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VARIAÇÃO SAZONAL DAS ASSEMBLEIAS DE FORAMINÍFEROS BENTÔNICOS DO SISTEMA LAGUNAR DE SAQUAREMA - RJ

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VARIAÇÃO SAZONAL DAS ASSEMBLEIAS DE FORAMINÍFEROS BENTÔNICOS DO SISTEMA LAGUNAR DE SAQUAREMA E DOS PARÂMETROS QUE CONDUZEM A SUA DISTRIBUIÇÃO

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“Sem saber que era impossível, ele foi lá e fez. “

- Murad, João Batista Sérgio

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RESUMO

As lagoas costeiras têm sido utilizadas pelas populações humanas para o desenvolvimento de cidades, indústrias e outras atividades que promovem o estresse ambiental. As descargas excessivas de nutrientes de efluentes domésticos e industriais, combinadas com o escoamento urbano e agrícola, intensificam o processo de eutrofização, considerado o principal fator de estresse em ambientes costeiros. Infelizmente, as áreas mais poluídas são muitas vezes naturalmente estressadas, o que dificulta a caracterização das mudanças em naturais ou antropogênicas. Neste contexto, a compreensão das oscilações sazonais representa um pré-requisito para garantir um monitoramento ambiental correto e confiável. A abundância e a composição da comunidade bentônica varia em curtos períodos de tempo ao longo do ano em resposta à reprodução sazonal específica e às mudanças ambientais. O presente estudo investiga a variação sazonal das assembleias de foraminíferos bentônicos durante o ciclo de maré no inverno (I) e verão (V) no Sistema Lagunar de Saquarema (SLS). Foram identificados, 29 e 19 espécies no verão e inverno, respectivamente. A *Ammonia tepida* foi dominante em ambas as estações seguidas por *Ammonia parkinsoniana* e *Cribroelphidium excavatum*. No entanto, não foi possível detectar qualquer correspondência entre V e I através da análise de agrupamento, uma vez que existem espécies que só apareceram no W e vice-versa. A presença de *Bulimina patagonica* e *Miliolinella antartica* apenas em amostras de V pode revelar a influência do fenômeno da ressurgência próximo a costa. O SLS se mostrou homogeneo durante o inverno onde os parâmetros variaram muito pouco, Porém durante o verão apresentaram uma grande oscilação. A análise DCA nos permitiu relacionar as assembleias com os parâmetros abióticos que conduzem sua distribuição. As espécies calcáreas como *Adelosina carinatastriata*, *B. patagonica* e *M. antartica* foram principalmente influenciadas por valores elevados de oxigênio dissolvido e baixa temperatura, enquanto os aglutinnantes foram indicadores de um ecossistema mais confinado, uma vez que os valores de pH e salinidade foram os menores dentro do SLS. As análises atuais mostram que existe variação sazonal no SLS e que essa variação exerce maior influência sobre as comunidades foraminíferas bentônicas do que os impactos antropogênicos. Portanto, o presente estudo mostra a importância do estudo sazonal para programas de biomonitorição costeira.
Palavras-chave: foraminíferos bentônicos; dinâmica costeira; bioindicadores.

ABSTRACT

Coastal lagoons have long been attractive for human populations for the development of cities, industries and other activities that have promoted environmental stress. The excessive discharges of nutrients from domestic and industrial effluents, combined with urban and agricultural runoff intensify the eutrophication process, which is considered the main factor of stress in the coastal environments. Unfortunately, the most severely polluted areas are often naturally stressed and this makes difficult to separate the natural or anthropogenically induced changes. In this context, the understanding of the seasonal oscillations represents a prerequisite to ensure a correct and reliable environmental monitoring. The abundance and composition of benthic foraminiferal assemblage vary over short time periods throughout the year in response to both specific-seasonal reproduction and environmental changes. The present study investigates the seasonal variation of benthic foraminiferal assemblages during the tide cycle in Winter (W) and Summer (S) on the Saquarema Lagoon System (SLS). In the study area, 29 and 19 living foraminiferal species are identified in S and W, respectively. *Ammonia tepida* is dominant in both seasons followed by *Ammonia parkinsoniana* and *Cribroelphidium excavatum*. It is not however possible to detect any correspondence between S and W assemblages through the cluster analysis, since there are species that only appeared in the W and vice versa. The presence of *Bulimina patagonica* and *Miliolinella antartica* only in S samples might reveal the influence of upwelling in the coast. The SLS shows a strong seasonality where parameters remain quite homogeneous in W but exhibit great oscillation in S. The DCA analysis allows us to relate the benthic foraminiferal assemblages to the abiotic parameters that drive their distribution. Calcareous species such as *Adelosina carinatastriata*, *B. patagonica* and *M. antartica* are mostly influenced by high values of dissolved oxygen and low temperature, while the agglutinated are indicators of more confined lagoon ecosystem since the values of pH and salinity were the lowest within the SLS. The present analyses explain that the seasonal variation in the SLS exerts a greater influence on the benthic foraminiferal assemblages than the anthropogenic impacts and shows the importance of seasonal study for coastal biomonitoring programme.

KEY WORDS: benthic foraminifera; coastal lagoon dynamic; bioindicators.

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1 INTRODUÇÃO

Os foraminíferos são organismos unicelulares, heterotróficos, pertencentes ao Reino Rhizaria, Filo Foraminifera (Jones, 2014). Produzem uma substância especial, a tectina, que formam carapaças denominadas testas ou tecas e podem possuir várias formas e tamanhos (Boltovskoy, 1965; Bignot, 1988). Estes envoltórios podem ser de dois tipos: aglutinantes, as quais agregam partículas variadas como grãos de areia, fragmentos calcários de outras carapaças ou conchas, e espículas de esponja, que são cimentadas sobre uma camada orgânica; e calcários, mais comuns, formadas por carbonato de cálcio (principalmente calcita), sendo estas divididas de acordo com a estrutura das paredes em: microgranulares (já extintos), porcelânicas e a hialina (Boltovskoy, 1965; Boersma, 1978; Sen Gupta, 1999).

Estes organismos também podem ser classificados quanto ao seu modo de vida: bentônicos (quando vivem sobre ou dentro do sedimento) ou plantônicos (quando vivem flutuando na zona fótica). Eles estão presentes em todos os ambienteis marinhos desde águas salobras até as regiões mais profundas dos oceanos (Scott & Medioli, 1980; Murray, 1991).

As zonações de foraminíferos estão frequentemente relacionados a fatores abióticos como limites naturais de massas d´água, mudanças sazonais, correntes, processos biogeoquímicos e fatores bióticos como competição, predação, entre outros. (Eichler et al., 2006). Estes padrões de distribuição das assembléias de foraminíferos têm sido utilizados com sucesso em interpretações ambientais e paleoambientais, uma vez que apresentam elevada frequência, diversidade, abundância, curto ciclo de vida e bom potencial de preservação em sedimentos marinhos (Boltovskoy, 1965; Hannan & Rogerson, 1997).

Os Foraminíferos bentônicos têm sido largamente empregados como ferramenta para reconstrução de ambientes marinhos e costeiros desde o Cambriano até o Recente. A grande variabilidade desses organismos e sensibilidade ao ambiente permite que eles sejam bioindicadores ambientais, uma vez que respondem rapidamente às mudanças de origem natural ou antropogênica.

Os primeiros estudos sobre impactos ambientais, utilizando foraminíferos como bioindicadores foram realizados por Resig (1960) e Watkins (1961). Entretanto, alterações na composição das associações de foraminíferos devido a impactos ambientais já haviam sido mencionadas anteriormente por Zalesny (1959). A partir de então, muitos outros estudos foram realizados com o intuito de avaliar e monitorar possíveis impactos ambientais devido à disposição de esgotos domésticos e industriais em ambientes estuarinos e marinhos, construções de portos, derrame de petróleo e aportes de metais pesados (Madeira & Falcetta, 1974; Sá Brito & Vicalvi, 1982; Yanko et al., 1994; Alve, 1995; Armynot du Châtelet et al., 2004; Burone et al., 2006; Romano et al., 2008).

2. Foraminiferos como indicadores ambientais em regiões lagunares

Em lagunas costeiras os estudos aplicando as assembleias de foraminíferos como ferramenta ambiental iniciaram com Murray (1970) na laguna de Abu Dhabi no Golfo Pérsico onde foi possível identificar e caracterizar ecologicamente assembleias vivas de foraminíferos em diversos subambientes da laguna como corais, grama marinha e no sedimento de fundo. Woo et al. (1997) utilizou a comunidade de foraminíferos bentônicos para avaliar os estresses iniciais que afetam a qualidade ambiental. Em 1999, Bernhard & Sen Gupta utilizou a microfauna de foraminíferos para caracterizar alterações ambientais, incluindo eutrofização por atividade antrópica.

Muitos estudos têm aplicado a microfauna de foraminíferos bentônicos na identificação do impacto ambiental na costa oeste e mediterrânea da Europa. Frontalini e Coccioni (2008) utilizaram as assembleias de foraminíferos encontradas na costa da Itália para monitorar a contaminação por metais pesados. Frontalini et al. (2009) utilizou foraminíferos como bioindicadores de poluição por elementos traço na lagoa de Santa Gila, também na Itália.

Em Portugal, Martins et al. (2010) associou os efeitos ecológicos de assembleias de foraminíferos expostos a metais pesados na Ria de Aveiro. Martins et al. (2013) associou as assembleias de foraminíferos diretamente com os metais pesados como uma ferramenta para medir a qualidade do sedimento da região.

Na Nova Caledônia, Debenay et al. (2009) identificou e caracterizou as assembleias de foraminíferos que sobreviviam em regiões de cultivo de camarão. Debenay et al. (2015) utilizou as assembleias estudadas anteriormente como bioindicadores de poluição causadas por efluentes da criação de camarão em manguezais e reparou que mesmo nas regiões mais impactadas existiam assembleias vivas.

Na Tunísia, Martins et al. (2015) realizaram um estudo relacionando a microfauna de foraminíferos bentônicos com os parâmetros físico-químicos da água na laguna de Bizerte, e pode constatar que as assembleias de foraminíferos responderam as condições oceanográficas e a concentração de elementos traço neste ambiente.

2.2 – Estudos realizados no Brasil

No Brasil grande parte dos estudos sobre foraminíferos se concentram na região sul e sudeste. Os trabalhos de Closs (1962 e 1964) dividiram a lagoa dos Patos em seis compartimentos, estabelecidos pela variação da fauna de foraminíferos e da salinidade: zonas pré-marinha, submarinha, pré-mixohalina, mixohalina, pré-limnica e limnica. Outros trabalhos realizados no sul do Brasil seguiram os mesmos critérios para a divisão de ambientes confinados e semiconfinados (Closs & Madeira, 1962, 1967, 1968, 1971; Closs & Medeiros, 1965, 1967; Madeira & Falcetta, 1974).

Na lagoa da Conceição, localizada na ilha de Florianópolis, Debenay et al. (1998) utilizou as assembleias de foraminíferos para identificar a influência marinha dentro do corpo lagunar e também as regiões com maior concentração de matéria orgânica.

Na Lagoa Rodrigo de Freitas no Rio de Janeiro, Vilela et al. (2011) coletou foraminíferos ao longo de 44 estações para identificar o impacto das concentrações de metais pesados e de matéria orgânica sobre microfauna.

Debenay et al. (2001) realizou uma amostragem ao longo de 93 estações de coleta na lagoa de Araruama para identificar as assembleias de foraminíferos e os processos hidrodinâmicos os quais estão envolvidas, e pode constatar que as testas sofrem deformações ou má-formação devido à grande variação na salinidade.

