Distribution and density of the mollusk *Donax striatus* (Linnaeus, 1767) in a tropical estuarine region in the brazilian semi-arid

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Abstract

This study evaluated the spatial and temporal distribution and density of the bivalve *Donax striatus*, at beaches close to the Apodi/Mossoró River estuary, through, six semiannual sampling campaigns were performed between April/2009 and October/2011. The sampled area was delimited by 20 transects that were laid perpendicular to the beach line and extended over 300 m in the intertidal zone. Seven sampling points were established in each transect, organisms and sediment were collected, and water temperature and salinity were recorded. The highest *D. striatus* average density (103 individuals.m^{-2}) was observed in April/2009 and the lowest (18 individuals.m^{-2}) in October/2010. The highest *D. striatus* densities occurred in beaches further from the estuarine region as demonstrated by a significant positive correlation (r^2 = 0.67 and p = 0.0007). The *D. striatus* densities presented significant negative correlations with the percentages of organic matter in the water. This species demonstrated an aggregated distribution in the studied area.

Keywords: estuary, organic matter, temperature, salinity, rainfall.

Distribuição e densidade do molusco *Donax striatus* (Linnaeus, 1767) em região estuarina tropical do semiárido brasileiro

Resumo

O objetivo da pesquisa foi verificar a distribuição (espacial e temporal) e a densidade do bivalve *Donax striatus* em praias próximas ao estuário do Rio Apodi/Mossoró, Rio Grande do Norte (RN), através de seis coletas semestrais (abril/2009 a outubro/2011). Foram dispostos 20 transectos perpendiculares à linha da praia, com 300 m de comprimento na zona intertidal. Em cada transecto foram estabelecidos sete pontos de amostragem e obtidas amostras de organismos e sedimento, foram determinadas a temperatura e salinidade da água. Com os resultados obtidos foi em abril/2009 a maior densidade média de *D. striatus* (103 indivíduos/m²) e em outubro/2010 a menor densidade (18 indivíduos/m²). As maiores densidades de *D. striatus* ocorreram em praias afastadas da região estuarina, com correlação significativa e positiva (r²=0,67 e p=0,0007). As densidades de *D. striatus* apresentaram correlações significativas e negativas com a matéria orgânica. Pôde-se constatar ainda que esta espécie apresentou uma distribuição agregada.

Palavras-chave: estuário, material orgânica, temperature, salinidade, pluviosidade.

1. Introduction

The intertidal regions of sandy beaches are often dominated by bivalves of the family Donacidae. These filtering organisms are distributed in beaches worldwide, except at the poles (Ansell, 1983; Rios, 2009). Species in this family form high density populations in relatively unstable environments with strong wave action and are well adapted to the high energy intertidal region (Wilson, 1999). Several species of the genus *Donax* are important macrofauna components in sandy beaches and show considerable burial and migration capacity that aids them in better adapting to the waves actions (Ansell, 1983; Wade, 1967a).

Donax striatus is distributed from the Caribbean to the States of Rio Grande do Norte, Piauí, Maranhão, and Ceará, in Brazil (Borges-Azevedo et al., 1990; Wade, 1967b; Borrego et al., 2010). Their spatial distribution and density can be influenced by abiotic variables such as water salinity and temperature, sediment granulometry,

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and organic matter content (Borrego et al., 2010; Mazé and Laborda, 1988; Bayed and Guillou, 1985). Other factors such as feeding habits, reproduction, osmoregulation, climatic variations, and morphodynamics can also affect the dynamics and structure of these bivalves' populations (Herrmann et al., 2010; Gosling, 2003).

Fishing-related and bivalve ecology studies are well documented in South American countries (Orensanz, 1986; Defeo and Alava, 1995; McLachlan et al., 1996; Castilla and Defeo, 2001; Schumann, 2007; Gelcich et al., 2008). However, studies on the ecology of mollusks with economic importance, such as *D. striatus,* are still scarce in Brazil. In northeastern Brazil, marine and estuarine fish resources are of vital importance in promoting an integrated development in the region, primarily as the means of livelihood and food supply for local populations. Bivalves such as *D. striatus* and *Anomalocardia brasiliana* (Gmelin, 1791) represent valuable sources for artisanal fisheries, providing food that is consumed or sold locally (Carstensen et al., 2008). Thus, the study of edible mollusks is of extreme relevance, especially in Rio Grande do Norte, where several species of bivalves are used as human food (Gil et al., 2007; Rodrigues et al., 2010). The present study evaluated the temporal and spatial distribution and density of *D. striatus* and their correlation with some of the abiotic parameters in their habitat.

