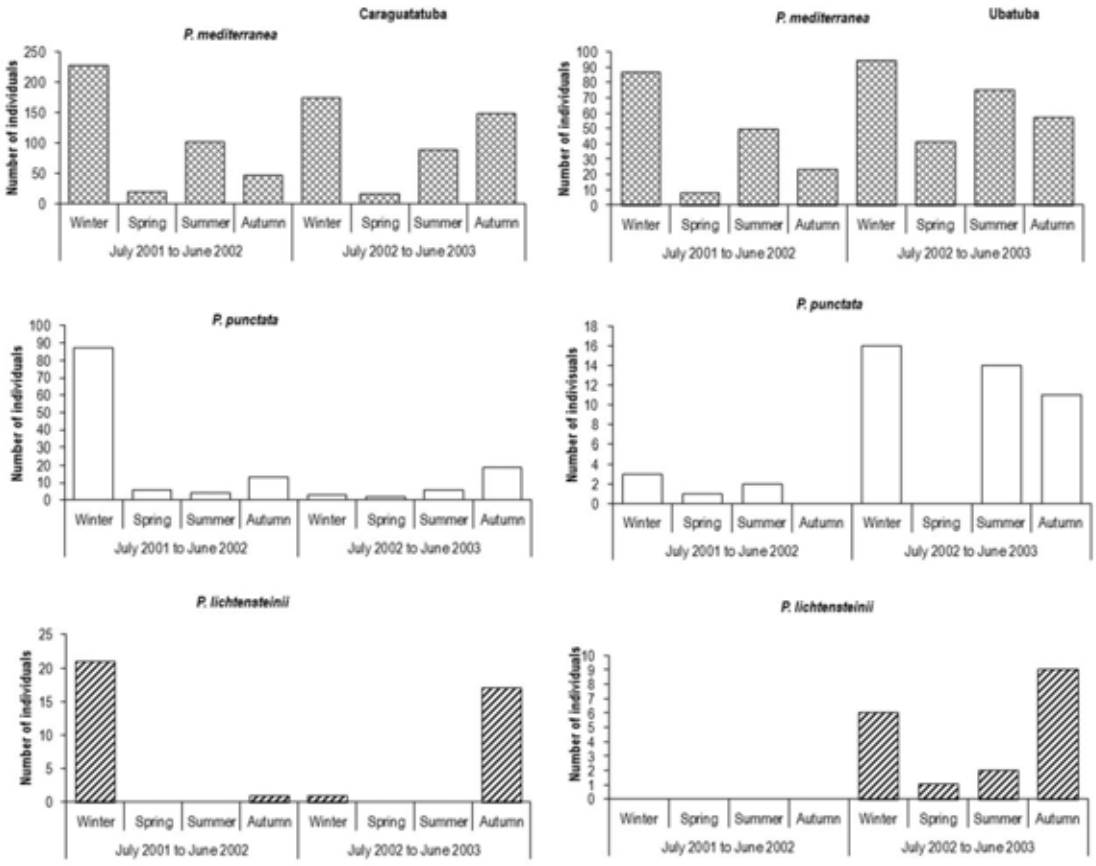

Figure 5 - Seasonal distribution of the species of genus *Persephona* in Caraguatatuba and Ubatuba regions, northern littoral of São Paulo State, Brazil.

The crab *P. mediterranea* was more abundant in intermediate transects, it showed greater abundance in 15 m and 20 m in Ubatuba and 15 – 30 m in Caraguatatuba. The lowest abundance was recorded in both regions in shallower transects. To *P. punctata*, the higher abundance was recorded in 5 m in Ubatuba, while in Caraguatatuba the greater abundance was in 15 m and 20 m. The crab *P. lichtensteinii* was collected only in 5 m - 15 m in Ubatuba, while in Caraguatatuba this species was more abundant in 25 and 30 m (Figure 6).

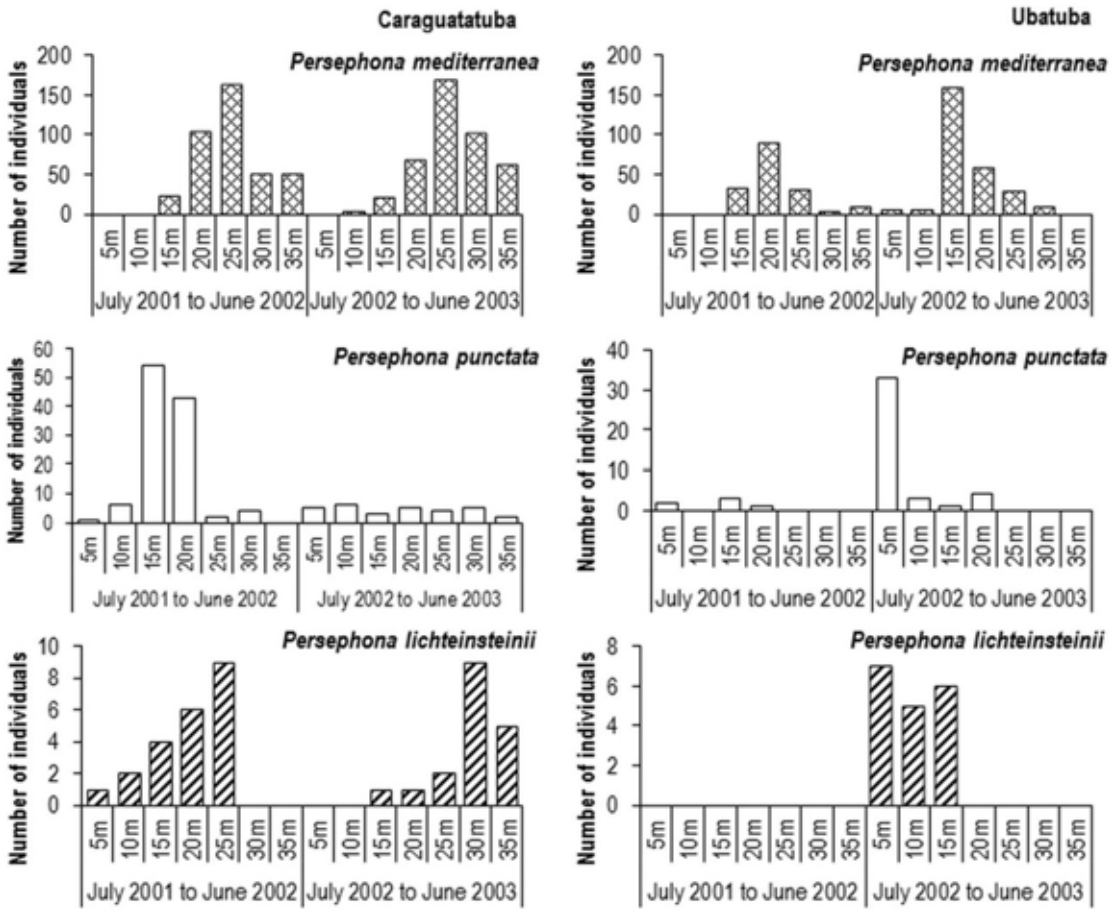

Figure 6 - Principal Component Analysis (PCA) for the two sampling regions. A – Caraguatatuba; B – Ubatuba. The acronyms represent the seasons (S: summer, A: autumn, W; winter, SP: spring) of each region (CA: Caraguatatuba and UBA: Ubatuba).

None of the environmental variables reached the Spearman correlation limit established in 0.7 and the VIF limit by 10. On the PCA, the main components PC1, PC2 and PC3 accumulated 85.55% of data variation (Table III). According to the PCA, the regions of UBA and CA were homogeneous in space and time as evidenced when observing the scores of main components 1 and 2. For better observing spatiotemporal patterns, the scores of main components 1 and 2 were plotted separately for each region (Ubatuba and Caraguatatuba) (Figure 7). Thus, all environmental variables were used for the association of *Persephona* species in the following analysis.

Table III - Principal Component Analysis (PCA) of collections of *Persephona* species in two regions of the northern littoral of São Paulo State, Brazil.

