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Temporal changes of a coastal small-scale fishery system within a tropical metropolitan city

Luciana Loto^{a,*}, Cassiano Monteiro-Neto^a, Raquel Rennó M. Martins^{a,b},
Rafael de Almeida Tubino^a

^a Universidade Federal Fluminense, Instituto de Biologia, Programa de Pós-Graduação em Biologia Marinha e Ambientes Costeiros, Laboratório ECOPECA, Caixa Postal 100644, Niterói, Rio de Janeiro, Brazil

^b Fundação Instituto de Pesca do Estado de Rio de Janeiro, Pç. Fonseca Ramos s/nº, Terminal Rodoviário Roberto Silveira, Sobreloja, CEP: 24030-020, Niterói, Rio de Janeiro, Brazil

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ABSTRACT

Small-Scale Fishery Systems have changed in the last decades under the influence of multiple human activities. The Itaipu Small-Scale Fishery System is under the influence of gentrification of an almost exclusive fishing village, allied to economic demands and technological advances. The present study aimed to understand the adaptive strategies of this system based on the analysis of changes that have occurred in the last four decades regarding the following parameters: catch composition and fish production, characteristic fishing methods and the gear and vessels used in the activity. The spatial distributions of gillnet and hook-and-line catches and their relationship with the defined area of the Itaipu Marine Extractive Reserve was also evaluated. The results indicate the capability of the Itaipu Small-Scale Fishery System to adapt over time concerning disturbances. These results may contribute to the management of the fishing system at the Marine Extractive Reserve.

1. Introduction

Small-Scale Fisheries (SSF) are globally important productive sectors, contributing to more than half of the world fish production (FAO, 2015). Over 90% of the 4.36 million active fishing vessels in the world are small-scale (Schuhbauer and Sumaila, 2016), acting as suppliers of local and regional markets (FAO, 2016). Teh and Sumaila (2013) also estimated that SSF support up to 22 million fishers, making up about 44% of all fishermen in the primary production sector, with an additional 100 million people involved in SSF post-harvest sectors (Béné et al., 2007). The most recent official data in Brazil indicates that SSF are responsible for 65.0% of the national seafood production (fish and shellfish), and employ 957,000 people, corresponding to 99.2% of the officially registered professional fishermen (IBAMA, 2007; MPA, 2012).

In addition to their economic importance, and their dynamic and diversified character, SSF are, many times, associated with local communities, often reflecting historical relationships with the environment and its natural resources, as well as traditions and adjacent values, favoring social cohesion processes incorporating globally relevant cultural wealth (FAO, 2015). Despite their importance, evidence of the decline or disappearance of small-scale fisheries is increasingly apparent (Ainsworth et al., 2008; Kittinger et al., 2013; Tesfamichael

et al., 2014), especially in marine coastal areas close to major urban centers, where approximately half of the world population lives or works (Small and Nicholls, 2003). While the importance of SSF is widely acknowledged, information about this sector is limited, which makes it challenging for defining management strategies adapted to their multiple contexts (Salas et al., 2007).

Urban populations increase pressure on ecosystems and their natural resources. The historical evolution of such pressures upon fishing communities led to the adaptation of these social groups to new scenarios, but also the disruption of both social structure and infrastructure (Olson, 2010; Colburn and Jepson, 2012). Coastal fishing communities are picturesque, attracting tourism and part-time residents from time to time. This population influx may be seen as a coastal gentrification process, where external, nonlocal economic forces alter these nonmetropolitan communities, establishing a new power structure and driving fishermen away from their working environment (Gale, 1991; Thompson et al., 2016).

Impacts of multiple human activities such as pollution, disputes over space and resources with other productive sectors, like industrial and recreational fishing, the oil industry, as well as overfishing, also cause SSF alterations (e.g., Jackson et al., 2001; Lotze et al., 2006; Harnik et al., 2012). Furthermore, SSF sustainability may be further

* Corresponding author.

E-mail address: lotoluciana@yahoo.com.ar (L. Loto).

jeopardized by global climate changes, especially in tropical countries (Sumaila et al., 2007; Lam, 2012). Small-scale fisheries in local communities may become vulnerable (*sensu* Kasperson and Kasperson, 2001) to these myriad threats. The degree of exposure to a given threat, how the local people are affected by this threat (sensitivity) and how they respond (resilience) are incorporated in the vulnerability concept (Thompson et al., 2016). As these threats persist, integrated approaches to management are needed to ensure SSF sustainability while benefiting resource users and protecting the marine environment (Afflerbach et al., 2014).

Territorial Use Rights for Fisheries (TURFs) are a spatial form of property rights granted to individuals or a group of fishermen, in which they have access privileges and fishing rights to exploit fisheries resources within a designated area (Christy, 1982; Quynh et al., 2017). In Brazil, public policies directed at traditional SSF include the establishment of a TURF-type reserve called Marine Extractive Reserves (RESEX-Mar). The Itaipu fishing community, located in the city of Niterói and within the metropolitan circle of the Guanabara Bay and the city of Rio de Janeiro, recently became one of these reserves (Itaipu RESEX-Mar). Local traditional fisheries have been studied since the 70's, describing fishing methods, and the local ecological knowledge related to fishery resources (Lima and Pereira, 1997; Pessanha, 2003; SEA/INEA, 2013). Available information encompassing three different periods across more than four decades, have provided an important dataset to test for significant changes in the traditional fishery system under several economic and gentrification pressures. Our hypothesis is that the gentrification of an almost exclusive fishing village, combined with economic demands and technological advances, have influenced artisanal fisheries, leading to changes and adaptations in fisheries technologies (from traditional to novel), fisheries production, and the use of the traditional fishing areas. Thus, the main aim of the present study is to use the Itaipu RESEX-Mar as a study case for identifying trend adaptation capacities in a SSF system, located in a large metropolitan region, facing the dilemma of fisheries collapse due to several economic, social and environmental pressures.

2. Methods

2.1. Study area

The research was carried out in a traditional fishing community located in the coastal zone adjacent to Guanabara Bay, in the South Atlantic Ocean. Guanabara Bay is one of the most important and urbanized estuarine environments in the Brazilian coast, surrounded by the metropolitan region of Rio de Janeiro, with a population of more than 12 million inhabitants (IBGE, 2016). The average annual population growth in the region was of 0.86% in the last decade (Chediek, 2014). The fishing area includes a variety of ecologically relevant environments, including two coastal lagoons (Itaipu and Piratininga lagoons) and a three-island cordon that aggregates high fish and invertebrate biodiversity (Mendonça-Neto et al., 2008; Chaves and Monteiro-Neto, 2009). The region is mainly influenced by tropical ocean currents, with the occasional upwelling of cold-water masses (SACW) predominantly in the summer, and a frequent supply of coastal waters from Guanabara Bay and Itaipu and Piratininga lagoons (Monteiro-Neto et al., 2008; Cerda et al., 2013, 2016) (Fig. 1).

