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Synergy between Seasonality and Climatic Anomaly and their Effects on the Growth of Oysters Cultivated in the Amazon Coast

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HIGHLIGHTS

- We detected a synergistic effect between the Amazon seasonality and the El Niño climate anomaly;
- In normal years, oysters develop grow during the dry season;
- In El Niño years, oysters develop grow during the rainy season;
- The influence of climatic anomalies on the growth of cultivated oysters can be an investment indicator.

Abstract: In this study, we aimed to evaluate the synergistic effect between the Amazon seasonality and the El Niño climate anomaly (2015/16 event) on the growth of oysters cultivated on the Amazon coast in comparison with the growth of oysters in a normal year (2013). It should be noted that both experiments determined the absolute growth of oysters *Crassostrea gasar* by reading microgrowth using an internal calcein marker. the results clearly indicate the synergistic effect of the Amazon seasonality with the El Niño climatic anomaly. thus, in normal years, the best oyster growth performance occurs in the dry season, while in El Niño years it occurs in the wet season. This is the first study carried out in the Amazon region that aims to analyze the effects of El Niño on the production of fishery resources from aquaculture. Such information enables adaptations in the planning of the production cycle of oyster farming, serving as an investment indicator.

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

INTRODUCTION

The aquaculture of bivalve molluscs has played an important role in human nutrition since the 1980s and has seen rapid growth up to the present day [1]. This growth in bivalve production is the result of the success of mussel farming and oyster farming, which have emerged as a viable alternative to mitigate the decline in fishing, reducing pressure on natural stocks [2-4] and becoming an economic source for coastal communities [5-7].

In Brazil, oyster farming is restricted to the cultivation of three oysters of the genus *Crassostrea* Sacco, 1897. The taxonomy of oysters *Crassostrea* spp. it was for a long time an unresolved question. However, an integrative taxonomic approach to native species of *Crassostrea* mangrove oysters on the Brazilian coast has recently been undertaken to assert the correct species names [8].

Several oyster cultivations are distributed along the Brazilian coast, with artisanal cultivation located in the North and Northeast regions and on an industrial scale in the South and Southeast regions [9]. In this scenario, the State of Santa Catarina is responsible for almost all Brazilian production in 2016 (approximately 98%) [10]. In a different scenario, the State of Pará produced only ~42 tons (0.2% of national production) [10]. This is a very clear result of the scale of cultivation in these two regions (South and North regions, respectively).

Success in oyster farming depends on the environmental conditions of the cultivation area, that is, the abiotic, biological and type of management or cultivation [11-16]. Such factors directly influence the growth of the cultivated oyster, and because of this, several studies are carried out [13, 17-20]. In addition, cultivated oysters are subject to effects caused by climate anomalies, such as El Niño and La Niña [21], which were previously undetectable due to the lack of understanding of such effects.

Currently, this reality has changed and there are abundant publications and many research groups (distributed throughout the world) that address the most diverse subjects related to these climatic phenomena. However, for the analysis of its influence, one must understand all phases of the climate anomaly, from its formation to the consequences across the globe [22-24].

Globally, the El Niño phenomenon varies in intensity and has negative and positive aspects [25]. El Niño interferes with the general circulation of the atmosphere on a large scale, consequently causing changes in climatic conditions in various continental regions around the planet, due to the large amount of energy involved in this process. Due to this dimension of the phenomenon, the understanding of the evolution of El Niño must be approached from a global perspective, instead of focusing only on the tropical Pacific [26].

In Brazil, the effects of El Niño occur differently in each region and are directly related to the intensity of the phenomenon [27]. In the North region, for example, El Niño causes a reduction in rainfall, from moderate to heavy, in the northern and eastern sectors of the Amazon [27, 28]

Thus, the impacts of El Niño on agriculture and food security depend on a complex interaction of meteorological factors, with different severity levels [29]. In this context, there are reports of negative and positive impacts of El Niño on the production of fisheries resources [30, 31]. In the production of molluscs, the mussel *Perna perna* (Linnaeus, 1758), showed an increase in growth rates, consequently increasing production [32]. However, the same authors cite the negative influence on the cultivation of the Japanese oyster *Crassostrea gigas* (Thunberg, 1793), adapted to cold waters, which presented a reduction in its production.