2. Material and Methods

The study area included 22 km of beach extension between the municipalities of Grossos and Tibau-RN, located in the saline production subzone in the State of Rio Grande do Norte, close to the estuarine region of the Apodi/Mossoró River ($04^o58'47''$S and $37^o09'17''$W). This coastal region is inserted in the region known as Costa Blanca, the only site in Brazil where the caatinga meets the sea. The region's climate is semi-arid with an average annual temperature of 27 °C; this region is subjected to cycles of semi-diurnal tides (Fidrgn, 1991). The vegetation is mainly composed of semi-arid vegetation, shrubs, and mangroves.

Six sampling campaigns were conducted between April of 2009 and October of 2011. Samples were collected semi-annually during the low tide using transects that were laid perpendicular to the beach line towards the sea and extended over 300 m length in the intertidal zone. Seven collection points were defined in each 20 transect, 50 m apart from each other.

Donax striatus individuals were collected with a circular tube measuring 15.7 cm in diameter and 12 cm in length; samples were placed in a 2 mm mesh sieve to remove excess sediment. Sediment samples were collected with a circular galvanic iron collector, 5.6 cm wide and 10 cm long. Mollusk and sediment samples were stored in plastic bags and identified by the sampling sites; the bags were stored in coolers in the field and frozen in the laboratory until analysis. Water temperature was measured with a multisensor for limnological variables; salinity was measured with the aid of a manual optical refractometer.

The counting and biometrics of live *D. striatus* individuals were performed with the aid of a caliper (at 0.01 mm precision). Sediment samples were dried in an oven at 50 °C, and the granulometry analysis was subsequently performed using sieving techniques (Suguio, 1973). Sediment weights were recorded for each sieve pore (2.0; 1.0; 0.5; 0.25; 0.125; and 0.053 mm) and classified as (i) gravel, (ii) coarse and very coarse sand, (iii) average sand, (iv) sand fine, and (v) very fine sand and silt + clay (Shepard, 1954). The organic matter content was determined using the gravimetric method according to Wetzel and Likens (1991). The rainfall data in the studied region were obtained from the National Water Agency from Brazil (ANA); the arithmetic mean of the data from eight climatological stations distributed around the hydrographic basin of the Apodi /Mossoró River was used.

The spatial distribution of *D. striatus* was evaluated in each sampling period through the Morisita index (1δ), and statistical significance was verified by the F test (Ludwig and Reynolds, 1988) considering $I\delta = 1$ when in random distribution; $I\delta > 1$ when in aggregated distribution; and $I\delta < 1$ when in uniform distribution (Where $(I)(\delta)$ = Morisita index; N = number of sample units; Σx = Sum of individuals present per units) (Equation 1).

$$I\delta=N((\textstyle\sum x^2-\sum x)/((\sum x)^2-\sum x)) \qquad (1)$$

Thematic maps were produced to assess the potential variation in *D. striatus* densities correlated to distance from the estuary. The study area image was captured in JPG format, through the program Google Earth (GOOGLE) and was transformed into TIFF format for the preparation of maps. The separation of bands in the image was performed through the IMPIMA program, which is included in the SPRING package 5.1. Subsequently, the recording of bands 1, 2, and 3, in true color, was done using the SPRING 5.1 program. The spatial data interpolation was achieved with the *ArcView* 3.2 geographic information system using the *IDW* method (*Inverse Distance Weighted*) described by Mello et al. (2003) (Equation 2).

$$X_p=(\textstyle\sum_i^N=1(1/d_i^2) \times X_i)/(\sum_i^N=1(1/d_i^2)) \qquad (2)$$

Calculation of the interpolated value by the IDW method. Where Xp is the interpolated attribute; Xi is the attribute value of the ith sampling point; di is the euclidean distance between the ith point in the neighborhood and the sampled point; and n is the number of samples.

The Kruskall-Wallis non-parametric test was used to verify significant differences in the abundance of *D. striatus*. The Student-Newman-Keuls test was applied retrospectively when these differences were significant ($p<0.05$). Spearman correlation tests were applied between *D. striatus* densities and abiotic variables.

3. Results and Discussion

The highest rainfall values occurred in 2009 and could be related to heavy rains caused by the La Niña phenomenon. In this year, the annual precipitation was

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1,206 mm throughout the hydrographic basin area of the Apodi/Mossoró River, and the highest rainfall level occurred in April (323 mm). The total rainfall recorded in 2010 was 642 mm, of which 211 mm occurred in April; only 30% of the total rainfall occurred between May and December. The highest rainfall value in 2011 was recorded in April (216 mm).

