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Inter-annual changes in fish communities of a tropical bay in southeastern Brazil: What can be inferred from anthropogenic activities?

Francisco Gerson Araújo *, Samara Macedo Pinto, Leonardo Mitrano Neves, Márcia Cristina Costa de Azevedo

Laboratorio de Ecologia de Peixes, Universidade Federal Rural do Rio de Janeiro, BR 465, Km 7, 23.890-000 Seropédica, Rio de Janeiro, Brazil

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ABSTRACT

We assessed inter-annual changes in fish assemblages of a tropical bay which experienced a heavily industrialized process in the last decades. A highly significant difference in community structure among the bay zones, and a decrease in fish richness and abundance over time were found. Changes in fish richness and abundance between the two first (1987–1988 and 1993–1995) and the two latter time periods (1998–2001 and 2012–2013) were sharpest in the inner bay zone, the most impacted bay area, and in the middle zone, whereas the outer zone remained comparatively stable over time. These changes coincided with increased metal pollution (mainly, Zn and Cd) in the bay and with the enlargement of the Sepetiba Port. Spatial changes in the fish community structure among the bay zones were related to differences in salinity, transparency and depth with this latter variable acting as a buffer stabilizing temporal community changes.

1. Introduction

Shallow inshore areas such as bays and other semi-closed systems are highly productive and capable of sustaining great diversity and densities of organisms (Nagelkerken et al., 2001; Ray, 2005; Vasconcelos et al., 2011). A plentiful supply of food resources and high habitat availability turn these estuarine ecosystems into a focal point around which many coastal fish communities develop and grow (Martínez et al., 2007; Barbier et al., 2011). However, these aquatic ecosystems are also among the most extensively modified and threatened by human activities (Kennish, 2002; Ribeiro et al., 2008; Defeo et al., 2009; Van der Veer et al., 2015).

Anthropogenic activities in coastal areas have changed fish community distribution patterns, decreasing richness and abundance across various spatial and temporal scales (Sax and Gaines, 2003; Johnston and Roberts, 2009). Often, such changes are linked to overfishing (Ecoutin et al., 2010; Last et al., 2011; Staglicic et al., 2011), pollution (Hewitt et al., 2008; Johnston and Roberts, 2009) and habitat degradation (Kennish, 2002; Pihl et al., 2006; Hewitt et al., 2008; Defeo et al., 2009; Sobocinski et al., 2013). There is a need to understand long-term changes in fish communities, and what management measures should be implemented to protect fish biodiversity. In this sense, studies on fish distribution and community structure are fundamental for detecting changes in the ichthyofauna and crucial for understanding the dynamics and functioning of the system to help managers in policies of natural resource conservation.

Estuarine areas are naturally dynamic ecosystems exposed to numerous human pressures, making it difficult to distinguish between natural and anthropogenic-induced changes to the biological community (Macpherson, 2002; Elliott and Quintino, 2007; Basset et al., 2013). These areas have long been regarded as environmentally naturally stressed because of the high degree of variability in their physico-chemical characteristics. Accordingly, the biota is adapted to such changes, being naturally stress tolerant and hence resilient to change (Elliott and Quintino, 2007; McLusky and Elliott, 2007).

Sepetiba Bay is a sedimentary embayment in the southeastern Brazilian coast that supports a rich and diversified fish fauna, and is used as rearing grounds for several coastal fish species, harboring mangroves, mudflats, sandy beaches and rocky shore habitats (Araújo et al., 2002; Azevedo et al., 2007). The bay has been subjected to intense environmental pressure, because of overfishing (Freitas and Rodrigues, 2014), eutrophication (Amado-Filho et al., 1999; Magalhães et al., 2003), building construction (Molisani et al., 2004; Cunha et al., 2006) and pollution (Lacerda and Molisani, 2006; Fonseca et al., 2013), resulting in general environmental degradation (Lacerda et al., 1987; Molisani et al., 2006). The most recent human interferences in the bay were the enlargement of the Sepetiba Port, including dredging of the access channel to 20 m depth, and the construction of a large steel factory in 2010 and a terminal for building submarines in 2013 (Araújo et al., 2016). Such activities contribute to shoreline degradation, impoverishing of natural habitats, and increasing pollutants loads into the bay (Carneiro et al., 2013; Ribeiro et al., 2013; Pereira et al., 2015).

* Corresponding author.
E-mail address: gerson@ufrrj.br (F.G. Araújo).

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Studies that evaluate long-term changes in fish communities associated with anthropogenic activities are uncommon in developing countries. The lack of robust and consistent environmental quality monitoring programs impairs direct association between fish and environmental data. Therefore, it is necessary to adjust and to relate the available information on fish occurrence with historical available data on environmental quality to uncover probable environmental-biotic relationships.

The aim of this study was to assess the fish community in three bay zones (inner, middle and outer) of the Sepetiba Bay over four time periods encompassing three decades, and to evaluate changes in community structure and in the abundance of selected species over time. This long-term series of fish data for the Sepetiba Bay used in the present study offers an unusual opportunity to study the effects of environmental changes and anthropogenic influences on a tropical fish community. It was our hypothesis that decreases in habitat quality and increases in anthropogenic stress would negatively impact the fish community composition, species richness and abundance of individual species. We expect that (1) the fish community structure changed over the three decades (1987–1988, 1993–1995, 1998–2001, and 2012–13); that (2) the fish richness and abundance decreased over time; and that (3) changes in the assemblage structure differed among the three bay zones associated to different environmental conditions.

2. Materials and methods

2.1. Study area

Sepetiba Bay (22°54′–23°04′ S; 43°34′–44°10′ W) has a wide opening to the sea and was originated by extensive sand deposition, which formed a barrier beach as its southern boundary (Fig. 1). The bay has a surface area of approximately 450 km^2, a mean depth of 8.6 m, a maximum depth of 30 m, and a drainage area of 2700 km^2. This microtidal system has a tidal range of approximately 1 m. Water circulation in the bay generally follows a clockwise direction (Cunha et al., 2006), with seawater going inside the bay through the west side, mixing with freshwater inputs of small rivers in the northern part of the bay, then moving across the southbound, and going outside the bay through the southwestern bound. Predominant northeasterly and southwesterly winds activate thermal currents between the bay and the ocean. The annual rainfall in the area varies between 1000 mm and 2100 mm (Clarke et al., 2004).

The bay can be divided into three zones (inner, middle and outer), according to environmental conditions and human influences (Araújo et al., 2002; Azevedo et al., 2006). These zones are geographically continuous and reflect hydrology and sedimentology. The inner zone is influenced by discharges of perennial small rivers, that contribute to increased turbidity and temperature and decreased salinity; the substratum is mainly muddy, with depths that are mostly <5 m, and an average salinity of 28. This zone is the most altered because of the industrial development nearby (Leal Neto et al., 2006). The outer zone, located near the sea, has comparatively lesser influence of anthropogenic activities and exhibits contrasting environmental conditions: the substratum is predominantly sandy, water temperature is comparatively lower and salinity and transparency are comparatively higher; the maximum depth is ca. 30 m, and the average salinity is 33. This zone did not cover shallow waters. Furthermore, several islands in the west part of the bay bound the outer zone. The middle zone displays intermediate environmental conditions between the inner and the outer zones, and is limited by the islands in the west, and by the lowest depth (<5 m) of the inner zone located on its northern part.

2.2. Fish sampling

Bi-monthly samplings in each bay zone (inner, middle and outer) were conducted from June 1987 to June 1988 and from July 1994 to

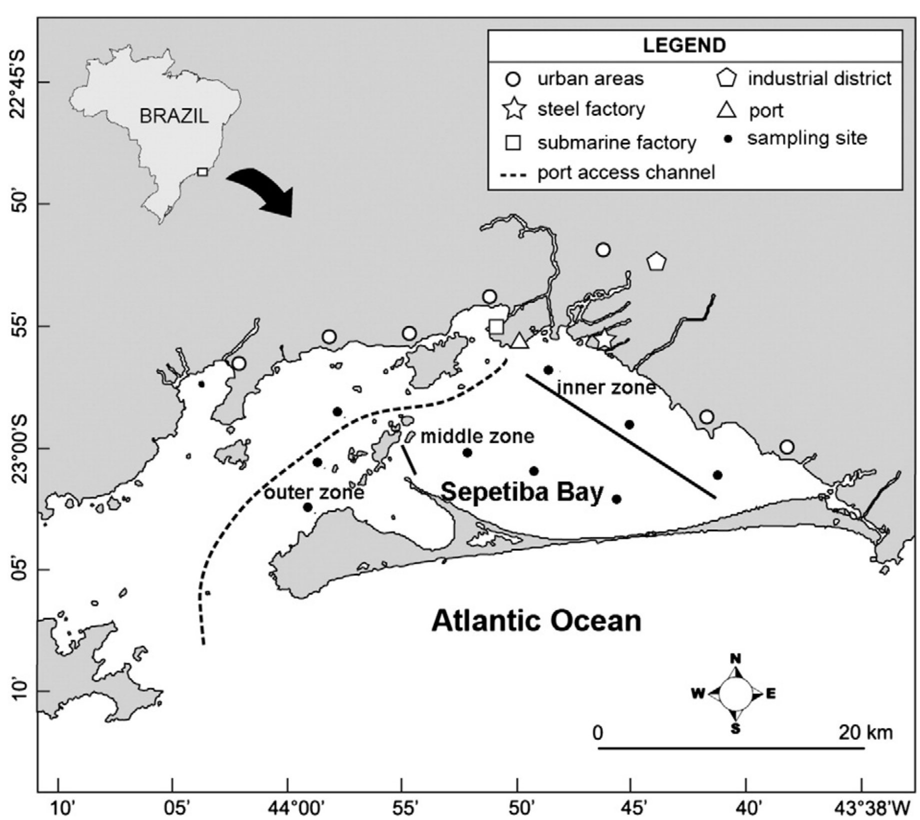

Fig. 1. Map of the study area, Sepetiba Bay in Southeastern Brazil, showing the sampling sites in the three bay zones (inner, middle and outer) and the main anthropogenic activities near the shoreline.

April 1995, monthly samplings from June 1993 to June 1994 and from October 1998 to September 1989, and quarterly sampling from June 1999 to May 2001, and from August 2012 to June 2013. Samplings were taken in three sites of each zone (Table 1). Sampling monthly averages for each bay zone were calculated for fish data to reduce the number of samples and to enable temporal comparisons, resulting in a total of 121 samples evenly distributed among the three zones (39 samples in the inner, 40 in the middle, and 42 in the outer zone), with 17 samples in 1987–1988, 48 in 1993–1995, 44 in 1998–2001 and 12 in 2012–2013.

