

Before–after environmental impact assessment of an artificial channel opening on a south-western Atlantic choked lagoon system

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This study aimed to evaluate the human induced impact of a channel opening in a choked lagoon and attempted to establish the cause-effect links for the observed changes. The same lagoon system was sampled before and after the channel opening event, and the differences in fish and crustacean assemblages and environmental variables between these periods analysed. The opening of the artificial channel resulted in salinity increases, leading to a shift in species composition, favouring marine species and reducing abundance and diversity of previously dominant freshwater species. Furthermore, saltwater entrance into the choked lagoon caused an unexpected decrease in species richness and biomass, plus deterioration of ecosystem processes, reducing fishing capacity. The effects of salinity on the ecosystem vary depending on the ecosystem's composition and capacity to overcome salinity changes, thus specific monitoring projects are important strategies for developing coastal lagoon conservation management.

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Key words: anthropogenic factors; coastal lagoon; fishes; man-induced effects; south-eastern Brazil.

INTRODUCTION

Marine ecosystems are threatened by a suite of anthropogenic stressors, and transitional waters are particularly impacted by conflicting human activities (Halpern *et al.*, 2007; Vasconcelos *et al.*, 2007), which impact ecological functions, such as the maintenance of spawning, nursery and feeding areas for fish and crustacean species (Ferreira & Freire, 2009; Vasconcelos *et al.*, 2010; Ribeiro *et al.*, 2012), and biodiversity (Griffiths, 2001). Their high productivity underscore the need for assessing human impacts and environmental factors that may influence fish and crustacean communities in coastal areas (Vasconcelos *et al.*, 2010), estuaries (Barletta *et al.*, 2005; Castillo-Rivera *et al.*, 2010; Contente *et al.*, 2011) and coastal lagoons (Akin *et al.*, 2005; Sánchez-Botero *et al.*, 2008). Understanding such cause–effect relationships is an important

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conservation and ecosystem management goal for marine and brackish water studies.

Estuaries and coastal lagoons usually develop sand bars across the mouth, limiting or closing water exchange with the adjacent sea (Young & Potter, 2002). The lack of communication may change the system's hydrodynamics (Webster, 2010), preventing recruitment of estuarine-dependent fishes and crustacean larvae and the return of adult individuals for reproduction at sea (Bell *et al.*, 2001; Vasconcelos *et al.*, 2010; Webster, 2010). Moreover, these coastal ecosystems are often subjected to pollution, dredging, landfill and habitat loss, causing eutrophication, oxygen depletion, and reduction of diversity and fisheries resources (Saad *et al.*, 2002; Franco *et al.*, 2008; Verdiell-Cubedo *et al.*, 2012). To improve water quality and biological productivity in coastal lagoons, one of the most common interventions is to increase water circulation through the opening of artificial channels (Lima *et al.*, 2001; Suzuki *et al.*, 2002). Nevertheless, little is known about the effects of such human modifications on fish and crustacean assemblages (Pérez-Castañeda & Defeo, 2001).

Disturbances and ecosystem responses to environmental changes over time and human impacts on natural ecosystems need to be constantly assessed by community ecologists, aiming to develop effective management and conservation strategies for maintaining environmental quality and separating natural from human induced changes (Hewitt *et al.*, 2001). The lack of baseline information on community structure and dynamics limits ecosystem evaluation, usually leading to unsuitable management approaches (Agostinho *et al.*, 2005) hindering the direct association between the cause (human impact) and effect (environmental and community changes) of a disturbance. Environmental impact assessment consists of measuring differences in natural and anthropogenic impacted assemblages' patterns. Therefore, experimental designs aiming to assess environmental impacts should include data collected before and after the occurrence of the impact (Guidetti *et al.*, 2003).

This study used the same experimental design to sample fish and crustacean communities in the Piratininga-Itaipu Lagoon system (PILS), at two distinct periods: before and after the establishment of an artificial channel communicating PILS to the sea. The working hypothesis was that environmental changes associated with changes in the circulation pattern within PILS after channel opening of the previously choked lagoon, caused changes in the fish-crustacean community structure, reducing abundance and diversity. The aim of the present study was to compare fish and crustacean abundances, biomasses and frequencies of occurrence before and after channel opening; correlate environmental factors with the observed community changes between the two periods; identify the main environmental factors influencing fish and crustacean community patterns linking them to the channel opening event; to evaluate the impacts of human intervention on fish and crustacean communities.

MATERIALS AND METHODS

STUDY AREA

Piratininga and Itaipu Lagoons are located in Rio de Janeiro State, south-eastern Brazil (22° 56' S; 43° 02' W). The local climate is hot and humid (Koppen, 1948), with a wet summer (December to March, average monthly rainfall >100 mm), and dry winter (June to September, average monthly rainfall c. 50 mm) (UFF, 2012).

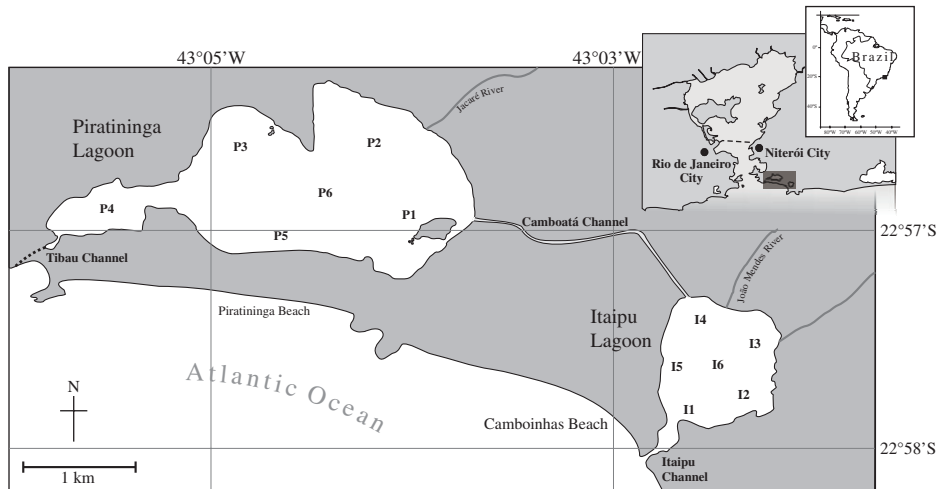


FIG. 1. Location of Piratininga-Itaipu coastal lagoon system in Rio de Janeiro State, Brazil, with the six sampling sites in each lagoon and the new channel in Piratininga Lagoon (Tibau Channel).