The temperature records did not show large amplitude of variation in the sampling sites during the study period. The highest temperature records occurred in April/2009 with an average of 32.9 °C; the lowest average value (28.6 °C) was recorded in October/2011 (Figure 1a). According to Rodrigues et al. (2010) and Cruz-Neta and Henry-Silva (2013), this low amplitude in temperature variation results from the climate in this region. Cruz-Neta and Henry-Silva (2013) determined that temperature did not influence the distribution of the gastropod *Neritina virginea* (Linnaeus, 1758) in their population structure studies. Borrego et al. (2010) explained the lack of correlation between population density and water temperature as related to climatic homogeneity in a study on population structure of *D. striatus* in Cuba.

The salinity records showed high amplitude of variation during the sampling period (22 to 40). The lowest salinity average value (26) was observed in April/2009, and the highest average value (40) was observed in October/2009 (Figure 1b). The average salinity values were 38 and 39 in April and October/2010, respectively, and 37 and 38 in April and October/2011, respectively. No significant correlation (p = 0.0622) was observed between *D. striatus* densities and salinity values during the studied period. The low salinity values near the estuarine region in April/2009 were probably related to high levels of rainfall in the hydrographic basin of the Apodi/Mossoró River, which consequently caused an increase in fresh water supply in the estuary, thus reducing salinity.

The percentage of organic matter in the area of occurrence of *D. striatus* ranged from 0.9% to 5.6%. The highest average percentage of organic matter was observed in April/2009 (2.3%) and the lowest in October/2011 (1.6%) (Figure 1c). The correlation between *D. striatus* average densities and average percentage of organic matter was significant and negative (p = 0.0202; r²= 0.265). The highest average percentage of organic matter observed in April/2009 was probably related to the amount of particulate matter from the Apodi-Mossoró River basin during the atypical period of rainfall in the region.

The textural class assigned as fine sand contained the highest percentage in the sediment as determined by granulometry analysis with a predominance in all sampled periods, except for April/2009, when very fine sand, silt, and clay (45.5%) constituted the highest percentage in the sediment. This might have resulted from the high level of rainfall during this period leading to large amounts of sediment from the Apodi-Mossoró River. Therefore, fine sand could be defined as the primary textural class prevalent in this region (Figure 2).

The highest *D. striatus* density was observed in April/2009, showing an average of 103 individuals.m⁻² at the sampling sites. The *D. striatus* density decreased in October/2009 when compared to the density in the previous period, showing an average value of 65 individuals.m⁻². The average density of 36 individuals.m⁻² was observed in April/2010, 18 individuals.m⁻² were observed in October/2010, and 20 individuals.m⁻² in April/2011. The average density of 37 individuals.m⁻² was observed in October of 2011.
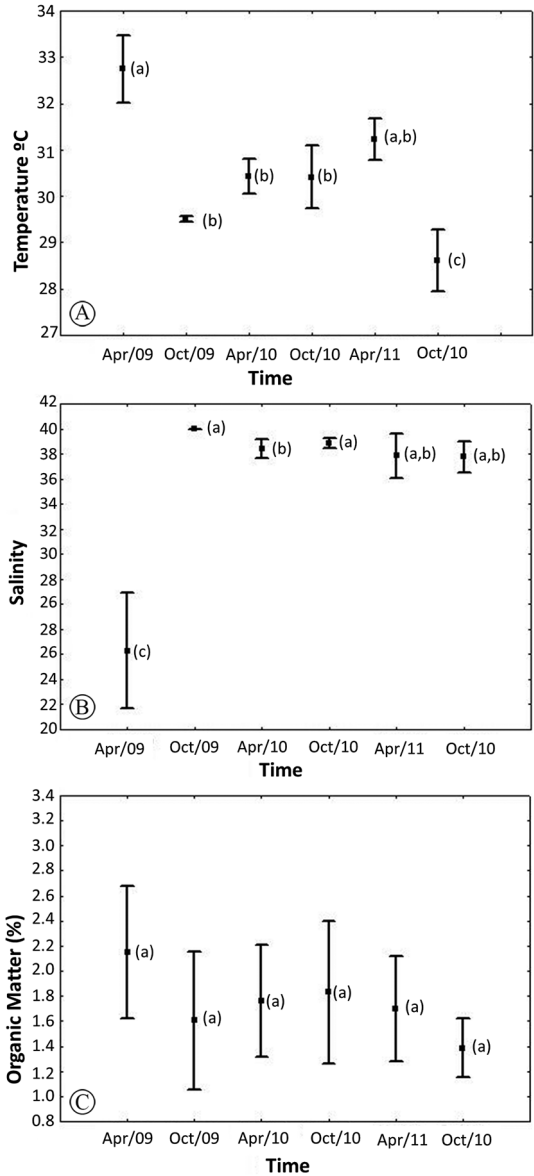

