Mangrove sedimentary characteristics and implications for crab *Ucides cordatus* (Crustacea, Decapoda, Ucididae) distribution in an estuarine area of the Amazonian region

José Diego GOMES[1], Fernando Araújo ABRUNHOSA[2], Darlan de Jesus de Brito SIMITH[3], Nils Edvin ASP[2]*

ABSTRACT

At the coastal zone sediments, water and organisms interact intensely. At equatorial tidal-dominated coast mangroves are abundant. These areas are well-known for their ecological importance. Considering the mangroves of Atlantic South America, the mangrove crab, *Ucides cordatus* has ecological and economic prominence. High densities of this crab are found on the Amazon coast. This study investigates the sediment distribution of the Bragança mangrove area (Amazon coast, Brazil) and its correlations with vegetation and mangrove crab distribution. Sediments of 47 sites, as well as crabs from sites with different sediment and vegetation, were sampled. Results show that surface sediment of the area is mainly composed by silt (59%), with 21% sand and 20% clay. Variations in sorting and skewness are the product of local variations in clay and sand content. The vegetation type was significantly correlated to mangrove crab characteristics, abundance and weight/size. Sediment characteristics are also substantially different according to the vegetation type. Areas where *Avicennia germinans* prevails have more sand and clay than areas of *Rizophora mangle*, in which silt is dominant and crabs were significantly heavier. The present results have showed that the distribution of sediments, crabs and vegetation at mangrove areas are strongly correlated. Thus, they should be studied in conjunction.

KEYWORDS: coastal plain, sediment distribution, tides, vegetation, North Brazil, mangrove crab

Características sedimentares de manguezal e implicações para a distribuição do caranguejo-uçá *Ucides cordatus* (Crustacea, Decapoda, Ucididae) em uma área estuarina amazônica

RESUMO

Na zona costeira, sedimentos, água e organismos interagem intensamente. Nas costas equatoriais dominadas por maré os manguezais são abundantes. Estas áreas são conhecidas por sua importância ecológica. No caso dos manguezais da costa atlântica da América do Sul o caranguejo-uçá *Ucides cordatus* (Linnaeus, 1763) se destaca por sua relevância ecológica e econômica, sendo que altas densidades deste organismo são encontradas na zona costeira amazônica. O presente estudo investiga a distribuição de sedimentos nos manguezais de Bragança (costa Amazônica, Brasil) e suas correlações com a vegetação e a distribuição do caranguejo-uçá. Quarenta e sete amostras de sedimento foram avaliadas, assim como caranguejos de 8 destas áreas foram coletados, onde o tipo dominante de vegetação foi também identificado. Os resultados demonstram que os sedimentos superficiais, assim como no extrato 0,8 a 1 m de profundidade, na área são principalmente compostos por silte (59%), incluindo em média 21% de areia e 20% de argila. O tipo de vegetação predominante foi significativamente correlacionado com a abundância e tamanho/peso dos caranguejos. As características sedimentares também foram substancialmente diferentes dependendo da vegetação. Áreas dominadas por *Avicennia germinans* tiveram mais areia e argila que as áreas dominadas por *Rizophora mangle*, onde a fração silte prevalece grandemente e os caranguejos eram significativamente maiores e mais abundantes. Os resultados demonstraram que sedimentos, invertebrados bentônicos e vegetação estão intimamente relacionados nos manguezais e devem ser estudados de maneira integrada.

PALAVRAS-CHAVE: planície costeira, distribuição de sedimentos, maré, vegetação, norte do Brasil, caranguejo de mangue.

1 Faculdade de Engenharia de Pesca – Universidade Federal do Pará (FEPESCA-UFPA); Campus Bragança: Alameda Leandro Ribeiro, s/n – Bairro Aldeia – Bragança, PA – Brazil – CEP: 68600-000; Tel: 55 91 3425-1593; E-mail: jdiegogv@hotmail.com.

2 Instituto de Estudos Costeiros – Universidade Federal do Pará (IECOS-UFPA); Campus Bragança: Alameda Leandro Ribeiro, s/n – Bairro Aldeia – Bragança, PA – Brazil – CEP: 68600-000; Tel: 55 91 3425-1593; *: autor correspondente, E-mail: nilsasp@ufpa.br.