	PC1	PC2	PC3	PC4
Standard deviation	1.259	1.0384	0.8709	0.7605
Proportion of Variance (%)	0.3963	0.2696	0.1896	0.1446
Cumulative Proportion (%)	0.3963	0.6658	0.8554	1

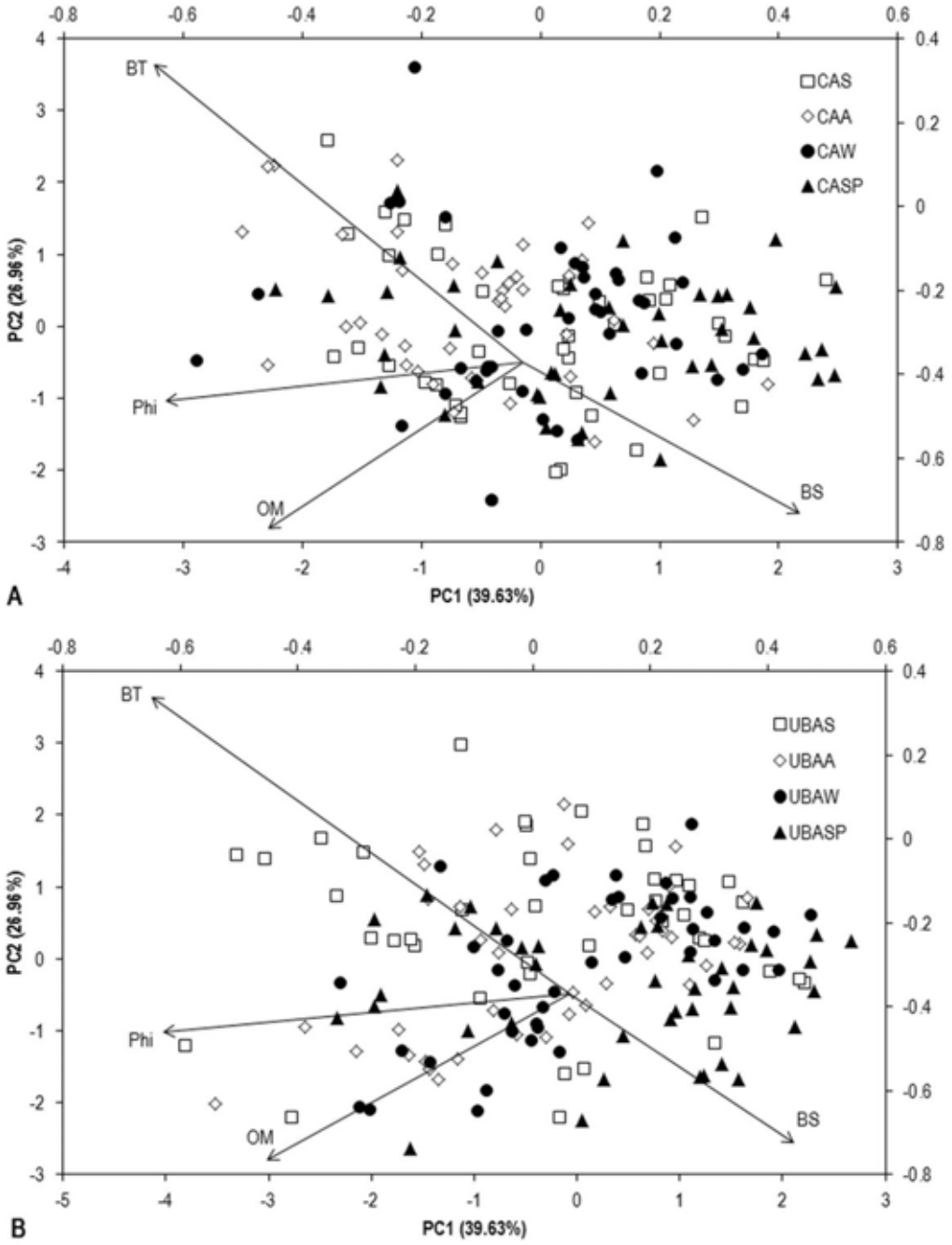

Figure 7 - Redundancy analysis (RDA) for three species of the genus *Persephona* in the regions of Caraguatatuba and Ubatuba. The acronyms represent the transects (T1 to T7) of each region (CA and UBA). Only significant environmental variables were represented, according to 'envfit'.

The abundance of species associated to environmental factors (BT, OM, Phi, BS) of both sampled regions evidenced by means of RDA that the most influent environmental factor over the distribution of the three studied species was sediment granulometry (Phi, $r^2 = 0.5549$, Pr = 0.0091) (Figure 8), being the ascendant order of influence *P. lichtensteinii, P. punctata* and *P. mediterranea.*

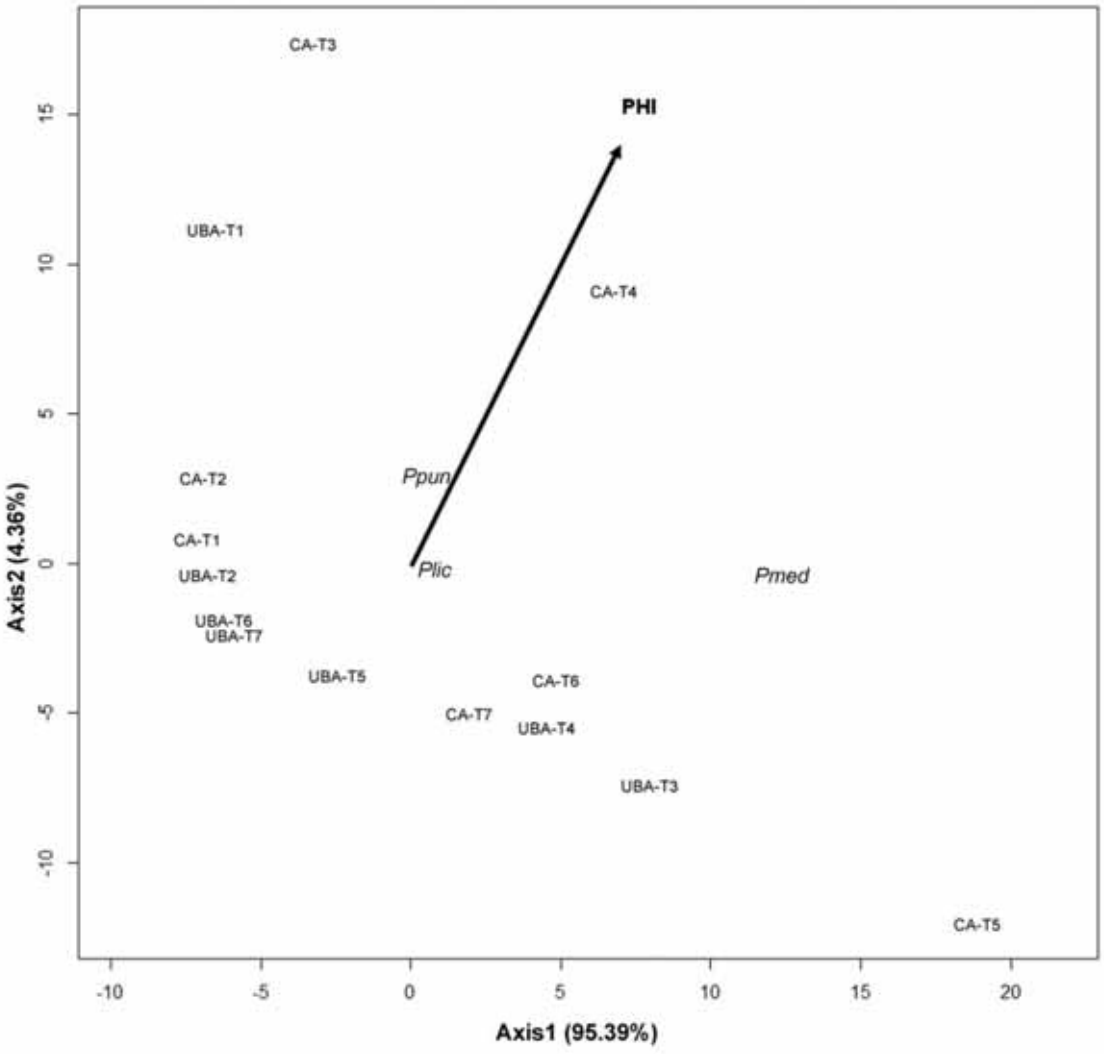

Figure 8 - Variation in abundance of the genus *Persephona* per transect in Caraguatatuba and Ubatuba regions, northern littoral of São Paulo State, Brazil.

In Ubatuba the greater abundance was recorded in shallower transects, where finer sediments predominate, while in Caraguatatuba the distribution of individuals were more homogenous, with greater abundance in transects of 25 and 30 m, in which values of Phi were intermediate. In Ubatuba Phi values ranged from 3.1 to 4.0 and in Caraguatatuba they varied from 2.1 to 6.0 (Figure 8).

The occurrence of overdispersion on GLMM ZIP attested the use of GLMM ZINB (Zuur *et al.* 2009) for each species. Results of GLMM ZINB corroborated those indicated by RDA, showing that Phi influences more the abundance of *P. mediterranea* (Table IV) and *P. punctata* (Table V). However, GLMM ZINB results for *P. lichtensteinii* (Table VI) were not significant for any evaluated factor, both for counting and occurrence data. This is evident in Figure 8 in which *P. lichtensteinii* is very next to the origin in the RDA plot.