Figure 1. Averages and standard error of abiotic variables in the area of occurrence of *Donax striatus*, in the estuary of Apodi/Mossoró River, Rio Grande do Norte State (RN), Northeast Brazil, at different times of the year. (A) Temperature, (B) Salinity, and (C) Percentage of organic matter.
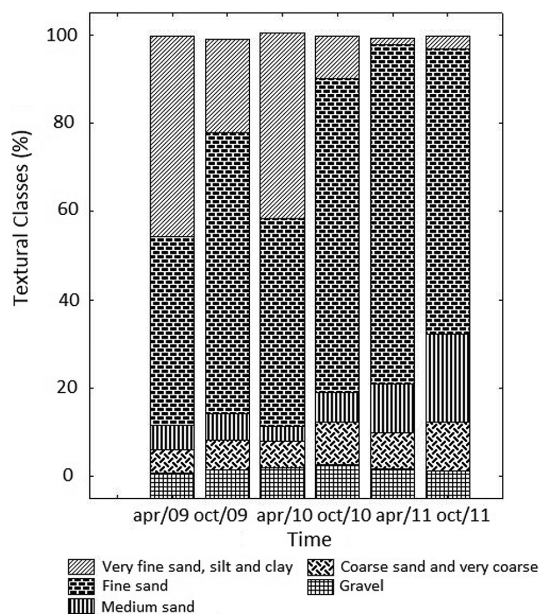
Figure 2. Percentage of textural classes in the six studied periods (Apr/09, Oct/09, Apr/10, Oct/10, Apr/11, and Oct/11), in the estuary of Apodi/Mossoró River, Rio Grande do Norte State (RN), Northeast Brazil.
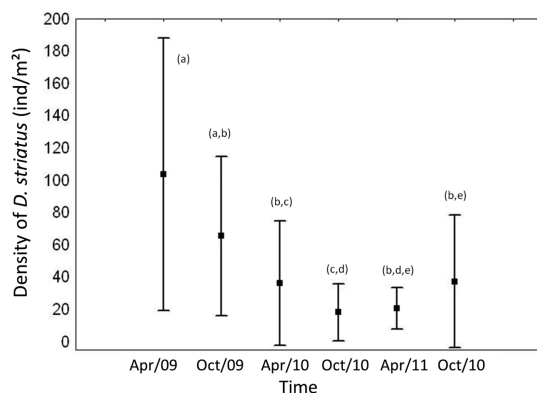

Figure 3. Averages and standard deviations of *Donax striatus* densities at the sampling sites, in the estuary of Apodi/Mossoró River, Rio Grande do Norte State (RN), Northeast Brazil. Different letters indicate significant differences.

Significant differences between *D. striatus* densities in different sampling periods (Kruskal-Wallis: H = 19.94; p = 0.0013) were observed. The average density in April/2009 proved to be significantly higher than in the other analyzed periods, with the exception of October/2009 (Figure 3). According to Gil and Thomé (2000), species belonging to the genus *Donax* are known to exhibit large fluctuations in population density both between locations and seasons.

The highest density of *D. striatus* was recorded in April/2009 when this mollusk's populations were largely concentrated within 20 km from the estuary. In October of the same year, the distribution range of *D. striatus* was less than in April, resulting from an extensive reduction in the number of individuals. In 2010, the population density continued to decline when the greatest densities occurred in places further away from the estuary. The lowest density during the study period was recorded in 2011 in populations inhabiting these same areas away from the estuary (Figure 4).

The Morisita index values (Iδ), calculated for all studied periods (Apr/09, Oct/09, Apr/10, Oct/10, Apr/11, and Oct/11) showed that the *D. striatus* population have an aggregated distribution in the region because the index values were greater than 1.0 throughout the study. This index value was 3.09 and 3.34 in April and October/2009, respectively. In 2010, the Iδ values were 2.76 and 2.54 in April and October, respectively; the range of *D. striatus* distribution was broader in April than in October because of the extreme reduction in the number of individuals. In April/2011, the Morisita index (Iδ = 1.99) was smaller than in October (2.62). The highest *D. striatus* density

occurred in the initial rows at the beach line (in transects 0 and 50 meters, Figure 5). The aggregated distribution occurs when there are favorable conditions for survival and reproduction (Ricklefs, 2008). This type of distribution can also be a strategy for survival used by mollusks because it helps them find food, self protecting from predators, and finding partners for mating (Martell et al., 2002; Morton et al., 2002).