Bonfim et al. (2012) analisou 15 amostras a fim de realizar a caracterização ecológica do complexo lagunar Maricá e pode observar que a região é dominada por espécies de foraminíferos aglutinantes (*Miliammina fusca*, *Trochammina inflata*, *Ammobaculites dilatatus* e *Arenoparrella mexicana*) que são indicadoras de ambientes costeiros parálicos e com baixa salinidade. Apesar de o ambiente estar sujeito a poluição antrópica, foi possível constatar que ainda não afetam gravemento o ecossitema bentônico.

Estudos como os de Raposo et al (2016) e Belart et al (2017) são os primeiros no estado do Rio de Janeiro a abordar somente a assembleia viva de foraminíferos bentônicos. Esses estudos são fundamentais para compreensão e caracterização da microfauna bentônica, pois os que utilizam assembleia total (vivos e mortos) podem levar a interpretações equivocadas, uma vez que quando esses organismos morrem podem sofrer transporte e dissolução e quebra das testas causadas pela hidrodinâmica e acidez do sedimento. Em ambos os estudos, *Ammonia tepida*, *Ammonia parkinsoniana* e *Cribroelphidium* spp. foram encontrados como espécies dominantes. Os foraminíferos de testas aglutinantes ficaram restritos a regiões mais confinadasd o que contradiz os resultados Bruno (2013) que utilizou assembleia total.

3 OBJETIVO

3.1 Objetivo Geral

O presente estudo tem como objetivo caracterizar as comunidades de foraminíferos bentônicos do Sistema Lagunar de Saquarema associados a parâmetros físico-químicos em duas estações extremas (chuvosa e seca) para desenvolver um modelo microfaunístico e sedimentológico que possa ser utilizado em estudos de caracterização e monitoramento ambiental e que possam servir de base para os modelos de variação do nível relativo do mar do Quaternário.

3.2 Objetivos Específicos

- Identificar taxonomicamente a biocenose de foraminíferos no inverno e no verão nas lagunas que compõe o Sistema lagunar de Saquarema;
- Caracterizar ecologicamente a comunidade de foraminíferos bentônicos e verificar sua distribuição a partir de descritores ecológicos e análises estatísticas;
- Caracterizar a dinâmica sazonal da comunidade de foraminíferos e seu potencial para o monitoramento ambiental e para os estudos paleombientais;

CAPITULO i

Artigo para ser subtido à *Estuarine Coastal and Shelf Science:*

EXPLORING THE SEASONAL DYNAMIC WITHIN THE BENTHIC FORAMINIFERAL BIOCOENOSIS IN SAQUAREMA LAGOON SYSTEM, RIO DE JANEIRO – BRAZIL

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ABSTRACT: Coastal lagoons have long been attractive for human populations for the development of cities, industries and other activities that have promoted environmental stress. The excessive discharges of nutrients from domestic and industrial effluents, combined with urban and agricultural runoff intensify the eutrophication process, which is considered the main factor of stress in the coastal environments. Unfortunately, the most severely polluted areas are often naturally stressed and this makes difficult to separate the natural or anthropogenically induced changes. In this context, the understanding of the seasonal oscillations represents a prerequisite to ensure a correct and reliable environmental monitoring. The abundance and composition of benthic foraminiferal assemblage vary over short time periods throughout the year in response to both specific-seasonal reproduction and environmental changes. The present study investigates the seasonal variation of benthic foraminiferal assemblages during the tide cycle in Winter (W) and Summer (S) on the Saquarema Lagoon System (SLS). In the study area, 29 and 19 living foraminiferal species are identified in S and W, respectively. *Ammonia tepida* is dominant in both seasons followed by *Ammonia parkinsoniana* and *Cribroelphidium excavatum*. It is not however possible to detect any correspondence between S and W assemblages through the cluster analysis, since there are species that only appeared in the W and vice versa. The presence of *Bulimina patagonica* and *Miliolinella antartica* only in S samples might reveal the influence of upwelling in the coast. The SLS shows a strong seasonality where parameters remain quite homogeneous in W but exhibit great oscillation in S. The DCA analysis allows us to relate the benthic foraminiferal assemblages to the abiotic parameters that drive their distribution. Calcareous species such as *Adelosina carinatastriata*, *B. patagonica* and *M. antartica* are mostly influenced by high values of dissolved oxygen and low temperature, while the agglutinated are indicators of more confined lagoon ecosystem since the values of pH and salinity were the lowest within the SLS. The present analyses explain that the seasonal variation in the SLS exerts a greater influence on the benthic foraminiferal assemblages than the anthropogenic impacts and shows the importance of seasonal study for coastal biomonitoring programme.

KEY WORDS: benthic foraminifera; coastal lagoon dynamic; bioindicators.

Introduction

Transitional waters-bodies such as coastal lagoons with narrow connections to the sea are typically characterized by strong seasonal cycles resulting from periodical rainfall and wind-forcing events that affect the circulation and the residence time of water (Kjerfve, 1994; Prado et al., 2014).

Coastal areas have traditionally been occupied by human civilization for the development of cities, industries and other activities promoting environmental stress (Agardy and Alder, 2005). The excessive discharges of nutrients from domestic and industrial effluents, combined with urban and agricultural runoff determine the enrichment of organic and inorganic nutrients in paralic ecosystems (Silva *et al*., 2013; Borja *et al* 2012). These inputs intensify the eutrophication process, which is considered the main factor of stress in the coastal and marine environments (Meyer- Reil & Koster, 2000).

Foraminifera is commonly used as bioindicators because they have a short life cycle, which provides quick response to environmental changes, and are abundant, largely diversified, with a widespread distribution and specific ecological requirements (Murray, 2006; Laut *et al*., 2016). The distribution of benthic foraminifera is controlled by many factors, such as temperature, salinity, dissolved oxygen, sediment grain size (Murray, 1991,2001) and changes in the quality and amount of nutrients (Murray, 2006). Sediment characteristics strongly influence their distribution: they are more abundant in finer sediments but they are also influenced by sediment pollution (Bhalla & Nigam, 1986; Alve & Olsgard, 1999: Frontalini & Coccioni, 2007; Martins *et al*., 2013, 2015a). Benthic foraminifera are widely used as bioproxies for coastal environmental monitoring across a wide variety of marginal environments such as estuaries (Alve 1995, Luan & Debenay 2005, Bhattacharjee et al. 2013), marshes (Gehrels & Newman 2004, Horton & Murray 2007) and lagoons (Samir 2000, Martins et al. 2013). However, the accuracy of such proxies is susceptible to seasonal variations in the assemblage structure. Complexities in identifying seasonal changes in benthic foraminiferal assemblages inhabiting coastal marginal habitats arise from diurnal variations in tidal regime (Murray 2006). The effect of tide in shaping benthic foraminiferal communities is more pronounced in the intertidal zone (Horton et al. 2003, 2005, Horton & Murray, 2007). Subtidal assemblages are shaped by salinity and the supply of detrital food matter (Murray 2006, Papaspyrou et al. 2013), factors that are influenced by tidal shifting in the water table alongside seasonal changes. Coastal lagoons with limited connection to an open marine source may be considered as marginal environments, where foraminiferal assemblage dynamics can be observed with the near-absence of tidal variations over a substantial period of time.

The knowledge about lagunal foraminiferal biodiversity in the Brazilian southeast coast was based on total assemblages (Debenay et al., 1997 and 2001; Vilela *et al*., 2003; Duleba, 2004). These studies can lead to bias environmental interpretations because after death foraminiferal tests are exposed to taphonomic processes, such as transport, breaking and dissolving of carbonates.

The studies of Raposo *et al*. (2016) and Belart *et al*. (2017) were the only ones in Brazilian lagoons based exclusively on living assemblages. Both of them have considered a checklist of foraminiferal species without an ecological approach. However, the number of living species was lower than that in total foraminiferal assemblages implying possible seasonal differences and/or the occurrence of allochthonous taxa that might lead to wrong paleoenvironmental interpretations.

A study such as Sen and Bhadury (2016) in the Chilika lagoon - Bengal bay, suggest that the seasonal variation of the abiotic parameters can be reflected in the alteration of the benthic community since the abundance and composition of benthic foraminifera assemblage vary over short time periods throughout the year in response to both specific-seasonal reproduction and environmental parameters (Murray, 1991). Population dynamics and dissimilarities of biological nature (differences in turnover rate and seasonal alterations in standing stock) can cause significant divergences between foraminifera study (*e.g.*, Jorissen & Wittling, 1999; de Stigter *et al*., 2007; Duros *et al*., 2014).

The main goal of the present study is investigating the seasonal variation within the subtidal benthic foraminiferal assemblages of Saquarema Lagoon System during the summer (rain season) and winter (dry season) to generate an understanding about its dynamics in a stressed coastal habitat with a restrict tidal influence.

3- Material and Methods

Saquarema Lagoon System is located in Rio de Janeiro State, southeast Brazil, between the latitudes of 22°55′S and 22°56′S and longitudes of 42°35′ W and 42°29′ W (Fig. 1). The lagoon system covers an area of ~21.2 km^2 and extends for ~11.8 km along the coast; it has an average depth not greater than 2.0 m. SLS consists of four large connected lagoons: Urussanga (12.6 km^2), Jardim (2 km^2), Boqueirão (0.6 km^2) and Saquarema (6 km^2). Urussanga Lagoon is bordered by swamps to the north and receives fresh water from Mato Grosso (or Roncador), Tingui and Jundiá rivers. Jardim Lagoon, which is surrounded by swamps, receives the fresh water input from Seco River. Saquarema Lagoon receives the discharge of Bacaxá River and has a mangrove fringe on the northern bank (Bruno, 2013). The Boqueirão Lagoon has no inflowing rivers (Moreira, 1989).

The climate in the entire Rio de Janeiro State is warm and humid with a rainy summer season and a dry winter season. The average rainfall is between 1,000 and 1,500 mm/year (Barbieri and Coe-Neto, 1999). The climate in SLS is sub-humid, with prolonged periods of drought, and high temperatures (Carmouze and Vasconcelos, 1992). Climatic conditions are also influenced by Serra do Mato Grosso at the western side. The orographic processes of this mountain effect primarily the rivers that discharge into Urussanga Lagoon (Carmouze and Vasconcelos 1992). This lagoonal-coastal complex ecosystem is connected to the ocean through Barra Franca Channel. This channel is artificial with margins stabilized by stone blocks.

According to Instituto Brasileiro de Geografia e Estatística (IBGE, 2004), the human population of Saquarema grew 72.2% between 1990 (37,888 inhabitants) and 2001 (59,938 inhabitants). Despite including 31,623 households, 47.97% of them are not occupied most part of the year. In 2007, population of Saquarema increased for 62,174 inhabitants (IBGE, 2004), indicating a growth of about 24.6% since 2012. This uncontrolled urbanization surrounding Saquarema, coupled with the natural effects of silting in Barra Franca Channel, have effectively increased domestic sewage in the lagoon and intensified the environmental disturbance (Bruno, 2013). Studies such as Dias et al. (2017) indicated that the Urussanga and Jardim lagoons have higher values of organic matter, not necessarily of anthropic origin. Therefore, these are the regions with the greatest pollution potential within these lagoon systems.

