Vol.64: e21190650, 2021
https://doi.org/10.1590/1678-4324-2021190650
ISSN 1678-4324 Online Edition

Article - Biological and Applied Sciences

Growth Performance of the Mangrove Oyster Cultivated on the Amazon Coast

Rafael Anaisce das Chagas[1]*
http://orcid.org/0000-0002-1555-6154

Mara Rúbia Ferreira Barros[1]
http://orcid.org/0000-0003-1354-7550

Valdo Sena de Abreu[2]
http://orcid.org/0000-0001-8838-7841

Rosana Esther Oliveira da Silva[2]
https://orcid.org/0000-0001-6431-5042

Matheus Silva de Almeida[2]
https://orcid.org/0000-0003-0431-3226

Wagner César Rosa dos Santos[2]
http://orcid.org/0000-0001-8172-9917

Marko Herrmann[2]
http://orcid.org/0000-0001-9891-6700

[1]Federal University of Pará, Institute of Biological Sciences, Belém, Pará, Brazil; [2] Federal Rural University of the Amazon, Belém, Pará, Brazil

Editor-in-Chief: Paulo Vitor Farago
Associate Editor: Camila Fediuk de Castro Guedes

Received: 2019.10.28; Accepted: 2020.09.10.

*Correspondence: rafaelanaisce@hotmail.com or rafaelanaisce@gmail.com; Tel.: (+5591) 984809124 (R.A.C.).

HIGHLIGHTS

- Total and percentage growth rates, higher performance was observed in the oysters classified by juvenile and seed, respectively.
- The relationship of salinity to oyster growth was evidenced only in the class of juvenile oysters.
- The cultivation time required to obtain native oysters in the commercial size varied between four and seven months.

Abstract: In the last decades the oyster faming stands out as the main mitigating measure to the decline of the fishery, as it presents socio-economic and environmental viability. However, for the success of the activity, it is necessary to understand the stages of cultivation, as well as the growth performance of the species to be cultivated. The present work aims to characterize the growth and survival of *Crassostrea tulipa*, cultivated on the Amazon coast. For this purpose, oysters were grouped by commercial size class (*seed*, *juvenile*, *baby*, *average* and *masters*) and compared the growth rates and their relationships with the abiotic variables. There was no difference in the average growth between the oyster classes, however, when comparing them in the total and percentage growth rates, a higher performance was observed in the oysters classified by *juvenile* and *seed*, respectively. The relationship of salinity to oyster growth was evidenced only in the class of *juvenile* oysters. The cultivation time required to obtain native oysters in the commercial size varied between four and seven months, being inferior to those found in other Brazilian regions.

Keywords: Amazon region; aquaculture; mollusk; oyster farming; native oyster; *Crassostrea tulipa.*

INTRODUCTION

World production from bivalve mollusk aquaculture plays an important role in human nutrition, and from the 1980s onwards it has grown rapidly until 2014 [1]. This growth in bivalve production is a result, for example, of the success of mussel farming and oyster farming, which appears as a viable alternative to mitigate fishery decline, reducing pressure on natural stocks [2] and becoming a source of income for coastal communities [3-5].

In Brazil, oyster faming is restricted to the cultivation of four oysters of the genus *Crassostrea* Sacco, 1897: the native oysters *Crassostrea tulipa* (Lamarck, 1819) (sin. *Crassostrea gasar* (Deshayes, 1830)), *Crassostrea rhizophorae* (Guilding, 1828), *Crassostrea brasiliana* (Lamarck, 1819) and the exotic oyster *Crassostrea gigas* (Thunberg, 1793) [6,7]. However, Brazil is only a producer of *Crassostrea* sp. oysters because of the taxonomical instability of oysters grown [see 8 and their references].

There are oyster crops throughout the Brazilian coast, however in the North and Northeast regions they are handmade and, in the South and Southeast, industrially [9]. In this scenario, the State of Santa Catarina stands out [2, 10], responsible for 97.9% of Brazilian production in 2016 [11]. In the same year, oyster faming in the State of Pará presented a productivity of ~ 42 tons, (0.2% of the national production) [11].

Success in oyster farming depends heavily on the environmental conditions of the growing area, that is the physical, chemical and biological characteristics of the environment [4,7,10,12-19]. These factors directly influence the growth of the cultivated oyster, and because of this, several studies have been carried out [6,12,15,18,20-26].

In this sense, the present work aims to characterize the growth of the *C. tulipa* mangrove oyster, cultivated in the Amazon coast, and compare it with the performance of oysters grown on the Brazilian coast.

MATERIAL AND METHODS

The study site is located in the estuarine zone of the Urindeua river basin, Salinópolis Municipality, State of Pará, Northern Brazil (Figure 1). In “Associação dos Agricultores, Pecuaristas e Aquicultores – ASAPAQ” of the Vila de Santo Antônio de Urindeua the cultivate the oyster *C. tulipa*, buying the *seed* at the “Associação de Aquicultores de Vila de Lauro Sodré – AQUAVILA”, located in the Municipality of Curuçá [5,9]. According to the authors, the cultivation system used in ASAPAQ is of the fixed table type, using pillows and lanterns. According to oyster farmers, the lanterns are replaced by pillows and bags, mainly because of the amount of predators (e.g., *Stramonita brasiliensis*) [7].