October/2011 was the only period when no significant correlation between temperature and distance from the estuary was observed. In April and October/2009, a negative correlation was observed as temperature values reduced with the increase in the distance from the estuary. Positive correlations were observed in only two of the six studied periods (Apr/10 and Apr/11); the highest correlation occurred in April/2010 (r^2 = 0.7554). The highest temperature values near the estuarine region were recorded in April/2009.

A significant positive correlation between salinity and distance from estuary was only observed in April/2009 (p = 0.0090 and r^2 = 0.3224) as a consequence of heavy rains throughout the hydrographic basin in the Apodi/Mossoró River in that year. Reduced salinity levels were observed in beaches at 4 miles from the location where the river meets the ocean. In October/ 2009 and 2010, a significant negative correlation was observed between salinity and distance from the estuary (p = 0.0062 and r^2 = 0.3474; p = 0.0002 and r^2 = 0.5434, respectively). In October/2009 and 2010, the flow of fresh water from the Apodi-Mossoró River was smaller than in other periods, which explains the increased salinity and release of effluents from salines near the estuary.

April and October/2010 were the only periods when no significant correlation between the percentage of organic matter and distance from the estuary was observed. However, a significant negative correlation was observed in other periods (Apr/09, Oct/09, Apr/11, and Oct/11), i.e., organic matter values decreased with increased distances from the estuary.
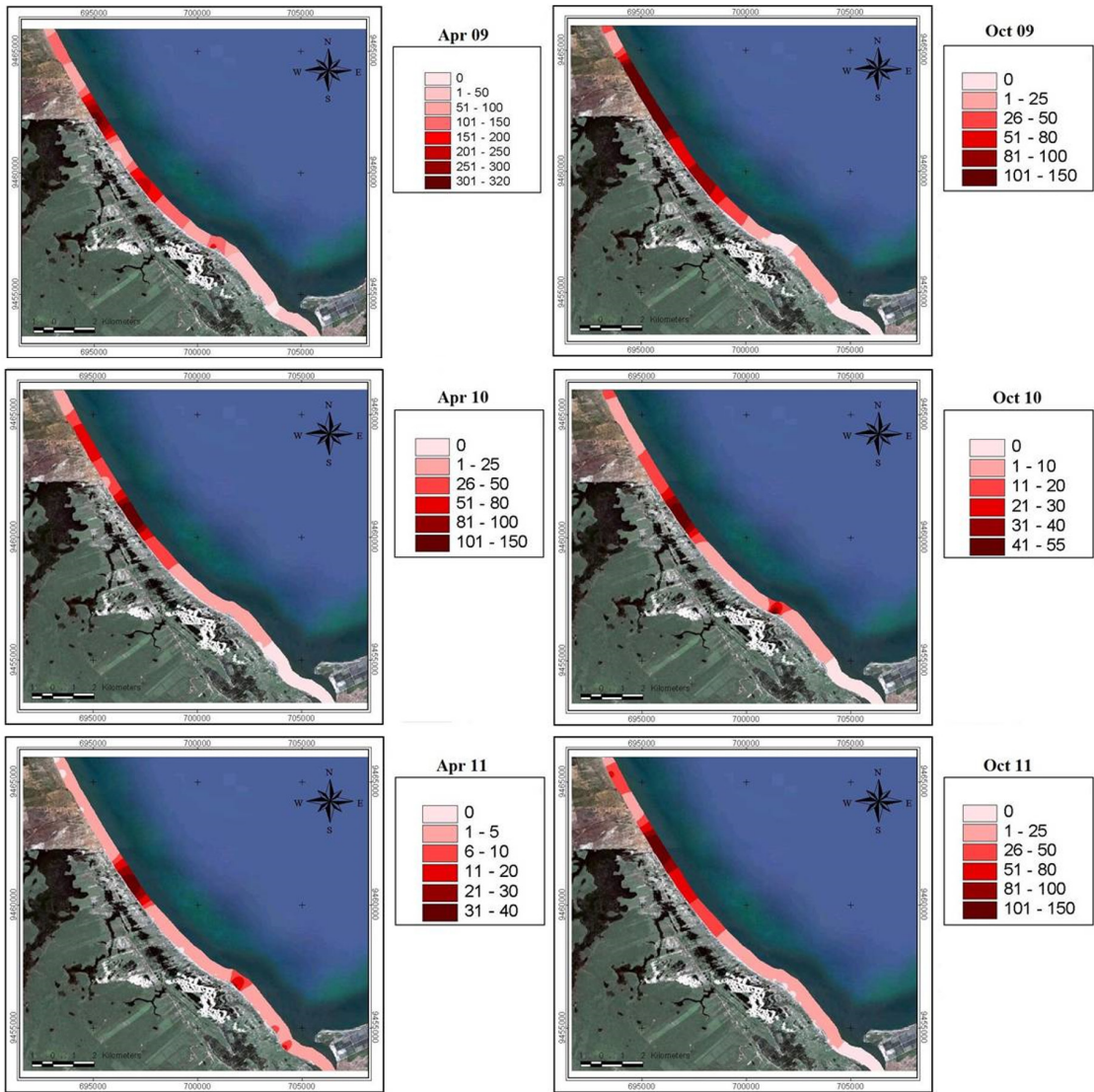
Figure 4. Maps of the potential distribution of the *Donax striatus* densities at the sampling sites in the studied periods (Apr/09, Oct/09, Apr/10, Oct/10, Apr/11, and Oct/11), in the estuary of Apodi/Mossoró River, Rio Grande do Norte State (RN), Northeast Brazil.