Table IV - GLMM ZINB for *Persephona mediterranea* in two regions of the northern littoral of São Paulo State, Brazil.

Count Model	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	2.3432	0.6071	3.86	0.000113***
BayUBA	-0.8282	0.5161	-1.605	0.108553
SeasonSpring	-1.0751	0.6447	-1.668	0.095384.
SeasonSummer	0.3052	0.5429	0.562	0.573955
SeasonWinter	1.1486	0.5354	2.145	0.031921*
Phi	-0.2213	0.1331	-1.663	0.096402.
BayUBA:SeasonSpring	1.1741	0.8861	1.325	0.185131
BayUBA:SeasonSummer	0.6768	0.8191	0.826	0.408684
BayUBA:SeasonWinter	-0.4492	0.7674	-0.585	0.558314
Log(theta)	-1.4338	0.2057	-6.97	0.00000000000318***

Binomial Model	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	-13.7772	1537.4	-0.009	0.99285
BayUBA	13.6362	1537.4	0.009	0.99292
SeasonSpring	15.3052	1537.4	0.01	0.99206
SeasonSummer	15.0413	1537.4	0.01	0.99219
SeasonWinter	14.5195	1537.4	0.009	0.99246
Phi	-0.5684	0.2181	-2.606	0.00915**
BayUBA:SeasonSpring	-13.44	1537.4	-0.009	0.99302
BayUBA:SeasonSummer	-13.1885	1537.4	-0.009	0.99316
BayUBA:SeasonWinter	-15.1665	1537.4	-0.01	0.99213

(Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.'0.1 ' ' 1).

(Signif. códigos: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1).

Table V - GLMM ZINB for *Persephona punctata* in two regions of the northern littoral of São Paulo State, Brazil.

Count Model	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	-3.1345	0.9858	-3.18	0.00147**
Bay UBA	1.3477	1.1839	1.138	0.25496
Season Spring	-0.3074	0.9891	-0.311	0.75594
Season Summer	-0.856	0.5493	-1.558	0.11914
Season Winter	1.2183	0.6084	2.002	0.04525*
Phi	0.6361	0.2086	3.05	0.00229**
Bay UBA: Season Spring	-3.7282	2.2748	-1.639	0.10123
Bay UBA: Season Summer	-0.6308	1.6312	-0.387	0.69899
Bay UBA: Season Winter	-2.8956	1.4624	-1.98	0.0477*
Log (theta)	-1.0293	0.3182	-3.235	0.00122**

Binomial Model	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	-13.6488	1668.66	-0.008	0.9935
BayUBA	18.6024	1668.66	0.011	0.9911
Season Spring	18.4933	1668.66	0.011	0.9912
Season Summer	-4.5893	60074	0	0.9999
Season Winter	16.3526	1668.66	0.01	0.9922
Phi	-0.8366	0.3687	-2.269	0.0233*
Bay UBA: Season Spring	-19.4697	1668.66	-0.012	0.9907
Bay UBA: Season Summer	3.6221	60074	0	1
Bay UBA: Season Winter	-19.4756	1668.66	-0.012	0.9907

(Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.'0.1 ' ' 1).

(Signif. códigos: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1).

Table VI - GLMM ZINB for *Persephona lichtensteinii* in two regions of the northern littoral of São Paulo State, Brazil.

Count Model	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	-1.59329	1.31019	-1.216	0.22396
Bay UBA	-0.44209	0.50554	-0.874	0.38186
Season Spring	-0.43149	1.55664	-0.277	0.78163
Season Summer	0.55715	1.47988	0.376	0.70656
Season Winter	0.03439	0.44604	0.077	0.93855
Phi	0.24376	0.27145	0.898	0.3692
Log(theta)	-1.05752	0.3424	-3.089	0.00201 **

Binomial Model	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	338.183	326.598	1.035	0.3
Bay UBA	68.085	90.02	0.756	0.449
Season Spring	383.504	348.673	1.1	0.271
Season Summer	297.597	309.694	0.961	0.337
Season Winter	-11.482	72.647	-0.158	0.874
Phi	-111.476	102.548	-1.087	0.277
Bay UBA:Season Spring	-162.62	154.133	-1.055	0.291
Bay UBA:Season Summer	-43.526	3177.59	-0.014	0.989
Bay UBA:Season Winter	-9.629	156.234	-0.062	0.951

(Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.'0.1 ' ' 1).

(Signif. códigos: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1).

DISCUSSION

Environmental factors may influence the distribution of marine organisms, defining the occupation in wide areas or restricting their distribution. In general it was observed more individuals of *P. mediterranea,* followed by *P. punctata* and *P. lichtensteinii*, respectively. The same relation of abundance was observed by Bertini *et al*. (2001) and Almeida *et al*. (2013). This difference may be associated with the limits of the species distribution. Considering the low abundance of *P. lichtensteinii* when compared to the other species, we suppose that it occurs due to this species limits of distribution that were related for São Paulo State by Melo (1996) and involves restrict environmental conditions related to this region on the Brazilian coast.

The Northern coast of São Paulo presents a characteristic composition of water masses with seasonal intrusion of a cold and saline water mass, South Atlantic Central Water, thus forming a thermocline (Castro-Filho *et al.* 1987) that has decisive role on the distribution of several Brachyura species (Fransozo *et al.* 1992, Pinheiro *et al*. 1996, De Léo & Pires-Vanin 2006). Thus, with extreme environmental conditions acting over the physiology and biology of the animal, its abundance is reduced in neighboring regions of its distribution.

In a comparative study of the distribution of *P. lichtensteinii* and *P. punctata* in Ilhéus, Northeastern coast of Brazil, Carvalho *et al.* (2010) verified a predominance of *P. lichtensteinii*, contrasting with the abundance pattern observed for the genus in Southern and Southeastern Brazil. However, in a six-year study (1996-2002) on the occurrence and abundance of accompanying crustaceans of the Atlantic seabob fishery *Xiphopenaeus kroyeri* (Heller, 1862) in Armação do Itapocoroy, Penha, Santa Catarina State, Branco & Fracasso (2004) recorded the presence of 53 individuals of *P.*

lichtensteinii between 2001 and 2002. This allows us to suggest that through the two years the species increased its limits of distribution because there was the improvement of this species records (Branco & Fracasso 2004), not following the pattern proposed by Melo (1996). Nevertheless, the species present lower abundance when compared to the other species of the genus, thus keeping the distribution pattern known for the genus.

Individuals of the three species were captured in different transects. This highlights that the distribution patterns of *P. mediterranea*, *P. punctata* and *P. lichtensteinii* are influenced by environmental factors that act together, and it is not possible to comprehend them analyzing only transects depth.

The greater abundance of *P. mediterranea* was recorded in the transects of 15 and 20 m, what is in accordance with results obtained by Pires (1992) and Bertini *et al.* (2001, 2010). These transects were similar in relation to Phi and OM values, which were composed predominantly by thin sediments, granulometric class C (silt and clay). Meanwhile, *P. punctata* and *P. lichtensteinii* were captured in greater amounts in shallower transects, corroborating the results obtained by Fransozo *et al*. (1992), Negreiros-Fransozo *et al*. (1992, 1999), Mantelatto & Fransozo (2000) and Bertini *et al.* (2001).

When comparing the abundance of species in relation to temporal variables, it can be observed that in general species were collected in greater amounts in autumn and winter months. Such difference in the abundance of crabs associated to the seasons is due to the influence of temperature variations in the biology of these organisms. It was noted that the lower abundance was recorded in spring and summer months, both under the influence of SACW (South Atlantic Central Water). This suggests the preference of such organisms by regions that present water with higher temperatures. The ecological distribution of such species corroborates results obtained by Bertini *et al.* (2001) only

for *P. lichtensteinii*, being this species more abundant in winter months. The same author collected *P. mediterranea* and *P. punctata* in greater amounts during spring months, differing from the results here presented. In a study performed on the coast of Ilhéus, Bahia, the greater abundance of *P. lichtensteinii* and *P. punctata* was recorded in autumn months (Carvalho *et al*. 2010).

When comparing patterns of spatiotemporal distribution of the three species, a differential distribution was observed. These variations may indicate a strategy to avoid competition among congeneric species, and it may be related to the specificity of substratum and to the organic matter associated with it, or the environmental characteristics that vary among seasons.