3 Programa de Pós-graduação em Biologia Ambiental – Universidade Federal do Pará (PPGBA-UFPA); Campus Bragança: Alameda Leandro Ribeiro, s/n – Bairro Aldeia – Bragança, PA – Brazil – CEP: 68600-000; Tel: 55 91 3425-1593; *: autor correspondente, E-mail: simithdjb@hotmail.com.

INTRODUCTION

Tides, waves and associated currents are the main drive forces for sediment transport and geomorphology of soft-sediment coasts around the world. Where tides prevail, estuaries and tidal flats are the most conspicuous sedimentary environments. If these tide-dominated areas present adequate (warm) climate, sedimentation and nutrients, mangroves rapidly cover the tidal flats and estuarine borders.

These areas are well-known for their high productivity, low diversity and general ecological importance, such as reproduction and nursing of vertebrate and invertebrate species, including several of economic relevance. Considering the Atlantic coast of the American continent, the mangrove crab, *Ucides cordatus* (Linnaeus, 1763), has an ecological and an economic prominence. It is a typical mangrove resident and occurs from Florida at the United States to Santa Catarina in southern Brazil (Melo 1996, Tavares 2003). High densities of that species are found in the Amazonian coast, northern Brazil (Castro 1986, Nordi *et al.* 2009).

The northern sector of the Brazilian coast is dominated by tides and by the Amazon River, with a catchment area of more than 6×10^6 km², a maximum water discharge in the order of 200×10^3 m³s⁻¹ and suspended sediment load in the order of 3.5×10^6 ton day⁻¹ (Meade *et al.* 1985). The interaction of tides, mud supply and equatorial climate result in substantial mangrove development and the referred important mangrove crab occurrence. There, the climate is controlled mainly by seasonal changes in the position of the Inter-tropical Convergence Zone (ITCZ), which stays in latitudes around 14° N during August and September, migrating southwards until around 2° S during March and April, exactly over the Amazon region (Souza Filho *et al.* 2009). Therefore, the region experiences high precipitation in the first months of the year, with 73% of the total rainfall from January to April, while September, October and November are especially dry months (Moraes *et al.* 2005). The annual regional rain fall is high, contributing for estuarine development, ranging from 2,300 to 2,800 mm (Moraes *et al.* 2005), where the rainiest month is usually March, and the driest month is usually October.

The described general setting of the area results in 7,600 km² of continuous mangrove forests (Souza Filho and Paradella 2003, Souza Filho 2005), including an extremely irregular and jagged coastline, harboring 23 estuaries (Souza Filho *et al.* 2009). The estuarine embayments are sand dominated, intercalated by the protruding of muddy dominated coastal plains, usually covered by mangroves. The sediment dynamics between the estuarine basins and muddy plains are interrelated and the coast line is continuously changing (Souza Filho *et al.* 2009).

At that area, the Bragança coastal plain is found, which is in average 8 km wide and 25 km long, mainly covered by mangrove forest and separating Taperaçu and Caeté estuaries (Figure 1), where the *U. cordatus* corresponds up to 84% of the benthic biomass (Fernandes 1997, Koch and Wolf 2002). It is being intensely captured by the local population, although its occurrence is locally not yet substantially affected by the economic catchment (Diele 2000, Glaser and Diele 2004, Diele *et al.* 2005). Besides, impacts of crab catchment were not focused in the present study.

