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RESEARCH ARTICLE

Do natural disturbances have significant effects on sandy beach macrofauna of Southeastern Brazil?

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ABSTRACT. The role of morphodynamic features such as grain size, swash climate and wave action on the macrofauna of beaches are well-known. However, few studies have investigated natural disturbances as potential drivers of temporal community variations. In southeastern Brazil, we sampled the intertidal macrofauna of two sandy beaches to test whether seasonal disturbances as the frequency of storm wave events (SWE) and rainfall have significant influence on their composition and abundance. The macrofauna assemblage differed significantly between the rainy and the dry seasons, but rainfall was not the main driver of community changes, although both beaches are in the vicinity of extensive river plumes. Actually, SWE explained most macrofauna richness overtime, with positive effects. Our results point to the importance of learning more about the effects of poorly studied disturbances on macrofaunal communities, and based on them we strongly recommend including these seasonal phenomena when monitoring sandy beaches.

KEY WORDS. Community structure, benthic community, intertidal, morphodynamics, seasonality.

INTRODUCTION

Morphodynamics play a key role in determining the structure of the benthic macrofauna, which is mainly structured by physical features such as grain size, wave action and tide (Defeo and Mclachlan 2005). From a global perspective, species' richness and diversity increase from narrow and steep beaches with coarse sediment (i.e., reflective) to wide beaches with gentle slopes and fine sediment (i.e., dissipative) (Defeo et al. 2017). The Swash Exclusion Hypothesis (SEH) is the main hypothesis for this general pattern and predicts that several intertidal species are unable to colonize harsh swash climates found on reflective beaches (Defeo and Mclachlan 2013).

Sandy beach macrofaunal communities are dynamic in time and space, due to the synergy of both abiotic and biotic factors (Gray 2016). However, dissipative and undisturbed beach populations may also be controlled by ecological interactions (e.g., density-dependent mechanisms) (Defeo and Mclachlan 2005). Other environmental conditions are thought to be important drivers of the community structure of the macrofauna, including temperature (Taylor and Mclachlan 1980), food availability (Bergamino et al. 2013), and natural disturbances such as storms (Harris et al. 2011, Machado et al. 2016, Corte et al. 2017) and rainfall (Lercari and Defeo 1999, 2015).

Some authors have suggested that the effects of storms may be deleterious, mainly on urbanized coasts (Witmer and Roelke 2014, Machado et al. 2016). However, macroinfaunal communities are resilient to moderate storm events on non-urbanized beaches, recovering to their pre-event conditions or even increasing their abundance and diversity after a few weeks (Machado et al. 2016, Smith and Fairweather 2016). Rainfall is particularly important on beaches in the vicinity of river mouths, since the freshwater outflow and organic matter input directly influence the surf zone productivity and food availability for the benthic macrofauna (Bergamino et al. 2013, Lercari and Defeo 2015).

Most studies assessing the role of environmental factors on beach macrofauna have mostly considered morphodynamic and hydrodinamic variables measured *in situ* (e.g. grain size and swash climate) (Veloso and Cardoso 2001, Coutinho and Bernadino 2017). Natural disturbances such as rainfall and storms are usually underestimated as potential predictors of short-term changes in macrofaunal communities. The objective of the present study was to assess the effect of environmental drivers on macrofauna richness and density on two sandy beaches. We tested the hypothesis that the frequency of storm wave events (SWE) and rainfall have significant influence on the intertidal macrofauna structure in short-term monitoring.

MATERIAL AND METHODS

This study was carried out on two sandy beaches, Grussaí (-21.728319°, -41.023988°) and Manguinhos (-21.448523°, -41.027338°), in the northern portion of the state of Rio de Janeiro, southeastern Brazil (Fig. 1). Grussaí is an intermediate beach, with a predominance of medium-sized sand grains, steep slope and intense wave action on the beach face (Machado et al. 2017). Manguinhos is a dissipative beach, with a predominance of fine sediment, gentle slope and waves dissipating their energy gradually over a wide surf zone (Machado et al. 2017). The area has a well-defined rainy season between October and April and a dry season between May and September (Marengo and Alves 2005). The rainy period corresponds to the higher outflow of the Paraíba do Sul (Fig. 2) and Itabapoana rivers, with their plumes reaching both beaches, respectively (Fig. 1). The highest frequency of storm wave events (waves ≥ 2.0 m) usually occurs during the winter months (Machado et al. 2016). We selected only non-urbanized sites to isolate natural influences from diffuse effects of urbanized beaches (e.g., trampling, vehicle traffic and beach cleaning) on the macrofaunal community (Machado et al. 2017).