Itaipu and Piratininga beaches maintain records of the occupation of ancient human hunter-gatherer populations, called sambaqueiros (4500 years ago). These pre-historic groups already explored fishery resources in the area for their own consumption (Kneip et al., 1981; Mello and Coelho, 1989; Anjos et al., 2010), indicating strong fishing traditional roots. The artisanal fisheries currently found at Itaipu date back more than 200 years (BRASIL, 1876; Araujo, 1945). Fishermen Traditional Ecological Knowledge (TEK) from ancestral populations has been transmitted throughout generations of fishermen (Lima and Pereira, 1997; Pessanha, 2003). Since the 1920s, local professional fishermen

have been institutionally linked to the Z-7 Fisheries Colony (Federal Bill Nº 11.699/2008), which also includes fishermen from neighboring areas or local fishermen's associations. Currently, most of the fisheries are concentrated within a TURF type reserve, the Itaipu Marine Extractive Reserve (Itaipu RESEX-Mar) (Fig. 1). The reserve was officially created by decree on September 30, 2013 (Decree No. 44.417, Official Gazette of the State of Rio de Janeiro). The Itaipu RESEX-Mar encompasses an area of 3943.28 ha, which was previously approved by the fishermen, and other representative groups, following the national legislation guidelines (SNUC, 2000).

2.2. Sampling and data analysis

Current data on catch composition and fish production were obtained by a daily landing monitoring program, developed by the Institute for Fisheries of the State of Rio de Janeiro (Fundação Instituto de Pesca do Estado do Rio de Janeiro - FIPERJ), from January to December 2013. During this period, the following information was recorded: date of landing, fishing gear, fishing area, composition and specific production (kg) of the catch. The species were identified based on relevant literature (Figueiredo, 1977; Figueiredo and Menezes, 1978, 1980; Menezes and Figueiredo, 1980, 1985, 2000; Carvalho-Filho, 1999). The fishing yield (Catch Per Unit Effort - CPUE) was calculated using the number of fishing trips as the unit of effort. Information on the characteristics of each type of fishing methods, the gear used and active vessels were obtained from structured and semi-structured interviews conducted with the fishermen, between March 2013 and February 2016.

To identify the spatial patterns of gillnet and hook-and-line catches, the fishing locations reported by the fishermen were geographically positioned within 2 nautical mile quadrants and plotted on maps. The presented information refers to the fishing yield (CPUE) per quadrant, calculated by the sum of the catch divided by the total number of trips performed in each quadrant.

To verify changes in fisheries over the last four decades, previously published information was compiled and used as reference for the following parameters: (i) catch composition, (ii) production, (iii) fishing yield (CPUE) (iv) general characteristics of the fishing methods, (v) boat type and (vi) fishing area. The main sources were: 1st period (1970–1973): Lima and Pereira (1997), and Pessanha (2003); 2nd period (2000–2003): Tubino et al. (2007, 2014); 3rd period (2013–2016), FIPERJ official statistical data and the present study. To assess possible modification vectors affecting the fisheries over time, relevant information about the evolutionary history of the local fishing system were chronologically compiled from the available literature.

3. Results

3.1. Fishermen and people associated with fish production

Currently, Itaipu fisheries comprise approximately 110 fishermen directly engaged in fishing activities, and 13 fish buyers (traders). Among the 81 fishermen interviewed, 73.6% were men, 49.0% were over 50 years old, and 43.0% between 30 and 50 years (average = 50.0 years, SD = 13.7). Just over half (51.0%) stated their father was also a fisherman and 85.0% were affiliated to the Z-7 fishermen's colony. Most were engaged in gillnet and hook-and-line fisheries (43.0% and 35.0%, respectively). A small number (13.0%) participated exclusively in beach seine fisheries.

Daily production is landed at a single point on Itaipu beach and the sale is carried out through an auction system between fishermen and local traders. Subsequently, the catches are sold in in-store benches on the beach to local restaurant owners, the general population, and brokers from nearby markets. At least 20 restaurants and snack bars that offer fish as part of their menu are located on the same beach where the landings take place.

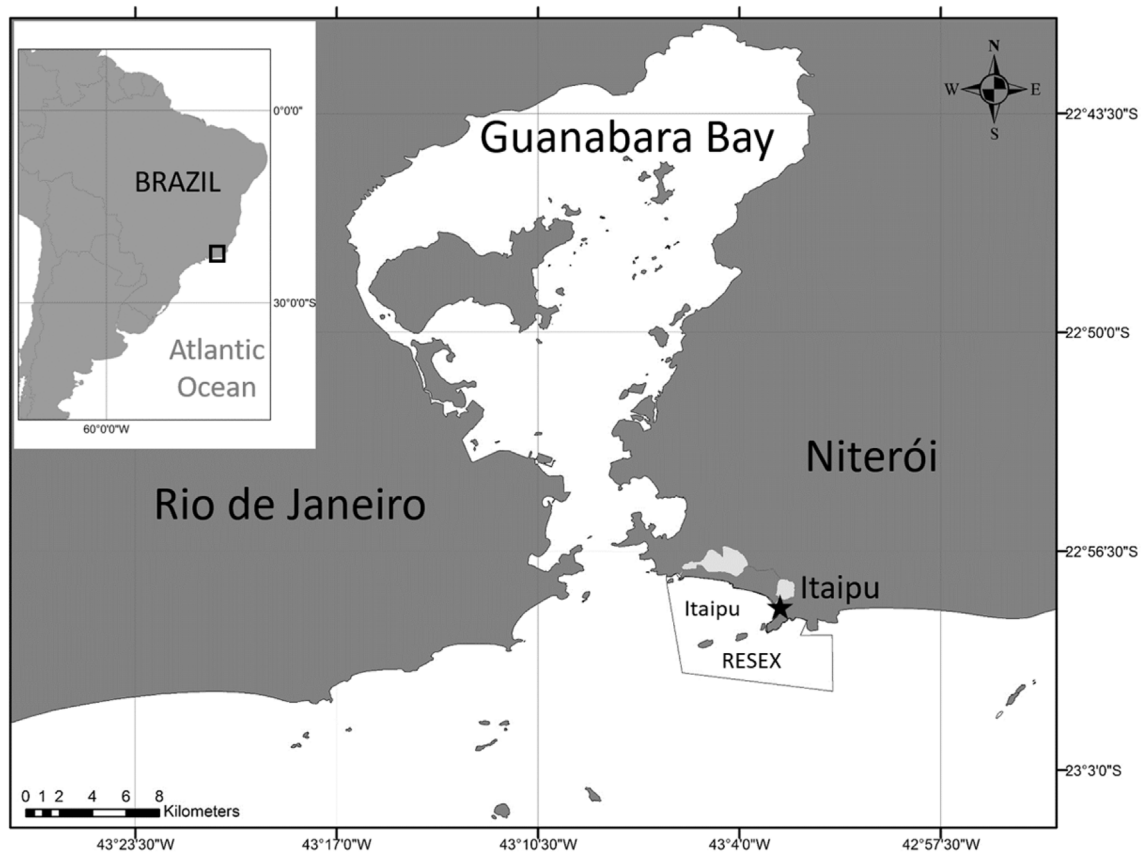


Fig. 1. Geographic location of the studied area in Brazil, South America, and the Itaipu coastal region within the metropolitan area of Rio de Janeiro. The polygon indicates the limits of the Itaipu RESEX-Mar.