No significant correlations between *D. striatus* density and distance from the estuary were observed in October/2010 and April/2011 (Oct/10 with p = 0.07, and Apr/11 with p = 0.90). Significant positive correlations were observed in the remaining periods (Apr/09, Oct/09, Apr/10, and Oct/11). In April/2009, the occurrence of *D. striatus* was recorded 8 km away from the estuary, with the largest number of individuals, including banks of young individuals, occurring between 12 and 20 km away from the estuary. The highest values of *D. striatus* densities were recorded 11 km away from the estuary, in October/2009. April and October/2010 were characterized by a rise in number of individuals, located at about 14 km away from the estuary. In 2011, the highest values of

D. striatus densities occurred at 14 km (April) and 16 km (October) away from the estuary (Figure 6).

A significant positive correlation was observed between the average values of *D. striatus* density and distance from the estuary ($r^2 = 0.67$ and $p = 0.0007$) (Figure 7). Borges-Azevedo et al. (1990) report high densities of *D. striatus* as indicative of high primary productivity or absence of predators in aquatic environments.

The largest variation in *D. striatus* size occurred in April/2009 (3.4 to 28.4 mm); individuals between 7 and 10 mm (approximately 70%) were the most frequent. The majority of individuals sampled in October/2009 ranged in size from 20 to 24 mm, representing 70.4% of the sampled population. In April and October/2010,
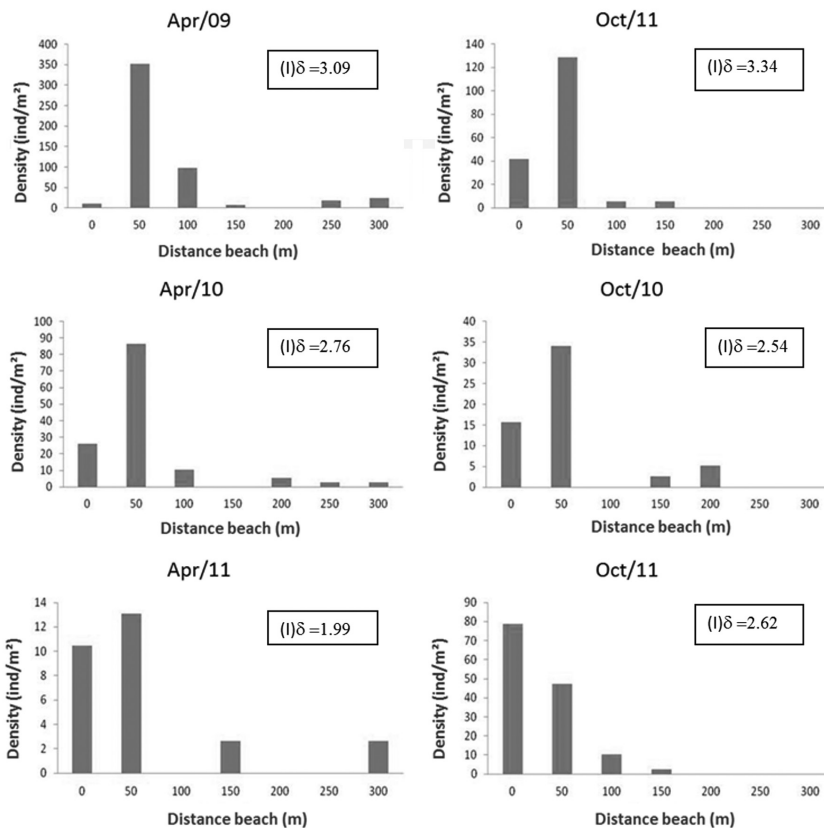
Figure 5. Average density of *Donax striatus*, in the estuary of Apodi/Mossoró River, Rio Grande do Norte State (RN), Northeast Brazil, acoording to different sampling times (Apr/09, Oct/09, Apr/10, Oct/10, Apr/11, and Oct/11) and corresponding Morisita index values (**I**δ).
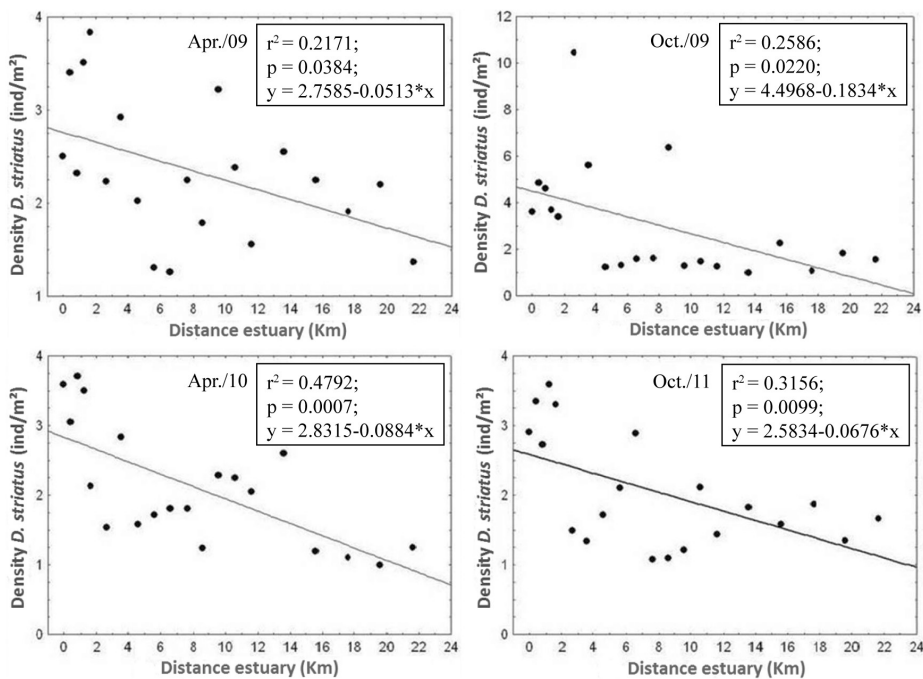