We conducted a two-year survey and sampled the intertidal macrofauna four times in the dry and rainy seasons on Grussaí and Manguinhos beaches (dry season: July/12, August/12, July/13 and September/13; rainy season: January/13, February/13, March/14 and April/14). The macrofauna was sampled following a stratified-random design to cover the entire across-shore intertidal gradient (Schlacher et al. 2008), adapted from the Brazilian Protocol of Benthic Macrofauna Monitoring of Sandy Beaches (Rosa Filho et al. 2015).

At each beach, sediment was collected with a cylindrical core (20 x 20 cm) in three across-shore sampling stations (50 m apart), which were divided in three strata (upper, medium and lower intertidal zones). At each sampling station we collected three random sediment samples per strata, at least 2 m apart from each other, totaling 27 samples in each survey. Our design encompassed nine independent samples for each beach and survey date, since the samples of each strata and sampling station were pooled as elementary sampling units (Schlacher et al. 2008) (Fig. 3). The position of each core was randomized, instead of arranging the samples systematically along an across-shore transect, to avoid autocorrelation among individual samples, as recommended by Schlacher et al. (2008). The sediment was sieved with 500 µm mesh and fixed with 10% formaldehyde. In

Figure 1. Map of the study area showing Grussaí Beach and Manguinhos Beach, in northern Rio de Janeiro, Brazil.

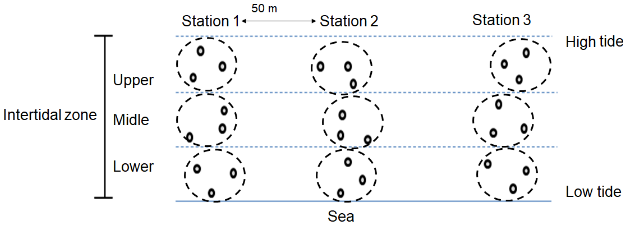

Figure 2. Sampling design for macrofauna collection in the intertidal zone. Each station included three pooled samplings per strata (upper, middle and lower) of the intertidal zone as sampling unit.

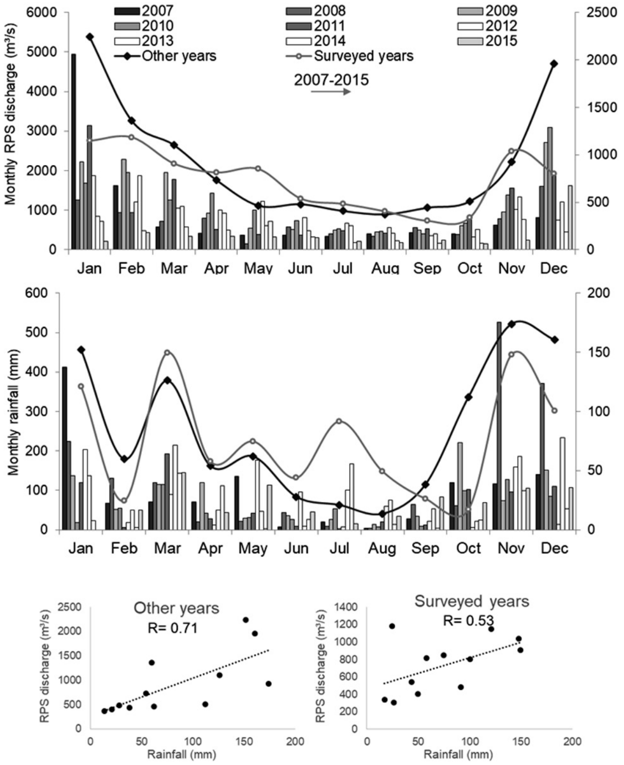

Figure 3. Monthly discharge of Paraíba do Sul River and rainfall. River discharge and rainfall are correlated variables (R> 0.5). Rainfall data refer to Campos dos Goytacazes municipality (40–50 km from Grussaí and Manguinhos beaches) and was obtained from National Institute for Meteorology (INMET: http://www.inmet.gov.br).

the laboratory, the macrofauna was counted and identified to the lowest possible taxonomic level, using appropriate taxonomic keys (Serejo 2004, Amaral et al. 2006).

We sampled simultaneously macrofauna and environmental parameters, which also included the number of storm wave events and mean rainfall volume as natural disturbance variables on a seasonal scale. Monthly data (30 days data prior each survey) of these last parameters was provided by the National Institute for Space Research (INPE: http://www.cptec.inpe.br), National Institute for Meteorology (INMET: http://www.inmet.gov.br) and National Water Agency of Brazil (http://www.ana.gov.br).

