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Do mud deposition events on sandy beaches affect surf zone ichthyofauna? A southern Brazilian case study

Renata Mont'Alverne*, Leonardo E. Moraes, Fábio L. Rodrigues, João P. Vieira

Ichthyology Laboratory, Institute of Oceanography – FURG, Av. Itália, km 08, Carreiros, Rio Grande/RS CEP: 96.201-900, Brazil

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ABSTRACT

Using fluid mud deposition events which occur regularly at Cassino Beach in south Brazil, we evaluated the influence of such events on the structure of the ichthyofauna inhabiting its shallow surf zone. Wave action was the dominant factor in differentiating between sampling sites, being lower or even absent at the mud-influenced sectors compared to beach area without mud. Samples were collected using a beach seine net at two control locations (A1 and A2), and at three locations influenced by mud deposition (B1, B2, and B3). During the study period (21 April–04 August 2009), 15,245 fishes were captured and separated into 26 taxonomic groups, from species to family. Individuals of a total length (TL) up to 50 mm accounted for 65% of the catch, while individuals of TL $<$ 30 mm were the most numerous and more responsible for the total abundance spatial pattern. The area with higher wave action (A2) had the lowest relative species abundance and greatest diversity, whereas the areas with mud-forced lowest wave action (B2 and B3) had the highest species abundance values. Three hypotheses were proposed to explain the higher concentration and capture of juvenile fishes at mud locations. First, longshore currents may be responsible for the displacement of juvenile aggregations toward areas of lower energy. Second, individuals may select habitats with turbid waters, which may provide greater protection from predators and increased food availability. Third, areas under the influence of fluid mud deposition show higher values of viscosity, which may reduce swimming activity and hinder the escape of juvenile fishes from nets, resulting in an increased capture of individuals compared to areas without mud.

1. Introduction

Natural mud deposits are often found near sandy shores in various regions worldwide, ranging from Arctic regions (Powers et al., 2002), through temperate regions (Lesueur et al., 1996), to tropical and subtropical regions (Wright, 1989; Calliari et al., 2009). Typically, these mud deposits are associated with significant river discharges or resuspension of deposits outside the coastal area (Holland et al., 2009; Anthony et al., 2010). According to Able (2005), during periods of high estuarine flow, certain conditions, such as low salinity and high mud deposition, are commonly observed in coastal areas of the inner continental shelf. However, few locations have been documented to have beaches with sandy bottoms that are occasionally covered by a layer of mud (Pereira et al., 2011). Some examples are the Kerala coast, India (Gopinathan and Qasim, 1974; Mathew et al., 1995); locations north to the Amazon river, such as Amapá state (Brazil), French Guiana and Surinam (Wells and Coleman, 1977; Dolique and Anthony, 2005; Anthony et al., 2010), and a mesotidal beach on the Mekong River delta coast, China (Tamura et al., 2010) and the southern coast of Brazil, at Tijucas Bay, Santa Catarina (Buynevich et al., 2005) and Cassino Beach, Rio Grande do sul (Calliari et al., 2001, 2009).

The oldest record of mud deposition at Cassino Beach was in 1901 (Calliari and Griep, 1999). However, during the last century, these phenomena have become more frequent and have featured in the media since the 1990s because of the negative impact on tourism-related activities (Calliari et al., 2009). The mud deposition event that occurred in 1998 and lasted about 14 months is notable. It was probably associated with substantial dredging operations in the inner Patos Lagoon estuary (Calliari et al., 2001) and with the strong El Niño event that occurred in the same year (Odebrecht et al., 2003). Although the natural source of fine lagoonal sediments to the inner shelf is a recent contribution of the Patos Lagoon (Calliari et al., 2001), periods of high freshwater flow (e.g. El Niño) (Grimm et al., 1998; Garcia and Vieira, 2001; Marques et al., 2009), as well as dredging operations on poorly-sited dumpsites, can amplify the production of fluid mud (Calliari et al., 2001). This

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* Corresponding author.
E-mail address: remontalverne@yahoo.com.br (R. Mont'Alverne).

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increase in the volume of sediments that are exported from the Patos Lagoon leads to a more significant contribution of fine sediments to the area of mud deposition adjacent to the coast (Holland et al., 2009). Villwock and Martins (1972) showed that the silty clay material of mud deposits reaching the Cassino Beach is from modern Patos Lagoon sediments.

Among the studies that report this type of mud deposition, most have focused on physical and geological aspects of the process, such as mud mineralogy, influence on coastal hydrodynamics, mud geotechnical properties and computational modeling (e.g., Dias and Alves, 2009; Vinzon et al., 2009), rather than assessing the impacts of these deposits on biodiversity (Damodaran, 1973; Alongi, 1991).

The mud deposition events at Cassino Beach promote changes in the surf zone hydrodynamics, especially in the attenuation of waves (Calliari et al., 2007). These changes alter dissolved inorganic nutrient availability in the region of the beach, with silicates, ammonia and phosphates presenting patterns of decreasing concentrations, in contrast with nitrate and nitrite (Odebrecht et al., 2010). They cause variation of most phytoplankton species, with a decline of the highly abundant diatom *Asterionellopsis glacialis* and significant increase in abundance of others (Odebrecht et al., 2010), and the obstruction of benthic fauna respiratory apparatus, causing high mortality among mollusks, crustaceans and other invertebrates (Calliari et al., 2001; Silva et al., 2008).

The Cassino Beach surf zone, like others elsewhere, is considered a juvenile area for several species (Beck et al., 2001; Monteiro-Neto et al., 2003; Rodrigues and Vieira, 2010), some of which are of economical importance to the artisanal and recreational local fisheries, such as plata pompanos, gulf kingfishes, mullets and White-mouth croakers (Szpilman, 2000; Basaglia and Vieira, 2005; Klippel et al., 2005; Peres and Klippel, 2005). Although several studies have investigated the deposition of mud at Cassino Beach, the effects of these phenomena on the fish assemblage have not been assessed. Due to the knowledge of mud-induced alterations on phytoplankton and benthos, we hypothesized that mud deposits also have an impact on ichthyofauna structure. In order to test that hypothesis, we examined the influence of one event of mud deposition on the structure of the ichthyofauna occurring in the surf zone of Cassino Beach in south Brazil.

