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Mortality of the Clam *Anomalocardia brasiliana* Population in the Pirajubaé Marine Extractive Reserve: Effect of Climate Events?

Mortalidade da População do Berbigão Anomalocardia brasiliana na Reserva Extrativista Marinha do Pirajubaé: Efeito de Eventos Climáticos?

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Abstract

In February 2015, an event of massive mortality of the clam *Anomalocardia brasiliana* was reported in the Pirajubaé Marine Extractive Reserve (RESEX), located in Florianópolis, SC. To investigate whether the cause of the event was related to climate and/or environmental factors, daily data of air temperature, precipitation, global solar radiation and lowest day tide from different databases of a 4-month interval (November, December, January, and February) from 2010 (beginning in November of 2010) to 2017 were collected. Based on the analyzed parameters, no changes that could be related to the occurrence of massive mortality of clams in February 2015 were observed. This analysis also indicates that there is no relation between the studied parameters and the absence of recovery of the natural stock of these organisms.

Keywords: Bivalve molluscs; Fishery; RESEX

Resumo

Em fevereiro de 2015, foi relatada a ocorrência de um evento de mortalidade massiva do berbigão *Anomalocardia brasiliana*, na Reserva Extrativista Marinha do Pirajubaé (RESEX), localizada em Florianópolis, SC. Para investigar se a causa do evento teve relação com fatores climáticos e/ou ambientais, dados diários de temperatura do ar, precipitação, radiação solar global e menor maré diurna de diferentes bancos de dados, no intervalo de 4 meses (novembro, dezembro, janeiro e fevereiro) de 2010 (iniciando em novembro de 2010) a 2017 foram coletados. Com base nos parâmetros analisados, não foram observadas alterações que pudessem estar relacionadas à ocorrência da mortalidade massiva do berbigão em fevereiro de 2015. Essa análise também indica que não há relação entre os parâmetros estudados e a ausência de recuperação do estoque natural desses organismos.

Palavras-chave: Molusco bivalve; Extração; RESEX

1 Introduction

Understanding the causes of massive mortality of bivalves, reported in different countries, is a challenge and has been studied by several researchers. Some proposed studies aim to unravel those causes, but the conclusions obtained are varied, including the interference of environmental factors (Farinati, Aliotta & Ginsberg 1992; Pretto et al. 2014; Samain & McCombie 2008; Yurimoto et al. 2014). Mortality is normally considered to be massive or abnormal for bivalve populations when there is a loss of more than 30% of the stock (Soletchnik et al. 2007).

From the publication of Decree No. 533 on May 20, 1992, the Pirajubaé Marine Extractive Reserve (*Reserva Extrativista* – RESEX) was created in Florianópolis, Santa Catarina, being the first Marine RESEX in Brazil. The creation of the Pirajubaé Marine RESEX was motivated by several factors, the most important being the presence and fisheries of the bivalve mollusk *Anomalocardia brasiliana*,

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locally known as Berbigão (Pezzuto & Echternacht 1999). There is a tidal plain in the reserve, which is subdivided into two neighboring sectors, called *Baixio Principal* (or Bank A) and *Praia da Base* (or Bank B) (Figure 1), where the clam is fished.

Anomalocardia brasiliana is found in calm waters with sandy-muddy sediments, where it burrows superficially, being considered an eurythermic, eurihaline and fast-growing species (Boehs, Absher & Cruz-Kaled 2008; Mouëza, Gros & Frenkiel 1999). These animals are a source of animal protein and income for the inhabitants of the RESEX (Pezzuto & Echternacht 1999; Souza 2007). In 2005, a total of 888.6 tons of clams with a size greater than 20 mm (97% of the animals) were extracted by fishermen at the Pirajubaé RESEX (Pezzuto & Souza 2015).

In February 2015, a massive mortality of more than 90% of the population of *A. brasiliana* was reported by fishermen from the reserve in the two shallows, Bank A and Bank B (Figure 1), as reported by Pezzuto (2017). This massive mortality event had a profound impact on the local community. Studies carried out by Abrahão et al. (2017) and Sampaio (2018) showed that the natural stock of this clam at the RESEX has not yet recovered. The presence of pathologies in the clams of Bank A (Figure 1) of the Pirajubaé RESEX between April 2017 and February 2018 was evaluated by Fortunato (2018), who observed the absence of parasites that could have caused the massive mortality.