In this sense, we aimed to evaluate the synergistic effect between the Amazon seasonality and the El Niño climatic anomaly (2015/16 event) on the growth of oysters *Crassostrea gasar* (Dillwyn, 1817) cultivated on the Amazon coast. This is the first study carried out in the Amazon region that aims to analyze the effects of El Niño on the production of fishery resources from aquaculture.

MATERIAL AND METHODS

The present study was carried out in the oyster farm of the *Associação dos Agricultores, Pecuaristas e Aquicultores* – ASAPAQ, located in the estuarine zone of the hydrographic basin of the Urindeua river, Municipality of Salinópolis, State of Pará, northern region of Brazil (Figure 1). At ASAPAQ, the mangrove oyster *C. gasar* is cultivated, buying the seeds at the *Associação de Aquicultores de Vila de Lauro Sodré* – AQUAVILA, located in the Municipality of Curuçá [7, 9].

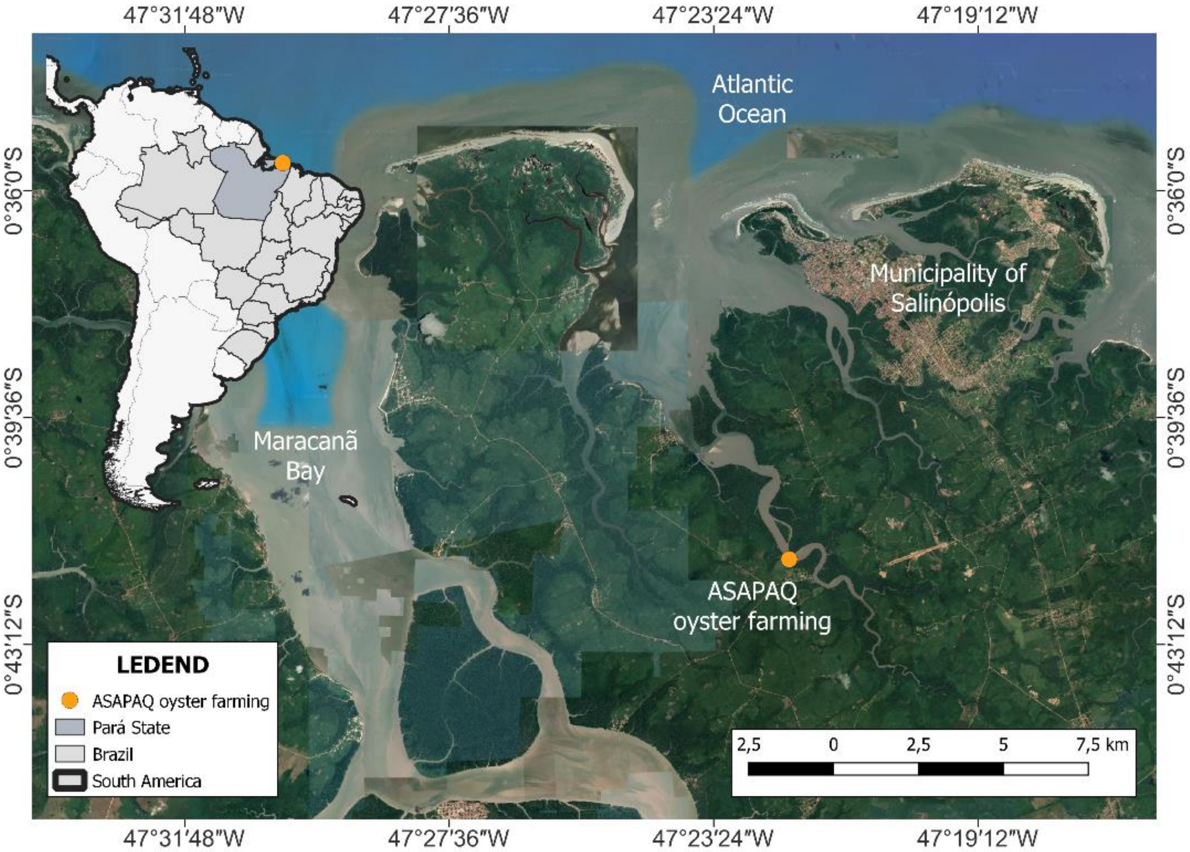

Figure 1. Location of the oyster farms of the Association of Farmers, Pecuaristas and Aquicultores - ASAPAQ, located in the Urindeua river, Amazon coast. Fonte: Chagas and collaborators [33].

To analyze the effect of Amazon seasonality on oyster growth, a marking-recapture experiment was carried out using four commercial oyster length classes (*seed*: 15 to 29 mm; *juvenile*: 30 to 59 mm; *baby*: 60 to 79 mm; and, *average*: 80 to 100 mm). The methodology used was proposed by Chagas and Herrmann [34], who recommend the use of fluorochrome calcein (150ml L-1 solution, for a period of 24 hours) in the internal marking of the shell in growth studies of bivalve molluscs. In addition, this method was used because it allows the determination of the absolute growth of the species [35].

The experiment started in April 2016 and a total of 200 oysters (50 of each size class) were used. After marking, the oysters were arranged in four lanterns, distributed by commercial size classes. It is noteworthy that in the present experiment, the oysters used came from the cultivation itself and were placed in a cultivation location without influence of the periodic management carried out by the oyster farmers. With the purpose of a precise comparison, this experiment was carried out in the same region, using oysters of the same species, in similar conditions of implantation and development of the experiment carried out in the year 2013.

After the implementation of the experiment, eight samplings (between May and December 2016) were carried out. In each sampling, the encrusting epifauna on the oysters was removed and five oysters of each size class were randomly selected. Approximately 25% more individuals of each class of oysters were used due to the local survival rate [36].

