

Inter-decadal changes in fish communities of a tropical bay in southeastern Brazil



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HIGHLIGHTS

- We compared fish community structure in a tropical bay over three decades.
- The fish assemblage structure differed significantly between the two bay zones.
- Decreases in the fish richness, abundance and biomass were detected over time.
- The highest decreases in the richness was recorded for the marine migrants species.
- This is the first study to examine long-term changes in the fish community in Brazil.

ARTICLE INFO

Article history:

Received 6 March 2015

Received in revised form

3 June 2015

Accepted 13 June 2015

Available online 16 June 2015

Keywords:

Estuarine fishes

Biodiversity

Habitat heterogeneity

Richness

Long-term change

Bay

ABSTRACT

Long-term evaluations of coastal fish communities worldwide have in many cases showed a decrease in the species richness and abundance as a result of anthropogenic impacts. Fish communities in two zones (inner and outer) of a tropical bay in southeastern Brazil were sampled monthly during six years over two decades (1983–1985, 1993–1995, 1999–2001) using identical sampling methods. Over time, an increase in temperature and a decrease in water transparency were detected, while salinity remained stable. Fish assemblage was dominated by benthivorous species both migrant and resident species. The fish assemblage structure differed significantly between the two bay zones. Significant decreases in the fish richness, abundance and biomass were detected over time. The highest decreases in the species richness was recorded between 1983–1985 and 1993–1995 for the marine migrants in both bay zones and for the resident and marine straggler species in the outer zone. Dominant species such as the clupeoids *Anchoa januaria*, *Anchoa tricolor*, *Harengula clupeiola*, the gerreid *Eucinostomos argenteus*, the sciaenid *Micropogonias furnieri*, the atherinopsid *Atherinella brasiliensis* and the ariid *Genidens barbatus* decreased over time, whereas the mugilid *Mugil liza* increased. Persistent differences in the fish assemblage structure between the two bay zones over the three periods can be attributed at least in part to differences in environmental variables between the zones and seem to be a key ecological element to maintenance of biodiversity. This is the first study to examine long-term changes in the fish community of a tropical bay in Brazil.

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1. Introduction

Changes in fish communities over time have been recorded in many coastal habitats and are often linked to abiotic variables (e.g. temperature, salinity) or anthropogenic impacts such as fishing (Jackson et al., 2001; Last et al., 2011), pollution and habitat degradation (Hewitt et al., 2008; Defeo et al., 2009; Ecoutin et al., 2010). Consequently, dramatic long-lasting changes in the relative abundance of species occur, enhancing a decline in fish

species richness and potential local extinctions. The intensification of anthropogenic activities have significantly changed community/species distribution patterns, leading to changes in the richness and composition of assemblages across various spatial scales (Vitousek et al., 1997; Sax and Gaines, 2003; Johnston and Roberts, 2009; Azevedo et al., 2013). Therefore, long-term studies on fish distribution and community structure are fundamental for detecting changes in the ichthyofauna and crucial for understanding the dynamics of coastal ecosystem functioning to help managers in natural resource conservation. Studies on long-term (inter-decadal) changes in fish populations have mainly been done for commercially valuable and exploited species, but such studies on fish communities are rare in tropical bays.

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Sepetiba Bay is a sedimentary embayment in the southeastern Brazilian coast that plays an important role in the ecology of nearby coastal fish populations (Araújo et al., 2002). This bay harbors mangroves, mud/sand flats and rocky shore habitats. In the last decades, increased anthropogenic activities have brought a great load of organic and industrial effluents into the bay through rivers and drainage channels in the outskirts of Rio de Janeiro City (Copeland et al., 2003), enhancing eutrophication and pollution problems (Molisani et al., 2006; Cunha et al., 2009). In addition, the bay has been subjected to overfishing, building construction and habitat degradation (Lacerda et al., 1987; Barcellos et al., 1991; Barcellos and Lacerda, 1994; Molisani et al., 2004; Cunha et al., 2006; Molisani et al., 2006). Recent enhancement of the Itaguá Port included dredging of the access channel to 20 m depth, which enables it to receive ships up to 150 000 t (Azevedo et al., 2007), the construction of a major steel company and the construction of a terminal for building submarines. All these recent changes have contributed to massive coastal habitat destruction and introduction of greater pollutant loads. It is, therefore, reasonable to suppose that such alterations are reflected in the change in the fish community structure in the last decades, resulting in decreased species richness and abundance.

Various abiotic factors have been associated with the structure of fish assemblages such as salinity, temperature, transparency, among others (Martino and Able, 2003; Aguirre-León et al., 2014). These variables are important drivers of fish distribution in estuarine areas. Changes in fish community linked to the changes in temperature and salinity have been reported for several estuarine systems (Martino and Able, 2003; Harrison and Whitfield, 2006; Last et al., 2011). In temperate estuaries, salinity has been reported as a major factor associated with fish richness because of physiological tolerance limits, whereas temperature affects fish densities associated with seasonal use of estuaries by abundant marine migrant species (Thiel et al., 1995; Whitfield and Elliott, 2002). Furthermore, there are complex suites of direct and indirect responses to coastal impacts including changes in water transparency, community composition, and changes in ecosystem functions (Cloern, 2001). For example, the level of suspended solids increases with the intensity of coastal development and the level of nutrient enrichment (Barcellos et al., 1997; Cunha et al., 2006). Increases in nutrients alter the ecosystems, reflected in high primary production capacity and reduced transparency (Costa et al., 2007; Defeo et al., 2009).

The aim of this study is to compare fish communities in two zones (inner and outer) of the Sepetiba Bay over two decades and to analyze the physico-chemical variables dynamics at spatial and temporal scales. We expect that (1) fish assemblage changes across the two decades (1983–1985, 1993–1995, 1999–2001) as consequence of increased pollution and habitat destruction, and that abiotic factors such as temperature, salinity, and transparency changes over the three-yearly period influenced fish communities; that (2) differences between the inner and the outer zone have decreased because of habitat homogenization; and that (3) in overall the fish richness, abundance and biomass decreased. The hypotheses are tested using a unique multi-annual dataset and a focus is made on ecological groups of fish and selected abundant species.

2. 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 formed by extensive sand deposition, which built a barrier beach as its southern boundary (Fig. 1) and has a surface area of approximately 450 km², a mean depth of 8.6

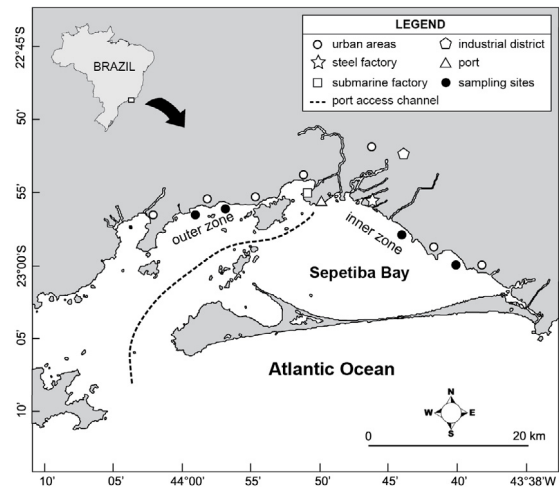


Fig. 1. Map of the study area, Sepetiba Bay, with indications of the sampling sites and the main human activities along the two bay zones (inner and outer).

m, a maximum depth of 30 m, and a drainage area of 2700 km². The bottom is predominantly muddy. Its shoreline is characterized by several small beaches and a few estuarine zones. This microtidal system has a tidal range of approximately 1 m. Predominant northeasterly and southwesterly winds activate thermal currents between the bay and the ocean. The annual rainfall varies between 1000 mm and 2100 mm (Barbieri and Kronemberger, 1994).

The bay has two different zones (Fig. 1) according to depth, salinity gradient and level of human influences (Azevedo et al., 2007). The inner zone is influenced by discharges from perennial small rivers characterized by a downstream–upstream gradient of increased turbidity and temperature and decreased salinity. In the inner zone, the salinity is on average 28 psu, the depth is mostly <5 m and the substratum is dominated by mud (Araújo et al., 2002; Leal Neto et al., 2006). The outer zone near the sea connection has contrasting environmental conditions with substratum mainly sandy, comparatively lower temperature and higher salinity and transparency, maximum depth is ca. 28 m, and salinity averages 33 psu (Pessanha and Araújo, 2003). Furthermore, the outer zone is bounded by several islands in the west part of the bay.

