



**PROGRAMA DE PÓS-GRADUAÇÃO EM OCEANOGRAFIA AMBIENTAL
UNIVERSIDADE FEDERAL DO ESPÍRITO SANTO**

UNIVERSIDADE FEDERAL DO ESPÍRITO SANTO
CENTRO DE CIÊNCIAS HUMANAS E NATURAIS
PROGRAMA DE PÓS-GRADUAÇÃO EM OCEANOGRAFIA AMBIENTAL

Luiz Eduardo de Oliveira Gomes

**Efeitos climáticos em assembleias macrobentônicas de um estuário
tropical da Ecorregião marinha Leste do Brasil**

VITÓRIA
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Dissertação apresentada ao Programa de Pós-Graduação em Oceanografia Ambiental da Universidade Federal do Espírito Santo, como requisito parcial para obtenção do título de Mestre em Oceanografia Ambiental.

Orientador: Prof. Dr. Angelo Fraga Bernardino

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Data ___ / ___ / _____

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RESUMO

Espera-se que as alterações climáticas e a intensificação das inundações e secas alterem significativamente os ecossistemas marinhos. Compreender os efeitos de secas e inundações nos estuários é de extrema importância para compreender os impactos climáticos potenciais em assembleias bentônicas. O estuário Piraque-Açú-Mirim é um ecossistema relativamente bem preservado localizado na Ecorregião Marinha do Leste Brasileira, e foi utilizado como um estudo de caso para a compreensão de variações sazonais e sua influência sobre as assembleias bentônicas. O monitoramento do estuário do Piraquê-Açú-Mirim é um dos mais extensos nos estuários brasileiros (n = 14 meses), sendo vantajoso pois o estuário está em uma área com evidente decréscimo na precipitação média anual durante a última década. Aqui apresentamos um monitoramento temporal (meses) de precipitação, salinidade e temperatura da água, e sedimentos na região estuarina, cujo objetivo foram i) identificar mudanças temporais em sedimentos e assembleias bentônicas no estuário Piraque-Açú-Mirim; e ii) relacionar a influência potencial do evento de seca às propriedades sedimentares e da macrofauna. Nossa hipótese é que as assembleias bentônicas seriam diferentes ao longo do tempo e entre as zonas halinas respondendo a mudanças na salinidade e temperatura da água. As zonas halinas foram definidas de acordo com dados ambientais anteriores do estuário e coletas pilotos feitas com data logger de condutividade/temperatura (OnSet) e multiparâmetro. Um evento de El-Niño ocasionou um intenso período seco entre os anos de 2015-2016, com drástica redução nas taxas de precipitação anual durante um dos mais fortes El-Niño registrados desde 1950. A salinidade e a temperatura em cada zona halina (euhalina e polihalina) entre as marés de sizígia e quadratura foram diferentes. O padrão temporal de salinidade e temperatura das zonas euhalina e polihalina do estuário Piraquê-Açú-Mirim modificaram entre os períodos de Seca e Chuvoso no ano de 2015 se comparados com o período de Seca em 2016, resultando em menores oscilações diárias na salinidade e temperatura estuarina. O conteúdo de lama ao longo do ano de 2015 foi significativamente menor que os observados durante o período de Seca em 2016 (~ 100%). A clorofila *a* nas estações Seca e Chuvoso 2015 foi significativamente maior que durante a estação Seca 2016. A intrusão da água marinha nas zonas polihalinas no estuário Piraquê-Açú-Mirim provavelmente contribuiu para o aumento do teor de lama nas zonas euhalina e polihalina. Durante o monitoramento do estuário do Piraquê-Açú-Mirim as assembleias bentônicas nas zonas euhalina e polihalina foram dominadas pelos mesmos poucos táxons (Magelonidae, Sternaspidae e Capitellidae). Porém, foram observadas mudanças na composição dos demais táxons menos abundantes e provavelmente menos tolerantes. Dentre as variáveis sedimentares, o teor de lama foi o principal fator que contribuiu para as mudanças temporais das assembleias bentônicas, e provavelmente evidencia mudanças no perfil salino estuarino. Temperatura da água esteve relacionada a mudanças na riqueza e equitabilidade J' das assembleias bentônicas, e com mudanças na composição das assembleias do estuário Piraquê-Açú-Mirim. Nossos resultados corroboram que a temperatura influencia mudanças nas assembleias bentônicas durante a seca, bem como a diminuição da diversidade e densidade de taxons dominantes no estuário Piraquê-Açú-Mirim. Ainda são necessários estudos para melhor compreender a relação entre as variáveis dependentes climáticas (ex. salinidade e temperatura) e assembleias bentônicas, bem como os fatores que controlam sua variabilidade. Projetos de monitoramento de longo prazo ainda são necessários, especialmente em países subdesenvolvidos e em desenvolvimento. No caso do Brasil, estes estudos, são essenciais para melhor gerir importantes sistemas, como o estuário do Piraquê-Açú-Mirim e as baías de Todos os Santos e Paranaguá versus as tendências causadas pelo iminente aumento da intensidade e frequência das secas no século atual.

Palavras-chave: Redução pluviométrica, Monitoramento, Ecologia bêmica, Mudanças climáticas

ABSTRACT

Climate change and the intensification of floods and droughts events are expected to significantly alter marine ecosystems. Understand the effects of droughts and floods on estuaries are of utmost importance to understanding the potential climate impacts on estuaries. The Piraque-Açú-Mirim estuary is a relatively well-preserved ecosystem located in the Eastern Brazilian Marine Ecoregion, and was used as a case study for the understanding of seasonal variations and their influence on benthic assemblages. The monitoring of the Piraquê-Açú-Mirim estuary is one of the most extensive of Brazilian estuaries (n=14 months) and advantageous because the estuary is in an area with evidence of significant decrease in annual average rainfall over the last decade. Here we present a temporal (months) monitoring of precipitation, salinity and temperature of water, and sediments in the estuarine region, whose objective is i) identify temporal changes in sediments and benthic assemblages in the Piraque-Açú-Mirim estuary; and ii) relate the potential influence of the drought event to the sedimentary and macrofaunal properties. Our hypothesis is that macrofaunal assemblages would be different over time and between haline zones responding to changes in salinity and water temperature. Haline zones were defined according to previous environmental data from the estuary and pilot samples with the data logger conductivity/temperature (OnSet) and multiparameter. An El Niño event caused an intense dry season between the years 2015-2016, with drastic reductions in annual precipitation rates during one of the strongest El-Niño recorded since 1950. Salinity and temperature at each haline zone (euhaline and polyhaline) were different between spring and neap tide tides. Temporal pattern of salinity and temperature in the Piraquê-Açú-Mirim estuary changes from dry and wet seasons of 2015 compared to dry season of 2016 resulting in lower daily oscillations in salinity and temperature of the estuary. Mud content throughout the year 2015 was significantly lower than those observed during the Drought season in 2016 (~ 100%). Chlorophyll-*a* in dry and wet seasons of 2015 were significantly higher than during dry season of 2016. Marine water intrusion in polyhaline zones in the Piraquê-Açú-Mirim estuary likely contributed to the increase of mud content at both euhaline and polyhaline zones. During the monitoring of the Piraquê-Açú-Mirim estuary the benthic assemblages in euhaline and polyhaline zones were dominated by the same few taxa (Magelonidae, Sternaspidae and Capitellidae). However, changes in the composition of the other less abundant and probably less tolerant taxa were observed. Mud content was the main factor that contributed to the temporal changes of the benthic assemblages, and probably shows changes in the estuarine saline profile. Water temperature was related to changes in richness *S* and Pielou *J'*, and to changes in the composition of the assemblages of the Piraquê-Açú-Mirim estuary. Our results corroborate that temperature influence changes in benthic assemblages during drought, as well as the reduction of diversity and density of dominant taxa in the Piraquê-Açú-Mirim estuary. Further studies are need to better understand the relationship between climatic dependent variables (e.g. salinity and temperature) and benthic assemblages, as well as the factors controlling their variability. Long-term monitoring projects are still required, especially in underdeveloped and developing countries. In the case of Brazil, these studies are essential to better manage important systems, such as the Piraquê-Açú-Mirim estuary and the bays of Todos os Santos and Paranaguá versus the trends caused by the imminent increase in intensity and frequency of droughts in the current century.

Keywords: Rainfall decrease, Monitoring, Benthic ecology, Climate change

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2 I. Introdução geral

3 As recentes alterações causadas pelas mudanças climáticas desencadearam
4 respostas a nível global, alterando componentes biológicos (ex. mudanças na composição
5 e distribuição de plantas e animais), ambientais (ex. impactos em manguezais e recifes de
6 corais) e econômicos (ex. redução de produção agrícola e diminuição da quantidade de
7 água (IPCC, 2001; Hughes et al., 2003). Os recentes acontecimentos são uma fração da
8 magnitude das mudanças previstas nos próximos séculos (IPCC, 2001). As mudanças
9 climáticas irão influenciar o ambiente marinho a partir do aumento da temperatura,
10 elevação do nível do mar, aumento na acidificação dos oceanos e intensificação dos
11 eventos de inundações e secas (IPCC, 2001; Harley et al., 2006; Doney et al., 2012; Cook
12 et al., 2014). A elevação da temperatura média global proporciona mudanças físicas e
13 químicas nos sistemas marinhos, como o derretimento do gelo polar, aumento da
14 temperatura da superfície do mar no último século, mudanças na circulação atmosférica
15 e padrões de precipitação, como inundações e secas (IPCC, 2001; Harley et al., 2006;
16 Doney et al., 2012; Cook et al., 2014). Os ecossistemas, sua biodiversidade e
17 produtividade respondem de forma não-linear as mudanças climáticas (IPCC, 2001;
18 Harley et al., 2006; Hewitt and Thrush, 2009; Hoegh-Guldberg and Bruno, 2010). Essas
19 mudanças vão de grandes escalas, como uma seca em Solitary Islands Marine Park,
20 Austrália, onde alguns estuários intermitentes apresentaram condições hipersalinas
21 (Hastie and Smith, 2006), a local-específico, onde uma seca prolongada no estuário de
22 Santa Lucia, África do Sul, hipersalinizou algumas áreas, causando declínio da fauna
23 bêntica (Pillay and Perissinotto, 2008; MacKay et al., 2010). Os estuários apresentam
24 funções importantes e benefícios sociais, como a captura de sedimentos, a degradação
25 orgânica, oferecem refúgio e alimento à biota, sendo altamente produtivos, colocando os
26 estuários como ecossistemas costeiros de alta importância ecológica e socioeconômica,
27 especialmente diante das mudanças climáticas (Elliott and Whitfiel, 2011; Vilar et al.,
28 2013; Worm et al., 2006). Apesar da importância dos serviços estuarinos, esses
29 ecossistemas são em grande parte influenciados por atividades humanas, como
30 desenvolvimento costeiro, poluição, alteração de habitats e regimes hidrológicos (Edgar
31 et al., 2000; Kennish, 2002; Gusmão et al., 2016). A interação múltipla do estresse
32 humano pode afetar os ecossistemas através de um processo único, cumulativo ou
33 sinérgico (Vinebrooke et al., 2004; Hoegh-Guldberg and Bruno, 2010; Worm et al., 2006).
34 Exemplos de interações múltiplas são: i) efeitos nocivos dos metais pesados sobre as
35 assembleias bentônicas no estuário do Subaé (Brasil, Krull et al., 2014) e ii) menores
36 decréscimos durante estresses climático na produção e na biodiversidade em bancos de
37 *Zostera noltii* comparada a áreas eutrofizadas (antiga *Z. noltii*) no estuário do Mondego
38 (Dolbeth et al., 2007).

39 Os estuários são a zona de transição entre os rios e o mar, variando em forma,
40 tamanho, hidrografia, salinidade, características das marés, sedimentação e energia do
41 ecossistema entre regiões geográficas (Kennish, 2002; McLusky e Elliott, 2004).
42 Estuários apresentam gradientes de salinidade, variando de euhalina, com maior
43 influência marinha (30-40) a água doce, dominada pelos rios e drenagem continental (0-
44 0,5, Sistema de Veneza 1958; McLusky e Elliott, 2004; Barros et al., 2012). Os
45 parâmetros físico-químicos, como salinidade, temperatura, oxigênio dissolvido e
46 turbidez, variam de marés a estações (McLusky e Elliott, 2004, Dolbeth et al., 2011).
47 Alterações nos padrões de precipitação, como eventos e enchentes e secas, influenciam
48 os rios ondas e marés, que alteram os gradientes espaciais e temporais em curto e longo
49 prazo (Day et al., 2008; García-Rodríguez et al., 2013). Os eventos de inundações e secas
50 alteram a salinidade, a temperatura, a qualidade da água e a composição dos sedimentos
51 nos estuários, que são chaves na distribuição da fauna bêntica (Attrill and Power, 2000;

52 McLusky and Elliott, 2004).

53 Organismos bentônicos estuarinos estão distribuídos em diversos táxons, sendo
54 compostos principalmente por anelídeos, crustáceos e moluscos (Lee, 2008). A fauna
55 pode ser classificada em diversos grupos funcionais como, depositívoros (superfície e
56 subsuperfície), carnívoros, omnívoros, filtradores e detritívoros (Jumars et al., 2015). As
57 assembleias bentônicas são amplamente utilizadas para estudos de monitoramento devido
58 à sua importância para a estrutura e função do ecossistema, respondendo rapidamente a
59 mudanças naturais (ex. respostas diretas à salinidade e temperatura) e estresse
60 antropogênico (McLusky e Elliott, 2004; Pollack et al., 2011; Chen et al., 2011). Durante
61 eventos de seca, o aumento da salinidade e da temperatura do estuário podem afetar as
62 assembleias bentônicas por estresse fisiológico, alterando sua composição,
63 comportamento e ocorrência (Garcia-Rodriguez et al., 2013; Dittmann et al., 2015; Little
64 et al., 2016). Estas alterações podem afetar as funções dos ecossistemas e os processos
65 biogeoquímicos de sistemas bentônicos em pequenas e grandes escalas, como i) bancos
66 de *Zostera noltii* no estuário do Mondego (Portugal), que diminuem a produção e a
67 biodiversidade (Dolbeth et al., 2007), ii) decréscimo na produção de espécies
68 comercialmente importantes devido à variabilidade climática no estuário do Mondego
69 (Portugal; Grilo et al., 2011), iii) Alta variabilidade na salinidade diminuem a abundância
70 e diversidade de bivalves e crustáceos, bem como a ocorrência de espécies bentônicas
71 não registradas no sistema em densidades elevadas (*Haminoea natalensis* e a espécie
72 exótica *Tarebia granifera*) que podem causar sérias ameaças ao estuário de Santa Lucia
73 (África do Sul; Pillay e Perissinotto, 2008) e iv) reduzir a produção de plâncton com
74 efeitos em cascata em níveis tróficos superiores no estuário de Neuse (Estados Unidos;
75 Wetz et al., 2011). Eventos de seca atuam de forma diferente entre estuários e zonas
76 estuarinas, podendo causar efeitos deletérios na carga de nutrientes, taxa de oxigênio
77 dissolvido e produção primária, além de afetar a composição de espécies devido a
78 presença de espécies marinhas (IPCC, 2001; Vinebrooke et al., 2004; Harley et al., 2006;
79 Hoegh-Guldberg and Bruno, 2010; MacKay et al., 2010; Dolbeth et al., 2011; Elliott and
80 Whitfield, 2011; Mcleod et al., 2011; Montagna and Palmer, 2012; Wetz and Yoskowitz,
81 2013).