2. Material and methods

2.1. Study area

Cassino Beach is located south of the Patos Lagoon mouth, the largest enclosed lagoon in the world, connected to the Atlantic Ocean through a single inlet between two rock-jetties (Kjerfve, 1986). It is an exposed sandy beach mainly dissipative, composed of fine quartz sand, presenting multiple shore parallel sand bars (Pereira et al., 2011). The beach exhibits waves with average energy levels, showing higher waves in winter, lower waves in summer and a transitional pattern in autumn and spring. The alternation between two anticyclonic systems favors the predominance of NE winds from September to March and of SW winds from April to August (Cavalcanti et al., 1986). Longshore currents have a direct correlation with the wind intensity and frequency. In that way, weak and constant currents directed SW are often observed during spring/summer, while NE currents are associated to autumn/winter (Tozzi and Calliari, 2000). The wind effect is also the main mechanism controlling the behavior of the Patos Lagoon coastal plume over the inner Southern Brazilian Shelf (SBS) in synoptic time scales (Marques et al., 2009).

The Patos Lagoon discharge represents an important local contribution to the nutrient and suspended sediments budget of the inner SBS (Marques et al., 2009). Although a continuous fluid mud belt occurs along the shoreface both to the north and south of the inlet, beach deposits only appear immediately to the south because fluid mud is only deposited at shallow depths around the depocenter, i.e. the site of maximum mud deposition (Calliari et al., 2009). The limits of the modern mud blanket southwards of the Patos Lagoon vary between 6 and 25 m, and the mud depocenter is situated 9 km to the south of the Patos Lagoon estuary mouth, 10 km from the shore and at a depth of 15 m (Calliari et al., 2009). Stormy conditions associated with periodic cold front passages, which occur frequently on the area, can rework and transport the fluid mud from the shoreface to the surf zone and foreshore of Cassino Beach (Calliari et al., 2007). Because of the proximity of the depocenter to Cassino Beach, mud deposition is most frequent in the central sector of Cassino village (Calliari et al., 2009) (Fig. 1).

2.2. Sampling design

Sampling was carried out from 21 April to 04 August 2009, starting a week after the mud deposition event on the beach. Twelve field trips to sampling were carried out; the first nine were weekly, whereas the last three were fortnightly. The difference in the sampling frequency was due to attenuation of the fluid mud deposit. The sampling effort was interrupted when we could not identify mud locations along the surf zone anymore. During this period, samples were collected from five sites distributed along the 21 km of the beach. Sites A1 and A2 were selected as control areas, because they were mud free during the sampling period. Sampling site A1 was located 500 m South of the west wetty of Patos Lagoon estuary and approximately 6 km North of the beginning of the observed mud deposit accumulation. Site A2 was located approximately 6 km to the south of the end of the mud deposit, while sites B1, B2, and B3 were located on the mud deposit. B1 and B3 corresponded to mud deposit interfaces (Fig. 1).

At each sampling point, five hauls were made perpendicular to the beach, using a beach seine net (9.0 m long × 1.5 m high, with two mesh sizes, 13 mm on the 3 m wings and 5 mm in the 3 m central area). Each haul represented one sample. The hauls were always performed during the daytime at a depth below 1.2 m.

All collected specimens were fixed with 10% formalin and identified to the highest possible taxonomic separation in the laboratory (Figueiredo and Menezes, 1978, 1980, 2000; Menezes and Figueiredo, 1980, 1985; D'Incao, 1999; Melo, 1999). Fish juveniles that could not be identified to the species level were grouped into other relevant taxonomic levels (genus or family). The total length (TL) of the animals was measured to an accuracy of 1 mm. For each fish species only a hundred individuals per sample were measured, with the remainder only counted.

2.3. Environmental variables

Water temperature, salinity, dissolved oxygen, pH (Multiparameter Probe, Model YSI 556), and water transparency (Secchi Disk) were measured at all sampling sites. To quantify the possible effect of wind on the fauna, principally through wave action, an "average factor of wind" (W) was calculated (Gibson et al., 1993) that considered the 24 h period prior to each collection. For this analysis, we used only the meridional wind component V_v of the decomposition of vectors (Miranda et al., 2002). W is positive when wind direction is between 50° and 230° and negative when between 231° and 49°. When the values of W are high and positive, this indicates strong winds towards the coast, with wave action on the beach being maximal. When the values of W are negative (winds along the coast or toward the open sea), wave action is low or even negligible. The values of W were obtained using wind speed and direction data provided by meteorological forecasting Pilot