Fishes were collected by bottom trawl with a 12 m long net with 25-mm mesh at the wings and 12-mm mesh at the cod end. The length of the ground rope was 8 m and the head rope was 7 m. The distance travelled was obtained using the coordinates registered at the beginning and at the end of each trawl with a global positioning system (GPS, Garmin III) used to determine the swept area in 1998–2001 and 12 in 2012–2013; in the previous sampling periods we estimated the distance travelled using geographic marks in a hydrographic map of the area and a Simrad sonar. For each sample, the swept area (A) was estimated: $A = D \times h \times X_2$, where D is the length of the path, h is the length of the head rope and X_2 is that fraction of the head rope which encompasses the width of the path swept by the trawl, i.e. the net spread (Sparre and Venema, 1995). The samples were taken at speeds between 2 and 2.5 knots during 20 min covering an extension of ca. 1.5 km, and it was assumed that $X_2 = 0.6$, with the swept area corresponding to approximately 6000 m^2. Each trawl followed a given depth contour to minimize the impact of any depth change during a trawl. The actual position of the sampling sites insides the zones was chosen to encompass most of the bay area. The fish were fixed in 10% formalin, and after 48 h, transferred to 70% ethanol. All fish were identified to species and counted. Vouchers specimens were deposited at the reference collection of the Laboratory of Fish Ecology of the University Federal Rural of Rio de Janeiro. At each fish sampling occasion, we measured water temperature and salinity near to the bottom using a multiprobe Horiba model U-10 in 1987–1988 and 1993–1995, and a Horiba model W-23 (Horiba Trading Co. Ltd., Shanghai) in 1998–2001 and 2012–2013. Transparency was measured using a Secchi Disk, and depth was measured with a weighted line marked in 10-cm intervals in 1987–1988 and 1993–1995, and with a digital sounder Speedtech model SM-5 in 1998–2001 and 2012–2013.

2.3. Statistical analyses

Environmental data were transformed to standard z-scores, i.e., they were converted in the same unit of standard deviation because they have different units of measurements, whereas fish data were square root transformed to reduce the bias of abundant species. A two-way factorial Analysis of Variance (ANOVA) was used to compare environmental variables among the three zones and the four different sampling periods. Where ANOVA showed a significant difference, an "a posteriori" Tukey HSD test was used to determine which means were significantly different at the 0.05 level. Moreover, a principal component analysis (PCA) was applied on environmental data to identify spatial patterns, i.e., group of samples coded by zones according to environmental variables.

Each fish species was assigned to one of the ecological guilds, based on trophic (1) and habitat use (2) patterns, adapted from Elliott et al. (2007); Franco et al. (2008) and Araújo et al. (2016): (1) benthivorous; hyperbenthivorous, piscivorous, planktivorous; and opportunists; (2) residents; marine stragglers; marine migrants; and semi-anadromous species.

The fish community structure expressed as the number of individuals per species was compared among the zones and sampling periods using Analysis of Similarity ANOSIM (Clarke, 1993). Pair-wise ANOSIM comparisons were performed among the zones and periods, using 50,000 simulations in each case. Before ANOSIM, sample similarity matrices based on the Bray-Curtis similarity were generated. We used R-values to assess among-period changes in community structure for each bay zone. A non-metric Multidimensional Scaling (nMDS) ordination was used to detect temporal (sampling periods) and/or spatial (zones) patterns of the fish community. A Similarity Percentage - SIMPER - analysis was used to determine species that most contributed to within-group average similarity for zones and sampling periods.

For each zone, we used a Permutational Analysis of Variance (PERMANOVA) (Anderson et al., 2008) on square-root Bray-Curtis similarity matrix with a Type I (sequential) sum of squares to calculate the *p*-values, where the fish assemblage was the response variable, the environmental variables (temperature, salinity, transparency and depth) were covariates, and the sampling periods (4 levels: 1987–1988, 1993–1995, 1998–2001, 2012–2013) were the fixed factors. PERMANOVA on the Euclidian distance was also used to test for differences in the fish richness and density, in the number of species by fish guilds (trophic and habitat use), and in the abundance of selected fish species among the sampling periods and zones (fixed factors). Significant differences among the factors were followed by a PERMANOVA pair-wise comparisons test. Selected dominant species were those that accounted for >2.0% of the total number of fish and that exhibited tendency for increase/decrease over the sampling periods.

We model the relationships between the fish community structure and the explanatory environmental variables (temperature, salinity, transparency and depth) using the distance-based linear model (DistLM, McArdle and Anderson, 2001). DistLM analysis was used to identify which of the potential predictors explained most of the variability in fish structure for each sampling period. The most significant predictors in the conditional tests were analysed using the "step-wise" selection method, and the Akaike Information Criterion (AIC) to select the final model.

3. Results

3.1. Environmental variables

Water temperature ranged from 19.7 to 28.1 °C. No significant difference in water temperature was found among the sampling periods ($F = 1.27$; $p = 0.28$) or the bay zones ($F = 0.63$; $p = 0.54$) (Table 2). Salinity ranged from 25.9 to 36.0. Significant differences were found in salinity among the zones ($F = 12.2$; $p = 0.001$) and periods ($F = 6.1$; $p = 0.001$). The outer zone had the highest salinity whereas the inner zone had the lowest (Table 2).

Water transparency ranged from 0.5 to 5.1 m. The outer zone had higher transparency compared with the middle zone that on its turn

Table 1
Number of fish samples by sampling periods and zones (inner, middle and outer) in the Sepetiba Bay.

Sampling periods	1987–1988			1993–1995			1998–2001			2012–2013		
Zones	Inner	Middle	Outer	Inner	Middle	Outer	Inner	Middle	Outer	Inner	Middle	Outer
Number of samples	10	9	17	32	32	45	45	44	44	12	12	12
Samples (after pooling sites)	6	5	6	15	16	17	14	15	15	4	4	4
Frequency	Bi-monthly			Monthly/bi-monthly			Monthly/quarterly			Quarterly		
Period	Jun 1987–Jun 1988			Jul 1993–Apr 1995			Oct 1998–May 2001			Aug 2012–Jun 2013		

Table 2
F-values from two-way ANOVA and significant differences (Tukey test) for environmental variables among the sampling periods and zones of the Sepetiba Bay. Average ± standard error of environmental variables in brackets.

Environmental variables	Period	Zone	Period × zone	Significant differences (means ± sd)
Temperature (°C)	1.3ns	0.6ns	0.2ns	–
Salinity	6.1**	12.2**	2.6*	1999–2001 (31.1 ± 0.3) > 1987–1988 (29.4 ± 0.4)
				Outer (31.7 ± 0.3) > middle (30.5 ± 0.3) > inner (29.6 ± 0.2)
Transparency (m)	2.7ns.	40.5**	3.3*	Outer (3.4 ± 0.1) > middle (2.7 ± 0.1) > inner (1.5 ± 0.1)
Depth (m)	17.9*	152.2**	29.8*	1999–2001 (10.5 ± 0.6) > 1993–1995 (7.9 ± 0.4)
				Outer (14.3 ± 0.7) > middle (8.9 ± 0.2) > inner (4.8 ± 0.3)

ns. non-significant.
** $p < 0.01$.
* $p < 0.05$.

had higher transparency compared with the inner zone ($F = 40.5$; $p = 0.001$). No significant difference in water transparency was found among the periods ($F = 2.65$; $p = 0.052$). Depth where the samples were conducted ranged from 2.0 a 23.7 m, with significant differences among the bay zones ($F = 152.2$; $p = 0.001$) and periods ($F = 17.9$; $p = 0.01$). The outer zone had the highest depths followed by the middle zone, whereas the inner zone had the lowest depths (Table 2).

A well-defined spatial pattern in the distribution of samples was detected along the first axis of the Principal Component Analysis on the environmental variables. Samples from the outer zones were closely related to the highest depth, transparency and salinity, in opposite to the samples of the inner zone that were associated to the lowest values for those variables. Moreover, samples from the middle zone were located near to the center of the diagram, with intermediary conditions between the inner and the outer zones. Depth, transparency and salinity were closed associated with axis 1, whereas temperature was associate to axis 2, thus defining the spatial pattern of environmental bay conditions (Fig. 2).

3.2. Spatial changes in fish communities

In total, a hundred twenty-seven species were recorded in the bay, corresponding to 33,140 individuals in 93 genera and 41 families (see Appendix A, in Supplementary data; Table 1). Distinct fish communities were detected for each bay zone, according to nMDS ordination (Fig. 3). Samples from the inner and the outer zone were clearly separated from each other, whereas samples from the middle zone were located between samples from the inner and the outer zones (Fig. 3). Differences in the structure of fish communities were detected by ANOSIM (R Global $= 0.41$, $p = 0.001$), with each pairwise comparison showing highly significant differences (inner zone versus central zone $R = 0.26$; $p = 0.001$; inner zone versus outer zone $R = 0.66$, $p = 0.001$; and middle zone versus outer zone $R = 0.33$; $p = 0.001$). Average similarity within each zone ranged from 45.3 to 52.2% (Table 3). Species that most contributed to average similarity within the inner zone were *Genidens genidens*, *Micropogonias furnieri* and *Chloroscombrus chrysurus*, whereas in the middle zone were *G. genidens*, *M. furnieri* and *Prionotus punctatus*. In the outer zone *P. punctatus* and *Diplectrum radiale* were the typical species, contributing most to average similarity.

3.3. Temporal changes in fish communities

Temporal changes in fish community structure for each bay zone were found according to nMDS ordination with each sampling period clustering separately (Fig. 4). The most conspicuous changes were shown for the inner zone that presented a clear separation between the samples of the two first periods (1987–1988 and 1993–1995) and the samples of the two latter periods (1998–2001 and 2012–2013). A comparatively lesser conspicuous change in assemblage structure was found among the four sampling periods for the middle zone, whereas no clear yearly separation was detected for the outer zone.

Significant differences in community structure among the four sampling periods for each zone was detected by ANOSIM with the highest global R (0.91, $p = 0.001$) for inner zone compared with the middle (R Global $= 0.549$, $p = 0.001$) and the outer zones (R Global $= 0.314$, $p = 0.001$). All pairwise sampling periods comparisons were also significant ($p < 0.05$) for each zone, with exception of the 1998–2001 and 2012–2013 for the outer zone.