82 Entender os efeitos das secas e inundações nos estuários é de extrema importância
83 para compreender os potenciais impactos climáticos nesses ecossistemas (Bernardino et
84 al., 2015), bem como melhorar a gestão dos ecossistemas no próximo século (Dai, 2011,
85 2013; Cook et al. 2014). A avaliação a longo prazo da oscilação natural permite esclarecer
86 os padrões, sendo extremamente útil para a gestão, fornecendo modelos mais precisos
87 (Dolbeth et al., 2011, Mcleod et al., 2011; Bernardino et al., 2016). Surpreendentemente,
88 a literatura sobre eventos de seca em estuários é escassa numa perspectiva global, apenas
89 16 estuários possuem monitoramento a longo prazo. Mais da metade dos estuários
90 monitorados estão localizados na Austrália (5) e nos Estados Unidos (4), com dados
91 publicados principalmente durante o século 21 (Attrill e Power, 2000, Pillay e
92 Perissinotto, 2008; Dai, 2011, 2013). Dez estuários têm um grande acompanhamento
93 temporal (> 10 anos), com informações bem documentadas e grande conjunto de dados
94 sobre eventos de seca em assembleias bentônicas estuarinas, sendo estes, i) Nueces,
95 Lavaca-Colorado, Guadalupe and Caloosahatchee nos Estados Unidos (4), ii) Europa (3,
96 Golfo do Leão na França, estuários do Mondego em Portugal, e do Guadalquivir na
97 Espanha), iii) Austrália na foz Murray e lagoas Coorong no sistema Murray-Darling, e
98 iv) estuário da Santa Lucia na África do Sul (Montagna e Palmer, 2012; Palmer et al.,
99 2015). O estuário de Santa Lucia funciona como um modelo vivo das previsões sobre
100 intensificações de eventos de seca durante o século XXI, este sistema apresenta longos
101 períodos naturais de seca, ex. cinco anos, que acarretam em fechamento da foz e

102 condições de hipersalidade, evidenciando a necessidade de compreender estes eventos
103 (Pillay e Perissinotto, 2008; MacKay et al., 2010). Em geral, faltam informações sobre o
104 monitoramento de estuários na América do Sul, África e Ásia, que destacam as maiores
105 ameaças a esses ecossistemas.

106 As mudanças climáticas em escalas espaciais e temporais mudarão os padrões de
107 precipitação, salinidade e temperatura (Attrill e Power, 2000; Dai, 2011, 2013). Estas
108 alterações influenciarão os padrões macrofaunais e as funções do ecossistema de forma
109 diferente entre áreas preservadas e impactadas (por exemplo, banco de *Zostera noltii* e
110 área eutrofizadas no estuário do Mondego; Dolbeth et al., 2007). A compreensão dos
111 efeitos dos estressores naturais e antropogênicos é essencial para uma melhor gestão dos
112 estuários (Vinebrooke et al., 2004; Sweetman et al., 2010; Dolbeth et al., 2011;
113 Bernardino et al., 2015). O estuário Piraque-Açú-Mirim, localizado na Ecorregião
114 Marinha do Leste Brasileiro em uma área relativamente bem preservada, foi utilizado
115 como um estudo de caso para a compreensão dos efeitos climáticos sobre as assembleias
116 bentônicas. O monitoramento do estuário do Piraque-Açú-Mirim é um dos mais extensos
117 dos estuários brasileiros (n = 14 meses, Bernardino et al., 2016) sendo vantajoso, pois o
118 estuário está em uma área com evidência de significativo aumento na temperatura média
119 anual durante a última década (Bernardino et al., 2015). Aqui apresentamos um
120 monitoramento temporal (tempo de meses) de precipitação, salinidade e temperatura da
121 água, e sedimentos na região estuarina, cujo objetivo é i) identificar mudanças temporais
122 nos sedimentos e conjuntos bentônicos no estuário Piraque-Açú-Mirim; e ii) relacionar a
123 influência potencial do evento de seca às propriedades sedimentares e da macrofauna
124 bentônica. Nossa hipótese é que as assembleias macrobentônicas seriam impactadas por
125 fatores ambientais com correlação temporal a mudanças na salinidade e temperatura da
126 água.

127

128 **II. Climatic effects in macrobenthic assemblages on an estuary in the Eastern Brazil** 129 **Marine Ecoregion**

130
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137 **Abstract**

138
139 In estuaries, changes in rainfall, including flood and drought events may influence water
140 salinity, temperature and sediment grain size, with consequences to the composition of
141 benthic macrofaunal assemblages. With predicted climate change impacts on coastal
142 ecosystems worldwide, understanding the effects of natural stressors is essential to
143 evaluate effects on the biota and on ecosystem function of estuarine ecosystems. This 14-
144 month study on an estuary in the Eastern Brazil Marine Ecoregion, revealed temporal
145 changes in sediment composition and macrofaunal benthic assemblages in response to a
146 drought event likely associated with the 2015-2016 El-Niño. We detected seasonal
147 changes on sedimentary properties, with a predominance of clay particles and low
148 sedimentary Chlorophyll-*a*, following the drought event. Macrofaunal assemblages in
149 euhaline and polyhaline zones were similar, but observed changes occurred during the dry
150 season in 2016. Water temperature influenced macrofaunal diversity and species
151 composition within the estuary, supporting the occurrence of assemblages shifts during
152 drought events as well as a decrease in diversity and abundance of dominant taxa in the
153 Piraquê-Açu-Mirim estuary. Long-term monitoring stations will be invaluable in future
154 years of climate change in order to better quantify impacts on estuaries and other coastal
155 ecosystems with the likely increase in intensity and frequency of droughts in some regions
156 of Brazil.

157
158 **Keywords:** Rainfall decrease, Monitoring, Benthic ecology, Climate change

159 **1. Introduction**

160
161 Climate change and the intensification of floods and droughts events are expected
162 to significantly alter marine ecosystems (IPCC, 2001; Harley et al., 2006; Dai, 2011,
163 2013; Doney et al., 2012; Cook et al., 2014). Rise in global mean temperature provides
164 physical and chemical change in marine systems, such as polar ice melting, rising sea
165 surface temperatures in the last century, changes in atmospheric circulation, and
166 precipitation patterns such as floods and droughts (IPCC, 2001; Harley et al., 2006; Dai,
167 2011, 2013; Doney et al., 2012; Cook et al., 2014). Climate changes promote non-linear
168 changes on ecosystems function, biodiversity and productivity due multiple stressors
169 interaction (IPCC, 2001; Harley et al., 2006; Hoegh-Guldberg and Bruno, 2010). These
170 changes range from large scales, such as a drought in Solitary Islands Marine Park,
171 Australia, where some intermittent estuaries have hypersaline conditions (Hastie and
172 Smith, 2006), to site-specific, as a prolonged drought in the Santa Lucia estuary, South
173 Africa (Pillay and Perissinotto, 2008; MacKay et al., 2010). Estuaries present important
174 functions and societal benefits, such as sediment trapping, organic degradation, offer
175 refuge and food to the biota, being highly productive, these services place estuaries as
176 coastal ecosystems of high ecological and socioeconomic importance, especially in face
177 of climatic changes (Elliott and Whitfiel, 2011; Vilar et al., 2013; Worm et al., 2006).

178 Despite the importance of estuarine services, these ecosystems are largely influenced by
179 human activities, such as coastal development, pollution and altered habitat (Edgar et al.,
180 2000; Kennish, 2002; Gusmão et al., 2016). The multiple interaction of human stress can
181 impact ecosystems through single, cumulative or synergistic process (Vinebrooke et al.,
182 2004; Hoegh-Guldberg and Bruno, 2010; Worm et al., 2006), as i) Harmful effects of
183 heavy metals on benthic assemblages in the Subaé estuary (Brazil; Krull et al. 2014) and
184 ii) lower decreases during climatic stresses in production and biodiversity in *Zostera noltii*
185 banks compared to the eutrophic area in the Mondego estuary (Dolbeth et al., 2007).

186 Estuaries are the transitional zone between rivers and the sea, which vary widely
187 in hydrological, morphological and chemical conditions. Physicochemical parameters, as
188 salinity, temperature, dissolved oxygen and turbidity, vary from tides to seasons. Haline
189 gradients are evidentes across the estuary, from euhaline (30-40) to freshwater (0-0.5,
190 Venice System 1958; Kennish, 2002; McLusky and Elliott, 2004; Dolbeth et al., 2011).
191 Changes in rainfall patterns, as floods and droughts events, influences riverine, wave or
192 tidal processes, which changes spatial and temporal gradients by short to long-terms (Day
193 et al., 2008; Garcia-Rodriguez et al., 2013). Floods and droughts events change salinity,
194 temperature, water quality and sediment composition in estuaries, which are keys of
195 benthic assemblages distribution and occurrence (Attrill and Power, 2000; McLusky and
196 Elliott, 2004).

197 Changes from droughts seasons will likely promote a large number of responses,
198 from i) maintance or increased in primary production (Molen and Perissinotto, 2011), ii)
199 changes in sedimentation rates and its biogeochemical interactions (Dittmann et al., 2015;
200 Montagna and Palmer, 2012) to iii) hipersalinization (Pillay and Perissinotto, 2009;
201 Palmer et al., 2015), iv) close of the estuarine mouth (Pillay and Perissinotto, 2009;
202 MacKay et al., 2010). Changes on estuarine ecosystems by droughts can be intensifyed
203 or masked due human pressure as pollution, proximity to large cities, deforestation,
204 agriculture, dams, and others (Kennish 2002; Dolbeth et al., 2007; Cardoso et al., 2008).
205 Again, the responses of macrofaunal assemblages to the drought will be in single,
206 cumulative or synergistic processes, ranging from i) increase in density, diversity, number
207 and biomass of taxa, ii) do not respond imediatly to the drought by external influece, as
208 support of nutrientes from non-treated waste, or iii) presents the complete inverse, as
209 decrease in density, diversity, number and biomass of taxa (IPCC, 2001; Pillay and
210 Perissinotto, 2008, 2009; Grilo et al., 2009, 2011; Table 5, references therein).

211 Benthic assemblages are widely used to monitoring studies due its importance to
212 the structure and function of the ecosystem, responding rapidly to natural changes (e.g.
213 direct responses to salinity and temperature) and anthropogenic stress (McLusky and
214 Elliott, 2004; Kotta et al., 2009; Pollack et al., 2011). During drought, the increase of
215 estuarine salinity and temperature can influence benthic assemblages by physiological
216 stress changing its composition, behavior and occurrence (Garcia-Rodriguez et al., 2013;
217 Dittmann et al., 2015; Little et al., 2016). These changes may alter ecosystem functions
218 and biogeochemical processes provided by benthic assemblages on small and large scales,
219 as i) decrease of commercially important species production due climate variability in the
220 Mondego estuary (Portugal; Grilo et al., 2011), ii) high variability changes in salinity
221 decrease abundance and diversity of bivalves and crustaceans, as well unrecorded
222 macrofaunal species to the system in high densitys (*Haminoea natalensis* and the alien
223 species *Tarebia granifera*) which can cause serious threats to the Santa Lucia Estuary
224 (South Africa; Pillay and Perissinotto, 2008) and iii) reduce plankton production with
225 cascade effects on higher trophic levels in Neuse estuary (United States; Wetz et al.,
226 2011).

227 Understand the effects of droughts and floods on estuaries is of utmost importance

228 to understand potential climate impacts on these ecosystems (Bernardino et al., 2015), as
229 well improve ecosystem management in the next century (Dai, 2011, 2013; Cook et al.,
230 2014). Long-term evaluation of natural oscillation allows elucidating patterns, being
231 extremely useful for management by more accurate models (Dolbeth et al., 2011; Elliott
232 and Whitfield, 2011; Mcleod et al., 2011; Bernardino et al., 2016). Drought literature' on
233 estuaries is scarce from a global perspective, only 16 estuaries have been surveyed in
234 view to analyse drought effects, most of those as a result of long term monitoring. Ten
235 estuaries have large temporal monitoring (>10 years), with well documented information
236 to droughts events on benthic assemblages, with data mostly published during the 21
237 century (Attrill and Power, 2000; Montagna et al., 2002; Pillay and Perissinotto, 2008;
238 Dai, 2011, 2013; Palmer et al., 2015; Table 5, references therein). Santa Lucia estuary
239 works as a living model of possible drought intensification during the 21 century, by
240 natural several seasons of droughts, as five years of drought, mouth closure and
241 hypersaline conditions, evidencing the necessity to better understand the drought events
242 (Pillay and Perissinotto, 2008, 2009; MacKay et al., 2010). In general, are lacking
243 information of monitoring estuaries in South America, Africa and Asia, which highlight
244 majors' threats to these ecosystems.