In each sampling, the oysters were duly coded and transported to the Laboratory of Tropical Benthic Ecology of the Federal Rural University of the Amazon (UFRA), located in the capital Belém, for morphometric analyzes and growth determination.

Additionally, the surface temperature of the water and salinity were measured during low tide in each collection, with the aid of a digital immersion thermometer and the use of a portable refractometer with a scale of 1/100, respectively. Rainfall data was obtained from the National Water Agency webpage (http://www3.ana.gov.br/).

In the laboratory, the oysters were sectioned to remove the soft body and, subsequently, the shells were washed to completely remove the organic material. After this process, he arranged the shells to dry in the open air, protected from the sun, for approximately 24 hours, to prevent the development of fungus. The following process was limited to the separation of the left (or lower) valve to form blocks in crystal resin, in a 100:1 ratio (resin:catalyst), remaining for 24 hours for the resin to harden.

The next procedure consisted of longitudinal sectioning of the blocks – in the direction of the longest axis of growth –, with a diamond saw, for sampling a 5 mm thick section of the block. Subsequently, the sections were successively polished on a glass panel with different degrees of silicon carbide powder (125, 68, 30, 12 and 5 μm) and, finally, with a 1 μm aluminum oxide suspension.

For the analysis of the growth marks, the sections of the oysters were observed in a fluorescence microscope, equipped with blue light (Motic, filter 450 to 490 μm) through digital photographs and examinations through the use of the processing program Digital images AxioVision (2018) version SE64 Rel. 4.9.1 SP2. The detailed description of the process of marking oysters, detecting growth marks and estimating oyster growth are in accordance with Chagas and collaborators [33].

After preparing and analyzing the sampled shells, the absolute growth rate was determined by measuring the shell growth increment between the calcein mark and the shell margin over time (t):

$$absolute\ growth\ rate = \frac{L_2 - L_1}{t_1 - t_2} = \frac{\Delta L}{\Delta t} \quad (1)$$

Where L_1 is the total length (mm) of the oyster at the beginning of the experiment (t_1), L_2 the total length (mm) in the sampled month (t_2), ΔL the marginal increment (mm) and Δt the experiment time (in days).