Urbanization and industrialization are recent trends in the region. Agriculture has been replaced by industrial development since the 1960s and expanding during the 1970s mainly chemical and metallurgical factories (Barcellos and Lacerda, 1994). The inner zone sediment has indications of more concentrations of heavy metal compared with the outer zone (Molisani et al., 2006). Sediment deposition rates varied from 5 (in the outer) to 50 mg cm⁻² day⁻¹ (inner zone) (Barcellos et al., 1997). On the other hand, the outer zone has undergone a higher increase in the population and expansion of the urban area compared with the inner zone (Molisani et al., 2004).

2.2. Survey design

Monthly samplings were performed between July and June in two sites of the two different bay zones (inner and outer) during three periods (1983–1985, 1993–1995 and 1999–2001) over two decades, with exception of July 1994 to June 1995 when samples were bimonthly. A total of 83 samples in 1983–1985, 59 samples in 1993–1995 and 105 samples in 1999–2001 were analyzed (Table 1).

Fish were collected by a beach seine net (12 m long × 2.5 m height; 13 mm mesh), with a pocket of 5 mm mesh size in its rear portion. Hauls were 30 m long, parallel to and closing to shore, and were taken out to approximately 1.5 m depth. The total sampled

Table 1
Sampling design carried out in two zones of the Sepetiba Bay during 1983–1985, 1993–1995, and 1999–2001.

Time period	1983–1985		1993–1995		1999–2001	
Bay zones	Inner	Outer	Inner	Outer	Inner	outer
Number of samples	41	42	33	26	47	58
Sampling frequency	Monthly		Monthly/Bi-monthly		Monthly	
Sampling period	July 83–June 85		July 93–June 95		July 99–June 01	

area was taken to be the distance the net was laid offshore (30 m) multiplied by the mean width of the haul (10 m), resulting in an effective fishing area of approximately 300 m². Water temperature, transparency and salinity were taken at each sampling occasion at approximately 0.5 m below surface water. Temperature and salinity were measured with a Horiba W-21 multiprobe (Horiba Trading Co. Ltd., Shanghai), and transparency was measured with a Secchi disk. Immediately after collection, fish were fixed in 10% formaldehyde-seawater solution. After 48 h, they were transferred to 70% ethanol. All fish were identified to species, counted, measured for total length (TL) in millimeters, and weighed in grams (g). Vouchers were deposited at the reference collection of the Laboratory of Fish Ecology of the Federal Rural University of Rio de Janeiro.

Each fish species was assigned to one of the ecological guilds, based on habitat use patterns (1) and trophic guilds (2), adapted from Franco et al. (2008): (1) residents; marine stragglers; marine migrants; and semi-anadromous species; (2) benthivores; hyperbenthivores, detritivores; planktivores; piscivores; and opportunists.

2.3. Statistical analysis

All data (fish abundance, biomass and environmental variables) were logarithmic transformed ($\log_{10}(x + 1)$) to meet assumptions of normality and homoscedasticity for parametric statistical tests and to reduce the bias of abundant species. The relative abundance was expressed as the number of fish per 100 m² of the sampled area. Two-way Analysis of Variance (ANOVA) was used to compare environmental variables, the number of species, number of fish and biomass and the number of species per ecological guild between the two zones and the three different periods. An *a posteriori* Tukey test was performed to identify significant differences. The expected number of species for each time period and zones were estimated using rarefaction of individuals abundance using the software EstimateS v. 7.5.2 (Gotelli and Colwell, 2001). The first and second order Jackknife estimators were used to calculate the number of species expected for years and zones.

The fish community structure expressed as the number of individuals per species was compared between zones and among the years by Analysis of Similarity ANOSIM (Clarke, 1993). Pairwise ANOSIM comparisons were made between zones and years, using 50,000 simulations in each case. Sample similarity matrices based on the Bray-Curtis similarity coefficient were generated. We also used a Similarity Percentage – SIMPER – analysis to determine species that most contributed to within-group average similarity of the zones and years. The SIMPER procedure was used to identify which species were principally responsible for differences between the three periods in each site (Clarke and Gorley, 2006), considering as typical species those that most contributed to within-group average similarity. All these procedures were included in the software PRIMER 6.0 (Clarke, 1993; Clarke and Gorley, 2006).

Selected dominant species that contribute more than 1.5% of the total number of fish and had frequency of occurrence >20% in each zone/period were compared between years and zones. A non-parametric Kruskal–Wallis test was used because data did not attain the assumptions of normality and homogeneity of variance. When significant differences were detected, Mann–Whitney tests

were applied in order to identify which groups significantly differed.

Canonical Correspondence Analysis (CCA) was performed to assess environmental influences on the selected dominant species by using CANOCO version 4.5 (ter Braak and Šmilauer, 2002) on fourth-root transformed data. Statistical significance was assessed by a Monte Carlo permutation test, using 1,000 sample permutations ($P < 0.01$). Only the selected dominant species were considered in this analysis in order to remove the influence of rare species. Such removal of rare species may prevent the strong dependence of ordination procedures on single outlier species (McCune and Mefford, 1999).

3. Results

3.1. Environmental variables

Water temperature ranged from 19 to 34.8 °C. The inner zone had significantly higher temperatures ($P < 0.001$) compared to the outer zone (Table 2). Significant differences ($P < 0.001$) were also detected among years, with the highest values being recorded in 1999–2001 compared with the lowest values in 1993–1995 and 1983–1985.

Water transparency ranged from 0.1 to 1.0 m. The outer zone had higher transparency compared to the inner zone (Table 2). Significant differences were also detected among the three periods ($P < 0.001$), with the highest values being recorded in 1983–1985 and 1993–1995 and the lowest values in 1999–2001.

Salinity ranged from 16 to 36. The outer zone had higher salinity compared to the inner zone (Table 2). Significant differences were also detected for salinity among the three periods ($P < 0.001$), with significantly higher values being recorded in 1983–1985 and 1999–2001 and lower values in 1993–1995.

3.2. Fish abundance and richness

We collected 103 species of fishes (42 families) from the Sepetiba Bay (Table 3). A total of 128 samples were performed in the outer zone collecting 16,887 individuals, whereas in the 134 samples in the inner zone 13,864 individuals were recorded (Table 3). In the outer zone, species richness was higher in 1983–1985 (73 species) compared with 1993–1995 (31 species) and 1999–2001 (32 species). In the inner zone, species richness was higher in 1983–1985 (46 species), decreased in 1993–1995 (30 species), and had the lowest values in 1999–2001 (26 species).

The number of species, individuals and total biomass decreased significantly (ANOVA, $P < 0.01$) over time with higher means values for 1983–1985 compared with 1993–1995 and 1999–2001 (Fig. 2; Table 4). On the other hand, no significant difference for the number of species (ANOVA, $P > 0.05$), individuals (ANOVA, $P > 0.05$) and biomass (ANOVA, $P > 0.05$) were found between the inner and the outer bay zones (Fig. 2, Table 4).

The first and second order Jackknife estimator for species richness for the 1983–1985 period was 69 and 76 species for the inner zone, and 95 and 107 for the outer zone. These estimators decreased in 1993–1995 for 47 and 49 species for the inner zone and for 52 and 62 species for the outer zone, respectively. A stabilization of these numbers was recorded for 1999–2001, when the first and second order Jackknife estimator of species richness were 45 and 51 for the inner, and 54 and 66 species for the outer zone, respectively.

Table 2
F-values and significance levels for two-way ANOVA of environmental variables, testing for differences between zones (inner and outer) and years (1983–1985; 1993–1995 and 1999–2001). Post-hoc Tukey's HSD test results are given when significant differences were detected for main effects.