In recent years, several studies have sought to elucidate the effect of climate change on the ecology of bivalve populations (Beukema, Dekker & Jansen 2009;

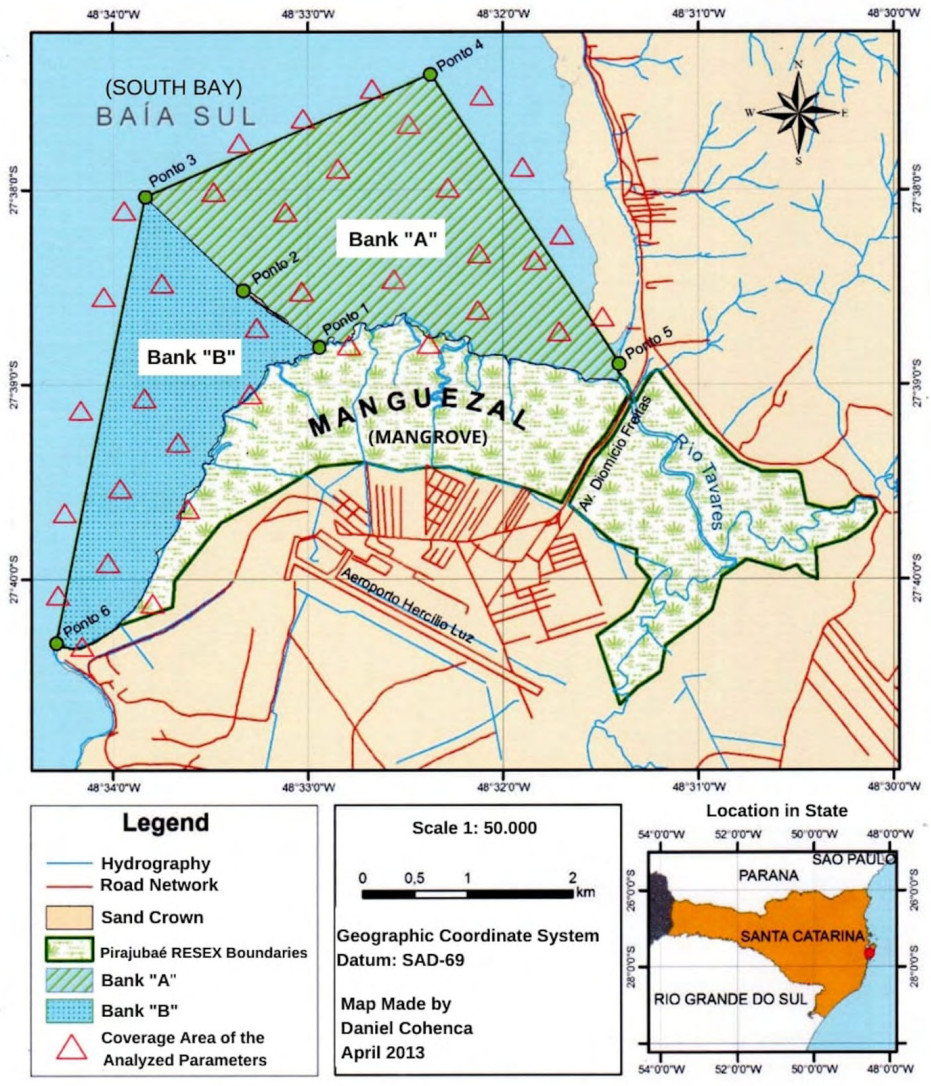

Figure 1 Pirajubaé Marine RESEX area, highlighting the two shallows (Bank A and Bank B) and the approximate coverage area of the parameters analyzed in this study (adapted from ICMBio 2013).

Freitas et al. 2007; Kaustuv, Jablonski & Valentine 2001; Philippart et al. 2003; Waldbusser et al. 2015). This change encompasses several factors such as changes in temperature and precipitation levels compared to historical averages. The temperature is an important factor in studies with bivalves. *Anomalocardia brasiliana* physiological processes related to temperature and/or climate seasons, such as reproduction (Corte 2015; Lagreze-Squella et al. 2018), storage of energy in the form of glycogen (Aveiro et al. 2011) and physiological rates (filtration and ingestion rates) (Lavander et al. 2014), have already been studied.