Three sediment aliquots were collected in the upper, medium and lower intertidal zone in each survey. The organic matter content was determined based on the loss-on-ignition method, calculating the difference between lyophilized and incinerated sediment at 350 °C for 12 hours (Goldin 1987). The percentage of fine sediment (<0.5 mm) was determined after sieving to represent the predominant grain size (Lunardi et al. 2012). Fine sediments (<0.5 mm) was usually prevalent on both Grussaí and Manguinhos beaches (Machado et al. 2017). Gravel, silt and argilla-sized have low contribution (<1%) in all sediment aliquots. Thus, the mean grain size is expected to be directly related to the percentage of any dominant sediment fraction.

The swash climate was determined by the distance of the sand stretch between the water line and the upper limit of the backshore (swash length); the spreading time was based on the time interval between the formation and the end of each swash (swash time) (McArdle and McLachlan 1992). Wave height was visually estimated considering the distance between the top of the sea surface and wave crest (Alves and Pezzuto 2009). Wave period was estimated by counting the number of waves breaking into the beach face 10 times during 1-min interval each. Water temperature was measured with a Horiba U-50 portable multiparameter. Although these variables do not provide a complete morphodynamic characterization, they are good proxies of physical beach harshness and usually have strong influence on the macrofaunal community (Muehe 1998).

Permutational Analysis of Variance (PERMANOVA) was used for both comparison of the macrofaunal univariate descriptors (richness and density) and community assemblages, with the species as variables based on Bray Curtis similarity. The PERMANOVA matrix encompassed pooled samples of each strata and sampling station as single sampling units (n = 9). Richness and density values (pooled as continuous variables, see Fig. 3) were compared between dry and rainy seasons (fixed factor), including “beach” (intermediate x dissipative) and “survey date” (nested in season) as fixed and random factors, respectively. A Similarity Percentage Analysis (SIMPER) was conducted to assess the species percentage contribution to the dissimilarity among seasons. The multivariate analyses were performed in the PRIMER version 6 software.

Multiple linear regression analysis was performed to evaluate the significance of the variables that affect species richness and density of the intertidal macrofauna on each survey at both sandy beaches. We assessed multicollinearity using multiple pairwise correlations and the Variance Inflaction Factor (VIF). Variables with a high VIF value (> 3) were removed from the models until all remaining VIFs were below 3 (Zuur et al. 2010). Water temperature, percentage of fine sediments and swash length were deleted due to VIF values and high correlation (R > 0.5). After removing correlated variables, we performed a stepwise model selection (i.e. predictors combination) based on Akaike Information Criterium (AIC) by choosing the model with the lowest AIC values (Burnham and Anderson 2002).

The regression analysis followed the statistical assumptions since the model residuals had normal distribution (according to Shapiro-Wilk test) and the variances were homoscedastic (according to Cochran's C Test). We pooled all intertidal samples to consider each survey as a sampling unit (mean values as continuous variables), to avoid an increasing of the sample size and, consequently the increasing power of the statistical test, as a result of pseudo-replication. Thus, all the response (macrofauna richness and density) and predictive variables were pooled into a single mean value for the regression models, except the number of storm wave events, which was considered as a sum of events for the 30 days prior the survey.

The same environmental measurements were included as explanatory variables of changes of macrofauna taxa in the Canonical Correspondence Analysis (CCA). VIF scores were also used for explanatory variables removing from the CCA. The models diagnostics, regression and CCA analysis were performed in R-statistic software Version 3.4.3, using the packages "car" for VIF calculation (Fox and Weisberg 2011), "MuMIN" for model selection based on AIC (Barton 2018), "GAD" for Cochran's C Test (Sandrini-Neto and Camargo 2017) and "vegan" for CCA (Oksanen et al. 2017).

RESULTS

Environmental variables

The storm wave events were about four times more frequent during the dry seasons (n = 68) compared to rainy ones (n = 14) on both beaches (Appendix 1). However, rainfall volume was more intense in rainy months (~114 mm/month) compared to dry ones (~57 mm/month) during the survey years (2012, 2013 and 2014) (Fig. 2). Both rainfall volume and river discharge were lower during the surveyed period compared to previous years from December to February (Fig. 2).

Wave height and wave period were usually higher on Grussaí (102 cm e 2.9 s, respectively) compared to Manguinhos (46 cm and 2.2 s, respectively). On the other hand, swash length and time were higher on Manguinhos (8.2 m and 5.5 s, respectively) compared to Grussaí (5.8 m and 2.9, respectively). In general, mean water temperature was higher (28.4 °C) in rainy season than in dry ones (26.7 °C). The fine sediment fraction was usually higher on Manguinhos (83%) compared to Grussaí (52%) (Appendix 1).