The greater influence of sediment (Phi) on limiting the distribution of crabs of the genus *Persephona* may be associated with their life habit, which is to bury itself and capture polychaetes from infauna, its main food item (Petti *et al.* 1996, Bellwood 2002). The crabs of genus *Persephona* were more abundant in thin sediment, which facilitates its burying habit. The preference for thinner sediment can also be related to the search for food. When there is more organic matter available it is verified an increase in the number of organisms that feed of it (e.g. polychates). As these organisms are prey to *Persephona*, according to the food availability the crabs tend to increase. The same association with food availability was verified to the brachyuran *Callinectes ornatus* Ordway, 1863 (Mantelatto 2000). Although the three species presented differential spatial distribution regarding to the bathymetry, all of them occupy areas with fine sediment composed mainly by silt and clay, as verified by Fransozo *et al*. (1992), Negreiros-Fransozo *et al*. (1999) and Bertini *et al*. (2001). The relation between OM and Phi and its influence on the distribution was also verified for other decapods, such as *Achelous spinimanus* (Latreille, 1819), *Hepatus pudibundus* (Herbst, 1785) and

Petrochirus diogenes (Linnaeus, 1758), by Santos *et al*. (1994), Mantelatto *et al*. (1995) and Bertini & Fransozo (1999), respectively.

Environmental factors act together influencing the distribution of the three species of the genus *Persephona*. It is possible that biotic relations act over the distribution patterns of *P. mediterranea*, *P. punctata* and *P. lichtensteinii*, thus altering them. Thereby, we suggest that studies regarding intra- and inter-specific interactions of such crabs must be developed in order to obtain information that help in the comprehension of the observed patterns of distribution. Furthermore, more studies related to the food habits of *Persephona* species must be done in order to understand if sediment characteristics influence the distribution of such organisms and their preys.

The present study represent a gain of information about patterns of bathymetric distribution of three species of the genus *Persephona* on the Southeastern Brazilian continental shelf, once the knowledge regarding such patterns were limited to the transects of 20 m in three bays of Ubatuba region (Bertini *et al*. 2001). Results here presented allows the improvement of information related to bathymetry because of the greater capture effort (5 to 35 m) and also to the comparison of two regions considered distinct regarding their oceanographic characteristics (Ubatuba and Caraguatatuba).

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CAPÍTULO 4

ENVIRONMENTAL FACTORS MODULATING THE ABUNDANCE AND DISTRIBUTION OF *Callinectes danae* SMITH, 1869 (DECAPODA, PORTUNIDAE) FROM TWO AREAS OF THE SOUTHEASTERN COAST OF BRAZIL

ABSTRACT

The distribution and abundance of marine organisms are directly or indirectly a function of biotic and abiotic features such as sediment and water. In this study we analyzed the spatial and temporal distribution of *Callinectes danae* in two distinct littoral areas of the northern coast of the State of São Paulo, Brazil and associated them with local geomorphologic features and environmental factors. Were collected specimens on a monthly basis, from July 2001 to June 2003, using a fishing boat equipped with double-rig net, in two locations: Ubatuba (UBA) and Caraguatatuba (CAR). Collecting was carried out in seven transects with different depths, which were further subdivided into two regions: bay region (5, 10, 15 and 20 m deep); and inner shelf region (25, 30 and 35 m deep). We obtained a total of 776 individuals, 624 (UBA = 518; CAR = 106) during the first period (Jul 2001 to Jun 2002) and 152 (UBA = 118; CAR = 34) during the second period (Jul 2002 to Jul 2003). Samples from different periods and transects differed significantly in abundance. A positive correlation was found between the abundance of *C. danae* and the following parameters: temperature at the bottom, organic matter content and Phi. By contrast, a negative correlation was established between specimen abundance and salinity at the bottom. In UBA, individuals were more abundant in the autumn, whereas in CAR they were more abundant in the winter. The total abundance was highest in 5 m deep transects in both regions. The season when individuals were least abundant in both areas was the summer. We concluded that the spatial and temporal distribution of *C. danae* are determined by a set of environmental factors and not just by one single factor.

Keywords: Brachyura, salinity, spatial and seasonal distribution, temperature.

INTRODUCTION

The abundance and distribution of marine organisms are usually modulated by environmental factors. These can act singly or in combination, expanding or reducing the area occupied by a given species (Vernberg & Vernberg 1970, Pinheiro *et al*. 1996, Mantelatto *et al*. 1995, Fantucci *et al*. 2009). Salinity, temperature, sediment texture and organic matter content are the principal environmental factors implicated in the distribution of decapod crustaceans (Santos *et al*. 1994, Pinheiro *et al*. 1996, Atrill *et al*. 1999, Bertini *et al*. 2001, Martinez *et al*. 2009, Carvalho *et al*. 2010, Carvalho & Couto 2010). Additionally, some authors have suggested that variations in the benthic marine composition are closely linked to the depth gradient (Aschan 1990, Bertini & Fransozo 2004, Fransozo *et al*. 2007, Hiroki *et al*. 2011). Given that the interaction among factors generates different patterns of spatial and seasonal distribution, research aimed to comprehend the biology of marine crustaceans should include various environmental determinants and depth gradients (Buchanan & Stoner 1988).

The swimming crab *Callinectes danae* Smith, 1869 is widely distributed in the East Coast of the Americas, ranging from Florida (USA) to Rio Grande do Sul (Brazil) and can be found in estuarine areas and mangroves up to depths of 70 m (Melo 1996). The species is a fishing resource in many regions of Brazil (Branco & Masunari 1992, Barreto *et al*. 2006, Pereira *et al*. 2009) and it is also found in seabob fishing by-catch (Baptista-Metri *et al*. 2005).

The biology of *C. danae* in the Brazilian coast has been addressed in the following studies: Pita *et al*. (1985) studied the distribution and size of individuals at first maturation, Branco (1996) and Branco & Verani (1997) examined the feeding

dynamics, Medeiros & Oshiro (1990), Costa & Negreiros-Fransozo (1998) analyzed population and reproductive biology, Chacur & Negreiros-Fransozo (2001) investigated the spatial and seasonal distributions, Baptista-Metri *et al*. (2005) analyzed the population biology and reproduction by looking at by-catch of *Xiphopenaeus kroyeri* (Heller, 1862) tailing fishing, and Keunecke *et al*. (2008) studied the growth of specimens collected during shrimp fishing. Strong habitat partitioning was found for *C. danae*: while males and juveniles are collected mostly at the inner estuary, adult females are found in the entire bay, and ovigerous females occur almost exclusively at deeper layers where salinity is higher (Sforza *et al*. 2010).

In this study we compared the spatial-temporal distribution of *C. danae* in two different areas of the southeastern Brazilian coast and endeavored to find associations between distributional patterns and environmental factors.

MATERIAL AND METHODS

Individuals were collected monthly from July 2001 to June 2003, from two areas (Ubatuba = UBA 23°26'27"S – 45°03'18"W; and Caraguatatuba = CAR 23°36'09"S – 45°20'25"W) on the northern coast of São Paulo, southeastern Brazil. Seven transects were sampled in each area, at 5, 10, 15 and 20 m, herein called bay region, and 25, 30 and 35 m deep, referred to as inner shelf region (Figure 1). We used a GPS (Global Positioning System) to delimitate the beginning and the end of each transect, and recorded the depths with an ecobathymeter attached to a GPS. A shrimp boat equipped with a double-rig net (20 mm mesh size and 15 mm in the cod end) was used for to trawling, which lasted 30 min in each transect, sampling a total area of 18,000 m².

