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Aspects of the population dynamics of *Anomalocardia brasiliana*: subsidies for sustainable fishing in the west coast of Ceará, Brazil

Aspectos da dinâmica populacional de Anomalocardia brasiliana: subsídios para a pesca sustentável no Litoral Oeste do Ceará, Brasil

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Abstract
Shellfish is an artisanal activity and family subsistence way of the coastal communities. Being the *Anomalocardia brasiliana* is one of the main mollusc species exploited. This paper aims to obtain information about the temporal distribution, growth, yield and the gonadosomatic index of the bivalve mollusc *A. brasiliana* in a natural bank in order to provide subsidies for the sustainable extraction of this resource. The present study was carried out in an area of the Acaraú River estuary, in Volta do Rio Beach, in Acaraú city. Samples were collected monthly during a year at spring low tide, using the random squares method. The temperature of the water, the sediment and the salinity were measured in situ. Sediment samples were collected for granulometric analysis. The specimens were quantified, measured and weighed individually. A total of 8,507 specimens of *A. brasiliana* were sampled, the highest density recorded was 2,534 individuals/m², those with the longest shell length were between 21 and 25 mm, the meat yield presented an average value of 12.42%. The means of the biometric variables of the individuals presented significant differences during the sample period. Frequency histograms evidenced the presence of adult individuals, in the process of sexual and juvenile differentiation, indicating a continuous reproductive cycle in the natural stock studied. These results will aid in the sustainable shellfish exercise on the Volta do Rio beach. It recommended the capture of *A. brasiliana* with length above 20 mm and the reduction of the capture effort in the months of April to September, when the highest density of juveniles was observed, in order to maintain the sustainability of this stock.
Keywords: Shellfish; Fishing Resource; Fisheries Regulations.

Resumo
A mariscagem é uma atividade artesanal e meio de subsistência familiar de diversas comunidades litorâneas ao longo da costa brasileira, sendo *Anomalocardia brasiliana* uma das principais espécies de molusco exploradas. Esse trabalho objetivou obter informações sobre a distribuição temporal, crescimento, rendimento e o índice gonadossomático do molusco bivalve *A. brasiliana* em um estoque natural a fim de fornecer subsídios para a extração sustentável deste recurso. O estudo foi realizado em uma área do estuário do rio Acaraú, na Praia Volta do Rio, município de Acaraú, Ceará, Brasil. As coletas foram realizadas mensalmente durante um ano na maré baixa de sizígia, utilizando o método dos quadrados aleatórios. A temperatura da água, do sedimento e a salinidade foram aferidas *in situ*. Foram coletadas amostras de sedimento para análise granulométrica. Os espécimes foram quantificados, mensurados e pesados individualmente. Foram amostrados um total de 8.507 exemplares de *A. brasiliana*, a maior densidade registrada teve 2.534 indivíduos/m², aqueles com maior comprimento de concha tinham entre 21 e 25 mm, o rendimento da carne apresentou um valor médio de 12,42%. As médias das variáveis biométricas dos indivíduos apresentaram diferenças significativas durante o período amostral. Os histogramas de frequência evidenciaram a presença de indivíduos adultos e juvenis, indicando um ciclo reprodutivo contínuo no estoque natural estudado. Estes resultados auxiliarão no exercício da mariscagem sustentável na praia da Volta do Rio. Recomenda-se a captura de *A. brasiliana* com comprimento acima de 20 mm e a redução do esforço de captura nos meses de abril a setembro, período em que foi observada a maior densidade de juvenis, a fim de garantir a sustentabilidade desse estoque.
Palavras-chave: Mariscagem; Recurso Pesqueiro; Regulamentação pesqueira.