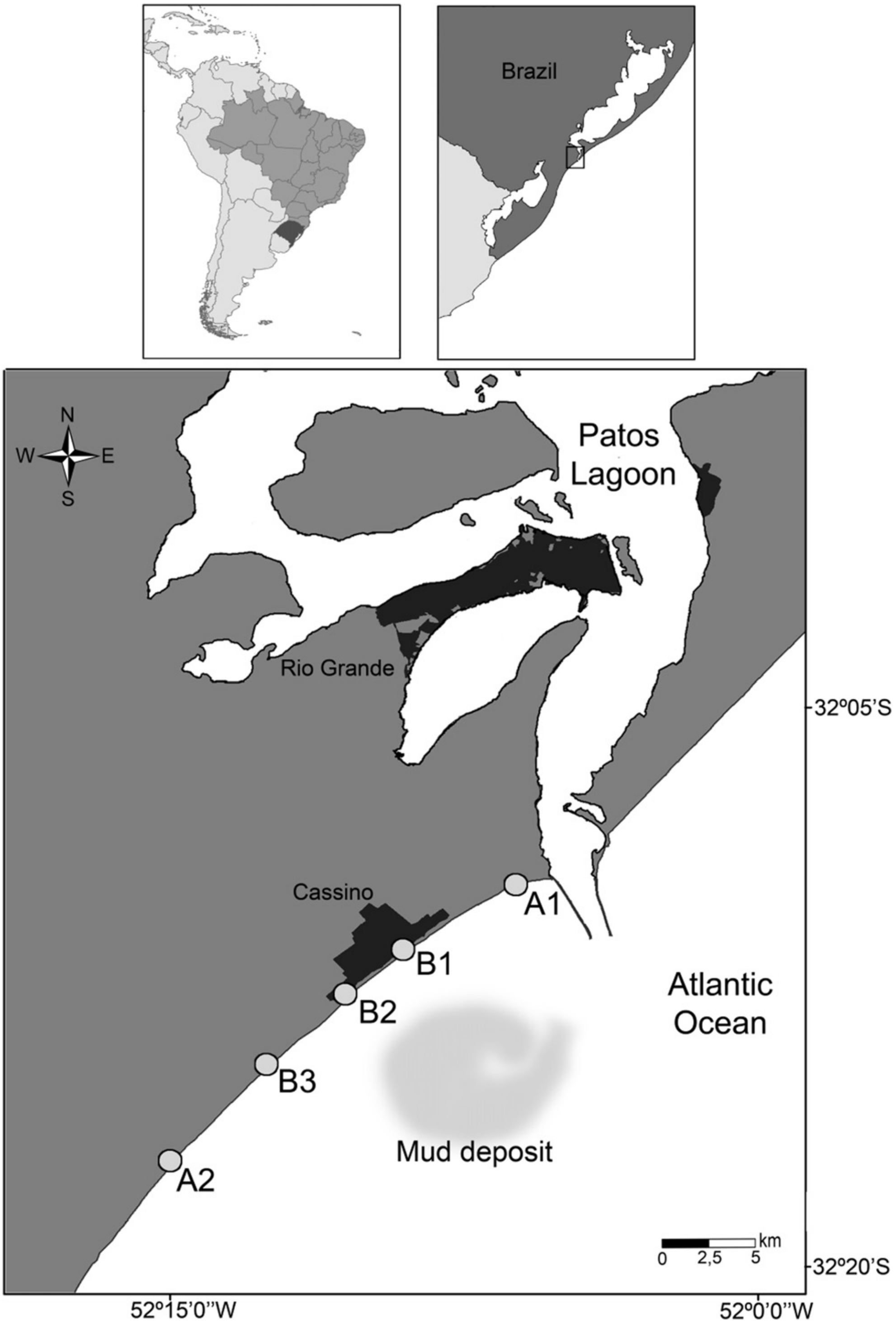

Fig. 1. Map showing the location of sampling sites at Cassino beach, southern Brazil. Sites A1 and A2 are the control areas and B1, B2 and B3 represent mud deposition areas.

Station at the Rio Grande harbor, located at a distance of about 10 km from the study area.

2.4. Data analysis

The spatial and temporal variation of environmental variables was assessed by Kruskal–Wallis nonparametric analysis of variance, once the values did not meet the assumptions of normality and homogeneity of variances. The presence of missing values for water transparency made it difficult to obtain a balanced matrix for this variable. Hence, water transparency was only assessed through explanatory analysis. A Spearman's Rank Order correlation (r_s) was run to determine the relationship between environmental variables and total relative abundance (catch per unit effort, CPUE) (Zar, 1999). The CPUE was calculated as the ratio of the total abundance by the five hauls accomplished at each sampling site, and expressed as number of individuals per haul. All data were previously transformed by $\log_{10}(x+1)$.

In order to determine the relative importance of each species, as well as their dominance pattern at each one of the sampling sites, we combined numerical percentage values (N%) and frequency of occurrence (FO%) values. The values of N% and FO% were compared against their respective means (μN% and μFO%) and, according to the results, the species were classified as Abundant and Frequent (dominant), Abundant and Not Frequent (occasional), Frequent and Not Abundant (common), or Present (rare) (Garcia et al., 2006; Artioli et al., 2009).

The number of individuals by size class per sample was obtained by multiplying the ratio of the total number of individuals caught to the total number of individuals measured by the number of individuals measured for each 10 mm size class (Vieira, 2006). Three size classes were established based on the size frequency distribution of caught fishes and identified as 'Size Ecological Taxa' (SET): individuals smaller than 50 mm TL, between 50 and 100 mm TL, and equal to or larger than 100 mm TL. The total abundance of a SET was computed by summing the total abundance of each size class (10 mm) within that SET (Vieira, 2006).

The biological variation between controls (A) and mud locations (B) was tested using ANOSIM method, after assumptions of normality and homoscedasticity had been tested by the Multivariate Normality test (Mardia) and Box M's test, respectively. A thorough analysis regarding all locations in separate was tested through repeated measures ANOVA, where the sampling points were considered as a factor and catch per unit effort (CPUE) values were used as replicates. Data were transformed by $\log_{10}(x+1)$ and, assumptions of normality and homoscedasticity tested by Shapiro–Wilks and Cochran C tests respectively. All statistical analyses were completed using the software PAST v. 2.02 (Hammer et al., 2001) and p values lower than 0.05 were considered significant.

The fish assemblage diversity study was based on the species richness, which was calculated by rarefaction (Krebs, 1989) and species evenness, based on the Evar method, with 0 representing the minimum and 1 the maximum evenness (Smith and Wilson, 1996).

The similarity among the sampling sites was assessed through cluster analysis, using the Euclidian distance to generate the similarity matrix, and the minimum-variance method (Ward's) as the clustering strategy. The abundance data (CPUE) was previously selected (species responsible for accumulating 99% of the total catch) and transformed by $\log_{10}(x+1)$. The consistency of the clusters was tested by Bootstrap resampling technique ($n = 5000$). The contribution of each species to clusters organization and the dissimilarity between groups was assessed through similarity percentages analysis (SIMPER). Correspondence analysis was used to evaluate the associations between the study sites and the principal species of the same dataset (Malmgren et al., 1978).

In the multivariate statistical analysis, only data for the species *Mugil liza* (Menezes et al., 2010), *Mugil curema* and *Mugil hospes* (Chao et al., 1982) were grouped into a single category called Mugilidae. This grouping was performed because those species are hard to identify when juveniles and because they play the same ecological function in the environment (Vieira, 1991).