3.2. Current fisheries

The total production landed in 2013 came from 2793 trips, totaling 108,400 kg (CPUE = $38.8 \text{ kg} \cdot \text{trip}^{-1}$). Most of the landings (88.0%) had their species composition identified and fishing modality accounted for, representing a production of 90,775 kg ($36.9 \text{ kg} \cdot \text{trip}^{-1}$) (Table 1). Ninety-four species or species categories of bony and cartilaginous fishes, crustaceans and mollusks were recorded. Four species were responsible for 77.0% of the total landed production, and each represented more than 5.0% of the total catch, individually. Whitemouth croaker (*Micropogonias furnieri*) was the main landed species (37.3% of the identified catch) and was captured mainly by “corvineira” gillnets (gillnets used to capture mostly *M. furnieri* - 98.4%). Bigeye (*Priacanthidae*) contributed with 20.6%, and largehead hairtail (*Trichiurus lepturus*) with 11.6%, both captured mostly by hook-and-line (86.2% and 86.9%, respectively). White snake mackerel (*Thysitops lepidopoides*) represented 7.4% of the identified catch, and was captured, for the most part, by beach seining (70.5%). Other noteworthy species included toadfish (*Porichthys porosissimus*), with 99.3% of the production coming from “corvineira” gillnets, squid (*Doryteuthis* spp.), mainly caught by squid jigging, and bluefish (*Pomatomus saltatrix*) with 53.8% of the catch coming from “corvineira” gillnets (Table 1).

The type of fishery with the greatest participation in the total of the identified catches was the “corvineira” gillnet fishery, contributing with 52.4% of the total catch and a yield of $30.9 \text{ kg} \cdot \text{trip}^{-1}$. The predominant species in the “corvineira” catches were *M. furnieri*, *P. porosissimus*, *T. lepidopoides*, *T. lepturus*, *P. saltatrix* and Atlantic bigeye (*Priacanthus arenatus*). The hook-and-line fishery was the second most important regarding the landed volume. Its contribution was 32.0% of the total catch ($52.6 \text{ kg} \cdot \text{trip}^{-1}$), mainly composed of *P. arenatus*, *T. lepturus*, Weakfishes (*Cynoscion* spp.) and Florida pompano (*Trachinotus carolinus*). The beach seine fishery accounted for 10.0% of the total landed

production, and showed the highest yield among all of Itaipu fisheries ($103.3 \text{ kg} \cdot \text{trip}^{-1}$), capturing a wide variety of species, including *Cynoscion* spp., Mojarras (*Eucinostomus* spp.), *Doryteuthis* spp., *Selene* spp., *M. furnieri* and *P. arenatus*. The “Rede alta” gillnet fishery contributed with 3.7% ($25.6 \text{ kg} \cdot \text{trip}^{-1}$) of the total landings, and was used for capturing mostly *P. saltatrix*. Other species included *P. arenatus*, *P. saltatrix*, *T. lepidopoides*, *T. lepturus*, Atlantic bonito (*Sarda sarda*) and Snook (*Centropomus* spp.). Squid jigging contributed with 1.6% ($11.4 \text{ kg} \cdot \text{trip}^{-1}$) of the landings, and had *Doryteuthis* spp. as target species. Spear fishing, “linguadeira” (gillnet used to capture mostly flatfishes), and traps contributed to less than 1.0% of the total landed production (Table 1).

The spatial distribution of the pooled gillnet effort (“corvineira”, “rede alta”, “linguadeira”) indicates that the fishing area comprises the polygon formed by the area adjacent to the entrance of the Guanabara Bay, closest to the coast of the city of Rio de Janeiro and the coastal region of Maricá in the latitudinal direction, and outside Rasa Island at the longitudinal boundary, near the 50 m deep isobath (Fig. 2A). The obtained yields per quadrant indicated higher values in the vicinity of Rasa Island. The operations carried out off Itaipu down to a depth of approximately 30 m were also very productive. Regarding the number of operations per quadrant, the area of the Itaipu RESEX-Mar constituted the predominant fishing area for gillnets.

The distribution area of the hook-and-line fishery (Fig. 2B), was restricted within the polygon formed by the region adjacent to the entrance of Guanabara Bay, closest to the coast of the city of Rio de Janeiro, the coastal region and Maricá Island in the latitudinal direction, and in the longitudinal limit outside Rasa Island and Redonda Island, near the 50 m deep isobath. The highest yields were recorded near Redonda Island, off the coast of Maricá, and Itaipu. The yields obtained within the Itaipu RESEX-Mar area were also considerably high.