Salinity is one of the main environmental factors that order the horizontal distribution of marine invertebrates that lives in tropical estuaries, including *A. brasiliana* (Lima et al. 2009). Precipitation is an important factor in regions of fishery or aquaculture of marine bivalves, where the occurrence heavy rain period can reduce the salinity of the water, either by the input of rainwater or water from the rivers that flow into the region that could compromise water quality.

Considering the importance of the clam *A. brasiliana* for the local community, this study evaluated a series of climate data on air temperature, precipitation and global solar radiation, and environmental data on lowest day tides in years before and after the event of massive mortality of *A. brasiliana* at the Pirajubaé RESEX in 2015.

2 Materials and Methods

In this study, daily climate and environmental data of the months of November, December, January and February in the five years that preceded the massive mortality event (2010, 2011, 2012, 2013 and 2014), beginning in November of 2010; in the year of the event (2015); and in the two subsequent years (2016 and 2017) were collected.

Climate data of air temperature (n=842; °C) and precipitation (n=842; mm) of the coordinates 27°22'–27°50'S and 48°205'–48°35'W were obtained from the meteorological reanalysis Modern-Era Retrospective analysis for Research and Applications, Version 2 (MERRA-2).

Global solar radiation data (GSR; n=600; kJ/m²) for coordinates 27°36'S and 48°36'W during the years 2012 to 2017 were obtained from the National Institute of Meteorology (*Instituto Nacional de Meteorologia* - INMET) database, which provides the daily data per hour of the radiation accumulated throughout the day; however, data for 2011 (November and December) and 2012 (January and February) were not available.

The tide data (n=842; m) for the coordinates 27°35'16" S and 48°33'25" W were obtained from the website of the National Institute for Space Research (*Instituto Nacional de Pesquisas Espaciais* - INPE; http://ondas.cptec.inpe.br). For tide data, daily "lowest day tide" data were used since the organisms could be exposed to physiologic stress (example: air exposure, high temperature in sunny days, and others) during these tides.

Two analyzes with the data of climate parameters (air temperature, precipitation and radiation) and with the environmental parameter (lowest day tides) were performed: the first, with data from November and December of the year 2014 and January and February of the year 2015 (summer season), and the second with the data from the same months between 2010 and 2017, respectively. The normality and homoscedasticity of the residues were analyzed using the Shapiro-Wilk and Levene tests, respectively. Parametric data of air temperature were analyzed by Analysis of Variance (ANOVA) and Tukey's test, and non-parametric data of precipitation, radiation and tides were analyzed by Kruskal-Wallis test using the R Studio software.

3 Results and Discussion

3.1 Air Temperature

During the study period, the air temperature (Figure 2) ranged from 37.4°C (December 26, 2013) to 22.0ºC (December 23, 2014), with monthly averages of 29.8 ± 3.36°C and 28.3 ± 3.28°C in December 2013 and 2014, respectively. In 2015, the average temperature in January (29.4 ± 3.6ºC) was significantly higher ($p<0.05$) than in November (26.39 ± 1.79°C). However, no difference was observed between 2015 and the others analyzed years.

The data indicate that the greatest temperature variation in 2015 occurred between December 23, 2014 (22.0°C) and January 12, 2015 (34.7°C), with a difference of 12.7°C in a period of 20 days. In the summer period, Monteiro (2001) reported the occurrence of tropical air masses in Santa Catarina, with minimum temperatures around 20°C and maximum temperatures generally exceeding 30°C. Higher temperatures occur when a cold front approach the state, when they reach approximately 33°C in areas close to the coast.

In the year that highest air temperature (37.4°C on December 26, 2013) was registered, the fishermen from RESEX report no occurrence of clams massive mortality event, suggesting that the air temperature has not influenced the occurrence of massive mortality event in 2015. Air temperature observed in the RESEX during the studied period seems not to affect clams survival. Clams are bivalves with the capacity to resist temperature variations, since they are eurythermic organisms (Schaeffer-Novelli 1976) and to form natural stocks, with significant biomass, in habitats with high

temporal temperature variability (Pezzuto & Echternacht 1999). However, data of seawater temperature at the place of clam mortality event are needed for a better understanding the mortality event.