Environmental variables	F-value: Zone	Post-hoc Zones	F-value: Years	Post-hoc Years	Interaction Zone × Years
Temperature (°C)	38.7**	Inner > Outer 27.8 ± 0.3 25.1 ± 0.2	9.8**	99-01 > 83-85; 93-95 27.4 ± 0.3 25.7 ± 0.3 25.5 ± 0.4	n.s
Transparency (m)	170.6**	Outer > Inner 0.67 ± 0.02 0.25 ± 0.01	15.6**	83-85; 93-95 > 99-01 0.5 ± 0.03 0.56 ± 0.04 0.38 ± 0.02	n.s
Salinity	21.8**	Outer > Inner 29 ± 0.3 26.9 ± 0.3	8.0**	83-85; 99-01 > 93-95 27.7 ± 0.5 28.9 ± 0.2 26.5 ± 0.5	n.s

n.s., not significant. Average values ± SE also indicated.

** $P < 0.01$.

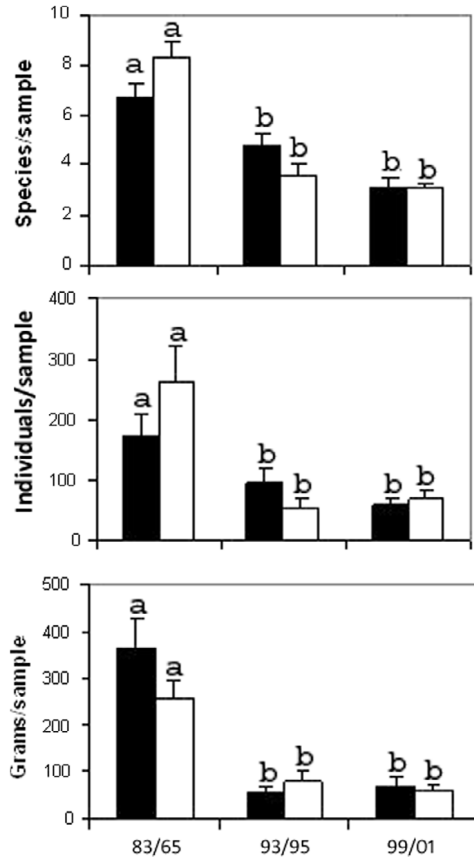


Fig. 2. Means + 1 standard error (whiskers) of the number of fish species, individuals and biomass per sample in the inner (black bars) and the outer (white bars) zones of the Sepetiba Bay, during the three time periods (1983–1985, 1993–1995 and 1999–2001). Letters indicate significant difference levels from ANOVA at $P < 0.05$.

3.3. Fish community structure

Significant differences in fish community structure were detected between the two zones and among the three time periods according to ANOSIM. The community structure in the inner zone differed significantly from the outer zone in all the studied periods, with the highest difference in 1983–1985 (R Global = 0.412; $P < 0.01$) followed by 1993–1995 (R Global = 0.226; $P < 0.01$) and 1999–2001 (R Global = 0.284; $P < 0.01$). The three time periods differed significantly from each other in both the inner (R Global = 0.130, $P < 0.01$) and the outer (R Global = 0.126, $P < 0.01$) zones. The within-group average similarity for each bay zone in each bi-annual period was relatively low (<31%), as the species changed their occurrence in each area over the years (Table 5). Dissimilarity was high among the years and zones always averaging above 75%.

Atherinopsidae, Engraulidae, Sciaenidae, Gerreidae and Mugilidae were the dominant families in the total number of individuals

over the three periods. Average similarity in the inner zone in 1983–1985 (31%) had the highest relative contribution of *Atherinella brasiliensis*, *Anchoa januaria* and *Micropogonias furnieri*. In the outer zone (average similarity = 27%) the species that most contributed to within average similarity were *Anchoa tricolor*, *A. brasiliensis* and *Eucinostomus argenteus* (Table 5).

In 1993–1995, average similarity recorded in the inner zone was 26% with the highest relative contribution of *A. januaria*, *Mugil liza* and *E. argenteus*, while the outer zone (average similarity = 19%) the greatest relative contribution was recorded for *A. brasiliensis*, *A. tricolor* and *E. argenteus*.

In 1999–2001, the inner zone had average similarity of 26% with the highest contribution of *A. brasiliensis*, *M. liza* and *M. furnieri*, whereas the outer zone (average similarity = 26%) had the highest contribution of *A. brasiliensis*, *A. tricolor* and *Trachinotus carolinus* (Linnaeus, 1766).

3.4. Ecological groups

In terms of habitat use, the Sepetiba Bay fish assemblages were dominated by marine migrant and resident species, followed by marine stragglers and a few semi-anadromous species. There was an overall decrease in richness of all groups between 1993–1985 and 1993–1995, stabilizing in 1999–2001. The most conspicuous decrease in richness over time was recorded for the marine migrant in both zones (ANOVA, inner zone, $F_{2,109} = 24.3$, $P < 0.00001$; outer zone, $F_{2,107} = 20.2$, $P < 0.00001$) and for the resident species in the outer zone (ANOVA, $F_{2,107} = 22.2$; $P < 0.00001$) (Fig. 3).

The benthivorous, followed by the hyperbenthivorous, detritivorous and planktivorous species dominated the assemblages. The benthivorous species had the highest decreases in richness in the outer zone (ANOVA, $F_{2,109} = 4.2$; $P = 0.017$) between 1983–1985 and 1993–1995, reaching the lowest richness in 1999–2001 (Fig. 4). The hyperbenthivorous, detritivorous and planktivorous species had a comparative slower decrease over the studied period.

3.5. Dominant species abundance

A decrease in the relative abundance over the studied periods was detected for the following dominant species: *A. januaria*, *E. argenteus*, *M. furnieri*, *A. tricolor*, *A. brasiliensis*, *Harengula clupeiola* and *Genidens barbatus* (Table 6, Fig. 5). In contrast, abundance of *M. liza* increased from 1983–1985 to 1999–2001 whereas no significant differences along the studied periods were detected for *Oligoplites saurus* and *T. carolinus*. The inner zone had comparatively higher abundance of *A. januaria*, *M. furnieri* and *M. liza* compared with the outer zone, whereas the outer zone had the highest abundance of *A. tricolor* and *T. carolinus*.

Table 3

Total number of individuals and percentage (in brackets), trophic and use guilds, in the inner and outer zones, during the yearly periods in Sepetiba Bay.