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Introduction

One of the oldest practices of artisanal fishing is shellfish gathering – extraction of bivalve mollusks – dating back to the prehistoric period when the first civilizations used these organisms as a bargaining chip.[1] Shellfish gathering is an extractive activity carried out mainly by women called shellfish gatherers, and they extract mollusks from the natural environment using household items, such as spoons and other varied paraphernalia.[2,3,4,5] Shellfish collection occurs along the entire Brazilian coast.[6]

Among the main species collected is *Anomalocardia brasiliana* (Linnaeus, 1767), a bivalve mollusk of the family Veneridae, found naturally on the Brazilian coast with different local popular names such as marisco-pedra, vôngole, berbigão, and búzio, among others.[7] The venerid *A. brasiliana* is euryhaline and eurythermic with wide geographic distribution from the West Indies (Antilles) to Brazil and Uruguay.[8,9] This species is adapted to a wide variety of habitats such as coves, bays, mouths of estuaries, tidal marshes, and unvegetated tidal flats, where it lives buried superficially in sediment, mainly sandy-muddy sediments.[8,10]

However, the disorderly exploitation of the bivalve *A. brasiliana* throughout the year with predatory techniques has compromised the stocks of this mollusk in several regions of the Brazilian coast.[11,12] In Brazil, most extractive fisheries stocks do not have specific rules and regulations for the management of *A. brasiliana*.[13]

Thus, studies on the population dynamics of the species, describing its distribution, biomass, and environmental interactions in estuarine areas of Northeast Brazil, have been developed, such as the research by Araújo and Rocha-Barreira,[14] Rodrigues, Maia, Medeiros, and Henry-Silva,[15] and Silva-Cavalcanti and Costa.[12] The state of Ceará has no studies that show a decrease in the size of the bivalve *A. brasiliana* related to overfishing or environmental impacts. This lack of data on the real situation of the stocks and the absence of studies could harm the sustainability of this resource and, consequently, the shellfish gathering activity in the region.

Therefore, this study aimed to obtain information on the temporal distribution, growth, yield, and gonadosomatic index of the bivalve mollusk *A. brasiliana* in a natural stock on Volta do Rio Beach on the west coast of Ceará, Brazil, to provide subsidies for sustainable extraction of this resource.

Material and methods

Study area

The study was carried out in an area of the Acaraú River estuary on Volta do Rio Beach, located in the municipality of Acaraú, Ceará, Brazil. Collections were carried out in a stock of *A. brasiliana* (02°51′28″ S and 039°57′10″ W), reported by shellfish gatherers (personal communication) (Figure 1).

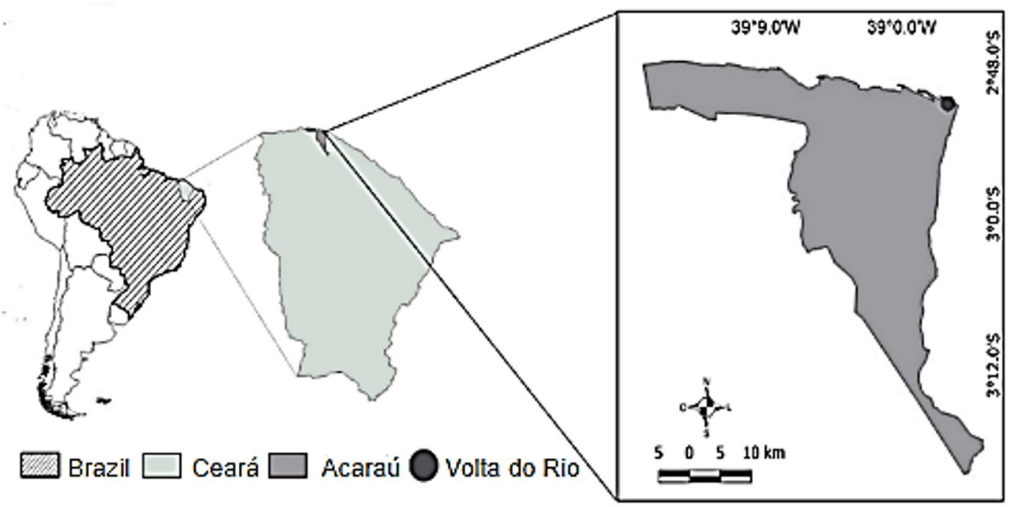

Figure 1. Location of the study area in relation to Brazil and the state of Ceará, with the location of the collection point in the studied natural stock on Volta do Rio Beach in Acaraú.