The lagoons communicate with each other by the narrow Camboatá Channel and Itaipu Lagoon is connected to the sea through the Itaipu Channel forming PILS (Fig. 1). Piratininga Lagoon was a choked coastal lagoon with an area of 2.9 km², and an average depth of 0.6 m and natural sporadic connection to the sea. Since its connection with Itaipu Lagoon through the Camboatá Channel in 1946, the water level at Piratininga Lagoon dropped and prevented its connection with the sea. The water cycle became mostly influenced by freshwater inflow and sewage discharge from residences within the lagoon catchment, maintaining low salinities and a flushing half-life of 16 days (Knoppers *et al.*, 1991). Itaipu Lagoon has an area of 1.0 km², an average depth of <1.0 m, and is permanently connected with the sea through the Itaipu Channel. The water regime is mostly influenced by tides and has a flushing half-life of 1 day (Knoppers *et al.*, 1991). In 2008 an artificial channel was built (Tibau Channel) permanently connecting Piratininga Lagoon to the sea, aiming to improve its biological and hydrological conditions (Fig. 1). That is the human induced change in the system evaluated in this study.

This lagoon system was selected (1) due to its history of artificial changes without appropriate impact studies; (2) a new intervention in the system, the opening of the Tibau Channel; (3) the availability of baseline information prior to channel opening.

SAMPLING SURVEYS

Samples were taken in both lagoons during the day (0800–1200 hours), twice in the dry (July and August) and twice in the wet (January and February) seasons, before (2006) and after (2011) the opening of the Tibau Channel. Each lagoon was divided into six sites (Piratininga: P1–P6; Itaipu: I1–I6) ensuring that sampling covered the whole lagoon area (Fig. 1). Sampling was conducted by the same fisherman using two cast nets (12 and 20 mm mesh) with an area of 32.2 m² each. Three replicates per site per net were made (six sites × three replicates = 18 sampling units, per cast net).

Fishes and crustaceans were stored and transported on ice to the laboratory and preserved frozen for species identification. Fish species were identified based on Figueiredo & Menezes (1978, 1980), and Menezes & Figueiredo (1980, 1985) and crustaceans on Williams (1974); Coelho & Ramos-Porto (1992) and Costa *et al.* (2003). For each sample and period the total number of individuals and biomass (weighed to the nearest 0.1 g) of each species caught were recorded.

Simultaneously in the field, four replicates of salinity, dissolved oxygen (mg l^{-1}), water temperature ($^{\circ}\text{C}$), pH, water depth (WD) (m) and transparency were measured in the middle of the water column. Three replicates of bottom sediments were taken to determine the mean percentage of organic matter (mass difference method) and grain size (Blott & Pye, 2001). The precipitation rate (PR) was obtained from the Rio de Janeiro's Geotechnical Institute records (Alerto Rio, 2011).

DATA ANALYSIS

Fish and crustacean abundances were used to compare the two periods (before and after channel opening) considering faunal distribution in each season and the main environmental factors that contributed to this distribution. Habitat differences between sampling sites were not considered due to previous non-significant results (Fortes *et al.*, 2014). Abundance data were fourth root transformed to construct the association matrix aiming to reduce dominant species effects, and then the Hellinger distance calculated, following Legendre & Gallagher (2001) in order to reduce data distortions (Rao, 1995), and to maintain the best compromise between linearity and resolution (Legendre & Legendre, 1998). The following data analyses were performed with this transformed matrix.

A permutational multivariate analysis of variance (PERMANOVA; Anderson, 2005) design was used to test for spatial variation between Itaipu and Piratininga Lagoons and to evaluate if they behave as a single system or two different sub-systems. A before and after environmental impact assessment experiment was performed using a two-way fully nested PERMANOVA analysis [period (season)] to test for significant differences in the multivariate assemblage data between periods (2006 and 2011) within seasons (dry and wet). A similarity percentage analysis (SIMPER) was used to evaluate which species were responsible for the dissimilarity between PERMANOVA significant groups (Clarke, 1993). A resemblance matrix was calculated using the Bray-Curtis distance. This analysis was performed using PRIMER 6 + PERMANOVA software (Clarke & Gorley, 2006).

The relationship between species assemblages and environmental variables for each period was analysed using canonical correspondence analysis (CCA). Analysis was performed using fish and crustacean abundance data of the most abundant and frequent species (frequency of occurrence $>0.5\%$) in each lagoon. Monte Carlo permutation analysis with the forward selection option was used to test the significance ($P = 0.05$) of each variable contribution to all CCA axes. A t -value biplot diagram was used to reveal pair-wise statistically significant relationships between species and environmental variables. This projection approximates the t -values of a regression coefficient from a multiple regression, with each species acting as a response variable and the environmental variables acting as predictors (Leps & Smilauer, 2003). Significant relationships are indicated by species position inside the regression limits (indicated by circles) (Leps & Smilauer, 2003), with the full line and the dotted line circles representing the positive and the negative limits, respectively. In order to isolate the amount of explanation from each variable measured (environmental and temporal) on fish and crustacean community changes, a variation partitioning analysis was performed for each lagoon, following Borcard *et al.* (1992) standards. This analysis assumes that ecological variation may be divided into different factors (temporal, environmental, their correlations and unknown factors) and analysed separately to measure the relative contribution of sets of explanatory variables and partial out components of community data sets (Borcard *et al.*, 1992). The same analysis was conducted by isolating the amount of explanation generated by the salinity measures found in Piratininga Lagoon, then evaluating the effects of increased salinity due to channel opening on fish and crustacean community structure. All three analysis were conducted on CANOCO 4.5 software (Leps & Smilauer, 2003).