Species	Guilds ^a		Outer			Inner		
	U	T	83/85 (%)	93/96 (%)	99/01 (%)	83/85 (%)	93/96 (%)	99/01 (%)
<i>Anchoa januaria</i> (Steindachner, 1879)	SA	PL	723 (6.5)	249 (15.5)		3254 (45.2)	930 (27.9)	517 (15.6)
<i>Eucinostomus argenteus</i> Baird e Girard, 1855	R	BE	2,645 (23.8)	598 (37.2)	131 (3.0)	191 (2.7)	140 (4.2)	183 (5.5)
<i>Micropogonias furnieri</i> (Desmarest, 1823)	MM	BE	1,605 (14.5)		1 (<0.1)	1049 (14.6)	553 (16.6)	385 (11.6)
<i>Anchoa tricolor</i> (Spix e Agassiz, 1829)	MM	PL	3,538 (31.9)	138 (8.6)	1975 (45.7)	86 (1.2)	1 (<0.1)	145 (4.4)
<i>Harengula clupeiola</i> (Cuvier, 1829)	MS	PL	539 (4.9)		41 (0.9)	10 (0.1)		124 (3.8)
<i>Atherinella brasiliensis</i> (Quoy e Gaimard, 1825)	R	OP	524 (4.7)	137 (8.5)	418 (9.7)	772 (10.7)	192 (5.8)	201 (6.1)
<i>Genidens barbatus</i> (Lacepède, 1803)	SA	OP				336 (4.7)		
<i>Mugil liza</i> (Valenciennes, 1836)	MM	DE	103 (0.9)	65 (4.0)	477 (11.0)	57 (0.8)	842 (25.2)	1317 (39.8)
<i>Eucinostomus melanopterus</i> (Bleeker, 1863)	R	BE	197 (1.8)	26 (1.6)	28 (0.6)	3 (<0.1)		2 (0.1)
<i>Mugil curema</i> Valenciennes, 1836	MM	DE	173 (1.6)		2 (<0.1)	46 (0.6)	8 (0.2)	
<i>Sphoeroides testudineus</i> (Linnaeus, 1758)	R	BE	98 (0.9)	31 (1.9)	1 (<0.1)	29 (0.4)	14 (0.4)	3 (0.1)
<i>Oligoplites saurus</i> (Bloch & Schneider, 1801)	MM	PI	91 (0.8)	2 (0.1)	108 (2.5)	188 (2.6)	83 (2.5)	13 (0.4)
<i>Bairdiella ronchus</i> (Cuvier, 1830)	MS	HY	89 (0.8)			9 (0.1)	1 (<0.1)	
<i>Citharichthys spilopterus</i> Gunther, 1862	MM	HY	80 (0.7)	34 (2.1)	43 (1.0)	8 (0.1)		
<i>Diapterus rhombeus</i> (Cuvier, 1829)	R	BE	56 (0.5)	20 (1.2)	2 (<0.1)	6 (0.1)	22 (0.7)	64 (1.9)
<i>Platanichthys platana</i> (Regan, 1917)	R	PL	52 (0.5)			2 (<0.1)	64 (1.9)	
<i>Anchoa marinii</i> Hildebrand, 1943	MS	PL	50 (0.5)			1 (<0.1)		
<i>Anchoviella brevirostris</i> (Günther, 1868)	R	PL	45 (0.4)	3 (0.2)				
<i>Trachinotus carolinus</i> (Linnaeus, 1766)	MS	HY	44 (0.4)	15 (0.9)	379 (8.8)	16 (0.2)	23 (0.7)	8 (0.2)
<i>Trachinotus falcatus</i> (Linnaeus, 1758)	MS	HY	44 (0.4)	5 (0.3)	77 (1.8)	21 (0.3)	2 (0.1)	2 (0.1)
<i>Umbrina coroides</i> Cuvier, 1830	MM	BE	38 (0.3)					
<i>Sphoeroides greeleyi</i> (Gilbert, 1900)	MM	BE	37 (0.3)	52 (3.2)	2 (<0.1)	3 (<0.1)		1 (<0.1)
<i>Mugil platanus</i> (Günther, 1880)	MM	DE	18 (0.2)			21 (0.3)	13 (0.4)	
<i>Eucinostomus gula</i> (Baird e Girard, 1824)	MS	BE	17 (0.2)	4 (0.2)	1 (<0.1)	1 (<0.1)	2 (0.1)	
<i>Symphurus plagusia</i> (Bloch & Schneider, 1801)	MM	HY	17 (0.2)	7 (0.4)		2 (<0.1)		
<i>Synodus foetens</i> (Linnaeus, 1766)	MS	PI	17 (0.2)	2 (0.1)	5 (0.1)	1 (<0.1)		
<i>Citharichthys cornutus</i> (Günther, 1880)	MS	HY	15 (0.1)					
<i>Diplectrum radiale</i> (Quoy & Gaimard, 1824)	MS	PI	15 (0.1)	1 (0.1)		2 (<0.1)		
<i>Menticirrhus americanus</i> (Linnaeus, 1758)	MM	BE	14 (0.1)	1 (0.1)	8 (0.2)	92 (1.3)	95 (2.8)	37 (1.1)
<i>Achirus declivis</i> Chabanaud, 1940	R	BE	10 (0.1)				3 (0.1)	
<i>Mugil gaimardianus</i> Desmarest, 1831	MM	DE	10 (0.1)			283 (3.9)		
<i>Oligoplites palometa</i> (Cuvier, 1832)	MM	PI	10 (0.1)		7 (0.2)	28 (0.4)	7 (0.2)	2 (0.1)
<i>Ctenogobius shufeldti</i> (Jordan & Eigenmann, 1887)	R	BE	9 (0.1)					
<i>Prionotus punctatus</i> (Bloch, 1793)	MS	HY	9 (0.1)	3 (0.2)				
<i>Citharichthys arenaceus</i> Evermann & Marsh, 1900	MM	HY	8 (0.1)		13 (0.3)			
<i>Ulaema lefroyi</i> (Goode, 1874)	MS	BE	8 (0.1)	147 (9.1)			6 (0.2)	
<i>Bathygobius soporator</i> (Valenciennes, 1837)	R	BE	7 (0.1)			19 (0.3)		
<i>Menticirrhus littoralis</i> (Holbrook, 1847)	MS	BE	7 (0.1)	3 (0.2)	21 (0.5)	7 (0.1)		
<i>Cetengraulis edentulus</i> (Cuvier, 1829)	MM	PL	6 (0.1)			137 (1.9)		1 (<0.1)
<i>Chaetodipterus faber</i> (Broussonet, 1782)	MS	BE	6 (0.1)					
<i>Gobionellus oceanicus</i> (Pallas, 1770)	R	BE	6 (0.1)	1 (0.1)		3 (<0.1)	3 (0.1)	
<i>Strongylura timucu</i> (Walbaum, 1792)	MM	PI	6 (0.1)		2 (<0.1)	2 (<0.1)	1 (<0.1)	
<i>Ctenogobius boleosoma</i> (Jordan & Gilbert, 1882)	R	BE	5 (<0.1)					2 (0.1)
<i>Haemulon steindachneri</i> (Jordan & Gilbert, 1882)	MS	BE	5 (<0.1)					
<i>Selene vomer</i> (Linnaeus, 1758)	MS	HY	5 (<0.1)		1 (<0.1)	3 (<0.1)	1 (<0.1)	
<i>Anchoa lyolepis</i> (Evermann e Marsh, 1900)	MS	PL	4 (<0.1)	1 (0.1)	402 (9.3)			
<i>Evorthodus lyricus</i> (Girard, 1858)	R	BE	4 (<0.1)					
<i>Balistes capriscus</i> Gmelin, 1789	MS	BE	3 (<0.1)					
<i>Centropomus parallelus</i> Poey, 1860	MM	PI	3 (<0.1)					
<i>Dactyloscopus crossotus</i> Starks, 1913	R	HY	3 (<0.1)		1 (<0.1)			
<i>Etropus longimanus</i> Norman, 1933	MM	HY	3 (<0.1)		1 (<0.1)			
<i>Lycengraulis grossidens</i> (Spix & Agassiz, 1829)	MM	PL	3 (<0.1)			10 (0.1)		
<i>Microgobius meeki</i> Evermann e Marsh, 1899	R	HY	3 (<0.1)			1 (<0.1)		
<i>Fistularia petimba</i> Lacepède, 1803	R	PL	2 (<0.1)	3 (0.2)				
<i>Gobionellus stomatus</i> Starks, 1913	R	BE	2 (<0.1)					
<i>Gymnothorax ocellatus</i> Agassiz, 1831	MS	PI	2 (<0.1)	2 (0.1)				
<i>Hyporhamphus unifasciatus</i> (Ranzani, 1841)	MS	HE	2 (<0.1)	2 (0.1)	11 (0.3)	2 (<0.1)	2 (0.1)	
<i>Trachinotus goodei</i> Jordan & Evermann, 1896	MS	HY	2 (<0.1)			2 (<0.1)		
<i>Caranx latus</i> Agassiz, 1831	MS	PI	1 (<0.1)	2 (0.1)	5 (0.1)	2 (<0.1)		
<i>Elops saurus</i> Linnaeus, 1766	MM	PI	1 (<0.1)		48 (1.1)		2 (0.1)	3 (0.1)
<i>Etropus crossotus</i> (Jordan & Gilbert, 1882)	MM	HY	1 (<0.1)	1 (0.1)				
<i>Gobiesox strumosus</i> Cope, 1870	R	HY	1 (<0.1)					
<i>Hemiramphus brasiliensis</i> (Linnaeus, 1758)	MS	HE	1 (<0.1)	2 (0.1)	1 (<0.1)			
<i>Oligoplites saliens</i> (Bloch, 1793)	MM	PI	1 (<0.1)		1 (<0.1)			1 (<0.1)
<i>Oligosarcus hepsetus</i> (Cuvier, 1829)	FR	PI	1 (<0.1)					
<i>Ophioscion punctatissimus</i> Meek & Hildebrand, 1925	MS	BE	1 (<0.1)			40 (0.6)		
<i>Orthopristis ruber</i> (Cuvier, 1830)	MS	BE	1 (<0.1)		7 (0.2)		1 (<0.1)	
<i>Poecilia vivipara</i> Bloch e Schneider, 1801	FR	OP	1 (<0.1)			5 (0.1)		
<i>Polydactylus oligodon</i> (Günther, 1860)	MS	HY	1 (<0.1)					
<i>Polydactylus virginicus</i> (Linnaeus, 1758)	MS	HY	1 (<0.1)	1 (0.1)	8 (0.2)			
<i>Pomadasys corvinaeformis</i> (Steindachner, 1868)	MM	HY	1 (<0.1)					
<i>Symphurus diomedeanus</i> (Goode & Bean, 1885)	MS	HY	1 (<0.1)					
<i>Serranus phoebe</i> Poey, 1851	MS	PI	1 (<0.1)					