Table 1

Common name	Scientific name	Beach seine		Gillnets		Hook-and-line				Squid jigging		Spear fishing		Trap		TOTAL				
				Corvineira		Rede alta		Linha												
		C	Y	C	Y	C	Y	C	Y	C	Y	C	Y	C	Y		C (%)	Y		
TELEOSTS																				
Whitemouth croaker	<i>Micropogonias furnieri</i>	386	4.4	33,365	21.7	34	0.3	93	0.2	20	0.2						33,898	37.3	13.8	
Atlantic bigeye	<i>Priacanthus arenatus</i>	268	3.1	684	0.4	1501	11.5		29.2	112	1.0			6	3.0	18,677	20.6	7.6		
Largehead hairtail	<i>Trichiurus lepturus</i>	221	2.5	987	0.6	170	1.3	9179	16.6							10,557	11.6	4.3		
White snake mackerel	<i>Thyrstopsis lepidopoides</i>	4738	53.8	1568	1.0	200	1.5	4	0.8	212	0.4	2	< 0.1			6724	7.4	2.7		
Mixed catch		1302	14.8	3376	2.2	170	1.3	986	1.8					15	1.5	5849	6.4	2.3		
Toadfish	<i>Portichthys porosissimus</i>			3233	2.1	23	0.2									3256	3.6	1.3		
Weakfishes	Sciaenidae	16	0.2	756	0.5	5	< 0.1	688	1.3							1465	1.6	0.6		
Bluefish	<i>Pomatomus saltatrix</i>	107	1.2	693	0.5	273	2.1	214	0.4							1287	1.4	0.5		
Florida pompano	<i>Trachinotus carolinus</i>	3	< 0.1	188	0.1	34	0.3	589	1.1	18	0.1	1	0.1			833	0.9	0.3		
Mojarra	<i>Eucinostomus</i> spp.	620	7.1	10	< 0.1	2	< 0.1									632	0.7	0.3		
Blue runner	<i>Caranx crysos</i>	1	< 0.1	235	0.2	50	0.4	178	0.3	4	< 0.1					468	0.5	0.2		
Dusky grouper	<i>Epinephelus marginatus</i>			14	< 0.1	6	0.1	310	0.6					11	1.1	341	0.4	0.1		
Atlantic moonfish	<i>Selene setapinnis</i>	301	3.4	35	< 0.1	1	< 0.1	1	< 0.1							338	0.4	0.1		
Marine catfish	<i>Genidens</i> spp.			265	0.2	51	0.4	22	< 0.1							338	0.4	0.1		
Snook	<i>Centropomus</i> spp.	8	0.1	150	0.1	153	1.2	2	< 0.1							313	0.3	0.1		
Clupeiforms	Clupeidae	195	2.2	10	< 0.1	13	0.1									218	0.2	0.1		
Grunts	Haemulidae			204	0.1	4	< 0.1	3	< 0.1							211	0.2	0.1		
Frigate tuna	<i>Auxis thazard</i>	1	< 0.1	67	< 0.1	127	1.0	2	< 0.1							197	0.2	0.1		
Atlantic bonito	<i>Sarda sarda</i>			12	< 0.1	182	1.4									194	0.2	0.1		
Mutton snapper	<i>Lutjanus analis</i>	30	0.3	83	0.1	41	0.3	9	< 0.1							163	0.2	0.1		
Bicuda	<i>Sphyræna</i> spp.	11	0.1	15	< 0.1	1	< 0.1	127	0.2							154	0.2	0.1		
Brazilian codling	<i>Urophycis brasiliensis</i>			154	0.1											154	0.2	0.1		
Planehead filefish	<i>Stephanolepis hispidus</i>	3	< 0.1	128	0.1	10	0.1	6	< 0.1	1	< 0.1	1	0.1	4	2.0	153	0.2	0.1		
Lebranche mullet	<i>Mugil itea</i>	2	< 0.1	22	< 0.1	121	0.9	4	< 0.1							149	0.2	0.1		
Atlantic spadefish	<i>Chaetodipterus faber</i>	122	1.4	17	< 0.1								2	0.2		141	0.2	0.1		
King mackerel	<i>Scomberomorus cavala</i>	5	0.1	87	0.1	42	0.3	2	< 0.1							136	0.1	0.1		
Silver porgy	<i>Diplodus a. argenteus</i>			42	< 0.1	25	0.2	57	0.1							124	0.1	0.1		
Brazilian flathead	<i>Percophis brasiliensis</i>			84	0.1	3	< 0.1	21	< 0.1							108	0.1	< 0.1		
Red porgy	<i>Pagrus pagrus</i>			66	< 0.1			38	0.1							104	0.1	< 0.1		
Leatherjack	<i>Oligoplites saurus</i>			91	0.1	2	< 0.1	3	< 0.1							96	0.1	< 0.1		
Atlantic bumper	<i>Chloroscombrus chrysurus</i>			69	< 0.1	12	0.1	1	< 0.1							82	0.1	< 0.1		
Flatfishes	Paralichthyidae, Achiridae and Bothidae	2	< 0.1	71	0.1											75	0.1	< 0.1		
Catitpa mojarra	<i>Diapterus rhombeus</i>	31	0.4	37	< 0.1	5	< 0.1	2	0.4							73	0.1	< 0.1		
Grouper	<i>Mycteroperca</i> spp.			46	< 0.1	10	0.1	7	< 0.1				1	0.1		64	0.1	< 0.1		
Crevalle jack	<i>Caranx hippos</i>			10	< 0.1	21	0.2	23	< 0.1							54	0.1	< 0.1		
Skipjack tuna	<i>Katsuwonus pelamis</i>			20	< 0.1	30	0.2	1	< 0.1							51	0.1	< 0.1		
Black drum	<i>Pogonias cromis</i>	2	< 0.1	47	< 0.1			1	< 0.1							50	0.1	< 0.1		
Blackfin goosefish	<i>Lophius gastrophysus</i>			50	< 0.1											50	0.1	< 0.1		
Moray	<i>Gymnothorax</i> spp.	1	< 0.1					46	0.1							47	0.1	< 0.1		
Others (< 0.1% of Total Catch)		37	0.4	177	0.1	31	0.2	77	0.1				2	0.2		324	0.4	0.1		
Total		8413	95.6	47,168	30.6	3353	25.6	6	1.2	29,008	52.6	157	1.2	33	3.3	10	5.0	88,148	97.1	35.9

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(continued on next page)

Table 1 (continued)

Common name	Scientific name	Beach seine		Gillnets				Hook-and-line				Squid jigging		Spear fishing		Trap		TOTAL	
				Corvineira		Rede alta													
		C	Y	C	Y	C	Y	C	Y	C	Y	C	Y	C	Y	C	Y		C (%)
Sharks	Squatinae, Sphymidae, Lamnidae and Unidentified Sharks			61	< 0.1	1	< 0.1										62	0.1	< 0.1
Total				325	0.2	1	< 0.1	9	1.8	40	0.1						375	0.4	1.2
CRUSTACEANS																			
Crabs	Portunidae	31	0.4	61	< 0.1												92	0.1	< 0.1
Slipper lobster	Scyllaridae			16	< 0.1												16	0.0	< 0.1
Lobster	Panulirus spp.			6	< 0.1												6	0.0	< 0.1
Total		31	0.4	83	0.1												114	0.1	0.1
MOLLUSKS																			
Squid	Doryteuthis spp.	644	7.3	10	< 0.1							1297	10.1				1951	2.1	0.7
Mussel	Perna perna													130	13.0		130	0.1	0.1
Octopus	Octopus vulgaris	1	< 0.1	5	< 0.1	2	< 0.1			5	< 0.1	1	< 0.1	43	4.3		57	0.1	< 0.1
Total		645	7.3	15	< 0.1	2	< 0.1			5	< 0.1	1298	10.1	173	17.3		2138	2.4	0.8
Identified fishing gear	Total catch (kg)	9089	103.3	47,591	30.9	3356	25.6	15	3.0	29,053	52.6	1455	11.4	206	20.6	10	5.0	90,775	36.9
	Trips	88		1541		131		5		552		128		10		2		2457	
Unidentified fishing gear	Total catch (kg)																17,625	52.5	
	Trips																336		
Total	Total catch (kg)																108,400	38.8	
	Total Trips																2793		

Scaenidae - *Cynoscion leiarchus* (64.8%); Unidentified Weakfish (31.8%); *C. jamaicensis* (1.8%); *C. striatus* (1.4%); *C. acoupa* (0.1%); Clupeidae - *Sardinella brasiliensis* (65.1%); *Brevoortia aurea* (33.5%); *Opisthonema oglinum* (0.9%); *Harengula clupeola* (0.5%); Haemulidae - *Haemulon plumieri*; *Boridia grossidens*; *Orthopristis ruber*; Paralichthyidae, Achiridae and Bothidae - *Citharichthys arenaceus*; *Syacium papillosum*; *Achirus lineatus*; *Bothus ocellatus*; Dasyatidae and Rhinobatidae - Unidentified Rays (38.0%); *Dasyatis* spp. (31.9%); *Pseudobatos* spp.; *Zapteryx brevirostris* (30.0%); Squatinidae, Sphymidae, Lamnidae - Unidentified Sharks (48.4%); *Squatina* spp. (25.8%); *Sphyrna lewini* (19.4%); *Isurus oxyrinchus* (6.5%); Portunidae - *Callinectes* spp., *Arenaeus cribrarius*.