Macrofauna

We did not find significant differences in macrofaunal richness between dry (July, August and September) and rainy (January, February and March) seasons (pseudo-F = 0.35; p = 0.81) and density (pseudo-F = 1.82; p = 0.31) (Fig. 4). However, the differences in the community assemblages between seasons were significant ($p < 0.05$) (Table 1). According to SIMPER, the dominant taxa on both beaches, *Excirolana braziliensis* Richardson, 1912 (Cirolanidae), *Hemipodia californiensis* (Hartman, 1938) (Glyceridae), *Atlantorchestoidea brasiliensis* (Dana, 1853) (Talitridae), *Emerita brasiliensis* Schmitt, 1935 (Hippidae), *Scolelepis* sp. (Spionidae) and Nemertea contributed the most (cumulative contribution = 66%) to 81% dissimilarity between seasons (Table 2). These and other species were usually more abundant during the dry surveys compared to rainy ones (Table 2).

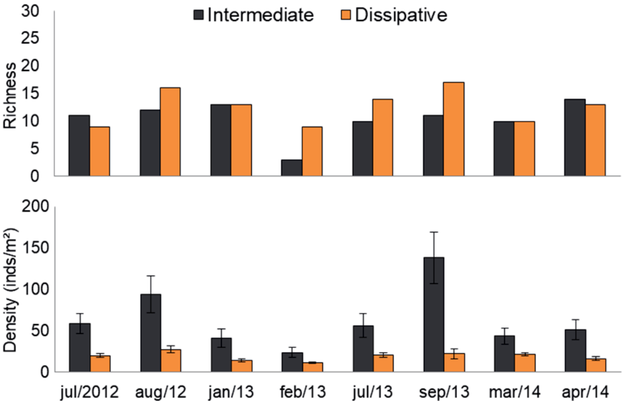

Figure 4. Number of species (richness) and density (individuals/m^2) for the dissipative (Manguinhos Beach) and intermediate (Grussaí Beach) beaches in the dry (July/2012, August/2012, July/2013 and September/2013) and rainy (January/2013, February/2013, March/2014 and April/2014) seasons.

Table 1. PERMANOVA and Pair-wise comparison among seasons (fixed factor), beach and survey date (random factors) of the macrofauna association pattern. *$p < 0.05$.

Source	Df	SS	MS	Pseudo-F	P(MC)	Perms
Beach (BEA)	1	35883	35883	10.437	0.001*	478
Season (SEA)	1	3960	3960	3.016	0.044*	300
Survey (SUR)	2	2626	1313	0.753	0.692	999
BEA X SEA	1	1757	1757	0.511	0.782	517
BEA X SUR (SEA)	1	3438	3438	1.972	0.024*	997
Residuals	136	2.371	1744			
Total	143	2.882				

Environmental influence

The frequency of storm wave events (SWE) was the only significant predictor ($p < 0.01$; $R^2 = 0.41$) of macrofaunal richness (Table 3; Fig. 5), and wave height was positively ($p< 0.02$; $R^2 = 0.58$) correlated with macrofaunal density (Table 3; Fig. 5). Rainfall did not predict macrofauna richness or density (Table 3).

The first and second axis of the CCA significantly explained ($p = 0.031$; $F = 1.864$) 43% and 25% of the total variance

Table 2. SIMPER analysis of de macrofauna between winter and summer seasons in Grussaí and Manguinhos beaches. Average dissimilarity = 81.34.

Species	Mean density (individuals/m^2)			
	Winter	Summer	Contribution (%)	Cumulative (%)
Excirolana braziliensis	4.74± 8.91	1.85± 3.46	21.81	21.81
Hemipodia californiensis	0.74± 1.38	0.30± 0.48	9.76	31.57
Nemertea	0.84± 2.20	0.72± 1.88	9.00	40.56
Atlantorchestoidea brasiliensis	0.59± 0.59	0.43± 0.43	8.62	49.18
Scolelepis sp.	0.25± 0.62	0.41± 1.08	8.42	57.60
Emerita brasiliensis	1.64± 5.42	0.16± 0.43	8.34	65.93
Oligochaeta	0.25± 0.66	0.42± 1.67	5.55	71.48
Pisionidens indica	0.21± 0.72	0.26± 0.72	5.44	76.92
Donax hanleyanus	0.19± 0.70	0.15± 0.73	3.40	80.32
Talorchestia tucurauna	0.38± 1.73	0.05± 0.25	3.39	83.71
Puelche sp.	0.19± 0.80	0.05± 0.28	2.89	86.59
Insecta	0.03± 0.10	0.10± 0.28	2.21	88.80
Dispio sp.	0.04± 0.15	0.03± 0.12	2.09	90.89

Table 3. Regression analysis of the macrofaunal community descriptors (richness and density) as a function of environmental drivers on Grussaí and Manguinhos beaches. *p < 0.05.