(continued on next page)

Table 3 (continued)

Species	Guilds ^a		Outer			Inner		
	U	T	83/85 (%)	93/96 (%)	99/01 (%)	83/85 (%)	93/96 (%)	99/01 (%)
<i>Trinectes micropthalmus</i> (Chabanaud, 1928)	R	BE	1 (<0.1)			1 (<0.1)		
<i>Achirus lineatus</i> (Linnaeus, 1758)	R	BE		7 (0.4)	1 (<0.1)		180 (5.4)	2 (0.1)
<i>Brevoortia aurea</i> (Spix e Agassiz, 1829)	MS	PL						1 (<0.1)
<i>Cathorops spixii</i> (Agassiz, 1829)	SA	OP				212 (2.9)		2 (0.1)
<i>Chloroscombrus chrysurus</i> (Linnaeus, 1766)	MS	PL			3 (0.1)		1 (<0.1)	6 (0.2)
<i>Conodon nobilis</i> (Linnaeus, 1758)	MS	HE				7 (0.1)		
<i>Chilomycterus spinosus spinosus</i> (Linnaeus, 1758)	MS	BE					4 (0.1)	
<i>Cynoscion acoupa</i> (Lacepède, 1801)	MS	HY					1 (<0.1)	
<i>Cynoscion jamaicensis</i> (Vaillant & Bocourt, 1883)	MS	HY					89 (2.7)	
<i>Cynoscion leiarchus</i> (Cuvier, 1830)	MS	HY				28 (0.4)	35 (1.0)	27 (0.8)
<i>Cynoscion microlepidotus</i> (Cuvier, 1830)	MS	HY						2 (0.1)
<i>Eugerres brasiliensis</i> (Cuvier, 1830)	MS	BE						14 (0.4)
<i>Genidens genidens</i> (Cuvier, 1829)	SA	OP				169 (2.3)	2 (0.1)	50 (1.5)
<i>Jenynsia lineata</i> (Jenyns, 1842)	FR	OP						1 (<0.1)
<i>Lagocephalus laevigatus</i> (Linnaeus, 1766)	MS	BE				1 (<0.1)		
<i>Mugil curvidens</i> Valenciennes, 1836	MM	DE				4 (0.1)		
<i>Monacanthus ciliatus</i> (Mitchill, 1818)	MS	BE		10 (0.6)	4 (0.1)		2 (0.1)	
<i>Odontoscion dentex</i> (Cuvier, 1830)	MS	HY				1 (<0.1)		
<i>Paralichthys brasiliensis</i> (Ranzani, 1842)	MS	HY			2 (<0.1)			
<i>Paralonchurus brasiliensis</i> (Steindachner, 1875)	MS	BE						16 (0.5)
<i>Pseudophallus mindii</i> (Meek & Hildebrand, 1923)	MS	PL		1 (0.1)				
<i>Selar crumenophthalmus</i> (Bloch, 1793)	MS	HY			17 (0.4)			
<i>Aspistor luniscutis</i> (Valenciennes, 1840)	SA	OP				6 (0.1)	10 (0.3)	
<i>Sardinella brasiliensis</i> (Steindachner, 1879)	MS	PL						136 (4.1)
<i>Stellifer rastrifer</i> (Jordan, 1889)	MM	BE				12 (0.2)		
<i>Stellifer stellifer</i> (Bloch, 1790)	MM	BE				3 (<0.1)		37 (1.1)
<i>Syngnathus elucens</i> Poey, 1868	MS	PL		1 (0.1)		1 (<0.1)		
<i>Syngnathus folletti</i> Herald, 1942	MS	PL		2 (0.1)		7 (0.1)		
<i>Tilapia rendalli</i> (Boulenger, 1897)	FR	OP						1 (<0.1)
<i>Uraspis secunda</i> (Poey, 1860)	MS	BE					1 (<0.1)	
Number of individuals			11,053	1579	4255	7202	3336	3306
Number of species			73	36	38	54	36	33
Number of samples			42	30	56	42	35	57

^a **Habitat use guilds (U):** ER, resident species; MM, Marine migrants; MS, Marine stragglers; SAN, semianadromous species; FR, freshwater species. **Trophic guilds (T):** HE, Herbivorous; PI, Piscivorous; BE, Benthophagous; HY, Hyperbenthophagous; PL, Planktivorous; DE, Detritivorous; OP, Opportunistic.

Table 4

F-values and significance levels for two-way ANOVA of the number of fish and species, and biomass, testing for differences between zones (Z) and years (Y). Post-hoc Tukey's HSD test results are given when significant differences were detected for main effects.

Parameter	Zone (Z)	Year (Y)	Interaction Z × Y	Post-hoc Years Means ± s.e.
Number of species	n.s.	42.9**	n.s.	83–86 > 93–96; 99–01 2.5 ± 0.1 1.4 ± 0.1 1.0 ± 0.06
Number of individuals	n.s.	15.8**	n.s.	83–86 > 93–96; 99–01 72.4 ± 11 25.2 ± 4.8 21 ± 3.0
Biomass	n.s.	55.5**	n.s.	83–86 > 93–96; 99–01 103.7 ± 12 22.5 ± 4 21.2 ± 4.0

n.s., not significant. Average values ± SE also indicated.

** P < 0.01.

Table 5

Species contribution (%) to the within-group average similarity (years and zone) according to SIMPER analysis.

Species	1983–85		1993–95		1999–01	
	Inner (31.0)	Outer (27.4)	Inner (25.8)	Outer (18.6)	Inner (25.7)	Outer (26.0)
<i>Anchoa januaria</i>	22.4	–	21.4	–	–	–
<i>Anchoa tricolor</i>	–	26.7	–	20.1	–	35.5
<i>Atherinella brasiliensis</i>	26.4	2.0	–	31.6	26.3	24.8
<i>Mugil liza</i>	–	–	19.0	–	22.1	–
<i>Micropogonias furnieri</i>	21.2	–	–	–	22.1	–
<i>Eucinostomus argenteus</i>	–	18.8	13.5	13.6	–	–
<i>Trachinotus carolinus</i>	–	–	–	–	–	22.4

3.6. Environmental variables and fish assemblage structure

In the outer zone (zone 1), the first two axes from CCA explained 85.2% of the total variance of the species–environment correlation (Fig. 6(a)). The first axis revealed that salinity was the most important variable explaining separation of typically marine species (e.g., *E. melanopeterus*, *A. tricolor*, *P. platana* and *S. foetens*) from species

widely distributed in the area (e.g., *M. curema*, *M. furnieri* and *A. lyolepis*). The second axis showed a separation along three studied periods with species associated with high transparencies in the 1983–1985 and 1993–1995 (e.g., *M. gaimardianus*, *C. spilopterus* and *D. radiale*) in opposition to species associated to high temperature in the 1999–2001 period (e.g., *O. saurus*, *O. palombeta* and *M. liza*).

Table 6

Chi-Square values and significance levels according to Kruskal–Wallis test for comparisons of the ranks of the 10 most abundant fish species between the two zones and the three time periods. Mann–Whitney test results are given when significant differences were detected.