In the inner zone, species that most contributed to average similarity were *Cathorops spixii*, *D. radiale* and *Cynoscion leiarchus* in 1987–88, and *M. furnieri* and *G. genidens* in 1993–1994, 1998–2001 and 2012–2013 (Table 4). In the middle zone, *C. spixii*, *M. furnieri*, *C. leiarchus*, *D. radiale*

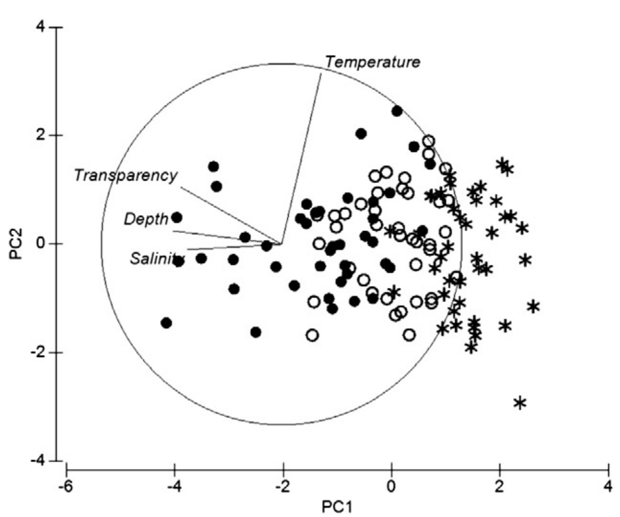

Fig. 2. Ordination diagram from the first two axes of the principal component analysis on environmental variables of the Sepetiba Bay. Samples coded by zones: asterisks, inner zone; white circles, middle zone; black circles, outer zone.

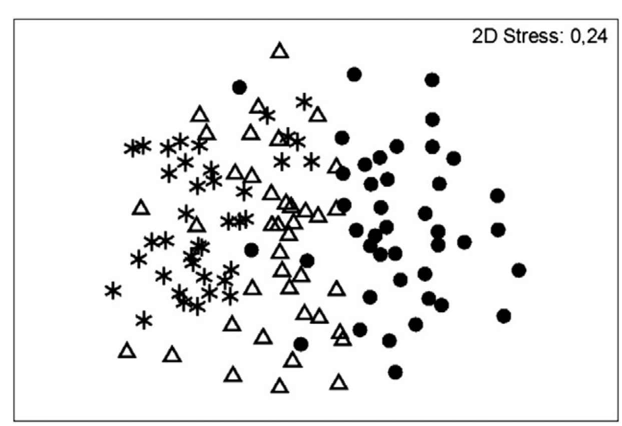

Fig. 3. Ordination diagram of non-Metric Multidimensional Scaling on species abundance, with samples coded by bay zones: asterisks, inner zone; triangles, middle zone; circles, outer zone.

Table 3
Discriminant species for each zone of Sepetiba Bay, according to SIMPER analysis.

Average similarity (%)	Inner zone (52.2)	Middle zone (47.1)	Outer zone (45.3)
Genidens genidens	14.8	13.6	
Micropogonias furnieri	14.1	10.0	
Chloroscombrus chrysurus	8.2		
Prionotus punctatus		8.3	10.1
Diplectrum radiale			9.2

and *Aspistor luniscutis* had the most contribution in 1987–1988, whereas *Eucinostomus argenteus* and *G. genidens* contributed mostly in 1993–1995, 1998–2001 and 2012–2013. Moreover, *P. punctatus* had great contribution to average similarity in 1998–2001 and 2012–2013, *C. chrysurus* in 1998–2001, and *Ctenosciaena gracilicirrhus* in 2012–2013. In the outer zone, *P. punctatus* had high contribution to average similarity over all periods, *Symphurus tessellatus* only in 1987–1988, *C. leiarchus* in 1987–1988 and 1993–1995, *D. radiale* in 1987–1988, 1993–1995 and 1998–2001, *Orthopristis ruber* in 1998–2001, and *M. furnieri* in 1998–2001 and 2012–2013.

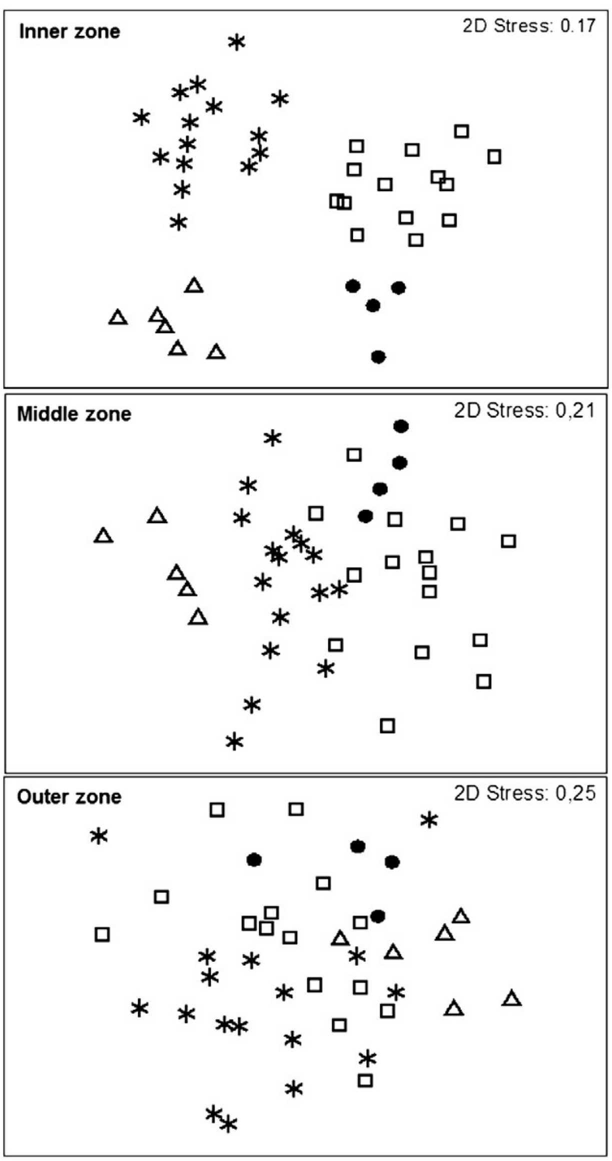

Fig. 4. Ordination diagrams of non-Metric Multidimensional Scale on fish assemblage abundance for each bay zone, with samples coded by sampling periods. Periods: triangles, 1987–1988; asterisks, 1993–1995; squares = 1998–2001; circles = 2012–2013.

Table 4
Species that most contributed to within-average similarity (%) by sampling periods for each zone of the Sepetiba Bay, according to SIMPER analyses.

Sampling periods	1987–88	1993–95	1998–01	2012–2013
Inner zone	70.5%	62.6%	64.6%	75.9%
Cathorops spixii	11.8	8.41		
Diplectrum radiale	9.4			
Cynoscion leiarchus	8.3			
Micropogonias furnieri		11.9	16.5	16.1
Genidens genidens		10.2	19.3	18.5
Chloroscombrus chrysurus			10.2	
Aspistor luniscutis				10.6
Middle zone	71.8%	60.1%	58.1%	78.8%
Cathorops spixii	26.5	11.0		
Micropogonias furnieri	15.4	8.1		14.8
Cynoscion leiarchus	12.6			9.6
Diplectrum radiale	11.9			
Aspistor luniscutis	8.9			
Eucinostomus argenteus		21.4	10.7	9.6
Genidens genidens		10.6	21.3	18.9
Prionotus punctatus			14.4	10.8
Chloroscombrus chrysurus			11.6	
Ctenosciaena gracilicirrhus				18.3
Outer zone	64.7%	56.3%	58.9%	63.8%
Ctenosciaena gracilicirrhus	15.1		8.1	26.7
Cynoscion leiarchus	11.2	10.5		
Prionotus punctatus	15.7	9.6	11.4	14.2
Diplectrum radiale	14.0	10.5	9.6	
Etropus crossotus	10.3		9.1	8,1
Symphurus tessellatus	10.93			
Orthopristis ruber			14.8	
Micropogonias furnieri			10.7	16.5

3.4. Environmental influences on community structure

PERMANOVA detected significant differences in fish community structure among the sampling periods for each of the three bay zones ($p < 0.001$). However, temporal changes were more pronounced in the inner (ECV, percent estimated components of variation = 48.1%) and in the middle zone (ECF = 41.8%) than in the outer (ECV = 28.4%) zone (Table 5). The four explanatory environmental variables explained a small but significant proportion of the variance (Pseudo-*F* ranging from 1.2 to 5.1). Depth was the only variable to show significant effect on the fish community temporal changes for all the three zones, whereas temperature and transparency had significant explanation for the inner, salinity for the middle, and temperature, transparency and salinity for the outer zone (Table 5).

The distance-based multivariate linear model (DistLM) analysis indicated significant relationships between fish assemblage and the environmental predictors. Depth (19.7% of the variance), salinity (10%) and transparency (8.3%) were the significant predictors of community structure in 1987–1988, whereas depth (27%), temperature (4.2%) and transparency (4.2%) were the significant predictors in 1998–2001. In 1993–1995 and 2012–2013, depth was the only significant predictor accounting for 15.8% and 29.0% of variance, respectively.

3.5. Descriptors of richness and abundance

Species richness changed significantly among the zones (Pseudo-$F = 10.6$, $p = 0.001$) and, to a lesser extent, among the sampling periods (Pseudo-$F = 2.65$, $p = 0.05$) according to PERMANOVA (Table 6). Overall, the inner zone had comparative more fish species than the middle and outer zone. For the inner and the middle zone, the number of species decreased significantly over time with significant highest means values for 1987–88 compared with the lowest values in 1998–2001 and 2012–2013 (Fig. 5; Table 6). On the other hand, no significant difference for the number of species among the periods ($p > 0.05$) was found for the outer zone.

Table 5
Results of PERMANOVA testing for differences in fish assemblage structure, in response to temperature, salinity, transparency, depth (covariates) and sampling periods (fixed factor).