	Estimate	Std-Error	T-value	R^2	P-value
Number of species (AIC= 79.0)					
Intercept	9.776	0.828	11.812	–	0.005*
Storm wave events (SWE)	0.348	0.104	3.351	0.405	0.005*
Total R^2	–	–	–	0.445	–
Adjusted R^2	–	–	–	0.405	–
Density (AIC= 25.6)					
Intercept	2.246	0.602	3.729	–	0.003*
Storm wave events (SWE)	0.028	0.021	1.302	0.029	0.219
Swash time	-0.101	0.073	1.633	0.050	0.198
Wave height	0.014	0.005	2.789	0.579	0.017*
Wave period	0.179	0.110	1.633	0.046	0.131
Total R^2	–	–	–	0.704	–
Adjusted R^2	–	–	–	0.598	–

on the biotic data, respectively (Fig. 6). Wave height (score = 0.86) and swash time (0.78) were the main environmental variables explaining the first axis. *E. brasiliensis*, *H. californiensis*, *D. haleyanus*, *P. indica*, *A. brasiliensis* and Nemertea were positively associated with wave height, while *Scolelepis* sp., *Mysida* sp. and Oligochaeta were positively related to higher swash times (Fig. 6). SWE was the main predictor (score = 0.89) to explain the second axis and it was positively related to *E. brasiliensis* and low-abundant taxa (see Table 2, such as *Puelche* sp., *Talorchestia tucurauna* (Müller, 1864) and *Olivancillaria vesica* (Gmelin, 1791) (Fig. 6).

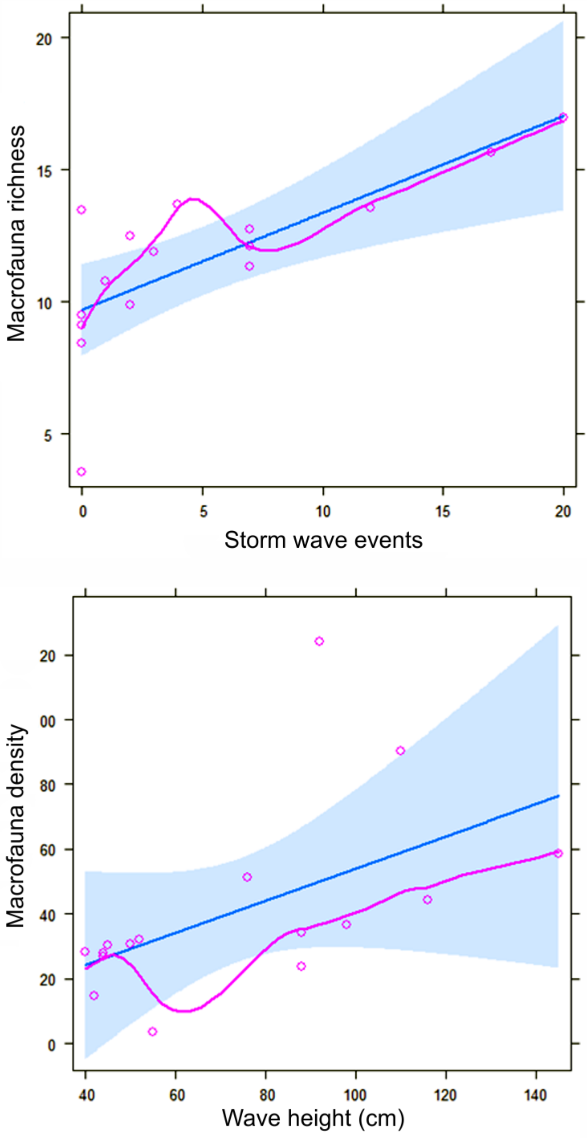

Figure 5. Regression analysis of the macrofauna richness and density as function of the number of storm wave events (SWE) and wave height, respectively. The pink dots represent each dependent (marine debris on ghost crab burrow) and independent variables (distance from urban settlements). Blue shaded area indicates 95% confidence intervals and pink line is the distribution of residuals. Blue line is the regression straight. Only significant ($p < 0.05$) predictors were considered in the effects plot.