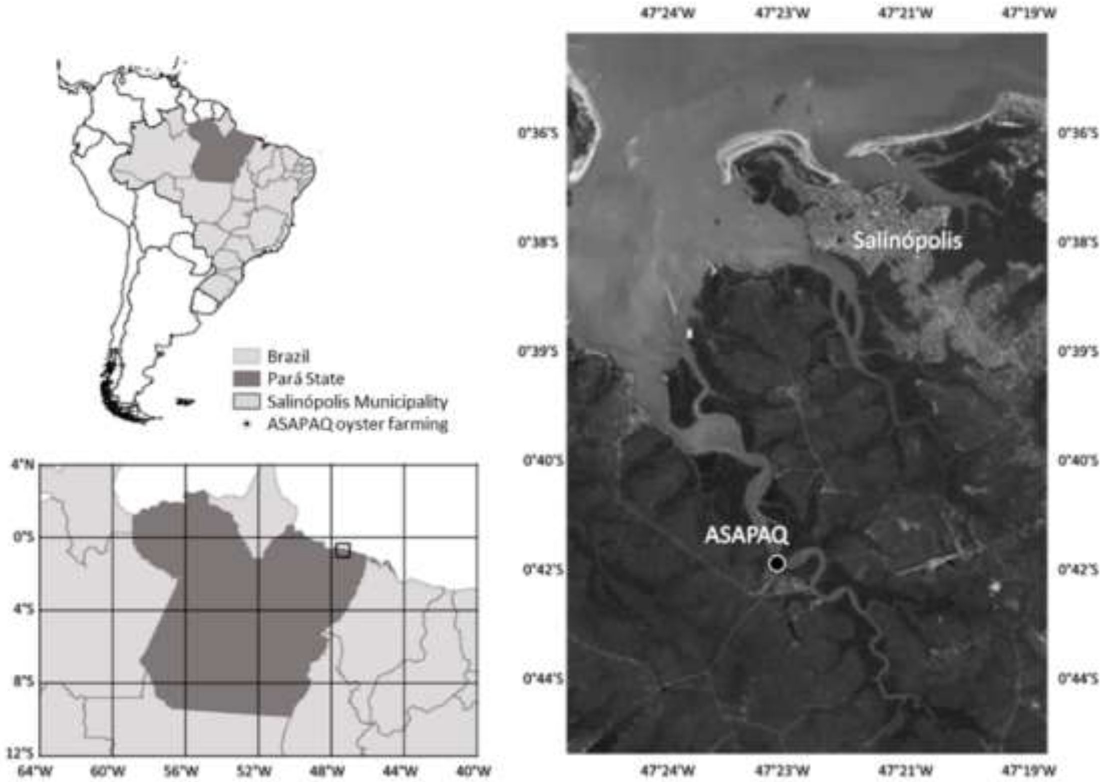

Figure 1. Location of the oyster farms of the Association of Farmers, Pecuaristas and Aquicultores - ASAPAQ, located in the Urindeua river, Amazon coast.

In April 2016, for this growth study in oyster *C. tulipa* cultivated was used 600 oyster of ASAPAQ that was arranged in four lanterns and distributed in commercial size classes (*seed*: 15 to 29 mm long, *juvenile*: 30 to 59 mm, *baby*: 60 to 79 mm, *average*: 80 to 100 mm, and *master*:> 100 mm). In the sampling the oyster shells were cleaned, according to Chagas [7], and the total shell length was measured according to Quayle [27], using a digital caliper (mark: TESA - Datadirect, accuracy: 0.01 mm).

For characterization of *C. tulipa* growth, the morphometric data were previously grouped by size classes. From this, the average monthly growth (T_{cm}) and total (T_{ct}) were estimated according to Equation 1 and 2 below:

$$T_{cm} = \frac{\sum(C_{mt} - C_{mi})}{N_{oyster}} \qquad (1)$$

$$T_{ct} = \frac{C_{mf} - C_{mi}}{N_{months}} \qquad (2)$$

Where, T_{cm} is the average monthly growth rate, C_{mt} is the total length of each oyster measured in the current month, C_{mi} is the average of the total length of the oysters at the beginning of the experiment. T_{ct} represents the average rate of total oyster growth at the end of the experiment, C_{mf} is the mean total length of the oysters measured in the last month and N_{months} the number of months of the experiment.

The survival rate of *C. tulipa* was estimated by size classes through Equation 3 below:

$$S = \frac{N_t}{N_0}.100 \qquad (3)$$

Where, S is the percentage survival of oysters at the end of the experiment, N_t is the number of surviving individuals and N_0 is the initial number of individuals in the experiment.

The Shapiro-Wilk test (p <0.05) was applied to verify the normality of the data. Then, in order to compare the T_{cm} obtained from each class of total oyster length at the end of the study, the analysis of variance (ANOVA *one-way*) was performed. When differences between the T_{cm}, were found, the means were compared through the Tukey test, at a significance level of 5%.

It was verified the correlation between the abiotic variables (salinity and TSA) and the classes of cultivated oyster. For this, simple regressions were performed between the variables (through Equation 2), with the dependent variable (Y) corresponding to the T_{cm} per class of oysters and the independent variable (X) being the abiotic factors. The data were log transformed with the intention of reducing the amplitude of variation among the correlated variables. Pearson's correlation coefficients (r) were classified according to the classification proposed by Hopkins [28].