Source	df	SS	MS	ECV	Pseudo-*F*	*p*
Inner zone						
Temperature	1	1451.4	1451.4	1.2	2.1	**
Transparency	1	2205.9	2205.9	2.6	3.2	***
Depth	1	2845.3	2845.3	5.1	4.1	***
Period	3	16,467	5488.8	48.1	8.0	***
Residuals	32	22,179	693.11			
Total	38	45,149				
Middle zone						
Temperature	1	1149.1	1149.1	0.7	1.5	ns
Salinity	1	1388.4	1388.4	1.2	2.1	*
Transparency	1	868.06	868.06	0.2	1.2	ns
Depth	1	1926.9	1926.9	2.4	2.6	**
Period	3	14,999	4999.8	41.8	6.7	***
Residuals	32	23,768	742.74			
Total	39	44,099				
Outer zone						
Temperature	1	2397.8	2397.8	2.8	3.1	***
Salinity	1	2946.5	2946.5	4.8	3.7	***
Transparency	1	1558	1558.0	1.4	2.1	*
Depth	1	2021.3	2021.3	3.4	2.5	**
Period	3	8398	2799.3	28.4	3.5	***
Residuals	34	27,319	803.5			
Total	41	44,641				

df = degrees of freedom, SS = sum of squares (type I), MS = average sum of squares, ECV = percentage of estimated components of variation, *F* = pseudo-*F*.
* $p < 0{,}05$.
** $p < 0.01$.
*** $p < 0.001$.

Fish abundance changed significantly between zones (Pseudo-$F = 5.39$, $p = 0.005$) and periods (Pseudo-$F = 4.56$, $p = 0.002$) (Table 6). The inner zone had more fish numbers than the middle and the outer zones. For the inner and the middle zones, significant higher values were recorded in the two first periods (1997–1998 and 1993–1995) compared with the two latter periods (1998–2001 and 2012–2013). For the outer zone, no significant differences were found among the sampling periods.

In relation to trophic guilds, the Sepetiba Bay fish assemblages were dominated by the benthivorous, followed by the hyperbenthivorous, and to a lesser extent, the piscivorous species, with few planktivorous and opportunist species. The highest decreases overtime in fish richness was found in the inner and middle zones for the benthivorous ($F = 6.27$, $p = 0.001$) and hyperbenthivorous ($F = 4.40$, $p = 0.001$) species (Table 7). In relation to habitat use, the assemblages were dominated by the marine migrant and resident species, followed by marine stragglers and a few semi-anadromous species. There was an overall decrease in the richness of the most abundant groups between 1993–1985 and 1993–1995, stabilizing in 1999–2001 (Table 7). The most conspicuous decrease in richness over time was recorded for the marine migrant in all the three zones (Pseudo-$F = 17.24$, $p = 0.001$) and for the resident species ($F = 10.13$, $p = 0.001$) in the inner and middle zones.

3.6. Selected species

A total of six abundant species (each one accounting for >2% of the total number of fishes) that showed tendency for increasing/decreasing abundance over the temporal series were chosen. *Diplectrum radiale* had a clear decreased trend form 1987–1988 to 2012–2013 in all the three zones (Fig. 6). *Cathorops spixii*, recorded in the inner and middle zone only, had a sharp decrease from 1987–1988 to 1993–1995, being rare in the last two periods. *Cynoscion leiarchus* decreased in the inner and middle zone from 1987–1988 to 1988–2001, with a recovery in 2012–2013; in the outer zone, this species did not change abundance over the sampling periods. *Genidens genidens* was restricted to the inner and middle zone, increasing in both zones over time, mainly in the inner zone. *Micropogonias furnieri* was widely distributed over the three zones, and increased in abundance over time in the inner and outer zone, but no change in abundance was shown in the middle zone. *Ctenosciaena gracilicirrhus* was restricted to middle and outer zone, reaching the highest abundance in 2012–2013 in both zones (Fig. 6).

4. Discussion

This study provides a standardized long-term assessment of changes in fish assemblages encompassing three decades in a tropical bay that experienced a heavily increase in industrial activities at its shoreline. Decreases in the fish richness and density, and changes in assemblage structure occurred, but their intensity was dependent from the bay zone. The inner, and to a lesser extent, the middle zone, changed significantly over the four examined periods, whereas the outer zone remained comparatively stable over time. Although our knowledge of the mechanisms for these changes in response to perturbations is limited, there were several findings that deserve discussion.

The spatial distribution of fish communities along environmental gradients that characterize the three bay zones was a very conspicuous finding detected in this study. Differences in depth, transparency and, to a lesser extent, salinity, form an environmental gradient that coincided with changes in fish community structure from the inner to the outer bay zones, which is an indication that species distribution is constrained by these environmental variables. Differences in these environmental variables and their relationships with fish community structure were reported in previous studies carried out in the Sepetiba Bay (Araújo et al., 2002; Azevedo et al., 2006, 2007). The fish community in the bay seems to be composed of species that have different environmental requirements. Azevedo et al. (2006) reported that segregation in habitat use by fish species may explain the pattern of reduced co-occurrence of the species among zones, evidencing, the presence of two communities of demersal fish (one in the outer zone, and the other in the inner zone, with the middle zone acting as a transition area) associated with different abiotic characteristics of the Sepetiba Bay.

Table 6
Results for PERMANOVA comparisons of number of species and number of individuals among sampling periods and zones in the Sepetiba Bay.

Source	df	Pseudo-*F*	P (Perm)	Significant sampling periods pairwise comparisons ($p < 0.05$)
Number of species				
Period	3	2.65	0.053	Inner zone: 1987–88 > 1993–95 > 1998–01; 2012–13
Zone	2	10.57	0.001	Middle zone:1993–94 > 1998–01; 2012–13
Period × zone	6	1.33	0.244	Outer zone: no significant difference among periods
Number of individuals				
Period	3	4.58	0.002	Inner zone: 1987–88; 1993–95 > 1998–01; 2012–13
Zone	2	5.39	0.005	Middle zone:1993–94; 1993–95 > 1998–01; 2012–13
Periods × zone	6	1.48	0.170	Outer zone: no significant difference among periods

df = degrees of freedom, *F* = pseudo-*F*.
[a] P (permanova).

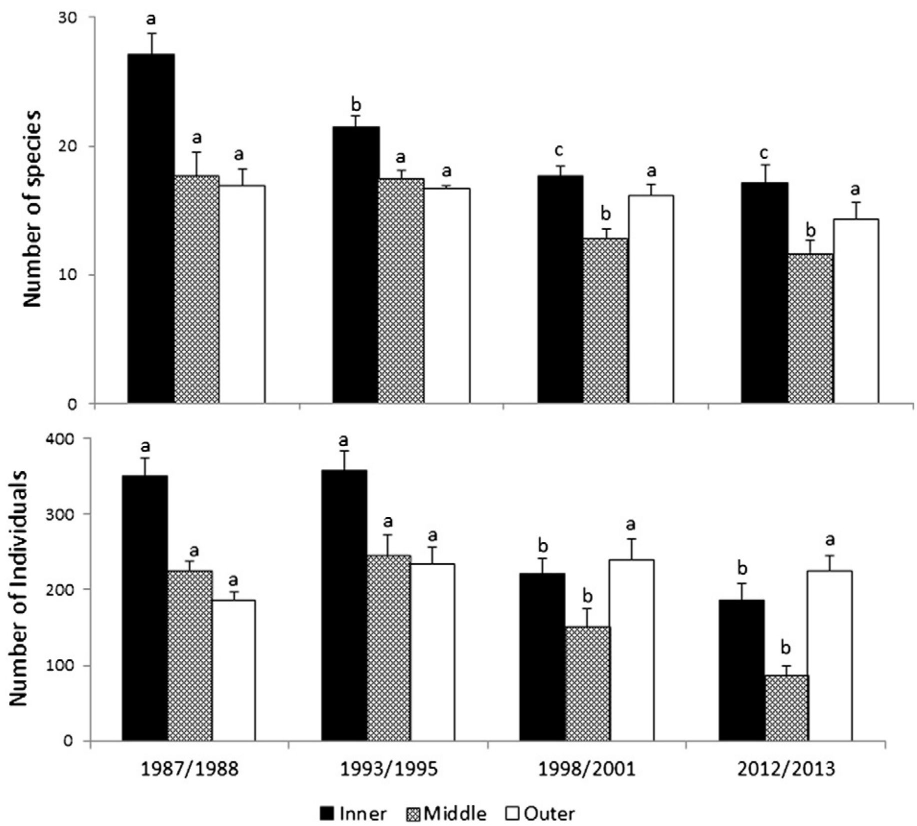

Fig. 5. Means (bars) and standard error (lines) for the number of species (above) and the number of individuals (below) for each sampling period in the three zones of the Sepetiba Bay. Letters indicate significant different/equality among the sampling periods for each zone.

Patterns of bay use by dominant fishes are species-specific. According to Costa and Araújo (2003), juveniles of *M. furnieri*, an abundant species in the bay, recruit in the sandy beaches in the inner bay, then move toward deeper areas as they reach larger sizes. As subadults, they move to the outer bay zone, and finally to the adjacent platform to spawn. This species is classified as marine migrant being one of the most abundant fish of South American estuaries, and an important component of commercial and recreational fisheries in Brazil, Uruguay, and Argentina (Isaac, 1988; Mendoza-Carranza and Vieira, 2008). Marine catfishes are also abundant in the inner zone of Sepetiba Bay. Azevedo et al. (1999) found indication of spatial niche partitioning among marine catfishes, with *G. genidens* being abundant in the inner Bay, *C. spixii* and *G. barbus* near to rivers mouths, and *S. luniscutis* being widespread all over the bay. It is believed that *G. barbus* and *A. luniscutis* move into and outside the bay during their life cycle. Azevedo et al. (1999) also observed that these two species migrate into lower river's reaches of the Sepetiba Bay during their reproductive season. Another abundant group of fishes widely distributed all over the bay are the mojarras of the Gerreidae family that also are important components of the ichthyofauna in tropical bays and an important resources in the artisanal fisheries worldwide (Chen et al., 2007). Franco et al. (2012) found indication of spatial partitioning among these gerreids in a tropical estuary in southeastern Brazil, with *D. rhombeus* and *E. gula* being found exclusively in the lower estuary, whereas *Eucinostomus melanopterus* and *Eugerres brasilianus* were found in the middle estuary, whereas *E. argenteus* was common in the two estuarine zones. In the Sepetiba Bay, members of the Gerreidae family are found across the three bay zones (Araújo and Santos, 1999).

