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Daily and seasonal fluctuations of the fish community in the surf zone of an estuarine-coastal area of Southeast Brazil

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Abstract The surf-zone environment experiences oscillations on different temporal scales, and as a consequence, abiotic factors may influence the surf-zone fish community differently when these fluctuations are analyzed on short and long temporal scales. To verify this, the surf-zone fish community was sampled on three beaches located in the south of Comprida Island, Southern coast of São Paulo state, Brazil. Samples were collected every two days from 23 January to 18 February 2009, for the daily fluctuations (short-term), and monthly, from December 2008 to February 2010, for the seasonal fluctuations (long-term). Regardless of the temporal sampling scale, the main features and composition of the surf-zone fish community were kept the same. However, when comparing effects of variations in abiotic factors on the fish fauna, it was observed that temperature was significant only in the seasonal sampling scale and the percentage of explanation for the beaches with different exposure levels was higher when data were analyzed from the daily samples.

Key words: ichthyofauna, beaches, composition, different temporal scales

Resumo: Flutuações diária e sazonal da comunidade de peixes da zona de surfe de uma área costeira-estuarina do sudeste do Brasil. O ambiente da zona de surfe sofre oscilações em diferentes escalas temporais e, como consequência, os fatores abióticos podem influenciar a comunidade de peixes desse ambiente de diferentes maneiras, quando analisada numa escala temporal de curto e de longo prazo. Para verificar essas diferentes influências, foram amostrados peixes da zona de surfe de três praias localizadas no sul da ilha Comprida, litoral sul do estado de São Paulo, Brasil. As amostras foram obtidas em dias alternados de 23 de janeiro a 18 de fevereiro de 2009, para as flutuações diárias (curto prazo), e mensalmente, de dezembro de 2008 a fevereiro de 2010 para as flutuações sazonais (longo prazo). Independente do esforço amostral, as principais características e a composição da comunidade de peixes estudada foi mantida. Entretanto, ao comparar o efeito dos fatores abióticos na variação da ictiofauna, observou-se que temperatura teve influência significativa apenas na análise sazonal e a porcentagem de explicação das praias com diferentes níveis de exposição foi maior nas amostras obtidas diariamente.

Palavras chave: ictiofauna, praias, composição, diferentes escalas temporais

Introduction

Despite being characterized by shallow depths, high hydrodynamic energy and sensitive coastal areas, the surf-zone of sandy beaches is a feeding and growth area of several fish species during their life cycles, due to the high food availability and protection against predators (Lasiak 1981; McLachlan *et al*. 1981; McLachlan 1983). The environment changes in short (diel, daily) and median (monthly) scales, due to processes such as tidal cycles, seasonal variations in temperature and salinity, wave action, and meteorological oscillations, such as cold fronts (Lasiak 1984a; Lasiak 1984b; Santos & Nash 1995). Such environments are also impacted by human population growth, leading to destruction of habitats and overexploitation of natural resources (Defeo *et al.* 2009).

The number of studies aiming to determine juvenile fish patterns and processes in the surf zone of sandy beaches has been increasing, due to a demand for biological information to assist the monitoring and conservation of coastal environments. The Southeastern coast of Brazil presents great diversity of surf-zone morphology and dynamics, and many studies in the Brazilian coast have described possible associations between the seasonal variations of abiotic factors that may be responsible for variations in fish abundance, diversity and assemblages (e.g. Paiva Filho *et al*. 1987; Pereira 1994; Giannini & Paiva Filho 1995; Saul & Cunningham 1995; Gaelzer & Zalmon 2003; Gomes *et al*. 2003; Araújo *et al*. 2008; Lima & Vieira 2009; Favero and Dias, 2013). However, even worldwide, there are only a few studies assessing the influence of short temporal oscillations on the surf-zone fish community (e.g. Lasiak 1984b; Clark 1997; Félix-Hackradt *et al*. 2007, 2010). Thus, understanding short- and long-term uses of surf-zone habitat by the fish fauna could be an important factor in understanding fish survival in this dynamic habitat.

In this context, the present study aims to describe the composition and main features of the fish community in the surf zone of an estuarine-coastal area of Southeast Brazil when analyzed at two different temporal scales, seasonal (long-term) and daily (short-term).

Methods

Study area

The Cananéia-Iguape coastal system is a broad and well-preserved mangrove forest-surrounded estuary on the Southern coast of São Paulo State, Brazil, covering a total area of 110 km^2 (Schaeffer-Novelli *et al*. 1990). The complete system consists of four islands and different natural channels with two main connections to the adjacent ocean: the Icapara bar (to the North) and the Cananéia bar (to the South) (Fig.1).