Despite its relevance, the relationships of mangrove crab distribution and ecology with sediment and vegetation distribution is complex and the number of studies involving this theme increased just in the late years (Nordhaus *et al.*
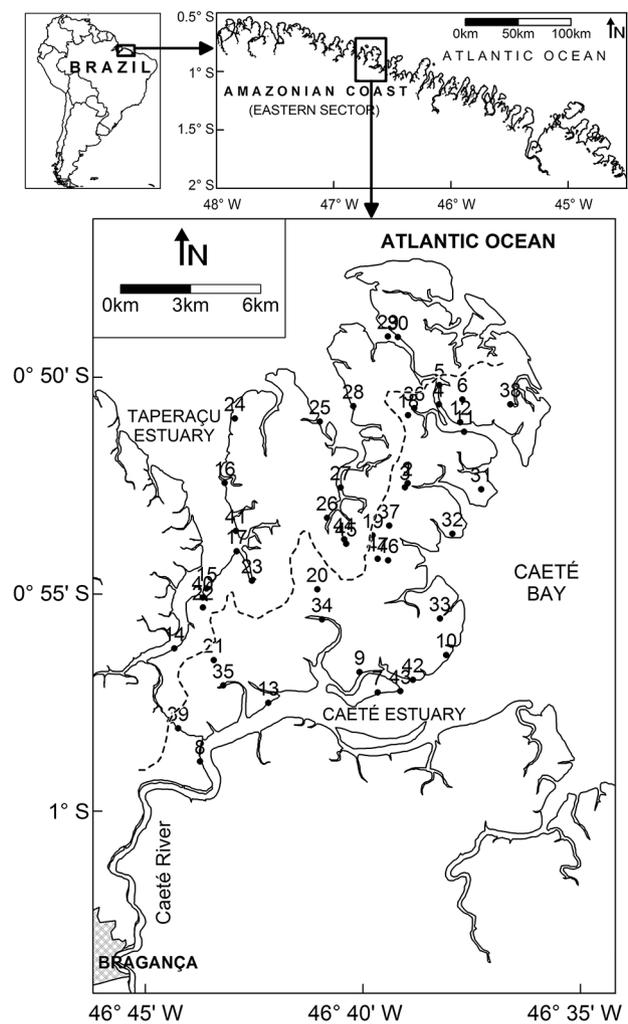
Figure 1 - Location of the study area (Bragança coastal plain), including the sampling sites. The dashed line indicates the area division in two estuarine sides, according to the ebbing and flooding pattern.

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2006, Diele and Simith 2006). Depending on the coastal morphodynamics and the geological setting, substantial sediment distribution differences are observed along the mangroves, where the type of prevailing mangrove species (e.g. *Rizophora mangle* and *Avicennia germinans*) is also related with the sedimentary characteristics (Mehlig 2001). Depending on the sand/mud and organic contents, a type of vegetation may prevail and both, sediment and vegetation coverage, have impacts on crabs distribution and ecology, due to, for instance, the availability of food and burrowing easiness (Nordhaus *et al.* 2006). Furthermore, crab distribution is also affected by mangrove leaf litter load and decomposition, which is also variable depending on the prevailing mangrove tree species (see Amouroux and Tavares 2005).

On the other hand, sediment deposition and its granulometric variation is strongly correlated with the tide hydrodynamics, especially regarding current velocity and frequency of inundation, which also affects mangrove trees settling and growth (Dittmar 1999). Therefore, a correlation between sediment distribution and crabs abundance and size/weight is expected. For instance, there seems to be a tendency for *A. germinans* to establish itself more successfully in slightly elevated areas (frequently sandier than lower areas), whereas *R. mangle* prevails in more frequently inundated locations with soft, muddy sediments (Mehlig 2001).

In this context, the present work investigates the superficial sediment characteristics of the Bragança mangrove area (Amazon coast, Brazil – Figure 1) and its correlations with vegetation coverage, as well as, the implications for the mangrove crab distribution and ecology.

MATERIALS AND METHODS

In order to evaluate the characteristics of the superficial sediment distribution at the mangroves of the Bragança coastal plain, as well as its implications to mangrove crab distribution and correlations with vegetation coverage, sediments and crabs were sampled, correlated and compared to the available vegetation coverage maps.

Sampling

Concerning the sediments, 47 points were sampled, comprising different parts of the mangrove, such as the margins of Caeté and Taperaçu estuaries, central parts of the peninsula, innermost and outermost mangrove areas (Figure 1). To avoid seasonal variation effects in both, crab and sediment characteristics, sediment samples and crabs were taken only during wet season (March to July) from 2008 to 2010.

Sampling sites were located using Global Positioning System (GPS), with the hand GPSmap CSx Garmin™, which provides a precision of few (e.g. 3 to 9) meters even under vegetation shade. All information was geographically disposed and compared using the software Surfer™ 8. The used interpolation method was the triangulation with linear interpolation, including 200 m of grid spacing. The interpolation method was chosen because of its high fidelity to the original values.

Sediment samples were taken with a shovel, which collected approx. 1 kg of soil from the upper 10 cm. At 8 selected sites (40 to 47 - Figure 1) crabs were also caught, where 10 squares of 4 m² were sampled and all specimens found in these areas were caught. The sampling squares were disposed along a 100 m line, where their positions were chosen randomly, as proposed by Alcântara Filho (1978) and already successfully applied in Amazonian mangroves (Fernandes and Carvalho 2007). Furthermore, all collected specimens were measured (weight, carapace width and length) and the sex was also determined.