3. Results

Throughout the study period, the temperature ranged between 10.5 °C and 24.5 °C, the salinity between 21.7 and 36.2, and pH between 6.7 and 8.7. The dissolved oxygen ranged between 5.0 mg/L and 10.9 mg/L, with one extreme low value (0.62 mg/L) measured at B2 site on the fifth field sampling. There was no spatial variation for the described environmental variables (Fig. 2a, b, c, d) but all presented temporal variation, with the temperature and salinity values presenting a sharp decreasing trend over time (Fig. 2e, f, g, h). The average values of water transparency were lower in areas with mud deposition (B1, B2, and B3), indicating higher turbidity (Fig. 3a). During the sampling period, W–SW winds (negative values of W) predominated, generating low energy waves in the beach area (Fig. 3b). These waves were more attenuated in the locations with mud deposition than in the controls sites due to the presence of a near-bed fluid mud layer (Fig. 4). When comparing mud sampling sites, the northern interface (B1) exhibited higher wave action generated by wind than others locations (visual records).

A total of 15,245 individuals were captured (Table 1). After identification these individuals were separated into 26 taxonomic groups: four at the family level, two at the level of genera, and 20 at the species level. Eleven taxonomic groups comprised 99% of the total catch. Only *Mugil liza* was abundant and frequent at all sampling sites, whereas *Mugil curema* was the only abundant and frequent at the three mud deposition sites.

The fish fauna used in the 'Size Ecological Taxa' (SET) analysis indicated that individuals smaller than 50 mm TL were more abundant (64.6% of the total), of which 80.8% were Mugilidae. Fishes between 50 and 100 mm TL accounted for 34.3% of the total catch, of which 94% of individuals belonged to Mugilidae, *Trachinotus marginatus* and *Brevoortia pectinata*. Fishes of size $\geq$100 mm TL represented just 1% of the total catch, with *T. marginatus* constituting 39.3% of those samples (Fig. 5 and Table 1). There was no statistically significant difference between size classes distribution pattern among the five sampling sites (Rep. Measures ANOVA, $F = 1.18$ and $p = 0.99$).

ANOSIM results for abundance data were significantly different ($p = 0.008$) when comparing control site A vs. muddy site B, but very little separable ($R = 0.10$). This result justified the need for further interrogation and hence the use of an analysis considering all five sampling locations in separate. CPUE values had significant spatial differences ($p < 0.0001$), with B2 and B3 showing higher means (85.7 ind./hauls and 102.4, respectively) compared with those of the control sites (A1 - 37.4 and A2 - 8.9) and local B1 (19.6) (Table 2). Juvenile individuals smaller than 30 mm TL were mainly responsible for the spatial pattern of relative abundance observed above, except for site A1 which did not show significant differences relative to other sites, and B2 that was significantly different from B1 ($p = 0.001$).

The Mugilidae group was primarily responsible for the high abundance values associated with sites B2 (2939 *Mugil liza* individuals caught in just one sampling trip – in 08 June 2009) and B3 (2816 *Mugil curema* and *Mugil hospes* individuals caught in just one sampling trip – in 21 April 2009). In fact, when we analyzed the collected fish fauna at a temporal scale, without spatial differentiation, we see that Mugilidae group abundance was significantly higher when compared to the abundance of all others captured taxa (Rep. Measures ANOVA, $F = 23.65$, $p = 3.29\text{E-}06$) (Fig. 6).

The evenness index values for all five points were low (0.11–0.21) and, although mud locations have presented the lowest values, no significant difference was observed among sites. The richness index (rarefaction method) ranged from 11.2 to 14.9, but no statistically significant differences were found among sites. The lowest abundance value (A2) was observed at the site of greatest diversity (higher evenness and higher expected richness) (Table 2).

Cluster analysis indicated the presence of three groups in terms of sampling sites similarity. One group was represented by sites B2 and B3; another group was represented by the most hydrodynamically energetic control site (A2) and the mud deposit's northern interface (B1); whereas the last group consisted of two branches, with one represented by A1 and the other by A2/B1 group (Fig. 7). The consistency of the three observed groups in this