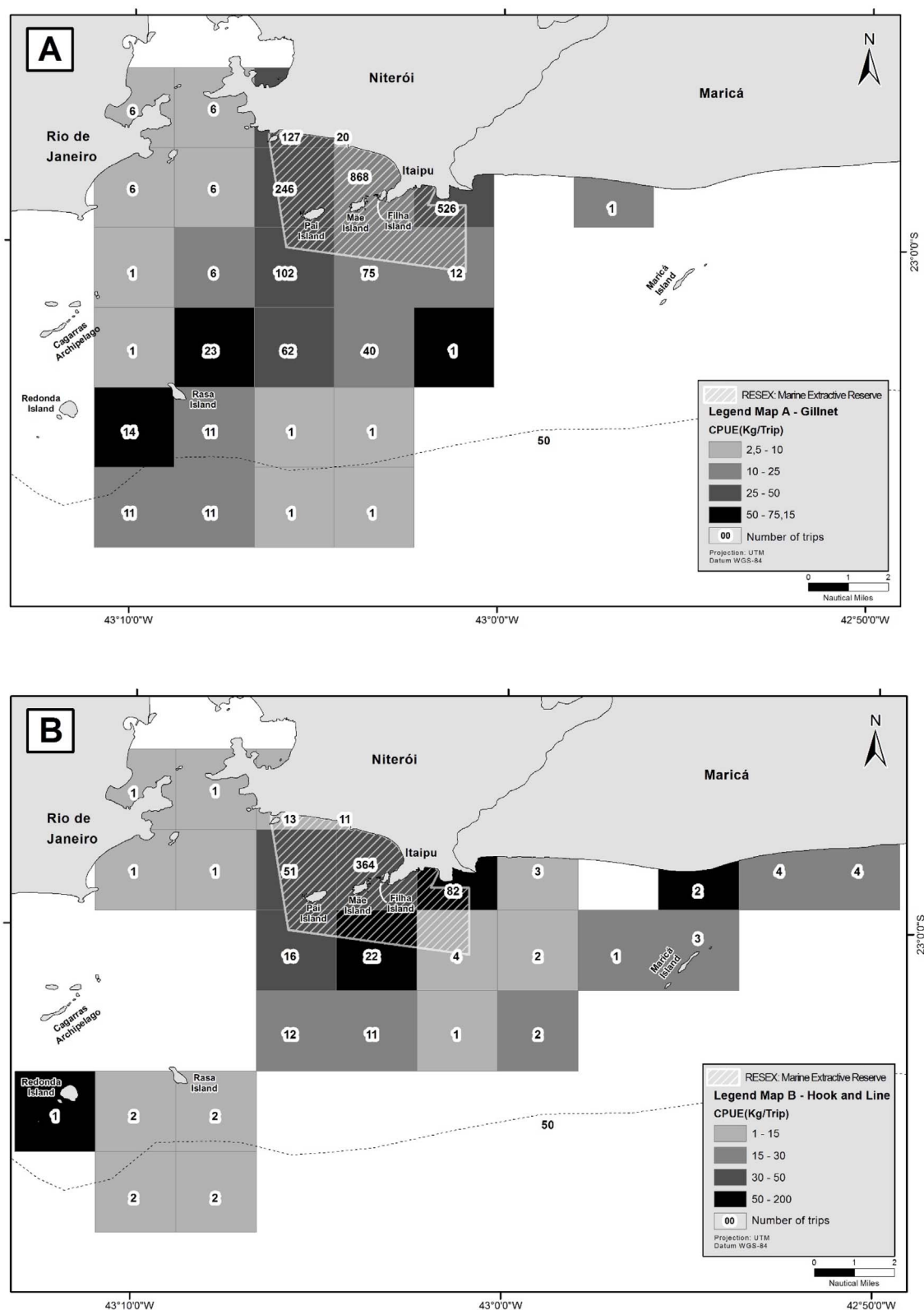


Fig. 2. Spatial distribution of gillnet (A) and hook-and-line (B) fisheries yields ($\text{kg} \cdot \text{trip}^{-1}$) obtained in 2013. The shadowed area corresponds to the Itaipu RESEX-Mar. The numbers within the quadrants correspond to the number of trips made.

3.3. Changes in fisheries over the past decades

The comparison between the different study periods (1st – 1974–75; 2nd – 2000–03 and 3rd – 2013) regarding the fisheries production, catch composition and yields (CPUE) (Table 2) indicated a gradual

decrease of approximately 30,000 kg of the total annual production between periods, equivalent to a decline of 33.3% throughout the whole period (0.5% per year). The drastic fall in the total yield between the 1st and the 2nd periods was followed by a relative stability at around $35\text{--}39 \text{ kg} \cdot \text{trip}^{-1}$ in the third most recent period.

Table 2

Annual production (kg) and proportions of the total catch (%) of the major categories of species caught in the 1st period (1974–75) estimate from Lima and Pereira (1997) and Pessanha (2003), 2nd period (2001–03) from Tubino et al. (2007) and 3rd period (2013) from current study, changes in the proportions of species in the total catch (%) between 1974–75 and 2013, and trends of variation in proportion (%) of total production.

Species or commercial category		Annual production						Changes in the proportions of species in the total catch (%)	Trends of variation in proportion of total production	
		1 st period		2 nd period		3 rd period				
Common name	Scientific name	Kg	%	Kg	%	Kg	%			
Lebranche mullet	<i>Mugil liza</i>	33840	20.8	1044	0.8	149	0.2	-20.7	↘	↘
Carangids	<i>Caranx</i> spp.	33000	20.3	1044	1.8	149	0.6	-19.8	↘	↘
Atlantic moonfish	<i>Selene setapinnis</i>	25785	15.9	1638	1.2	338	0.4	-15.5	↘	↘
Scombrids	*a	18600	11.4	38	0.03	578	0.6	-10.8	↘	↘
Clupeiforms	*b	3300	2.0	7070	5.2	218	0.2	-1.8	↘	↘
Planehead filefish	<i>Stephanolepis hispidus</i>	3000	1.8	19	0.01	153	0.2	-1.7	↘	↘
Largehead hairtail	<i>Trichiurus lepturus</i>	20067	12.3	25992	19.0	10557	11.6	-0.7	↘	↘
White snake mackerel	<i>Thyrsitops lepidopoides</i>	12570	7.7			6724	7.4	-0.3		
Sharks	*c	210	0.1	3019	2.2	62	0.1	-0.1	↘	↘
Smooth puffer	<i>Lagocephalus laevigatus</i>			1494	1.1			0		
Mojarra	<i>Eucinostomus</i> spp.			6707	4.9	632	0.7	0.7		↗
Squids	<i>Doryteuthis</i> spp.	2085	1.3	8439	6.2	1951	2.1	0.9	↘	↗
Bluefish	<i>Pomatomus saltatrix</i>	292	0.2	145	0.1	1287	1.4	1.2	↘	↗
Weakfishes	<i>Cynoscion</i> spp.			5726	4.2	1465	1.6	1.6		↗
Toadfish	<i>Porichthys porosissimus</i>			8	0.01	3256	3.6	3.6		↗
Others	*e	1844	1.1	15000	11.0	4459	4.9	3.8	↘	↗
Mixed catch	*d	4200	2.6	6520	4.8	5849	6.4	3.9	↘	↗
Atlantic bigeye	<i>Priacanthus arenatus</i>	3480	2.1	94	0.1	18677	20.6	18.4	↘	↗
Whitemouth croaker	<i>Micropogonias furnieri</i>	270	0.2	51309	37.5	33898	37.3	37.2	↘	↗
Total (Kg)		162543	100.0	136687	100.0	90775**	100.0			
CPUE (Kg*trip- 1)		286.1		35.0		38.8***				

*a - *Auxis thazard*; *Sarda sarda*; *Scomberomorus cavalla*; *Katsuwonus pelamis*.