RESULTS

A total of 72 samples were collected in each lagoon (18 units in 4 months) in each period, resulting in the collection of 3978 specimens weighing a total of 119.2 kg. A

total of 53 species were recorded, distributed in 26 families, 46 fishes (24 families), and seven crustaceans (two families). A decrease in species richness (24 species in 2006, to 19 in 2011), abundance (2651 individuals in 2006, to 1327 in 2011) and biomass (80.9 kg in 2006, to 38.3 kg in 2011) was observed, with 22 species occurring exclusively in 2006, 10 in 2011 and 22 occurring in both periods (Table I).

A similar pattern was observed in environmental variables which changed considerably between periods (Table II).

One-way PERMANOVA comparing fish and crustacean abundances between Itaipu and Piratininga was significant ($MS = 37803$, $P_{MC} > 0.001$) suggesting a spatial segregation between lagoons. SIMPER analysis revealed a dissimilarity of 79.6% between both lagoons with *Diapterus rhombeus* (Cuvier 1829) [δ :s.d.(δ) = 1.75], *Elops saurus* L.1766 [δ :s.d.(δ) = 0.97], *Oreochromis niloticus* (L.1758) [δ :s.d. (δ) = 0.88], *Callinectes danae* (Crustacea Portunidae) [δ :s.d.(δ) = 1.22] and *Eucinostomus gula* (Quoy & Gaimard 1824) [δ :s.d.(δ) = 0.99] accounting for 38.0% of that difference. Based on these results, it was assumed that Piratininga and Itaipu are independent sub-systems, and were treated as such in all further analyses.

PIRATININGA LAGOON

A total of 1162 specimens were captured in Piratininga Lagoon of which 68.4% were fishes, representing 18 species in 12 families, and 31.6% decapod crustaceans of seven species in two families. Significant differences were observed between the two sampling periods. Abundance of fishes and decapod crustaceans decreased in numbers and biomass from 2006 to 2011 (Table I). The five most abundant fish species in 2006 were *O. niloticus*, *E. saurus*, *Brevoortia aurea* (Spix & Agassiz 1829), *Mugil liza* Valenciennes 1836 and *Atherinella brasiliensis* (Quoy & Gaimard 1825), and comprised 86.9% of total fish abundance. In contrast in 2011, the top five species and ranks changed with *Eucinostomus argenteus* Baird & Girard 1855, *B. aurea*, *Brevoortia pectinata* (Jenyns 1842), *E. saurus* and *E. gula*, comprising 80.8% of total fish abundance. Seven crustacean species *Farfantepenaeus brasiliensis*, *C. danae*, *Callinectes ornatus*, *Farfantepenaeus paulensis*, *Litopenaeus schmitti*, *Callinectes bocourti* and *Callinectes sapidus* occurred in 2006, whereas only three (*C. danae*, *L. schmitti*, *C. ornatus*, and *C. sapidus*) were captured in 2011, with *C. danae* and *L. schmitti* representing 96.7% of total crustaceans caught in the period.

A nested PERMANOVA analysing community structure in Piratininga Lagoon demonstrated differences between periods within seasons [period (season)] ($MS = 14894$, $P_{MC} < 0.001$). SIMPER analysis showed a dissimilarity of 85.5% between periods with *O. niloticus* [δ :s.d.(δ) = 0.82], *E. saurus* [δ :s.d.(δ) = 0.78], *M. liza* [δ :s.d.(δ) = 0.90], *E. argenteus* [δ :s.d.(δ) = 0.90] and *Cetengraulis edentelus* (Cuvier 1829) [δ :s.d.(δ) = 0.61] being responsible for 46.0% of that difference.

The first two axes of CCA analysis explained 19.3% of data variation. Their cumulative percentage variance of the species–environment relationship accounted for 64.4% of the biotic matrix explanation. The first axis alone explained 11.8% of the variation in species data and was strongly associated with salinity. Salinity showed a positive relation with 2011 samples, regardless of the season. Dry and wet seasons in 2006 were distinguished mainly by PR and WD (Fig. 2).

The *t*-value biplot diagram identified a significant relationship between species and three environmental variables: salinity [Fig. 3(a)], PR [Fig. 3(b)] and water

TABLE I. Total abundance in numbers (AB) and biomass (B) of the species captured in Itaipu and Piratininga Lagoons in 2006 and 2011