Sampling Method

Fourty-three stations located through SLS were sampled in August of 2016 (winter) and January of 2017 (summer) always in tide of sizigia (Fig. 1). Each sampled station was georeferenced with a GPS (model GPSMAP® 64S). Physicochemical data such as salinity (Sal), temperature (T), dissolved oxygen (DO), pH, TDS (total dissolved solid) were obtained with a multiparameter probe model YSI 6600 V2 in water in low and high tides. The sediment samples were collected with a little box core aboard of a small ship. The first upper centimeter of sediment was recovered in triplicate and stained with Rose Bengal according to Schönfeld et al (2012).

Foraminiferal Analisys

Stained sediment samples were washed over sieves with mesh openings of 500 and 63 µm. The residual fraction in each sieve was dried at 50°C and the foraminiferal specimens were concentrated from the remaining sediment by flotation in trichloroethylene (Belart *et al*. 2017). All foraminiferal stained (living specimens) and unstained tests (dead specimens) were picked, identified, and counted under stereoscopic microscopic at 80x magnification. At least, 100 living individuals were counted per sample (Fatela & Taborda, 2002). The number of specimens found in the three replicates was therefore averaged. The generic taxonomical classification of Loeblich & Tappan (1987), and specific concepts of Boltovskoy *et al*. (1980), Debenay *et al*. (2002), and Martins & Gomes (2004) were followed. After identification, the names of species were checked using the World Register of Marine Species (WoRMS 2014). Diversity was calculated using the Shannon-Weaver (H’) index, expressed by the formula: $H' = \sum p_i \, Ln(p_i)$. The mean evenness (or homogeneity) was calculated by the formula: $J' = H' \, Ln(S)^{-1}$, using the software MVSP.

Tidal Influence analysis

To measure the amplitude of sizigia tide variation, 3 points were defined within the Saquarema Lagoon System where a millimetric ruler was placed (Fig. 1). The tide time was taken from the website of the Brazilian Navy based on data from the nearest port (Porto do Forno in Arraial do Cabo City).

Granulometric Analysis

Sediment samples used in this study were dried at ambient temperature for 48 hours, homogenized and quartered for separating 50 grams of material for grain size analysis. These samples were: 1) washed with distilled water to remove soluble salts; 2) treated with hydrochloric acid (HCl) and hydrogen peroxide (H_2O_2) for removal of carbonate and organic particles; 3) dried in an oven at 60 °C and; 6) sieved using a Ro-tap system (sieve shaker) with sieves of 1.00 mm; 0.50 mm and 0.063 mm. Remined Sediments smaller than 0.063mm (silt and clay) were weighed and the percet of mud in each sample was calculated.

Interpolation maps

The maps shaped with ArcMap 10.5 and the Spline with Barriers (SWB) tool were configured with cell size 15 and 0 of a smooth factor, for this study in accordance to Dias et al. (2017). The interpolation shows the spatial distribution of the parameters concentration inside the lagoon and spatial distribution of ecological indexes and foraminifera species. Coordinates are provided in WGS84 datum.

Statistical analysis

Only samples with foraminiferal number >100 in were considered for statistical analyses. Detrended Correspondence Analysis (DCA) was used to correlate the multiple environmental variables and their influence on ecological relationships and distribution assemblages in both seasons. DCA analysis was performed in PCord 5.0 Software and based on the Relative Euclidean Distance for calculation of variance coefficient. DCA analysis was based on the relative abundance of foraminifera species (Appendix 1), as well as the physicochemical parameters (pH, DO, salinity, Eh) and granulometric data such as sand, mud, carbonate and organic matter. Before the DCA analysis, these data were standardized to the square root of 0.5 to decrease the difference between the parameters scale.

Also in PCord 5.0 software a Q and R-mode Cluster Analysis (CA) using the relative abundance of all species identified (Appendix 1) and based on the Euclidian Distance with Ward Linkage was applied to order the stations in groups with similar characteristics.

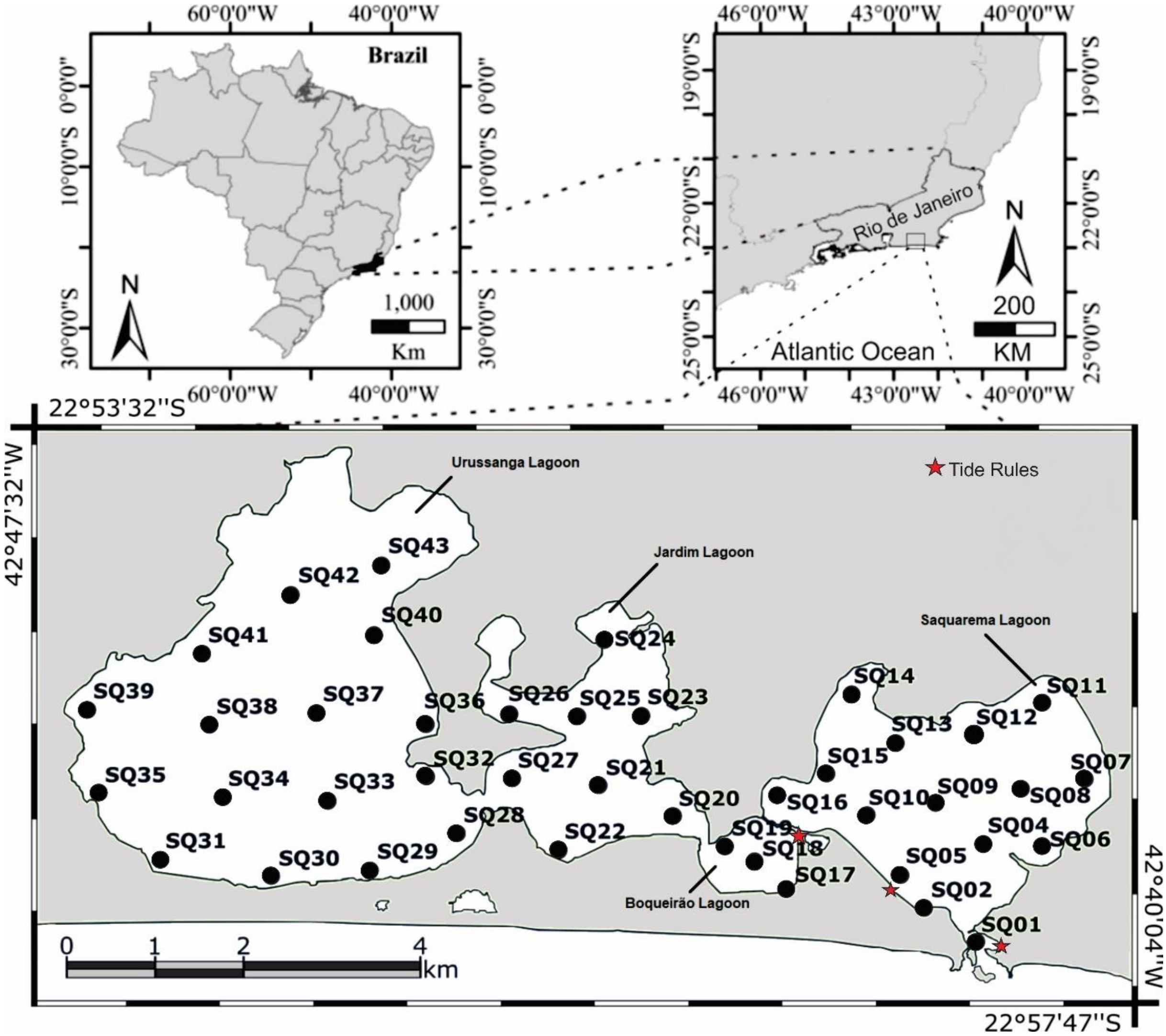

Figure 1 – Studies samples of Saquarema Lagoon System.

4-Results

4.1 Seasonal and tidal cycle

The largest tidal variation was measured at point 1 in the communication channel with the Atlantic Ocean (67 cm) while at point 3 only 3 cm was measured, indicating the low tide influence from this region. For that reason, the physico-chemical parameters of the stations SQ21 to SQ43 were only measured once.

For tidal variation, the results presented here take into account only the stations SQ01 to SQ20, which are on the influence of marine waters (Figure 1).

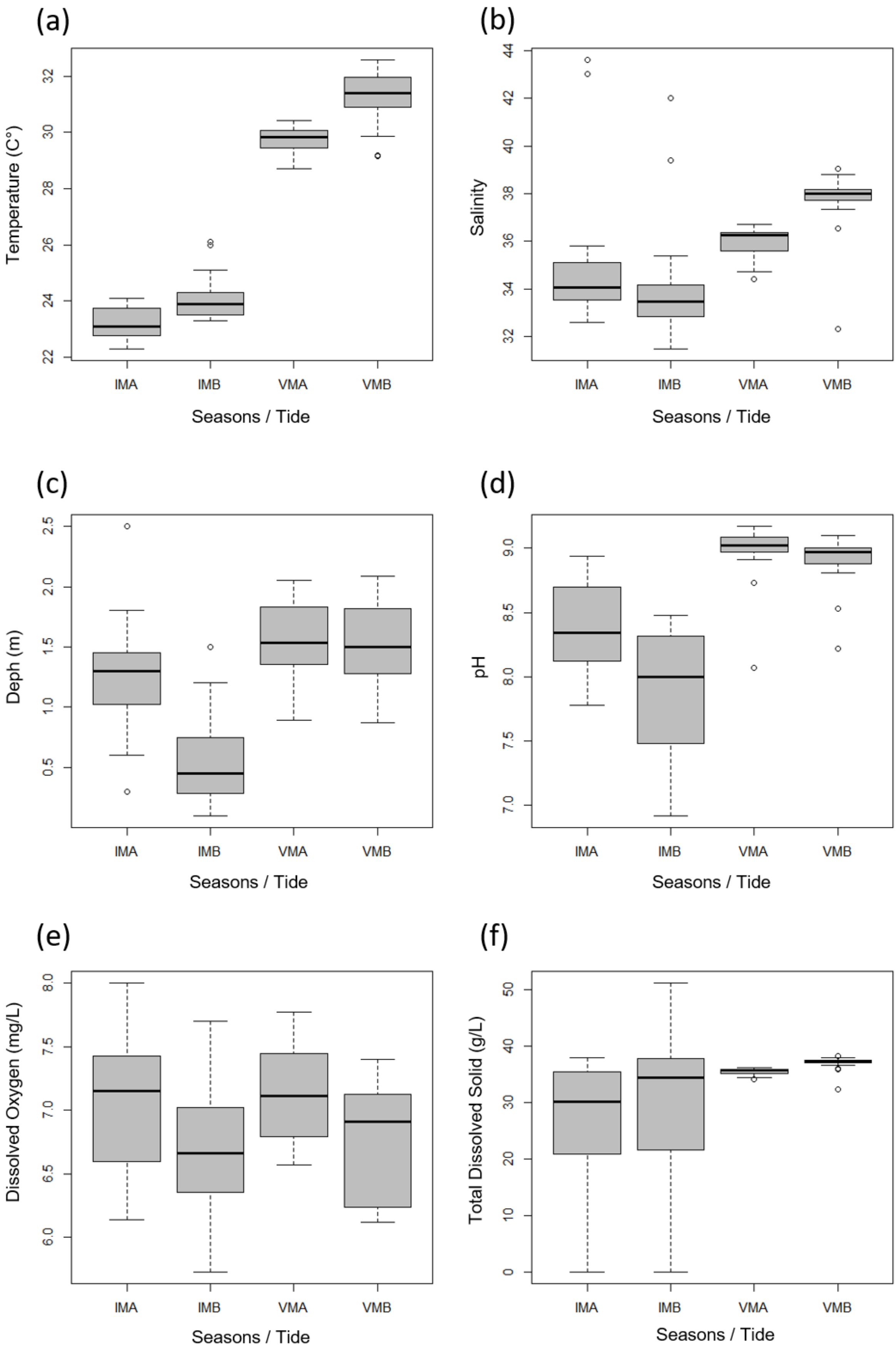

Figure 2 – Results of influence of tidal dynamics in the studied parameters. IMA- winter high

tide; IMB – winter low tide; VMA – summer high tide; VMB – summer low tide;

The results presented in figure 2 showed that there is great amplitude of parameters values between the seasons and tidal cycle. The highest temperature value was measured on summer in low tide (SQ15- 32.58 °C), while the lowest was measured on winter in high tide (SQ02 - 22.7 °C) (Fig. 2). Winter values ranged from 23.3 °C at SQ09 to 26.1 °C at SQ06, both at the Saquarema lagoon during low tide and ranged from 22.7 °C in SQ02 near to Barra Franca channel to 24.1 °C (SQ14) in north margin of Saquarema lagoon. The results for temperature showed that the average values among lagoons during the winter were 25.92 °C in Urussanga, 24.6 °C in Jardim, 23.87 °C in Boqueirão and 23.6 °C in Saquarema (Fig. 3), and on the Summer, were 31.2 °C in Saquarema, 31.65 °C in Boqueirão, 31.07 °C in Jardim and 29.35 °C in Urussanga (Fig. 3).