To study the effect of Amazon seasonality on the growth of cultivated oysters, the rainy period from December to May and the dry period from June to November were considered [37]. For this purpose, the mean salinities obtained in the normal year and in an El Niño year were initially tested using a t-Test. This test was important to rule out the mean difference in salinity in oyster growth between the analyzed periods.

Normality was verified using a Shapiro-Wilk test and for homogeneity of variances a Levene test was used. The synergistic effect of Amazon seasonality and the El Niño climate anomaly on oyster growth was tested using a Analysis of Variance two-way (ANOVA two-way) followed by a post-hoc Tukey test. The ANOVA two-way test was used because it allows the simultaneous assessment of the effect of two variables on a response variable. In the present study, the categorical variables were seasonality (dry season and rainy season) and annual period (normal year and El Niño year), with the response variable being the daily absolute growth rate.

In this context, the postulated hypotheses were:

- **Hypothesis 1:** Average total and daily growth rates by seasonal influence are equal;
- **Hypothesis 2:** Average total and daily growth rates between normal and El Niño years are equal;
- **Hypothesis 3:** Average total and daily growth rates of oysters under the synergistic effect of Amazon seasonality and the El Niño climate anomaly are equal.

Thus, the alternative hypothesis for cases 1 and 2 is that the mean absolute growth rates are not equal. The alternative hypothesis for case 3 is that there is an interaction between seasonality and the El Niño climate anomaly, i.e., the daily absolute growth rates in a seasonal comparison differ in El Niño years.

Data were analyzed in the R program [38] and the *ggplot2* package was used for graphics.

RESULTS AND DISCUSSION

Salinity variation in the normal year was limited between 8 (May) and 31 (October), with an amplitude of 23. In the El Niño year (2015/16), salinity varied between 15 (May) and 39 (November), with a maximum amplitude of 24 (Figure 2). It was observed that the salinity averages between the periods do not present significant differences (t=2.082, df=11, p=0.061).

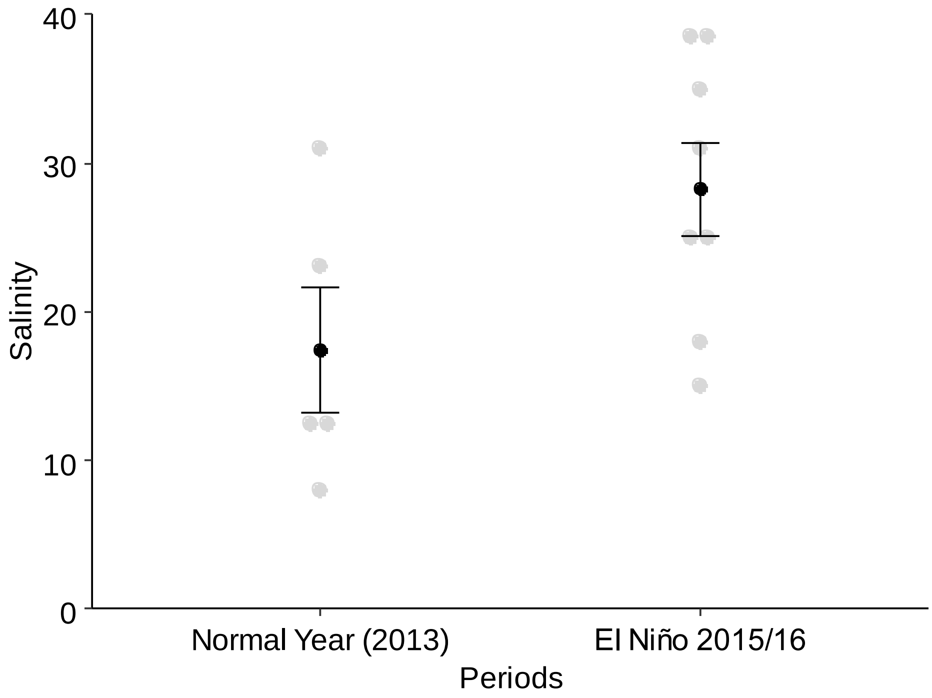

Figure 2. Salinity variation measured during spring tides in the ASAPAQ oyster farm on the Urindeua River, Salinópolis, Pará, in normal and El Niño years.