3.2 Precipitation

During the analyzed period (Figure 3), rainfall ranged from 0 mm on different days of the study period to 39.0 mm on January 10, 2011. Two months before massive mortality event in February 2015 rainfall was low, with mean of 2.48 ± 5.98 mm in December 2014 and 1.19 ± 1.67 mm in January 2015. There was no significant difference in precipitation between the months of 2015, as well as between 2015 and the same months of the other years of the study.

The data obtained in this study confirm the humid mesothermal climate of hot summers with rainfall well distributed throughout the year. During the summer, the heat intensity associated with high humidity levels favors the formation of a tropical convection, with highly developed cloud bands of the cumulonimbus type, which result in rain showers, mainly in the afternoon (Monteiro 2001).

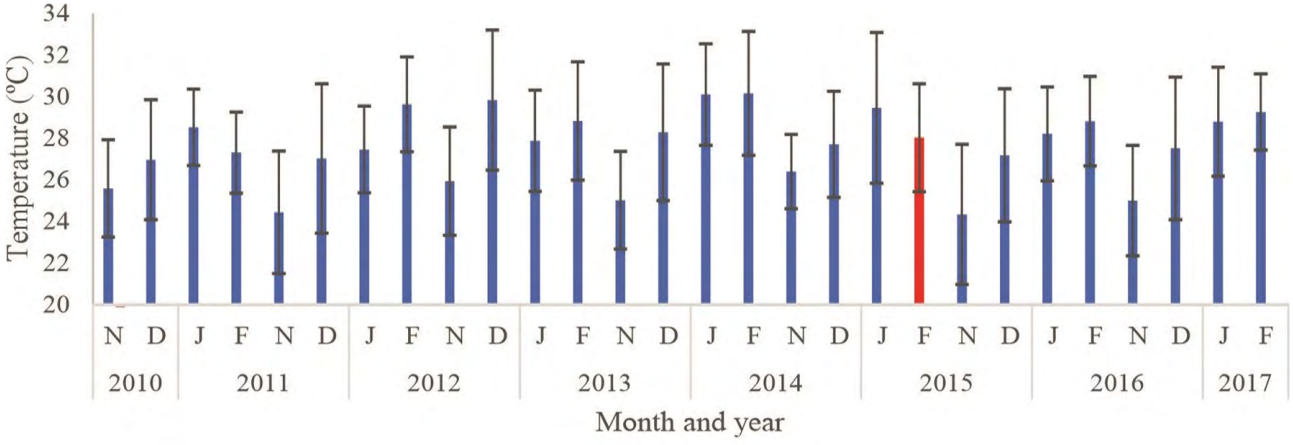

Figure 2 Monthly averages of air temperature (°C) in the South Bay region of Florianópolis in the months of November (N), December (D), January (J) and February (F) from 2010 to 2017. The red bar in the graph indicates the month of massive mortality of clams in the Pirajubaé Marine RESEX occurrence. Data obtained from the MERRA-2 meteorological reanalysis.