All statistical analyzes were considered at a significance level of 95% (α = 0.05) [29], using the *software* PAST – *PAlaeontological STatistics* (Version 4.0) [30].

At the same time, the abiotic data (salinity and TSA) were measured during the ebb tide in each month, using a manual refractometer and a digital immersion thermometer, respectively. The rainfall data were obtained from the website of the National Water Agency (http://www3.ana.gov.br/).

RESULTS AND DISCUSSION

Variability in abiotic data is observed throughout the collection months. The highest variation was observed in the salinity, with a mean of 22.5±12.6 (mean±SD), minimum value of 3 (Apr/16) and maximum of 39 (Nov/16). The temperature presented little variation, with 31.2±0.9ºC, minimum of 30.1ºC (Jul/16) and maximum of 33.7 ºC (April/16). The average monthly rainfall was inversely proportional to salinity, with a mean of 5.8±7.3 mm.day^{-1}, presenting months with no rainfall (Set/16 and Oct/16) and maximum of 20.59 mm. day^{-1} (Apr/17) (Figure 2).

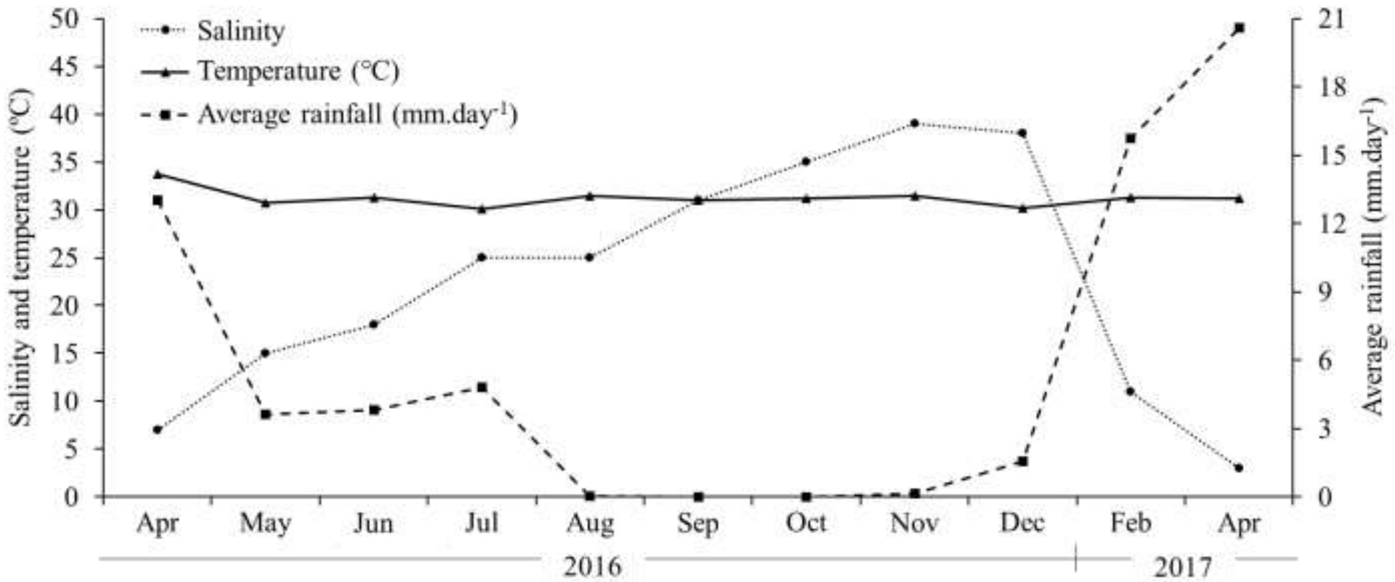

Figure 2. Variation of salinity and surface water temperature (TSA) during spring tides and monthly average rainfall in ASAPAQ oysters in the Urindeua river, Salinópolis, Pará, between 2016/April and 2017/April.

The temperature is a variable that depends on the time of collection and the seasonal season, however the average surface temperature of the water found in the Urindeua river is in agreement with other rivers in the Amazon [31]. The salinity rise and rainfall decline is related to the beginning of the less rainy season (dry season), delimited by the authors between June and November.

The monthly morphometric data of *C. tulipa* are available in Chagas [32], on the *Data Publisher for Earth & Environmental Science* - PANGAEA (https://www.pangaea.de/) platform. From these data, oyster growth was observed in all commercial classes, by means of the monthly average lengths measured (Figure 3) and the percentage of growth over the sampled period (Figure 4). Greater performance in the growth of oysters classified by *seed*s (116%) in the study period.