DISCUSSION

Benthic communities of sandy beaches are synergistically influenced by many biotic and abiotic factors, which make it difficult to identify the responses of the macrofauna to single

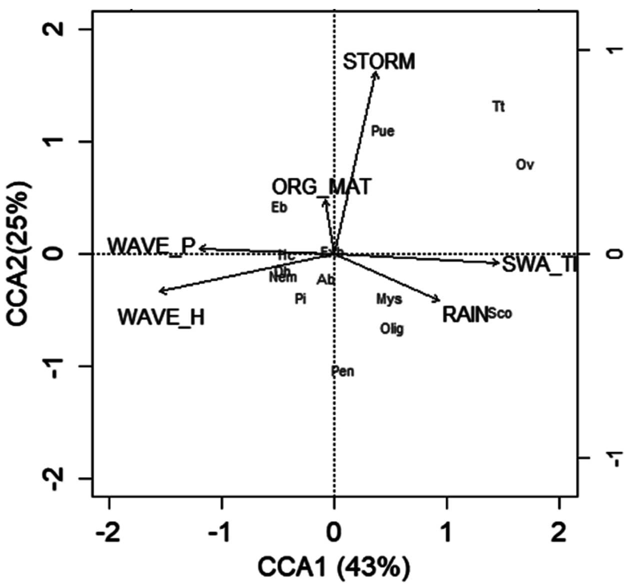

Figure 6. Factorial diagram of the Canonical Correspondence Analysis, including environmental variables (wave height, wave period, swash time, organic matter%, rainfall and frequency of storm wave events) and macrofauna species on Grussaí and Manguinhos beaches. Ab: *Atlantorchestoidea brasiliensis*; Dh: *Donax hanleyanus*; Eb: *Emerita brasiliensis;* Exb*: Excirolana braziliensis*; Hc: *Hemipodia californiensis*; Mys: *Mysida* sp.; Nem: Nemertea; Olig: Oligochaeta; Ov: *Olivancillaria vesica*; Pen: Peneidae; Pue: *Puelche* sp.; Sco: *Scolelepis* sp.; Tt: *Talorchestia tucurauna*.

variables. The influence of morphodynamic features on the macrofauna of sandy beaches is usually modulated by differences in grain size and swash climate (Defeo and Mclachlan 2005). However, our results showed that morpho and hydrodynamics factors (swash climate and grain size) might not be single drivers of macrofaunal richness and density overtime at a local scale (Veloso and Cardoso 2001). Actually, differences in the community structure can be related to other seasonal disturbances such as storm wave events. The frequency of natural disturbances is usually underestimated in spatio-temporal comparisons of intertidal macrofauna on sandy beaches. However, this data can be feasibly provided by national research institutes and explained most of the variability in macrofauna dynamics overtime in the northern coast of Rio de Janeiro.

Manguinhos Beach has the typical dissipative characteristics (e.g., fine sediment, and mild swash climate) that would support higher macrofaunal richness compared to Grussaí (intermediate) (Defeo and McLachlan 2013). In fact, the number of species was usually higher on the dissipative beach (Appendix 2), associated with larger swash length and swash time, including greater frequency of species from the infralitoral fringe (e.g. *Puelche* sp. and *O. vesica*). However, typical intertidal species such as *E. braziliensis*, *H. californiensis*, *A. brasiliensis* and *E. brasiliensis* were always more abundant on the intermediate beach compared to the dissipative one. These species show high mobility and distinct abilities (e.g., sophisticated sensory and burrowing mechanisms) to deal with harsh swash climate and to maintain themselves in specific intertidal areas during tidal cycles, according to their environmental requirements and tolerances (Brown and McLachlan 2010). Orientation to environment condition is developed to a high degree, particularly to air-breathing amphipods and isopods (e.g., *E. braziliensis* and *A. brasiliensis*), since they cannot risk being immerged by long time neither can allow themselves to wander too far inland (Brown and McLachlan 2010). Typical swash inhabitants (e.g., *H. californiensis* and *E. brasiliensis*) display vigorous and rapid burrowing capability to deal with direct wave action (Brown and McLachlan 2010). On the other hand, the sedentary polychaete *Scolelepis* sp. were more abundant in Manguinhos Beach related to higher swash times, corroborating their usual dominance on dissipative beaches in the Brazilian coast and (Amaral et al. 2006, Rocha and Paiva 2012). Fine sediment and stable swash climate allow the construction of semi-permanent burrows, increasing the importance of deposit feeders (e.g., *Scolelepis*) in the communities (Brown and McLachlan 2010).