*b - *Sardinella brasiliensis*; *Brevoortia aurea*; *Opisthonema oglinum*; *Harengula clupeola*.

*c - *Squatina* spp.; *Sphyrna lewini*; *Isurus oxyrinchus*; unidentified sharks.

*d - < 1.0% of Total Catch.

*e - Variety of non-commercial species.

** - Value related to the total production landed from identified fishing gears.

*** - Value of the total production landed (identified and unidentified fishing gears).

The catch composition indicated important changes over time throughout the evaluated periods (Table 2). In the 1970s, (1st period) landed production was predominantly dominated by pelagic fish species, such as mullet (*Mugil liza*), *Caranx* spp., *T. lepturus* and scombrids, captured mainly by the beach seine fishery. Two modalities existed at that time: beach seines with and without the “watchman”. The beach seine with the “watchman” was a special modality in which the whole operation occurred with the help of an expert man on land, “the watchman”, who spotted the arrival of fish schools within a certain fishing area. The beach seine without “the watchman” is practiced today, and lacks the expertise of this expert to locate fish schools. In the 1st period, both types were predominant among fisheries and were practiced seasonally. Notably, the capture of the above species decreased dramatically in the following periods, and *M. furnieri* assumed the main position in landed volumes. This species alone accounted for more than 30.0% of the total catch composition in both periods 2nd and 3rd. Catches were predominantly from gillnets. In addition, *T. lepturus*, and more recently, *P. arenatus*, became important in the landings from the hook-and-line fishery.

Sardines (Clupeidae), *Doryteuthis* spp., sharks, *Eucinostomus* spp. and scianid fishes decreased their relative participation in the total production during the 3rd period. On the other hand, species of low commercial interest in the past (e.g. *P. porosissimus*, smooth puffer - *Lagocephalus laevigatus*) became relatively important in the present

(Table 2).

3.4. Changes in fishing gear and fishing fleet

Fishing practices today are nearly the same as previously recorded by Tubino et al. (2007) during 2nd period. These included beach seines, gillnets (“corvineira”, “rede alta” and “linguadeira”), hook-and-line, spear fishing and traps. However, comparing the 2nd and 3rd periods with the 1st, important changes are observed. The most dramatic was the disappearance of beach seines with watchmen used to capture mullet and white mullet shoals. Beach seine without watchmen also suffered a decrease in the number of productive units, of over 50.0%. Seines maintained nearly the same mesh size, but increased in length from the 1st to the 3rd period (Table 3).

On the other hand, there was a significant ($X^2 = 23.4$, $p < .05$) two-to three-fold increase in the number of gillnet productive units within the gillnet fishery from the 1st period to the most recent periods. The “corvineira” gillnet was the predominant equipment used throughout all periods, followed by “rede alta” and “linguadeira”. Mesh size was highly variable, but the lengths of the equipment increased towards more recent periods (Table 3).

Data on the number of productive units within the hook-and-line fishery were unavailable for comparisons with the 1st period. Nevertheless, recent data for periods 2nd and 3rd indicated an increase

Table 3

Amount of productive units by fishing gears in operation during the different study periods: 1st period (1974–75), from Lima and Pereira (1997) and Pessanha (2003), 2nd period (2001–03) from Tubino et al. (2007) and 3rd period (2013–16) from current study. Length (m) and mesh (mm) size of gillnets and seines. Yield values (CPUE: kg*trip⁻¹) per fishing modality (ND = No Data).

Fishing gear	Period											
	1 st				2 nd				3 rd			
	In operation	Length	Size mesh	CPUE	In operation	Length	Size mesh	CPUE	In operation	Length	Size mesh	CPUE
White mullet beach seine with watchman	3	200	20	ND	0	–	–	–	0	–	–	–
Mullet beach seine with watchman	8	320	45–50	ND	0	–	–	–	0	–	–	–
Beach seine	8	120	40–45	ND	6	200	18–32	109.0	3	250	18–45	103.3
"Corvineira" gillnet	ND	330	45–60	ND	ND	1031	45–70	25.0	20	500–1600	45–70	30.9
"Rede alta" gillnet	ND	660	45–60	ND	ND	600	40–55	10.0	13	200–1000	40–55	25.6
"Linguadeira" gillnet	ND	ND	ND	ND	ND	556	100–120	7.0	4	230–1000	100–110	3.0
Gillnets total	12			ND	51				37			
Hook-and-line	ND			ND	15			21.0	17			52.6
Longline	1			ND	0			–	0			–
Squid jigging	ND			ND	20			3.0	43			11.4
Trap	2			ND	1			11.0	2			5.0
Spear fishing	1			ND	5			4.0	4			20.6
Total				286.2				35.0				38.8

in this type of fishing modality and an important difference in the length of the "corvineira" gillnets used in the most recent periods when compared to the 1st period, despite the mesh amplitude remaining the same (Table 3).

Trends concerning the fishing fleet across periods included significant increases in the number of large dory-type woodboats ($X^2 = 16.7$, $p < .05$) and outboard aluminum boats ($X^2 = 35.0$, $p < .05$), used mostly in gillnet and hook-and-line fisheries, respectively. A significant strong decline ($X^2 = 11.4$, $p < .05$), about six-fold, occurred in the dugout canoe fleet used mainly in beach seining (Table 4).

Currently, almost all fishing boats are motorized. The use of oars for propulsion is restricted to the remaining dugout canoes and the small dory-type woodboats. Engine power varied considerably, but 25 HP outboard engines were most common. Two large dory-type woodboats and three outboard aluminum boats possessed 40 HP engines. Data on engine power for dugout canoes and small dory-type woodboats were available for the 2nd and 3rd periods only. Dugout canoes possessed 12 HP engines, and small dory-type woodboats 3.3 HP, in both periods. Wheelhouse gillnetters (boats with inboard diesel engines, of average length of 9 m) were powered by 33 HP engines in the 2nd period and 18 HP in the 3rd period.