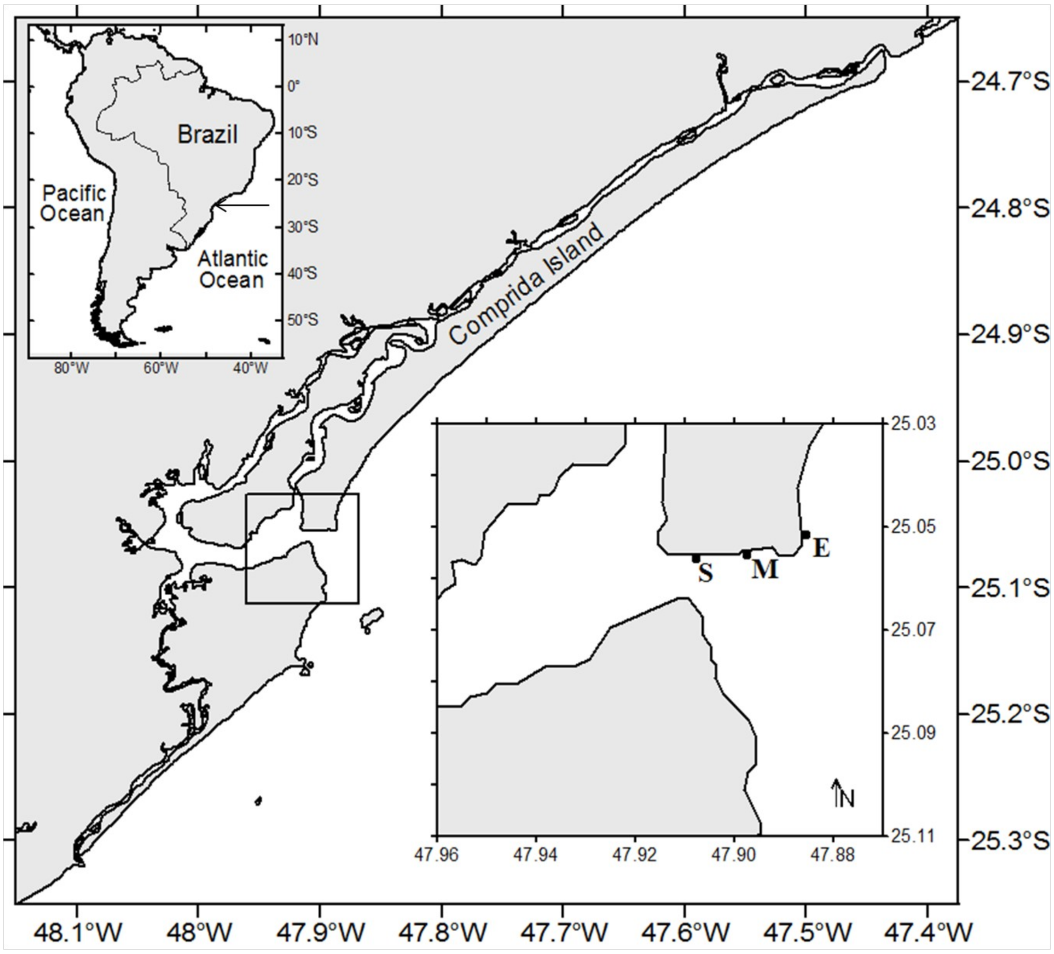

Figure 1. Location of the three sample beaches (S= Sheltered, M= Moderate, E= Exposed) at Comprida Island, southeast Brazil.

Sampling

Samples were collected every two days from 23 January to 18 February 2009 for the daily fluctuations; and monthly, from December 2008 to February 2010, for the seasonal fluctuations, totaling 14 days and 14 months. At each beach, in the points showed at figure 1, four consecutive 30 m hauls were done parallel to the coast, using a 9 m long and 1.5 m height seine net, with a stretched mesh size of 5 mm. The hauls never exceeded one meter depth, during the low (morning) and the high (afternoon) tide. During the seasonal effort the samples were obtained at the spring tide. The short-term samples were performed during one summer month because it is the period of recruitment at the beach environment for many fish species (e.g. Lasiak, 1984b; Bennett, 1989; Clark, 1996a; Félix *et al.* 2006; Araújo *et al.* 2008; Favero & Dias, 2013).

A total of 336 samples were obtained within both temporal sampling scales. Water temperature was measured with a mercury thermometer and the salinity with a refractometer, on all sampling dates and beaches.

Individuals caught were preserved on ice and identified according to Figueiredo and Menezes (1978, 1980, 2000); Menezes and Figueiredo (1980, 1985) and Richards (2006). All juvenile mugilids collected were separated based on Vieira (1991). The following nomenclatures were used: *Mugil hospes* (previously *Mugil gaimardianus*), *Mugil liza* (previously *Mugil platanus*) according to Menezes *et al.* (2010), Mugil 1 for mugilids that were identified by their anal fin having 13 elements (two spines and 11 rays) and Mugil 2 with two spines and eight rays on the anal fin. Mugil 1 and Mugil 2 have not been described yet.

All fish were measured (total length 1 mm) and weighed (0.01 g), except when the number of individuals from the same species exceeded 50. In these instances, 50 individuals were randomly selected for measurement. The excess was weighed, counted and incorporated as weight and number units. In addition, sex and maturity stages were documented for the subsample through direct observation, according to Vazzoler (1996) for males and Dias *et al.* (1998) for females.

Data analysis

Analysis of variance (one-way ANOVA) was used to test the differences in the values of water temperature and salinity when compared per day, per month, per beach and per tide. Tukey *post-hoc* tests were conducted to evaluate between-mean differences at each situation.

The fish numerical abundance was used to calculate ecological indexes of dominance, Shannon diversity, Margalef richness and evenness according to Begon *et al.* (2006). Only the occurrence constancy (C) was calculated according to Dajoz (1983), who classified the species as: constant ($C \geq 50$), accessory ($50 < C > 25$), and accidental ($C \leq 25$). The differences among the indexes were tested using the Bootstrap method, with 95% of significance level and total of 999 simulations.