The lack of variability in the community richness and density between dry and rainy periods means that assemblage structure is relatively stable over time, with shifts exclusively in species association patterns. This corroborates with the results of other studies in southeastern Brazil, where environmental seasonality is not pronounced (Veloso and Cardoso 2001, Coutinho and Bernardino 2017). Oppositely, at temperate and subtropical regions temporal changes on macrofauna structure is usually significant (Leber 1982, Neves et al. 2007). Macrofauna association patterns might differ among season due to the occurrence of rare species related to low-studied seasonal disturbances, such as moderate storms wave events (Machado et al. 2016).

The frequency of storm wave events was a positive driver of macrofauna richness. Although storms are expected to enhance erosive processes and directly kill macroinvertebrates (Mclachlan et al. 1996), studies have suggested that several macrofaunal species, mainly detritivorous ones, as the crustacean *E. braziliensis*, are resilient to moderate events on non-urbanized sandy beaches, regardless of morphodynamics (Alves and Pezzuto 2009, Harris et al. 2011, Machado et al. 2016). As suggested by other authors (Machado et al. 2016, Corte et al. 2017), storm wave events may enhance both redistribution of sediment fauna and productivity at sandy shores, reducing competition and increasing macrofauna richness, density and diversity. Moderate storms may increase short-term deposition of organic detritus (e.g. large macroalgae and dead animals) in drift line and also the concentration of surf diatoms, enhancing food availability for many detritivores and suspension-feeders macroinvertebrates (Alves and Pezzuto 2009, Odebrecht et al. 2010). The passive transport of low-mobile species from infralitoral fringe to the intertidal area is also responsible for higher species richness and abundance after storm waves (Hughes et al. 2009, Machado et al. 2016).This was the main driver of increasing species richness on the studied beaches. Some species of macrofauna with indirect development are also benefited by a higher hydrodynamism (Harris et al. 2011, Machado et al. 2016), although severe changes can alter the dispersal of larvae and macrofaunal species recruits of (Wieking and Kröncke 2011). For example, after storm events, *Emerita brasiliensis*is was mainly represented by juveniles, probably as a recruitment response (Saloman and Naughton 1977, Machado et al. 2016).

In general, studies show that moderate storm waves can influence positively the benthic macrofauna (Posey et al. 1996, Alves and Pezzuto 2009), but McLachlan et al. (1996) and Gallucci and Netto (2004) found negative effects, like severe benthic mortality, especially due erosion processes. At high-intense disturbances, intolerant species may become locally impaired. For this reason, storms have a negative influence (i.e., erosion process and mass mortality) if they were more intense than we monitored. However, natural disturbances may also enhance productivity, food availability and complexity to usual homogeneous beach environments (Corte et al. 2017), fitting in the IDH ("Intermediate Disturbance Hypothesis" by Connel 1978). Thus, the effects of storm wave events on sandy beaches macrofauna are complex; further studies are needed to clarify these effects and the combination with possible synergic variables.

The increase in macrofauna density associated to the occurrence of storm waves was observed by Alves and Pezzuto (2009) and Harris et al. (2011) and indicate that these natural disturbances are important factors driving benthic intertidal dynamics and their resilience (Machado et al. 2016). Climate changes have altered the physical proprieties of several sandy beaches, as a result of increasing sea surface temperatures, storm frequency and intensity, velocity and periodicity of onshore winds, which are all in synergy (Ortega et al. 2013). Most global change predictions for beach biota are based on short-term responses of communities and populations to variables related to climate or sea level, or even derived from other ecosystems (Defeo et al. 2009).Time series of biological and potential climate predictors, even those from short-term assessments, are therefore still useful to understand how the sandy beach macrofauna responds to climate variability (Celentano and Defeo 2016). This is even more important when considering that other poorly studied natural disturbances could potentially be influenced by climate, such as storm wave frequency, which seems to be an important driver of local macrofaunal dynamics.

Rainfall was expected to have a significant association (positive or negative) with the macrofauna in response to higher river outflow in rainy seasons. Allochthonous particulate organic matter (e.g., plants, insects) from terrestrial sources (i.e., river) have an important contribution to trophic supply of benthic communities, mainly for non-dissipative beaches (Colombini et al. 2011). On dissipative beaches, phytoplankton is the main source for beach suspension-feeders and it usually takes advantage of both increasing nutrient discharges from freshwater outflow and wave action in the surf zone (Odebrecht et al. 2010). Otherwise, if rainfall and river outflow were very intense, they could provide a saline stress for beach communities (Lercari and Defeo 1999). However, in typical rainy periods, river discharge were less intense during the survey dates (e.g., December to February) compared to previous years (see Fig. 2), showing their minor influence on adjacent environments, due to both reduction on rainfall volume and increasing siltation of Paraíba do Sul River related to land use (Araujo et al. 2003, Almeida et al. 2007) (see Fig. 2).