Field procedures

Specimens of *A. brasiliana* were collected monthly from January to December 2015, during spring low tide. The random square method was used during the collections to capture and pack the animals, as described by Araújo and Rocha-Barreira.[14] The abiotic variables, water and sediment temperature, and salinity were measured in situ using a thermohygrometer and a refractometer, respectively. The regional rainfall was obtained from the Fundação Cearense de Meteorologia e Recursos Hídricos[16] website.

Three sediment samples were collected monthly using a cylindrical PVC sampler (core), according to the methodology used by the Monitoring Protocol for Estuarine Benthic Ecosystems.[17] The granulometric analysis of the sediment was carried out using the sieving and pipetting methodology.[18]

Laboratory procedures

The collected specimens were quantified in the laboratory and immersed in a solution of magnesium chloride ($MgCl_2.6H_2O$) for 10 minutes to anesthetize them. Subsequently, the morphometric variable shell length was measured using a digital caliper with a 0.05-mm precision, according to Gosling.[19] The total weight, soft tissue (body without shell) weight, shell weight, and gonad weight were obtained using a precision scale. The gonadal tissue of each individual was dissected following Rocha-Barreira and Araújo.[20]

Statistical analysis

The fresh soft parts weight yield (Y) was estimated for each month, using the equation: R = Wb × 100/Wt, where Wb is the soft part weight and Wt is the total weight. The gonadosomatic index (GSI) was expressed by the formula GSI = (gonad weight/total weight) * 100.

One-way analysis of variance (ANOVA) was used to compare the temporal variation in density, weight, size, and yield of *A. brasiliana* over the twelve months of sampling.[21] Tukey's test of multiple comparisons was used when differences at a 5% significance level ($p<0.05$) between the means were detected. Frequency histograms for the size (shell length) were plotted, interpreted, and analyzed to determine population parameters such as growth, recruitment, and mortality.[22] The number of classes was determined according to the formula by Sturges: Vi = A/K, where Vi is the interval of classes, A is the range of the variable, and K is the number of classes calculated by the formula 1 + (3.32 log n), where n is the total number of individuals.

Biological data on density, shell length, soft tissue weight, gonad weight, yield, and the gonadosomatic index were compared and correlated with the environmental parameters obtained in the sampling period. The program STATISTICA for Windows® version 7.0 was used in all analyses.

Results and discussion

A total of 8,507 specimens of *A. brasiliana* were sampled during the study period. The density of *A. brasiliana* showed a significant difference ($p<0.05$) between the studied months, showing an increase in the number of individuals from May, remaining high until August (Figure 2).

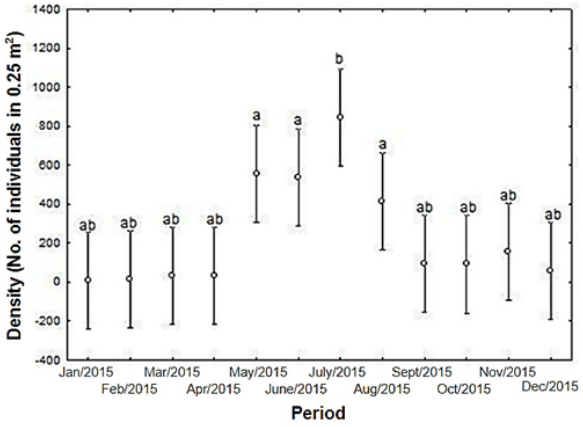

Figure 2. Mean density of *Anomalocardia brasiliana* individuals captured in the Acaraú River estuary, Ceará, Brazil. Bars indicate the standard error. Different letters indicate significant differences ($p<0.05$), according to Tukey's test.

Density decreased in the period of the highest rainfall of the year and with the lowest salinity values. According to data from FUNCEME,[16] the highest rainfall of the year was 414.4 mm in April and the study recorded the lowest salinity (25). The highest salinity (48) coincided with the rainfall index of zero, referring to November (Table 1).

Table 1. Monthly values of abiotic parameters recorded in the Acaraú River estuary, Ceará, Brazil.