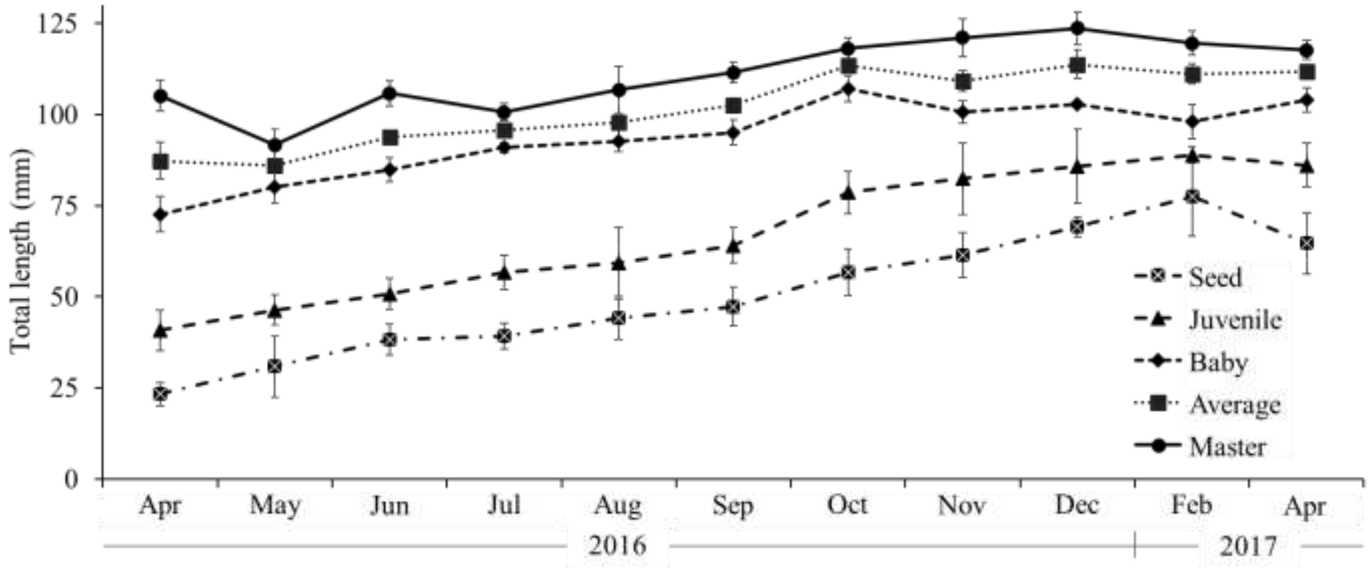

Figure 3. Mean values of total length of oysters collected monthly in ASAPAQ cultivation in the Urindeua river, Salinópolis, Pará, between April/2016 and April/2017. Error bars (upper and lower) represent the standard deviation of the measured total length averages.

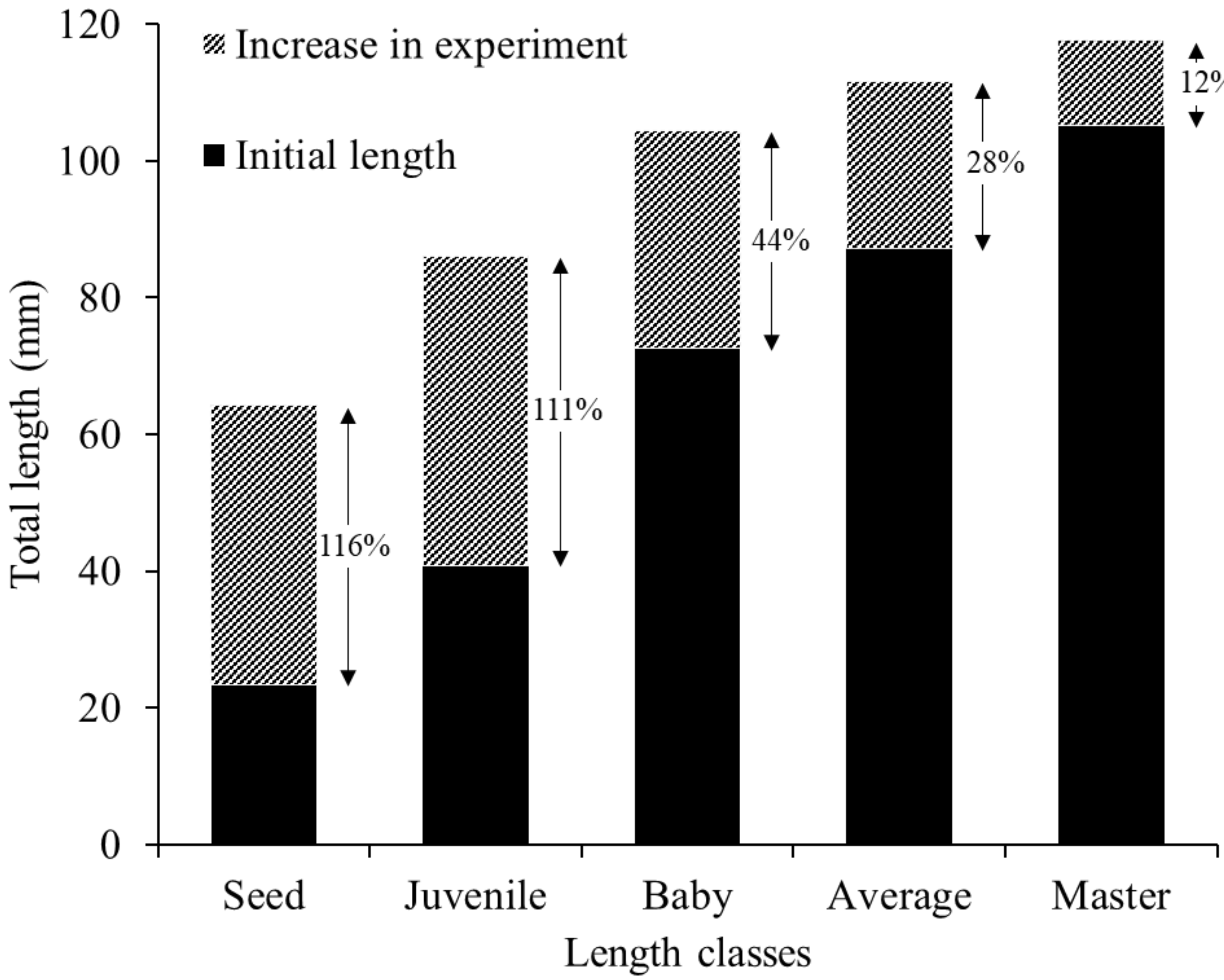

Figure 4. Percentage growth of oysters during the experiment.