Species	Chi-Square Zones	Mann–Whitney	Chi-Square Years	Mann–Whitney
<i>Anchoa januaria</i>	32.6**	inner zone > outer zone 11.6 ± 3.2	38.1**	83–86; 93–96 > 99–01 15.7 ± 4.7
<i>Anchoa tricolor</i>	51.6**	outer zone > inner zone 14 ± 3.5	15.0**	83–86; 99–01 > 93–96 14.3 ± 5.1
<i>Atherinella brasiliensis</i>	n.s.		19.3**	83–86 > 93–96; 99–01 5.1 ± 1.2
<i>Mugil liza</i>	14.5**	inner zone > outer zone 7.2 ± 2.5	14.9**	93–96; 99–01 > 83–86 4.6 ± 2.2
<i>Micropogonias furnieri</i>	80.9**	inner zone > outer zone 7.9 ± 0.7	4.3**	83–86; 93–96 > 99–01 10.5 ± 6.5
<i>Eucinostomus argenteus</i>	n.s.	2.2 ± 0.7	14.0**	83–86; 93–96 > 99–01 11.3 ± 4.1
<i>Trachinotus carolinus</i>	17.0**	outer zone > inner zone 1.1 ± 0.3	n.s.	
<i>Harengula clupeola</i>	n.s.		5.7*	83–86; 93–96 > 99–01 2.1 ± 1.2
<i>Genidens barbatus</i>	n.s.		5.9*	83–86; 93–96 > 99–01 1.3 ± 1
<i>Oligoplites saurus</i>	n.s.		n.s.	0.1 ± 0.1

ns, not significant. Average values ± SE also indicated.

* $P < 0.05$.

** $P < 0.01$. *** $P < 0.001$.

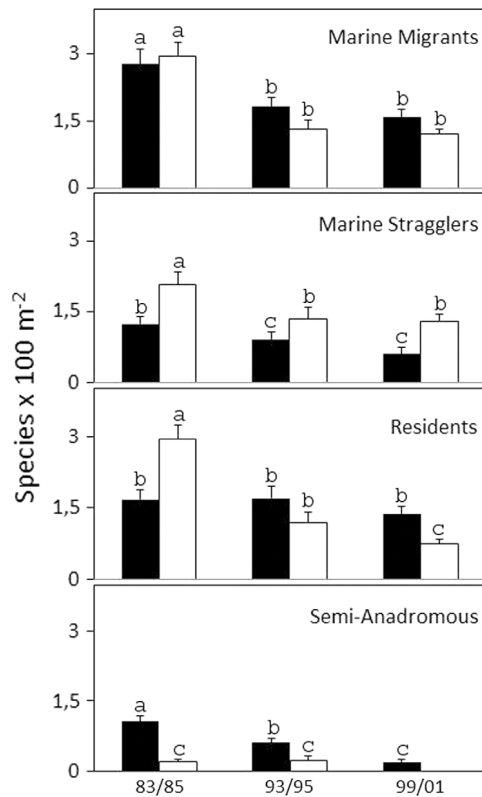


Fig. 3. Means +1 standard error (whiskers) of fish species richness according to habitat use patterns for the inner (black bars) and the outer (white bars) zone of the Sepetiba Bay, during the three time periods (1983–1985, 1993–1995 and 1999–2001). Letters indicate significant difference levels from ANOVA at $P < 0.05$.

In the inner zone (zone 2), the first two axes explained 86.9% of the total variance of the species–environment correlation (Fig. 6(b)), with transparency being the most important variable directly associated to high abundances of *A. januaria*, *S. testudineus* and *S. foetens* during the first two examined periods, whereas temperature was directly related to high abundances of *H. clupeola*, *O. palombeta* and *M. gaimardianus* of the third studied period (1999–2001).

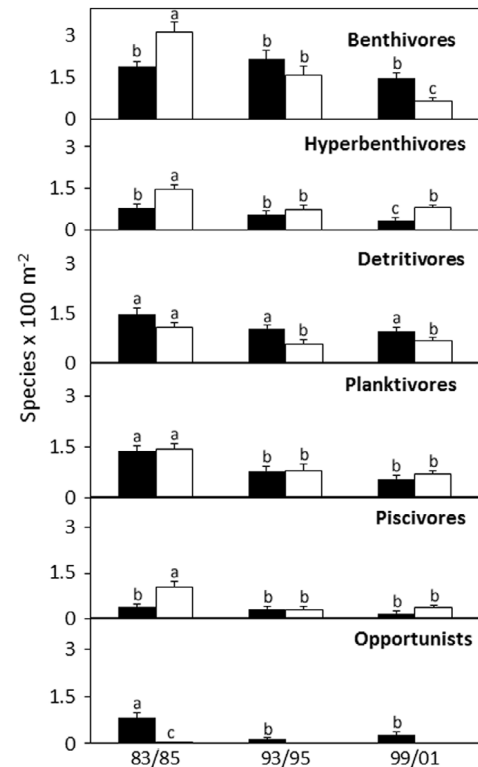


Fig. 4. Means +1 standard error (whiskers) of fish species richness according to trophic guilds for the inner (black bars) and the outer (white bars) zones of the Sepetiba Bay, during the three time periods (1983–1985, 1993–1995 and 1999–2001). Letters indicate significant difference levels from ANOVA at $P < 0.05$.

4. Discussion

This study, to the best of our knowledge, represents the first attempt to describe long-term changes in the fish assemblages of a marine coastal ecosystem in Brazilian waters. We found significant decreases in the fish abundance and richness over time. Moreover, the fish assemblage structure differed between the inner and the outer bay zones for the three examined periods spanning two decades. The greatest difference in assemblage structure between

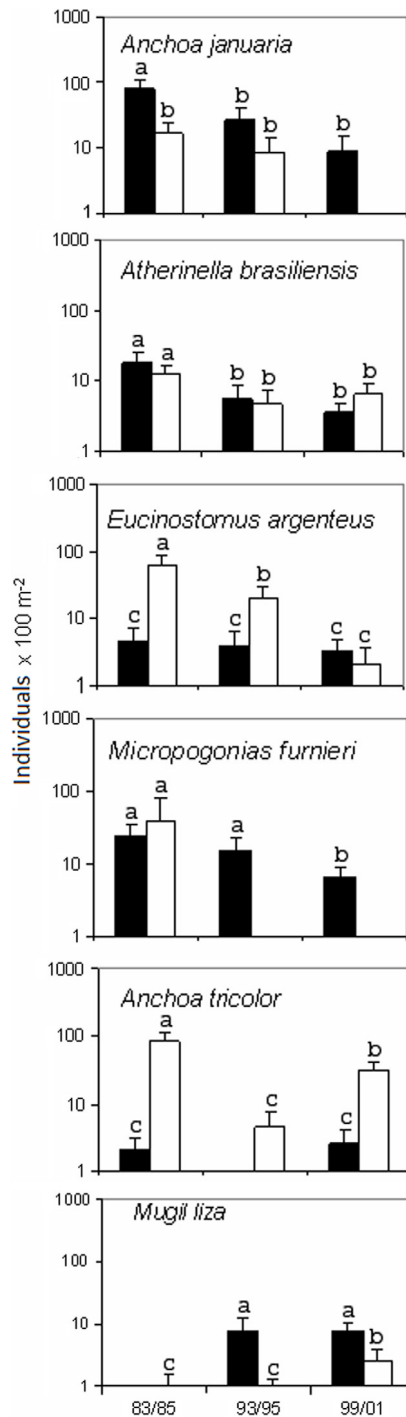


Fig. 5. Means + 1 standard error (whiskers) of the number of selected abundant fish species in the inner (black bars) and the outer (white bars) zones of the Sepetiba Bay, during the three time periods (1983–1985, 1993–1995 and 1999–2001). Letters indicate significant difference levels according to Kruskal–Wallis test for comparisons of the ranks at $P < 0.05$.

the inner and the outer zone was recorded for the 1983–1985 period. In 1993–1995 and 1999–2001, differences in community structure between the two bay zones were comparatively lower, which suggest a trend for homogenization of the fish assemblage over time.