Period (2015)	Salinity (PSU)	Rainfall (mm)	Water temperature (°C)	Sediment temperature (°C)
Jan.	40	0	28.7	30.9
Feb.	43	85.8	31.7	31.7
Mar.	30	307	37.4	38.1
Apr.	23	414.4	34.5	34.7
May	37	65	36.8	36.5
June	36	85	30	37
July	40	43.8	28.4	31.3
Aug.	42	0	29.9	30.3
Sept.	43	0	31.1	30.4
Oct.	45	0	31.4	31.6
Nov.	48	0	32.8	33
Dec.	44	0	29.9	34

A. brasiliana tolerates a range of minimum salinity of 15 and a maximum of 45.[23] The values presented in this study showed that the months of high rainfall, that is, February, March, and April 2015, had a decrease in salinity and a reduction in *A. brasiliana* density. This reduction in the population of bivalves in the studied natural stock was probably a consequence of a decrease in salinity, leading to the mortality of individuals. Rodrigues Maia, Medeiros, and Henry-Silva[15] carried out a study on Barra and Pernambuquinho beaches in an estuarine region of the semi-arid region of Rio Grande do Norte and observed a direct relationship between rainfall and density. The authors reported that the month of highest rainfall and, therefore, the highest supply of fresh water into the estuary, showed lower mean density values of *A. brasiliana*.

The mean water temperature at the collection sites throughout the sampling period was 29 °C (Table 1). In contrast, the mean sediment temperature for the same period was 33.2 °C (Table 1). However, the variables water temperature and sediment temperature were not determining factors to explain the temporal distribution of bivalves on the bank under study. Belém, Moura, and Henry-Silva[24] observed no influence of water temperature on the distribution of *A. brasiliana*. According to the ANOVA results, the shell length of *A. brasiliana* varied significantly ($p<0.05$) relative to the sampling period. Individuals with the longest shell length were collected in January, February, and March, with sizes between 21 and 25 mm (Figure 3).

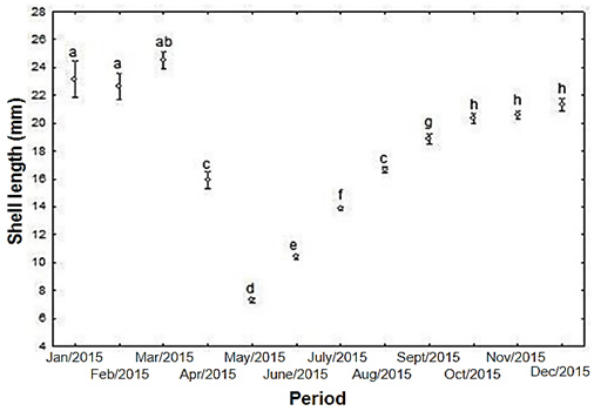

Figure 3. Mean value of shell length (mm) of *Anomalocardia brasiliana* individuals captured in the Acaraú River estuary, Ceará, Brazil. Bars indicate the standard error. Different letters indicate significant differences ($p<0.05$), according to Tukey's test.

The frequency histogram (Figure 4) allows the identification of adult individuals with shell lengths above 20 mm and juvenile individuals with shell lengths between 12.9 mm and 17.9 mm[20,25] throughout the sampling period, which suggests values similar to the sizes of species already observed in the Northeast coast[20,25] and a continuous reproductive cycle in the studied natural stock.[25]

We suggest the capture of organisms above 20 mm. According to Ferreira Jr. et al.,[26] the reproductive rate of *A. brasiliana* decreases in larger and older organisms, not compromising the sustainability of the population when exploited, as it would reduce intraspecific competition for food and space for juveniles that are structuring in the environment. According to Luz and Boehs,[27] the reproductive cycle of the species occurs continuously, with less frequency of gamete release in the rainy season.