After accounting for these consistent spatial patterns, we found evidence that the inner zone and, to a lesser extent, the middle zone, underwent more conspicuous temporal changes in fish community compared with the outer zone that had the more stable fish community from the 1980's to the 2000's. The environmental variables explained little of the variation in the temporal changes, except the depth. Salinity and temperature had more influence structuring fish community over the sampling periods in the outer zone only. Depth was consistently the most important environmental variable to explain fish community patterns during the four periods in all zones according to DistLM model. Fish community in deeper areas of the outer zone was more resilient to changes over the sampling periods compared to those in the shallower inner zone. It seems that in deeper areas of the outer zone changes is community structure are less likely to occur, with depth, together with other factors not measured in this study, acting as a "buffer" protecting fish community from disturbances. Unlike Bailey et al. (2009), that reported an unexpected indication that the impacts of fisheries can be transmitted into deeper offshore areas in Northeast Atlantic, the relatively well compartmentalized zones of the bay allow different oceanographic conditions in the outer zone. Cunha et al. (2006), modeling hydrodynamics and water quality of Sepetiba Bay, found a small percentage of organic loading in the outer bay zone compared to the remainder of the bay area, an indication that the increased pollution of the inner bay may have lesser influence on the outer bay communities. On the other hand, in the inner zone, the shallow water effect is appreciable in the current variations and is responsible for decreased water quality. The tidal influence is very evident in the Sepetiba Bay (Signorini, 1980), with fresher and warmer water flowing out of Bay in surface layers, whereas the deeper waters have marine influence, especially in the outer zone.

Slight changes in the structure of the fish community structure between 1987–1988 and 1993–1995 were recorded, followed by sharp changes in the following periods were detected by the ANOSIM and nMDS analyses. Both, fish abundance and species richness were greater in 1987–1988 decreasing slightly in 1993–1995, then sharply 1998–2001, and reaching the lowest values in 2012–2013, revealing that these descriptors of the fish community structure changed significantly over time. Again, these differences were more conspicuous for the inner

Table 7
Results for PERMANOVA comparisons of the number of fish species for trophic and habitat use guilds among sampling periods and zones in the Sepetiba Bay.

Source	df	Pseudo-*F*	P (Perm)	Significant sampling periods pairwise comparisons ($p < 0.05$)
Trophic guilds				
Benthivorous				
Period	3	6.27	0.001	Inner zone: 1987–88 > 1993–95 > 1998–01; 2012–13
Zone	2	11.07	0.001	Middle zone: 1987–88 > 2012–13
Period × zone	6	4.28	0.001	Outer zone: no significant difference among periods
Hyperbenthivorous				
Period	3	7.17	0.001	Inner zone: 1987–88 > 1993–95 > 1998–01; 2012–13
Zone	2	4.30	0.008	Middle zone: 1993–95 > 1998–01; 2012–13
Period × zone	6	1.83	0.071	Outer zone: no significant difference among periods
Piscivorous				
Period	3	14.52	0.001	Inner zone: 1987–88 > 1993–95;1998–01; 2012–13
Zone	2	21.806	0.001	Middle zone: 1987–88; 1993–95 > 2012–13
Period × zone	6	2.02	0.052	Outer zone: 1987–88 > 1993–95; 1998–01; 2012–13
Planktivorous				
Period	3	0,76	0.51	Inner zone: no significant difference among periods
Zone	2	0.32	0.718	Middle zone: no significant difference among periods
Period × zone	6	0.94	0.446	Outer zone: no significant difference among periods
Opportunistic				
Period	3	5.99	0.003	Inner zone: 1993–94 > 1998–01; 2012–13
Zone	2	7.77	0.001	Middle zone: 1987–88; 1993–95 > 1998–01; 2012–13
Period × zone	6	2.05	0.057	Outer zone: no significant difference among periods
Habitat use guilds				
Marine migrants				
Period	3	17.24	0.001	Inner zone: 1987–88 > 1993–95 > 1998–01; 2012–13
Zone	2	5.48	0.003	Middle zone: 1993–95 > 1998–01; 2012–13
Period × zone	6	1.82	0.087	Outer zone: 1987–88 > 1993–95; 1998–01; 2012–13
Marine straggles				
Period	3	2.18	0.077	Inner zone: 1987–88 > 1993–95; 1998–01; 2012–13
Zone	2	11.07	0.001	Middle zone: no significant difference among periods
Period × zone	6	3.49	0.001	Outer zone: no significant difference among periods
Resident				
Period	3	10.13	0.001	Inner zone: 1987–88 > 1993–95 > 1998–01; 2012–13
Zone	2	4.39	0.014	Middle zone: 1993–95 > 1998–01; 2012–13
Period × zone	6	1.03	0.374	Outer zone: no significant difference among periods
Semi-anadromous				
Period	3	2.44	0.066	Inner zone: no significant difference among periods
Zone	2	4.81	0.009	Middle zone: 1987–88 > 1993–95; 1998–01; 2012–13
Period × zone	6	1.61	0.135	Outer zone: no significant difference among periods

df = degrees of freedom, *F* = pseudo-*F*.
[a] P (permanova).

and middle zones. Decreases in species richness were mainly due to the disappearance of the marine migrant species in all three bay zones, and resident species in the inner and middle zones. These species have predominant benthivorous, hyperbenthivorous and, to a lesser extent, piscivorous feeding habits. While the resident species complete all the life cycle within the bay, the marine migrants use estuarine habitats mainly as nursery areas (Elliott et al., 2007; Franco et al., 2008). Although resident species have developed several traits adapted to estuarine environmental conditions, intense sedimentation or habitat destruction may jeopardize eggs and larvae development, which should have marked impact on survival. Furthermore, recruitment into estuarine areas by the marine migrant species may be also extremely dependent on habitat and feeding resources availability (Whitfield and Elliott, 2002; Vasconcelos et al., 2011).

Some historical changes that occurred in the Sepetiba Bay coincided with decreases of fish richness and abundance in the inner and middle bay zones by the between 1993–1995 and 1998–2001 (Table 8). For example, accidental discharges of Zn and Cd that occurred in 1996 in the northeast area of the bay, which correspond to the inner zone (Ribeiro et al., 2013), coincided with sharp decreases in the fish richness and abundance recorded in 1998–2001. The large zinc smelting plant (The Mercantil Ingá Company) closed operations in 1996, but over 2 million tons of Zn-Cd-Pb-rich tailing were left on the bay's coast being washed out easily by heavy local rains (Gomes et al., 2009). Moreover, Rezende et al. (1991) found increasing Zn concentration in intertidal sands for 7 beaches along the Sepetiba Bay coastline in 1990 when compared to the concentrations reported for 1980 by Lacerda et al. (1985) at the same beaches. High Zn and Cd concentration causes dysfunction in liver, kidney and other organs, causing neurotoxicity and modification of ionic balance to organisms, resulting in degeneration of muscle, lesions in the spinal cord, decreases of fish size, convulsion that impair reproduction and survival (Canli and Atli, 2003; Scott and Sloman, 2004; Authman et al., 2015). Coincidences in these effects of anthropogenic activities and decreases in fish richness and abundance over these periods are compelling evidence of metal pollution influences on the fish assemblages.

The enlargement of the Sepetiba Port in the late nineties also coincided with changes in community structure and decreased fish richness and abundance recorded in 1998–2001 and in 2012–2013 (Table 8). The Sepetiba Port had a 2-fold increase in its original capacity of 20 million tons × year^{-1} in 2006, and the access channel was dredged to 20 m depth and 200 m wide in 2009. The widening and dredging of channels for navigation and infrastructures are widely considered some of the most serious threats for fish losses globally (Airoldi and Beck, 2007). Other recent human interventions in the Sepetiba Bay area were the beginning of operation of a steel factory (ThyssenKrupp Siderúrgica do Atlântico Company - TKCSA) in 2010 and a terminal for building submarines in 2013 (Brazil Navy Force). Moreover, it is estimated that almost all of the coastal cities around the Sepetiba Bay lack proper sewage treatment plants and discharge untreated wastewaters directly into the marine environment (Copeland et al., 2003). Cunha et al. (2006) estimated that 70,000 kg of biochemical oxygen demand per day (BOD/day) is dumped untreated into the rivers and channels that carry mainly untreated waste into the bay in 2000 and forecasted

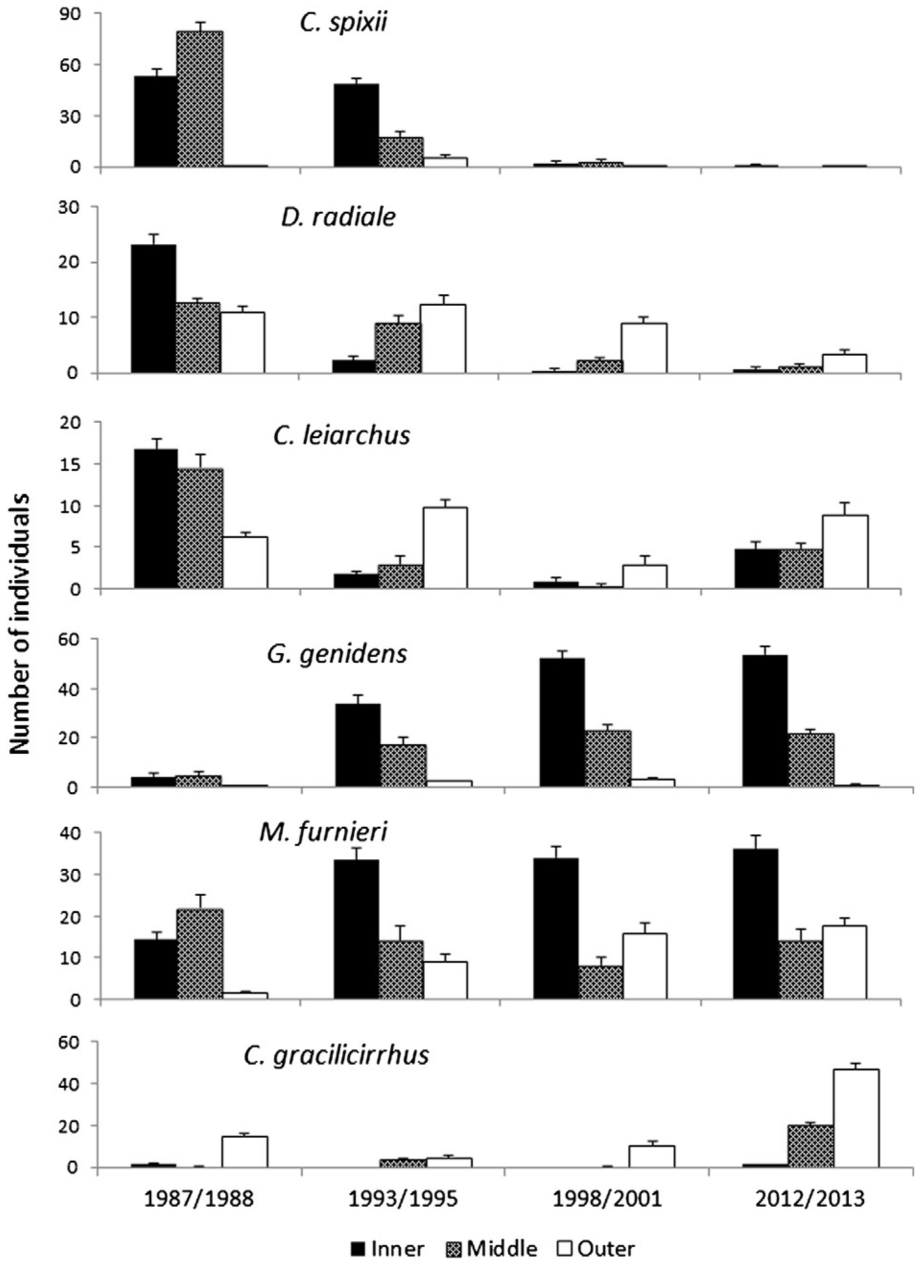

Fig. 6. Means (bars) and standard error (lines) for the number of individuals of selected species for each sampling period in the three zones of the Sepetiba Bay.