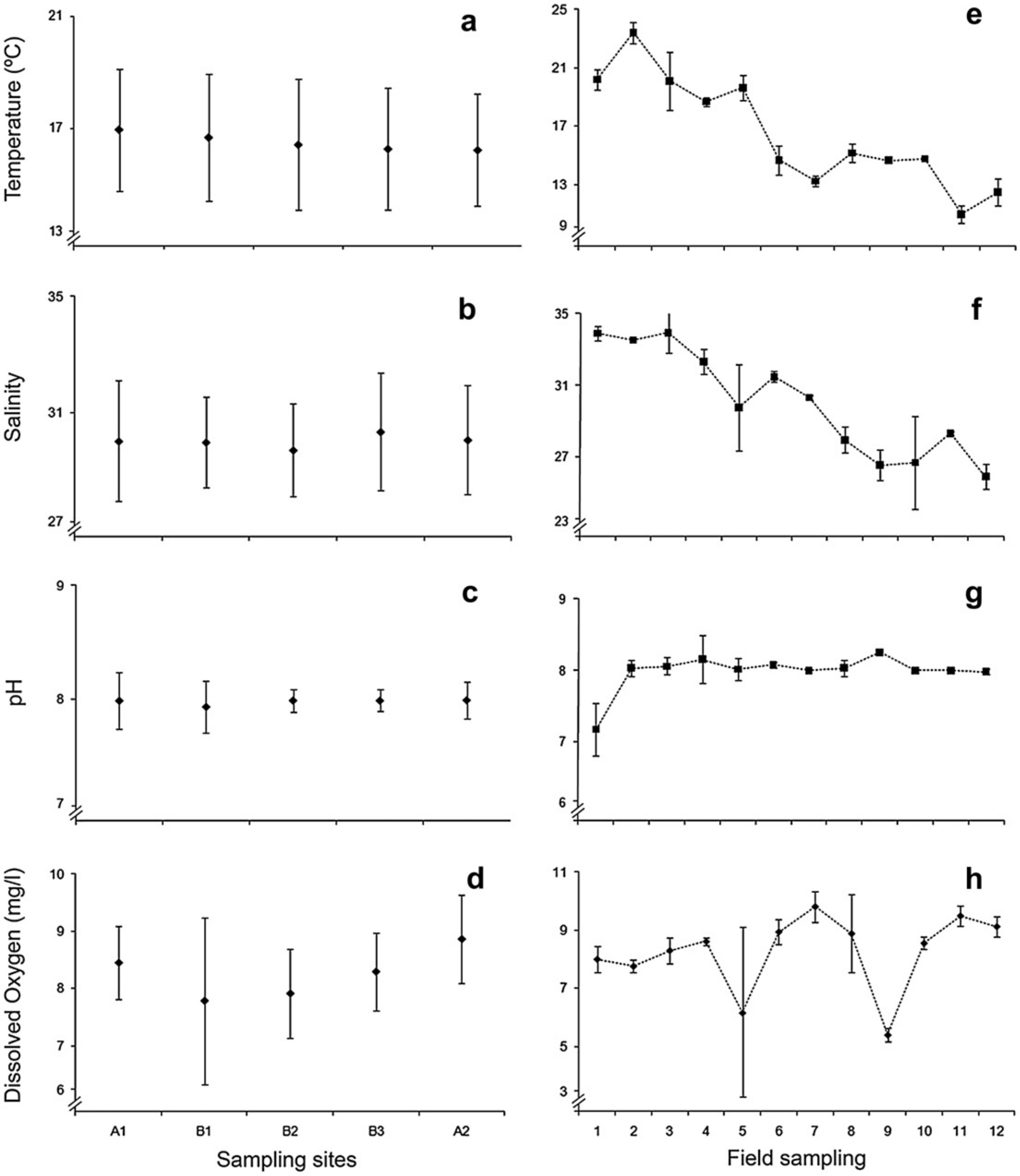

Fig. 2. Spatial (left column) and temporal (right column) environmental variables variation recorded at sampling sites in Cassino Beach: Temperature (a, e); salinity (b, f); dissolved oxygen (c, g) and pH (d, h).

analysis, generated by bootstrapping, was moderate, with the higher value being 62% for A2/B1 group. The consistency value for B2/B3 was 50% and for A1/A2/B1 was 42%. A SIMPER analysis indicated 40% dissimilarity between A1 and the group A2/B1. The taxa Mugilidae was the main responsible for that existent inter-group dissimilarity, accounting for 30.13%, followed by Clupeidae (22.43%) and *Brevoortia pectinata* (16.24%). The dissimilarity value between B2/B3 group and the cluster represented by the sampling sites A1, A2 and B1 was 43.02%, with the taxa Mugilidae again having the biggest contribution (25.52%) and *Micropogonias furnieri* and Clupeidae accounting for part of difference (combined 34.66%).

Axes 1 and 2 from the correspondence analysis (Fig. 8) accounted for 39.4% and 30.8%, respectively, of the total data variability, with the arrangement of the sampling sites being maintained as that described in the cluster analysis. The taxa *Micropogonias furnieri*, Engraulidae, Atherinopsidae and Clupeidae had a greater association with sites B2 and B3. *Brevoortia pectinata* was primarily associated with the northernmost site of the mud deposit (B1). *Atherinella brasiliensis* and *Menticirrhus littoralis* were primarily associated with the control sites, while *Trachinotus marginatus* was associated with the group A2/B1 (Fig. 8). Mugilidae, the most abundant category in the study area, remained closer to the center of the axes, indicating no particular association with any of the sampling sites. Although apart from each other at cluster analysis, all muddy sampling sites were situated above Axis 2, whereas control sites were located below the axis.

Amongst the environmental variables tested using Spearman's correlation, dissolved oxygen, salinity, and water temperature were significantly correlated with species abundance ($p < 0.001$). However, only temperature exhibited a strong, positive correlation with species abundance values ($r_s = 0.61$).

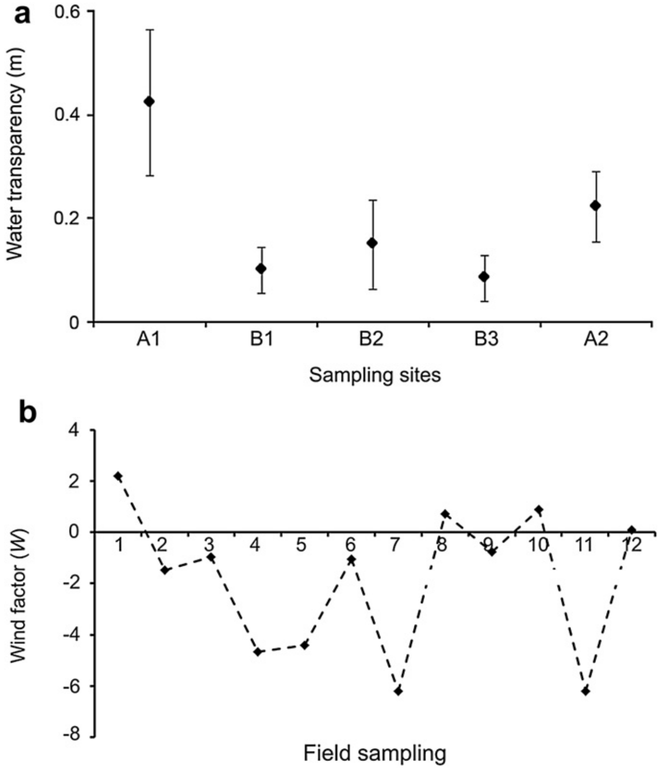

Fig. 3. Mean values of (a) Water transparency and (b) "wind factor" (*W*) recorded at sampling sites.

4. Discussion

The present study was carried out across a four month period during a single event of mud deposition at Cassino Beach. The study period covered both autumn and winter, when the abundance of fish species is naturally lower at the coast of Rio Grande do Sul state, especially because of low temperatures. It is also of note that our results are characterized by high spatial and temporal variability, which is typical of naturally stressful and dynamic habitats such as the surf zone (Lima and Vieira, 2009; Odebrecht et al., 2010). In particular, this condition complicated the identification of contrasts between control and mud deposition sites. Despite these limitations, it was possible to recognize spatial variations in the abundance, evenness, and composition of fish fauna at Cassino Beach surf zone. These variations may be related to changes in local wave action generated by wind at areas which were under the influence of mud deposition.