According to the review prepared by Chagas and Herrmann [33], it is observed that 46% of the studies present the *juvenile* class as minimum size at the beginning of the experiment, 32% with *pre-seed*, 12% with *seed* and 10% with *baby*. Studies that address oyster growth performance in the Brazilian coast compare the average monthly growth without distinction of classes [6,22], which leads to biased or misleading comparisons. As a result, at the standardization level, the performance of oysters grown with studies using equivalent grades was compared.

The commercial size of the oyster is related to the form of consumption, the species and the regional preference [6]. *C. tulipa* presents 60 mm as initial commercial size in the State of Pará [5, 9] and in this study, the oysters classified by *seed* and *juvenile*s, took, on *average*, seven and four months, respectively, to reach commercial size (Figure 3).

The oysters classified by *seed*s presented T_{cm}=5.17±1.42mm (mean ± SD), varying between 3.07 and 7.63 mm, *juveniles* with T_{cm}=5.03±0.88mm, varying between 3.61 and 6.46mm, *baby* with T_{cm} = 4.19±1.64mm, varying between 2.01 and 7.42mm, *average* with T_{cm}=4.08±1.80mm, varying between 1.40 and 7.94mm, and *master* with T_{cm} = 6.22±4.10mm, varying between 2.36 and 14.12mm.

In the first three months of the experiment, there was a greater oscillation in the T_{cm} of the oysters, with emphasis on the oyster *masters* that showed a sharp decrease in T_{cm} between the months of June and July 2016. The considerable range of T_{cm} of the *average* oysters between May and June of the same year is highlighted. After July 2016, a balance was observed in the T_{cm} of the oysters, with small variations in the following months. It is noteworthy that *juvenile* oysters presented the smallest variation T_{cm} in the experiment period (Figure 5).

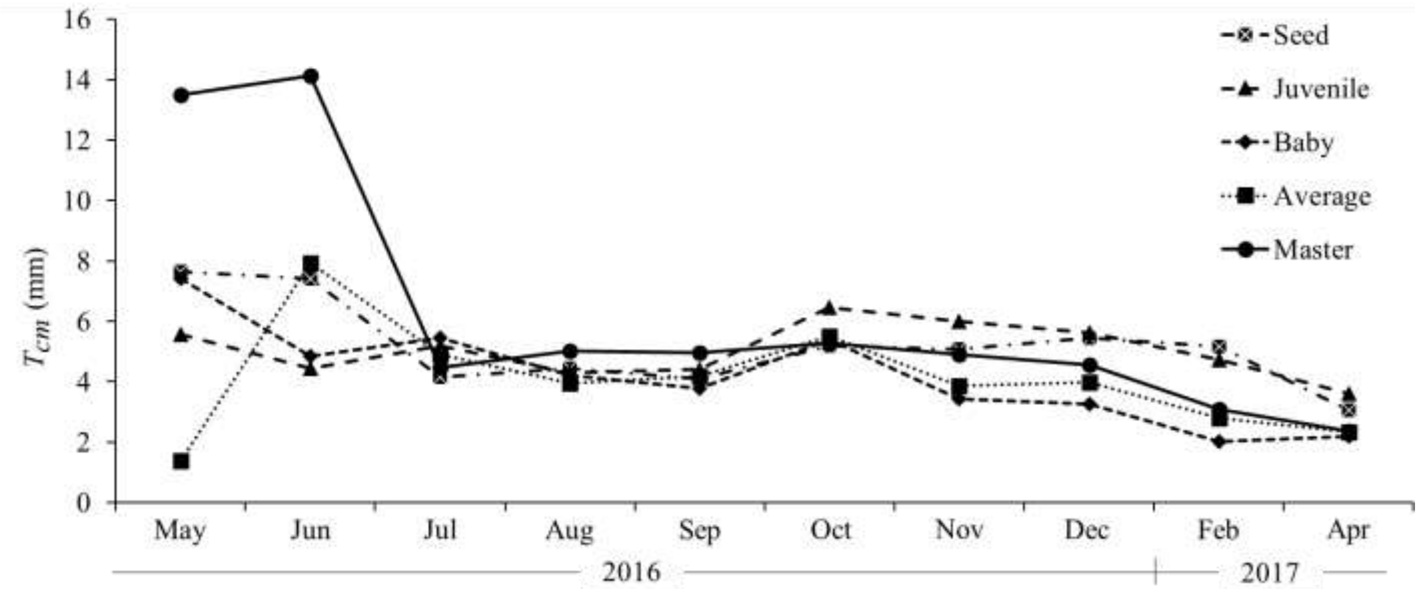

Figure 5. Variation of the average monthly growth rates (T_{cm}) in the respective oyster length classes: *seed*, *juvenile*, *baby*, *average* and *master*.