Overall, salinity values were higher in the summer, the highest value was measured on Summer Low Tide and the lowest was measured on winter low tide (Figure 2). The values on summer ranged from 23.6 in SQ39 in the north margin of Urussanga lagoon to 39.04 in SQ14 on the north of Saquarema lagoon, while the highest value of salinity on winter were found in Saquarema Lagoon (mean of 34.7) and the lowest were found in Urussanga lagoon (33.7) (Figure 3).

The depth values varied between the tide cycle only in winter, since the values remained constant and higher during the summer. The highest values were measured on Summer´s high tide while the lowest were measured on Winter´s low tide. On winter these values ranged from 0.1 m in SQ03 and SQ14 to 1.5 m in SQ01 in low tide, while in high tide these values ranged from 0.3 m on SQ03 to 2.5 m on SQ01 (Fig. 3). On summer the values ranged from 0.869 m (SQ01) to 2.087 m (SQ09) in low tide and from 0.895 (SQ02) to 2.054 m (SQ04) in high tide. The mean values per lagoon were higher on Boqueirão (0.9 m) and lower in Jardim (0.6 m) (Fig. 3).

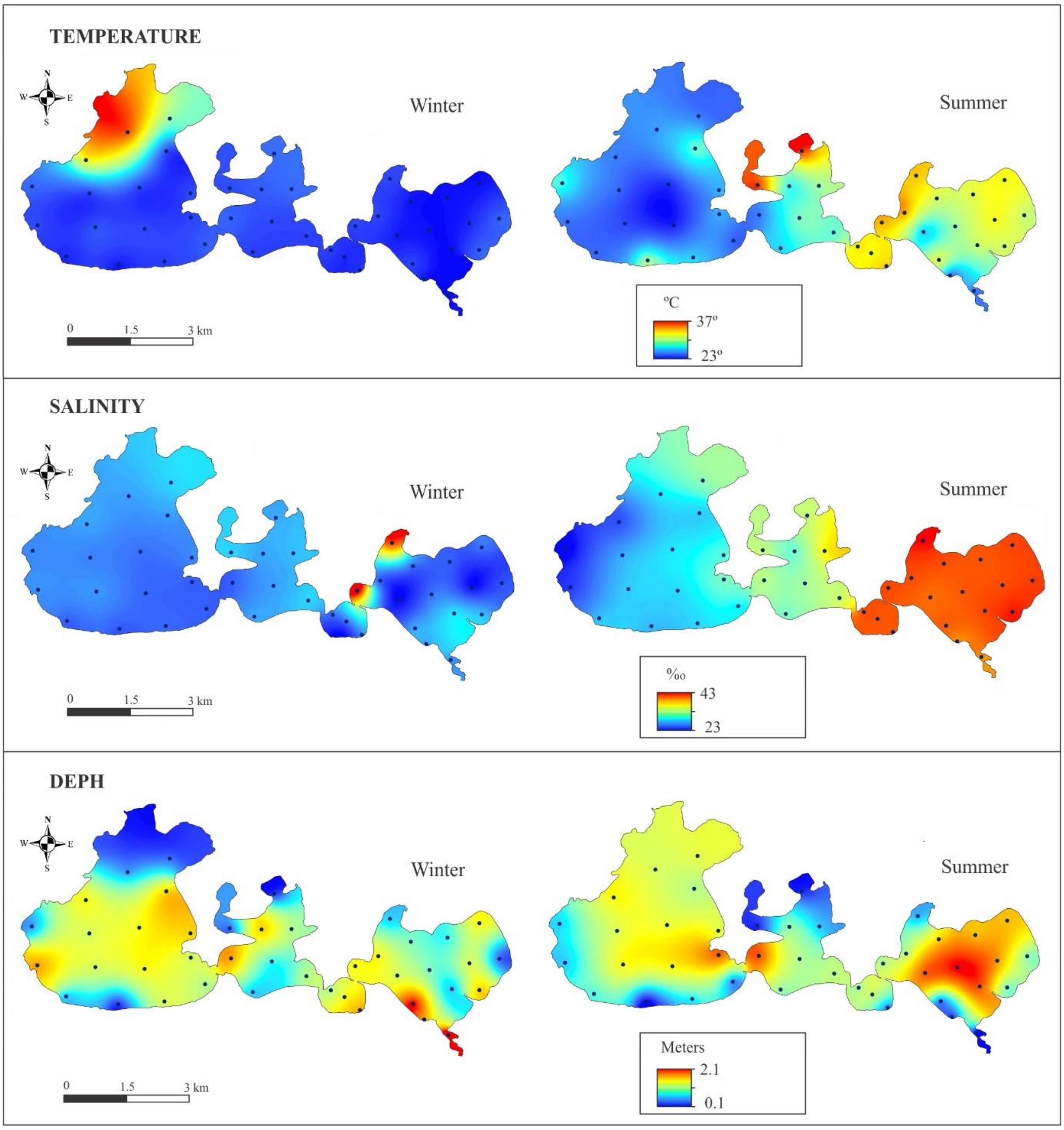

Figure 3 – Average values of temperature, salinity and deph for each sample station.

The pH presented the highest value for high tide at SQ15 station (8.94) and lowest measured at SQ13 station (7.78) (Fig. 2). For low tide the values ranged from 6.09 on SQ12 to 8.48 on SQ15 station (Fig. 2). About the mean values for lagoons, the highest average was measured 8.3 in Boqueirão lagoon and lowest 7.6 in Urussanga lagoon (Fig. 4)

The maximum value of DO recorded in high tide was 8.0 mg/L (SQ09) and the minimum was 6.14 recorded at SQ13 located at north margin of Saquarema lagoon. On the other hand, the maximum value of DO in low tide was found at SQ02 (7.7 mg/L) near to Barra Franca channel and de minimum (5.73 mg/L) was recorded at SQ10 station (Fig. 2).

About mean values, the higher was measured at Urussanga lagoon (7.26 mg/L) and lower at Boqueirão lagoon (6.62 mg/L) (Fig. 4).

The TDS values varied more during the tide cycle in the winter than when we compared between the seasons of the year. On winter, the values for low tide ranged from 0.018 g/L in SQ04 to 38.52 g/L in SQ09 both in Saquarema lagoon, about high tide, the values ranged from 0.0 g/L in SQ04 to 36.3 g/L in SQ11, while on the summer the values ranged between 32.3 and 38.2 on low tide and 34.11 and 35.95 on high tide. The average between the lagoons that composed this system were highest in Saquarema and Boqueirão lagoons (28.5 g/L) (Fig. 4), Saquarema lagoon shows values between 0.009 g/L (SQ04) and 36.85 g/L (SQ05) and Boqueirão from 17.29 g/L (SQ19) to 36.12 g/L (SQ17) (Fig. 4), the lowest values were measured in Jardim lagoon (15.8 g/L), with the low value in SQ28 (5 g/L) and the high in SQ22 (32.5 g/L) (Fig. 4).

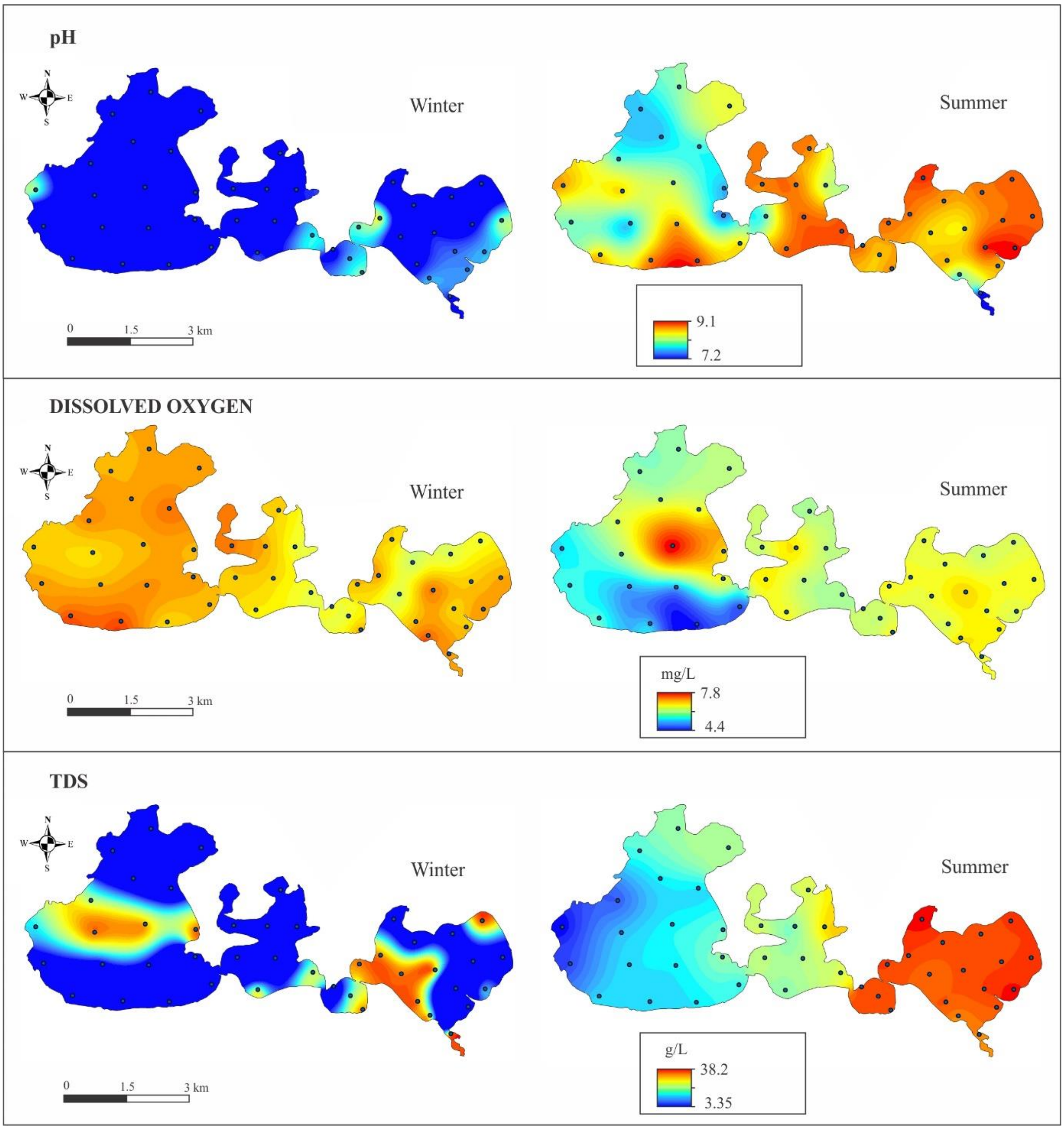

Figure 4 – Average values of pH, DO and TDS for each sample station.