Species	Anagram	Itaipu Lagoon				Piratininga Lagoon			
		2006		2011		2006		2011	
		AB	B (kg)	AB	B (kg)	AB	B (kg)	AB	B (kg)
Actinopterygii									
<i>Achirus lineatus</i>	ACHLIN	6	0.0	6	0.0			1	0.0
<i>Anchoa tricolor</i>	ANCTRI	5	0.0						
<i>Anchovia clupeioides</i>	ANCCLU	1			0.0				
<i>Anchoviella lepidentostole</i>	ANCLEP	1	0.0	8	0.0				
<i>Archosargus rhomboidalis</i>	ARCRHO	1	0.0						
<i>Atherinella brasiliensis</i>	ATHBRA	7	0.1			25	0.5	3	0.0
<i>Brevoortia aurea</i>	BREAU	3	0.0	6	0.2	40	0.5	40	1.2
<i>Brevoortia pectinata</i>	BREPEC			5	0.1			35	1.0
<i>Caranx latus</i>	CARLAT	2	0.0	3	0.0				
<i>Centropomus parallelus</i>	CENPAR	7	0.2			10	0.4		
<i>Centropomus undecimalis</i>	CENUND	1	0.2	5	0.4	23	1.9		
<i>Cetengraulis edentulus</i>	CETEDE	37	1.5	2	0.0				
<i>Chilomycterus spinosus</i>	CHISPI	2	0.1						
<i>Chloroscombrus chrysurus</i>	CHLCHR					1	0.0		
<i>Citharichthys arenaceus</i>	CITARE			5	0.1				
<i>Citharichthys spilopterus</i>	CITSPI	30	0.5						
<i>Diapterus auratus</i>	DIAAUR	25	0.5	8	0.2			1	0.0
<i>Diapterus rhombeus</i>	DIARHO	911	8.9	664	10.5	7	0.1	12	0.1
<i>Diplectrum formosum</i>	DIPFOR	1	0.1						
<i>Diplectrum radiale</i>	DIPRAD			1	0.1				
<i>Elops saurus</i>	ELOSAU	21	1.6	59	4.5	123	12.4	34	2.2
<i>Eucinostomus argenteus</i>	EUCARG	100	0.5	33	0.3	16	0.1	48	0.3
<i>Eucinostomus gula</i>	EUCGUL	72	0.6	43	0.5	5	0.0	28	0.2
<i>Eucinostomus melanopterus</i>	EUCMEL	2	0.1						
<i>Genidens genidens</i>	GENGEN			8	0.7				
<i>Gobionellus oceanicus</i>	GOBOCE	30	0.7	11	0.3				
<i>Haemulon plumieri</i>	HAEPLU	1	0.0						
<i>Harengula clupeiola</i>	HARCLU	19	0.4	1	0.0				
<i>Microgobius meeki</i>	MECMEE	2	0.6	1	0.2	1	0.2		1.3
<i>Micropogonias furnieri</i>	MICFUR	11		5		7	0.0	6	
<i>Mugil curema</i>	MUGCUR	33	2.1	12	1.8	4	0.1	5	1.0
<i>Mugil liza</i>	MUGLIZ	32	5.8	15	3.4	37	3.5	6	1.0
<i>Oligoplites saurus</i>	OLISAU			3	0.1				
<i>Opisthonema oglinum</i>	OPIOGL	2	0.1	1	0.1				
<i>Oreochromis niloticus</i>	ORENIL	11	0.9	1	0.1	267	28	9	2.2
<i>Phalloptychus januaris</i>	PHAJAN							1	0.0
<i>Prionotus punctatus</i>	PRIPUN	3	0.1						
<i>Sardinella brasiliensis</i>	SARBRA			43	2.1				
<i>Selene vomer</i>	SELVOM	1	0.0						
<i>Sphoeroides greeleyi</i>	SPHGRE	1	0.0						
<i>Sphoeroides testudineus</i>	SPHTES	1	0.0						
<i>Stephanolepis hispidus</i>	STEHIS			1	0.0				
<i>Stephanolepis setifer</i>	STEST	1	0.0						

TABLE I. Continued

Species	Anagram	Itaipu Lagoon				Piratininga Lagoon			
		2006		2011		2006		2011	
		AB	B (kg)	AB	B (kg)	AB	B (kg)	AB	B (kg)
<i>Symphurus plagusia</i>	SYMPLS	4	0.1						
<i>Synodus foetens</i>	SINFOE	2	0.0						
<i>Trachinotus carolinus</i>	TRACAR			2	0.0				
Malacostraca									
<i>Callinectes bocourti</i>	CALBOC					20	1.5		
<i>Callinectes danae</i>	CALDAN	66	0.9	71	1.0	65	1.2	44	0.7
<i>Callinectes ornatus</i>	CALORN	65	0.3			43	0.5	1	0.1
<i>Callinectes sapidus</i>	CALSAP					8	0.4	1	0.0
<i>Farfantepenaeus brasiliensis</i>	FARBRA	87	0.4			109	0.8		
<i>Farfantepenaeus paulensis</i>	FARPAU	46	0.2			36	0.3		
<i>Litopenaeus schmitti</i>	LITSCH	127	0.7	16	0.1	26	0.2	14	0.1
Total individuals			1780		1039		873		289
Total species			40		28		21		18

Grey boxes, frequency of occurrence >30%; blank cells, zero; 0.0, biomass <0.1 kg.

transparency [Fig. 3(c)]. Salinity showed a significant positive relationship with *E. gula*, *E. argenteus* and *B. pectinata* and negative with *C. bocourti*, *F. brasiliensis*, *F. paulensis*, *Centropomus undecimalis* (Bloch 1792) and *Centropomus parallelus* Poey 1860. PR and water transparency showed a negative significant relationship with *F. brasiliensis* and *F. paulensis*.

Variation partitioning analysis demonstrated that environmental variables alone accounted for one third of the total species matrix variation (34.0%), whereas c. 10.0% was explained by non-environmental temporal variation and the correlation between these two factors (3.5 and 6.6%). The amount of explanation of the species matrix variation by salinity itself was very high (8.8%) for a single environmental factor.

ITAIPU LAGOON

A total of 2818 specimens were captured in Itaipu Lagoon, 83.0% fishes, represented by 44 species of 25 families, and 17.0% crustaceans, represented by five species from two families. Fish abundance in numbers decreased from 1387 individuals in 2006 to 951 in 2011, but biomasses were nearly the same for both years (25.8 and 25.6 kg). The number and biomass of crustaceans decreased from 2006 (391 individuals, 2.5 kg) to 2011 (87 individuals, 1.0 kg). The occurrence of fish species was similar between sampling periods. The gerreid *D. rhombeus* was by far the most abundant species collected in both periods, comprising 65.6% of total fish abundance in 2006 and 69.7%, in 2011. The five most abundant fish species in 2006 (*D. rhombeus*, *E. argenteus*, *E. gula*, *Mugil curema* Valenciennes 1836 and *M. liza*) comprised 82.7% of the total abundance, whereas in 2011 *D. rhombeus*, *E. saurus*, *Sardinella brasiliensis* (Steindachner 1879), *E. gula* and *E. argenteus* comprised 88.4% of total abundance. The two most abundant crustacean species, *C. danae* and *L. schmitti*, accounted for 58.6% of total