According to the ANOVA result, no evidence of significant differences was found (F_c=1.464 < F_t=2.578; p=0.22), accepting the null hypothesis. Therefore, the values of T_{cm} obtained in each class of total length of the oysters at the end of the study do not present differences (Figure 6). This result was also perpetuated in the Tukey test, with no significant differences.

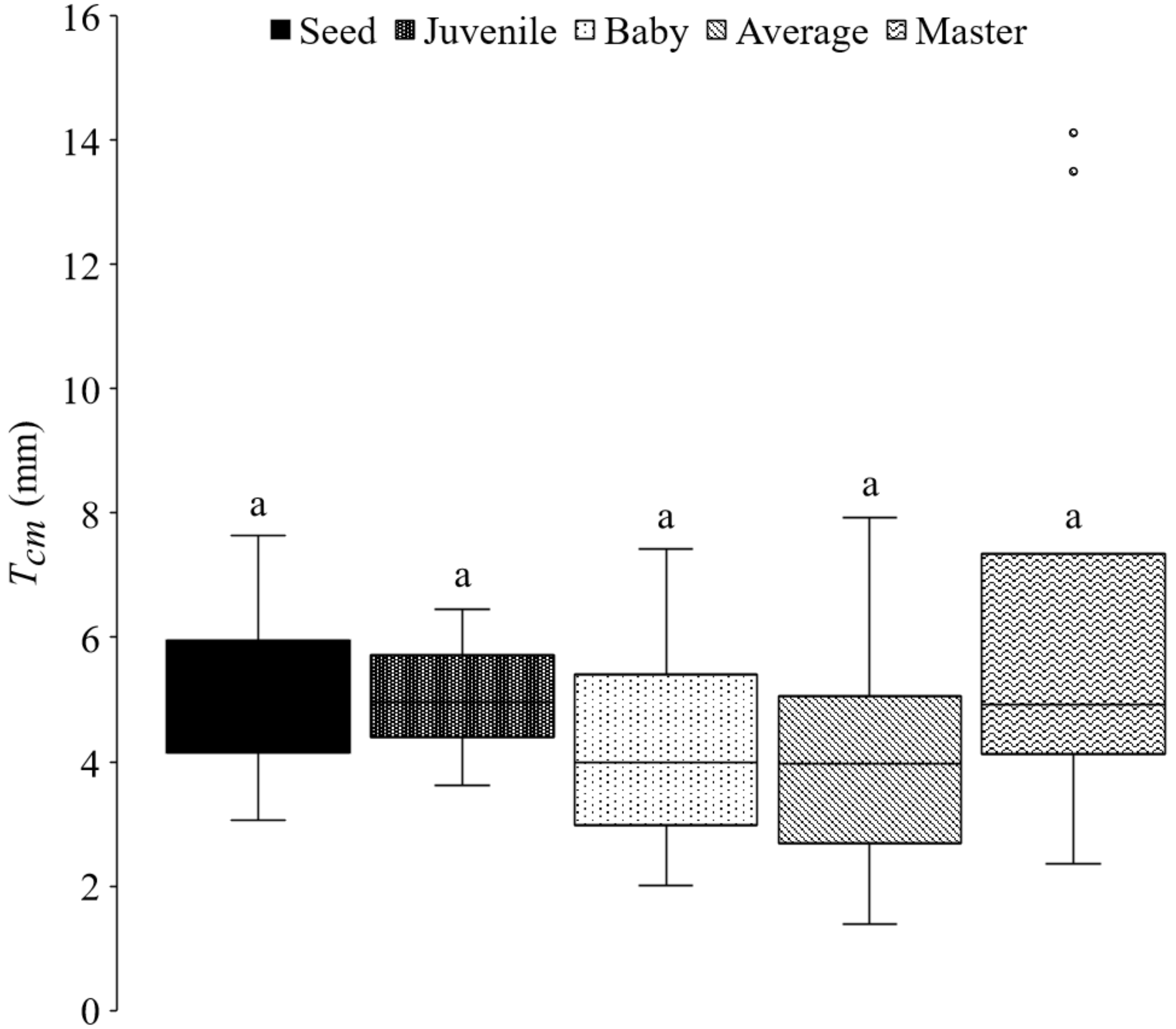

Figure 6. Average monthly growth rates (T_{cm}) in oyster length classes. Equal letters indicate statistical equality at a significance level of 5%.

According to the classification proposed by Hopkins [28], from the Pearson correlation coefficient (r), they indicate a low correlation between the T_{cm} of the oyster classes and the monthly TSA (Table 1). When analyzing the T_{cm} of the oysters and the monthly variation of salinity, a correlation classified as "moderate" between the abiotic variable and the *seed*, *baby*, *average* and *master* classes is verified. The relationship between the *juvenile* class and the salinity is highlighted, classifying the correlation as "very high" (Table 1). This higher performance of *juvenile* oysters is evident in Figure 5, where in the months with the highest salinities (October, November and December 2016), the T_{cm} of this class was higher than the others.

Table 1. Pearson correlation coefficients (*r*) obtained from the correlations between the size of oysters marketed and the abiotic variables (salinity and TSA) monthly, classifying them in: *a*=very low, *b*=low, *c*=moderate and *d*=very high.