Figure 6. Correlation between density values of *Donax striatus* and distance from the estuary of the Apodi-Mossoró River, Rio Grande do Norte State (RN), Northeast Brazil.

sizes between 22 and 24 mm, and 3 mm were the most frequent, respectively. In April/2011, sizes ranged from 4.5 to 25.0 mm; with sizes of 4 and 15 mm being most frequent (18% for both). However, in October of the same year young individuals were not observed, sample sizes ranged from 12 to 27 mm, and sizes between 19 to 23 mm were predominant (Figure 8).

The pattern of length distribution in *D. striatus* shows continuous recruitment and reproduction. In every season
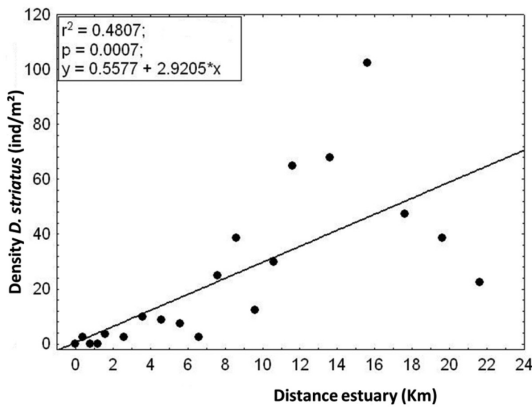

Figure 7. Correlation between average values of density of *Donax striatus* and distance from the estuary of the Apodi-Mossoró River, Rio Grande do Norte State (RN), Northeast Brazil.

(except for October 2011), young individuals (indicating reproduction) and adults (indicating growth) were present. These results corroborate the hypothesis of Ansell (1983), which suggests that spawns occasioned by environmental changes and coordinated by chemical stimuli are not the default to *Donax* species. Therefore, the basic pattern of reproductive activity in *Donax striatus* is probably that of repeated spawns throughout the year, which guarantees that at least part of the reproductive effort meets the necessary conditions for their full development. However, it is important to highlight that detailed studies on sexual cycle and monthly population dynamics during several years are required for conclusive answers about the reproductive behavior of *D. striatus* in the estuarine region of the Apodi/Mossoró River.

Recruited individuals (< 5 mm) were evenly distributed throughout the beach extension, but did not occur at 100 m away from the coast. Juvenile individuals (5-15 mm) and adults (> 15 mm) occurred throughout the beach extension. Adults predominated over other classes at 0-100 m from the coast and were evenly distributed in this range (Figure 9).