Vegetation distribution

The evaluation of vegetation coverage and prevailing species at the mangrove area of Bragança was performed by Mehlig (2001), based on the combination of satellite imagery and field observations and phytosociological studies. Since comparisons of sediment and crab distribution between areas of different vegetation were intended, sites for crab catch were chosen based on that mangrove vegetation mapping (Mehlig 2001), where the prevailing vegetation type was verified on the field, during the sediment and crab sampling.

Sediment processing and data analysis

Sediment samples were submitted to organic matter and grain size analysis. They were processed according to the methodology described by Suguio (1973), consisting firstly in the removal of salt from samples, followed by the removal and measurement of organic matter content (%OM) by oxidation with H_2O_2. Then, samples were submitted to wet sieving to separate fine (< 62.5 μm) and coarse sediments. The dried coarse sample fraction was sieved using ¼ PHI ( ) interval and the fine sediments were evaluated based on the settling velocities. Granulometric distribution and statistic parameters were calculated according to Folk and Ward (1957), based on the logarithm grain size scale Phi, as proposed by Wentworth (1922), where the grain size Phi corresponds to the negative two-based logarithm of the grain size in millimeter. Further, the spatial variation of sediments was analyzed.

In order to compare the differences between biological traits of crabs (e.g. carapace length: CL, carapace width: CW and wet weight) and different types of vegetation (*Rizophora mangle*: RM, and *Avicennia germinans*: AG), the biological samples were analyzed in the laboratory. The differences in crab characteristics in relation to sediment and vegetation coverage were then analyzed through a non-parametric test

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(Mann-Whitney U-test), where crab biometric data (CL, CW and weight) and sediments from *R. mangle* and *A. germinans* sampling sites were compared. Significant differences were then considered when $p < 0.05$ (95% of confidence of interval).

In order to statistically correlate sedimentology and crab biometry, a 'BEST' (Biota and/or Environment Matching) was also performed using the software *Primer®*, where the used resemblance measure was Euclidian Distance, with rank correlation method of Spearman, using the BIOENV method. The percentage of sand, silt and clay were correlated with crab weight, carapace width and length.

Further comparisons considering the peninsula side of sampling (west/Taperaçu; east/Caeté) were also performed, since sediment analyses have shown lateral differences. In order to divide the peninsula in two sides, satellite imagery was used (Landsat TM of 1st Aug/2001; Aster of 23th Nov/2003; and CBERS of 3rd Aug/2005). All images are RGB compositions, with original spatial resolutions of 30, 15 and

20 m, respectively. Based on the drainage of tidal channels and creeks, a divisor line was established. The satellite images, as the sediment distribution, were georeferred and plotted using the *Surfer®* v.8 software.