Canonical Correspondence Analysis (CCA) assessed the influence of each abiotic variable on the fish assemblage (Legendre & Legendre 1998). Rare species, arbitrary chosen as those with less than 0.2% relative abundance, were eliminated from the biological matrix. As the species abundance distribution was skewed, the numerical abundance of each species was transformed by log (x+1). Low weight was given to the rare species to avoid their influence in the results. For the daily analysis, environmental (temperature and salinity), spatial (the three different beaches: Sheltered, Moderate and Exposed) and temporal variables (high tide, low tide, spring tide, neap tide and the different days that were sampled) were used. The only difference in the seasonal analysis was that besides using the different days as a temporal variable, it was used the different months sampled, representing seasonality. As the continuous variables are two different measurements, temperature and salinity, they were transformed by log (x). All the categorical variables (tides, beaches, day/months) were used as dummy matrix. The percentage of explanation of each abiotic variable and their interaction was calculated according to Borcard *et al.* (1992), dividing the variation of species abundance into independent components: pure spatial, pure environmental and undetermined. Forward stepwise model selection using permutation tests was done to identify the abiotic variables that could best explain the variation in the biological data ($p<0.05$).

All the analysis was done using the packages “stats” (R Core Team, 2012) and “vegan” (Oksanen *et al*., 2012) for the R software.

Results

Daily biotic and abiotic variation

Environmental Data

The environmental data analysis showed no significant difference in the temperature values at the different sampled beaches ($F=0.112$, $p=0.894$). There was significant variation in the temperature values along the sampled days ($F=10.71$, $p<0.01$) (Fig. 2).

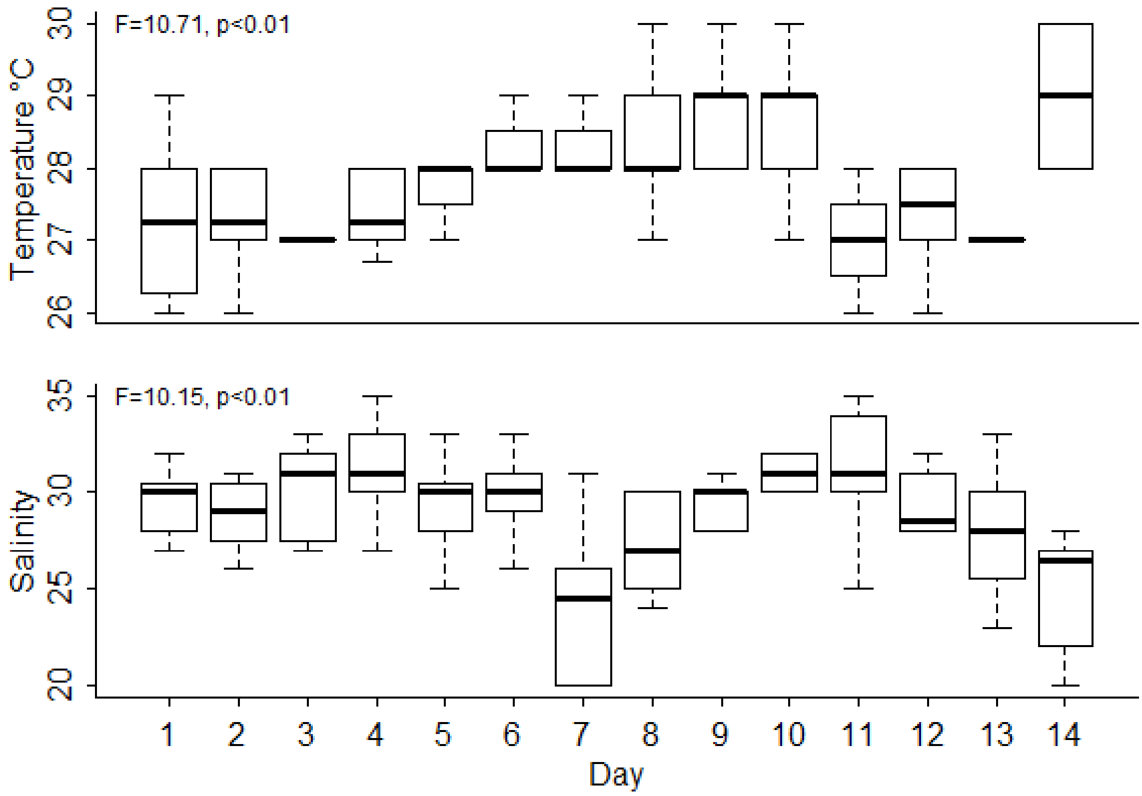

Figure 2. Temperature (°C) and salinity variations measured in the surf-zone of Comprida Island from January 23rd, 2009 to February 18th, 2009 (horizontal line represents the median, rectangle represents the lower and upper quartile and I the lower and upper adjacent value. No outlier was plotted).

The temperature variation was also significant when analyzing the values obtained for high and low tides (F=8.04, p=0.006), with higher values during the high tide. The maximum temperature was 30°C, and the minimum was 26°C.

Similar to temperature, salinity varied significantly on the different sampling days (F=10.15, p<0.01) (Fig. 2) and under different tides (F=10.68, p=0.002), with higher salinity values during the high tide.

Unlike temperature, salinity varied significantly for the different sampled beaches (F=7.981, p=0.001), with higher values observed on the Exposed beach (maximum 35; minimum 25), and the lower ones for the Sheltered beach (maximum 32; minimum 20) and the Moderate beach (maximum 31; minimum 20). No significant difference was found between the Moderate and the Sheltered beaches.