A higher expressiveness of organisms with shell lengths lower than 7 mm was observed in May 2015. According to Rodrigues Maia, Medeiros, and Henry-Silva,[15] a high entry of young individuals into *A. brasiliana* populations demonstrates continuous recruitment. The size of the population structure of *A. brasiliana* can be regulated by the availability of resources that support the population and the degree of overlap with other species of the same ecological and trophic guilds.[28,29]

The analysis of variance also showed significant differences ($p<0.05$) for gonad weight during the sample period and peaked between January and March 2015 (Figure 5). Similar behavior was observed for the gonadosomatic index and the sampling period ($p<0.05$) (Figure 6).

Gonad weight and the gonadosomatic index tended to decrease gradually from April and remained reduced until September, showing the lowest values from May to August, which evidences a possible release of gametes. A study on the reproductive cycle of *A. brasiliana* on Canto da Barra Beach, Fortim – Ceará, Brazil, identified two periods of gamete release: the first from July to October and the second from February to April.[20] According to Silva, Caroslfeld, and Gálvez,[30] the same species may vary in its reproductive cycle depending on the different climate and environmental conditions to which individuals are subject.

The temporal analysis of meat yield showed variation for the entire sampled period. The meat yield (Y) of *A. brasiliana* presented a mean value of 12.42% in the sampled months (Figure 7). The highest mean value of Y was observed in January 2015 (16.05%), which is similar to what was recorded by Lavander et al.[25] in January 2009 on the north coast of Pernambuco, with a value of 16.73% (±1.97%). According to Rebelo, Amaral, and Pfeiffer,[31] the high values of Y can show gonads full or partially full of gametes, and, consequently, the reduction of these values can be associated with the release of gametes. Shellfish gatherers usually say that the seafood is "fat" during this period.[25]