RESULTS

Sediment characteristics and variation

From all 47 collected samples, only one was classified as Sandy (very fine sand), and 6 samples were classified as Clayey. Most of samples (40) were classified as Silty. The average of all samples reveals contents of 20% sand, 59% silt and 21% clay. Mean organic matter content was 5.5%. At 8 disperse sites along the area sediment samples were also taken at 0.8 to 1 m depth, beside surficial samples. Granulometric analysis did not show substantial differences between superficial and the deeper samples. Therefore, sampling and analysis involve basically superficial samples, which are also strongly related to settling of the different mangrove trees. Figure 2 presents an
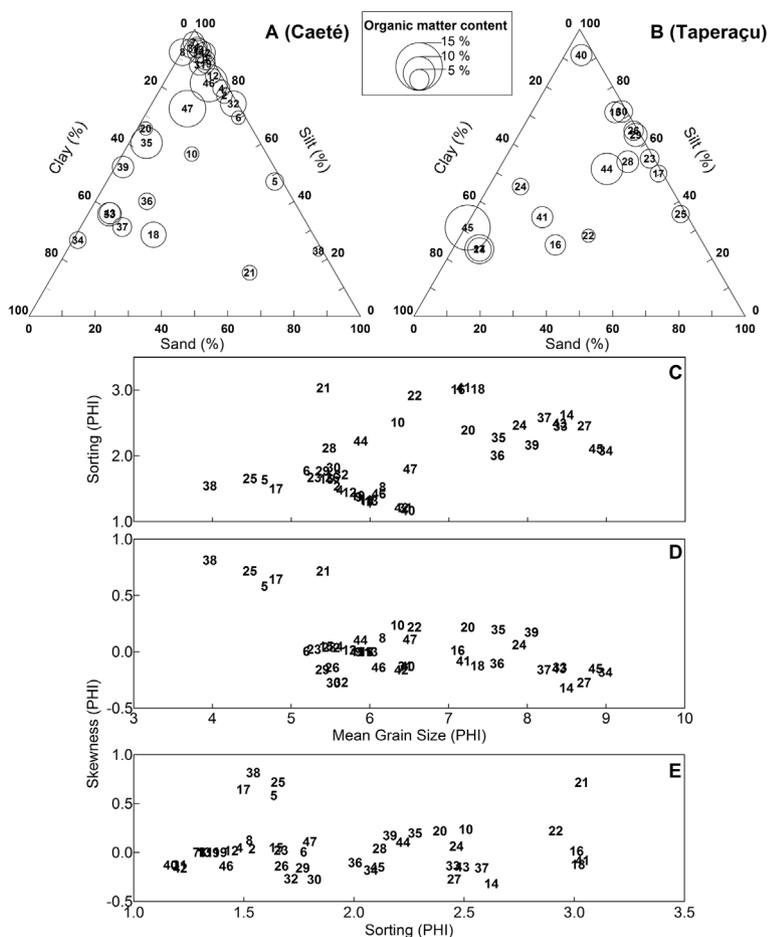
Figure 2 - Overview of superficial sediment characteristics at the Bragança mangroves. A (Caeté side) and B (Taperaçu side): Ternary diagrams of sand/silt/clay fractions, where the circles correspond to organic matter content; C, D and E: Dispersion diagrams correlating skewness, sorting and mean grain size.

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overview of the granulometric characteristics and variations among the samples.

Considering the statistical analysis of grain size distribution, the overall mean grain size was 6.44 Phi, ranging from 3.97 to 8.99 Phi. Most of the samples were classified as not well-sorted. Approx. the half of samples presented a symmetric distribution. One quarter showed negative skewness (coarser grains surplus) and other quarter presented positive asymmetric distribution ('excess' of finer grains). This pattern is the result of variations in sand and clay content in essentially silty samples.

To evaluate the variations in mean grain size, sorting and skewness of sediments along the Bragança mangrove, so-called dispersion diagrams (Suguio 1973) were built (Figure 2, C, D and E). However, no significant grouping was observed.

Maps of sediment distribution including sand, silt and clay fractions were performed and showed the differences in the sediment coverage of the west/Taperaçu side and the east/Caeté side, despite local variations (Figure 3). It can be observed that sediments at the west/Taperaçu side are sandier, whereas the sediments at the east/Caeté side are siltier, as suggested by the ternary diagrams on Figure 2. The clay fraction is overall frequent and locally abundant, but there is no a clear pattern of distribution.

In relation to the prevailing vegetation type, the t-test was applied to correlate sedimentological and vegetation variations, but these were significant (= 0.05) only for silt (t-test = 6.555, p < 0.001), where silt content is significantly higher at *Avicennia* areas.

## Crab biometry and sediment – vegetation correlations

A total of 111 specimens of the mangrove crab *Ucides cordatus* were caught in the study area. The sampled individuals were then grouped according to the type of vegetation and estuary (Caeté and Taperaçu). In the Caeté estuary, a total of 44 crabs (68.2% males and 31.8% females) were collected in the *Rhizophora mangle* area (RM) and only 13 specimens (92.3% males and 7.7%) in the *Avicennia germinans* area (AG). In the Taperaçu estuary were caught 36 individuals (50% males and 50% females; RM) and 18 crabs (72.2% males and 27.8% females; AG).

In the Caeté estuary, the carapace length (CL) of the crabs sampled in RM ranged from 46 to 78 mm and from those specimens caught in AG had the carapace length varying from 44 to 68 mm. The carapace width (CW) showed values ranging from 30 to 61 mm (RM) and from 35 to 59 mm (AG). The wet weight of the sampled crabs in RM ranged from 38.0 to 219.2 g and in AG it varied from 39.0 to 133.0 g. No significant differences (p > 0.05) were found between the average values of CL and CW, and wet weight of the sampled crabs between the two different types of vegetation (RM and AG) (Figure 4).