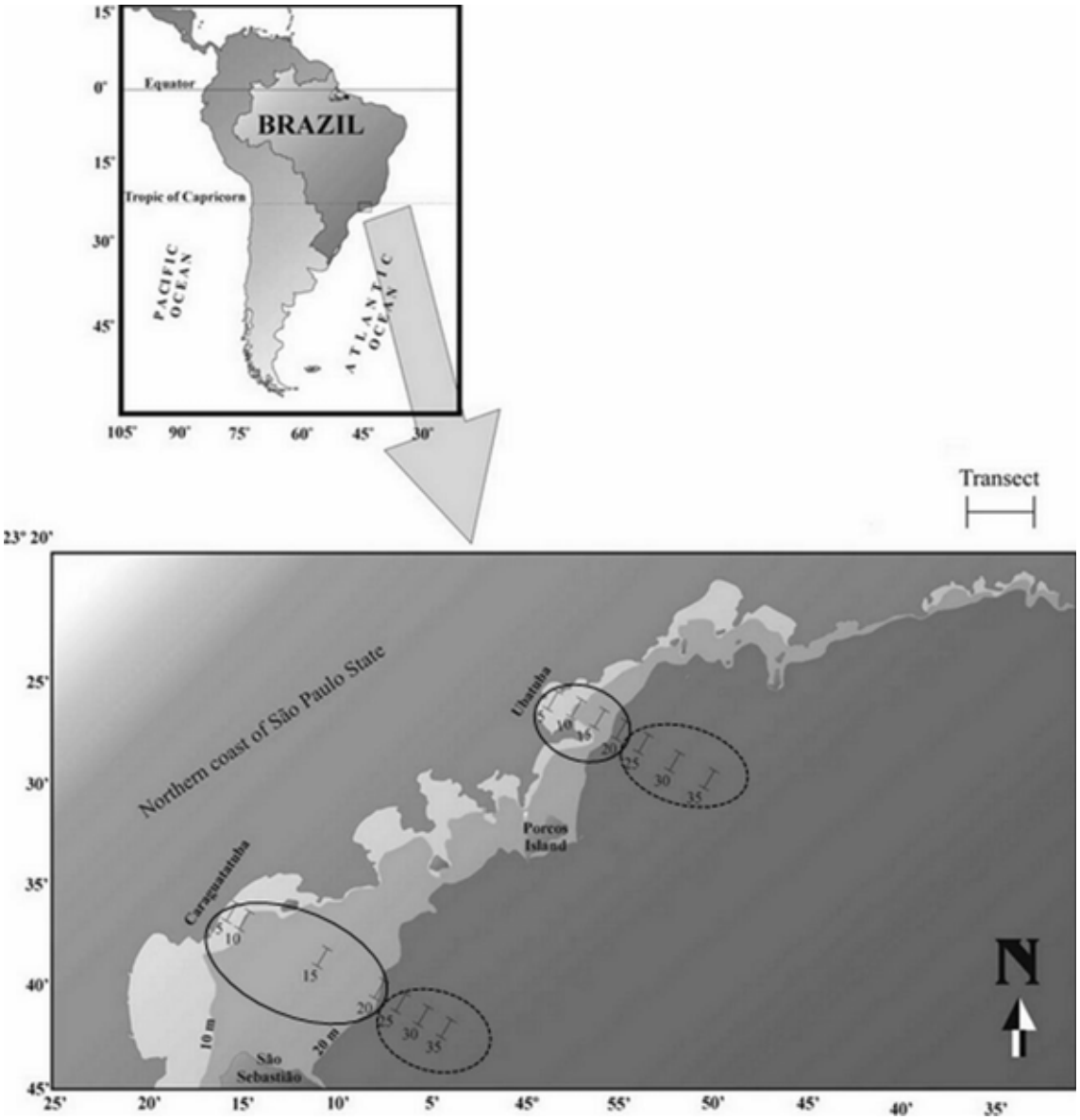

Figure 1 - Study area: location of Ubatuba and Caraguatatuba, indicating the sampling sites of transects. Transects 5, 10, 15 and 20 m were considered as shallow water area and 25, 30 and 35 m as inner shelf area.

We used a Nansen bottle to sample the bottom and surface water at the beginning, middle and end of each transect. We also measured salinity (psu), with the aid of an Atago S/1000 optical refractometer, and temperature (°C) with a mercury

thermometer. In analyses, we input the average of these three values. Sediment samples were collected in each season with a 0.06 m² Van Veen Grab Sampler. In the laboratory, the sediment was dried at 70ºC for 72 h in an oven. For the analysis of grain size composition, two 50 g sub-samples were separated, treated with 250 ml of a 0.2 N NaOH solution, and stirred for 5 min to release the silt and clay particles. Subsamples were then rinsed on a 0.063 sieve.

Sediments were sieved through 2 mm (gravel); 2.0-1.0 mm (very coarse sand); 1.0-0.5 mm (coarse sand); 0.5-0.25 mm (medium sand); 0.25-0.125 mm (fine sand); 0.125-0.063 mm (very fine sand); smaller particles were classified as silt-clay. Cumulative particle size curves were plotted on a computer using the phi scale; values corresponding to the 16^{th}, 50^{th}, and 84^{th} percentiles were used to determine the mean diameter of the sediment, using the equation $Md = (\varphi 16 + \varphi 50 + \varphi 84)/3$. Finally, phi was calculated using the equation $hi(\varphi) = -log_2 d$, where d= grain diameter (mm) (Hakanson & Jansson 1983, Tucker 1988). The organic matter content (%) was obtained by ash-weighing: three aliquots of 10 g each per transect were placed in porcelain crucibles and incinerated for 3 h at 500°C. The samples were then reweighed.

Sediment texture was represented graphically by plotting a triangular diagram using the three most important grain size classes, as in Magliocca & Kutner (1965). Class A corresponds to sediments in which medium sand (MS), coarse sand (CS), very coarse sand (VCS), and gravel (G > 0.25 mm) account for more than 70% of the total weight. In class B, fine sand (FS), and very fine sand (VFS) make up more than 70% of the total weight of sediment samples. More than 70% of sediments in class C are silt and clay (S+C). These three categories were further combined to form different categories PA = (MS+CS+VCS+G) > 70%; PAB = prevalence of A over B (FS+VFS);

PAC = prevalence of A over C (S+C); PB = B > 70%; PBA = prevalence of B over A; PBC = prevalence of B over C; PC = C > 70%; PCA = prevalence of C over A; PCB = prevalence of C over B.

The normality and homoscedasticity of the data were tested by the Shapiro-Wilk and Levene tests, respectively. As the data did not fit a normal distribution, non-parametric tests were used. The abundance values were compared among transects, months and seasons using the Kruskal-Wallis test, followed by the Dunn's test. Abundance between areas and years were tested by the Mann-Whitney test. The relationship between abundance of individuals and environmental factors was tested by using the Spearman correlation. The adopted significance level in all statistical analysis was 5% (Zar 2010).

RESULTS

We collected 776 individuals, 624 in the first sampling period and 152 in the second (Table I). We observed significant differences in the abundance of *C. danae* between sampling periods (Mann -Whitney U = 12068.50 , $p < 0.005$). A total of 636 crabs were caught in Ubatuba and 140 in Caraguatatuba (Table II). However, there was no significant difference in the abundance of crabs between regions (Mann -Whitney U = 13641.00; $p > .05$).

Table I - *Callinectes danae* Smith, 1869, monthly collections of in each area (1st period = July 2001 to June 2002; 2nd period = July 2002 to June 2003), and total for each season.

	UBA				CA			
Month	1st	2nd	Total	UBA seasons	1st	2nd	Total	CA seasons
Jul	19	1	20		31	3	34	
Aug	61	5	66	Winter = 151	20	0	20	Winter = 67
Sep	58	7	65		11	2	13	
Oct	25	11	36		13	5	18	
Nov	19	29	48	Spring = 123	4	2	6	Spring = 31
Dec	30	9	39		4	3	7	
Jan	17	13	30		6	2	8	
Feb	46	5	51	Summer= 117	6	1	7	Summer = 19
Mar	36	0	36		2	2	4	
Apr	98	2	100		1	2	3	
Mai	61	25	86	Autumn = 245	3	6	9	Autumn = 23
Jun	48	11	59		5	6	11	
Total	518	118	636		106	34	140	

UBA = Ubatuba, CA = Caraguatatuba.

Table II - *Callinectes danae* Smith, 1869. Absolute abundance in each area during sampling period, by depth.

Depth (m)	UBA	CA	Total
5	498	46	544
10	115	59	174
15	21	22	43
20	2	8	10
25	0	3	3
30	0	0	0
35	0	2	2
Total	636	140	776

UBA = Ubatuba, CA = Caraguatatuba.

In Ubatuba, *C. danae* was more abundant in the winter, whereas in Caraguatatuba it was more abundant in the fall. In both areas (Table I, Figure 2), specimens were less abundant during the summer. However, neither this difference (Kruskal - Wallis, $H = 4.5438$, $p > 0.05$), nor the differences among seasons or months (Kruskal - Wallis, $H = 9.5517$, $p > 0.05$) were significant. The number of *C. danae* individuals in both Ubatuba and Caraguatatuba was greater in the 5 m transects, which differed significantly from the others (Kruskal-Wallis, $H = 156.6025$; $p < 0.001$) (Figure 3, Figure 4).