Species Composition

A total of 4,709 specimens from 37 species and 18 families were captured. Carangidae and Mugilidae represented 83.1% of the total individuals sampled, with 31.6% and 51.5% respectively. The more abundant species were *Trachinotus carolinus* (27.6%), *Trachinotus goodei* (22.2%), *Mugil curema* (17.1%), and *Mugil hospes* (13.8%) (Table I). The smaller specimens collected was *Ophioscion punctatissimus* and *Menticirrhus americanus*, with 8 and 9 mm of total length, respectively. Conversely, the largest ones, at 112 mm total length, were *Oligoplites saliens* and *T. goodei*.

Most of the specimens sampled were represented by individuals in their juvenile phase. For these individuals it was not possible to identify the sex, due to the small size of individuals and gonads. *Elops saurus*, *Menticirrhus americanus*, and *Micropogonias furnieri*, all the Gerreidae and some Engraulidae specimens were collected in their larval phase, identified by the lack of scales. No adult fish were sampled.

Three constant species (*T. goodei, T. carolinus*, and *M. curema*), a single accessory species (*M. hospes*) and a variety of accidental species (Table I) comprised this fish community. This pattern remained similar when the types of beach and tides were analyzed separately. The main differences were the higher constancy of *M. hospes* in the Sheltered beach at high tide, and *T. falcatus* as an accessory species in the Sheltered beach and low tide.

Table I. Relative frequency (%), total contribution and constancy index (C) of fish sampled in the surf zone of Comprida Island, São Paulo, Brazil, from January 23rd to February 18th 2009 (daily) and from 2008 December to 2010 January (seasonal). *= larvae.

Family/Specie	Daily		Seasonal	
	%	C	%	C
Elopidae				
*Elops saurus**	3.61	19.05	1.0	9.5
Engraulidae				
Anchoa januaria	-	-	0.3	2.4
Anchoa lyolepis	0.04	1.19	0.0	1.2
Anchoa tricolor	1.70	5.95	0.5	4.8
Anchoviella lepidentostole	0.40	2.38	0.0	2.4
Cetengraulis edentulus	-	-	0.1	3.6
Lycengraulis grossidens	0.04	1.19	-	-
Non-identified larvae	3.84	9.52	2.7	17.9
Clupeidae				
Harengula clupeola	0.23	2.38	4.4	10.7
Opisthonema oglinum	0.15	1.19		
Sardinella brasiliensis	-	-	0.0	1.2
Synodontidae				
Synodus foetens	0.02	1.19	0.0	1.2
Mugilidae				
Mugil curema	17.05	66.67	27.6	48.8
Mugil hospes	13.76	46.43	14.4	44.0
Mugil liza	0.32	4.76	3.3	36.9
Mugil 1	0.49	11.90	0.7	10.7
Mugil 2	-	-	0.0	1.2
Atherinopsidae				
Atherinella brasiliensis	0.13	3.57	-	-
Atherinella sp.*	-	-	0.0	1.2
Odonthestes argentinensis	-	-	0.1	6.0
Belonidae				
Strongylura timucu	0.15	3.57	0.2	4.8
Tylosurus acus	-	-	0.0	3.6
Exocoetidae				
Hyporhamphus unifasciatus	-	-	0.0	1.2
Hemiramphus sp.	-	-	0.0	1.2
Syngnathidae				
Syngnathus folletti	0.02	1.19	0.0	1.2
Syngnathus sp.	0.02	1.19	-	-
Serranidae				
Mycteroperca sp.	0.02	1.19	0.0	1.2
Mycteroperca tigris	-	-	0.0	3.6

Table I. Continuation

Family/Specie	Daily %	Daily C	Seasona %	Seasona C
Pomatomidae				
Pomatomus saltatrix	0.45	4.76	0.1	6.0
Carangidae				
Caranx latus	0.15	2.38	0.2	1.2
Chloroscombrus chrysurus	0.30	3.57	-	-
Oligoplites saliens	0.79	14.29	0.7	19.0
Oligoplites sp.	0.04	2.38	0.0	2.4
Selene vomer	-	-	0.0	1.2
Trachinotus carolinus	27.59	96.43	30.6	86.9
Trachinotus falcatus	0.45	19.05	0.4	16.7
Trachinotus goodei	22.17	96.43	9.3	82.1
Lobotidae				
Lobotes surinamensis	0.02	1.19	-	-
Gerreidae				
Non-identified larvae	5.03	11.90	1.3	17.9
Haemulidae				
Pomadasys corvinaeformis	-	-	0.0	1.2
Polynemidae				
Polydactylus virginicus	-	-	0.0	1.2
Sciaenidae				
Menticirrhus americanus	0.15	2.38	0.3	4.8
Menticirrhus littoralis	0.45	13.10	1.2	28.6
*Micropogonias furnieri**	0.11	1.19	0.0	1.2
Ophioscion punctatissimus	0.11	2.38	-	-
Umbrina coroides	0.13	1.19	-	-
Pomacentridae				
Abudefduf saxatilis	0.02	1.19	0.0	2.4
Blenniidae				
Parablennius pilicornis	0.02	1.19	0.0	1.2
Paralichthyidae				
Citharichthys arenaceus	-	-	0.0	2.4
Monacanthidae				
Stephanolepis hispidus	0.02	1.19	0.0	1.2
Tetraodontidae				
Sphoeroides sp.	-	-	0.1	3.6
Diodontidae				
Chilomycterus spinosus	0.02	1.19	0.0	1.2

Fish community structure

The Sheltered beach had the highest numbers of individuals (n=2,451), species (n=31) and diversity (2.06), followed by Moderate (n individuals = 1446; n species=26, diversity=1.92), and then Exposed (n individuals = 812; n species=13, diversity=1.35). There were no significant differences between the Sheltered and Moderate beaches with respect to richness and evenness. Both beaches were more rich and uniform than the Exposed one. The Exposed beach exhibited higher dominance, with 88% of abundance comprised by *T. goodei, T. carolinus*, and *M. hospes*.