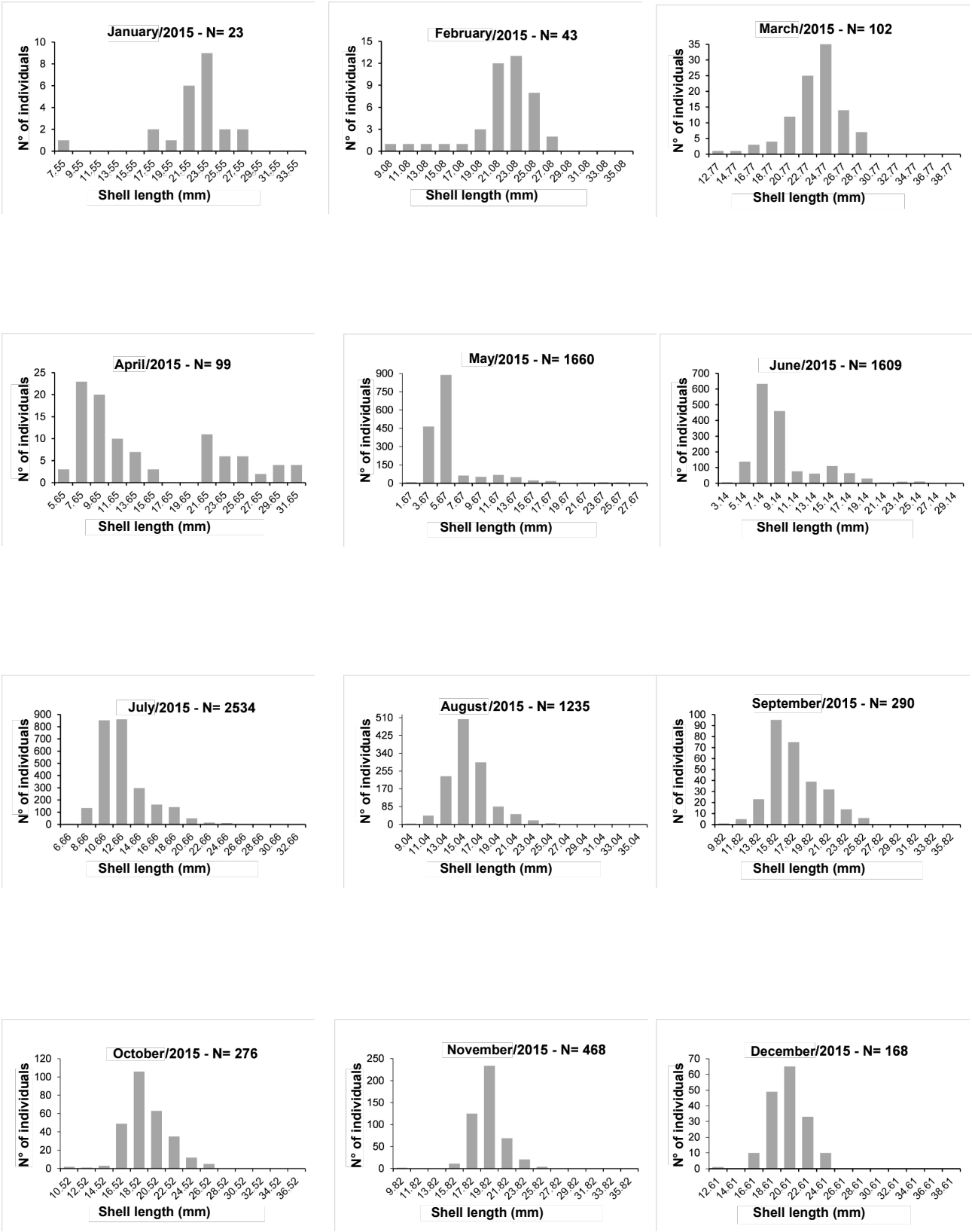

Figure 4. Histograms of shell length (mm) size classes of *Anomalocardia brasiliana* individuals captured in the Acaraú River estuary, Ceará, Brazil.

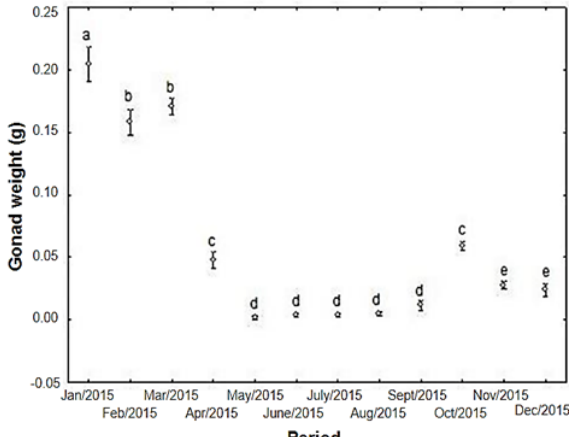

Figure 5. Mean value of gonad weight (g) of *Anomalocardia brasiliana* individuals captured in the Acaraú River estuary, Ceará, Brazil. Bars indicate the standard error. Different letters indicate significant differences ($p<0.05$), according to Tukey's test.

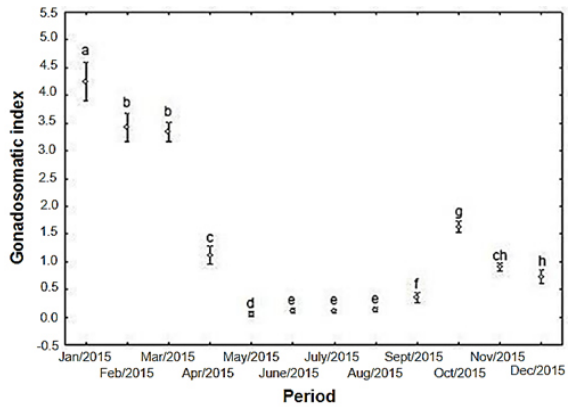

Figure 6. Gonadosomatic index of *Anomalocardia brasiliana* individuals captured in the Acaraú River estuary, Ceará, Brazil. Bars indicate the standard error. Different letters indicate significant differences ($p<0.05$), according to Tukey's test.