Oyster classes	Salinity	TSA (°C)
Seed	0.35^{c} (p=0.31)	0.03^{a} (p=0.92)
Juvenile	0.71^{d} (p=0.02)	0.24^{b} (p=0.47)
Baby	0.46^{c} (p=0.17)	0.28^{b} (p=0.40)
Average	0.49^{c} (p=0.14)	0.07^{a} (p=0.83)
Master	0.35^{c} (p=0.31)	0.03^{a} (p=0.91)

Legat [6] reported that *C. tulipa* oysters presented better growth performance in Santa Catarina, when compared to those grown in the State of Maranhão. However, the growth performance found in this study is well above those found by other authors in the South and Southeast regions (Table 3).

In the Brazilian coastal studies, the oysters classified by *pre-seeds* had a mean growth rate (T_{ct}) of 6.08±2.65mm (mean ± SD), ranging from 2.53 to 9.96 mm. When comparing the performance of those classified by *seeds*, it is observed that the *average* T_{ct} found in this study (T_{ct}=3.41mm) was well below the national average (T_{ct}=5.19±2.74mm). This result is similar to that found by Pereira and Chagas Soares [34], in his experiment with *C. brasiliana*. A very different result was found when comparing the performance of *juveniles* and *baby*, who presented T_{ct} well above the average found in other regions (T_{ct}=2.95±2.24mm and T_{ct}=0.16±0.03mm, respectively). The absence of experiments regarding the growth of *average* and *master* oysters and the high number of publications concerning *pre-seeds* and *juveniles*, occurs for different reasons. In the case of oysters classified by *pre-seeds*, it is important to understand their initial development, as well as their relation to environmental parameters. The *juveniles*, however, represent the most commercialized oyster lengths in Brazil, and because of this, the largest studies are aimed at these length classes.

Survival rates of oysters were high, with oysters classified as *baby* with a better percentage of survival (~85%) and *masters* with the lowest percentage (~66%) (Table 2). The survival rates of *C. tulipa* observed in the experiment period (Table 2) are considered optimal for man-oyster cultivation. The data obtained in other studies with the same cultivation period corroborate this assertion Legat [6] observed a superior survival rate (> 87% and 91%, respectively) to that found in this study (between 66 and 85%) in their experiment with *C. tulipa*, in the states of Maranhão and Santa Catarina. Oliveira [35] has survived between 73 and 80% of the *C. brasiliana* oyster and between 87 and 94% of *C. rhizophorae*, both cultivated in the state of Bahia. However, using the same culture period, other studies have a low survival, such as ~ 30% [34] and ~50% [36], both using the *C. brasiliana* oyster in the state of São Paulo, and survival of 40% found in *C. gigas* culture in Santa Catarina [13].

On the other hand, some studies, using a shorter cultivation period, present a high survival rate of *Crassostrea* oysters on the Brazilian coast. Among these studies, we highlight ~ 90% survival, in ten months of cultivation of *C. brasiliana*, in São Paulo [20], ~88% in four months of cultivation in Paraná [14] and ~93% in five months of cultivation in Santa Catarina [10], both using *Crassostrea* sp. in their experiments.

Table 2. Performance of oysters of the genus *Crassostrea* in different crops in the Brazilian coast, presenting values of initial length (C_0), final length (C_f), growing period (T) in the month, average monthly growth rate (T_{ct}) and percentage survival (S). Legend: Oysters sorted by *semente* (*a*), *juvenile* (*b*), *baby* (*c*), *average* (*d*) e *master* (*e*). Updated taxonomy of *Crassostrea gasar* (*) and values not available (**). Source: Chagas and Herrmann [33].