Muddy fraction ranged from 0 % to 98.4 % in stations SQ01 and SQ36, respectively, on the winter and from 0 % to 99.74 % in stations SQ08 and SQ04, respectively on the summer (Fig. 5). The predominant grain size fraction in both winter and summer was muddy, but in the stations located near the Barra Franca Channel (SQ01, SQ02, SQ03, SQ04 and SQ05) and in SQ29 station located on the south margin of the Urussanga lagoon, the sandy fractions dominated in both seasons (Fig. 5).

The minimum OM recorded value in the winter was 0.05 % in SQ01 station located in the communication channel with the Atlantic Ocean and maximum 25.1 % in SQ43 station located on the Urussanga lagoon (Fig. 5). In the summer, the values ranged from 0.09 % on SQ01 to 18.77 % on SQ24 on the norh of Jardim lagoon. The highest value of carbonate in winter (9.5 %), was recorded in SQ11 station located on the middle of Saquarema lagoon and the lowest were measured at SQ01 (0.1 %), while in the summer, the measured values ranged from 0.06 % on SQ01 to 7.5 % on SQ07 both situated in Saquarema lagoon (Fig. 5).

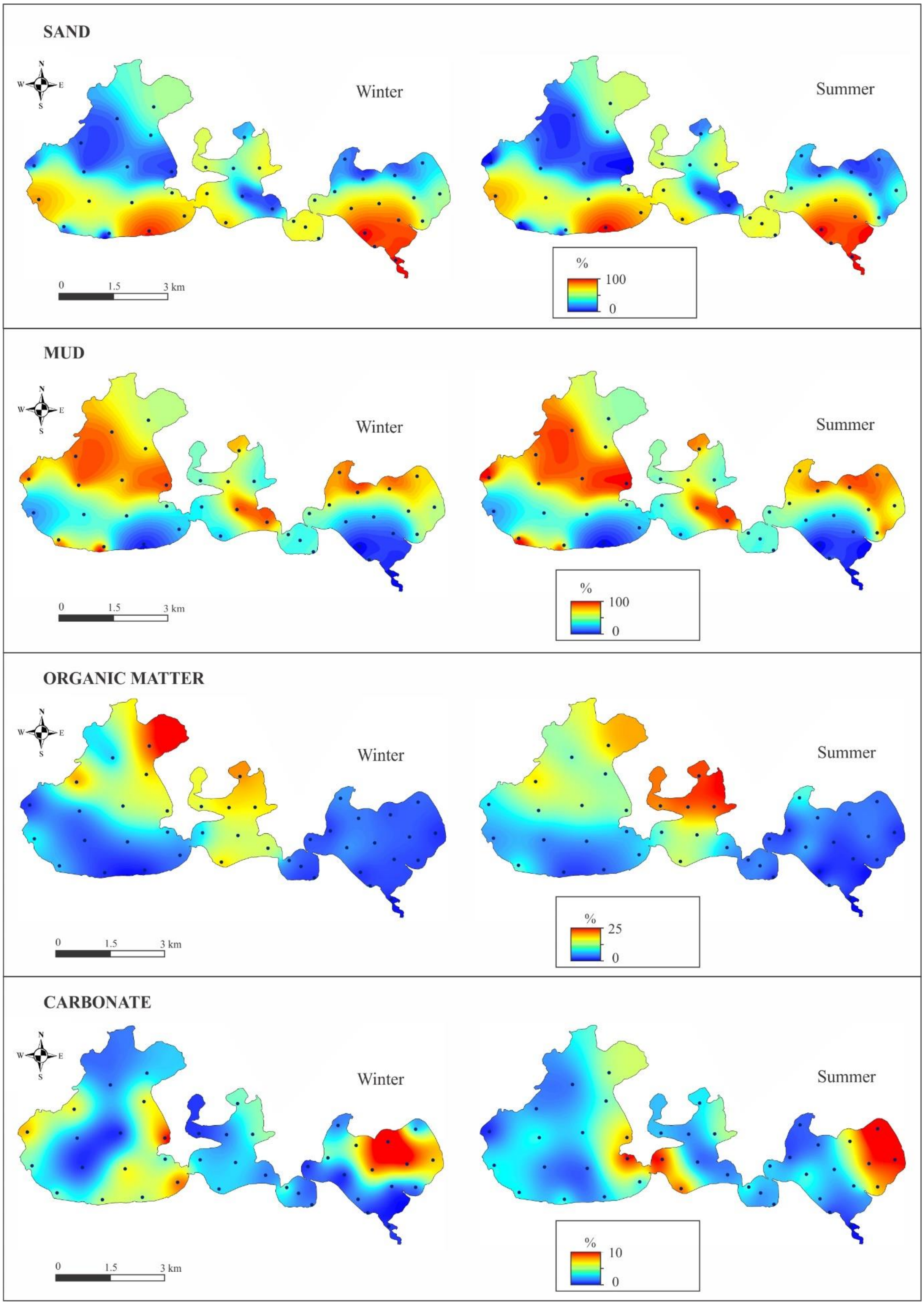

Figure 5 – Grain size values of sand, mud, organic matter and carbonate of each sample station.

4.2 Benthic foraminifera analysis

Winter

A total of 7928 specimens belonging to 19 species were picked and identified in SLS (Fig. 6). The lowest foraminifer density (101 tests/50 ml) was found in SQ24 in Jardim lagoon and the highest was found in SQ02 (1,664 tests/50 ml) (Fig. 6). In the stations SQ09, SQ15, SQ22, SQ27, SQ28, SQ31, SQ32, SQ33, SQ34, SQ35, SQ36 SQ37, SQ38, SQ39, SQ40, SQ41, SQ42 and SQ43 the foraminifera density was lower than 100 tests/50 ml and for that these stations were excluded from statistical analysis.

For the H’ and J’ index ranged from 0.5 to 2.394, the highest value was found in SQ24 at the Jardim lagoon and the lowest in SQ36 at Urussanga lagoon. The J’ values varied between 0.57 - 0.96 (Fig. 6).

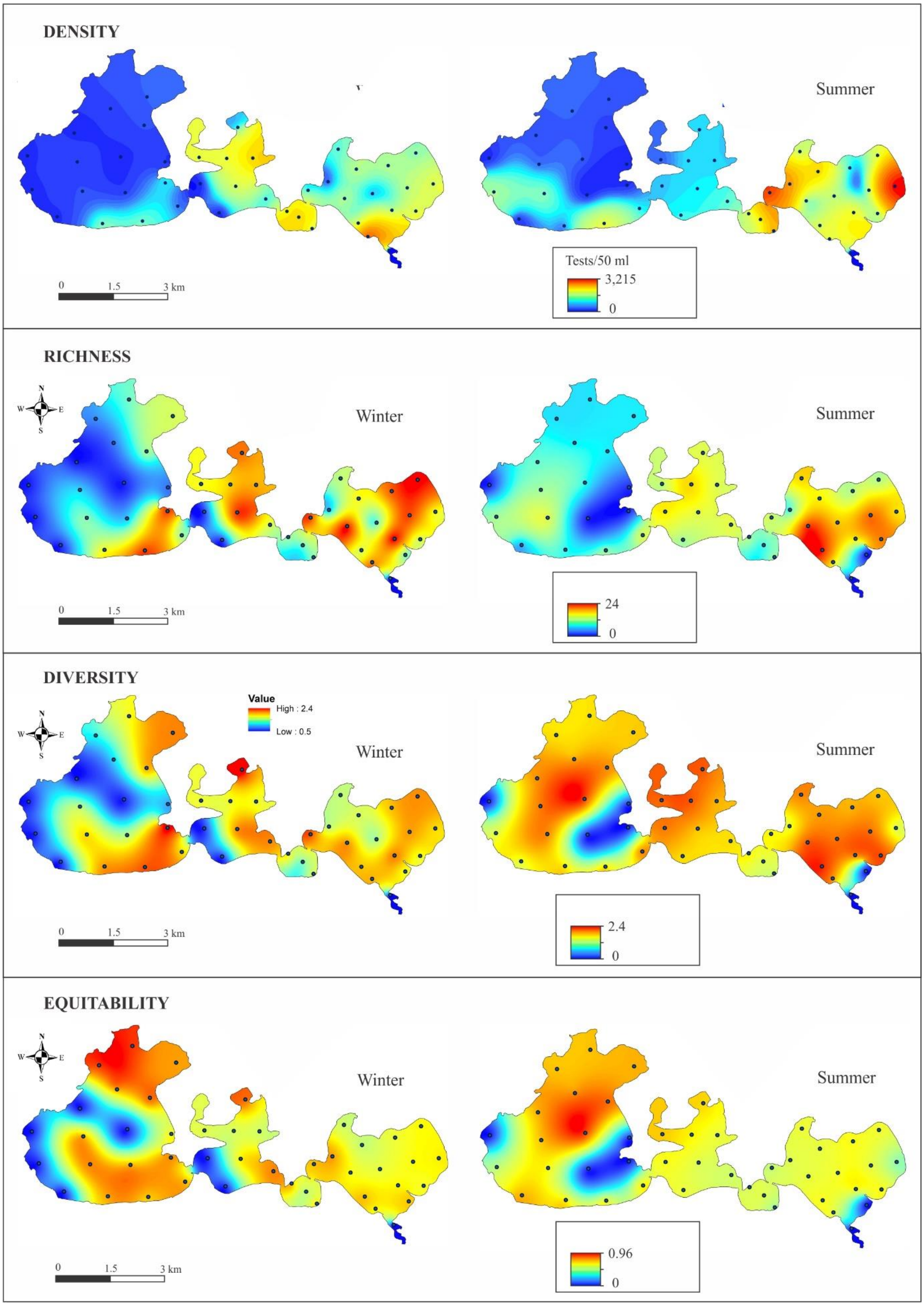

Figure 6 – Comparison of ecological index between winter and summer.

The dominant families were Ammoniidae, Elphidiidae and Hauerinidae. *Ammonia tepida* and *Ammonia parkinsoniana* were the most abundant species throughout the lagoonal system, followed by *Cribroelphidium excavatum* and *Quinqueloculina seminula*.

Ammonia tepida was present in all stations, except the one that foraminifera were absent. The highest density of *A. tepida* was found in Saquarema lagoon (752 tests / 50 ml in SQ02) and lowest in the Urussanga lagoon (4 tests/50 ml in SQ40).

The highest density of *Ammonia parkinsoniana* was found in SQ02 (176 specimens / 50 ml) near Barra Franca Channel, and the lowest was found in SQ16 (4 tests/50 ml).

Cribroelphidium excavatum was present along the lagoon body, but more abundant in Saquarema and Jardim lagoons. This species reached the highest density in SQ02 (176 tests/50 ml). *Cribroelphidium galvestonense* was founded only in the winter, with distribution restricted to Saquarema and Jardim lagoon, the high density was identified in SQ02 (24 tests/50 ml). *Cribroelphidium poeyanum* were found in low density (Less than 60 tests/50 ml) only in Saquarema lagoon. *Elphidium gunteri* (Elphidiidae Family) were identified in all of 4 lagoons of the system with high density in SQ19 (108 tests/50 ml) on Boqueirão lagoon.