The variability of the abiotic parameters found in this study corroborate the results of Paixão, Ferreira [39], measured in cultivation environments in the State of Pará. In a normal year, the water temperature did not have a significant variation, ranging from 29.7 ºC to 30.1 ºC. In an El Niño year, the temperature also showed little variation, between 30.1°C and 31.5°C. The variation in average monthly rainfall behaved inversely proportional to salinity, with an average of 52.33±60.00 $mm.day^{-1}$, with months with no rain (September and October) and a maximum of 143.9 $mm.day^{-1}$ (July) [36].

The little change of temperature in this study is in line with the average of other rivers in the Amazon [39, 40]. This temperature behavior is very different from the crops found in the Northeast region, with a variation of 25 to 31°C [18, 19, 41], and in the South and Southeast regions of Brazil, between 15 and 29.5°C [14, 19, 42, 43], thus observing a significant variation of this parameter in these regions. Furthermore, Manzoni and Schimitt [44] cite that in the summer months, due to temperatures above 28°C, they are not conducive to the beginning of oyster cultivation, since high temperatures cause delay in growth and seed mortality, and thus, mild temperatures (< 26°C) allow higher survival and growth rates. This is something that should be evaluated, because in the present study, in both analyzed periods, the temperature was higher than that mentioned by Manzoni and Schimitt [44].

The average salinity found is similar to that of other regions of Brazil, however it presents a high annual oscillation. The variability found is close to those found in the Northeast region, between 5 and 32 [18, 19, 41], however, much higher than the other Brazilian regions (South and Southeast), between 8 and 34 [14, 19, 42, 43]. In Brazil, studies mention that the variation in optimal salinity for the development of oysters *Crassostrea* spp. in crops it is between 15 and 25 [17, 42, 45-48], however in the natural environment it survives in salinities from 8 to 34 [42]. In this context, Alvarenga and Nalesso [11] cite that high salinity (> 30) does not favor the cultivation of oysters and, according to Guimarães, Antonio [47], salinities between 30 and 35 increase mortality. Chagas, Barros [36] observed that salinity influences the growth of oysters commercially classified as *juvenile*.

The rise in salinity and the decline in rainfall is related to the beginning of the less rainy season (dry season), delimited between June and November [37].

Several other environmental factors (e.g., primary production, biofouling, density and stock, culture type and structure, among others) directly influence oyster growth [2, 12, 14, 15, 17, 36, 49]. In this sense, the search for the identification of the isolated influence of a factor on the growth of oysters is highly relevant for the success of cultivation.

From the results of the ANOVA two-way, carried out from the total absolute growth data, we can conclude that there is no difference in the average rates of by seasonal influence (F=1.015; p=0.062), nor by period, that is, between a normal year and an El Niño year (F=3.488; p=0.314) and, consequently, there is no synergistic effect of the Amazon seasonality and the El Niño climatic anomaly ($F=2.099$; $p=0.148$). This confirms all postulated hypotheses about total absolute growth comparisons (Figure 3A-C, Table 1).

When comparing the absolute daily growth data, no significant differences were observed in the average rates of seasonal influence ($F=2.096$; $p=0.148$). However, it was verified that the daily absolute growth is statistically different between the periods ($F=9.405$; $p=0.002$), indicating that in normal years, farmed oysters grew an average of 0.05 mm more per day than in El Niño years ($p<0.001$). This refutes hypothesis 2, when comparing the daily absolute growth per period.