In the Taperaçu estuary, the crabs collected in RM showed a CL ranging between 50 and 74 mm and those individuals caught in AG presented values varying between 45 and 66 mm. The CW varied from 38 to 75 mm in RM and from 34 to 48 mm in AG. The weight of the sampled specimens ranged between 50.2 and 165.2 g in RM and between 39.7
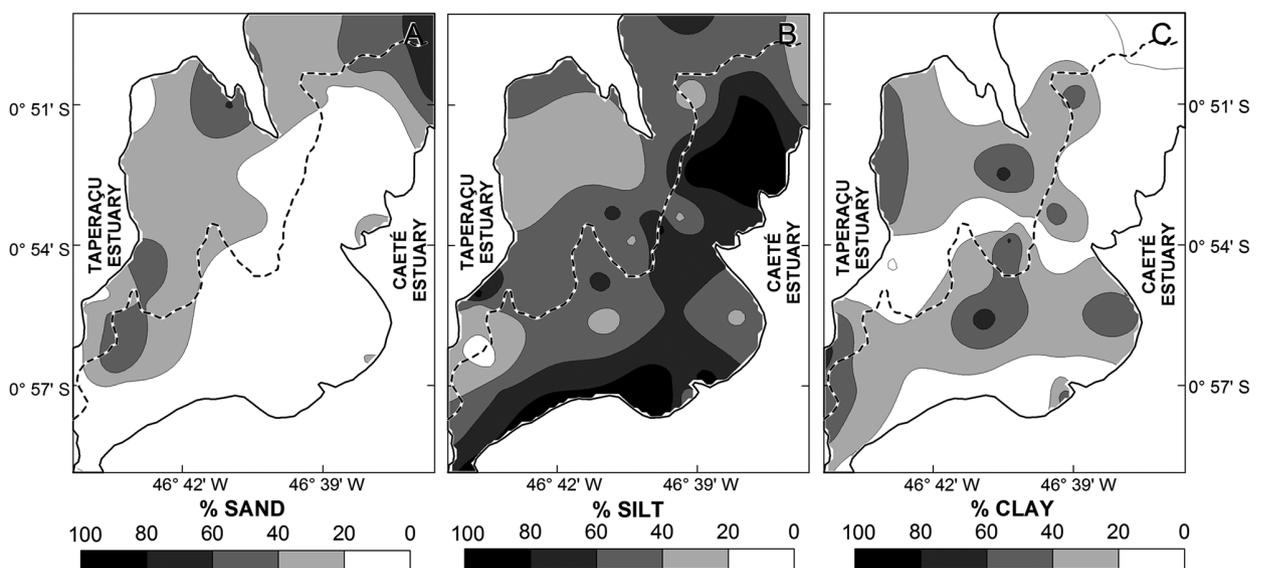
Figure 3 - Maps of sediment distribution, including sand (A), silt (B) and clay (C) fractions. The outer black line, encompassing the contour maps, represents the border of the coastal plain, whereas the dashed line indicates the area division in two estuarine sides, as showed in Figure 1.
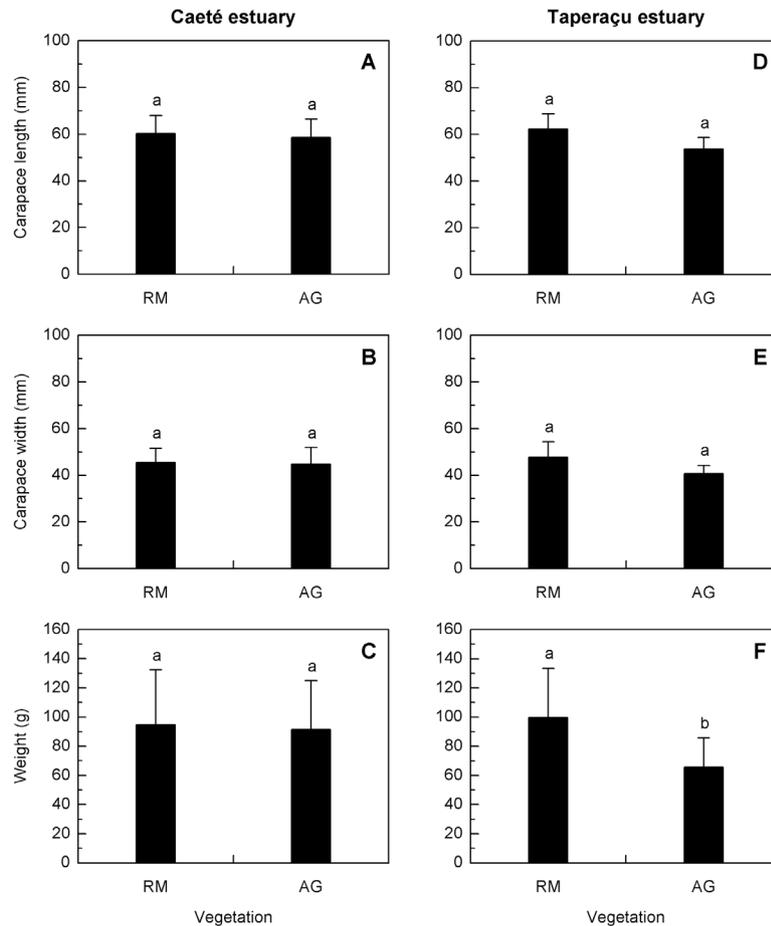
Figure 4 - Carapace length and width (mm, average ± standard deviation) and wet weight (g, average ± standard deviation) of the sampled crabs in the respective mangrove areas (*Rhizophora mangle*: RM; *Avicennia germinans*: AG) belonging to the Caeté and Taperaçu estuary.