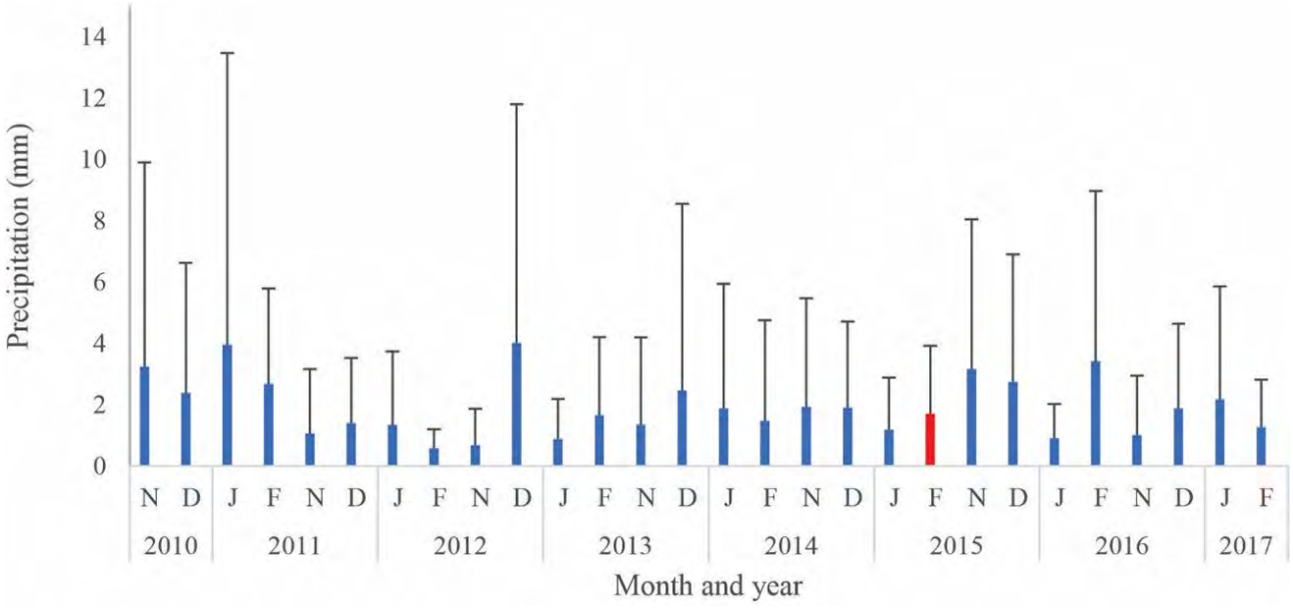

Figure 3 Monthly rainfall averages (mm) in the South Bay region of Florianópolis in the months of November (N), December (D), January (J) and February (F) from 2010 to 2017. The red bar in the graph indicates the month of occurrence of massive mortality of clams in the Pirajubaé Marine RESEX. Data obtained from the MERRA-2 meteorological reanalysis.

Populations of *A. brasiliana* can suffer high mortality in periods of high rainfall (Mouëza, Gros & Frenkiel 1999). The analysis of rainfall data between 2015 and the other years suggests that rainfall is not related to the causes of the event of massive mortality of clams, nor has it interfered with the lack of recovery of the natural stock of *A. brasiliana* in Pirajubaé Marine RESEX throughout the years, as reported by Sampaio (2018).

3.3 Global Solar Radiation

Global solar radiation during the period analyzed in this study (Figure 4) ranged from 32,343 kJ.m^{-2} (December 17, 2014) to 2,848 kJ.m^{-2} (January 5, 2014). Global solar radiation in December 2014 and January 2015 (21,788.34 ± 6.925.35 kJ.m^{-2} and 21,984.45 ± 6,619.68 kJ.m^{-2} mm, respectively) was no different significantly from February 2015 (19,720.01 ± 6.007.95 kJ.m^{-2}). Also, there were no significant differences in radiation between the months of 2015, and between 2015 and the other analyzed years.

These data show that radiation values in the years prior to the mortality event (2015) were maintained, which corroborates Monteiro (2001), who states that the large volume of rain in this summer season hardly affects the number of hours of insolation, since the isolated cumuliform clouds are predominant and intensify during the afternoon.

Radiation analysis showed not affect the clams mortality in February 2015. Narchi (1972) observed that clams quickly burrow into the sediment during low tides, reducing the risks of thermal shock and desiccation, in addition to being capable of horizontal mobility, allowing migrations in the intertidal ranges to areas with less environmental adversity.

3.4 Lowest Day Tides

The lowest day tides during the period of this study (Figure 5) ranged from 0.8 m (November 8, 2011) to 0 m (November 3, 2015; November 11 and 12, 2017). Lowest day tide in December 2014 and January 2015 (0.39 ± 0.10 m and 0.37 ± 0.09 m, respectively) was no different significantly from February 2015 (0.31 ± 0.10 m). Also, there were no significant differences in tide values between the months of 2015, as well as between the months of 2015 and the other years analyzed.

The Pirajubaé RESEX, an open environment inside a bay, presents low tide levels mainly influenced by the action of the gravity of the Moon and, to a lesser extent, of the Sun.

In lagoon or inland marine environments, winds are the third factor to influence the tides during the passage of cold fronts, which can cause a rise in the water level in coastal regions and propagate into the estuary, influencing the estuarine dynamics (Pugh 2004).