The seasonal pattern of fish abundance and diversity at Cassino Beach is strongly influenced by fluctuations in physical–chemical parameters, such as temperature, salinity and wave exposure (Lima and Vieira, 2009). Hence, localized short-term variations were expected in the structure of the fish assemblage in response to environmental factors (Romer, 1990). During the study period, the fish assemblage abundance followed the declining trend of temperature and salinity from autumn to winter. According to Monteiro-Neto et al. (2003), the water temperature of Cassino Beach plays an important role in regulating the migration and spawning period of adult fish. Thus, juvenile recruitment determines the species associations and seasonal variations in abundance of the surf zone assemblage. As a result, an even greater abundance of individuals is observed during the spring and summer (Lima and Vieira, 2009). Among the studied taxa, only the abundance of the dominant Mugilidae remained virtually unchanged throughout the study period. This observation indicated the constancy and numerical abundance of juvenile mullets in the study area (Vieira, 1991; Monteiro-Neto et al., 2003).

Salinity plays a major role on fluid mud formation, even though its effect on the studied fish community structure was lower when compared to the temperature effect. The reduction in salinity at the inner shelf is one of the contributing factors in the generation of fluid mud (Udaya Varma and Kurup, 1969; Nair, 1976). At Cassino Beach this salinity reduction process is promoted by periods of high freshwater water flow from Patos Lagoon (Odebrecht et al., 2010) and especially for the presence of the La Plata plume during winter (Piola et al., 2005; Möller et al., 2008).

The most important characteristic of a mud bank is its ability to attenuate surface waves (Mathew et al., 1995). Hence, a mud deposition event is visually characterized by a complete absence of surf zone (Calliari et al., 2001; Pereira et al., 2011). Wave action is one of the main factors that affects the fish and invertebrate community structure of sandy beaches (Romer, 1990; Clark, 1997). In the way that wave action is directly affected by mud presence, and vice versa, their interaction product was the dominant environment factor detected in the present study. The sampling sites located outside the influence of mud (A1 and A2) had greater wave action generated by wind, and were subjected to higher waves when compared to the other sampling sites. Although influenced by mud, B1 had higher wave action generated by wind compared to B2 and B3. In fact, B2 was in an area devoid of surface water oscillations. The highest total abundance values were observed at the sampling sites with lower or absent wave energy (B2 and B3). In contrast, low abundance values were associated with sampling sites that were more exposed to wave action (A1, A2, and B1), suggesting an inverse relationship between wave action and species abundance. Similar studies elsewhere had also observed this pattern (Romer, 1990; Clark, 1997; Watt-Pringle and Strydom, 2003; Vasconcellos et al., 2007).

Although the study comprehended a time period of mud deposition, the sampled fish community did not differ from

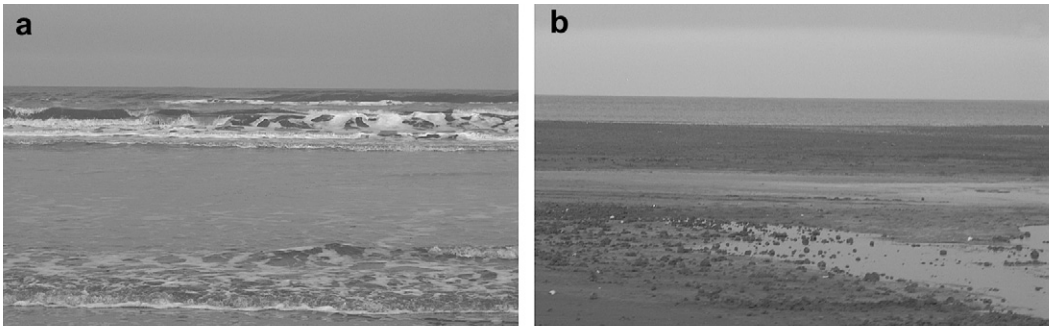

Fig. 4. Site A2 exhibiting wave action (a) and site B3 showing wave damping effect caused by mud (b). Both pictures were captured at the same day (June 08, 2009).

Table 1

Number and size (total length in mm) of species caught in shallow surf zone at the sampling sites in Cassino Beach. Species are classified by relative importance decreasing order and sorted as abundant and frequent (black), abundant and not frequent (dark grey), frequent and not abundant (light grey) and Present (white).