During low tide, higher species richness (4.25), diversity (2.16), and uniformity (0.61) were observed. In contrast, during high tide there was the dominance of *T. carolinus* and *T. goodei.*

A percentage of 32.75% of biological data variability was explained by the measured abiotic variables. The environmental data of temperature and salinity were not significant (p≥0.05). The first two canonical axes explained 54.25% in the species-environment relationship. The first axis was positively correlated with low tide, day 5 and, negatively correlated with the Exposed beach. The second axis was positively correlated with day 12, spring tide and negatively correlated with day 7. The biological data were correlated mainly with the first (0.864) and the second axes (0.825) (Table II). Permutation test confirmed the significance difference of the canonical axes (p= 0.001). Figure 3 represents the ordination plot showing the species distribution in relation to the abiotic variables.

Table II. Summary of the CCA performed on abundance of 17 most numerous fish species sampled at Comprida Island, during 2009 summer.

Correlation of environmental variables	Axes				
	1	2	3	4	
Low tide	0.439	0.036	-0.216	0.141	
Exposed Beach	-0.523	0.192	0.148	0.611	
Day 1	-0.272	0.235	0.178	0.195	
Day 2	-0.019	-0.262	0.194	-0.029	
Day 4	0.161	0.076	0.643	-0.088	
Day 5	0.664	0.257	0.016	0.533	
Day 7	0.059	-0.574	-0.213	0.270	
Day 12	-0.023	0.615	-0.575	-0.107	
Spring tide	0.466	0.681	0.279	-0.196	
Summary statistics for ordination axes					
Eigenvalues	0.114	0.067	0.057	0.036	
Species-environment canonical correlations	0.864	0.825	0.760	0.739	
Cumulative percentage variance:					
of species data	11.230	17.770	23.340	26.850	
of species-environment relation	34.290	54.250	71.270	82.010	
Sum of all eigenvalues					1.023
Sum of all canonical eigenvalues					0.335

The spatial variation (the different beaches) explained 7.07% of the variation in the fish community structure (sum of all canonical eigenvalues = 0.072). Excluding the temporal influence, the percentage of explanation increased to 10.27%. *Trachinotus goodei* and *Menticirrhus littoralis* are correlated to the Exposed beach (Fig. 3).

Temporal variation explained 36.32% of the fish community structure (sum of all canonical eigenvalues = 0.371). Excluding spatial influence, the percentage of explanation increased to 38.52%. The significant days corresponded to days when meteorological changes occurred, and it was possible to notice two influences in the temporal variation: one was related to different tide amplitudes (low and high tide), while the other was related to the different sampled days and their environmental and meteorological descriptors, as well the neap and spring tide. The low and high tide variation explained only 2.67% of the fish community structure, while the effect of variation along the collection days explained 34.34%. *Trachinotus goodei* was correlated with the sampling during high tide (Fig. 3).

Trachinotus carolinus, the most abundant species, did not show a clear explanation trend for any of the studied abiotic variables, being positioned close to the center of ordination diagram (Fig. 3).

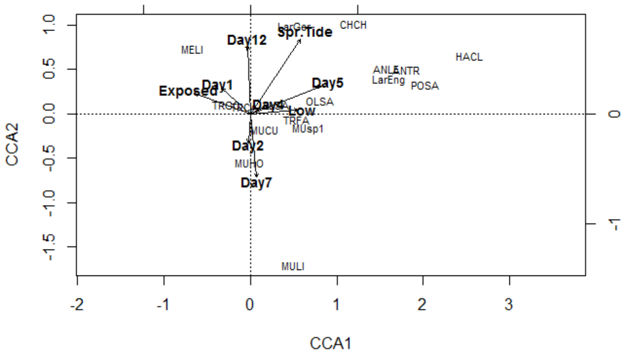

Figure 3. Ordination diagram (biplot) from CCA including fish species and the significant abiotic variables (represented by vectors) sampled from January 23rd, 2009 to February 18th, 2009. Species coded by the first two words of genus and species scientific names (example: TRCA= *Trachinotus carolinus*).

Seasonal fluctuations

Environmental Data

Average temperature values obtained varied seasonally along the sampled months (F=187.2, p<0.01). The lowest significant temperatures were obtained during the May-October interval (Fig. 4). No significant differences were observed for the different beaches (F=0.007, p=0.993) and different tides (F=0.288, p=0.596). The maximum temperature was 30.5ºC, and the minimum was 18ºC.

Even with a significant difference in the salinity values along the sampled months (F=7.563, p<0.01), there was no pattern in this variation (Fig. 4). The highest salinity values were measured in the Exposed beach (maximum = 36) (F=4.912, p=0.0125), and the lowest in the Moderate (minimum = 16) and Sheltered (minimum = 21) beaches, with no significant difference between the Moderate and Sheltered beach. No significant difference was estimated for salinity when comparing low and high tide (F=3.508, p=0.072).