Species	C_0 (mm)	C_f (mm)	T	T_{ct} (mm/ month)	$S_{\%}$	E	Source
C. tulipa [a]	23.3±3,1	64.2±8.3	12	3.4	~74	PA	Present study
C. tulipa [b]	40.7±5,5	86.0±5.9	12	3.7	~76	PA	Present study
C. tulipa [c]	72.5±4,8	104.4±3.3	12	2.6	~85	PA	Present study
C. tulipa [d]	87.2±5,0	111.7±1.9	12	2.0	~79	PA	Present study
C. tulipa [e]	105.1±4,2	117.6±2.6	12	1.0	~66	PA	Present study
*C. tulipa**	13.7±5,5	49.6±7.3	11	**	**	SC	[24]
*C. tulipa**	9.6±5,4	61.9±13.0	11	**	**	SC	[24]
*C. tulipa**	5.8±2,0	71.9±8.0	13		~93	SC	[6]
*C. tulipa**	5.8±2,0	55.3±6.0	13		~91	SC	[6]
*C. tulipa**	5.8±2,0	46.9±9.1	13		~95	MA	[6]
*C. tulipa**	5.8±2,0	30.9±10.7	13		~87	MA	[6]
*C. tulipa***	40.8±8,7	50.3±8.7	4	2.37	67	SE	[22]
C. brasiliana	32.2	60.5	12	2.36	~50	SP	[36]
C. brasiliana	5.6±0,06	25.8±0.3	8			SP	[15]
C. brasiliana	19.8	59.1	12	3.3	~30	SP	[34]
C. brasiliana	~50	81.8	10	2.64	~90	SP	[20]
C. brasiliana	~50	76.8	10	2.16	~90	SP	[20]
C. brasiliana	~50	74.1	9	2.18	64	SP	[20]
C. brasiliana	~40	55.8	12	1.75	~87	BA	[35]
C. brasiliana	~40	60.8	12	2.65	~91	BA	[35]
C. brasiliana	~40	53.3	12	1.58	~87	BA	[35]
C. brasiliana	~40	55.6	12	2.28	~94	BA	[35]
C. gigas	9.1±2.5	82.8±8.5	12	**	40	SC	[13]
C. rhizophorae	~40	53.3	12	1.48	~73	BA	[35]
C. rhizophorae	~40	53.1	12	1.51	~74	BA	[35]
C. rhizophorae	~40	46.5	12	1.29	~80	BA	[35]
C. rhizophorae	~40	44.0	12	1.08	~75	BA	[35]
C. rhizophorae	9	54.1±7.4	5	9.9	**	SC	[37]
C. rhizophorae	9	55.8±7.4	5	10.2	**	SC	[37]
C. rhizophorae	9	49.8±6.9	5	9	**	SC	[37]
C. rhizophorae	9	58.8±8.5	5	10.8	**	SC	[37]
C. rhizophorae	6.2±1.0	37.6±8.0	10	3.1	45	ES	[16]
C. rhizophorae	42.4	55.5±5.8	3	4.3	~45	CE	[38]
C. rhizophorae	42.4	55.7±4.2	3	4.4	~28	CE	[38]
C. rhizophorae	42.4	55.7±6.3	3	4.4	~17	CE	[38]
C. rhizophorae	24.8±0.7	41.3±4.8	3.5	5.5	28	PE	[21]
C. rhizophorae	24.8±0.6	39.0±5.0	3.5	4.7	~31	PE	[21]
C. rhizophorae	24.8±0.4	38.4±4.2	3.5	4.5	~24	PE	[21]
C. rhizophorae	~40	~80	7	~6.6	**	AL	[39]
C. rhizophorae	46.5±3.4	54.76±2.7	1	6	~83	BA	[12]
C. rhizophorae	46.0±3.8	53.1±2.7	1	5.1	~83	BA	[12]
Crassostrea sp.	~10	60	5	9.9	~93	SC	[10]
Crassostrea sp.	64.1±1.7	65.1±1.7	8	**	~88	PR	[14]
Crassostrea sp.	64.5±1.8	66.0±1.7	8	**	~88	PR	[14]
Crassostrea sp.	64.3±1.8	65.5±1.7	8	**	~87	PR	[14]
Crassostrea sp.	64.1±1.8	65.6±1.8	8	**	~89	PR	[14]

Table 3. Growth performance of oysters reaching commercial size.

Species	Commercial size	Cultivation period (months)	State	Source
C. tulipa (*seed*)	60 mm	7	PA	Present study
C. tulipa (*juvenile*)	60 mm	4	PA	Present study
C. tulipa	50 mm	9	SC	[24]
C. rhizophorae	70 mm	18	SC	[40]
C. brasiliana	50 mm	19.5	SP	[23]
C. brasiliana	70 mm	18	SC	[40]
C. brasiliana	50 mm	14	SP	[34]
C. gigas	70 mm	7	SC	[13]
C. gigas	60 mm	5	SP	[41]
Crassostrea sp.	50 mm	18	SC	[10]

According to Gosling [42], several factors are related to the growth of bivalve mollusks, however the synergy between them makes it difficult to estimate the effect of an isolated factor. Pereira [20] cite that oyster growth and survival rates are directly influenced by biotic and abiotic factors (e.g., salinity, tidal amplitude, primary production, cropping systems). This assertion is corroborated by several authors [6,10,13,21,22,35,37,39].

For a precise estimation of the growth rates of the cultured oyster in a tropic climatic area, Chagas and Herrmann [43] recommend a marking-recapture experiment, using the in situ fluorescent labeling method (the calcein solution base) and sizes. This method is effective because it presents excellent markers and does not negatively influence the survival of tagged individuals [43-47].

CONCLUSION

The variability in the growth rates of the *Crassotrea tulipa* oysters in the first months of the crop evidences a stress to the environmental conditions. However, from the minimization of this stress (occurring in the third month of cultivation), the equilibrium of the growth rates occurs. It is concluded, through the statistical analysis, that there is no difference between oyster growth rates at the end of the experiment, however, there are differences in total and percentage growth rates, especially oysters classified by *juveniles* and *seeds*, respectively. The salinity influenced only the growth of *juvenile* oysters, mainly because these oysters presented the highest monthly growth rates in the months where it showed the highest salinity values. The survival rates of oysters in this study were satisfactory and correlated to those found in other studies in the Brazilian coast.

In this study, the period of oyster cultivation to reach commercial size was shorter (four to seven months) than in other regions (e.g., south and southeast), even when compared to the same species.

Funding: To the National Council for Scientific and Technological Development (CNPq), for granting scholarships to carry out this research.
Acknowledgments: The authors thank the “Associação dos Agricultores, Pecuaristas e Aquicultores – ASAPAQ” of the Vila de Santo Antônio de Urindeua for the support to the development of the research. In particular the oyster farming: Dona Maria (current president), Tito, Miro and his Antônio (former president). The Federal Rural University of Amazon (UFRA), especially to the Socioenvironmental and Water Resources Institute (ISARH/UFRA), for the logistical support in the assignment of transportation to the authors' displacement to the research site.
Conflicts of Interest: The authors declare no conflict of interest.

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