that this estimation will increase to 90,000 kg BOD/day in 2015. Therefore, pollutants are introduced to waterways from point sources such as sewer overflows, municipal and industrial discharges, and spills; or may be introduced from nonpoint sources such as surface runoff and atmospheric deposition. According to Wilber and Clarke (2001), little is known of behavioral responses of many estuarine fishes to suspended sediment plumes. Likewise, the effects of intermittent exposures at periodicities that simulate the effects of tidal flushing or the conduct of many dredge operations have not been addressed. There are clear evidences of direct habitat destruction caused by increased human activities in the bay shoreline that has contributed to degrade habitats and to increase pollution in the area (Leal Neto et al., 2006; Molisani et al., 2006; Cunha et al., 2009). Therefore, such anthropogenic activities are also likely to affect mostly the inner bay zone that receives directly these discharges.

Anthropogenic changes in water quality have been reported in other bays as responsible for long-term changes in fish communities (Ribeiro et al., 2008; Sobocinski et al., 2013). Kennish (2002) reported that the effects of pollution inputs, the loss and alteration of habitat, and other anthropogenic stress indicate that water quality in estuaries, particularly in urbanized systems, where the overloading of nutrients and organic matter, the influx of pathogens, and the accumulation of chemical contaminants usually impair biotic communities. Jin (2004) and Ribeiro et al. (2008) reported changes in the fish community structure and decreases in fish richness and abundance associated to pollution, urbanization industrial development, discharges of biological effluents and channel dredge. Van der Veer et al. (2015) found that increased water temperature, habitat destruction in the coastal zone are the most likely explanatory variables for reduction of the nursery function of the Wadden Sea since the 1980s.

For some numerically abundant fish species changes in relative abundance were recorded; however, the direction of the change differed among species (i.e., there was not a monotonic response among individual species), as might be expected given individual species response to disturbance. *Diplectrum radiale*, *C. spixii* and *C. leiarchus* had a decreasing trend in numerical abundance over the sampling periods

Table 8
Some historical events that occurred in the Sepetiba Bay and main changes in fish communities. Events thought to be more important as result of anthropogenic activities in bold.

Event	Period	References	Fish changes
Beginning of industrialization in Brazil	1950s		
Beginning of activities of the Sepetiba Port	1982	Clarke et al., 2004	–
Population increase (600,000 to 2 million)	1980–2000	Leal Neto et al., 2006	Increases in relative abundances of *M. furnieri* and *G. genidens* from 1993 to 2013.
Accidental Cd and Zn discharges into the bay	**1996**	Ribeiro et al., 2013	**High overall decreases in fish abundance and richness in 1998–2001**.
Enlargement of the Sepetiba Port	1998	Clarke et al., 2004	Decreases in abundance of *D. radiale, C. spixii and C. leiarchus* from 1998 to 2013.
Contamination by Cd (24 tons × year^{-1}) and Zn (3.660 tons × year^{-1})	**1999**	Gomes et al., 2009	–
Decreased in Cd (1.28–0.63) and Zn (105–96) tons × year^{-1}	1980–2005	Lacerda and Molisani, 2006	–
Increased production of municipal waste (0.5 kg/hab/day to 1.2 kg/hab/day)	1980–2004	Cunha et al., 2009	–
Decreased fish richness in sandy beaches (80 to 55 spp)	1983–1994	Pessanha et al., 2000	–
28% increase in the sediment load (270 × 10^3 tons × year^{-1})	2003	Molisani et al., 2006	–
New enlargement of Sepetiba Port access channel to meet requirements of a new steel company (TKCSA)	**2009**	Gomes et al., 2009	Increases in abundance of *C. gracilicirrhus* in 2012–2013.
Beginning of activities of a steel company TKCSA	2010	Ribeiro et al., 2013	**More overall decreases in fish richness and abundance in 2012–2013**
Construction of a terminal for submarines (Brazilian Navy)	2013	Araújo et al., 2016	–

in the inner and middle zones. *Cynoscion leiarchus* seems to be moving from the inner, where it was abundant in 1987–1988, to the outer zone, whereas *D. radiale* had a conspicuous decrease in abundance over the sampling periods in all three zones. *Cynoscion leiarchus* is an important commercial fishery resource that occur mainly in the more stable environmental conditions favored by marine influences of the outer zone (Araújo et al., 2006). On the other hand, other dominant species such as *G. genidens*, *M. furnieri* and *C. gracillicirrhus* increased numerical abundance over time. *Ctenosciaena gracillicirrhus* is associated with shallow areas of the coastal shelf and the outer bay zones (Araújo et al., 2006), where environmental conditions are more stable compared with the inner bay zone. In the outer zone of Sepetiba Bay, with lesser influence of anthropogenic activities, this species seem to have a favorable habitat to explore. *Genidens genidens* and *M. furnieri* are typical generalist and opportunist species well adapted to harsh conditions of estuarine environments taking advantage of the available resources of the inner bay zone (Azevedo et al., 1999; Costa and Araújo, 2003; Araújo et al., 2006). Moreover, increases of *G. genidens* in the inner and middle bay zones coincided with sharp decrease of another marine catfish (*C. spixii*) in the first two sampling periods. The causes for this apparent shift in abundance could be related to resources partitioning since they are close related species that coexist in the inner and middle bay zones, therefore likely to compete for space and resources. However, further studies are necessary to clarify the causes of such changes.

Fishery activities also may have a direct influence on the composition and abundance of species and remains as the major source of impact upon marine and coastal environments, contributing to global biodiversity loss (Watson and Pauly, 2001; FAO and UNEP, 2009). In the study area, *M. furnieri*, *E. argenteus*, *Trachinotus carolinus* and *Anchoa tricolor* are important fisheries resources that rank amongst the most abundant species having distinct patterns of estuarine use as well as differentiated association with several environmental features. There are indications that overfishing may have been responsible for decreasing populations of some of these species. Furthermore, bottom trawls are common in the Sepetiba Bay and this disruptive fishing technique has a long history of use, mainly in estuaries and bays waters (Tudela, 2004; Airoldi and Beck, 2007). Trawls affect extensive areas of benthic habitat with direct effects on benthivorous and hyperbenthivorous fish species that dominate Sepetiba Bay fish community.

Although not evenly distributed over the four periods, our sampling program seemed to be efficient to draw conclusions on the changes of fish community in the Sepetiba Bay. Standardizing sampling effort and methods will strengthen the ability to draw conclusion about long-term changes (Smith et al., 2008). Maintaining consistent methodology through time is very important for any survey whose goals include to track changes in abundance over time. Even biased estimates are not problematic for most abundance assessments as long as they are stationary in both space and time (Kotwicki et al., 2011). To consider changes over multiple periods (Cabral et al., 2001; Van der Veer et al., 2015) may further improve the ability to draw robust conclusions. This dataset allows us to reported dramatic reduction in fish richness and abundance in Sepetiba Bay, which coincided with increase anthropogenic activities in the bay shoreline. Several factors increase the robustness of the conclusion drawn from comparison among different sampling periods: (1) the primary investigator (FGA) participated of all surveys ensuring consistency in sampling methods among the periods; (2) sampling effort was standardize among the surveys; and (3) identical gear was used in all the surveys.

In conclusion, we have shown that estuarine fish community changes are constrained by environmental and anthropogenic activities that occur along spatial scales in different degree of alteration. It should be noted that progressive biodiversity loss sabotages the stability of marine environments and their ability to recover from stresses (Sax and Gaines, 2003; Worm et al., 2006; Azevedo et al., 2013). Moreover, most changes are occurring in the inner bay zone, because of their closer proximity of impact sources, compared with areas next to the sea connection that was comparatively more stable. Such bay areas tend to have environmental gradients at spatial scale that maintain consistent difference in their fish communities. This is, at least in part, related to the differences in their environmental conditions, especially high depth that seems to act as a buffer for community changes. Our results provide compelling evidence that anthropogenic activities along the last 30 years in the bay affected fish communities. Other unmeasured factors related to the species biology, such as niche use, trophic habits, and biotic interaction could also have influenced fish distribution, but they are not the focus of the present study.

Despite the difficulty of separating natural and anthropogenic stress in estuaries that have given rise to the suggestion of the 'Estuarine Quality Paradox' (Elliott and Quintino, 2007), differential changes in community structure in different bay zones were detected and associated to their probable causes. This "paradox" states that the dominant estuarine community is adapted to and reflects high spatial and temporal variability in naturally highly stressed areas but that it has features very similar to those found in anthropogenically stressed areas thus making it difficult to detect anthropogenically-induced stress in estuaries.