245 Climate change at spatial and temporal scales will change patterns of precipitation,
246 salinity and temperature (Attrill and Power, 2000; Dai, 2011, 2013). These changes will
247 influence macrofaunal patterns and ecosystem functions differently from preserved and
248 impacted areas (e.g. *Zostera noltii* bed and eutrophic area in the Mondego estuary,
249 Portugal; Dolbeth et al., 2007). Understanding the effects of natural and anthropogenic
250 stressors is essential to better manage estuaries (Vinebrooke et al., 2004; Sweetman et al.,
251 2010; Dolbeth et al., 2011; Bernardino et al., 2015). The Piraque-Açú-Mirim estuary,
252 located in the East Brazilian Marine Ecoregion in a relatively well preserved area, was
253 used as a case study for the understanding of climatic effects on benthic assemblages. The
254 monitoring of the Piraçê Açú estuary is one of the most extensive of Brazilian estuaries
255 (n=14 months; Bernardino et al., 2016) and advantageous because the estuary is in an
256 area with evidence of significant decrease in annual average rainfall over the last decade
257 (Bernardino et al., 2015). Here we present a temporal (time scale of months) monitoring
258 of precipitation, salinity and temperature of water, and sediments in the estuarine region,
259 whose objective is i) identify temporal changes in sediments and benthic assemblages in
260 the Piraquê-Açú-Mirim estuary; and ii) relate the potential influence of the drought event
261 to the sedimentary and macrofaunal properties. Our hypothesis is that macrofaunal
262 assemblages would be different over time and between haline zones responding to
263 changes in salinity and water temperature.

264 **2. Material and Methods**

265 **2.1. Study area and sample design**

267 This study was carried at the Piraquê-Açú-Mirim estuary (17°58'S; 40°00'W),
268 within the Eastern Brazil Marine Ecoregion (Bernardino et al., 2015; Fig. 1). This estuary
269 has a Y-shape morphology with extensive mangroves, about 12 Km², composed of
270 *Rhizophora mangle*, *Laguncularia racemosa* and *Avicennia schaueriana*; and tidal flats,
271 which are part of a Sustainable Development Reserve. The estuary is under a semi-diurnal
272 microtidal regime (< 2m). Coastal development led to mangrove removal in some areas
273 on the estuarine margin for agriculture, house construction and piers to fishermen access
274 the river (Bernardino et al., in review).

275 The Piraquê-Açú-Mirim estuary has an euhaline (30-40) and a polyhaline (18 to
276 30) zones, which were defined according to previous environmental data (Bernardino,
277 unpublished) and from pilot studies taken in April and May 2015 with a

278 conductivity/temperature data-logger (OnSet) and a multiparameter (Venice System,
279 1958; Gimenez et al., 2005; Mariano and Barros, 2015; Figure 1). We selected two
280 random study sites at each haline zone, one at each river margin distant about 100 m
281 (Euhaline: Site 1 19°56'17.1" S, 40°10'37" W; Site 2 19°56'38.5" S, 40°10'26.1" W;
282 Polyhaline Site 1 19°55'09.5" S, 40°12'28.5" W; Site 2 19°56'18"S, 40°12'24.7" W). Each
283 site was subdivided in two sampling areas distant 10 m from each other on the intertidal
284 mudflat region, distant at least 1m from the nearby mangrove forests. Sediments and
285 macrofaunal assemblages were sampled monthly from May 2015 to June 2016 at the same
286 areas. At each area, three faunal samples and a sediment sample (three replicates,
287 0.008m²) were collected for analysis of Particle size, Total organic content and Calcium
288 carbonate. A superficial sediment sample (15g, 0-3 cm) was sampled for Chlorophyll-*a*
289 and Phaeopigments analysis (Quintana et al., 2015). Samples were grouped by seasons,
290 Dry 2015 = May to September 2015, Wet 2015 = October 2015 to March 2016, and Dry
291 2016 = April to June 2016 (Reboita et al., 2010).

292 Mean daily rainfall were obtained from the website of the Brazilian National
293 Water Agency (ANA, 2016; Rainfall stations: 1940002, 1940021, 1940039, 194,0042,
294 2549007 and 2549087; Years from 1948 to 2016) and from the local climatic station at
295 UFES (2015-2016). Water pH, total dissolved solids (TDS, ppt) and dissolved oxygen
296 (mg/L, DO) were sampled at each area within the euhaline and polyhaline zones prior to
297 sediment sampling using a HANNA multiparameter near the mud flat (1 m depth, low
298 tide). The monitoring of salinity and Temperature (°C) were carried using an OnSet
299 datalogger (U24-002-C) deployed continually, during seasons of 5 to 24 days at 1 meter
300 above the bottom (~3 meters depth, low tide). A total of 40 days were monitored at the
301 euhaline zone (Dr 2015 (6d), Wet 2015 (24d) and Dry 2016 (10d)); and 35 days at the
302 Polyhaline zone (Dry 2015 (5d), Wet 2015 (22d) and Dry 2016 (8d)). Except during the
303 Dry 2015 season where only one spring tide was monitored, all other seasons were
304 monitored during spring and neap tides.

305

306 2.2. Laboratory analysis

307 Macrofaunal samples were sieved in the field (500µm mesh size) using local water
308 and preserved in 70% Ethanol until analysis. In the laboratory, all organisms were sorted
309 and identified to the lowest taxonomic level. After sorting, total macrofaunal biomass
310 (wet weight) was determined using a 0.0001g precision balance. The sediment particle
311 size was determined by dry-sieving and reported as mud sediment fraction (i.e. particles
312 sizes >2, 2-1,1-0.5, 0.5-0.25, 0.25-0.125, 0.125-0.063 and <0.063 mm). Total organic
313 content was measured by loss on ignition over 4 h at 500°C, after drying the samples at
314 60°C for 48 h. Calcium carbonate (CaCO₃) contents were determined by adding chloric
315 acid (10%; 2 mL) till effervescence ceased and then dried at 60°C for 48 h. Chlorophyll-
316 *a* and phaeopigment were analyzed according to Lorenzen (1967). In laboratory,
317 chlorophyll-*a* concentrations were measured spectrophotometrically (absorbance read at
318 430 and 665 nm) after extraction with 100% acetone. Phaeopigments were determined
319 after acidification with 0.1 N HCl (Lorenzen, 1967).

320

321 2.3. Statistical analysis

322 Total daily rainfall at the Piraquê-Açú-Mirim region (rainfall stations of ANA
323 local and climatic station at UFES) were grouped at scales of months, seasons and years
324 (mean and standard deviation) to describe the drought event. Water salinity and
325 temperature were monitored by conductivity and temperature data-loggers at euhaline
326 and polyhaline zones across the three seasons during the study (Dry 2015, Wet 2015, Dry
327 2016), and spanned major tidal changes (spring x neap) at each haline zone. PSS-78 was

328 used to calculate salinity using the logger conductivity and temperature measures
329 (UNESCO, 1981).

330 Based on the unbalanced design, a one-way Analysis of Variance (ANOVA) model
331 was used to compare salinity and temperature across tides and seasons. Sedimentary
332 properties (Mud content, Total organic matter, Calcium carbonate, Chlorophyll-*a* and
333 Phaeopigment) and macrofaunal assemblages (Density, Biomass, Species richness,
334 Shannon H' and Pielou J') were compared between haline zones (euhaline and
335 polyhaline) and seasons (Dry 2015, Wet 2015, Dry 2016). If significant, a *post hoc* pair-
336 wise comparison Tukey-Kramer test was used, due to unequal sample sizes (Dunnnett, 1980).

337 Spatial and temporal changes of the benthic assemblages were assessed by density
338 (ind.m²), biomass (g.m²), taxa composition and diversity analysis (Species richness,
339 Shannon H' and Pielou J'). Analysis of Multidimensional Similarity (MDS) was applied
340 using transformed square root abundance of all taxa in a similarity matrix (Bray-Curtis)
341 to evaluate changes between seasons, and euhaline and polyhaline zones. The significance
342 of clustering of MDS was assessed using the SIMPROF test and significance tests were
343 determined by ANOSIM (Warwick and Clarke 1993). Changes in benthic assemblages
344 and sedimentary parameters were analyzed using PERMANOVA (permutational analysis
345 of variance; Anderson et al., 2008). Two factors were used in PERMANOVA, seasons
346 (Dry 2015, Wet 2015 and Dry 2016), and haline zones (euhaline and polyhaline).
347 PERMANOVA of benthic assemblages was conducted using a Bray-Curtis similarity
348 matrix, transformed by the fourth root. The sedimentary parameters were transformed by
349 Euclidean distance.

350 Temporal correlations between water salinity and temperature with sedimentary
351 parameters (Mud content, Total organic matter, Calcium carbonate, Chlorophyll-*a* and
352 Phaeopigment), and macrofaunal assemblages properties (Density, Biomass, Species
353 richness, Shannon H' and Pielou J') and composition were tested by Multiple linear
354 regression analysis. Valid regression models were tested by an ANOVA (global quality of
355 fit; Legendre and Legendre, 2012). Water salinity and temperature were chosen as
356 predictors of pluviometric and macrofaunal changes, due to their inverse relationship with
357 rainfall variations and direct effects on macrofaunal assemblages (Palmer et al., 2015).

358 DistLM (distance-based linear model) routines (McArdle and Anderson, 2001;
359 Anderson *et al.*, 2008) were performed Selection = step-wise, selection criterion =
360 adjusted AICc); and applied to sedimentary parameters and macrobenthic assemblages
361 (Clarke and Gorley, 2006; Anderson et al., 2008). Benthic assemblage data were analyzed
362 using the Bray-Curtis similarity matrix, transformed by the fourth root. Sedimentary
363 parameters were transformed by Euclidean distance. BIO-ENV procedure was applied to
364 relate multivariate patterns of macrobenthic assemblages by sedimentary parameters
365 (classification of Spearman, *p* between the two matrices of similarity).

366 Analyses of Diversity, MDS, SIMPROF, ANOSIM, PERMANOVA, RELATE,
367 DISTLM and BIO-ENV were performed using the software PRIMER v 6.0 with the
368 PERMANOVA + add-on package (Clarke and Gorley, 2006; Anderson et al., 2008).
369 ANOVA with *post hoc* Tukey-Kramer test and Multiple linear regression analyses were
370 performed Using SPSS v 20.0 software (IBM SPSS Statistics Inc., Chicago, IL, USA).

371

372 **3. Results**

373 *3.1. Drought characterization*

374

375 Rainfall varied drastically during the study seasons in the Piraquê-Açú-Mirim
376 estuary, with higher monthly volumes during the Dry season of 2015 (62.5±52.5 mm/mo),
377 which were similar to the mean historic rainfall for the season (Dry 1948-2014, 62.6±19.5

378 mm/mo; Figure 2). However, during the Wet season of 2015 (46.9 ± 29.7 mm/mo) and the
379 following the Dry season of 2016, (13.3 ± 5.9 mm/mo), rainfall was lower than historical
380 means, with strong reductions of 40 to 80% in rainfall volume. The lowest monthly rainfall
381 volume occurred during the Dry season of 2016, with values of 8.9 to 11 mm/mo in
382 February, April and May 2016 (Figure 2). Historical data indicated that the high rainfall
383 at the Piraquê-Açú-Mirim estuary occurred in December 2013, with a mean monthly
384 rainfall of 649.8 ± 115.5 mm. Our data revealed that during the last decade, the Piraquê-
385 Açú-Mirim estuary has been under a continuous decline in mean rainfall, with the lowest
386 rainfall averages of the last 50 years occurring in 2015 and 2016 (Figure 2).

387 As expected, the mean water salinity of euhaline and polyhaline zones were
388 different at all seasons (dry and wet seasons of 2015 and Dry season of 2016), and
389 between spring and neap tides. Spring tide salinity was always higher in the euhaline zone
390 if compared to the polyhaline zone (26.7 to 26.9 and 23.5 to 24.1, respectively; ANOVA
391 $p < 0.001$ Figure 3). The same occurred with neap tide salinity ranges, which were higher
392 in the euhaline zone during all seasons sampled (Figure 3, ANOVA $p < 0.001$). However,
393 tidal patterns in salinity ranges changed within each zone across seasons. In the Euhaline
394 zone, salinity range during spring tides was significantly different to neap tides during the
395 Wet season of 2015 (ANOVA F 37.414, p 0.000; Figure 3), not during the Dry season of
396 2016. In the Polyhaline zone, salinity ranges between spring and neap tides was
397 significantly different during the Wet season of 2015 (ANOVA F 26.403, p 0.000) and the
398 Dry season of 2016 (ANOVA F 6.610, p 0.011). However, salinity ranges at both spring
399 and neap tides in the Polyhaline zone increased significantly, with lower oscillation,
400 between the Dry and Wet seasons of 2015 to Dry season of 2016 (ANOVA F 24.351, p
401 0.000; Tukey-Kramer p 0.000, both seasons; Figure 3).