Species Composition

A total of 8,012 specimens from 23 families and 44 species were captured. Mugilidae (46.0%), Carangidae (41.2%), Clupeidae (4.4%), Engraulidae (3.7%) and Sciaenidae (1.7%) dominated the catches numerically, accounting for nearly 98% of the total catch. The nine most abundant captured species were *T. carolinus* (30.6%), *M. curema* (27.6%), *M. hospes* (14.4%), *T. goodei* (9.4 %), *H. clupeola* (4.4%), *M. liza* (3.3 %), the unidentified larvae of Engraulidae and Gerreidae (2.7 and 1.3 %, respectively), and *M. littoralis* (1.2 %), which accounted for 94.7% of the total catch. *Trachinotus carolinus* and *T. goodei* were classified as constant, whereas *M. curema, M. hospes, M. liza* and *M. littoralis* were accessory species, and all the remaining ones were accidental (Table I).

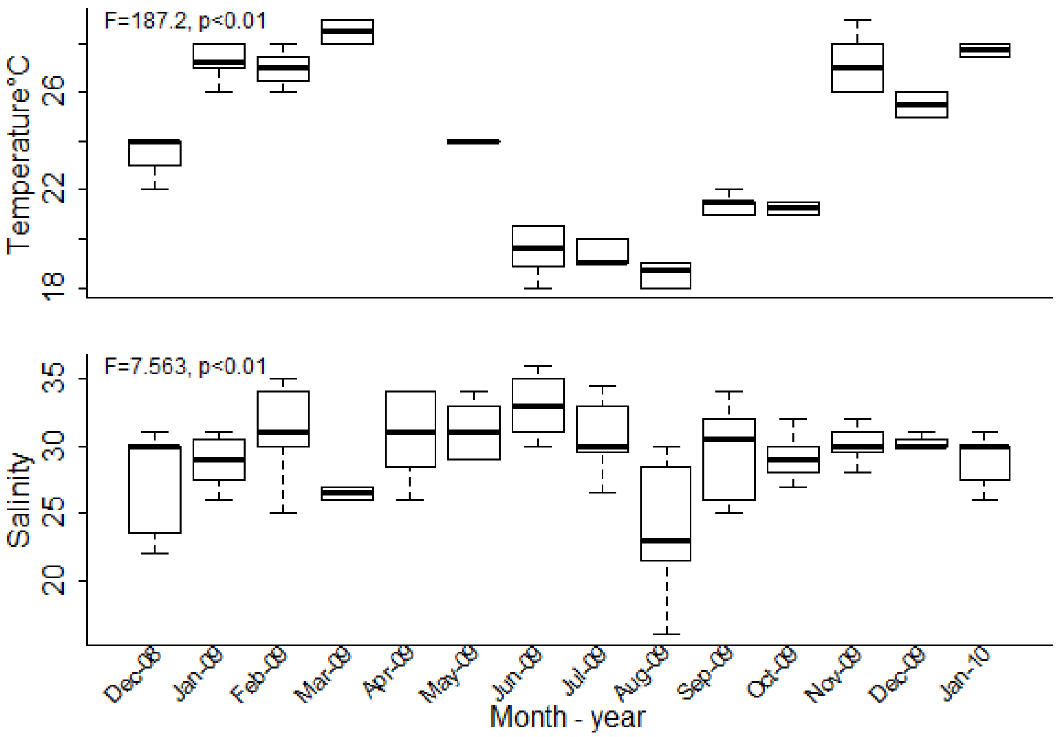

Figure 3. Ordination diagram (biplot) from CCA including fish species and the significant abiotic variables (represented by vectors) sampled from January 23rd, 2009 to February 18th, 2009. Species coded by the first two words of genus and species scientific names (example: TRCA= *Trachinotus carolinus*).

For most individuals, it was not possible to identify the sex and the gonadal maturation stage, as a consequence of the high abundance of individuals whose gonads were not found due to their small length. Only two females of *M. littoralis* were classified as 'immature' by gonad visualization and two females of *Odonthestes argentinensis* were classified as 'maturing'. All the remaining sampled specimens were classified as 'immature'. *Atherinella sp*., *Elops saurus, Micropogonias furnieri*, some Engraulidae and all Gerreidae were represented by specimens in the larval phase.

Fish community structure

There was a clear spatial variation in number of specimens, with the highest number being collected at Moderate (n=3,609), followed by Sheltered (n=2,285) and then Exposed beaches (n=2,118). There was no significant difference in the richness values between different beaches, but Sheltered was the most diverse (2.03) and uniform (0.27), with the lowest dominance (0.21). No significant difference in the ecological index was observed between Exposed and Moderate beaches.

During low tide, higher values of diversity (1.93), richness (4.39) and species (n=39) and specimen numbers (n=5,750) were estimated. There was no significant difference between the species evenness values (p=0.86). High tide samples exhibited a dominance value higher than the low tide samples.

The abiotic variables explained about 44.5% of the biological data variability. Only salinity was not significant ($p \geq 0.05$). The first two canonical axes explained 58.2% of total variance concerning species/environment relation. The first canonical axis is positively correlated to the months of July and August and negatively correlated to temperature. The second canonical axis is positively correlated to low tide and December/2008. The species-environment canonical correlations presented high values with the first (0.92) and the second axis (0.90) (Table III). Permutation test attested to the significance difference of the canonical axes (p= 0.0001).

Table III. Summary of the CCA performed on abundance of 18 most numerous fish species sampled at Comprida Island from December 2008 to January 2010.