The Brazilian government has declared as a strategic priority the development of the Sepetiba Port and its related industries. Given the expected fast industrial development and population growth in the

Sepetiba basin, there is an urgent need for a pollution management system in the region. Port activities have increased dramatically around the world. It is timely to link conservation and management planning with historical information. Habitat degradation and pollutants discharges into coastal systems are the main issues that must be addressed to recover fish communities. To understand how the fish communities respond to anthropogenic induced perturbations is crucial to develop and establish long-term multidisciplinary monitoring programs that assess both the water quality and these communities, in order to document natural variations in the communities, against which changes due to environmental degradation could be compared (Whitfield and Elliott, 2002; Smith et al., 2008). It is important to bear in mind that the inner areas need more attention in conservation programs, because they suffer more anthropogenic influences, whereas deep areas remain relatively stable. Continued monitoring of fish fauna in these habitats will improve our ability to detect anthropogenic changes from natural variability. A method for selecting species-specific metrics to fulfill various specified indicator roles was proposed for demersal fish communities in the North Sea (Greenstreet et al., 2012). Barbier et al. (2011), studying the global decline in estuarine and coastal ecosystems (ECEs) suggested an action plan for protecting and/or enhancing the immediate and longer-term values of ECE services by assessing the connectivity of ECEs across land-sea gradients and management of the entire seascape. This approach is difficult to be achieved in developing countries because of the high financial cost, although other measure could be attained. For example, further ecological and economic collaborative research on valuing ECE services, controlling and regulating destructive economic activities, and developing ecological restoration options. This is particularly relevant in systems such as Sepetiba Bay that plays an important role for a large number of fish species but is suffering increasing anthropogenic influences resulting in changes in structure of the community and decreasing richness and abundance. This could ensure that the remedial management necessary to bring about recovery could be was implemented in near future.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.marpolbul.2016.08.063.

References

Airoldi, L., Beck, M.W., 2007. Loss, status and trends for coastal marine habitats of Europe. Oceanogr. Mar. Biol. 45, 345–405.

Amado-Filho, G.M., Andrade, L.R., Karez, C.S., Farina, M., Pfeiffer, W.C., 1999. Brown algae species as biomonitors of Zn and Cd at Sepetiba Bay, Rio de Janeiro, Brazil. Mar. Environ. Res. 48, 213–224.

Anderson, M.J., Gorley, R.N., Clarke, K.R., 2008. Permanova+ for Primer: Guide to Software and Statistical Methods. PRIMER-E, Plymouth, UK (214 pp).

Araújo, F.G., Santos, A.C.A., 1999. Distribution and recruitment of mojarras (Perciformes, Gerreidae) in the continental margin of Sepetiba Bay, Brazil. Bull. Mar. Sci. 65, 431–439.

Araújo, F.G., Azevedo, M.C.C., Silva, M.A., Pessanha, A.L.M., Gomes, I.D., Cruz-Filho, A.G., 2002. Environmental influences on the demersal fish assemblages in the Sepetiba Bay, Brazil. Estuaries 15, 441–450.

Araújo, F.G., Guimarães, F.J.C., Costa, M.R., 2006. Environmental influences on distribution of four Sciaenidae species (Actinopterygii, Perciformes) in a tropical bay at Southeastern Brazil. Rev. Bras. Zool. 23, 497–508.

Araújo, F.G., Azevedo, M.C.C., Guedes, A.P.P., 2016. Inter-decadal changes in fish communities of a tropical bay in southeastern Brazil. Reg. Stud. Mar. Sci. 3, 107–118.

Authman, M.M.N., Zaki, M.S., Khallaf, E.A., Abbas, H.H., 2015. Use of fish as bio-indicator of the effects of heavy metals pollution. J. Aquac. Res. Develop. 6 (328), 1–23.

Azevedo, M.C.C., Araújo, F.G., Cruz-Filho, A.G., Santos, A.C.A., 1999. Distribution and relative abundance of marine catfishes (Siluriformes, Ariidae) in the Sepetiba Bay, RJ. Rev. Bras. Zool. 15, 853–865.

Azevedo, M.C.C., Araújo, F.G., Pessanha, A.L.M., Silva, M.A., 2006. Co- occurrence of demersal fishes in a tropical bay in southeastern Brazil: a null model analysis. Estuar. Coast. Shelf Sci. 66, 315–322.

Azevedo, M.C.C., Araújo, F.G., Cruz-Filho, A.G., Pessanha, A.L.M., Silva, M.A., Guedes, A.P.P., 2007. Demersal fishes in a tropical bay in southeastern Brazil: partitioning the spatial, temporal and environmental components of ecological variation. Estuar. Coast. Shelf Sci. 75, 468–480.

Azevedo, I., Ramosa, S., Mucha, A.P., Bordalo, A.A., 2013. Applicability of ecological assessment tools for management decision-making: a case study from the Lima estuary (NW Portugal). Ocean Coast. Manag. 72, 54–63.

Bailey, D.M., Collins, M.A., Gordon, J.D.M., Zuur, A.F., Priede, I.G., 2009. Long-term changes in deep-water fish populations in the northeast Atlantic: a deeper reaching effect of fisheries? Proc. R. Soc. Lond., B, Biol. Sci. 276, 1965–1969.

Barbier, E.B., Hacker, S.D., Kennedy, C., Koch, E.W., Stier, A.C., Silliman, B.R., 2011. The value of estuarine and coastal ecosystem services. Ecol. Monogr. 81, 169–193.

Basset, A., Barbone, E., Elliott, M., Li, B., Jorgensen, S.E., Lucena-Moya, P., Pardo, I., Mouillot, D., 2013. A unifying approach to understanding transitional waters: fundamental properties emerging from ecotone ecosystems. Estuar. Coast. Shelf Sci. 132, 5–16.

Cabral, H.N., Costa, M.J., Salgado, J.P., 2001. Does the Tagus estuary fish community reflect environmental changes? Clim. Res. 18, 119–126.

Canli, M., Atli, G., 2003. The relationships between heavy metal (Cd, Cr, Cu, Fe, Pb, Zn) levels and the size of six Mediterranean fish species. Environ. Pollut. 121, 129–136.

Carneiro, C.S., Mársico, E.T., Ribeiro, R.O.R., Jesus, E.F.O., 2013. Total mercury bioaccumulation in tissues of carnivorous fish (*Micropogonias furnieri* and *Cynoscion acoupa*) and oysters (*Crassostrea brasiliana*) from Sepetiba Bay, Brazil. J. Aquat. Food Prod. T. 22, 96–102.

Chen, W.J., Ruiz-Carus, R., Orti, G., 2007. Relationships among four genera of mojarras (Teleostei: Perciformes: Gerreidae) from the western Atlantic and their tentative placement among percomorph fishes. J. Fish Biol. 70, 202–218.

Clarke, K.R., 1993. Non-parametric multivariate analyses of changes in community structure. Aust. J. Ecol. 18, 117–143.

Clarke, C., Hilliard, R., de Junqueira, A.O.R., de Neto, A.C.L., Polglaze, J., Raaymakers, S., 2004. Ballast water risk assessment, Port of Sepetiba, Federal Republic of Brazil, December 2003: final report. GloBallast Monograph Series No. 14. IMO, London.

Copeland, G., Monteiro, T., Couch, S., Borthwick, A., 2003. Water quality in Sepetiba Bay, Brazil. Mar. Environ. Res. 55, 385–408.

Costa, M.R., Araújo, F.G., 2003. Use of a tropical bay in southeastern Brazil by juvenile and subadult *Micropogonias furnieri* (Perciformes, Sciaenidae). ICES J. Mar. Sci. 60, 268–277.

Cunha, C.L.N., Rosmam, P.C.C., Ferreira, A.P., Monteiro, T.C.N., 2006. Hydrodynamics and water quality models applied to Sepetiba Bay. Cont. Shelf Res. 26, 1940–1953.

Cunha, B.C.A., Rocha, D.S., Geraldes, M.C., Pereira, S.D., Almeida, A.C., 2009. Pb isotopic signatures in sediments of a subtropical coastal lagoon: anthropogenic source for metal contamination in the Sepetiba Bay (SE – Brazil). International Coastal Symposium. J. Coast. Res. 56, 797–801 (Special Issue).

Defeo, O., McLachlan, A., Schoeman, D.S., Schlacher, T.A., Dugan, J., Jones, A., Lastra, M., Scapini, F., 2009. Threats to sandy beach ecosystems: a review. Estuar. Coast. Shelf Sci. 81, 1–12.

Ecoutin, J.M., Simier, M., Albaret, J.J., Laë, R., Tito de Morais, L., 2010. Changes over a decade in fish assemblages exposed to both environmental and fishing constraints in the Sine Saloum estuary (Senegal). Estuar. Coast. Shelf Sci. 87, 284–292.

Elliott, M., Quintino, V., 2007. The Estuarine Quality Paradox, Environmental Homeostasis and the difficulty of detecting anthropogenic stress in naturally stressed areas. Mar. Pollut. Bull. 54, 640–645.

Elliott, M., Whitfield, A.K., Potter, I.C., Blaber, S.J.M., Cyrus, D.P., Nordlie, F.G., Harrison, T.D., 2007. The guild approach to categorizing estuarine fish assemblages: a global review. Fish Fish. 8, 241–268.

FAO, UNEP, 2009. Report of the FAO/UNEP expert meeting on impacts of destructive fishing practices, unsustainable fishing, and illegal, unreported and unregulated (IUU) fishing on marine biodiversity and habitats. FAO Fisheries and Aquacultur e Report No. 932. Food and Agriculture Organization of the United Nations, Rome.

Fonseca, E.F., Baptista Neto, J.A., Silva, C.G., 2013. Heavy metal accumulation in mangrove sediments surrounding a large waste reservoir of a local metallurgical plant, Sepetiba Bay, SE, Brazil. Environ. Earth Sci. 70, 643–650.

Franco, A., Elliott, M., Franzoi, P., Torricelli, P., 2008. Life strategies of fishes in European estuaries: the functional guild approach. Mar. Ecol. Prog. Ser. 354, 219–228.

Franco, T.P., Neves, L.M., Teixeira, T.P., Araújo, F.G., 2012. Patterns of spatial distribution of five species of mojarras (Actinopterygii: Gerreidae) in a small tropical estuary in south-eastern Brazil. J. Mar. Biol. Assoc. UK 92, 1217–1225.

Freitas, M.B., Rodrigues, S.C.A., 2014. Deterritorialization of artisanal fisheries in Sepetiba Bay (State of Rio de Janeiro, Brazil): an overview of occupational health and environmental issues. Cien. Saúde Colet. 19, 4001–4009.

Gomes, F.C., Godoy, J.M., Godoy, M.L.D.P., Carvalho, Z.L., Lopes, R.T., Sanchez-Cabezad, J.A., Lacerda, L.D., Wasserman, J.C., 2009. Metal concentrations, fluxes, inventories and chronologies in sediments from Sepetiba and Ribeira Bays: a comparative study. Mar. Pollut. Bull. 59, 123–133.