Miliolinella antartica, *Miliollinela subrotunda* and *Quinqueloculina seminula* (Hauerinidae family) were found in higher density in Saquarema lagoon. The species of *Miliolinella* genus are distribuited along SLS, but absent in Urussanga lagoon and *Q. seminula* was identified in all lagoons.

The species *B. inflata*, *B. striatula* and *B. variabilis* were founded in large quantity in Saquarema and Boqueirão lagoon, but were identified only in SQ29 and SQ30 in Urussanga lagoon. *B. inflata* was the most abundant of this genus while *B. variabilis* had the opposite behavior.

Buliminella elegantissima (Buliminellidae family) was found in great quantity only in SQ02 (104 specimens / 50 ml) this species follows the distribuition of *Bolivina* genus with a few organisms in Urussanga lagoon (only in SQ29 and SQ30).

The agglutinated species (Order Lituolida) behaved differently from each other, while *Ammobaculites dilatatus*, *Ammobaculites exiguus* and *Ammotium salsum* were distributed in all lagoons that compose this lagoon system *Haplophragmoides wilberti* and *Trochamminita salsa* were exclusively identified in the Urussanga lagoon. These species were founded in low relative abundance while we compare with calcareous ones (Fig. 7).

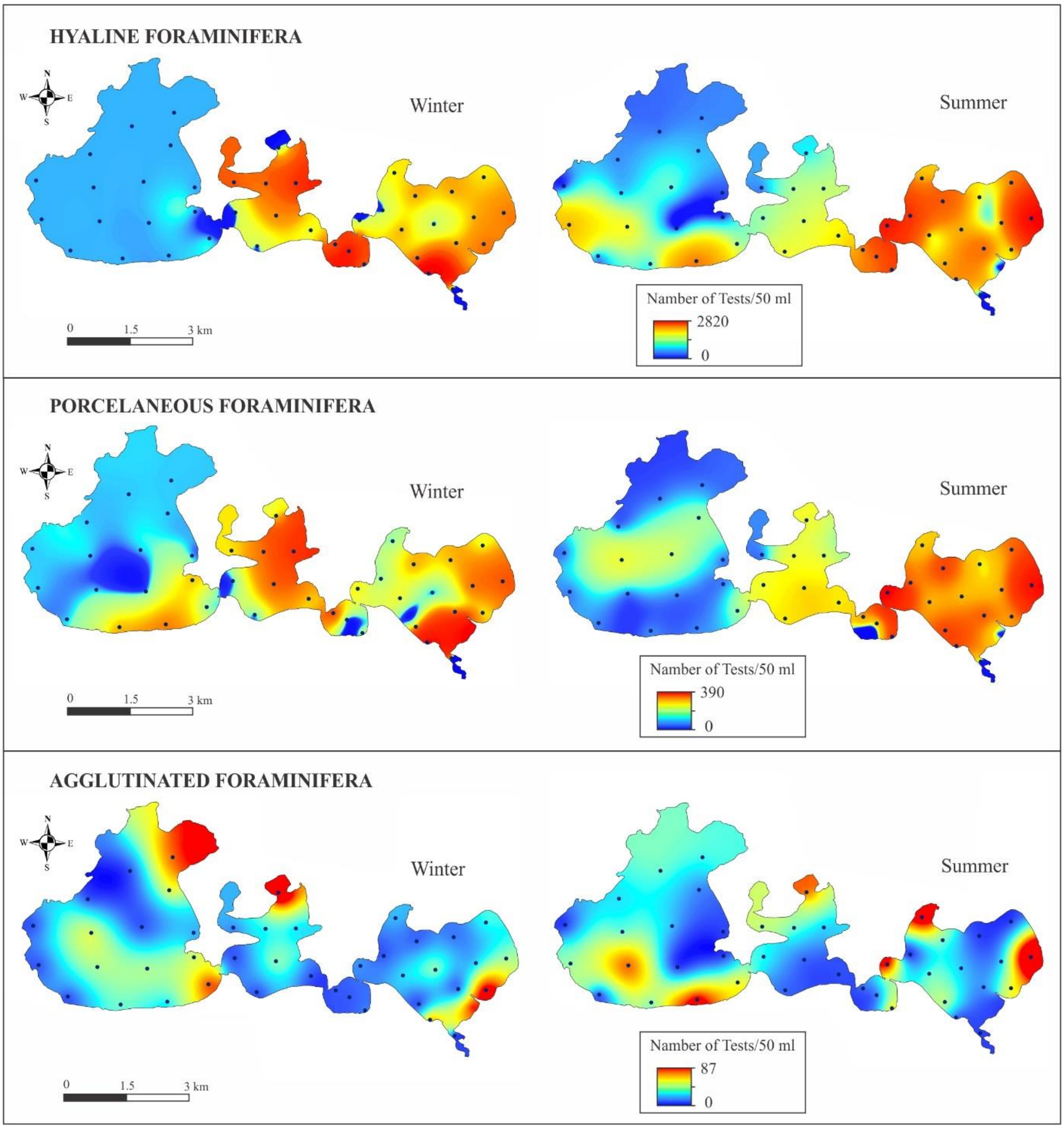

Figure 7 - Comparison of biotic values between winter and summer.

Summer

A total of 12613 specimens belonging to 29 species identified in SLS on summer (Fig. 6). The foraminifera density ranged from 102 tests/50 ml in SQ20 in Boqueirão lagoon to 3215 tests/50 ml in SQ07 on Saquarema lagoon (Fig. 6). In the stations SQ01, SQ03, S12, SQ21, SQ22, SQ23, SQ24, SQ25, SQ26, SQ27, SQ28, SQ30, SQ31, SQ32, SQ33, SQ36, SQ37, SQ38, SQ39, SQ40, SQ41, SQ42 and SQ43 the foraminifera density was lower than 100 tests/50 ml.

For the H’ the values ranged from 1.2 in SQ17 on Boqueirão lagoon to 2.04 on SQ05 on Saquarema lagoon. The J’ values on summer varied between 0.448-0.937, the highest was measured at SQ37 in the north margin of Urussanga lagoon and the lowest was found at SQ07 in the middle of Saquarema lagoon (Fig 6).

The dominant families were Ammoniidae, Bolivinitidae, Elphidiidae and Hauerinidae. *Ammonia tepida* and *Miliolinella subrotundra* were the most abundant species throughout the lagoon system followed by *C. excavatum* and *A. parkinsoniana*.

As in the winter, *A. tepida* was present in all stations, except the one that foraminifera were absent. The highest density of this species was found in SQ07 (2,400 tests/50 ml) in Saquarema lagoon and the lowest density was found in SQ26 in Jardim lagoon and SQ41 in Urussanga lagoon with only 3 tests/50 ml.

The high density of *A. parkinsoniana* was found in SQ13 (91 tests/50 ml) and the low in SQ38 (1 test/50 ml). This specie was more abundant in Saquarema and Jardim lagoon and less in Boqueirão and Urussanga.

The *Cribroelphidium* genus was represented by *C. excavatum* and *C. poeyanum* and had the distribution different from each other, while *C*. excavatum were found in all lagoons that composed this system, *C.* poeyanum was identified only in Saquarema lagoon with low density (Less than 60 tests/50 ml). *Elphidium gunteri* (Elphidiidae Family) were not identified in Urussanga lagoon, and had high density in SQ07 (64 tests/50 ml) on Saquarema lagoon.

Adelosina carinatastriata (Cribrolinoididae family*), Miliolinella antartica, Miliolinella subrotunda, Miliolinella webbiana* and *Quinqueloculina seminula* (Hauerinidae family) were found in higher density in Saquarema lagoon. The species of Miliolinella genus are distribuited along SLS, but absent in Urussanga lagoon, while *Q. seminula* was identified in all lagoons. *A. carinatastriata* and *M. webbiana* were found only in the summer samples, the high density of this species was identified in SQ07 (32 tests/50 ml) and SQ13 (23 tests/50 ml) respectively.

The *Bolivina* genus, in the summer was composed by *B. inflata*, *B. striatula*, *B. translucens* and *B. variabilis* and they were distributed along all the four lagoons of this system. *B. striatula* was the most abundant species of this genus followed by *B. inflata*, while *B. variabilis* had the distribution restricted to Saquarema lagoon.

Bulimina patagonica (Buliminidae family), *Cornuspira involvens (*Cornuspirinae family) and *Pseudononion japonicum* (Nonionidae family) were exclusively found in summer samples. *B. patagonica* was restricted to Saquarema lagoon and it had the high density (9 tests/50 ml) in SQ02 near to communication to oceanic water. *C. involvens* was absent in

Urussanga lagoon and had the high density in SQ16 (67 tests/50 ml), this same pattern was repeated for *P. japonicum* wich had the high density in SQ16 (42 tests/50 ml).

Buliminella elegantissima (Buliminellidae family) was distributed in low density values in Saquarema to Jardim lagoon (<50 tests/50 ml) and in Urussanga was found only in SQ28. The high density was identified in SQ15 (44 tests/50 ml) near to north margin of Saquarema lagoon.

The agglutinated species, such as *Ammobaculites dilatatus*, *Ammobaculites exigus* and *Ammotium salsum* were distributed in all lagoons that compose this lagoon system. *Haplophragmoides wilberti* and *Trochamminita salsa* were exclusively identified in the Urussanga lagoon.

4. 3 Statistical Analysis

The DCA analysis (Fig. 6) with 73% variance coefficient for the axis 1 and 8% for the axis 2 shows that the agglutinated species like *A. salsum, A. dilatatus, A. exiguus, C. exilis, H. wilberti, R. nana* and *T. salsa* and the calcareous *A. parkinsoniana* were mostly influenced by higher OM values and lower values of salinity being the bioindicator assemblage of more confined regions. The bioindicator of marine influence were drived by higher values of salinity, TDS and pH and lower values of organic matter. The species that compose this assemblage were *A. carinatastriata, B. inflata, B. translucens, B. patagonica, C. involvens, C. poeyanum, M. antartica, Miliolinella webbiana, P. japonicum* and *T. paranaguensis.* The species *Ammonia tepida, B. striatula, C. excavatum, E. gunteri* and *Q. seminula* did not have their distribution associated with any studied parameter while they were in center of graphic.