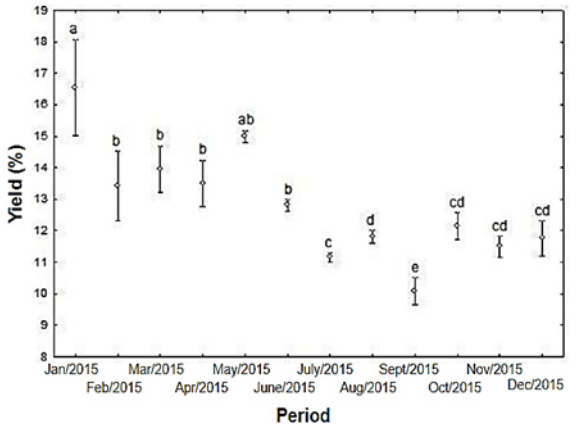

Figure 7. Percentage of meat yield of *Anomalocardia brasiliana* individuals captured in the Acaraú River estuary, Ceará, Brazil. Bars indicate the standard error. Different letters indicate significant differences ($p<0.05$), according to Tukey's test.

The granulometric analysis revealed that fine sand was the predominant sediment class, followed by coarse sand (Figure 8). The same was observed on Mangue Seco beach, PE, where *A. brasiliana* was found in sediments with a percentage above 90% of coarse and fine sand.[32] According to Araújo and Rocha Barreira,[14] sediment is an important factor for benthic fauna, as it provides shelter, food, and protection.

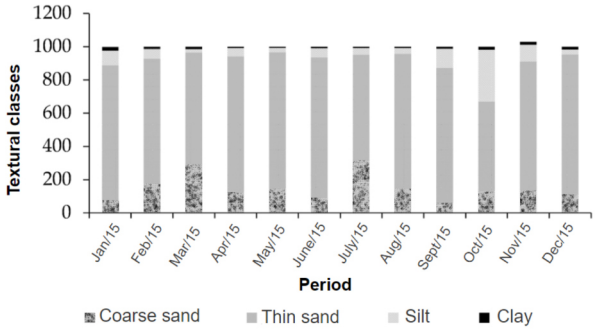

Figure 8. Values referring to textural classes (g/kg) resulting from the sediment granulometry on the collection bank of *Anomalocardia brasiliana* in the Acaraú River estuary, Ceará, Brazil.

The correlation analysis showed that the higher the amount of clay, the lower the density of bivalves. Boehs, Absher, and Cruz-Kaled[8] reported the absence of the species in areas where the sediment had high proportions of silt and clay in Paranaguá Bay. Therefore, the type of sediment influences the survival of individuals because the animal is exposed to desiccation, salinity, and high temperatures in the thickest sediment. In contrast, the fine sediment provides less environmental stress and higher food availability.[14] It is valid to assume that the sediment found favored the settlement and development of the bivalve *A. brasiliana* in the studied natural stock.

Conclusion

The studied natural stock of *A. brasiliana* showed variations in size, weight, yield, and the gonadosomatic index similar to those described in the literature for the species throughout the sample period. January, February, and March presented larger, heavier individuals with high yield and gonadosomatic index, whereas a decrease of these indicators was observed from April to September, evidencing a possible recruitment period. Thus, we recommend the capture of *A. brasiliana* specimens with a length above 20 mm and the reduction in the capture effort from April to September, when the highest density of juveniles was observed, to guarantee the sustainability of this stock. These results may help the sustainable shellfish gathering activity in natural stocks on the west coast of Ceará, Brazil.

Conflict of interests

The authors declare no conflict of interest.

Author contributions

Conceptualization: N.G. Nascimento and R.C. Maia. *Data curation:* N.G Nascimento, G.A.V. Silva, G.D.V. Silva, and R.C. Maia. *Formal analysis:* N.G. Nascimento, G.A.V. Silva, G.D.V. Silva, and R.C. Maia. *Research:* N.G. Nascimento and R.C. Maia. *Methodology:* N.G. Nascimento and R.C. Maia. *Resources:* N.G. Nascimento, G.A.V. Silva, G.D.V. Silva, and R.C. Maia. *Project management:* N.G. Nascimento, G.A.V. Silva, G.D.V. Silva, and R.C. Maia. Validation and visualization: N.G. Nascimento, G.A.V. Silva, G.D.V. Silva, and R.C. Maia. *Supervision:* R.C. Maia. *Writing (original draft):* N.G. Nascimento and R.C. Maia. *Writing (review and editing):* G.A.V. Silva, G.D.V. Silva, and R.C. Maia.

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