In this sense, the tides could influence the massive mortality event if a sequence of low super tides occurred, as long as they were low enough to expose the shallows to the air, where the natural stocks of clams are found in the RESEX, a fact that was not observed in the present study. Deleterious levels of physiological stress due to temperature and anoxia (Gonzalez & Camacho 1984; Guillou & Tartu 1994) can

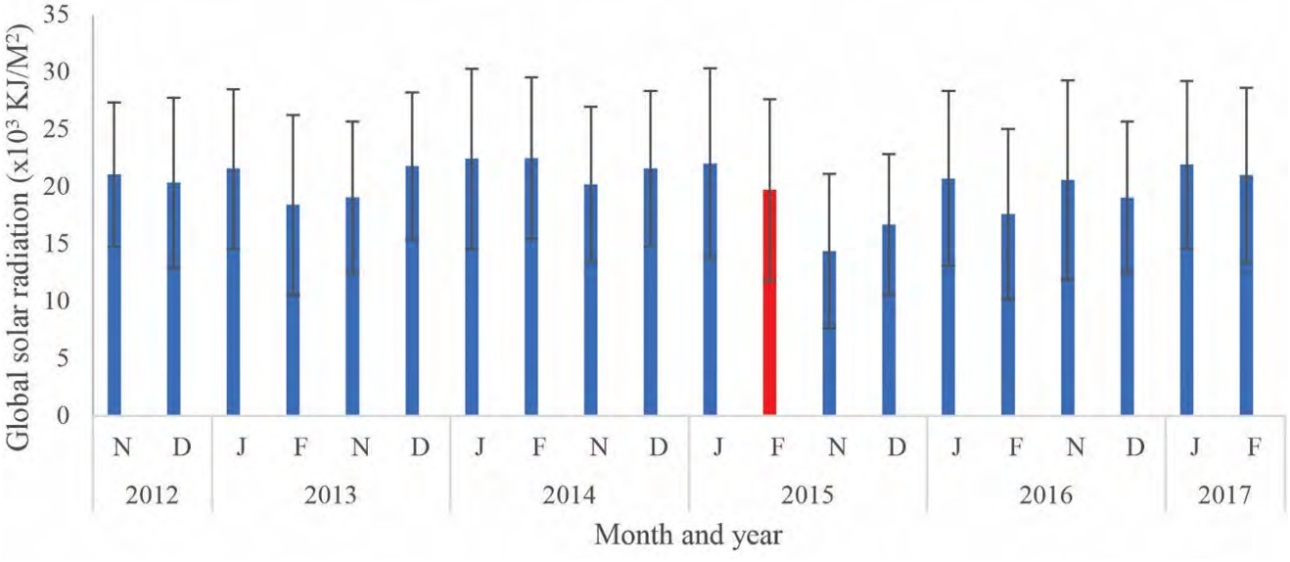

Figure 4 Monthly averages of global solar radiation (kJ/m^2) in the region of Florianópolis in November (N), December (D), January (J) and February (F) from 2012 to 2017. The red bar in the graph indicates the month of occurrence of massive mortality of clams in the Pirajubaé Marine RESEX. Data obtained from INMET database.