TABLE II. Mean $\pm$ s.d. and range (minimum–maximum) of environmental variables measured in Piratininga and Itaipu Lagoons in 2006 and 2011 (before and after channel opening, respectively). Transparency reported as percentage of the total depth

	Piratininga lagoon				Itaipu lagoon			
	2006		2011		2006		2011	
	Mean $\pm$ s.d.	Range	Mean $\pm$ s.d.	Range	Mean $\pm$ s.d.	Range	Mean $\pm$ s.d.	Range
Temperature ($^{\circ}$ C)	26.9 $\pm$ 3.9	20.7–33.9	27.2 $\pm$ 3.3	22.9–33.1	25.6 $\pm$ 2.4	22.7–29.9	26.7 $\pm$ 3.9	18.3–32.7
Salinity	11.4 $\pm$ 7.2	3.6–20.7	24.5 $\pm$ 3.3	20.4–31.8	31.2 $\pm$ 2.4	25.1–33.4	30.9 $\pm$ 0.8	29.1–32.1
pH	7.8 $\pm$ 1.9	3.9–9.8	8.5 $\pm$ 0.4	8.1–9.4	7.6 $\pm$ 1.0	6.0–8.8	8.4 $\pm$ 0.3	7.5–8.8
Dissolved oxygen (mg l ⁻¹)	7.4 $\pm$ 1.6	4.6–9.2	9.4 $\pm$ 2.5	4.5–13.9	6.6 $\pm$ 1.4	4.9–8.9	10.6 $\pm$ 2.0	8.8–16.0
Transparency (%)	77.8 $\pm$ 15.0	45.0–100.0	83.2 $\pm$ 15.6	50.3–100.0	64.5 $\pm$ 21.1	26.7–100	60.1 $\pm$ 18.7	33.1–101.7
Depth (cm)	51.6 $\pm$ 13.4	34.6–72.2	0.6 $\pm$ 0.2	0.3–1.2	94.8 $\pm$ 47	49.9–182.5	1.3 $\pm$ 0.4	0.7–2.3
Organic matter (%)	16.8 $\pm$ 6.6	4.4–28.5	18.6 $\pm$ 6.8	2.6–28.8	13.5 $\pm$ 8.6	1.8–29.1	13.8 $\pm$ 8.8	0.9–35.5
Sand (%)	7.6 $\pm$ 10.3	0.0–28.8	27.4 $\pm$ 24.8	0.0–70.2	8.4 $\pm$ 13.1	0.0–36.6	47.9 $\pm$ 28.1	0.0–95.5
Mud (%)	92.4 $\pm$ 10.3	71.2–100.0	72.6 $\pm$ 24.8	29.8–100.0	91.6 $\pm$ 13.1	63.4–100.0	52.1 $\pm$ 28.1	4.5–100.0
Precipitation rate	113.2 $\pm$ 76.1	37.6–226.6	92.0 $\pm$ 39.0	28.3–127.5	113.2 $\pm$ 76.1	37.6–226.6	92.0 $\pm$ 39.0	28.3–127.5

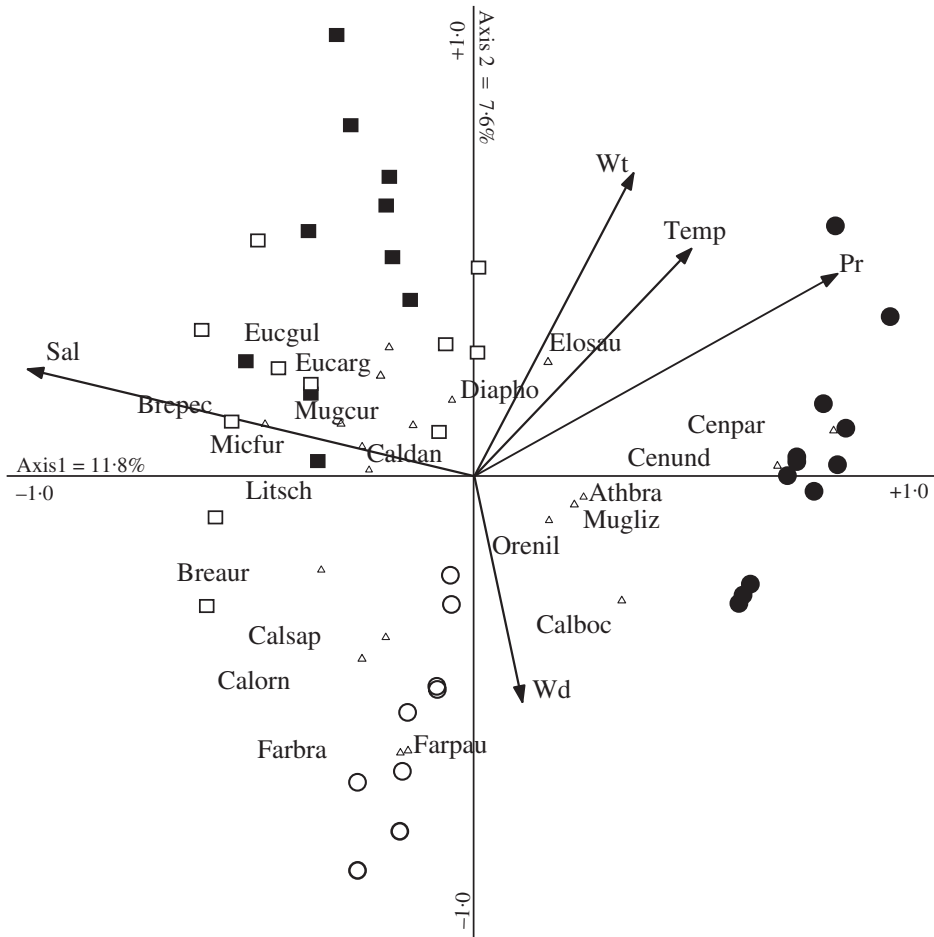


FIG. 2. Piratininga Lagoon canonical correspondence analysis (CCA) ordination diagram (triplot) on the first two axes based on samples, species (see Table I) and significant environmental variables ($P < 0.05$) data matrices. Length and direction of arrows indicate the relative importance and direction of change of environmental variables. WD, water depth; WT, water transparency; PR, precipitation rate; Temp, water temperature; Sal, salinity; ○, dry 2006; ●, wet 2006; □, dry 2011; ■, wet 2011.

abundance and were the only two decapod crustaceans collected in 2011, contrasting with the five species collected in 2006 (*C. danae*, *F. brasiliensis*, *L. schmitti*, *C. ornatus* and *F. paulensis*).