402 Spring tide temperatures in euhaline zones were constantly higher if compared to
403 the polyhaline zones in Piraquê-Açú-Mirim estuary (ANOVA $p < 0.000$; Figure 4). During
404 the Wet season of 2015 and Dry season of 2016, neap tide temperatures in the euhaline
405 zone were lower than polyhaline (ANOVA $p < 0.000$ Figure 4). Tidal patterns in
406 temperature ranges changed within each zone across seasons. In the Euhaline zone,
407 temperature range during spring tides was significantly different to neap tides during the
408 Wet season of 2015 (ANOVA F 6.938, p 0.009) and Dry season of 2016 (ANOVA F
409 71.762, p 0.000). In the Polyhaline zone, temperature ranges between spring and neap
410 tides was significantly different during the Wet season of 2015 (ANOVA F 4.009, p
411 0.047), not during the Dry season of 2016 (Figure 4). However, temperature ranges at
412 both spring and neap tides in the euhaline zone increased significantly, with lower
413 oscillation, between Dry season of 2015, Wet season of 2015 and Dry season of 2016
414 (ANOVA F 298.960, p 0.000; Tukey-Kramer p 0.000). The same pattern was evidenced
415 in the polyhaline zone temperature, which increased significantly, with lower oscillation
416 between Dry season of 2015, Wet season of 2015 and Dry season of 2016 (ANOVA F
417 572.984, p 0.000; Tukey-Kramer p 0.000 all seasons; Figure 4).

418

419 3.2. Spatial changes between haline zones

420 3.2.1. Water column and sediment

421

422 Water column pH, Total dissolved solids (TDS) and Dissolved oxygen (DO) were
423 similar at the euhaline and polyhaline haline zones (Table 1). All sediment properties
424 (Mud content, Total organic content, Calcium carbonate, Chlorophyll-*a* and
425 Pheopigments) were also similar between the euhaline and polyhaline zones
426 (PERMANOVA, F 0.467, p 0.79; Table S1).

427

428 3.2.2. Macrofaunal assemblages

429 A total of 3,736 individuals distributed in 32 taxa were sampled during the study
430 period. Annelida (17 taxa), Crustacean (7 taxa) and Mollusca (6 taxa) were predominant.
431 Macrofaunal density, biomass, richness, Shannon H' log e and Pielou J' were similar at
432 the euhaline and polyhaline zones (ANOVA, $p > 0.05$; Table S2).

433 Annelida was the most abundant taxa in the euhaline and the polyhaline zones.
434 The polychaetes Magelonidae, Sternaspidae, Capitellidae, Goniadidae and Paraonidae
435 dominated the euhaline ($234,000 \pm 51,282$ ind.m², 89.3%) and polyhaline
436 ($179,375 \pm 39,449$ ind.m², 87.5%) zones of Piraquê-Açú-Mirim estuary. Macrofaunal
437 composition markedly changed between euhaline and polyhaline zones. The crustacean
438 Cirolanidae (375 ± 29 ind.m², 0.1%) only occurred at the euhaline zone, while the
439 polychaetes Amphinomididae (125 ± 9.6 ind.m², 0.1%) and Sabellariidae (125 ± 9.6 ind.m²,
440 0.1%), and the crustaceans Atyidae (125 ± 9.6 ind.m², 0.1%), Alpheidae (125 ± 9.6 ind.m²,
441 0.1%) and Cumacea (125 ± 9.6 ind.m², 0.1%), the gastropod Vitrinellidae (750 ± 49.1
442 ind.m², 0.4%) and Sipuncula (250 ± 13.6 ind.m², 0.1%) only occurred at the polyhaline zone
443 of Piraquê-Açú-Mirim estuary. About 25% (8 taxa) of the sampled taxa were rare and
444 represented less than 1% of the relative abundance (Table 2; Table S3).

445 3.3. Temporal changes in the estuary

446 3.3.1. Water column and sediment

449 Water column pH, Total dissolved solids (TDS) and Dissolved oxygen (DO) were
450 similar at Dry and Wet seasons of 2015 and Dry season of 2016 at both haline zones
451 (Table 1). Dissolved Oxygen was lower at the euhaline and polyhaline zones during the
452 Dry season of 2016 (Table 1). The sediment Mud content increased significantly from
453 Dry 2015 and Wet 2015 to Dry 2016 (ANOVA, $F 10.023$, $p 0.001$). Sediment Chlorophyll-
454 *a* was also significantly lower during the Dry season of 2016, if compared to the two
455 previous seasons (ANOVA, $F 4.71$, $p 0.01$; Table S1). Sediment Pheopigments decrease
456 significantly between Dry season of 2015 and Wet season of 2015 (ANOVA $p 0.033$).
457 Sedimentary Mud content, Chlorophyll-*a* and Pheopigments of euhaline and polyhaline
458 zones in Piraquê-Açú-Mirim estuary vary significantly between seasons (PERMANOVA,
459 $F 11.295$, $p 0.001$; Table S1).

460 Temporal changes in sediment Chlorophyll-*a* and Pheopigments were influenced
461 by salinity in euhaline and polyhaline zones, respectively (Multiple linear regression F
462 2.520 ; $p 0.027$; $F -3.060$; $p 0.01$). Changes in Mud content (Multiple linear regression F
463 2.394 ; $p 0.034$) was influenced by temperature in euhaline zone. Changes in Mud content
464 (Multiple linear regression $F 4.034$; $p 0.002$) and Pheopigments (Multiple linear
465 regression $F -2.202$; $p 0.05$) were influenced by temperature in polyhaline zone.
466 Sedimentary properties (Mud content, Total organic content, Calcium carbonate,
467 Chlorophyll-*a* and Pheopigments) in euhaline and polyhaline zones were similar with
468 different changes across the Dry 2015, Wet 2015 and Dry 2016 seasons in Piraquê-Açú-
469 Mirim estuary (PERMANOVA, $F 1.1101$ $p 0.336$).

470 3.3.2. Macrofaunal assemblages

472 Seasonal changes on macrofaunal density decreased significantly between Dry
473 season of 2015 than Wet season of 2015 ($p 0.007$), and with Dry season of 2016 ($p 0.002$)
474 in both haline zones (Figure 5). Macrofaunal richness decreased significantly between
475 Dry season of 2015 than Wet season of 2015 ($p 0.000$), and to Dry season of 2016 (p
476 0.001) in both haline zones. Macrofaunal diversity Shannon decreased significantly from
477 the Dry to Wet seasons of 2015 ($p 0.028$), whereas macrofaunal evenness (J') increase

478 significantly in Dry season of 2015 and 2016 (p 0.008). Macrofaunal assemblages of
479 euhaline and polyhaline zones vary significantly between seasons in Piraquê-Açú-Mirim
480 estuary (PERMANOVA, F 11.295, p 0.001; Figure 5, Table S2).

481 Macrofaunal composition markedly changed across seasons in the Piraquê-Açú-
482 Mirim estuary. During the Dry and Wet season of 2015, Magelonidae, Sternaspidae,
483 Capitellidae, Goniadidae and Paraonidae dominated the euhaline (91%) and polyhaline
484 (87.8-90%) zones. However, the top five ranked taxa changed during the Dry season of
485 2016, with Oligochaete becoming a dominant taxa, with a marked decrease in Paraonidae
486 at the euhaline and polyhaline zones (Table 2). In overall, during the Dry season of 2016
487 there was a decrease in the dominance of the top ranked macrofaunal taxa (<84%), if
488 compared to the two previous seasons Dry 2015 (>87%) and Wet 2015 (~90%).

489 Sixteen macrofaunal taxa only occurred in a specific season, and most of them had
490 low relative abundances. Eight taxa (25% of total taxa) only occurred during the Dry
491 season of 2015, while the mussel Vitrinellidae only occurred in the Wet season of 2015,
492 all in low relative abundances (<0.1%). Seven taxa only occurred during the Dry season
493 of 2016, six in low relative abundances, with Oligochaete in high relative abundance to
494 euhaline zones (5.9%) and polyhaline zones (7.8%) to both haline zones, being a top five
495 ranked taxa in Piraquê-Açú-Mirim estuary (Table 2).

496 Water temperature influence the increase in Macrofaunal Pielou J' in euhaline
497 zones (Multiple linear regression F 3.217, p 0.007), and the decrease in Macrofaunal
498 Richness in polyhaline zones (Multiple linear regression F -3.889, p 0.002). Macrofaunal
499 assemblages in euhaline and polyhaline zones were similar (dominant taxa) across the
500 Dry 2015, Wet 2015 and Dry 2016 seasons in Piraquê-Açú-Mirim estuary
501 (PERMANOVA, F 1.0386, p 0.406).

502

503 3.3.3. *Multivariate analysis*

504 Multivariate analysis revealed a marked seasonal change in benthic assemblages
505 in the Piraquê-Açú-Mirim estuary (ANOSIM, R 0.305, p 0.001). Macrofaunal
506 assemblages differed between seasons (Dry 2015, Wet 2015 and Dry 2016;
507 PERMANOVA, Pseudo- F 11.693, p 0.001). The dissimilarity was mainly influenced by
508 13 of the 32 macrofaunal taxa (Global Test, R 0.951, p 0.1%). Annelids mostly influenced
509 the observed seasonal changes with the 10 top ranked taxa (Figure 6; Table 2).
510 Magelonidae, Spionidae, Sternaspidae, Nereididae and Goniadidae decreased in density
511 across the seasons in euhaline zones and polyhaline zones. Paraonidae decreased in
512 density from the Dry season of 2015 to the Wet season of 2015 and were absent in the
513 Dry season of 2016 in both zones. Oligochaete only occurred in the Dry season of 2016 in
514 euhaline and polyhaline zones of Piraquê-Açú-Mirim estuary (Figure 6; Table 2).

515 Macrofaunal assemblages in the euhaline zones and polyhaline zones were
516 dominated by the polychaetes Magelonidae, Sternaspidae, Capitellidae and Goniadidae
517 (46.3%; SIMPER analysis). Macrofaunal composition were influenced by the decrease in
518 density of the top dominant taxa (Magelonidae, Sternaspidae, Capitellidae, Goniadidae)
519 and less representative taxa (Spionidae, Nereididae, Phyllodocidae, Scalibregmatidae and
520 Nemertea), as well the increase of Pilargidae and Cossuridae across Dry season of 2015
521 to Dry season of 2016. Change in macrofaunal assemblage composition between seasons
522 were influenced by the absence of Paraonidae and Tellinidae in Dry season of 2016
523 compared to Dry and Wet seasons of 2015 of Piraquê-Açú-Mirim estuary (Figure 6; Table
524 2).

525 Sedimentary mud content contributed to the seasonal changes on macrofaunal
526 assemblages (DISTLM, Pseudo- F 13.392, p 0.001; Table 3). Changes in mud content
527 explained 12.7% of macrofaunal assemblage variation (BEST R 0.107; Table 4, Figure

528 7).

529 Water temperature influence significantly the decrease in macrofaunal density in
530 euhaline zones and polyhaline zones. Water temperature in the euhaline zone influence
531 the decrease in density of Phyllodocidae and Cirratulidae (Multiple linear regression
532 ANOVA F 14.500, *p* 0.001), whereas in the polyhaline zones influence the decrease in
533 density of Paraonidae, Lumbrineridae, Goniadidae and Phyllodocidae (Multiple linear
534 regression ANOVA F 45.484, *p* 0.000). The polychaete Phyllodocidae was the unique
535 taxa influenced by temperature in euhaline zones and polyhaline zones.

536

537 **4. Discussion**

538

539 Changes in rainfall patterns, with increases in flood and drought events, are
540 expected in response to climatic change (IPCC, 2001; Dai, 2011, 2013). The 21st century
541 is expected to have an increase in frequency and intensity of droughts, mostly influenced
542 by decrease in rainfall rates and increases in potential evapotranspiration (Dai, 2011,
543 2013; Cook et al., 2014). Evidences of warming at all Brazilian marine ecoregions
544 suggests that most of the Brazilian estuaries are under global warming effects, with this
545 study evidencing that drought events can intensify these changes during the dry seasons
546 (austral winter; Bernardino et al., 2015; Pampuch et al., 2016). The Piraquê-Açú-Mirim
547 estuary is under a marked rainfall oscillation, with more frequent strong rainfall anomaly
548 during in wet seasons. Heavy rainfall, which can cause floods, decrease salinity and
549 temperature, which can affect benthic assemblages (Montagna et al., 2002 Saifullah et al.,
550 2016). However, the years of 2015 and 2016 were markedly dryer than if compared to the
551 historical data from the last 60 years in the region, with rainfall volumes 3 to 8 times
552 lower than average. This 2015-2016 drought occurred during a very strong El-niño, the
553 highest in this century (> 2.0 ; ggweather, 2017). El-Niño influences local weather
554 worldwide and mostly leads to increased drought risk (Grimm et al., 1998; Dai, 2013).
555 Warms episodes of El-niño are more frequent, persistent and intense since 70', compared
556 to the previous 100 years (IPCC, 2001), which shows the possibility of other strong
557 drought in the coming decades. Drought can be characterized as a decline in rainfall below
558 the mean monthly precipitation, increases in evapotranspiration, or a combination of the
559 two (Cook et al., 2014). Mean values over a prescribed 30-year interval are sufficient to
560 filter inter-annual fluctuations and anomalies (Hare, 1979). In estuaries, drought seasons
561 may affect estuarine ecosystems by increasing salinity and temperature seasons due to the
562 lower fresh water flux from continental drainage and rainfall (McLusky and Elliott, 2004;
563 McLaughlin et al., 2009). The low rainfall during the drought event reduce fresh water
564 presence, increase marine water residence time and evapotranspiration, with resulting
565 salinization within the estuary (Dai, 2013; Saifullah et al., 2016).