The historical information compiled on the local fishing system allowed for the reconstruction of its evolutionary history and the recognition of events (changing vectors) that determined changes over

time (Table 5). The changing vectors were predominantly associated with urban expansion and gentrification, starting in the 50s. These pressures caused changes in the fishing space, including restrictions on beach use and access to fishing spots. At the same time, the decline of the abundance of pelagic fish resources (e.g. mullets and carangids), led to the disappearance of certain fishing practices within the beach seine fishery, and an expansion of the gillnet fishery. The introduction of nylon filament in the 1970s reduced costs of fishing material. Thus, nearly every fishermen became the owner of his/her own fishing gear (the gillnet), as opposed to the beach seine productive unit, the "companha" (*sensu* Lima and Pereira, 1997). More recently, the greater ease in the acquisition of the fishing gear and powerful vessels has resulted in an increase in these individually-owned productive units, especially within the hook-and-line and gillnet fisheries (SEA/INEA, 2013) (Table 5).

4. Discussion

The patterns of species composition and abundance identified in current catches reinforce the typical multispecies character of small-scale fisheries found in other parts of the world, especially in tropical regions, such as those reported by Salas et al. (2011); Pennino et al., 2016; Saldaña et al., 2016. The diversity of habitats in waters near Itaipu, including coastal lagoons and islands, and the proximity to Guanabara Bay, favor the occurrence of different species and

Table 4

Composition of the fishing fleets in operation during each study period: 1st (1974–75) from Lima and Pereira (1997) and Pessanha, 2003 2nd (2001–03) from Tubino et al. 2007 and 3rd (2013–16) from current study, type and amount of boats in operation, average length (m), propulsion mode and fishing gears in which they are used (main fishery indicated in bold).

Boats type	Fishing gear	Average length (m)	Period					
			1 st		2 nd		3 rd	
			In operation	Propulsion mode	In operation	Propulsion mode	In operation	Propulsion mode
Dugout canoes	Beach seine , gillnets	7.4	18	Rowing	9	Motor and Rowing	3	Motor and Rowing
Small dory-type woodboats	Hook-and-line , trap, spear fishing	3.6	2	Rowing	8	Rowing	6	Motor and Rowing
Large dory-type woodboats	Gillnets , hook-and-line	5.3			9	Motor	17	Motor
Outboard aluminum boats	Hook-and-line , gillnets	5.3			2	Motor	21	Motor

Table 5
Main events that influenced the changes and adaptations of the small-scale fishing system at Itaipu.

Decades	Events	Changes in the fishing system	Features of the fishing system
1920–1930	Creation of the Fishermen's Colony (current Z7) (Pessanha, 2003).	Formal recognition of the territory occupied by fishermen	Predominance of the beach seine fisheries with watchman
1940–1950	Itaipu incorporated into the Municipality of Niterói. Allotment of 'Balnearia City Itaipu' (Territorial Development Company) (Lima and Pereira, 1997).	Beginning of urban expansion in the region	
1960–1970	Construction of the Rio-Niteroi Bridge. Permanent opening of the Itaipu Lagoon channel by Veplan company (Lima and Pereira, 1997).	Increasing urban sprawl. Change in the dynamics of the connection between the lagoon and the sea. Expropriation of fishermen households from the coast in Cambinhas. Number of fishermen families residing in Itaipu is reduced. Change in the rules of use of the space and time of fisheries (gill nets used day and night).	
1980–1990	Introduction of nylon in gillnets. Expansion of the use of gillnets (Pessanha, 2003). Declaration of the Fisherman's Village at Itaipu as cultural heritage (State Institute of Cultural Heritage) (SEA/INEA, 2013). Promotion of industrial fishing through federal subsidies (Giulietti and Assumpção, 1995). Increased tourism and real estate speculation (FGV, 2011). Growth of the naval and oil industries (FGV, 2011).	Recognition of the traditional fishing area in Itaipu. Decrease in fishing resources. Changes in fishing gear and resources. Increase of constructions destined to tourism (restaurants, inns).	Predominance of the gillnet and hook-and-line fisheries.
2000–2013	More financial facility for the acquisition of fishing equipment and boats (The World Bank, 2017). Dredging for depollution of the Guanabara Bay (SUPMAM, 2008). Creation of the Itaipu Marine Extractive Reserve (Itaipu RESEX) (SEA/INEA, 2013).	Loss of fishing grounds. Increase of hook-and-line fishermen, increase in length of gillnets, and aluminum boats with engines replacing traditional woodboats. Increase in records of solid waste in fishing nets. Establishment of a marine protected area for exclusive use of the traditional artisanal fishing.	

population strata, which can be captured by the different fisheries in the area (Monteiro-Neto et al., 2008).

The differences observed in catch composition may be a consequence of multiple factors, including gear type, fishing area or season, either acting isolated or synergistically. Species may be more available during one time of the year, aggregate in one specific fishing ground and be vulnerable to one or more fishing gears. In this sense, fishermen may establish prognostics of potential catches, following the interpretation of the local environmental setting, using Traditional Ecological Knowledge (Lima and Pereira, 1997). In fact, Salas et al. (2004), while studying three fishing communities in the Yucatan-México peninsula, found that fishermen do not operate randomly, but consider information about the availability of resources and revenues generated on previous trips before selecting or changing their fishery targets.

The comparison between the current fisheries in Itaipu and previous data from the same system suggests that changes in the abundance of the target fisheries resources, the availability of new fishing technologies and environmental changes due to economic development and gentrification may have relevantly influenced the historical dynamics of the local fisheries (Lima and Pereira, 1997; Pessanha, 2003; Tubino et al., 2014). For instance, beach seining is one of the oldest, most traditional fishing method in coastal fishing communities in Brazil (Bernardes and Bernardes, 1950; Lima and Pereira, 1997; Duarte, 1999; Freitas Neto and Di Benedetto, 2007; Ramires et al., 2012). Nevertheless, the reduction in numbers of fishermen engaged in this fishery, such as the one observed in the present study, is apparent in several localities along the coast. The traditional beach seine fishery holds a complex knowledge of the local environment and biological responses of target species. Fishermen integrate their ecological knowledge of sea conditions (state, water temperature and visibility), bottom types, wind direction and phases of the moon to predict the types of fish expected to come within fishing grounds for directing the fishery (Lima and Pereira, 1997). At the end of the 1970s, during the 1st period, 18 productive units were engaged in the beach seine fishery. This number has reduced drastically towards the 3rd period, following the collapse of the mullet fishery. The disappearance of mullet and white mullet shoals from coastal waters of Itaipu, the most important resources of the traditional

beach seine with watchmen fishery (Lima and Pereira, 1997; Pessanha, 2003), led to the disappearance of this fishing modality targeting pelagic schooling fishes. These changes were followed by an increase in other fishing modalities, including gillnet and the hook-and-line fisheries (Monteiro-Neto et al., 2011; SEA/INEA, 2013; Tubino et al., 2014).

Fisheries resources changed considerably across periods. A drastic decrease in yields from the 1st period towards the 3rd period was observed, in the order of 33% over 40 years. Large schools of pelagic fishes (mullet, carangids, *Selene setapinis* and scombrids) nearly disappeared from the fishing grounds (Pessanha, 2003), possibly due to multiple factors limiting their occurrence in the area (Tubino et al., 2007). To date, the total catch is distributed among several species. In fact, a recent increase in CPUE in the 3rd period (2013), may be explained by an increased availability of non-traditional resources that became appreciated by consumers, generating new market demands (e.g. *P. porosissimus*), or the return of the once gone juvenile *P. arenatus* within the area. Nevertheless, despite the multitude of fishing modalities currently practiced, and the diversity of resources in the area, few species including *M. furnieri*, *T. lepturus* and *P. arenatus* accounted for more than half of the total production (58.2%). The dominance of *M. furnieri* and *T. lepturus* does not represent a novelty in coastal artisanal catches in Brazil (Martins and Haimovici, 1997; Vasconcellos et al., 2011; Amorim and Monteiro-Neto, 2016). Particularly *M. furnieri*, an abundant demersal fish, has sustained coastal fisheries in SE Brazil since pre-historical times (Lopes et al., 2016).