Species	A1				B1				B2				B3				A2			
	Size (mm)				Size (mm)				Size (mm)				Size (mm)				Size (mm)			
	Number	Mean	Min	Max	Number	Mean	Min	Max	Number	Mean	Min	Max	Number	Mean	Min	Max	Number	Mean	Min	Max
Mugil liza[a]	1812	27.49	22.0	44.0	350	27.75	22.0	131.0	4154	22.71	16.0	156.0	1225	27.89	20.0	93.0	310	27.44	22.0	75.0
Mugil curema[a]	96	77.09	54.0	133.0	190	68.55	41.0	106.0	325	76.00	20.0	135.0	1530	70.55	36.0	127.0	28	73.86	45.0	108.0
Trachinotus marginatus[a]	87	63.79	21.0	140.0	293	83.21	22.0	124.0	81	69.74	42.0	113.0	445	62.40	29	142	105	50.52	20.0	96.0
Brevoortia pectinata[a]	31	53.61	28.0	88.0	283	60.50	39.0	89.0	53	54.96	28.0	80.0	181	52.17	20.0	113.0	8	42.88	27.0	64.0
Clupeidae[a]	142	21.74	16.0	26.0	3	24.33	23.0	26.0	82	23.65	16.0	29.0	707	22.36	15.0	28.0	18	22.33	18.0	27.0
Micropogonias furnieri[a]	–	–	–	–	27	40.48	19.0	71.0	306	43.73	10.0	112.0	109	44.18	17.0	139.0	10	49.50	32.0	66.0
Menticirrhus littoralis[a]	12	48.42	34.0	60.0	1	137.00	137.0	137.0	1	93.00	93.0	93.0	21	50.14	22.0	115.0	35	49.31	25.0	90.0
Mugil hospes[a]	1	45.00	45.0	45.0	3	78.00	74.0	84.0	4	72.75	55.0	82.0	1650	63.44	39.0	91.0	1	64.00	64.0	64.0
Atherinella brasiliensis[a]	36	80.81	48.0	125.0	2	62.50	61.0	64.0	15	60.60	24.0	86.0	10	68.10	40.0	86.0	5	81.40	64.0	97.0
Odontesthes argentinensis	10	74.10	30.0	118.0	1	94.00	94.0	94.0	4	68.75	22.0	155.0	33	48.39	24.0	253.0	4	71.25	30.0	189.0
Atherinopsidae[a]	5	16.60	15.0	18.0	–	–	–	–	11	17.09	15.0	19.0	45	18.71	13.0	25.0	1	15.00	15.0	15.0
Lycengraulis grossidens	–	–	–	–	2	165.00	141.0	189.0	3	119.67	60.0	157.0	3	99.33	64.0	165.0	1	147.00	147.0	147.0
Menticirrhus sp.	4	34.25	32.0	36.0	–	–	–	–	7	29.86	12.0	43.0	6	25.00	18.0	31.0	5	24.00	17.0	29.0
Oncopterus darwinii	4	35.25	34.0	37.0	1	31.00	31.0	31.0	–	–	–	–	6	44.33	16.0	157.0	3	22.67	17.0	29.0
Pomatomus saltatrix	1	90.00	90.0	90.0	1	95.00	95.0	95.0	2	95.50	82.0	109.0	2	106.50	91.0	122.0	–	–	–	–
Engraulidae[a]	4	17.75	16.0	19.0	–	–	–	–	64	21.47	16.0	35.0	158	20.06	17.0	29.0	–	–	–	–
Genidens barbus	–	–	–	–	18	90.56	81.0	105.0	26	85.88	71.0	93.0	10	88.10	79.0	96.0	–	–	–	–
Scianidae	–	–	–	–	–	–	–	–	1	16.00	16.0	16.0	2	18.50	18.0	19.0	–	–	–	–
Caranx lattus	–	–	–	–	–	–	–	–	–	–	–	–	1	45.00	45.0	45.0	–	–	–	–
Chloroscombrus chrysurus	1	56.00	56.0	56.0	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Jenynsia multidentata	–	–	–	–	–	–	–	–	1	12.00	12.0	12.0	–	–	–	–	–	–	–	–
Paralichthys orbignyanus	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	167.00	167.0	167.0
Prionotus punctatus	–	–	–	–	–	–	–	–	1	123.00	123.0	123.0	–	–	–	–	–	–	–	–
Syngnathus folletti	–	–	–	–	–	–	–	–	1	88.00	88.0	88.0	–	–	–	–	–	–	–	–
Trachinotus carolinus	–	–	–	–	2	116.50	69.0	164.0	–	–	–	–	–	–	–	–	–	–	–	–
Trichiurus lepturus	–	–	–	–	1	430.00	430.0	430.0	–	–	–	–	–	–	–	–	–	–	–	–
Total abundance (N)	2246				1178				5142				6144				535			
Richness (E(S))	11.3				11.9				11.6				13.4				14.9			
Evenness (E_{var})	0.15				0.12				0.12				0.11				0.21			

[a] Species responsible for accumulate 99% of total capture.

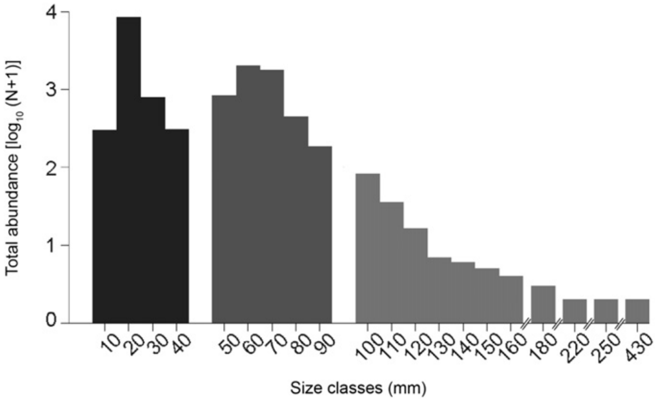

Fig. 5. Number of individuals $\log_{10}(x+1)$ by size classes (total length, TL) of fishes captured between April and August 2009 at Cassino beach surf zone.

previous works in the area considering fauna structure and composition (e.g. Monteiro-Neto et al., 2003; Lima and Vieira, 2009). The data showed few numerically important species which were primarily represented by juveniles.

Three hypotheses may explain the concentration of juveniles in mud dominated environments. The first one is related to the presence of longshore currents. An oblique wave's incidence and differences in the crests height are responsible for a water setup and, as a result, lateral pressure gradients arise from the accumulation of water on the coast. These gradients generate parallel flows along the shore line (Calliari et al., 2003) in sandy bottom areas located both to the north and south of muddy areas. Watt-Pringle and Strydom (2003) suggested that the aggregation behavior of shoals serves as a temporary shelter near the coast, aided by the littoral drift currents. Fishes could use these conditions to move without the swimming effort, thus saving energy. The SW–NE longshore currents direction, established by the predominance of W–SW winds, could therefore be responsible for driving juvenile fishes toward B3 and B2 locations. Layman (2000) also noted the preferential use of lower energy surf zone habitats by fishes and proposed that this phenomenon may be the end result of small-scale parallel movements along the coast. Therefore, lower wave energy found at mud deposition sites would favor fish aggregation, which in turn would lead to higher juvenile abundance.

The second theory is related to active habitat selection by fish for areas of higher turbidity. The presence of water with lower levels of transparency is generally considered advantageous for juvenile fishes, because this condition provides greater protection against predators. In addition, areas of lower visibility often exhibit higher densities of zooplanktons, which serve as food for these fishes (Blaber and Blaber, 1980; Lasiak, 1981; Clark et al., 1996; Garcia and Vieira, 1997; Layman, 2000). These two advantageous characteristics of higher turbidity areas could, therefore, contribute to a greater fish abundance in muddy areas.

The distribution and abundance values of the White-mouth croaker (*Micropogonias furnieri*) and the White Sea catfish (*Genidens barbus*) found predominantly at the sites under mud influence (B1, B2 and B3) during the study period (Table 1) reinforce this hypothesis of active habitat selection. These species, both classified as demersal estuarine dependent (Figueiredo and Menezes, 1978; Menezes and Figueiredo, 1980; Garcia et al., 2001), represent the largest overall abundance in southern Brazilian estuaries (Vieira, 2006). Commonly found in the inner estuary, where sediment type is usually classified as muddy (Araújo et al., 2002), they live shallow waters, of low salinity and transparency, and slightly higher temperature (Araújo et al., 2002, 2006; Vieira, 2006). Mud deposition events on Cassino Beach temporarily transform some surf zone areas to locals with inner estuary characteristics, by altering the substrate type (from coarse to muddy), dissipating wave energy and lowering water transparency values (Fig. 3). These

Table 2
Repeated measures analysis of variance (ANOVA) results for relative abundance of sampled ichthyofauna at Cassino beach.