The synergistic effect of Amazon seasonality and the El Niño climatic anomaly was evidenced only by comparing daily growth rates ($F=4.960$; $p=0.026$). The results indicate that in normal years and in the rainy season, cultivated oysters grow on average 0.04 mm more per day than in El Niño years in the same period ($p<0.001$). Similarly, in normal and dry years, farmed oysters grow an average of 0.09 mm more per day than in El Niño years in the same period ($p<0.001$) (Figure 3B-D, Table 1).

These results indicate that the best oyster growth performances in normal years occur in the dry period. In El Niño years, the best growth performance occurs in the rainy season. This information is important for planning the production cycle of oyster farming, allowing you to increase/decrease investments (e.g., purchase of *seeds*, increase in density, etc.). A great recommendation is to invest in oysters commercially classified by *seed*, *juvenil* and *baby* since they show better growth performance regardless of seasonality [33].

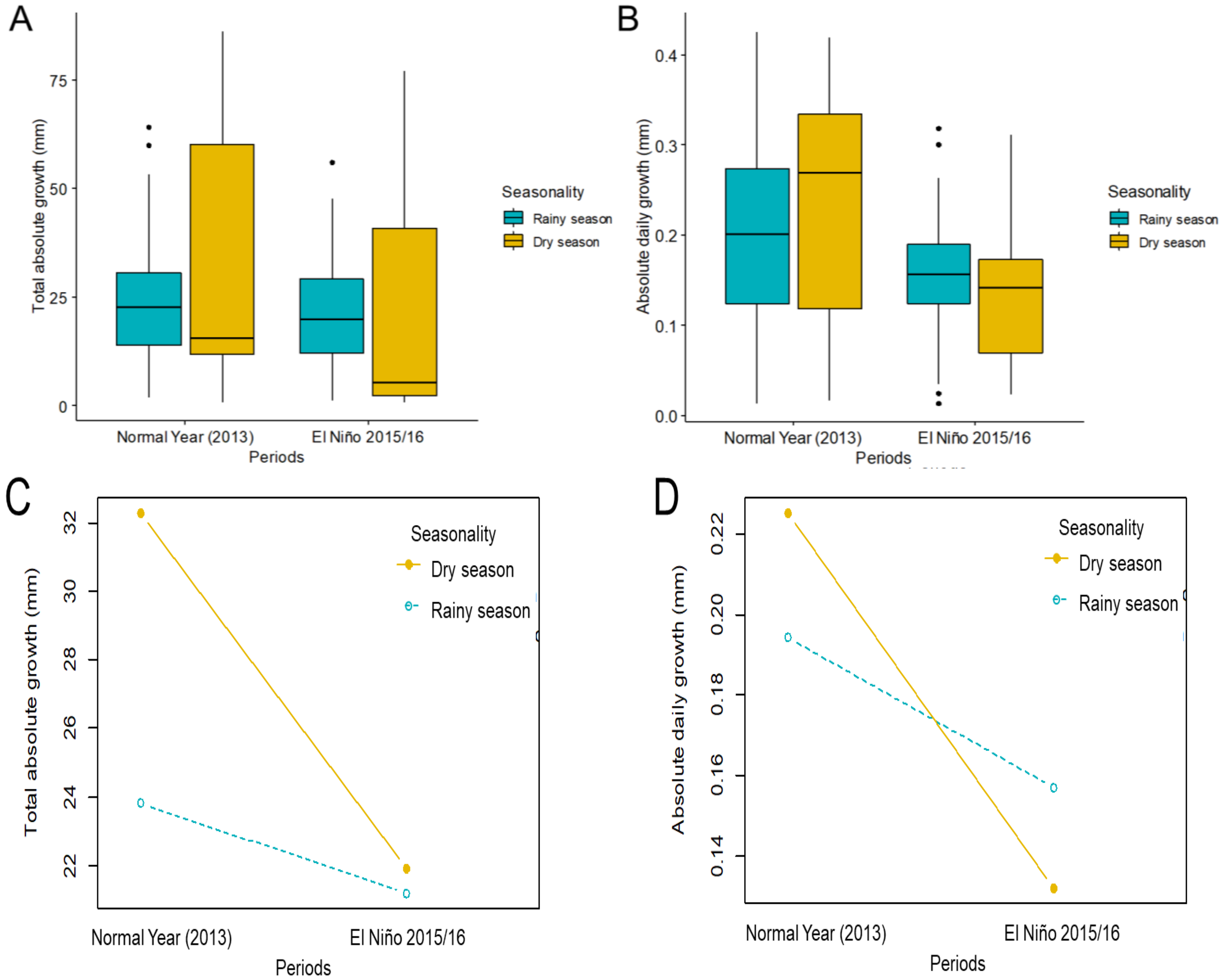

Figure 3. Total (A), daily (B), and interaction (C and D) absolute growth averages of oysters cultivated on the Amazon coast, comparing by seasonality and period.

Table 1. Results of Analysis of Variance two-way (ANOVA two-way) on the increment of shell growth in oysters *Crassostrea gasar* cultivated on the Amazon coast.

		Comparison between total absolute growth		
Effect	**Df**	**SumSq**	**F**	***p***
Intercept	1	30.634	115.689	<0.001
Seasonality	1	269	1.015	0.314
Period	1	924	3.488	0.062
Seasonality: Period	1	556	2.099	0.148
Residuals	254	67.257		
		Comparison between daily absolute growth		
Effect	**Df**	**SumSq**	**F**	***p***
Intercept	1	2.040	348.321	<0.001
Seasonality	1	0.050	9.405	0.002
Period	1	0.012	2.096	0.148
Seasonality: Period	1	0.029	4.960	0.026
Residuals	254	1.487		

As mentioned initially, studies related to environmental influences on the growth of oysters *Crassostrea* spp. cultivated are mainly attributed to abiotic factors (e.g., salinity, local temperature, tidal range, among others), biotic (e.g., primary production, biofouling, among others) and cultivation systems (e.g., location of cultivation, stocked density, types structures, among others). In this sense, studies on the environmental influence on the growth of cultivated oysters are limited to these aspects [13, 15, 18-20, 34, 36, 39, 42, 47]. Thus, there is a gap regarding the influence of climatic anomalies (e.g., El Niño) on the growth of oysters *Crassostrea* spp. cultivated.