Biotic homogenization is a process of increasing similarity between biotas (McKinney and Lockwood, 1999). Susceptibility of homogenized communities to environmental alteration might be particularly high in areas, such as urban ecosystems that

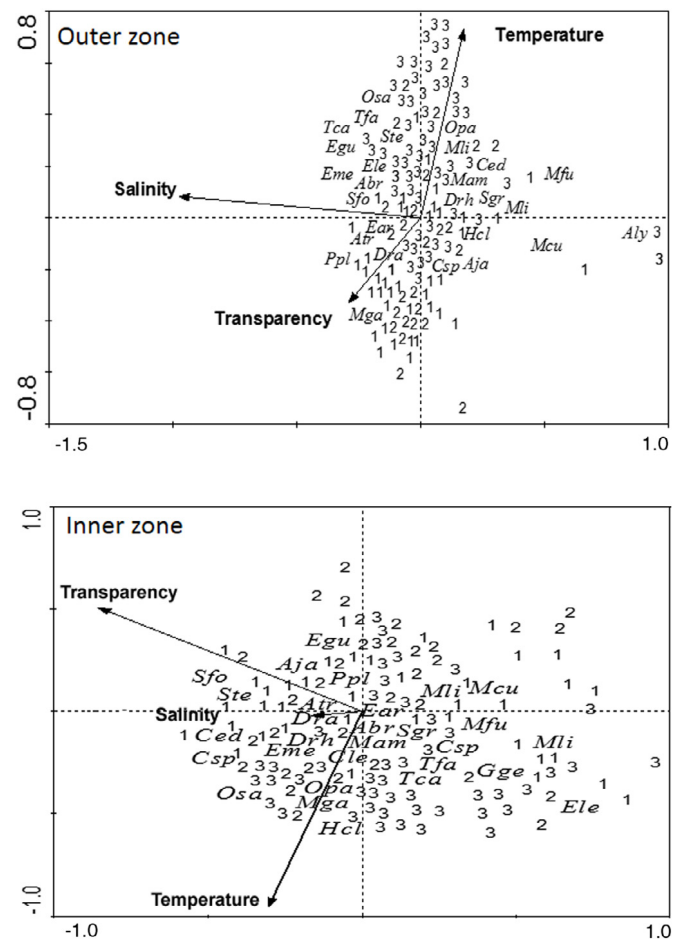


Fig. 6. Triplot of canonical correspondence analyses of the selected dominant fish species with abiotic variables and time periods. Codes for years: 1, 1983–1985; 2, 1993–1995 and 3, 1999–2001. Species codes: Aja, Anchoa januaria; Atr, Anchoa tricolor; Aly, Anchoa lyolepis; Abr, Atherinella brasiliensis; Ced, Cetengraulis edentulus; Csp, Citharichthys spilopterus; Cle, Cynoscion leiarchus, Dra, Diplectrum radiale; Drh, Diapterus rhombeus; Ear, Eucinostomus argenteus; Eme, Eucinostomus melanopterus; Egu, Eucinostomus gula; Gge, Genidens genidens; Hcl, Harengula clupeola; Mam, Menthirrhhus americanus; Mli, Menthirrhhus littoralis; Mfu, Micropogonias furnieri; Mcu, Mugil curema; Mga, Mugil gaimardianus; Mli, Mugil liza; Osa, Oligoplites saurus; Sgr, Sphaeroides greeley; Sfo, Synodus foetens; Tca, Trachinotus carolinus; Tfa, Trachinotus falcatus; Opa, Oligoplites palombeta; Ste, Sphaeroides testudineus; Csp, Cathorps spixii; Ele, Eulema lefroy; Ppl, Platanichthys platana.

experience more frequent and severe disturbance events and this may be the case of the Sepetiba Bay. A decrease in species richness probably corresponds to changes in functional diversity and might reduce overall community and ecosystem functioning, stability and resistance to environmental changes by simply narrowing the available range of species responses (Olden and Poff, 2003; Cassey et al., 2008; Baiser and Lockwood, 2011). However, functionally redundant species can dampen loss of functional diversity under loss of species richness (Mayfield et al., 2010). Our findings reveal trends of biodiversity losses observed at local scale mainly between 1983–1985 and 1993–1995. Such concerns should be addressed by environmental managers because progressive biodiversity loss sabotages the stability of marine environments and their ability to recover from stresses (UNEP, 2006; Worm et al., 2006).

The first and second order Jackknife estimator for species richness also detected a remarkable loss of species over time. From 1983–1985 to 1999–2001 there was a great decrease in the species richness, which suggests that more than 20 species were lost in the inner zone and much more (41–45) species were lost in the outer zone. Decreases in species richness, especially

was due to the disappearance of the marine migrant species in both zones, and for the resident species in the outer zone that have benthivorous feeding habits. These guilds had the largest species richness and their decreases probably reflect decreases in the habitat availability and in their main food resources (benthic organisms) due to overall habitat degradation though this was not directly tested here. It is widely known that pollution and habitat degradation in estuaries have a significant impact on different fish species, which is reflected as changes in the community structure (reduced species diversity) and function (reduced abundance of marine migrants and disturbance of sensitive species) (e.g. Power and Attrill, 2003; Harrison and Whitfield, 2004; Rochette et al., 2010). Trends of decreasing fish richness were reported in previous studies in the area (Araújo et al., 1997; Pessanha et al., 2000). Such temporal changes in fish community of this area although not addressed in a common integrative analysis, suggest an evident decrease in species richness. Pessanha et al. (2000) recorded 80 fish species in 1983–1984 in the Sepetiba Bay as result of monthly collection over one year, but Araújo et al. (1997) recorded only 55 species a decade later (1993–1994) in the same area using identical sampling methods.

Two of the most important estuarine fish assemblage components are the resident species and the marine migrant species (Franco et al., 2008). While the former complete all the life cycle within the bay, the latter uses estuarine habitats mainly as nursery areas. Although resident species have developed several traits adapted to estuarine environmental conditions, such as benthic eggs that are deposited in the substrate (Pampoulie, 2001), intense sedimentation or habitat destruction may jeopardize eggs and larvae development, which should have marked impact on survival. For seasonal users of the estuary, recruitment into estuarine grounds may be also extremely dependent on habitat and feeding resources availability. Moreover, habitat quantity and quality (abiotic environmental variables such as salinity and temperature, and biotic such as food availability and competition for resources) can affect recruitment, growth and survival of early life-stages and juveniles of marine migrant species (Vasconcelos et al., 2009, 2010). The majority of these fish species are offshore spawners, the eggs and larvae of which may be subjected to a passive or active migration towards coastal areas (e.g. Marchand and Masson, 1989; Symonds and Rogers, 1995).

Atherinopsidae, Engraulidae, Sciaenidae, Gerreidae and Mugilidae were the dominant families in the total number of individuals over the three decades. The most abundant groups of fish that use the more protected beaches of the Sepetiba Bay are the Sciaenidae *M. furnieri* (Costa and Araújo, 2003), the Gerreidae *E. argenteus* and *D. rhombeus* (Araújo and Santos, 1999), the Engraulidae *A. tricolor* and *A. januarina* (Silva and Araújo, 2003) and the Mugilidae *M. liza* (Silva and Araújo, 2000). Fish assemblages preserved specific composition of the dominant species in the three time periods with most changes due to the decreasing relative abundance of the most numerous species such as *A. januarina*, *E. argenteus*, *M. furnieri*, *A. brasiliensis*, *H. clupeola* and *G. barbuis*. On the other hand, *M. liza* increased abundance from the lowest abundance in 1983–1985 and reaching a peak in 1999–2001. The stability of the fish community in terms of species rank order was not expected since the physical and morphological structure of the bay has changed over the past three decades. Annual changes in rank of most abundant species in estuarine areas have been reported elsewhere, and were often related to several influences such as input of saline waters (James et al., 2008), organic matter contents (Ribeiro et al., 2008), changes in depth of the main channel (Leitão et al., 2007), and changes in freshwater discharges (Fernandez-Delgado et al., 2007).