Correlation of environmental variables	Axes 1	2	3	4	
Sheltered Beach	0.195	0.330	0.018	-0.099	
Low tide	0.232	0.637	-0.089	-0.185	
Dec/08	0.010	0.451	0.637	0.282	
Feb/09	-0.132	0.018	-0.199	0.097	
Apr/09	0.053	0.106	-0.369	-0.367	
May/09	-0.145	-0.235	0.171	-0.132	
Jul/09	0.474	-0.177	-0.107	-0.403	
Aug/09	0.676	-0.002	0.007	0.003	
Nov/09	-0.042	0.128	-0.653	0.610	
Temperature	-0.602	0.303	-0.541	-0.187	
Summary statistics for ordination axes					
Eigenvalues	0.289	0.122	0.090	0.635	
Species-environment canonical correlations	0.924	0.901	0.889	0.843	
Cumulative percentage variance:					
of species data	15.500	22.200	27.000	30.500	
of species-environment relation	40.900	58.200	70.900	79.900	
Sum of all eigenvalues					1.854
Sum of all canonical eigenvalues					0.825

Temperature corresponded to 15.43% of the biological variability (sum of all canonical eigenvalues = 0.286). However, removing the interaction of temperature with temporal and spatial data, the explanation decreased to only 3.32%. The larvae of *E. saurus* and all *Mugil* species were more abundant in warm waters, except *M. lisa*, which together with *O.*

saliens and *H. clupeola* were more abundant in cold waters (Fig. 5).

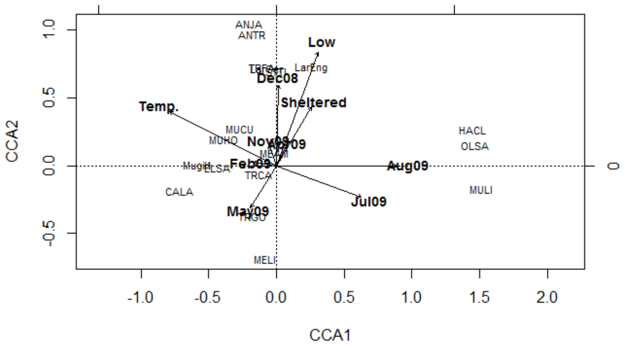

Figure 5. Ordination diagram (biplot) from CCA including fish species and the significant abiotic variables (represented by vectors) sampled from 2008 December to 2010 January. Species coded by the first two words of genus and species scientific names (example: TRCA= *Trachinotus carolinus*).

The spatial variation explained only 3.08% of the ichthyofauna structure (sum of all canonical eigenvalues = 0.057). Excluding the temporal influence, the explanation increased to 4.71%. *Trachinotus goodei* and *M. littoralis* were negatively correlated to the Sheltered beach, apparently preferring more exposed beaches (Fig. 5).

The highest variation was explained by temporal variables, which totaled 40.61% (sum of all canonical eigenvalues = 0.753). It was possible to verify two influences: a tidal one, related to different tide amplitudes, and a seasonal one, along the sampled months. The tidal variation, excluding the seasonal effect, explained 3.91%, whereas the seasonality, without the tides effect, explained 37.27%. The species *T. goodei* and *M. littoralis* were more abundant in the samples obtained at high tide. Conversely, *T. falcatus* and the larvae of Gerreidae and Engraulidae were more abundant at low tide.

As in the daily variation, *T. carolinus* did not show a clear trend for any of the analyzed abiotic variables, being placed close to the center of the ordination diagram (Fig. 5).

A comparison between the results of the two sampling strategies indicates that 8 species occurred only in samples of the daily range, while 15 species were exclusive from seasonal samples. The dominant and constant species were the same, but with differences in proportional abundance: *T. carolinus, T. goodei, M. curema* and *M. hospes*.

Discussion

Environmental data

The days with significant lower temperatures (days 1- 3, 11, 12 and 13 in Figure 2) occurred when cold fronts entered the region. Thus, despite being a sunny day, 23 January had strong winds followed by cloudy skies and drizzle over the next two sample days (personal observation). In the same way, 12, 14, and 16 February was rainy days (personal observation). The higher temperature during the high tide is likely related to sample time, as the high tide was sampled in the afternoon and the low tide during the morning. The significantly low salinity observed on 4 February (day 7) was related to sudden and strong rains that occurred on the previous day; and the significant low value of salinity from 14 February (day 12) was related to the passage of a cold front, which occurred on 12 February and caused rains over the following five days. The variation observed for the different tides was due to saline water intrusion in the channel during the high tide.

Biological data

Most studies on ichthyofauna of coastal environments have used monthly collections for one or more years to detect seasonal variations, and diel sampling effort to detect mainly tidal and light effects in the fish community of the surf zone. The sampling effort done in this study intended to identify variations over daily scale, without considering the diel ones and minimizing seasonal influences, trying to detect gradual changes in the structure of fish distribution and abundance. Few works have compared the ichthyofauna structure over different temporal scales in the same period and the same studied area, as it was done in the present study. Wilson and Sheaves (2001) observed that the monthly, spring and neap tide variations (long-term variations) had more influence over the fish fauna composition than the flood and ebb tides (short-term variation). Lasiak (1984a) observed a stable number of species in short- and long-term periods, with a higher abundance in short-term samplings and a more varied diversity in long-term ones. Pessanha *et al.* (2003) comparing diel and seasonal changes in the distribution of fish on a sandy beach, detected seasonal changes in abundance of dominant species, but diel patterns did not reveal any significant trends. The authors concluded that seasonal influence seems to be related to ontogenetic change, while diel influence seems to be more related to physiological requirements, such as the feeding activity of each particular fish species.