A nested PERMANOVA revealed significant differences in community composition between periods within season [period (season)] indicating that sampled periods had different community composition ($MC = 9629.2$, $P_{MC} < 0.001$).

SIMPER analysis revealed a dissimilarity of 63.1% between periods with *E. argenteus* [δ :S.D.(δ) = 1.44], *C. danae* [δ :S.D.(δ) = 1.19], *E. saurus* [δ :S.D.(δ) = 1.03], *E. gula* [δ :S.D.(δ) = 1.09] and *M. Liza* [δ :S.D.(δ) = 0.99] being responsible for 31.7% of that difference. CCA indicated difference between seasons and a difference between 2006 and 2011 dry seasons. The ordination of species and samples formed three main groups:

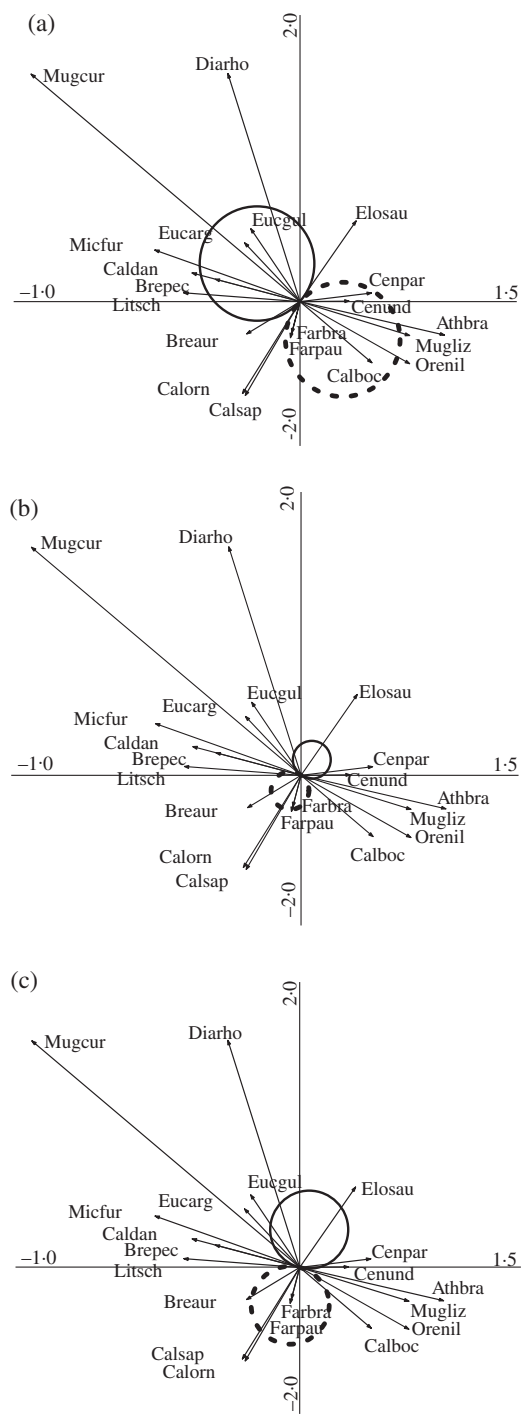


FIG. 3. Piratininga Lagoon t -value biplot diagram for (a) salinity, (b) precipitation rate and (c) water transparency (see Table I). $\bigcirc$ represent the significant relationship area, — represents positive relationship, and ---- represents negative relationship.