The results from this study are similar to those observed by Gianuca (1985) and Coscarón (1959) where adult individuals were found in the upper mesolitoral zone. However, in that study juveniles and recruits were found near the sea. In this study, juveniles and recruits were found scattered throughout the region. In studies with the bivalve *Mesodesma mactroides*, Olivier et al. (1971) and Defeo et al. (1992), reported that, during the recruitment
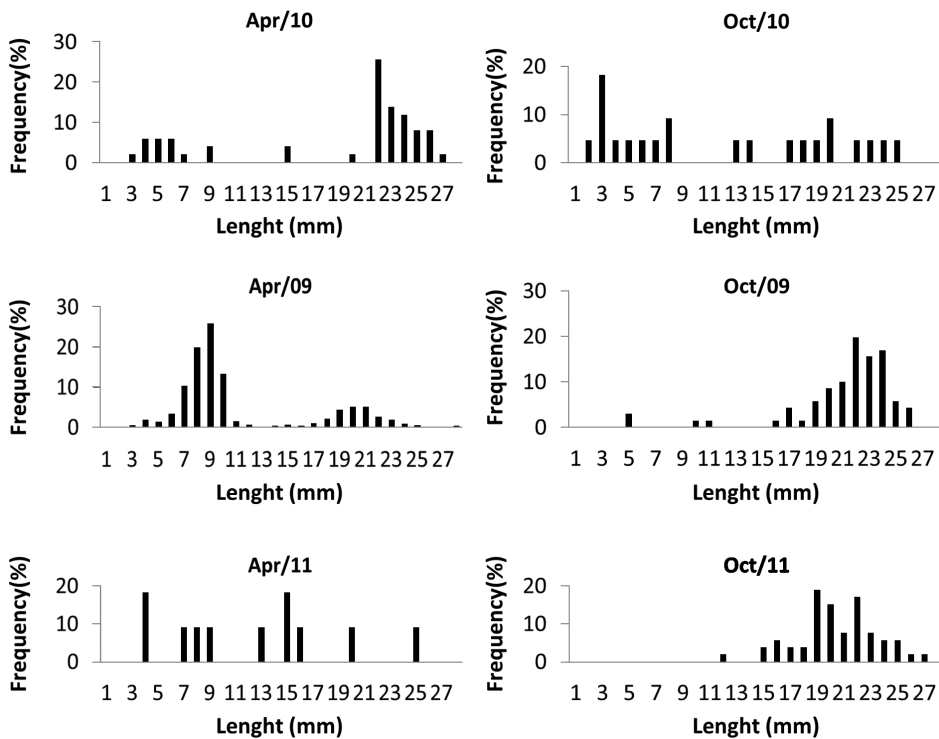

Figure 8. Size classes of *Donax striatus* (shell length) in the different sampled periods, in the estuary of Apodi/Mossoró River, Rio Grande do Norte State (RN), Northeast Brazil.
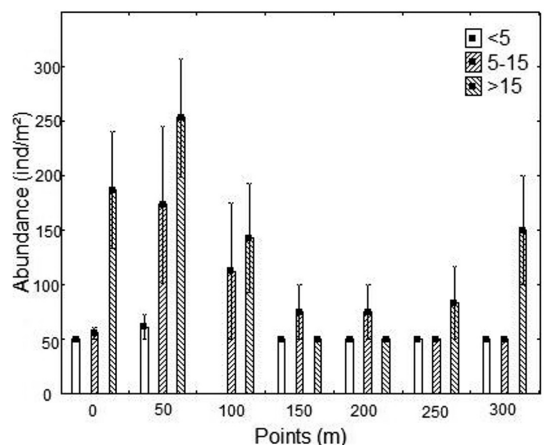
Figure 9. Distribution of *Donax striatus* abundance perpendicular to the coast according to size classes (recruits: < 5 mm; juvenile: between 5 mm and 15 mm; adults: > 15 mm), in the estuary of Apodi/Mossoró River, Rio Grande do Norte State (RN), Northeast Brazil.

process, adults tend to outnumber new generations (recruits) because of competition for space, larva's destruction caused by filtering mechanisms practiced by adults, and possible intra-specific competition for food. These factors could explain the observation that the number of recruits was zero at 100 m away from the coast while the adults' density was approximately 150 individuals/m^2 in this study.

4. Conclusion

We concluded that *D. striatus* demonstrated an aggregated distribution pattern with the greatest densities observed in beaches away from the estuarine region, and in the first 50 meters of the intertidal zone. The percentage of sediment organic matter negatively influenced the density of this bivalve's populations.

Acknowledgements

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