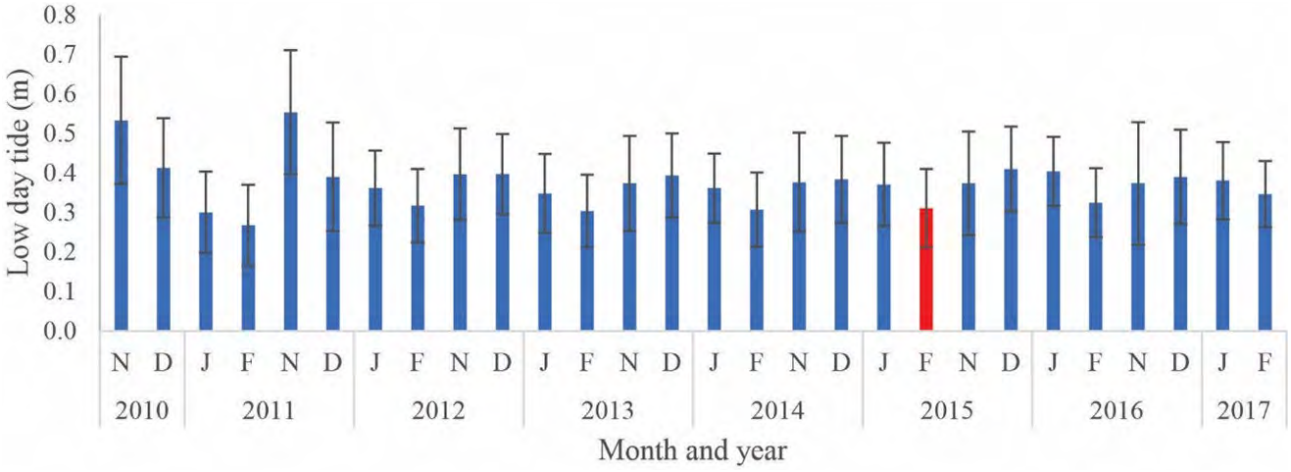

Figure 5 Monthly averages of lowest day tides for the region of Florianópolis in the months of November (N), December (D), January (J) and February (F) from 2010 to 2017. The red bar in the graph indicates the month of occurrence of massive mortality of clams in the Pirajubaé Marine RESEX. Data extracted from the website http://ondas.cptec.inpe.br/

affect shellfish survival. Thus, it is suggested to monitor the exposure time of clams to the air in the RESEX shallows.

Based on the analyzed parameters (air temperature, precipitation, global solar radiation and lowest day tide), no changes that could be related to the occurrence of massive mortality of clams in February 2015 were observed. Likewise, this analysis indicates that there is no relationship between the parameters studied and the absence of recovery of the natural stock of these organisms, as reported by Sampaio (2018).

Since no relationship was observed between the factors analyzed and the mortality event, it is necessary to analyze other parameters, such as the presence of organic and inorganic contaminants, pathologies and water temperature. In this sense, parasitism may be one of the biotic factors responsible for the dynamics of bivalve metapopulations in general, since repopulation, larval dispersal and the recruitment dynamics in bivalves allude directly to the concept of metapopulations (Strasser 2008).

Fortunato (2018) evidenced the absence of parasites, among the analyzed pathologies, that could cause massive mortality of these animals. Studies on other parasites are needed, as well as the evaluation of the presence of viruses and bacteria through molecular biology. As the RESEX is an environment with low water circulation and exposed to human action, it is necessary to establish a water quality monitoring program in the reserve, which includes, for example, the assessment of salinity, temperature, seston and presence of xenobiotics.

Adding to all these facts, the perception of the fishermen in relation to hotter summers can be included, as a phenomenon that is not based on the observed data, though it could be justified by a greater thermal sensation caused by some environmental parameter not measured in this study. Thus, to provide better management of the Pirajubaé Marine RESEX area and to have information in the case of future new massive mortally events in the clam natural stock, we suggested a systematic collection and monitoring of clam production and water quality parameters, as contaminants, SESTON and seawater temperature.

4 Conclusions

In conclusion, the parameters air temperature, precipitation, global solar radiation and lowest day tide during the summer of 2014/2015 showed no significant changes that could cause the massive mortality of clam *A. brasiliana* in February of 2015. Also, these parameters showed no significant changes that could interfere in the clam *A. brasiliana* stock recovery.

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Author contributions

Eduardo Cargnin-Ferreira: Conceptualization; Formal analysis, Methodology; Writing review and editing the original draft; Supervision; Visualization. **Ronnie Alexandre Moreira Vaquero:** Conceptualization; Formal analysis; Methodology; Writing – original draft; Visualization. **Simone Sühnel:** Conceptualization; Formal analysis, Methodology; Writing review and editing the original draft; Co-supervision; Visualization.

Conflict of interest

The authors declare no potential conflict of interest.

Data availability statement

Reference datasets for air temperature and precipitation can be downloaded from: https://daac.gsfc.nasa.gov/. Reference dataset for Global solar radiation is available on request from the National Institute of Meteorology (Instituto Nacional de Meteorologia - INMET) database. Tide dataset can be downloaded from: http://ondas.cptec.inpe.br.

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