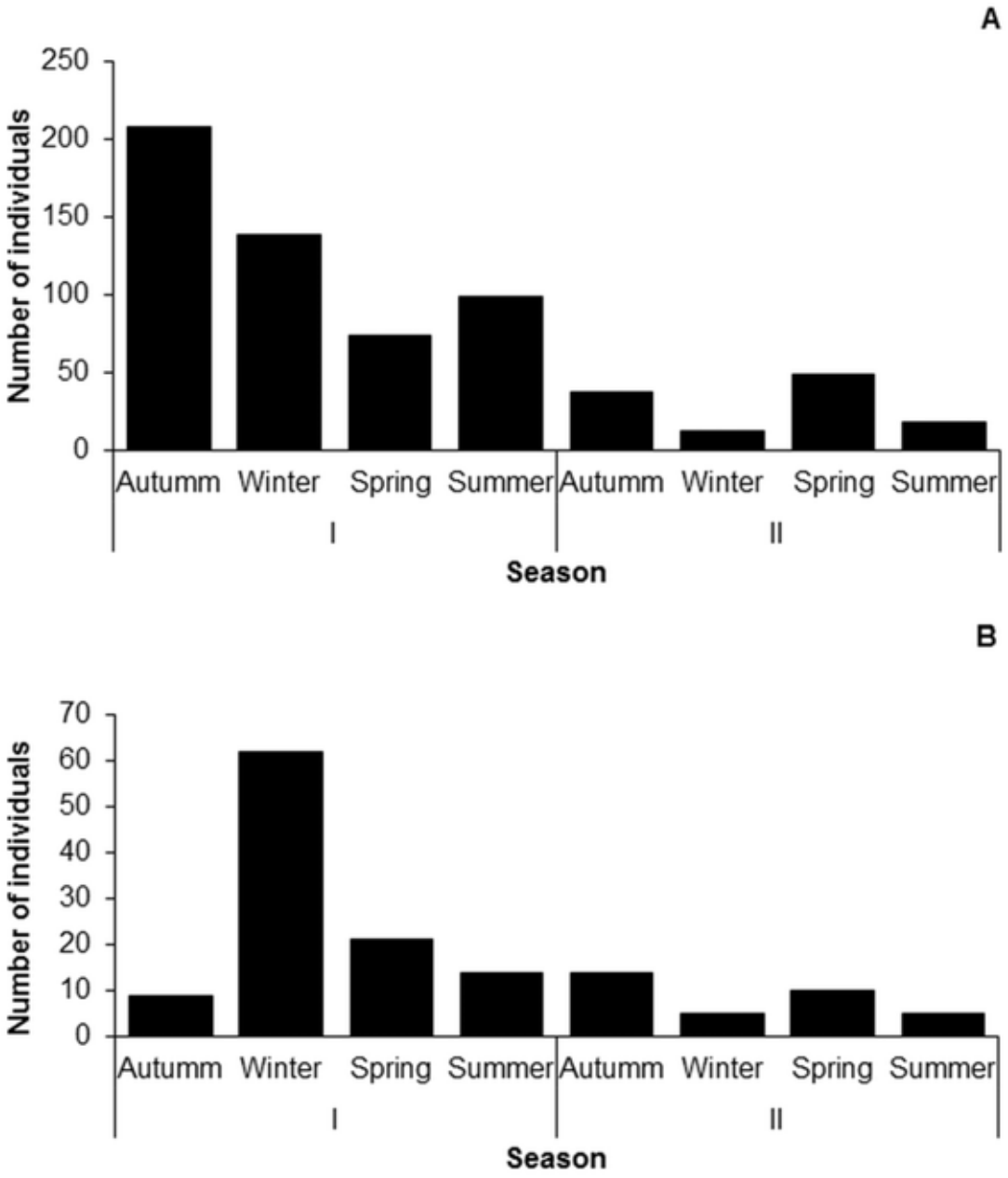

Figure 2 - *Callinectes danae* Smith, 1869. Seasonal distribution of individuals in the Ubatuba (A) and Caraguatatuba (B) areas.

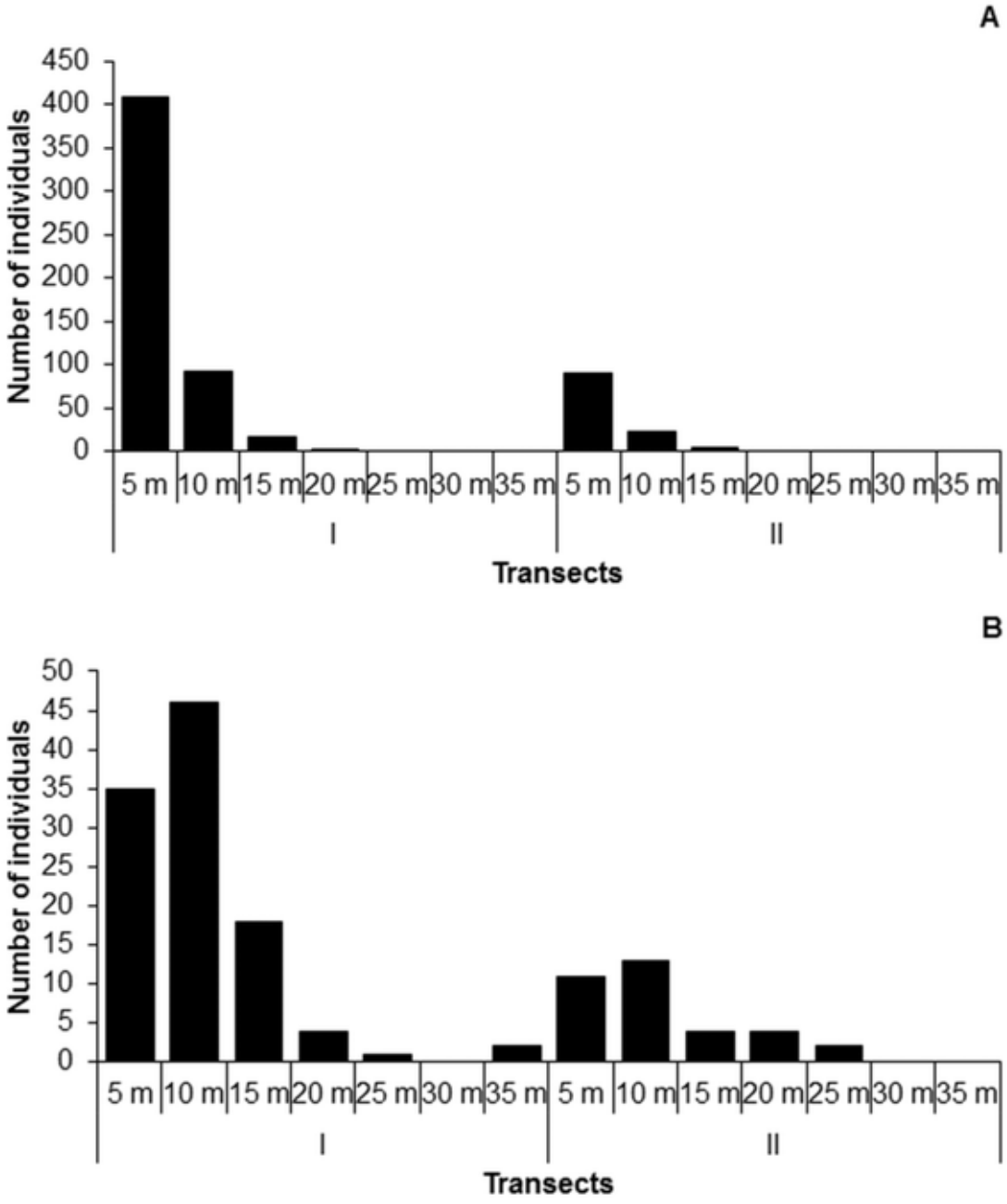

Figure 3 - *Callinectes danae* (Smith, 1869). Absolute abundance of individuals in the Ubatuba (A) and Caraguatatuba (B) areas.