and 126.8 g in AG. The average body size (CL and CW) of the collected crabs did not present significant differences (p > 0.05) between the respective types of vegetation (Figure 4). However, concerning to the average weight of the crabs, a significant difference was found between the two respective sampled areas (Figure 4). The specimens collected in RM showed the highest average wet weight (99.7 ± 33.6 g).

Further, the so-called BEST test also showed a moderate, but significant, correlation of weight with granulometric characteristics of the sediment, corresponding to a correlation value of 0.432. The correlation with carapace width or length was substantially lower. Therefore, it indicates that the prevailing of RM is correlated with sediment granulometric characteristics, as well as the prevailing of RM results in heavier crabs.
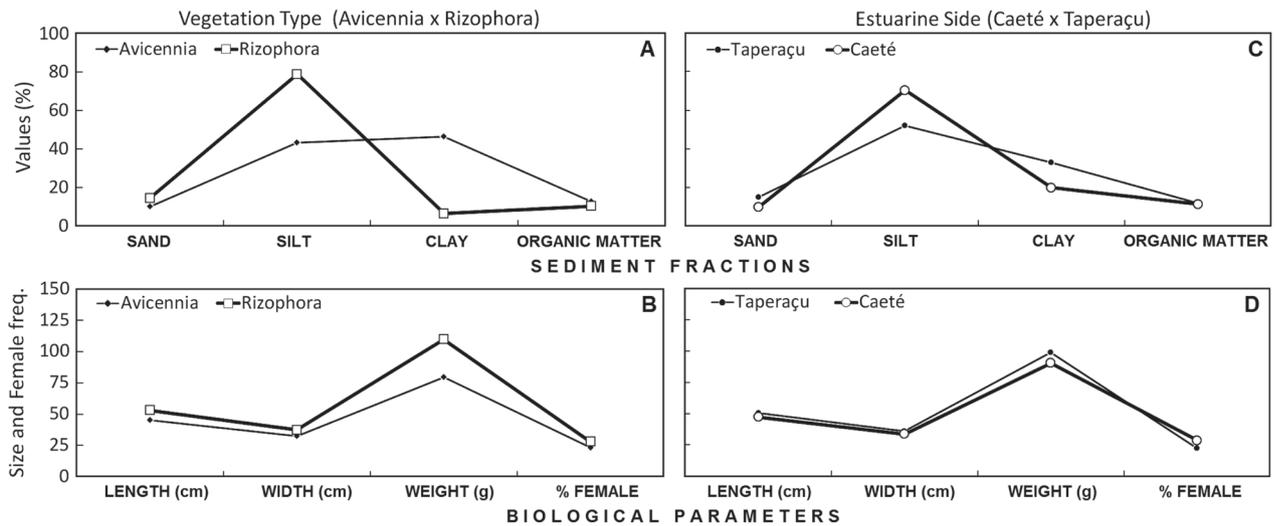
Figure 5 shows the sediment fractions and organic matter contents, as well as the crabs biometric information and female percentage, which are compared according to the prevailing vegetation and side of the peninsula. As other comparisons have showed, differences in crab dimensions and weight, as