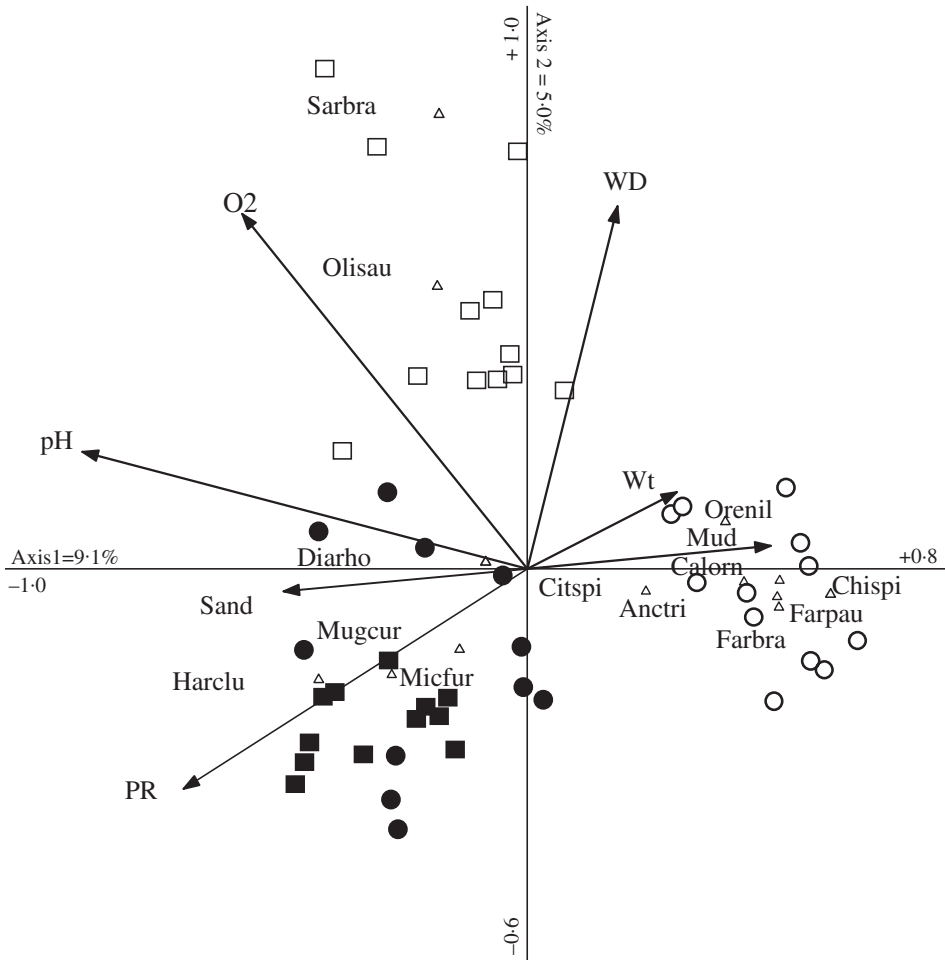


FIG. 4. Itaipu Lagoon canonical correspondence analysis (CCA) ordination diagram (triplet) on the first two axes based on samples, species (see Table I) and significant environmental variables ($P < 0.05$). Length and direction of arrows indicate the relative importance and direction of change of environmental variables [pH; per cent sand (Sand) and mud (Mud) in sediments; dissolved oxygen (O_2); water depth (WD); water transparency (WT); precipitation rate (PR)]. Species influencing <15% of data distribution were removed from the diagram. ○, dry 2006; ●, wet 2006; □, dry 2011; ■, wet 2011.

the first comprised wet season samples of both 2006 and 2011 periods showing a correlation with highest PRs and increased pH; the second consisted of samples from the dry season of 2006 and was correlated with increased water transparency and highest mud percentages in sediments; the third group comprised the dry season of 2011 and showed highest correlation with increased dissolved oxygen (O_2) and WD (Fig. 4). The first two axes were responsible for 14.1% of data variation. Most of the variance in the biotic matrix could be explained by environmental variables with 54.4% of the cumulative percentage variance of species–environmental relations in the first two axes.

High PRs in the wet season were associated with *Caranx latus* Agassiz 1831, *Harengula clupeiola* (Cuvier 1829), *Trachinotus carolinus* (L. 1766) and *Micropogonias furnieri* (Desmarest 1823) (Fig. 4). The dry season of 2006 was associated with *F. paulensis*, *F. brasiliensis*, *O. niloticus* and *C. ornatus* and increased water transparency and mud percentages in the sediment. On the other hand, the dry season of 2011 was particularly associated with high abundances of *S. brasiliensis* and *Oligoplites saurus* (Bloch & Schneider 1801) and increased dissolved oxygen and WD (Fig. 4). A *t*-value biplot diagram was unable to identify significant relationships between species and any of the environmental variables.

Results from variation partitioning analysis showed that non-temporal environmental variables explained 28.9% of the variation in the species matrix, whereas 4.5% was explained by the correlation between temporal and environmental patterns structuring species data. Only 3.2% was explained by non-environmental intrinsic temporal patterns.

DISCUSSION

The question whether human interventions may alter fish species composition and abundance patterns at spatial and temporal scales in coastal lagoons was addressed. Interactions between physical and biological factors may cause strong fluctuations in the distribution and abundance patterns of marine biological communities (Ramos-Miranda *et al.*, 2005; Terlizzi *et al.*, 2005; Mendes & Soares-Gomes, 2013). The quantitative description of such modified patterns helps in understanding the processes structuring species distribution (Underwood & Chapman, 2003; Terlizzi *et al.*, 2005). Studies that aim to perceive these patterns and how they vary over space and time are critical for understanding community dynamics, individual responses to natural and human induced environmental stressors and for proposing adequate management actions. Environmental factors such as temperature, habitat type and salinity may be responsible for shaping community structure, especially in transitional habitats such as coastal lagoons (Ramos-Miranda *et al.*, 2005; Castillo-Rivera *et al.*, 2010; Contente *et al.*, 2011). Several studies have evaluated the consequences of such factors on fish and crustacean communities in intermittently open lagoons (Saad *et al.*, 2002; Young & Potter, 2002; França *et al.*, 2012) and environments subjected to human interventions (Franco *et al.*, 2008; Ferreira & Freire, 2009; Verdiell-Cubedo *et al.*, 2012). Nevertheless, the present study was the first to analyse the relationship between changes in the fish and crustacean assemblage structure associated with a human induced environmental change, represented here by the opening of a sea communication channel into a permanently choked lagoon. A significant reduction of species richness and biomass occurred, associated with a salinity rise due to the inflow of coastal marine waters into the lagoon after channel opening.

Mendes & Soares-Gomes (2013) evaluated the influence of environmental variables on the benthic macrofauna at PILS, before and after the Tibau Channel opening. They observed a salinity increase, but were not able to detect statistical differences in the benthic community before and after channel opening. The present study, however, showed that the opening of the Tibau Channel increased salinity values in Piratininga Lagoon, causing major changes in the fish and crustacean assemblage. Five (*C. bocourti*, *F. brasiliensis*, *F. paulensis*, *C. undecimalis* and *C. parallelus*) out of six

exclusive species that occurred in 2006 in Piratininga were negatively associated with salinity, and were not present in 2011 samples. Two of the new species registered in Piratininga in 2011 [*Diapterus auratus* Ranzani 1842 and *Achirus lineatus* (L.1758)] occurred only in Itaipu in 2006, indicating a greater exchange of species between lagoons due to increased salinity, as suggested by other authors (Andreatta *et al.*, 1989; Barletta *et al.*, 2005). Therefore, the assemblage composition after channel opening was distinct from that observed before the impact, showing a human induced cause-effect change in community structure.