566

567 Water salinity and temperature are related to rainfall changes, with inverse relation
568 with rainfall variations (Palmer et al., 2015). In our study, salinity varied less at the
569 euhaline zones than the polyhaline zones, with higher values in euhaline zones.
570 Temperature was lower in euhaline zones than polyhaline zones at dry and wet seasons
571 of 2015 and Dry season of 2016, and temperature varied more at euhaline zones than
572 polyhaline zones. The decrease in salinity range with tidal oscillation in the euhaline zone
573 during the dry season of 2016, and the increase in temperature in euhaline and polyhaline
574 zones across seasons indicate a higher marine water intrusion in Piraquê-Açú-Mirim
575 estuary. During drought seasons water temperature increase, reducing the dissolved
576 oxygen solubility and mix with coastal water (Attrill and Power, 2000; Enquist et al.,
577 2003; Stow et al., 2005). Associated with the low rates of oxygen, the high temperature
increase oxygen demand by benthic biota, which can promote hypoxia (< 2 mg/L), as well

578 hypoxia-derived mortality of the biota (Brown et al., 2004; Harris et al., 2006; Vaquer-
579 Sunyer and Duarte, 2008). The low dissolved oxygen (<1 mg/L) at euhaline zones and
580 polyhaline zones may influence the decrease in benthic diversity in the Piraquê-Açú-
581 Mirim estuary at the Dry season of 2016.

582 Climate change will affect salinity, temperature, turbidity and nutrient availability,
583 which can impact primary production (Attrill and Power, 2000; IPCC, 2001). The scarcity
584 of nutrients during low rainfall and drought years can lead to lower Chlorophyll-*a*
585 variability (Abreu et al., 2010). The drought and El-niño likely influenced the low
586 Chlorophyll-*a* and pheopigments at both euhaline and polyhaline zones across all seasons
587 in the Piraquê-Açú-Mirim estuary (Attrill and Power, 2000; Drake et al., 2002; Grilo et
588 al., 2009; Abreu et al., 2010). Drought may act differently in each estuary, ranging from
589 major influences, as ENSO, to regional changes in precipitation and evapotranspiration.
590 Particle sedimentation in estuaries depend on aggregation dynamics, mostly influenced
591 by particle concentration, size, fluid dynamics and salinity (Eisma 1986; Mari 2008; Mari
592 et al., 2012). Droughts can change sedimentation in estuaries generally increasing silt
593 fractions of sediment towards the mouth of an estuary (MacKay et al., 2010; Mari et al.,
594 2012; Dittmann et al., 2015). Additionally, salinization and pH increases during droughts
595 modify the aggregation processes of adsorption and flocculation, which may promote fast
596 sinking of aggregates (Eisma, 1986; Komar, 1996; Mari et al., 2012). The marine water
597 intrusion in polyhaline zones in the Piraquê-Açú-Mirim estuary likely contributed to the
598 increase of mud content at both euhaline zones and polyhaline zones in the Piraquê-Açú-
599 Mirim estuary at the Dry season of 2016.

600 Benthic estuarine assemblages exhibit changed patterns of distribution, abundance
601 and structure during climatic events (Drake et al., 2002; Pillay and Perissinotto, 2008;
602 Pollack et al., 2011; Medeiros et al., 2016). These changes reorganize ecosystem functions
603 on regional and/or local scales, which can cause trophic cascade (Folke et al., 2004).
604 Salinity is an important factor controlling benthic estuarine assemblages, estuarine
605 environments acts as a filter, supporting species with functional or phenotypic
606 characteristics suitable for establishment and persistence in each haline zone (Pillay and
607 Perissinotto, 2008; Barros et al., 2012; Mariano and Barros, 2015). The power and
608 frequency increase of drought events can influence benthic assemblages by changes in
609 sediment and physiological stress, with can results in changes in biogeochemical process
610 and ecosystem functions (Elliott and Whitfield, 2011; Mcleod et al., 2011; Dittmann et
611 al., 2015; Montagna and Palmer, 2012). Grain size is a fundamental influence to
612 macrofaunal composition in soft sediments (Carvalho et al., 2017). The increase in
613 sediment complexity usually contain higher diversity of macrofaunal taxa, while the
614 reduction in grain size decrease the space between sediment, where benthic biota lives
615 (Gray and Elliott, 2009). The decrease in grain size reduce permeability, oxygen
616 penetration depth and nutrient rates (Pratt et al., 2014). Increase in mud content decrease
617 macrofaunal density and species richness (Thrush et al., 2003; Anderson 2008), which
618 affects ecological functions, due changes in benthic structure and loss of key species
619 (Pratt et al., 2014). In the present study mud content was high during all seasons, with
620 increase in dry season of 2016, that influences seasonal changes on macrofaunal
621 assemblages (total biomass, Richness, Pielou J' and Shannon H') of Piraquê-Açú-Mirim
622 estuary. Temperature of water has been reported as being a major controlling variable for
623 species, which could affect the metabolism, growth and reproduction (Attrill and Power,
624 2010; Bishop et al., 2006; Dolbeth et al., 2011; Munguia et al., 2013). The increase in
625 temperature of euhaline and polyhaline zones at Dry 2016 compared to Dry 2015 and Wet
626 2015 influences the decrease in Macrofaunal Richness and increase in Pielou J', while
627 salinity did not influence macrofaunal changes of Piraquê-Açú-Mirim estuary.

628 Similar habitats (e.g. healthy mudflats within the same haline zone) should have
629 a pool of similar species (both functionally and morphologically) and may reflect local
630 environmental filters that regulate the dispersion of species along haline gradients
631 (Medeiros et al., 2016). Salinity is considered the most important variable to macrofaunal
632 assemblages structure in estuaries, but other variables (e.g. temperature and grain size)
633 can be more important to these changes, which evidence that macrofaunal assemblages
634 are not effected in a simple or linear way (Teske and Wooldridge, 2003; MacKay et al.,
635 2010; Palmer et al., 2015; Medeiros et al., 2016). Drought events can lead to marked
636 changes in estuarine assemblages (IPCC, 2001; Pillay and Perissinotto, 2008, 2009;
637 MacKay et al., 2010; Dittmann et al., 2015; González-Ortegón et al., 2015; Table 5,
638 references therein). High presence of marine opportunistic taxa, including Capitellidae
639 and Oligochaete evidence salinity intrusion and changes in macrofaunal composition
640 (Hastie and Smith, 2006; Pillay and Perissinotto, 2008; MacKay et al., 2010; Table 5,
641 references therein). Euhaline and polyhaline zones of Piraquê-Açú-Mirim estuary were
642 dominated by the polychaets Magelonidae, Sternaspidae and Capitellidae, with shifts in
643 taxa composition (Oligochaete and Paraonidae). Salinity of water was not related to any
644 macrofaunal assemblages parameter across seasons, whereas temperature was related to
645 macrofaunal richness and Pielou J', and taxa distribution (e.g. Phyllodocidae and
646 Cirratulidae) in euhaline and polyhaline zones of Piraquê-Açú-Mirim estuary.

647 Brazil has 8,000 km of coast line with over one hundred estuaries from the tropical
648 equator in the North to South lagoons, with a general lack of long term ecological
649 monitoring programs (Bernardino et al., 2016). Geomorphological and oceanographic
650 conditions changes on Brazilian estuaries are evident, where dominated by riverine inputs
651 are more frequent in the N and NE, while bays, drowned estuaries and lagoons in SE and
652 S (Dominguez, 2006; Bernardino et al., 2016). This monitoring is one of the most
653 extensive studies ever carried within Brazilian estuaries, totalizing 14 months of
654 monitoring (May 2015 to June 2016; Bernardino et al., 2015, 2016). The temporal
655 analysis of euhaline and polyhaline zones of Piraquê-Açú-Mirim estuary provided
656 significant advance in the understanding of natural climatic oscillations on benthic
657 assemblages of east Brazilian estuaries. The system recovery can be faster to specific
658 permanent changes, depending to the intensity of the event and health of the estuary. All
659 of these evidence the necessity to understand the impacts caused by droughts and floods
660 from other impacts (natural or anthropogenic; IPCC, 2001; Worm et al., 2006; Table 5,
661 references therein). However, long-term assessment of natural oscillation, as droughts,
662 elucidated patterns changes and be useful to overall management, providing more
663 accurate models (Dolbeth et al., 2011; Elliott and Whitfield, 2011; Mcleod et al., 2011;
664 Bernardino et al., 2016).

665 Our results corroborate that temperature influence benthic shifts during drought.
666 Despite faunal composition shifts, macrofaunal density, biomass, richness, H' and J'
667 decrease, which evidence a decrease in diversity and dominant taxa density. Studies still
668 needed to better understand the relationship between weather-dependent variables and
669 benthic assemblages, as well factors controlling their variability.

670 **Conflict of interest**

671 The authors declare no actual or potential conflict of interest.

672 **Contribution**

673 LEOG participated in sampling and analyzed data. LEOG and AFB wrote the manuscript.
674 All authors have approved the final article.

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Table captions

Table 1. Changes of pH, Total of dissolved solids (TDS) and Dissolved oxygen (mg/L, DO) in euhaline and polyhaline zones between dry and wet seasons of 2015 and dry season of 2016 at Piraquê-Açú-Mirim estuary.

	<i>Euhaline zone</i>			<i>Polyhaline zone</i>		
	pH	TDS	DO	Ph	TDS	DO
May 2015	-	-	-	-	-	-
June 2015	-	-	-	-	-	-
July 2015	-	-	-	-	-	-
Dry1 August 2015	8.7±0	25.1±1.4	5.4±0	8.7±0	26.7±0.1	5.8±0.3
September 2015	7.8±0	27.8±0	3.9±0.3	8.1±0	25.4±0	3.2±0.2
October 2015	8.2±0	29.1±0	3±0.2	8.3±0.1	28±0.1	2±0.1
November 2015	8±0.1	29.6±0	1.9±0	8.3±0.1	29.2±0	1.2±0.2
December 2015	8±0	29.1±0.1	6.4±0.2	7.6±0	27±0	3.9±0.2
Wet 2015 January 2016	8.1±0.1	24.9±0.2	3.2±0.7	7.7±0	17.8±0.2	3.3±0
February 2016	8.8±0.4	28±0.1	1.7±0.1	7.8±0	25.8±0.2	1.4±0
March 2016	8.4±0	29.1±0.1	2.4±0.5	8.0±0.1	27.6±0.1	1±0.1
April 2016	8.3±0	29.4±0	0.7±0.3	7.9±0	27.8±0.2	0.6±0
Dry2 May 2016	8.9±0.2	30.2±0	<LQ	8±0	29.8±0	<LQ
June 2016	9.1±0.3	30.5±0	<LQ	8.3±0	30±0.1	<LQ

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Table 2. Density (ind.m²) and Relative abundance (%) of macrofaunal assemblages in euhaline and polyhaline zones between dry and wet seasons of 2015 and dry season of 2016 at the Piraquê-Açú-Mirim estuary. \$ = top ranked macrofaunal species. P = Polychaete, O = Oligochaete, M = Mollusk, C = Crustacean.

Taxa	<i>Euhaline zone</i>						<i>Polyhaline zone</i>					
	Dry 2015		Wet season		Dry 2016		Dry 2015		Wet season		Dry 2016	
	Density (SD)	Rel %	Density (SD)	Rel %	Density (SD)	Rel %	Density (SD)	Rel %	Density (SD)	Rel %	Density (SD)	Rel %
Magelonidae P \$	1202 (918)	47.8	619.8 (593.9)	52.1	253.5 (426.2)	35.6	885.4 (675.8)	47.9	576.4 (655.9)	58.0	270.8 (282.7)	43.3
Spionidae P	64.6 (148.2)	2.6	1.7 (14.7)	0.1	6.9 (29)	1.0	52.1 (87)	2.8	10.4 (62.1)	1.0	13.9 (49.8)	2.2
Sternaspidae P \$	800 (868.2)	31.8	288.2 (432.8)	24.2	66 (121.3)	9.3	360.4 (387.9)	19.5	158 (229.8)	15.9	41.7 (79.1)	6.7
Cossuridae P	4.2 (22.6)	0.2	6.9 (28.8)	0.6	20.8 (70)	2.9	12.5 (37.8)	0.7	17.4 (60.5)	1.7	13.9 (49.8)	2.2
Nereididae P	29.2 (962.5)	1.2	6.9 (28.8)	0.6	34.7 (97)	4.9	58.3 (106.6)	3.2	8.7 (32)	0.9	3.5 (20.8)	0.6
Capitellidae P \$	112.5 (192.1)	4.5	95.5 (228.4)	8.0	163.2 (233)	22.9	137.5 (211.8)	7.4	85.1 (177.8)	8.6	97.2 (140.5)	15.6
Goniadidae P \$	108.3 (140.9)	4.3	71.2 (86.1)	6.0	34.7 (64.1)	4.9	95.8 (128.9)	5.2	50.4 (95.4)	5.1	66 (101.3)	10.6
Pilargidae P	16.7 (42.9)	0.7	15.6 (51.1)	1.3	31.3 (75.4)	4.4	18.8 (64.4)	1.0	6.9 (28.8)	0.7	13.9 (49.8)	2.2
Paraonidae P \$	62.5 (101.6)	2.5	12.2 (52.1)	1.0	0.0 (0.0)	0.0	145.8 (167.8)	7.9	29.5 (57.4)	3.0	0.0 (0.0)	0.0
Cirratulidae P	2.1 (16.1)	0.1	1.7 (14.8)	0.1	0.0 (0.0)	0.0	10.4 (41.8)	0.6	5.2 (25.2)	0.5	3.5 (20.8)	0.6
Lumbrineridae P	18.8 (68.4)	0.7	0.0 (0.0)	0.0	0.0 (0.0)	0.0	2.1 (16.1)	0.1	0.0 (0.0)	0.0	0.0 (0.0)	0.0
Amphinomidae P	0.0 (0.0)	0.0	0.0 (0.0)	0.0	0.0 (0.0)	0.0	2.1 (16.1)	0.1	0.0 (0.0)	0.0	0.0 (0.0)	0.0
Scalibregmatidae P	18.8 (45)	0.7	15.6 (55.3)	1.3	3.5 (20.8)	0.5	2.1 (16.1)	0.1	0.0 (0.0)	0.0	0.0 (0.0)	0.0
Phyllodocidae P	18.8 (60.1)	0.7	3.5 (20.7)	0.3	0.0 (0.0)	0.0	8.3 (31.4)	0.5	0.0 (0.0)	0.0	0.0 (0.0)	0.0
Sabellidae P	0.0 (0.0)	0.0	0.0 (0.0)	0.0	3.5 (20.8)	0.5	0.0 (0.0)	0.0	0.0 (0.0)	0.0	13.9 (83.3)	2.2
Sabellariidae P	0.0 (0.0)	0.0	0.0 (0.0)	0.0	0.0 (0.0)	0.0	0.0 (0.0)	0.0	0.0 (0.0)	0.0	3.5 (20.8)	0.6
Oligochaete O	0.0 (0.0)	0.0	0.0 (0.0)	0.0	41.7 (126.8)	5.9	0.0 (0.0)	0.0	0.0 (0.0)	0.0	48.6 (153.2)	7.8
Gammaridae C	2.1 (16.1)	0.1	0.0 (0.0)	0.0	0.0 (0.0)	0.0	8.3 (31.4)	0.5	0.0 (0.0)	0.0	0.0 (0.0)	0.0
Ocypodidae C	4.2 (22.6)	0.2	5.2 (32.8)	0.4	17.4 (53.1)	2.4	2.1 (16.1)	0.1	3.5 (20.7)	0.3	0.0 (0.0)	0.0
Atyidae C	0.0 (0.0)	0.0	0.0 (0.0)	0.0	0.0 (0.0)	0.0	0.0 (0.0)	0.0	0.0 (0.0)	0.0	3.5 (20.8)	0.6
Penaeidae C	10.4 (34.9)	0.4	0.0 (0.0)	0.0	0.0 (0.0)	0.0	2.1 (16.1)	0.1	0.0 (0.0)	0.0	0.0 (0.0)	0.0
Cironalidae C	0.0 (0.0)	0.0	0.0 (0.0)	0.0	10.4 (62.5)	1.5	0.0 (0.0)	0.0	0.0 (0.0)	0.0	0.0 (0.0)	0.0
Alpheidae C	0.0 (0.0)	0.0	0.0 (0.0)	0.0	0.0 (0.0)	0.0	0.0 (0.0)	0.0	0.0 (0.0)	0.0	3.5 (20.8)	0.6
Cumacea C	0.0 (0.0)	0.0	0.0 (0.0)	0.0	0.0 (0.0)	0.0	0.0 (0.0)	0.0	0.0 (0.0)	0.0	3.5 (20.8)	0.6
Vitrinellidae M	0.0 (0.0)	0.0	0.0 (0.0)	0.0	0.0 (0.0)	0.0	0.0 (0.0)	0.0	10.4 (74.9)	1.0	0.0 (0.0)	0.0
Corbiculidae M	4.2 (22.6)	0.2	17.4 (76.5)	1.5	10.4 (76.5)	1.5	0.0 (0.0)	0.0	10.4 (45.7)	1.0	3.5 (20.8)	0.6
Solecurtidae M	0.0 (0.0)	0.0	10.4 (34.8)	0.9	3.5 (20.8)	0.5	0.0 (0.0)	0.0	13.9 (49.4)	1.4	6.9 (29)	1.1
Mytilidae M	0.0 (0.0)	0.0	3.5 (20.8)	0.3	3.5 (20.8)	0.5	0.0 (0.0)	0.0	3.5 (20.7)	0.3	0.0 (0.0)	0.0