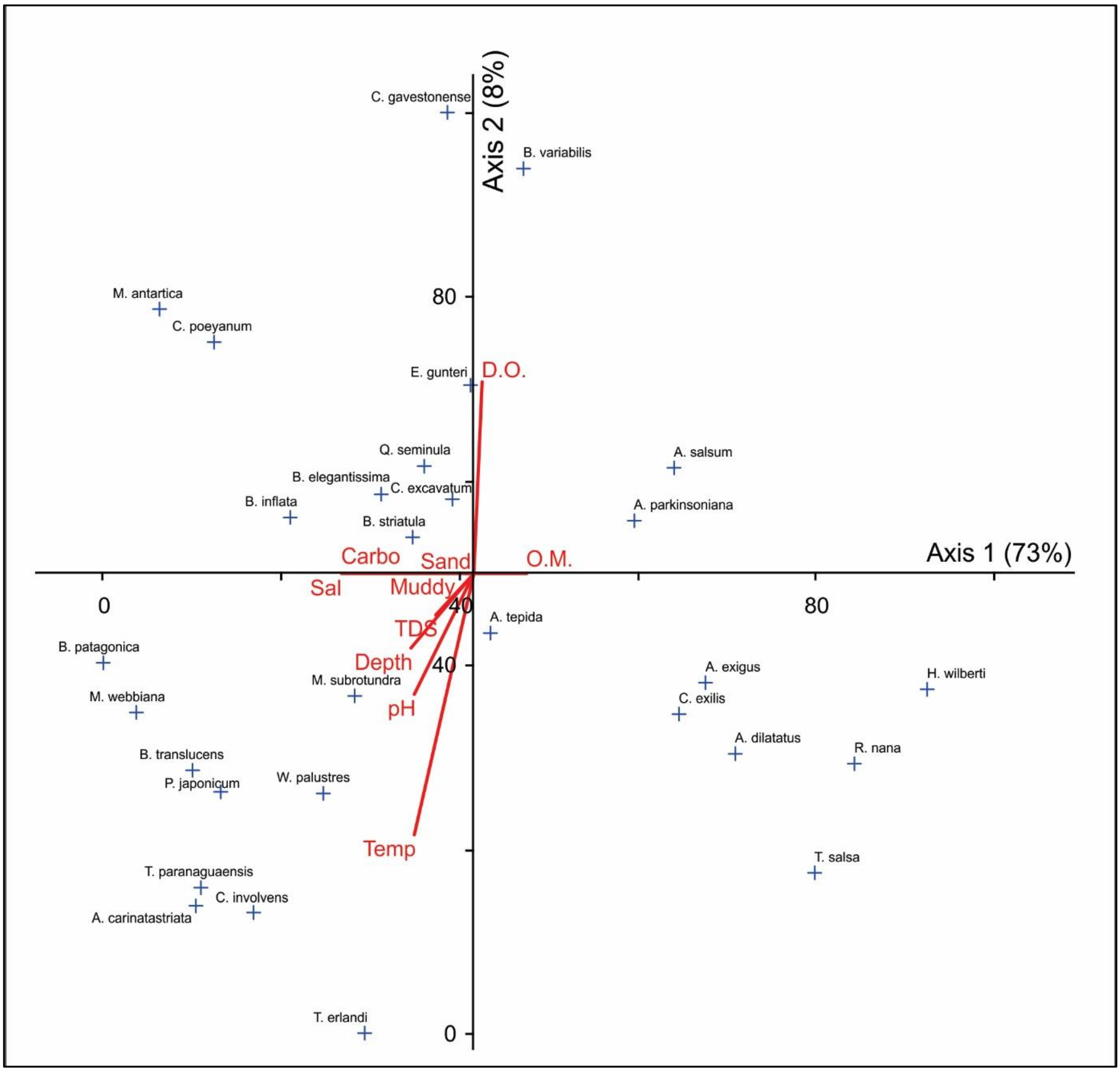

Figure 8 – DCA Analysis (O.M. – Organic Matter; Sal- salinity; Carbo – carbonate).

The Cluster analysis (CA) (Figure 7) with 65% of similarity for Q-mode allowed dividing the lagoon system into 6 different compartments. The groups II and III are composed only by one sample stations and group V are composed by 2 sample stations. The Group I showed that the stations SQ04 and SQ12 were similar in the two seasons of the year. Group IV did not present corresponding regions between the two seasons of the year. And the the SQ 18 station in group 6 indicated a similar region between the two seasons of the year.

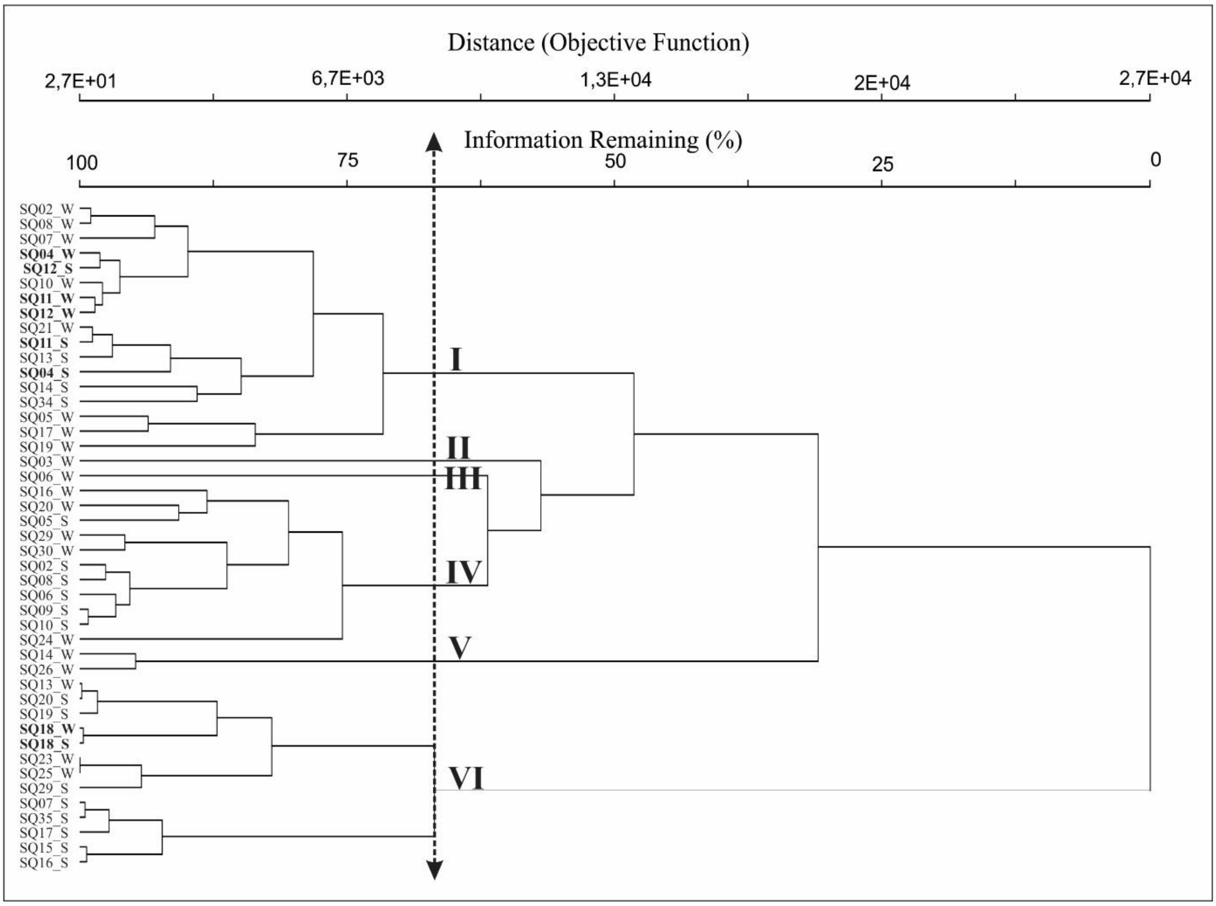

Figure 9 – Cluster Analysis in Q mode.

5. Discussion

5.1 – Environmental dynamics in a lagoon sytem

In general, salinity presented higher values in the winter compared to the summer, which can be explained by the low rainfall recorded in the period (104mm) according to data obtained at the National Institute of Meteorology (INMet, 2017). The salinity values obtained in the Saquarema Lagoon System with a high concentration of salt both in winter and in summer classify it as euhaline according to the Venice system (Smayda, 1983). The highest values of salinity found in the Saquarema lagoon were the consequence of sea water inflow and high evaporation rate. In this lagoon, active tidal currents associated to strong winds favor the accumulation sandy sediments in its central area (Dias et al. 2017). On the other hand, the Urussanga lagoon presented the lowest mean salinity in both seasons of the year, being considered the most confined region within the lagoon system, that is, with a lower exchange rate with the sea (Dias et al., 2017). According to Alves (2003), the water renewal time in the Urussanga lagoon is between 56 to 58 days, in the Jardim Lagoon from 48 to 56 days, in Boqueirão from 20 to 48 days and in Saquarema from 0 to 20.

The temperature showed a direct relationship with the hydrodynamism and bathymetry of the lagoon, since the shallower regions such as SQ42 in the winter and SQ24 in the summer had the highest values, the values obtained in winter agreed with Dias et al. (2017).

The Saquarema lagoon and Boqueirão lagoon presented great temperature variations between the two samples campaign, wich can be an indicative of seasonality in SLS. In the winter, the highest temperatures were recorded in the northern region of Urussanga (± 37 ºC) while the rest of the system remained at an average of 25 ºC. Similar results were found by Dias et al. (2017) where the temperature reached 47 ºC to the north of Urussanga. In this region, the low depths, muddy sediment and a lot of organic matter quantity possibly promote a fermentative activity (Dias et al., 2017). In the summer, the temperature values were lower in the Urussanga lagoon, and the larger concentrates were observed in the North of the Jardim Lagoon, in the region described by Dias et al. (2017) as peatbog area. Similar values were found by Kjerfve and Knoppers (1999) and by Bruno (2013).

Dissolved oxygen is an important factor for the maintenance of life in the aquatic environment besides being one of the main indicators of water quality (Leite, 2004). The values of dissolved oxygen found in SLS, both in winter and summer, were on average higher than those found in other lagoons in the state of Rio de Janeiro, such as in the Araruama lagoon (Debenay et al., 2001) and in the Maricá lagoon (Oliveira et al., 1955 and Guerra et al., 2011) indicating that SLS waters have enough oxygen to sustain aquatic life. In the other hand, the values obtained both in the winter and the summer are lower than the results described by Dias et al. (2017) in the same lagoon system. In general, there was a small increase in DO concentration in winter, which can be explained by the decrease in the temperature of the water body, which consequently decreases the volatilization of the gases contained in the water (Nogueira et al., 2015). The region near the Barra Franca channel, shallower and sandy, was considered the most oxygenated in the Saquarema lagoon, since in this region are constant exchanges of water with the Atlantic Ocean.

The sediment had basic pH in all the analyzed stations on the contrary to what has been recorded by Lacerda and Goncalves (2001). The pH can be considered one of the most important environmental parameters and at the same time it is also one of the most difficult to interpret due to the great number of factors that can influence it (Esteves, 1998). In SLS the pH presented great variation (7.2 to 9), results divergent to those found by Lacerda and Gonçalves (2001). The pH presented neutral to basic values in winter, reaching 9.1 in the Saquarema lagoon. The pH is very influenced by the amount of organic matter, ie, the larger the quantity available, the lower the pH value, since many acids are produced in the organic matter decomposition process (Esteves, 1998). Dias et al. (2017) found the lowest values of pH in the north of the Jardim and Urussanga lagoons, where the highest values of total organic carbon and biopolymeric carbon were found, which agree with those found in the present study.

The depth presented distinct values between the two seasons. The highest precipitation regime in the region during the summer may be an important factor for the higher recorded values, since 95 mm of rain was registered during the sampling in the region (Instituto Nacional de Meterologia, 2017).

The TDS values were mostly higher in summer than in winter. Pedrozo (2000) describes that high values of TDS may be related to the influence of domestic sewage disposal on the water body, which is consistent with the increase in the summer season in the SLS drainage basin (IBGE, 2004). According to Souza (2017), another fact that also provides the increase of TDS during the summer is the elevation of fluvial flows and rainfall galleries, which corroborates with the depth data found in the SLS.