well as sediment characteristics, are substantial in relation to the vegetation prevailing type. Important (but not statistically significant) differences are observed comparing the sides of peninsula, but they do not result in measurable differences in crab characteristics.

DISCUSSION

In a preliminary analysis the sediment distribution of each sample is the product of very local conditions, such as proximity to tidal creeks and very local vegetation variation. Thus, eventual correlations of samples according to type of prevailing vegetation or general location (e.g. east/Caeté *versus* west/Taperaçu side) are partially hidden by local influence. The absence of a clear pattern of distribution of the clay fraction reflects the influence of such local factors.

Nevertheless, the abundance of sand at the Taperaçu/west side, in relation to the siltier Caeté/east side could be associated with morphodynamic differences on the Taperaçu and Caeté estuaries. At Taperaçu a catchment area, and therefore continental sediment supply, is almost inexistent (Asp *et al.*

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Figure 5 - Comparison of sediment distribution and crab biometry according to the prevailing vegetation type (*Rizophora* or *Avicennia*) and estuarine side of collection (Taperaçu or Caeté side).

2012), while Caeté eastuary has a catchment area of approx. 1,550 km² and the higher silt contents observed at this side might by of continental origin (Souza Filho *et al.* 2009).

Regarding to the evaluated specimen of *Ucides cordatu*s, the respective biometric values found in the present study correspond to the sexual maturity for the species, according to Pinheiro and Fiscarelli (2001), but are inferior of the minimum allowed size for economic catchment, according to Brazilian laws. These results were expected, since the crab catchment within this study was not selective regarding size, in opposition to the exploitation. In the *R. mangle* area in the Taperaçu estuary, the crabs were significantly heavier and more abundant. These results are in agreement with a previous study (Fernandes and Carvalho 2007) and would be directly related with the availability of food and its specific biochemical composition (Nordhaus *et al.* 2006).

The differences observed in sediments suggest that *Rizophora* occupy more silty areas, whereas *Avicennia* occupies slightly sandier areas, as also suggested by Mehlig (2001). On the other hand, as *Avicennia* occupies an area, the clay deposition seems to increase due to the presence of pneumatophores. The areas showing higher concentrations of clay (Figure 3) usually present *Avicennia* dominance.

Furthermore, crab distribution (*Ucides* included) is also affected by mangrove leaf litter load and decomposition, showing a preference for *Rizophora* as food source (Amouroux and Tavares 2005, Nordhaus *et al.* 2006). Thus, the correlation of crab and sediment distribution might be even indirect, but substantial.

Furthermore, it can be summarized that the superficial sediment distribution of the mangrove peninsula of Bragança is mainly composed by silt, especially at the east/Caeté side.

Overall sediment proportion of main fractions is 59% for silt, 21% for sand and 20% for clay. The sediment distribution is the product, in first instance, of the general morphodynamics, and both corroborate for the prevailing of a mangrove tree (e.g. *Rizophora mangle* or *Avicennia germinans*). If samples are compared individually, vegetation seems to be a remarkable factor in determining the mangrove crab characteristics, especially abundance and weight.

If the whole area is considered, differences in sediment due to morphodynamic differences of the estuaries bordering the peninsula are relevant, therefore it was observed that the west/Taperaçu side is sandier, and the east/Caeté side is siltier. However, these differences are not resulting in substantial differences in the crabs' biometric values.

Sediment characteristics are also substantially different comparing areas of different types of prevailing vegetation, but their interaction is complex. Although, results showed a significant correlation of sediment characteristics, crab weight and prevailing of *Rizophora mangle*.

The present results have showed that the distribution of sediments, crabs and vegetation at mangrove areas are strongly correlated, especially in estuaries and tidal plains with important mangrove development, as here studied. Thus, sediments, vegetation and crabs should be studied in conjunction.

ACKNOWLEDGEMENTS

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