The significant biomass decrease in Piratininga Lagoon was a consequence of the reduced abundance of *O. niloticus* in 2011. This freshwater species has been introduced in several aquatic systems to improve fisheries and aquaculture, with considerable negative impacts on native communities and biodiversity (Canonico *et al.*, 2005; Attayde *et al.*, 2007). In PILS's case, the species was accidentally introduced in the 1970s when heavy rains flooded an aquaculture project into the PILS drainage basin (unpubl. obs.). Its great importance to before–after dissimilarity was probably associated with salinity increasing beyond the tolerance limits of *O. niloticus*, at rates that would not permit species acclimation, thus permitting the domination of marine species such as *Eucinostomus* spp., *Brevoortia* spp. and *E. saurus* in the lagoon. Most freshwater species are sensitive to salinity changes and the increasing sea water influx into a lagoon usually restricts these species to the upper estuarine zones and river-runoff areas (Frota & Caramaschi, 1998; Martino & Able, 2003; Ramos-Miranda *et al.*, 2005). Lack of direct connection with the sea in Piratininga Lagoon since 1946 caused the decrease in salinity favouring freshwater species dominance, as seen in other studies (Frota & Caramaschi, 1998; Ramos-Miranda *et al.*, 2005). The new scenario with higher salinity after the opening of Tibau Channel enabled the maintenance of marine species. On the other hand, brackish and freshwater water species suffered mortality and moved into local freshwater rivers and creeks and the upper estuary where salinities were lower (Frota & Caramaschi, 1998; Young & Potter, 2002).

Several studies indicate a positive relation between species population and increased circulation due to channel openings (Brito *et al.*, 2000; Pérez-Castañeda & Defeo, 2001). Both *F. paulensis* and *F. brasiliensis*, the most abundant crustaceans in 2006, were absent in the collections in 2011 in any of the lagoons. The absence of both species in 2011 may be related to other factors including fishing, since shrimps are important local fishery resources (Albertoni, 1998; Barroso *et al.*, 2000), and perhaps also loss of bottom vegetation leading to lower habitat complexity with less available food and shelter from predators, and therefore, lower biodiversity (Martino & Able, 2003; Ribeiro *et al.*, 2012; Verdiell-Cubedo *et al.*, 2012). Benthic species richness, however, increased in sites near the Tibau Channel (Mendes & Soares-Gomes, 2013), indicating that different taxa may respond differently to environmental changes and impacts, and that species tolerance across an abiotic gradient may determine community structure with species choosing specific environmental conditions (Martino & Able, 2003; Pombo *et al.*, 2005).

The present study demonstrated that, at the time scale examined, the opening of the Tibau Channel in Piratininga Lagoon channel did not improve ecosystem processes or its fishing capacity, but caused losses in species richness, biomass and diversity. Different patterns have been found in other studies, which suggest that the connection with the sea may benefit the community by increasing larval and juvenile recruitment, and enable estuarine dependent species to complete their reproductive life cycle

(Bell *et al.*, 2001; Saad *et al.*, 2002; Ferreira & Freire, 2009). These studies, however, often focus on systems adjusted to frequent sea isolation and communication periods. In the present case, Piratininga has been a choked lagoon for several decades. Furthermore, colonization processes after an environmental change may take from a few months to several years for restructuring the system (Pérez-Ruzafa *et al.*, 2006). The permanent opening of the Tibau Channel caused a large amount of disturbance over a short time scale, leading to a great change in its fish and crustacean community structure.

For Itaipu Lagoon, salinity showed no influence on community structure and was non-significant in the multi-scale CCA analysis. Despite species occurrence similarities, differences in species abundance and the new occurrence of less abundant species caused the differences between the periods observed in the PERMANOVA analysis. Almost all of the 2011 exclusive species recorded in this study occurred in this lagoon. Nevertheless, these species were previously recorded in adjacent areas supporting the habitat connectivity hypothesis (Valesini *et al.*, 1997; Monteiro-Neto *et al.*, 2008; Vasconcelos *et al.*, 2010). Changes occurred in Piratininga Lagoon apparently had no significant impacts on Itaipu Lagoon. The differences observed in Itaipu Lagoon, when comparing 2006 and 2011 sampling periods, may be linked to other anthropogenic causes.

Human interventions in natural habitats (*e.g.* dredging, landfill, sewage outfalls, aquaculture and fishing) may change habitat variability and conditions in lagoons and estuaries (Pérez-Ruzafa *et al.*, 2006; França *et al.*, 2012). Environmental changes may favour the distribution of certain species while limiting others (Saad *et al.*, 2002). In the present study, salinity was the predominant factor determining species composition indicating that species have specific responses to optimal environmental conditions (Contente *et al.*, 2011), and abrupt changes as seen in PILS caused major changes in community structure, especially in the choked Piratininga Lagoon. The existing problems in management plans lie in the fact that management actions can lead to different results in different ecosystems mainly due to (1) distinct drainage basin size, (2) environmental and natural evolutionary differences and (3) differences in anthropogenic use (Esteves, 1998; Lima *et al.*, 2001). Therefore, to improve conservation and management, long-term monitoring projects are important strategies for verifying lagoon system changes and development over time (Schifino *et al.*, 2004).

According to Di Carlo *et al.* (2011) reconstructive techniques in combination with 'beyond BACI' designs are powerful tools to assess disturbance effects in space and time. Still, authors should be careful when linking a specific disturbance to the observed differences (Underwood, 1991, 1992; Meseck *et al.*, 2012). In fact, professional judgment is required to decide whether there is enough evidence, or not, to make this connection (Conquest, 2000). A common problem in evaluating environmental impacts on community structure is the lack of prior knowledge about the ecosystem, hence leading to ambiguous or non-significant results (Rotherham & West, 2007). The use of similar sites for comparison (Parnell *et al.*, 2005; Musco *et al.*, 2009) may also lead to uncertain cause-effect responses. The present study enabled the observation of the fish and crustaceans community before and after the human impact (channel opening) in Piratininga Lagoon. The cause-effect relationship could be established mainly because the disturbance event was clear in space and time, and a salinity rise would not occur without the channel opening.

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