Nuculidae M	6.3 (27.5)	0.2	0.0 (0.0)	0.0	0.0 (0.0)	0.0	2.1 (16.1)	0.1	0.0 (0.0)	0.0	0.0 (0.0)	0.0
Tellinidae M	14.6 (46.6)	0.6	6.9 (35.7)	0.6	0.0 (0.0)	0.0	14.6 (40.5)	0.8	3.5 (20.8)	0.4	0.0 (0.0)	0.0
Nemertea	12.5 (59.6)	0.5	6.9 (35.7)	0.6	6.9 (29)	1.0	25 (55.4)	1.4	0.0 (0.0)	0.0	13.9 (65.3)	2.2
Sipuncula	0.0 (0.0)	0.0	0.0 (0.0)	0.0	0.0 (0.0)	0.0	4.2 (22.6)	0.2	0.0 (0.0)	0.0	0.0 (0.0)	0.0

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Table 3. Distance-based linear model (DistLM) of Bray-Curtis similarities on macrofaunal assemblages and sedimentary properties (Mud content, Total organic content, Calcium carbonate, Chlorophyll-*a* and Pheopigments) between dry and wet seasons of 2015 and dry season of 2016 in the Piraquê-Açú-Mirim estuary. Bold = *p* significant.

n=3	SS(trace)	Pseudo-F	<i>p</i>	Prop.
Mud content	13629	13.392	0.001	0.10853
Total organic content	1827.6	1.6247	0.135	1.46E-02
Calcium carbonate	1390	1.2313	0.278	1.11E-02
Chlorophyll- <i>a</i>	2007	1.7867	0.095	1.60E-02
Pheopigments	1442.2	1.2781	0.259	1.15E-02
res.df:	110			

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1035 Table 4. Best correlations of macrofaunal assemblages and sedimentary properties (Mud content, Total
 1036 organic content, Calcium carbonate, Chlorophyll-*a* and Pheopigments) in the Piraquê-Açú-Mirim estuary.
 1037 *P_w* - Weighted Spearman coefficients. Mud = Mud content, TOC = Total organic content, CaCO₃ = Calcium
 1038 carbonate, Chl-*a* = Chlorophyll-*a* and Pheo = Pheopigments.

No. of variables	<i>P_w</i>	Variables
1	0.107	Mud
2	0.103	Mud, CaCO ₃
3	0.066	Mud, TOC, CaCO ₃
3	0.061	Mud, CaCO ₃ , Chl- <i>a</i>
1	0.049	CaCO ₃
2	0.047	Mud, TOC
2	0.04	Mud, Chl- <i>a</i>
3	0.038	Mud, CaCO ₃ , Pheo
2	0.033	Mud, Pheo
4	0.032	Mud, TOC, CaCO ₃ , Chl- <i>a</i>

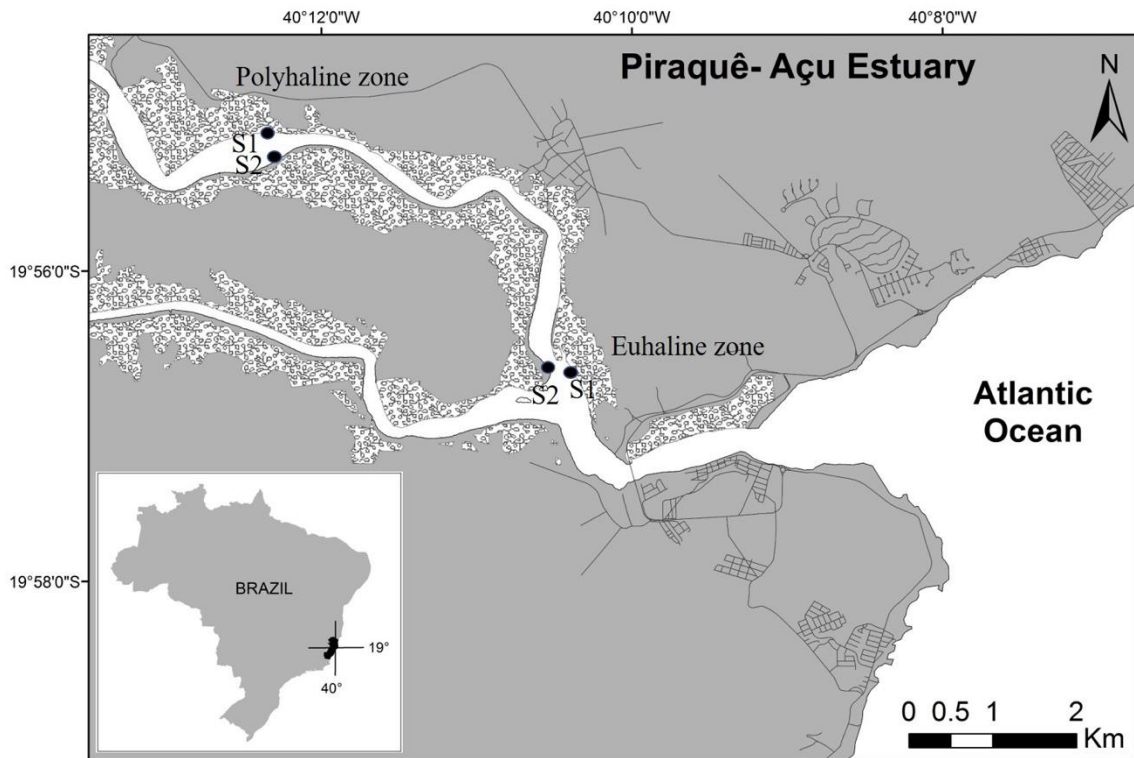
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Table 5. Sites, country and duration of the monitoring program with drought events in estuaries compared to Piraquê-Açú-Mirim estuary. Total = Total sampling events.

Sites	Contry	Duration of the monitiring	Total	Benthic invertebrate	References
Guadalupe estuary	United States	2 years, 3 months first and 2 second year	5	Macrofauna	Montagna and Kalke 1992
Guadalupe estuary	United States	2 years, 3 months first and 2 second year	5	Meiofauna	Montagna and Kalke 1992
Nueces estuary	United States	2 years, 3 months first and 2 second year	5	Macrofauna	Montagna and Kalke 1992
Nueces estuary	United States	2 years, 3 months first and 2 second year	5	Meiofauna	Montagna and Kalke 1992
Nueces estuary	United States	5 years, 4 months/year	20	Macrofauna	Montagna et. al. 2002
Nueces estuary	United States	5 years, 4 months/year	20	Meiofauna	Montagna et. al. 2002
Nueces estuary	United States	8 weeks	-	Macrofauna	Ritter <i>et al.</i> , 2005
Nueces estuary	United States	30 years, 1968-1970 and 1997-1998	10	<i>Macoma spp.</i>	Bishop <i>et al.</i> , 2006
Nueces estuary	United States	Over 14 years	25-114	Macrofauna	Montagna et. al. 2009
Lavaca-Colorado Estuary	United States	~20 years, Quarterly from April 1988 to October 2008	139	Macrofauna	Pollack <i>et al.</i> , 2011
Lavaca-Colorado estuary	United States	>15 years, montly	~180	Macrofauna	Montagna and Palmer 2012
Lavaca-Colorado estuary	United States	>15 years, montly	~180	Epifauna	Montagna and Palmer 2012
Guadalupe estuary	United States	>15 years, montly	~180	Macrofauna	Montagna and Palmer 2012
Guadalupe estuary	United States	>15 years, montly	~180	Epifauna	Montagna and Palmer 2012
Nueces estuary	United States	>15 years, montly	~180	Macrofauna	Montagna and Palmer 2012
Nueces estuary	United States	>15 years, montly	~180	Epifauna	Montagna and Palmer 2012
Nueces Estuary	United States	2 years, different sampling	-	Macrofauna	Montagna et. al. 2015
Nueces Estuary	United States	2 years, different sampling	-	Epifauna	Montagna et. al. 2015
Lavaca-Colorado estuary	United States	>15 years, between 1987 and 2009	-	Macrofauna	Palmer and Montagna 2015
Guadalupe estuary	United States	>15 years, between 1987 and 2009	-	Macrofauna	Palmer and Montagna 2015
Nueces estuary	United States	>15 years, between 1987 and 2009	-	Macrofauna	Palmer and Montagna 2015
Caloosahatchee Estuary	United States	10 years, February 1986 to April 1989, and October 1994 to December 1995	-	Macrofauna	Palmer <i>et al.</i> , 2015
Gulf of Lion	France	>30 years, 1963, 1969, 1972, 1975, 1976 and then every year from 1984 to 1986 and 1993 to 1996	12	Polychaets	Salen-Picard and Arlhac 2002
Rhone river delta	France	3 years, 3 months/year	12	Macrofauna	Salen-Picard <i>et al.</i> , 2003
Mondego estuary	Portugal	>10 years, fortnightly in first 18 months, monthly thereafter	~130	Macrofauna	Dolbeth <i>et al.</i> , 2007
Mondego estuary	Portugal	13 years, January 1993 to January 1997, and January 1999 to December 2005, monthly	~130	<i>Hydrobia ulvae</i>	Cardoso <i>et al.</i> , 2008
Mondego estuary	Portugal	>15 years, January 1993 to September 1995; March 1999 to November 2008, first 18 months fortnightly and monthly	~150	AmphipodS	Grilo <i>et al.</i> , 2009