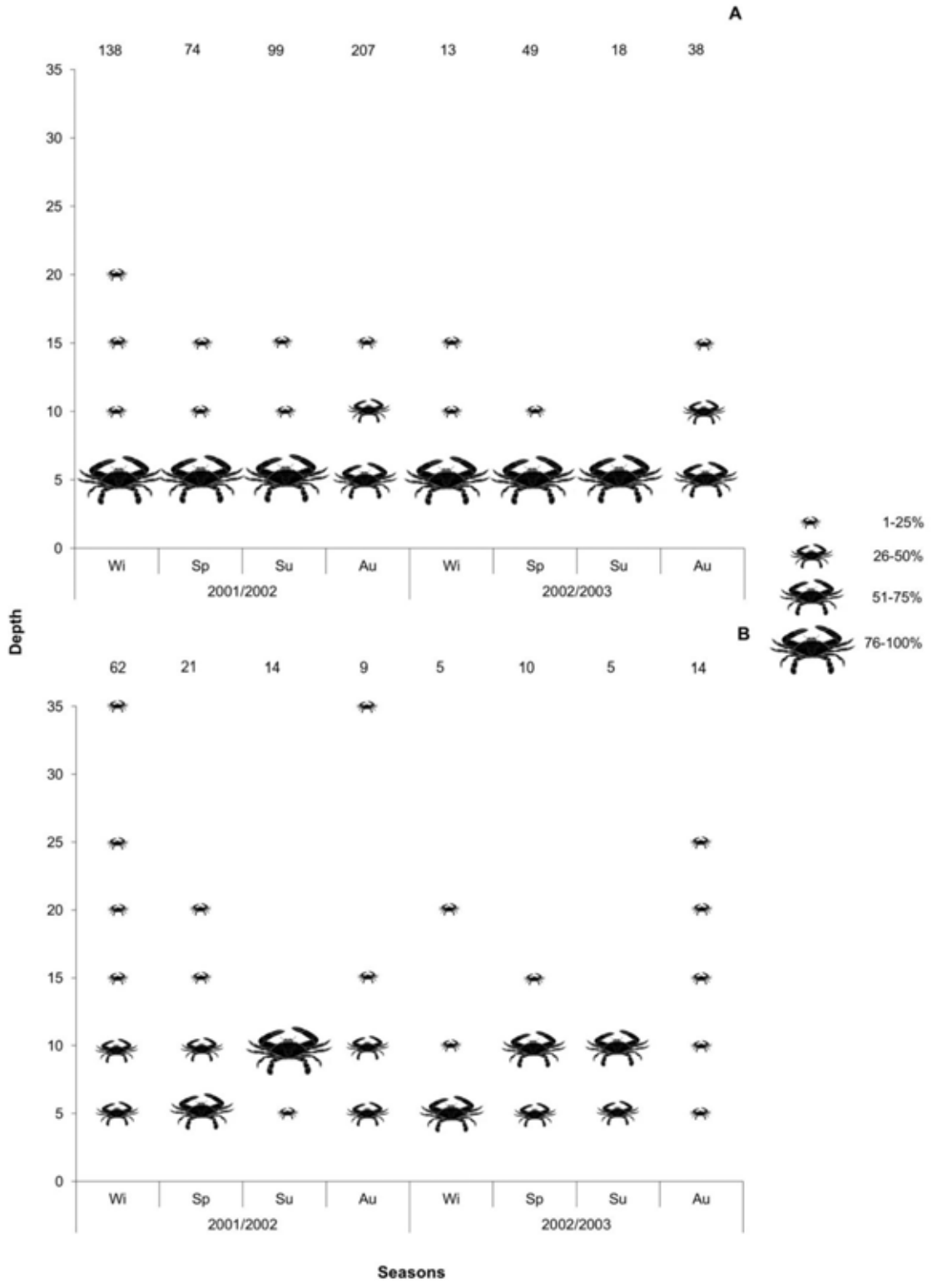

Figure 4 - *Callinectes danae* Smith, 1869. Frequency of individuals by season and depth, during the sampled period. A = Ubatuba, B = Caraguatatuba, Su = summer, Au =

autumn, Wi = winter, Sp = spring. Numbers at each graph top show the total abundance of collected individuals at area/depth/season.

Bottom salinity (BS) varied less in Ubatuba, ranging from 32 to 37 (35.1 ± 1.01). In this area, the lowest salinity values were recorded in the summer of the first and in the autumn of the second sampling periods. In Caraguatatuba, salinity ranged from 30 to 37 (35.3 ± 1.27). In this area, the values obtained for salinity were constant in the first sampling period. This value decreased in the fall of the second sampling period and reached its lowest value in the following winter. In both areas, the lowest salinity values were obtained in shallower waters (5 and 10 m).

The mean bottom temperature (TB) in Ubatuba waters was 22^{o}C (SD=1.81) and the thermal amplitude was 10.2. On the other hand, in Caraguatatuba the average temperature was 21.9^{o}C (SD=1.27) and the thermal amplitude was 8.6. There was a difference between the maximum and minimum average values in both study areas. In Ubatuba these values were recorded in February (23.7) (summer) of the first year and in Caraguatatuba in April (25.6) (autumn) of the second year.

In both areas, the lowest temperatures were obtained in October (17.9°C in Ubatuba and 19°C in Caraguatatuba) and November (16.7 °C in Ubatuba and 19 °C in Caraguatatuba), corresponding to the spring of the first year. Temperature values were inversely proportional to increasing depth in both areas. During the spring and summer the bottom temperature decreased in both areas, and temperature variation was more pronounced in Ubatuba (Figure 5).

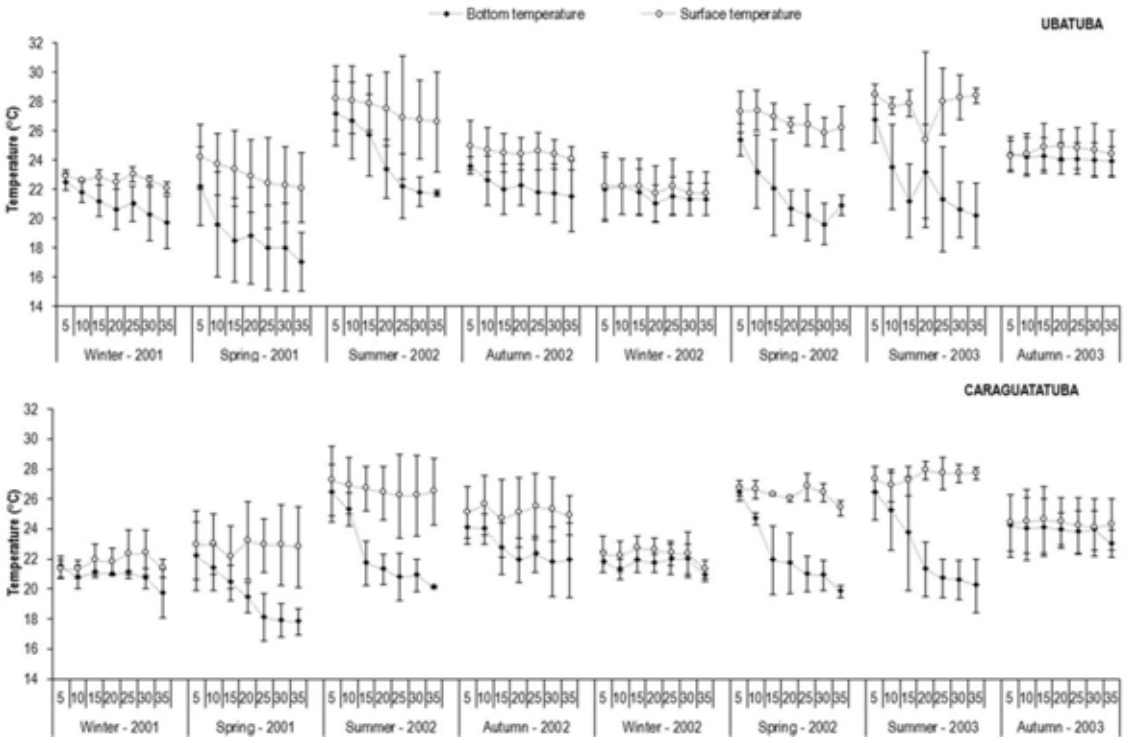

Figure 5 - Variations in the mean temperature obtained in Ubatuba and Caraguatatuba (± standard deviation) by transects in each season, from July 2001 to June 2003.

Aspects of the sediment, comprising the proportions of the granulometric classes, the average values of Phi and the content of organic matter (OM) revealed different patterns of texture for the two areas. In Ubatuba the percentage of Class C sediments was higher in shallower (5 and 10 m) transects, whereas deeper down (30 and 35m) sediment classes A and B predominated. In this same area, the values of Phi and MO were inversely proportional to depth (Figure 6). In Caraguatatuba there were higher percentages of class C sediments in the intermediate (15 and 20 m) transects, whereas the lowest values of Phi and MO were recorded in transects with greater and lesser depths, respectively. The following environmental factors were positively associated with the distribution of *C. danae*: BT, Phi and OM (Spearman correlation, $p < 0.05$). BS

was negatively associated with the distribution of the species (Spearman Correlation, $p < 0.05$).