Greenstreet, S.P.R., Rossberg, A.G., Fox, C.J., Quesne, W.J.F., Blasdale, T., Boulcott, P., Mitchell, W., Millar, C., Moffat, C.F., 2012. Demersal fish biodiversity: species-level indicators and trends-based targets for the Marine Strategy Framework Directive. ICES J. Mar. Sci. 69, 1789–1801.

Hewitt, M., Kovacs, T., Dubé, M., MacLatchy, D., Martel, P., McMaster, M., Paice, M., Parrott, J., van den Heuve, M.R., Van Der Kraak, G., 2008. Altered reproduction in fish exposed to pulp and paper mill effluents: a review of the roles of individual compounds and mill operating conditions. Environ. Toxicol. Pharmacol. 27, 682–697.

Isaac, V.J., 1988. Synopsis of biological data on the whitemouth croaker *Micropogonias furnieri* (Desmarest, 1823). FAO Fisheries Synopsis (150 pp).

Jin, X., 2004. Long-term in fish community structure in the Bohai Sea, China. Estuar. Coast. Shelf Sci. 59, 163–171.

Johnston, E.L., Roberts, D.A., 2009. Contaminants reduce the richness and evenness of marine communities: a review and meta-analysis. Environ. Pollut. 157, 1745–1752.

Kennish, M.J., 2002. Environmental threats and environmental future of estuaries. Environ. Conserv. 29, 78–107.

Kotwicki, S., Martin, M.H., Laman, E.A., 2011. Improving area swept estimates from bottom trawl surveys. Fish. Res. 110, 198–206.

Lacerda, L.D., Molisani, M.M., 2006. Three decades of Cd and ZN contamination in Sepetiba Bay, SE Brazil: evidence from the mangrove oyster *Crassostrea rhizophorae*. Mar. Pollut. Bull. 52, 974–977.

Lacerda, L.D., Pfeiffer, W.C., Fiszman, M., 1985. Intertidal beach sands as monitor for heavy metal pollution in coastal water bodies. Environ. Technol. Lett. 6, 123–128.

Lacerda, L.D., Pfeiffer, W.C., Fiszman, M., 1987. Heavy metal distribution, availability and fate in Sepetiba Bay, SE, Brazil. Sci. Total Environ. 65, 163–173.

Last, P.R., White, W.T., Gledhill, D.C., Hobday, A.J., Brown, R., Edgar, G.J., Pecl, G., 2011. Long-term shifts in abundance and distribution of a temperate fish fauna: a response to climate change and fishing practices. Glob. Ecol. Biogeogr. 20, 58–72.

Leal Neto, A.C., Legey, L.F.L., González-Araya, M.C., Jablonski, S., 2006. A system dynamics model for the environmental management of the Sepetiba Bay watershed, Brazil. Environ. Manag. 38, 879–888.

Macpherson, E., 2002. Large-scale species-richness gradients in the Atlantic Ocean. Proc. R. Soc. Lond. B Biol. Sci. 269, 1715–1720.

Magalhães, M.M., Marinho, P., Domingos, A.C., Oliveira, S.M., Costa, L.O., Azevedo, S.F.O., 2003. Microcystins (*Cyanobacteria hepatotoxins*) bioaccumulation in fish and crustaceans from Sepetiba Bay, (Brazil, RJ). Toxicon 42, 289–295.

Martínez, M.L., Intralawan, A., Vázquez, G., Pérez-Maqueo, O.M., Sutton, P., Landgrave, R., 2007. The coasts of our world: ecological, economic and social importance. Ecol. Econ. 63, 254–272.

McArdle, B.H., Anderson, M.J., 2001. Fitting multivariate models to community data: a comment on distance-based redundancy analysis. Ecology 82, 290–297.

McLusky, D.S., Elliott, M., 2007. Transitional waters: a new approach, semantics or just muddying the waters? Estuar. Coast. Shelf Sci. 71, 359–363.

Mendoza-Carranza, M., Vieira, J.P., 2008. Whitemouth croaker *Micropogonias furnieri* (Desmarest, 1823) feeding strategies across four southern Brazilian estuaries. Aquat. Ecol. 42, 83–93.

Molisani, M.M., Marins, R.V., Machado, W., Paraquetti, H.H.M., Bidone, E.D., Lacerda, L.D., 2004. Environmental changes in Sepetiba Bay, SE Brazil. Reg. Environ. Chang. 4, 17–27.

Molisani, M.M., Kjerfve, B., Silva, A.P., Lacerda, L.D., 2006. Water discharge and sediment load to Sepetiba Bay from an anthropogenically-altered drainage basin, SE Brazil. J. Hydrol. 331, 425–433.

Nagelkerken, I., Kleijnen, T.S., Klop, T., Van Den Brand, R.A.C.J., Cocheret de la Moriniere, E., van der Velde, G., 2001. Dependence of Caribbean reef fishes on mangroves and seagrass beds as nursery habitats: a comparison of fish faunas between bays with and without mangroves/seagrass beds. Mar. Ecol. Prog. Ser. 214, 225–235.

Pereira, H.H., Neves, L.M., Costa, M.R., Araújo, F.G., 2015. Fish assemblage structure on sandy beaches with different anthropogenic influences and proximity of spawning grounds. Mar. Ecol. 36 (1), 16–27.

Pessanha, A.L.M., Araújo, F.G., Azevedo, M.C.C., Gomes, I.D., 2000. Spatial and temporal changes in composition and structure of the juvenile fish community of the Sepetiba Bay, Rio de Janeiro. Rev. Bras. Zool. 17, 251–261.

Pihl, L., Baden, S., Kautsky, N., Rönnbäck, P., Söderqvist, T., Troell, M., Wennhage, H., 2006. Shift in fish assemblage structure due to loss of seagrass *Zostera marina* habitats in Sweden. Estuar. Coast. Shelf Sci. 67, 123–132.

Ray, G.C., 2005. Connectivities of estuarine fishes to the coastal realm. Estuar. Coast. Shelf Sci. 64, 18–32.

Rezende, C.E., Lacerda, L.D., Pfeiffer, W.C., 1991. Evolution of heavy metal contamination (1980–1989) of Sepetiba Bay determined by using beach sands as monitors. Ciênc. Cult. 43, 61–63.

Ribeiro, J., Monteiro, C.C., Monteiro, P., Bentes, L., Coelho, R., Gonçalves, J.M.S., Lino, P.G., Erzini, K., 2008. Long-term changes in fish communities of the Ria Formosa coastal lagoon (southern Portugal) based on two studies made 20 years apart. Estuar. Coast. Shelf Sci. 76, 57–68.

Ribeiro, A.P., Figueiredo, A.M.G., Santos, J.O., Dantas, E., Cotrim, M.E.B., Figueira, R.C.L., Silva Filho, E.V., Wasserman, J.C., 2013. Combined SEM/AVS and attenuation of concentration models for the assessment of bioavailability and mobility of metals in sediments of Sepetiba Bay (SE Brazil). Mar. Pollut. Bull. 68, 55–63.

Sax, D.F., Gaines, S.D., 2003. Species diversity: from global decreases to local increases. Trends Ecol. Evol. 18, 561–566.

Scott, G.R., Sloman, K.A., 2004. The effects of environmental pollutants on complex fish behaviour: integrating behavioural and physiological indicators of toxicity. Aquat. Toxicol. 68, 369–392.

Signorini, S.R., 1980. A study of the circulation in Bay of Ilha Grande and Bay of Sepetiba. Part 1. A survey of the circulation based on experimental field data. Bolm. Inst. Ocanogr. 29, 41–55.

Smith, K.L., Flores, I.C., Pringle, C.M., 2008. A comparison of current and historical fish assemblages in a Caribbean island estuary: conservation value of historical data. Aquat. Conserv. 18, 993–1004.

Sobocinski, K.L., Orth, R.J., Fabrizio, M.C., Latour, R.J., 2013. Historical comparison of fish community structure in lower Chesapeake Bay seagrass habitats. Estuar. Coasts 36, 775–794.

Sparre, P., Venema, S.C., 1995. Introduction to evaluation of tropical fisheries resources. Part 1 – manual. FAO Technical Paper, 306/1, pp. 339–344.

Staglicic, N., Matic-Skoko, S., Pallaoro, A., Grgicevic, R., Kraljevic, M., Tutman, P., Dragicevic, B., Dulci, J., 2011. Trends in the structure of eastern Adriatic littoral fish assemblages: consequences for fisheries management. Estuar. Coast. Shelf Sci. 94, 263–271.

Tudela, S., 2004. Ecosystem effects of fishing in the Mediterranean: an analysis of the major threats of fishing gear and practices to biodiversity and marine habitats. Studies and reviews. General Fisheries Commission for the Mediterranean 74. FAO, Rome Available http://www.fao.org/docrep/007/y5594e/y5594e00.htm (accessed 30 April 2066).

Van der Veer, H.W., Dapper, R., Henderson, P.A., Jung, A.S., Philippart, C.J.M., Witte, J.I.J., Zuur, A.F., 2015. Changes over 50 years in fish fauna of a temperate coastal sea: degradation of trophic structure and nursery function. Estuar. Coast. Shelf Sci. 155, 156–166.

Vasconcelos, R.P., Reis-Santosa, P., Costa, M.J., Cabral, H.N., 2011. Connectivity between estuaries and marine environment: integrating metrics to assess estuarine nursery function. Ecol. Indic. 11, 1123–1133.

Watson, R., Pauly, D., 2001. Systematic distortions in world fisheries catch trends. Nature 414, 534–536.

Whitfield, A.K., Elliott, M., 2002. Fishes as indicators of environmental and ecological changes within estuaries: a review of progress and some suggestions for the future. J. Fish Biol. 61, 229–250.

Wilber, D.H., Clarke, D.G., 2001. Biological effects of suspended sediments: a review of suspended sediment impacts on fish and shellfish with relation to dredging activities in estuaries. N. Am. J. Fish Manag. 21, 855–875.

Worm, B., Barbier, E.B., Beaumont, N., Duffy, J.E., Folke, C., Halpern, B.S., Jackson, J.B.C., Lotze, H.K., Micheli, F., Palumbi, S.R., Sala, E., Selkoe, K.A., Stachowicz, J.J., Watson, R., 2006. Impacts of biodiversity loss on ocean ecosystem services. Science 314, 787–790.