Teodoro *et al*. (2010) suggested that the dominance of silty fractions indicates reduced velocities of bottom water currents as occurs in the SLS, except in the Saquarema lagoon where sandy sediment and low values of Organic Matter dominate (Dias *et al*., 2017). Thus the hydrodynamic regime seems to be more intense in the Saquarema lagoon due to the proximity to the ocean connection through the Barra Franca channel, strong tidal currents, and winds. On the other hand, the Urussanga lagoon is considered the most confined region of the SLS, where the predominance of muddy sediments and high Organic Matter content were founded.

According to Dias *et al*. (2017), sandy sediments are more common in shallow areas with depth less than 0.5 m in SLS. It was possible to identify an increase of this sediment fraction in southern margin of SLS next to sandbar deposit. In Saquarema Lagoon the sandy sediment were predominant and form large sandbanks might have been supplied by tidal and wind transportation from adjecent dunes fields.

5.2 Factors that drive the distribution of benthic foraminifera

Foraminiferal richness commonly documented for coastal lagoons vary, in general, between twenty and thirty species (Fatela & Taborda, 2002; Laut et al. 2007), close to those found in SLS, wich corroborates this pattern. However, studies like Vilela et al. (2011) that recognized 52 foraminiferal species in the Rodrigo de Freitas lagoon; Bomfim et al. (2010) that identified 22 species in the Maricá lagoon and Debenay et al. (2001) that found of 74 species in the Araruama lagoon were based on the total assemblage, which may incorporate allochthonous species. When we consider only living organisms, the low richness might be a consequence of periodic variations due to seasonal reproduction of the species and differential life cycles.

The higher richness and density values in both seasons were founded in Saquarema lagoon, wich may be explained by their geographical position (Fig. 6). These stations were located close to the Barra Franca Channel that promotes the greater exchange of marine water and high-quality food supplied from ocean. Martins et al (2016a) and Delavy et al (2016) using living foraminifera reported diversity values between 0.75 and 1.7 in inner area of the Guanabara Bay values very similar to those founded in Urussanga lagoon (Fig. 6), the inner portion of SLS.

In the SLS, can be observed that the composition of the benthic foraminifera assemblage occurs predominantly of calcareous species with some of agglutinated species (Fig 7). The Hyaline foraminera were founded with highest density along the system lagoon in both seasons of the year. This group was composed mostly by Ammoniidae, Bolivinitidae, Elphidiidae families typically found in lagoon around the world (Debenay et. al. 2005; Raposo et al. 2016 and 2018; Belart et al. 2017).

Haplophragmoides wilberti and *T. salsa* in both seasons were restricted to the most confined areas in Urussanga lagoon. These species have been suggested by several authors as very resistant to salinity changes and reported as dominant in transitional environments such as coastal lagoons and mangroves (Laut et al., 2012, 2016, 2017; Martins et al., 2015). *A. dilatatus*, *A. exiguus* and *A. salsum* were associated with the areas of greater accumulation of organic matter that are located in regions of fluvial sediment deposition, theses species are also known to occur abundantly in mangrove areas elsewhere, wich not occurs in SLS (Debenay et al., 2002; Horton et al., 2005; Berkeley et al., 2009a; Ghosh et al., 2009).

The results obtained in SLS confirmed the adaptive behavior of *Ammonia tepida*, since this specie was present in all the analyzed stations, in both seasons, in different values of salinities, temperatures and pH. In according with DCA, *A. tepida* were not associated with any of studied parameter. *A. tepida* is commonly founded in transitional environments under pollution stress from natural or anthropogenic sources (Martins et al. 2016 a, b and c; Laut et al. 2016). This species was also found in other lagoons in Italy, such as lagoon of Orbetello (Tuscany, coast of Tyrrhenian Sea), Lake Varano (Southern Italy) and the Santa Gilla lagoon (Cagliari) related to the most confined areas (Frontalini et al., 2009). The proliferation of this species in coastal environments is favored by the reduced competition in hypo and hypersaline environments since it is an euryhaline species (Murray, 1991), wich are not observed in SLS.

Ammonia parkinsoniana was reported as a dominant species in several lagoons of Rio de Janeiro: the Maricá lagoon (Bomfim et al., 2010), the Rodrigo de Freitas lagoon (Vilela et al., 2011), Araruama lagoon (Debenay et al., 2001) and in Itaipu lagoon (Raposo et al., 2016 and 2018). This species shows eurytopic behaviors because it was reported in others coastal lagoons with very distinct environmental conditions, such as the Bizerte lagoon (Tunisia) and associated to large and sustainable flux of high quality nutrients (Martins et al. 2015). In the SLS, *A. parkinsoniana* was found in almost all stations, but reached the highest abundance at stations close to the connection with the ocean, under higher marine influence related to physicochemical parameters and food quality, this species also was not associated with any studied parameter, which prevented it from being considered a bioindicator of environmental conditions.

According to Hayward et al. (1996), *C. excavatum* is distributed preferably in coastal environments, where conditions of high salinity, nitrogen and phosphate prevail. This specie is also considered bioindicators of eurytopic conditions by several authors because of their ability to live in a wide variety of habitats and to tolerate a wide range of environmental conditions. It has been recorded in several lagoons of Brazil and around the world (Debenay et al., 2002; Vilela et al., 2003; Laut et al., 2012; Martins et al., 2015; Raposo et al., 2016 and 2018; Belart et al., 2017). *Cribroelphidium excavatum* is also common in estuarine systems like Potengi River in northeastern of Brazil (Souza et al., 2010) and in Paraiba do Sul River, Rio de Janeiro State (Laut et al., 2011). Based on DCA, this species was not associated with studied parameters, which also prevented it from being considered a bioindicator of environmental conditions.

The higher DO indicates influence of marine current in the inner lagoonal area, corroborated by the presence of the species *Adelosina carinatastriata*, *Bulimina patagonica*, *Cribroelphidium poeyanum*, *Miliolinella antartica* and *Miliolinella webbiana* (Eichler et al., 2003; Clemente et al., 2015). The presence of theses species only in the summer also can be associated to the upwelling in of Rio de Janeiro Coast. This phenomenon has a direct influence on primary productivity, contributing to the increase of richness and and with the occurrence of species from the Patagonian coast as reported to Sepetiba and Guanabara bays (Clemente et al. 2015; Laut et al. 2012).

In previous studies, *B. elegantissima* and *Q. seminula* were associated to stressed environments with muddy sediments under high concentrations of OM provided from natural or antropic sources and lower values of dissolved oxygen (Culver & Buzas, 1995; Sharifi et al., 1991; Yanko et al., 1994; Ruiz et al., 2005; Laut et al., 2014). This same pattern was found partially in SLS in both seasons, where *Q. seminula* were associated to mixohaline and brackish environments, with high organic matter in sediments and water with high dissolved oxygen level (Clemente et al. 2015; Laut et al. 2016; Martins et al. 2016a).

The DCA allowed the identification of the bioindicator assemblage of marine conditions, composed by *A. carinatastriata*, *B. patagonica*, *M. webbiana* and *T. paranaguensis*, these species were founded by Clemente et al (2015) in Guanabara Bay and were associated with the flow of cold waters from Patagonia. Some species were not associated with any studied parameter such as *A. tepida*, *B. elegantissima*, *M. subrotundra* and *Q. seminula*, these species dominate coastal environments around the world as the related by Debenay et al (2015), Alves Martins et al (2015), Frontalini and Coccioni (2009) and Sen and Bhadury (2017). The DCA analysis also indicate an assemblage bioindicator of confined regions composed by agglutinated species *A. dilatatus*, *A. exiguus*, *C. exilis*, *H. wilberti*, *R. nana* and *T. salsa* which were associated to regions with high values of organic matter such as the northern region of Urussanga lagoon and river sedimentation regions like right board of Saquarema lagoon associated to Bacaxá river inflow. These species were also related to confined regions in other coastal environments such as Itaipu lagoon (Raposo et al., 2016 and 2018) and Guanabara Bay (Clemente et al., 2015).

5.3 Seasonality in Saquarema Lagoon System

In general, the physical-chemical parameters varied drastically between the seasons, mainly in the lagoon of saquarema. Salinity and pH were much higher during the summer indicating a greater marine influence during this period. This pattern was reflected in the foraminifera assemblage, wich changes it composition drastically in the summer. Bioindicators of marine conditions species such as *A. carinatastriata, B. patagonica, M. antartica* and *M. webbiana* were founded exclusively in Saquarema lagoon on the summer associated to high values of salinity, pH and TDS, these species are also indicators of the entrance of marine waters and the upwelling phenom in the Saquarema coast. The presence of large amounts of miliolide is also indicative of the influence of marine water within the system (Orabi et al., 2017), and as seen in figure 7, these organisms had an expansion in its density for the summer from Saquarema to Boqueirão lagoon. In the winter, this groups of foraminifera are mostly represented by *Q. seminula* wich was dominant in Jardim lagoon. Also, we could observe that while the population of *Q. seminula* decreased in the summer, the community of other milliolides such as Adelosina spp and Miliolinella spp. increased dramatically. DO varied in an opposite way, while it was homogeneous during the winter, in the summer it had a very different behavior, with very low values in the southern margin of the urussanga lagoon. This pattern does not reflect on the microfauna composition wich are mainly composed by agglutinated species in Urussanga lagoon in both seasons. The hyaline species are present in Urussanga only in the summer, while the porcelaneous ones are present in Urussanga only in the winter. The Agglutinated species are present in the north of Urussanga and absent in the southern in the winter and has the opposite behavior in the summer wich they are present in the southern and absent in the north, these species in general are associated to high values of organic matter (Belart et al., 2017; Raposo et al., 2016; Martins et al., 2015) wich are the same pattern founded in the North of Urussanga lagoon on the winter. The results obtained in SLS shows several indicatives of the influence of the seasonality of the physical chemical parameters on the benthic assemblages. The way these parameters affect the composition of the benthic community should be extensively studied so that it is possible to accurately characterize the impacts that influence such sensitive environments.

6 CONCLUSION

The objectives of the present study were to characterize the live assemblage from a tropical coastal lagoon in Rio de Janeiro State, and study the seasonal variation observed on 2 samples campaing in the summer and the winter of 2017. The phisycal-chemestry parameters analysis revealed the existence of significant differences between the seasons of the year, demonstrating the importance of analyzing seasonality in the environmental assessment of coastal systems.

The dominant calcareous specimens of Ammonia spp, Cribroelphidium spp and Bolivina spp did not exhibit temporal variation. On the other hand, the presence of some species only in summer or winter indicates strongly that there is seasonal variation in benthic assemblies. Incorporation of seasonal variations in such proxies may generate wider application and better understanding of present estimates with respect to tropical and sub-tropical marginal marine environments. Overall, the benthic foraminifera dataset generated as part of this study could be used not only for long-term ecological monitoring of Saquarema lagoon System, but also to investigate biogeographic patterns of foraminifera communities in other coastal ecosystems.

The composition of assemblages in the SLS reflected the reduction of marine gradient influence in both studies seasons. The agglutinated species were bioindicators of most confined areas and the calcareous *Adelosina carinatastriata*, *Bulimina patagonica, Cribroelphidium poeyanum* and *Miliolinella* genus characterized the most marine influenced areas. The species *Ammonia tepida, Bolivina inflate and Cribroelphidium excavatum* cannot be considered as bioindicators in SLS, once they were dominant in both seasons and are presented in almost all studed samples.

The present study is the first in Latin America to characterize an environment based on the seasonal variation of the foraminifera assemblages and the physicochemical parameters that lead to their distribution. In addition to contributing to the knowledge about the benthic foraminifera in the region, this study is the basis for future studies aimed at characterizing the trophic state of coastal environments using a similar approach.

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