In conclusion, our results showed that common environmental measurements taken only during beach surveys (e.g., swash climate and grain size) may not be singly used to predict short-term variations on the macroinfauna. The frequency of storm wave events was the most important driver of species richness, which has been rarely considered during beach monitoring. Also, long-term monitoring of beach biota associated to the number and intensity of storm wave events just before each survey is a feasible approach to create future scenarios and to suggest management actions.

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Appendix 1. Environmental variables measured on Grussaí and Manguinhos beaches (dry season 1: July/12; 2: August/12, 3: July/13; 4: September/13; rainy season 1: January/13; 2: February/13; 3: March/14; 4: April/14).

		Storm waves	Wave height (cm)	Swash lenght (m)	Swash time (s)	Wave period (s)	Water temperature (°C)	Rainfall (mm)	Fine sediment (%)
Grussaí Beach	Dry season 1	3	88	4.0	2.4	5.2	28.6	1.3	40.3
	Dry season 2	2	110	4.3	2.6	2.4	27.2	3.0	55.2
	Dry season 3	0	98	7.0	4.1	3.0	31.9	1.4	74.9
	Dry season 4	7	88	7.6	2.6	3.1	33.1	1.7	53.9
	Rainy season 1	0	145	7.0	2.8	3.0	27.0	0.1	38.9
	Rainy season 2	0	92	6.1	2.5	2.0	28.1	2.4	48.5
	Rainy season 3	1	116	4.4	3.5	2.6	32.3	0.2	44.0
	Rainy season 3	2	76	6.3	3.1	2.2	30.5	4.8	62.5
Manguinhos Beach	Dry season 1	7	40	4.3	9.2	5.0	23.9	1.2	81.0
	Dry season 2	20	55	8.7	3.0	2.7	23.4	0.5	86.0
	Dry season 3	12	42	9.6	6.8	2.0	22.5	3.4	81.0
	Dry season 4	17	44	9.9	6.3	1.5	22.9	2.7	88.0
	Rainy season 1	7	45	5.8	3.6	1.7	27.7	2.0	81.0
	Rainy season 2	0	44	8.9	4.3	1.0	27.6	3.9	89.0
	Rainy season 3	0	50	9.2	4.2	2.0	27.7	0.2	81.0
	Rainyseason 3	4	52	8.9	6.3	2.0	26.2	6.1	74.0

Appendix 2. Taxonomic composition of the benthic macrofauna on Grussaí and Manguinhos beaches.

Phylum	Class	Family	Taxon	Grussaí Beach	Manguinhos Beach
Arthropoda	Crustacea	Albuneidae	*Lepidopa richimondi* (Benedict, 1903)		X
		Cirolanidae	*Excirolana braziliensis* (Richardson, 1912)	X	X
		Hippidae	*Emerita brasiliensis* (Schmitt, 1935)	X	X
		Talitridae	*Atlantorchestoidea brasiliensis* (Dana, 1853)	X	X
			Talorchestia tucurauna (Müller, 1864)	X	X
		Mysidae	*Mysida* sp.	X	X
		Paguridae	*Pagurus* sp.		X
		Phoxocephalidae	Puelche sp.	X	X
		Peneidae			X
		Diogenidae	*Clibanarius vittatus* (Bosc, 1802)		X
Annelida	Polychaeta	Glyceridae	*Hemipodia californiensis* (Hartman, 1938)	X	X
		Psionidae	*Pisionidens indica* (Aiyar & Alikunhi, 1940)	X	X
		Spionidae	*Dispio* sp.	X	X
			Scolelepis sp.	X	X
		Nephtydae	*Nephtys magellanica* (Augener, 1912)		X
	Oligochaeta			X	X
Echinodermata		Ophiuroidae			X
Mollusca	Bivalvia	Donacidae	*Donax hanleyanus* (Phillipi, 1842)	X	X
		Mactridae	*Mulinia cleryana* (d'Orbigny, 1846)		X
		Tellinidae	*Tellina lineata* (Turton, 1819)		X
			Stringilla pisiformis (Linnaeus, 1758)		X
	Gastropoda	Olividae	*Olivancillaria vesica vesica* (Gmelin, 1791)	X	X
Nemertea				X	X