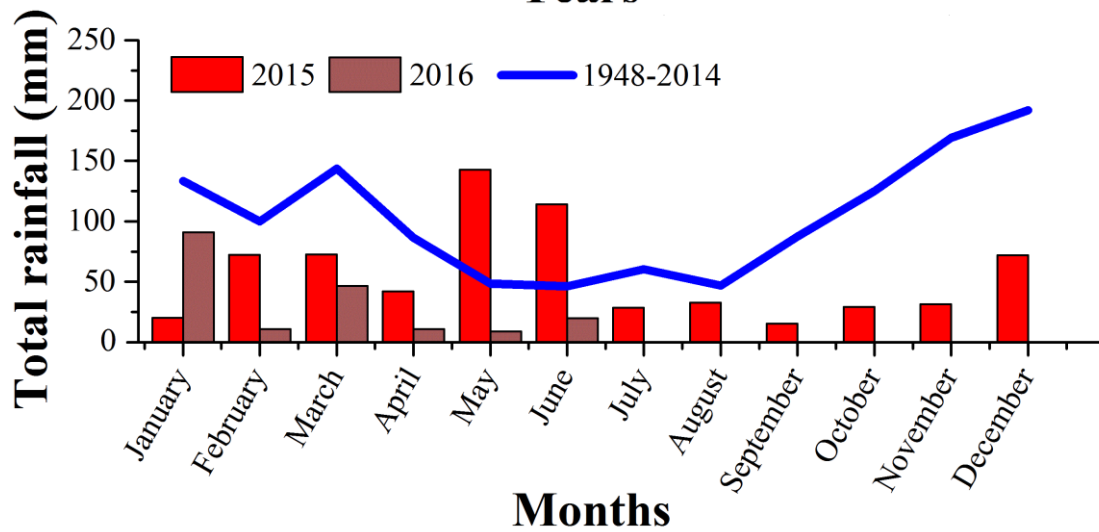
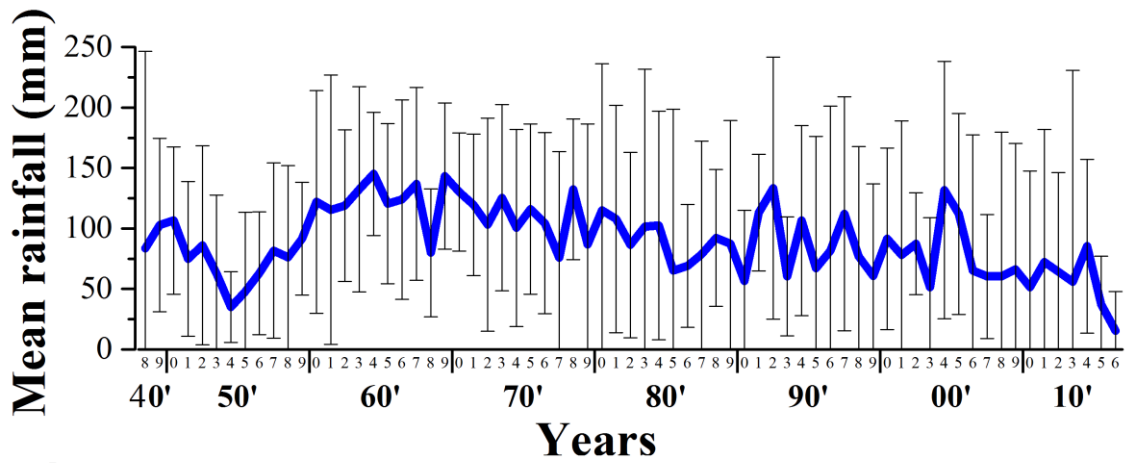
		thereafter			
Mondego estuary	Portugal	8 years, spring tide of 1990, 1992, 1998, 2000, 2002, 2004 to 2006	-	Macrofauna	Neto <i>et al.</i> , 2010
Mondego estuary	Portugal	14 years, fortnightly/first 18 months and monthly thereafter	186	Macrofauna	Dolbeth <i>et al.</i> , 2011
Mondego estuary	Portugal	>15 years, January 1993 to September 1995; March 1999 to November 2008, first 18 months fortnightly and monthly thereafter	~150	Macrofauna	Grilo <i>et al.</i> , 2011
Mondego estuary	Portugal	5 year, 2004 to 2008	-	Macrofauna	Veríssimo <i>et al.</i> , 2012
Mondego estuary	Portugal	5 year, 2004 to 2008	-	Macrofauna	Verissimo <i>et al.</i> , 2013
Mondego estuary	Portugal	10 years, February 1993 to June 1994 (fortnightly) and monthly until 2002	137	Macrofauna	Dolbeth <i>et al.</i> , 2014
Mondego estuary	Portugal	7 years, monthly from January 1999 to December 2005	84	<i>Scrobicularia plana</i>	Verdelhos <i>et al.</i> , 2014
Guadalquivir estuary	Spain	2 years, monthly from May 1997 to April 1999	24	Hyperbenthos	Drake <i>et al.</i> , 2002
Guadalquivir estuary	Spain	9 years, monthly from May 1997 to January 2005	24	Shrimps	González-Ortegón <i>et al.</i> , 2006
Guadalquivir river basin	Spain	12 years, monthly	140	Macrofauna	González-Ortegón <i>et al.</i> , 2015
Hawkesbury estuary	Australia	2 years, 3-4 months/year	7	Macrofauna	Jones 1990
Brunswick estuary	Australia	2 years, December 2000 to December 2002, sampled 1-2 months	16	Macrofauna	Eyre and Ferguson 2005
Brunswick estuary	Australia	2 years, December 2000 to December 2002, sampled 1-2 months	16	Meiofauna	Eyre and Ferguson 2005
Hopkins river estuary	Australia	2 years, 3 times in 1997 and 1 in 1998	4	<i>Soletellina alba</i>	Matthews 2006
Coorong lagoons	Australia	10 years, 1 sample/years	10	Macrofauna	Dittmann <i>et al.</i> , 2015
Murray Mouth	Australia	10 years, 1 sample/years	10	Macrofauna	Dittmann <i>et al.</i> , 2015
Nhlabane estuary	South Africa	3 years, 1 sample at intervals of three months	12	Macrofauna	Mackay and Cyrus 2001
Siyaya estuary	South Africa	3 years, 1 sample at intervals of three months	12	Macrofauna	Mackay and Cyrus 2001
Santa Lucia estuary	South Africa	1 year, 4 months	4	Macrofauna	Pillay and Perissinotto 2008
Santa Lucia estuary	South Africa	2 year, 4 months	5	Meiofauna	Pillay and Perissinotto 2009
Santa Lucia estuary	South Africa	5 years, 2 months/year, 1 sample in 2004 and 2005	8	Macrofauna	MacKay <i>et al.</i> , 2010
Santa Lucia estuary	South Africa	Laboratory experiment with estuarine water	-	<i>Solen cylindraceus</i>	Nel <i>et al.</i> , 2011
Santa Lucia estuary	South Africa	3 years, quarterly from August 2006 to May 2008	7	Meiofauna	Bownes and Perissinotto 2012
Santa Lucia estuary	South Africa	4 years	-	Macrofauna	Pillay and Perissinotto 2013
Piraquê-Açú-Mirim estuary	Brazil	1.5 years, 14 months, monthly	14	Macrofauna	This study

1042 **Figure captions**

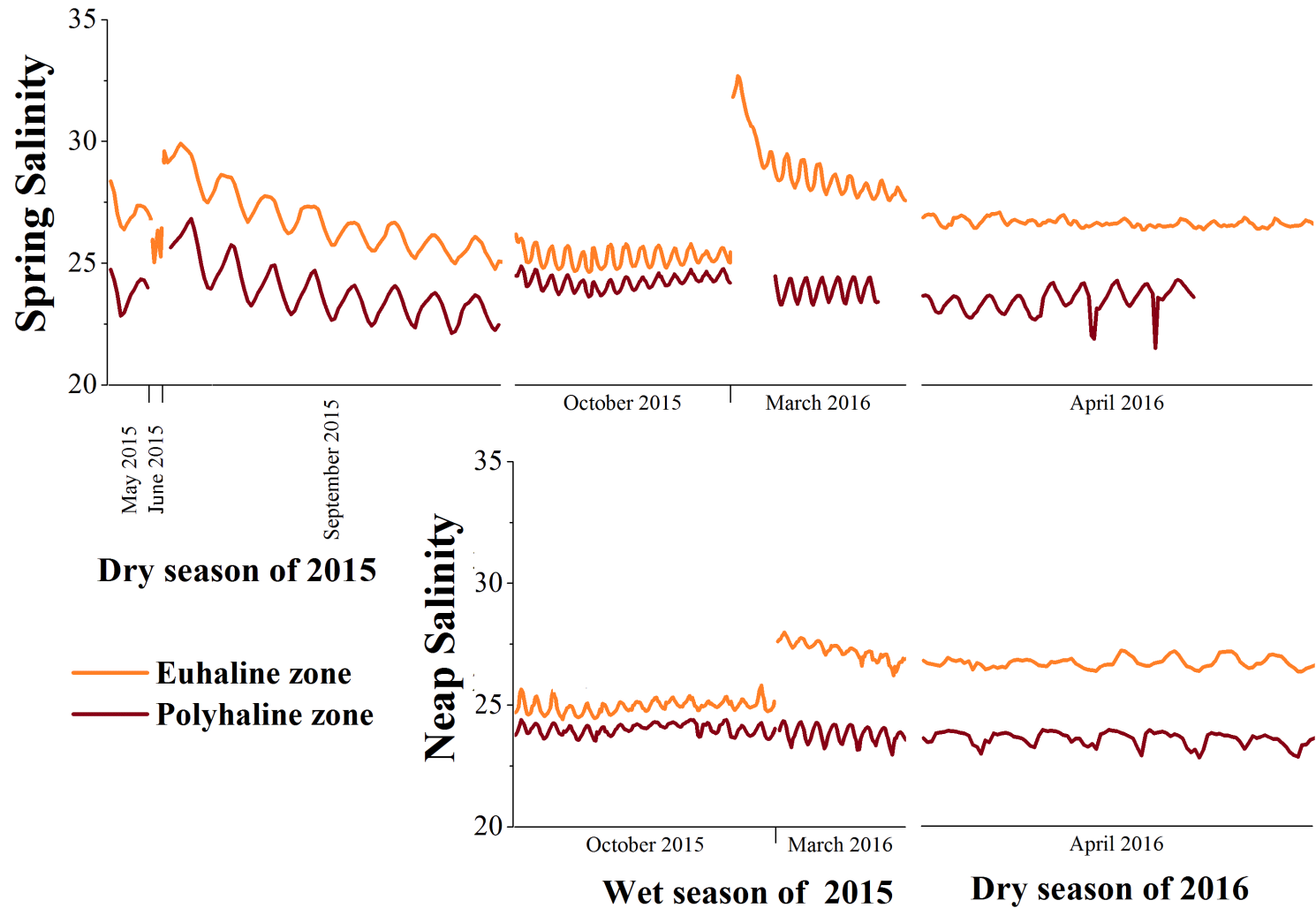


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Figure 1. Map of the Piraquê-Açu-Mirim estuary indicating the locations of sampling sites.

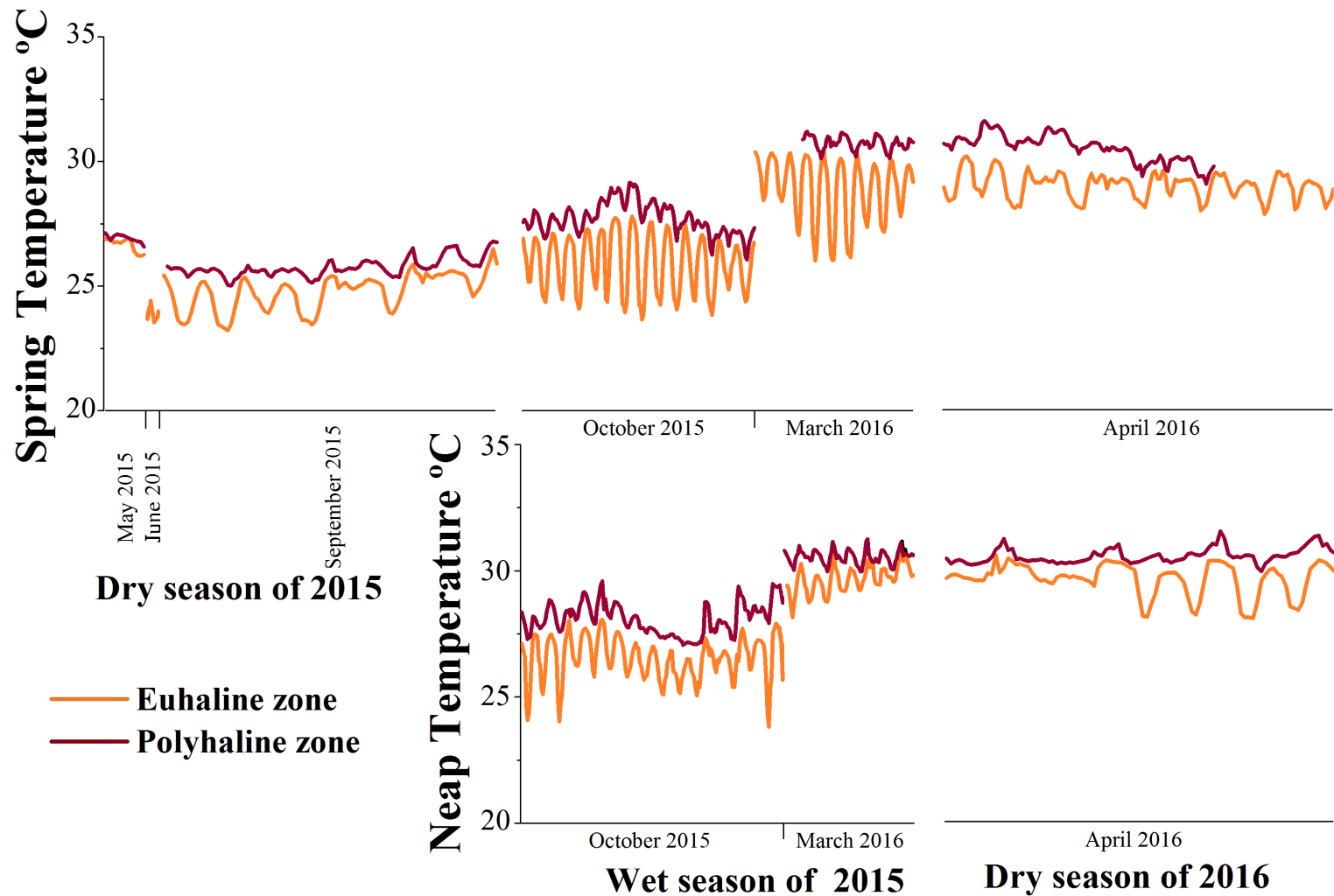


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 1046 Figure 2. Upper: Mean annual rainfall from 1948 to 2016 (ANA and UFES weather stations; 1948 to 2016)
 1047 at Piraquê-Açú-Mirim estuary; and Bottom: monthly total rainfall during this study (ANA and UFES
 1048 weather stations; 2015-2016) and background information (ANA weather stations; 1948 to 2014) from
 1049 Piraquê-Açú-Mirim. Estuary.