Our results showed that, regardless of the sampling effort (daily or seasonal), the main structure and composition of the surf-zone fish communities were maintained, such as the predominance of small-sized specimens, and the small number of dominant and constant species. Similar patterns have been described previously for surf zones in the Atlantic by Giannini and Paiva Filho (1995); Santos and Nash (1995); Godefroid *et al*. (2003a); Barreiros *et al*. (2004); Godefroid *et al*. (2004); Vasconcellos *et al*. (2007), Favero and Dias (2013).

The high abundance of juvenile and larval individuals collected corroborates the importance of this area for the initial ontogenic stages in the life cycles of the species. Godefroid *et al*. (2003a), Félix *et al*. (2007), Inoue *et al*. (2008) and Favero and Dias (2013) also found high proportions of larval and/or juvenile specimens in such environments.

Comparing the results obtained in the different temporal scale analysis, it is possible to note a similarity in the species number, predominant species and in the ichthyofauna structure.

However, in the comparison of the abiotic variables influencing the fish fauna variability, temperature was significant only in the seasonal analysis, and presented low percentage of explanation for the fish community variation. This fact reinforces the importance of seasonality for structuring the fish community. The seasonal changes in the surf-zone fish communities is reflected mainly by the recruitment patterns determined by reproductive activity and coastal circulation, as pointed out by Ross *et al*. (1987) and Félix *et al*. (2007). In general, the warmer months were those with a more rich, diverse, and abundant fish fauna, whereas the colder months exhibited higher dominance. As in the present study, many previous studies, including Lasiak (1984b), Bennett (1989), Giannini and Paiva Filho (1995), Clark (1996a), Godefroid *et al*. (2003a); Félix *et al*. (2006), Araújo *et al*. (2008) and Favero and Dias (2013), found higher diversities and abundances in the warmer months, coinciding with the reproductive period of many fish species. The higher temperatures appeared to favor phytoplankton blooms and, in turn, more zooplankton, increasing food availability for larvae and juvenile fish (Nybakken & Bertness 2004). Seasonal reproductive cycles of coastal fish species are adapted to maximize utilization of available resources, so the fish abundance fluctuations over the year are commonly attributed to changes in recruitment peaks (Gibson *et al*. 1993; Mariani 2001).

Additionally, oceanic or coastal fish species use the estuarine region at different times, depending on their reproductive pulses. Thus *T. carolinus* and *T. goodei*, the most abundant and frequent species over time, enter the area all year long, whereas smaller pelagic species such as *Opisthonema oglinun* and *Sardinella brasiliensis*, are found only in the warmer months of spring and summer.

The percentage of explanation of the fish community structure in the different beaches was higher for the daily catch (7.07%) than for the seasonal one (3.08%), showing the importance of minimizing seasonal influences to detect spatially gradual changes in the structure of fish distribution and abundance. In many studies, the more protected the beach, the higher the species richness, diversity and abundance values, whereas the more exposed beaches were dominated by fewer species (e.g. Paiva Filho and Toscano 1987; Romer 1990; Clark 1997; Gaelzer & Zalmon 2003; Godefroid 2003a; Félix *et al*. 2007; Vasconcellos *et al*. 2007; Favero & Dias, 2013). The same pattern was observed in the present study for both temporal scales.

Fish community variations in surf zones of sandy beaches may be related to physical factors not measured directly in this study, such as the slope of the shoreline and current velocity, resulting in an increase of the richness and number of individuals under shoaling and calm conditions (Inui *et al*. 2010). The higher abundance and richness in more sheltered beaches could be also related to a greater availability of food (Mcfarland 1963; Clark 1997) or to weaker turbulence, allowing more species to occupy the area where physical disturbances of lower intensity occur (Begon *et al*. 2006). Another factor to be considered would be the sampling effectiveness itself, because the strength of the waves in the more exposed beaches complicated sampling in many of the hauls.

The exposure level of coastal environments is considered one of the main factors structuring the surf-zone fish community (Romer 1990; Clark 1996b; Gaelzer & Zalmon 2003; Vasconcellos *et al*. 2007). However, this factor could be misunderstood, mainly due to supposition of effects from this variable, such as the abundance of macroalgae and/or decomposing organic material, salinity and water transparency (Clark 1997; Teixeira & Almeida 1998). It is important to emphasize that the study area has interactions with other variables, mainly related to the presence of an estuary. The beaches considered as Sheltered and Moderate experience strong influences of estuarine waters, whereas the Exposed beach has marine influences. *Trachinotus goodei* and *M. littoralis* were associated with high wave energy environments, whereas the highest salinities values were recorded reflecting the highest exposure. This fact was also observed by Félix *et al*. (2007) and Vasconcellos *et al*. (2007).

As the differences in the percentages of explanation for the tidal range was about 1% when it was analyzed under both temporal scales, it is possible to infer that, for such variable, the sample frequency will not alter the obtained result. Higher number of specimens and species captured during the low tide were also verified in surf zones by Gibson *et al*. (1996), Godefroid *et al*. (1998), Suda *et al*. (2002), and Gaelzer and Zalmon (2008), and in a tidal flat by Godefroid *et al*. (2003b). This probably occurs because during the high tide, only those species that migrate to shallower areas on the rising tide are sampled, such as the species of *Trachinotus*, which were as abundantly captured at low as at high tide. A different result, of higher richness during high tides, was observed by Layman (2000), due to presence of many specimens classified as transient adults looking for food. According to Brown and McLachlan (1990), high tide allows larger-sized fishes or adults to enter shallower waters looking for invertebrates of the intertidal zone. The greater abundance of *Trachinotus* sp. during high tide was also previously recorded by Layman (2000), Godefroid *et al*. (2003b) and Favero and Dias (2013).

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