	Sum of sqrs	df	Mean Square	*F*	*p* (same)
Between groups	4.8355	4	1.20889	7.851	0.000073
Subjects	7.8702	11	0.71547		
Total	19.4812	59			

Tukey's pairwise comparisons

	A1	B1	B2	B3	A2
A1		n.s.	n.s.	0.02519	n.s.
B1			n.s.	0.01949	n.s.
B2				n.s.	0.002549
B3					0.000205
A2					

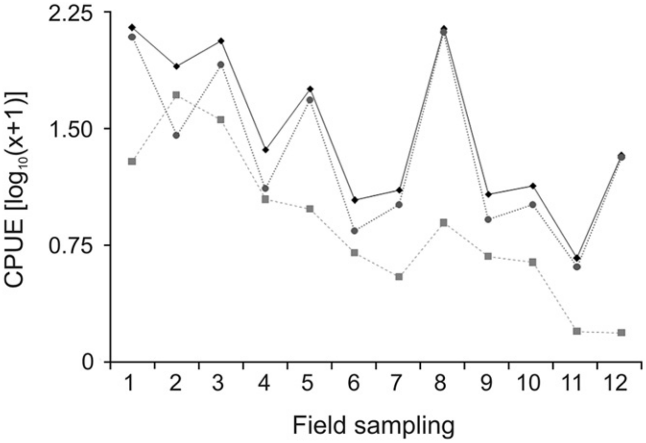

Fig. 6. General trend of fish fauna CPUE (– –■– –) without Mugilidae individuals; (•••●•••) only the Mugilidae group; and (——◆——) all 26 fish taxa captured during 12 field sampling at Cassino beach, Brazil.

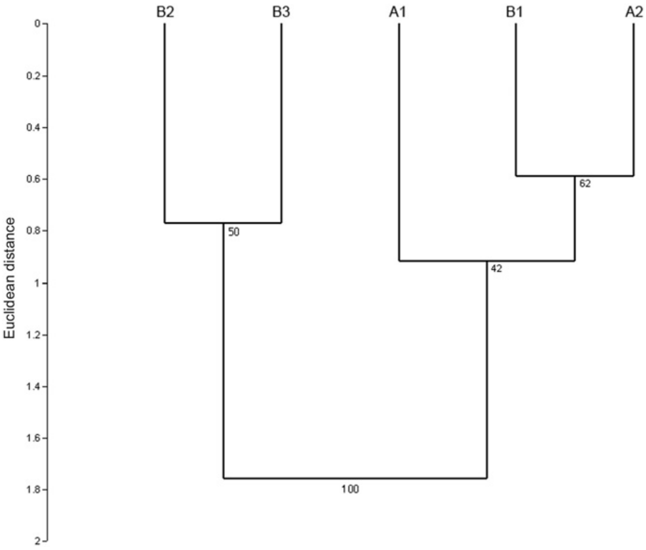

Fig. 7. Sampling stations dendrogram generated by Ward's minimum-variance method. Support for branching pattern was determined using bootstrap ($n = 5000$).

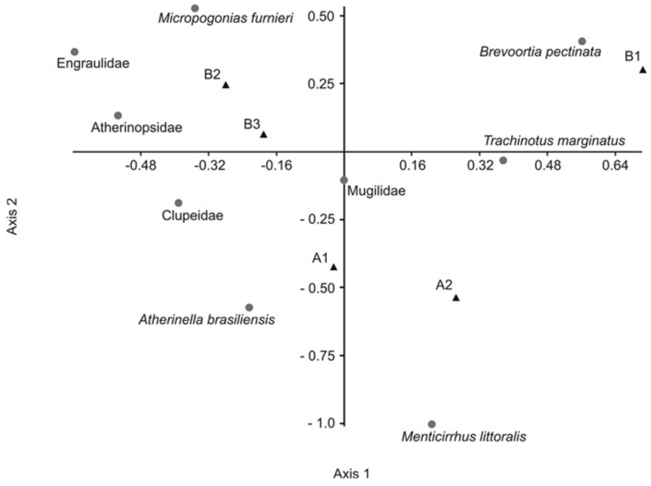

Fig. 8. Correspondence analysis map showing sampling sites (dark triangles) and the eleven species responsible for accumulate 99% of total capture (grey balls).

characteristics may attract fish species, such as the White-mouth croaker and the White sea catfish, used to areas under such conditions. The higher total abundance values found to B2 and B3 locations could also be related to this hypotheses once areas of higher water turbidity would reduce the visual acuity of fish, reducing their ability to detect the sampling fish net (Warfel and Merriman, 1944 apud; Lasiak, 1984), thus leading to higher capture rates than those in areas of lower turbidity.

The third hypothesis takes into account water viscosity and its influence on the swimming ability and vulnerability to the fish gear. Areas of the surf zone containing fluid mud are characterized by water with higher density and viscosity (Pereira, 2010). In particular, any change in viscosity is felt physically by juvenile fishes, which have low values of Reynolds number ($\sim 1 \times 10^3$) because of their small size and corresponding low speed, thus allowing the forces of viscosity to prevail over the forces of inertia (Fuiman and Batty, 1997; Massel, 1999). These forces negatively influence the ability of juvenile fishes to swim and, consequently, decrease their escape velocity. This results in greater capture rates compared with those in areas devoid of mud.

These three hypotheses are not necessarily independent and could have concomitant effects on the studied fish assemblages. Thus observed results may be explained by the longshore currents generating high concentrations of juveniles that are associated with the high turbidity and viscosity of water, which in turn hinders escape and facilitates the capture of these species. Such mud-induced changes in the turbidity and viscosity of water are not permanent, and it is likely that these species as a whole are able to recover to pre-disturbance conditions after the interruption of mud deposition events. Future in situ studies should be carried out in order to evaluate these hypotheses and their influences on fish abundance. The use of two or more sampling gears, being one of them the same employed at this study, would be important in order to check and compare the effectiveness of sampling gears at this special condition of the environment.

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