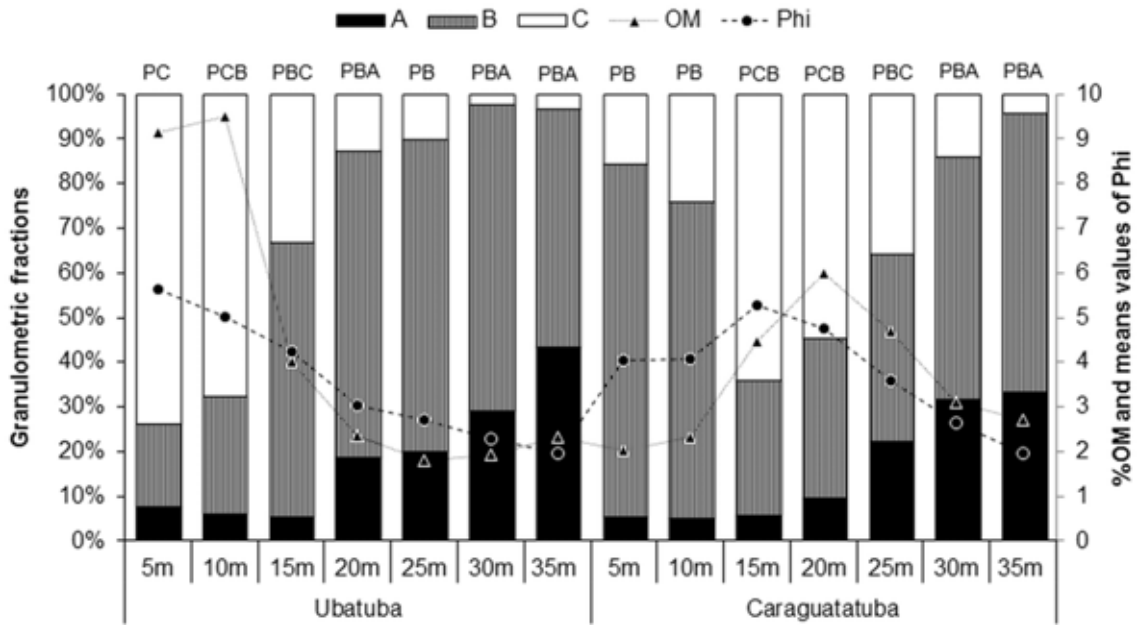

Figure 6 - Sediment results obtained in Ubatuba and Caraguatatuba: proportions of grain size classes, central tendency of sediments (●=Phi), and mean organic-matter content (▲=OM) for each depth. See Material and Methods for granulometric classifications (A, B and C).

DISCUSSION

According to Castro-Filho *et al*. (1987), the study area is strongly influenced by three water currents: South Atlantic Central Water current (SACW), with low temperature and salinity (T < 20ºC; S < 36), Tropical Water current (TW), with higher temperature and salinity (T > 20ºC; S > 36), and Coastal Water current (CW), with high temperature and low salinity (T > 20°C; S < 36). The SACW is one of the most important factors influencing the distribution of crustaceans in Ubatuba (Pires 1992). This water mass, besides altering salinity and temperature, also carries a significant amount of nutrients. According to Pires-Vanin & Matsuura (1993), in Ubatuba the extent to which the SACW penetrates the bottom layer that reaches the coastal region, where the water column becomes stratified during the summer, varies seasonally. In the winter, the SACW shrinks further away from the shore, and the CW predominates. This causes the water column to be more homogeneous with respect to temperature and salinity. In the present study, the influence of the SACW was felt during the spring and summer of both years, particularly from the 15 m depth, since there was a stratification of the water column in these seasons, which resulted in greater amplitude of the ground and bottom temperatures. Conversely, it seems that during the autumn and winter the SACW retreated, resulting in a more homogeneous water column with increased salinity and lower temperatures. The species can be considered euryhaline (Shumway 1983) as individuals are observed in estuarine regions and other areas with higher salinity.

It is possible that the great abundance of *C. danae* in Ubatuba waters in the fall is associated with the relatively homogenous temperature of the water column during this season. On the other hand, the wide variation in temperature in the water column

during the summer may have contributed to the lower abundance of this species. During the spring and summer, when bottom temperatures are the lowest from 15m down due to the reflex of the SACW, individuals concentrate in shallower waters, while during autumn and winter, some individuals move to greater depths. Furthermore, in the first sampling period, we observed a higher influence of the SACW in deeper waters, which may be the cause of the greater abundance of *C. danae* in the shallowest areas of sampling during this period. In both study areas the abundance was higher in transects where the granulometric fractions were smaller. Smaller fractions create more favorable conditions to the establishment of the species. In Ubatuba, abundance was greater in transects with higher Phi (finer sediment = Class C), hence with higher organic matter content. In Caraguatuba, the greatest values of abundance also occurred in shallower transects (5, 10 and 15 m), but class B sediments (fine sand and very fine) predominated in these. A few individuals were found deeper down in the water (25-35 m) in Caraguatatuba during the autumn and winter. These individuals were ovigerous females and adult females that probably migrated to deeper places where salinity is higher, to release their larvae. Larval dispersal is easier in deeper waters, due to the action of currents and winds (Hines *et al*. 1987, Chacur & Negreiros-Fransozo 2001, Sforza *et al*. 2010). After the post-embryonic development, the larvae in a more advanced stage of development (Megalopa) return to shallow areas with lower salinity to complete their life cycles (Chacur & Negreiros-Fransozo 2001). According Hsueh *et al*. (1993), the prevalence *C. danae* in estuarine areas (lower salinity) may be associated with the capacity of *Callinectes* Stimpson, 1870 species to osmoregulate. Another possibility may also be the need to shelter from predators, and food availability, particularly for juveniles (Lipcius & Van Engel 1990).

In this study we found that *C. danae* is most abundant in sites where sediment grain is finer, particularly silt and clay, which may be due to the larger amount of organic matter available in this type of sediment (Melo 1996, Teixeira & Sá 1998, Nevis *et al*. 2009). The preference for regions with thinner sediment may be associated with the need to search for food, because when a larger amount of organic matter is available there is an increase in the number of organisms that feed on it, including *C. danae* (Mantelatto 2000). Furthermore, the need to select sediments that facilitate burying may contribute further for the preference that individuals of *C. danae* show for these fine sediments. This burying behavior was also observed in other species of the same genus: *Callinectes ornatus* Ordway, 1863 and *Callinectes sapidus* Rathbun, 1986, indicating that his behavior is typical (Bellwood 2002).

The environmental factors considered to be more important in the distribution of benthic crustaceans are, in general, depth, salinity, and temperature and sediment texture. In this study, the importance of these factors on the abundance and spatial distribution patterns of *C. danae* have been corroborated.

We conclude that the joint influence of all environmental factors evaluated, but not any of them in isolation, modulates the distribution of *C. danae*. The influence of these factors on the distribution patterns of the species is evident when we observe the behavior of crabs that have a limited distribution, and are restricted to places which have characteristics more favorable to their survival. The results presented here support the distribution pattern observed in other studies, and provided basic information for future studies addressing the structure and biology of *C. danae*.

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CONSIDERAÇÕES FINAIS

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Os resultados apresentados nesta dissertação contribuíram com o conhecimento da biologia e ecologia de diferentes espécies de crustáceos que habitam a costa sudeste brasileira. Esses resultados ampliaram o conhecimento científico sobre o investimento reprodutivo e fecundidade de *Nematopalaemon schmitti*, sobre a distribuição, maturidade sexual e estrutura de *Persephona mediterranea*, sobre a distribuição de três espécies do gênero *Persephona* e ainda sobre a distribuição do siri *Callinectes danae*.

Foi possível observar quanto às estratégias reprodutivas de *N. schmitti*, no primeiro capítulo, que o investimento reprodutivo dessa espécie não está associado positivamente ao maior tamanho da fêmea, indicando a influência de outros fatores sobre esse aspecto reprodutivo. Assim novos estudos são recomendados, envolvendo a observação de fatores biológicos como as interações intra e interespecíficas, a fim de observar o que realmente afeta o investimento reprodutivo da espécie. Além disso, esse capítulo revelou novas informações relacionadas à fecundidade desta espécie.

O segundo capítulo contribuiu com a ampliação de informações relevantes quanto à aspectos distribucionais, reprodutivos e populacionais de *P. mediterranea*, uma espécie que habita uma área de proteção ambiental marinha recém criada.

Em relação aos padrões distribucionais das espécies do gênero *Persephona*, e de *C. danae*, capítulos 3 e 4, concluímos que existe uma divisão de habitat para as espécies, ocorrendo sobreposição de nicho em alguns locais. Observa-se que cada espécie ajusta sua distribuição mediante à disponibilidade de recursos favoráveis ao seu estabelecimento, seja ele a oferta de alimento, a textura do sedimento, as variações de temperatura ou de salinidade.

Todas as informações geradas nesta dissertação apresentam-se como dados potenciais para futuras comparações da história de vida e dos padrões distribucionais, reprodutivos e populacionais das espécies aqui estudadas e de outras que apresentam-se em mesmo nível taxonômico que estas.