Mugilidae, although capable of feeding on plankton, are mainly detritivorous, filtering, ingesting and concentrating their food in large quantities of organic matter, including that of sewage origin (Laffaille et al., 2002). Some studies (Yáñez-Arancibia, 1976;

De Silva and Wijeyaratne, 1977; Tosi and Torricelli, 1988) reported that members of the Mugilidae family at 50–60 mm TL shift feeding habit from planktophagous to vegetal detritivorous. This fish family contributes significantly to the ecological functioning of estuaries and embayment areas by using the organic matter and primary production, accelerating turnover of microalgae communities (Laffaille et al., 2002). Ribeiro et al. (2008) reported that species composition of the fish community of the Ria Formosa coastal lagoon in southern Portugal was very similar over two decades (1980–1986 and 2001–2002) with Atherinopsidae, Mugilidae, Sparidae and Gobiidae families dominating the community, and a decreased abundance of Mugilidae fishes was associated to decreased organic matter and nutrient concentration because of the improvement in sewage works and wider water circulation inside the coastal lagoon. In the Sepetiba Bay, the increase in abundance of Mugilidae might be associated with an increase in organic loads, though this was not tested. The highest relative abundance of species of *Mugil* spp. in the inner Sepetiba Bay zone may be associated to sheltered grounds where larvae and juveniles use these areas to avoid predators and take advantage of the food availability (Blaber, 1987; Silva and Araújo, 2000). Moreover, the inner bay has lower transparency which could be important for detritivores as Mugilidae; the proximity of urban centers of the inner zone also contributes to more organic loads and nutrients that are carried into the bay. Such nutrients are important to trigger primary productivity and phytoplankton blooms that are main food for species of *Mugil*. These findings reinforce the importance of fish communities as biological indicator of human induced changes in marine systems, since sewage pollution can alter the spatiotemporal distribution of fish assemblages, with both quantitative and structural changes (Henriques et al., 2014).

We found that environmental conditions changed over these two decades in the Sepetiba Bay with a trend for increasing temperature and decreasing transparency that were more conspicuous in 1999–2001, whereas the most marked decreasing in the fish richness, abundance and biomass was recorded between 1983–1985 and 1993–1995. Temperature can affect fish distributions through the thermal tolerance of different species (Logue et al., 1995; Teixeira et al., 2012). Araújo et al. (2002) did not find a clear relationship between seasonal temperature changes and patterns of the fish distribution in the Sepetiba Bay. However, in the present study that encompasses two decades, increases in temperature coincided with decreases in the fish richness and density. In this study, salinity had a greater influence on species distribution explaining the spatial changes in fish assemblage structure along the axis inner–outer bay. In this study, salinity in Sepetiba Bay seems to be stable over the two decades.

The decreased number of species over the two decades could be related to habitat degradation and pollution from increased industrial development that took place in the area adjacent to the bay during the eighties and nineties. The decreased water transparency that occurred from the nineties seems to be linked with this new industrial development and increased nonpoint source pollution that took place in the previous decade. Increased human activity in the bay shoreline during this period 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). Effects of sewage discharges on fish assemblages are also presumably associated with profound modifications of other biotic components, such as benthic invertebrates and macroalgae, with serious alterations of the structural and functional attributes of the ecosystem being likely to occur in proximity of sewages (O'Connor and Crowe, 2005).

Sewage discharge is a major problem for management of nearshore ecosystems, which experienced in the last decades a growing urbanization of coastal areas (Airoldi and Beck, 2007; Azurro et al., 2010). Residuals waters generated in urban settlements

are not properly treated in municipal treatment plants to remove fats, settleable solids and floating materials. In some cases, untreated waters rich of particulate organic matter (POM) are discharged into shallow coastal waters with dramatic consequences on water quality (Molisani et al., 2004; Cunha et al., 2006). Proper treatment and disposal of sewage are necessary to avoid or at least to reduce the impact on aquatic environments and associated activities, such as tourism, fishing and aquaculture, which have important socio-economic implications (Smith et al., 1999). However, almost all of the coastal cities around the Sepetiba Bay lack sewage treatment plants and discharge untreated wastewaters directly into the marine environment (Copeland et al., 2003; Cunha et al., 2006).

In the Sepetiba Bay, the environmental gradient was consistent across the two bay zones, with the inner zone closer to sources of anthropogenic influences such as pollutants brought by continental drainage, and consistently presenting higher temperature, lower salinity and transparency, while the outer zone having higher salinity and transparency and lower temperature. Persistent differences in the fish assemblage structure between the two bay zones over the three periods can be attributed at least in part to differences in environmental variables between the two zones and seem to be a key ecological element to maintenance of biodiversity. Since physical gradients in salinity and temperature are characteristic of estuarine systems and they influence physiological tolerances of different fish species (Araújo et al., 2002; Harrison and Whitfield, 2006), habitat heterogeneity in the Sepetiba Bay should be recognized as an important aspect of marine conservation planning to maximize the conservation of species diversity. However, further studies on this subject are needed.

Fishery activities have a direct influence on the composition and abundance of species and remains as a major source of impact upon marine and coastal environments, contributing to global biodiversity loss (Watson and Pauly, 2001; FAO, 2009). In the study area, *Micropogonias furnieri*, *M. liza*, *E. argenteus*, *T. carolinus* and *A. tricolor* rank amongst the most abundant species and are important fisheries resources. These species have distinct patterns of estuarine use as well as differentiated association with several environmental features (Araújo et al., 1997, 2002; Araújo and Santos, 1999; Silva and Araújo, 2000, 2003; Costa and Araújo, 2003; Azevedo et al., 2007). There is indications that overfishing may have been responsible for decreasing populations of some of these species. In Southeastern Brazil, the signals of depletion have been very clear for some stocks, notably sardine (*Sardinella brasiliensis*), a low-trophic level species, which represents the most severe case of collapse (Rossi-Wongtschowski et al., 2006). Overall, Brazil's catches declined from about 230 000 tonnes in 1973 to 33 000 tonnes in 1990 (Paiva, 1997).

The white croaker *Micropogonias furnieri* inhabits marine estuarine systems in Southeastern Brazil and is one of the main target species in fisheries. This species was identified as in overfishing status (Haimovici and Ignacio, 2005). Other species included in lists of overfishing according to Brazilian legislation were *M. liza*, and *G. barbuis* (MMA, 2004). However, there is no available information of the fishing status for other resident and marine migrant species in the area, which raises concerns on their actual status of conservation.

In recent years, marine protected areas (MPAs) have received increasing attention as a means of conserving marine biodiversity and restoring degraded marine ecosystems (National Research Council, 2001; Palumbi, 2002; Gerhardinger et al., 2009). The acceptance of reserves as a useful management strategy relies on evidence of their effectiveness in preserving stocks of harvested species and conserving biodiversity (Alexander and Gladstone, 2013). However, the establishment of MPAs without an improvement of water quality from the catchment area may not help the recovery of the fish community. The protection of marine and coastal

areas, and habitat restoration should not be seen as solutions replacing conventional management approaches, but need to be components of an integrated program of coastal zone and fisheries management in the Sepetiba Bay. Restoring marine biodiversity through an ecosystem based management approach – including integrated fisheries management, pollution control, maintenance of essential habitats and creation of marine reserves – is essential to avoid serious threats to global food security, coastal water quality and ecosystem stability. The protection and restoration of habitat are also common components of management programs under national law and these policies need to be enforced by Brazilian managers in order to recover bays and other coastal systems. We should take in mind the limitation of the sampling procedure used in this study. Beach seine is limited to sample shallow areas that are used by most juvenile fishes. Although this sampling procedure misses some species, it is cost-efficient, collect many fish species and have yielded very good results worldwide (e.g. Jackson and Jones, 1999; Nagelkerken et al., 2001; Veiga et al., 2006; Hallett and Hall, 2012). Our results offer an important glimpse at what the dynamic of fish biodiversity in tropical coastal systems may look like, and suggest that urgent measures are need to recovery marine communities.

Acknowledgments

We thank Antonio Gomes Cruz-Filho, André Luiz Machado Pessanha and Iracema David Gomes for helping in fieldwork. This work was partially supported by CNPq – Brazilian National Agency for Scientific and Technological Development (Grants for the first author, Process: 304954/2011-0).

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