In this context, it is observed that worldwide, the Overall Growth Performance index - OGP is used to characterize the growth performance of numerous species [50, 51]. In bivalve molluscs, it is historically effective in characterizing growth, such as: *Donax obesulus* Reeve, 1854 (updated taxonomy of *Donax marincovichi* Coan, 1983) [52], mytilids (e.g., *Mytillus* spp. and *Perna* spp.), *Donax serra* Röding, 1798 [53], *Aequipecten opercularis* (Linnaeus, 1758) [54], *Amarilladesma mactroides* (Reeve, 1854) (updated taxonomy of *Mesodesma mactroides* Reeve, 1854) [55, 56] and *Donax hanleyanus* Philippi, 1847 [57].

The OGP is efficient, because, in general, the species present growth patterns directly linked to the climatic area in which they live [58, 59]. This is due to the variation in temperature according to latitude, which is directly related to the growth of bivalves [60]. That is, bivalves from low latitudes tend to grow faster at room temperature than members of the same species from higher latitudes. This allows OGP to detect changes in species growth parameters (K and L_∞), which makes it efficient to detect climate influence or anomalies. The OGP is presented in a special graph, called auximetric grid, which allows the detection of the growth pattern of the species.

CONCLUSION

In this study, we clearly detected the synergistic effect of the Amazon seasonality with the El Niño climate anomaly. Thus, our results indicate that the best growth performance of oysters *Crassostrea gasar* in normal years occurs in the dry season, whereas in El Niño years, it occurs in the rainy season. Such information enables adaptations in the planning of the production cycle of oyster farming, serving as an investment indicator.

In addition, we recommend an analysis of the influence of the El Niño climatic anomaly on the growth of oysters *Crassostrea gasar* using the Overall Growth Performance index – OGP, so that a change in the growth parameter of oysters can be analyzed.

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