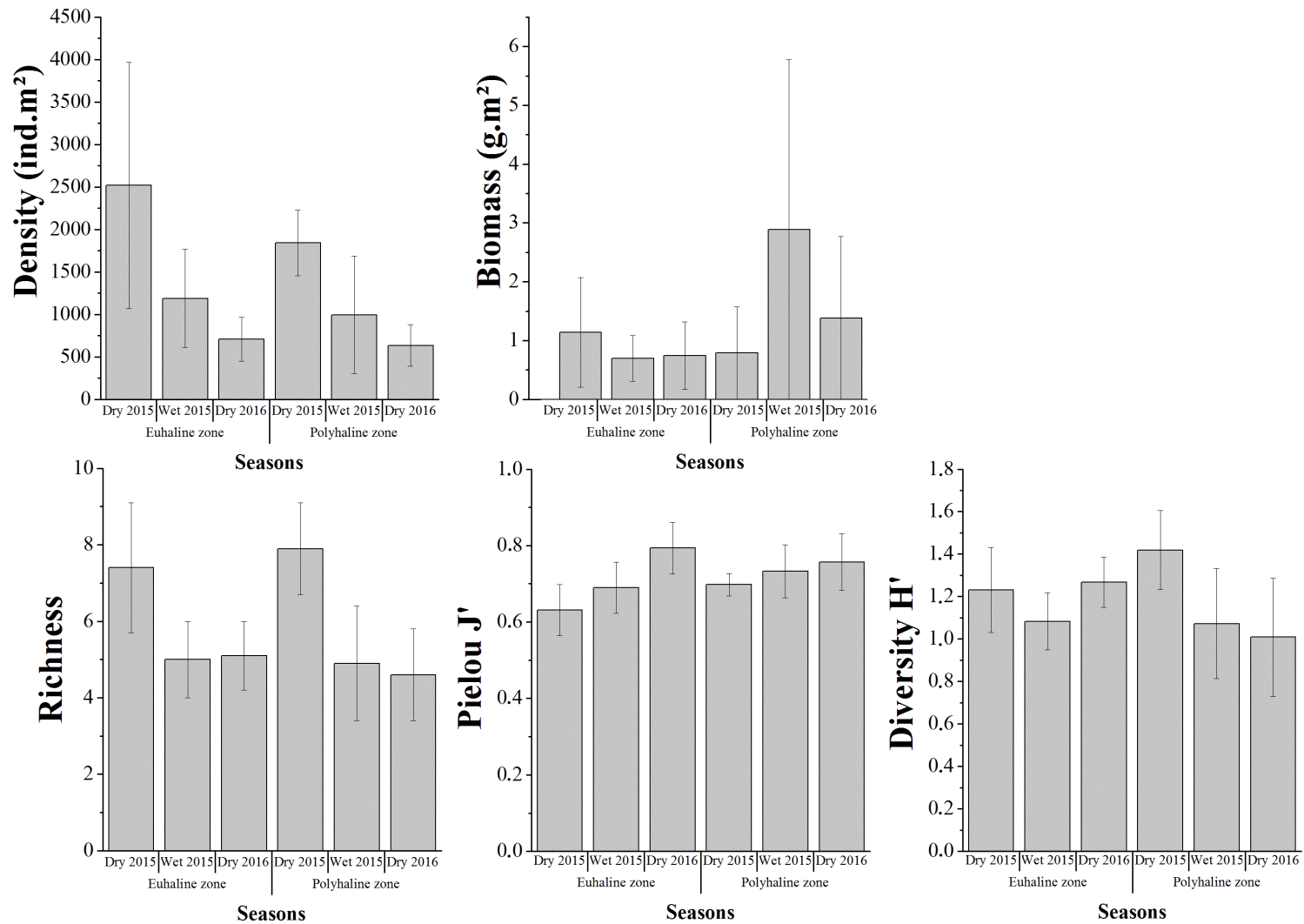
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Figure 3. Spring and neap tides salinity in the monitoring days of Dry and Wet seasons of 2015 and Dry season of 2016 seasons in euhaline and polyhaline zones at Piraquê-Açu-Mirim estuary. Monitoring days at Euhaline zones (40 days Dry season of 2015 (6d), Wet season of 2015 (24d) and Dry season of 2016 (10d)); and Polyhaline zones (35 days; Dry season of 2015 (5d), Wet season of 2015 (22d) and Dry season of 2016 (8d)).



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Figure 4. Spring and neap tides temperature (°C) in the monitoring days of Dry and Wet seasons of 2015 and Dry season of 2016 seasons in euhaline and polyhaline zones at Piraquê-Açú-Mirim estuary. Monitoring days at Euhaline zones (40 days Dry season of 2015 (6d), Wet season of 2015 (24d) and Dry season of 2016 (10d)); and Polyhaline zones (35 days; Dry season of 2015 (5d), Wet season of 2015 (22d) and Dry season of 2016 (8d)).



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Figure 5. Macrofaunal Density (ind.m⁻²), Biomass (g.m⁻²), Richness, Diversity H' and Pielou J' in euhaline zones and polyhaline zones of Dry and Wet seasons of 2015 and Dry season of 2016 at Piraquê-Açú-Mirim estuary.

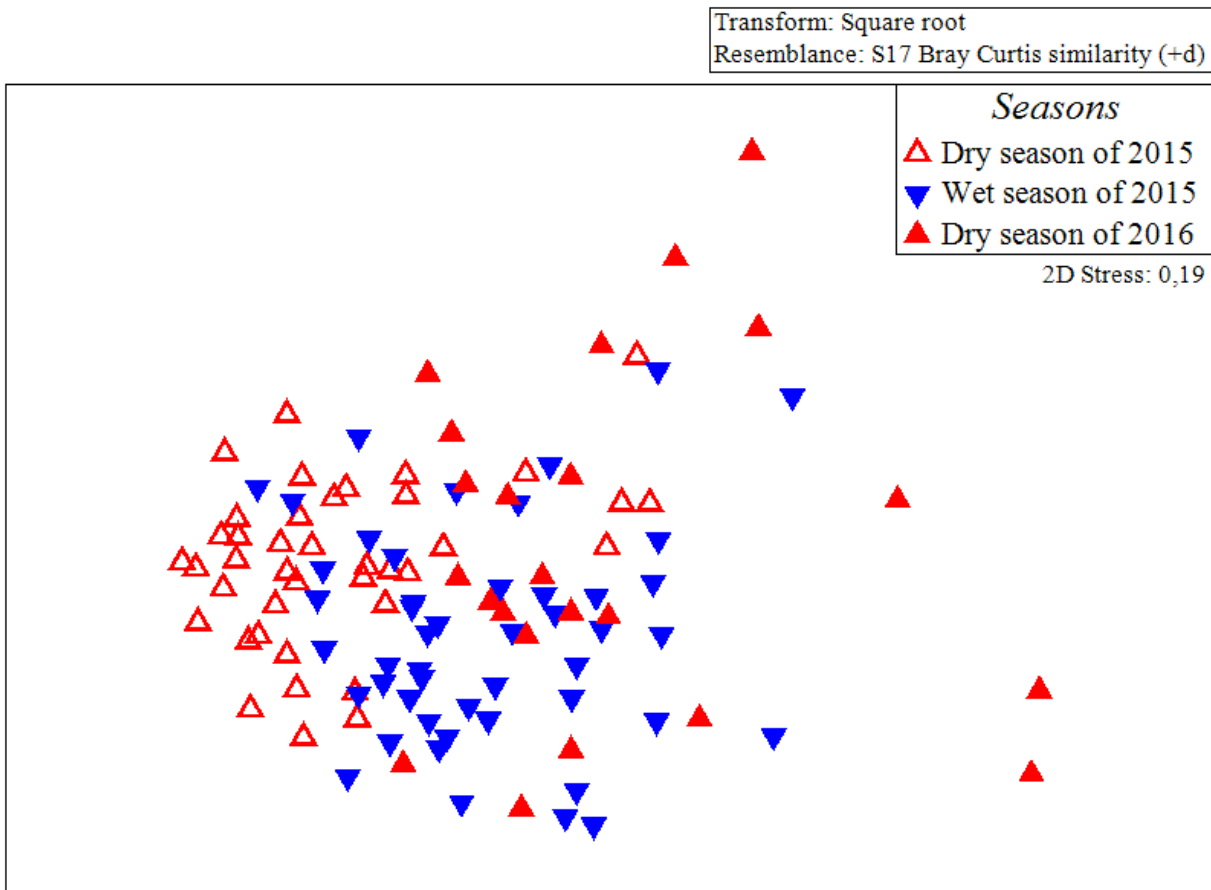


Figure 6. Non-metric multidimensional scaling (MDS) plot of macrofaunal assemblages in euhaline and polyhaline zones at Piraquê-Açu-Mirim estuary.

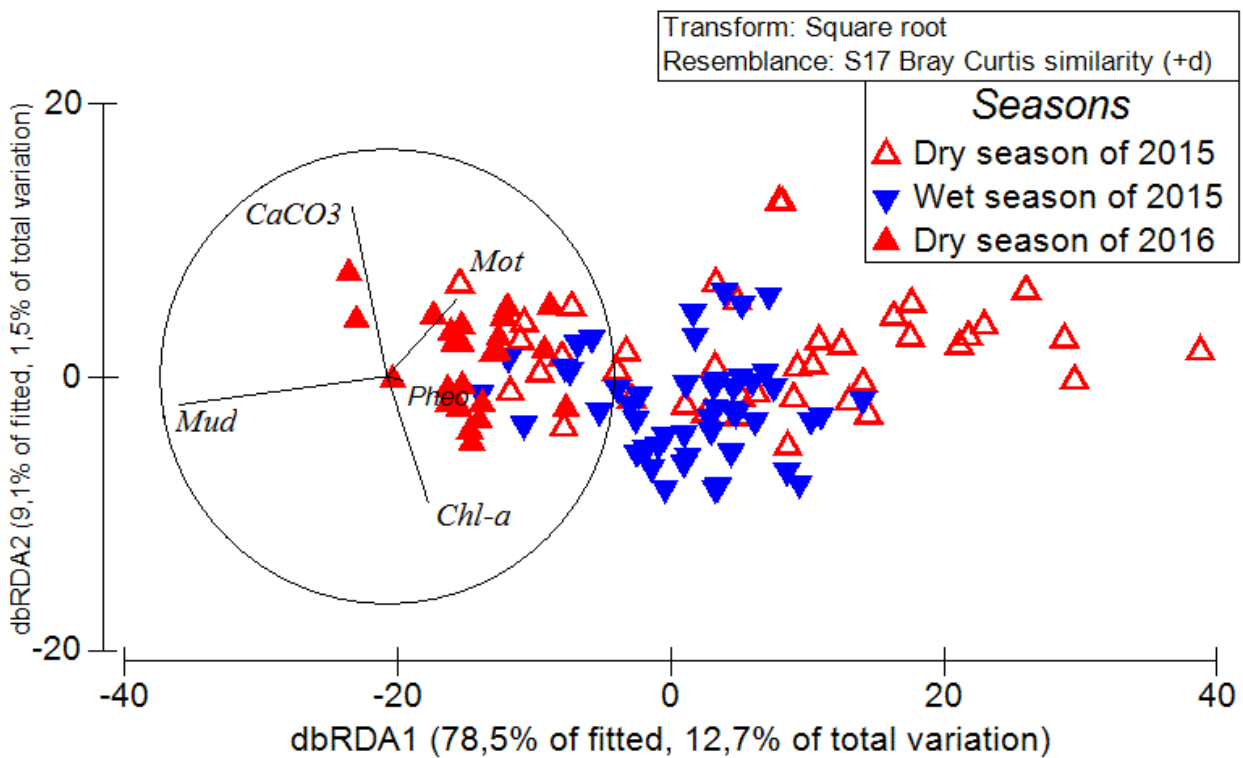


Figure 7. Distance-based linear model plot (dbRDA) using the sedimentary properties to explain macrofaunal assemblages changes in Piraquê-Açu-Mirim estuary. Mud = Mud content, TOC = Total organic content, CaCO₃ = Calcium carbonate, Chl-*a* = Chlorophyll-*a* and Pheo = Pheopigments.

III. CONCLUSÃO

Nossos resultados corroboram que a temperatura influencia mudanças em assembleias bentônicas durante eventos de seca. No estuário do Piraquê-Açú-Mirim temperatura da água influenciou a estrutura da macrofaunal bentônica (riqueza S e Pielou J'), e alterações da composição dos táxons das assembleias bentônicas (Phyllodocidae and Cirratulidae);

Globalmente são escassos os monitoramentos estuarinos, especialmente nos países subdesenvolvidos e em desenvolvimento. Este monitoramento é um dos estudos mais extensos já realizados nos estuários brasileiros, totalizando 14 meses de monitoramento, proporcionando um avanço significativo na compreensão das oscilações climáticas naturais em assembleias bentônicas em estuários do leste brasileiro;

Ressaltamos a necessidade de monitoramentos de longa duração, como os aqui exemplificados (> 10 anos), para entender as respostas estuarinas aos efeitos de seca e inundação. Este conhecimento possibilitará melhor gerir estuários importantes, como Piraquê-Açú-Mirim e as baías de Todos os Santos e Paranaguá, frente as previsões de aumento da intensidade e frequência de secas durante as mudanças climáticas no século atual.

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V. Anexos

Em anexos são apresentadas as normas de submissão da Revista “*Marine Environmental Research*”.



MARINE ENVIRONMENTAL RESEARCH

AUTHOR INFORMATION PACK

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Marine Environmental Research publishes original research papers on chemical, physical, and biological interactions in the **oceans** and **coastal waters**. The journal serves as a forum for new information on biology, chemistry, and toxicology and syntheses that advance understanding of **marine environmental** processes.

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