On the other hand, the increase in catches of less important species (e.g. *P. arenatus* and *P. porosissimus*) may be associated to the increase of the captures by hook-and-line fishery in recent years. In addition, species showing strong interannual fluctuations, such as the squid and *P. arenatus*, may also represent opportunities for the whole fisheries system, providing extra gains and stabilization against the decline of the more traditional resources. Saldaña et al. (2016) looking at adaptive strategies of small-scale fishers in Yucatan, Mexico verified the substitution of target species motivated by marketing values. Tubino et al. (2014) found that some species considered of low interest or “bad” for consumption in the past (Pessanha, 2003) have emerged as target species (e.g., *P. arenatus*, *P. porosissimus* and *Lagocephalus laevis*),

with considerable market value in recent years.

The biological characteristics related to individual species provide additional light towards understanding the increase in their own availability for local fisheries. According to Randall (1978) and Hureau (1990), shallow coastal waters (10–150 m) and hard bottoms (reefs) are typical environments for shoaling *P. arenatus*. In addition, the excellent species quality for consumption and high market value (Cervigón et al., 1992; Sumaila et al., 2007; Carvalho et al., 2009) make the Atlantic bigeye a valuable fishery resource. The high participation of this species in the current total production may be explained by the presence of shoals near the islands, facilitating their capture, especially by the hook-and-line fishery. The seasonal characteristic associated with gregarious behavior along shallow coastal areas may be linked to specific cyclic oceanographic conditions such as the presence of clear and warm waters. Amorim and Monteiro-Neto (2016), while studying a small-scale fishery near Itaipu, in the coastal zone adjacent to Guanabara Bay, recorded higher volumes of this species during spring and summer.

The recently established Itaipu Marine Extractive Reserve recognizes the fishing areas effectively claimed by the local traditional fishermen (SEA/INEA, 2013), following the procedures established in the Brazilian legislation (SNUC, 2000). Considering the spatial context of the current catches, the present study found that good yields are obtained within the area established for the Itaipu RESEX-Mar, and concentrating most of the fishing effort. However, good yields are also obtained in more distant areas, where the hook-and-line and the gillnet fisheries capture larger individuals of *M. furnieri* in the winter, and *P. saltatrix* in the summer. The present expansion of the fishing area previously recorded in the 1st (Lima and Pereira, 1997; Pessanha, 2003) and 2nd (Begossi, 2006; Tubino et al., 2007) periods, may represent a fishing tactic to obtain greater profits. These changes may also be explained by the increase in the number of motorized boats, which provided access to more distant and productive areas. Changes in catch patterns due to changes in the fleet have been recorded in other coastal fishing systems. Pennino et al. (2016), for example, when studying a small-scale fishing system in the northeastern coast of Brazil, observed that motorized boats showed strong spatially structured species catch composition in comparison to open water canoes.

The estimated number of fishermen showed a decrease of about 50% between periods. During the 1st period, Pessanha (2003), estimated 200 fishermen working in the fishing area. Lately, the number varied between 150 and 180 in the 2nd period (Tubino et al., 2007), and 98 in 2010 (SEA/INEA, 2013). The present study accounted for 110 fishermen. These changes may be associated with the limited number of beach seine productive units in recent years. These units usually hold at least eight fishermen fully engaged in the fishing operation. Although the number of gillnet and hook-and-line fisheries increased in the last decades, the increment was not enough to maintain the labour force, since the fishing method holds a smaller crew of only two fishermen. There are no previous studies to enable the comparison of age groups, numbers of licensed fishermen or proportion of traditional fishermen, but it can also be inferred that the core of users still maintains the cohesion of the traditional small-scale fishing system in Itaipu. This trend was also observed in the small-scale Copacabana fisheries, adjacent to the studied system (Amorim and Monteiro-Neto, 2016).

The main events summarized in Table 5 suggest that gentrification initiated in the 50s, with greater impacts in the early 70s, caused by the influx of tourism and second residency, driven by the aesthetic and recreation values of the area. These changes limited access to the beach and fishing areas for traditional fishermen. According to Thompson et al. (2016) the displacement of local fishermen population has multiple impacts, since coastal properties are necessary for their livelihoods. Fishermen no longer have shore property and the beach once used to dock boats and mend nets are now used for sunbathing by multiple users. The cooperative fishing system of the beach seine fishery, with a clear hierarchical division of labor and profits between eight people, was gradually substituted by the individually owned,

fewer partners systems (two fishermen) of the gillnet and hook-and-line fisheries. More recently, the economic boom of the oil industry increased competition between fishermen with their fishing grounds and the industry with their mooring areas for vessels and oilrigs (Sevá, 2013). Adaptation of the Itaipu fisheries system seems to be a resilient response to gentrification and economic pressures of a large metropolitan area of Rio de Janeiro. The system may be interpreted as a metaphor of complex adaptive systems (*sensu* Holland, 1995), in which fisheries traditions from ancient times are constantly updated through generations, responding to external pressures, either environmental, social or economic, acting alone or synergistically. Small-scale fishermen systematically use their knowledge (TEK) to “kill fish” for food security and income. Tradition and innovation, change and permanence, experience and adaptation, are the evolutive part of this complex adaptive system, playing an important role for resiliency of the fisheries system.

The constitution of the Itaipu RESEX-Mar represents a new vector of change and empowerment of the local fisheries system. This TURF type reserve established a co-management relationship with the sharing of power and responsibility between the government and local stakeholders. De Freitas et al. (2017) conducted an integrated institutional analysis of Marine Protected Areas in Brazil, including the Itaipu RESEX-Mar, regarding the fisheries situation in marine protected areas and the demands of fishermen for institutional changes. They acknowledged that increasing stakeholder participation could improve the performance of these socio-ecological systems. In fact, fishermen in Itaipu became strong participants in the early days of the Itaipu RESEX-Mar constitution (Seu Chico, personal communication of a fisherman). Nevertheless, there are many obstacles to overcome and efforts are focused in creating institutional arrangements to define boundary limits among users, and establish collective choice arrangements and rules consistent with local conditions.

One of the great challenges of fisheries management in Brazil is the lack of compliance with regulatory framework by fishermen who are strongly dependent on fisheries income (Karper and Lopes, 2014). Fishermen are users of renewable natural resources, with biological limitations to uncontrolled fishing efforts and seasonal climatological events. Fluctuations in the abundance and availability of fisheries resources may strongly influence their lives and income. On the other hand, the fragility of institutional arrangements, revealed by political instability and lack of constancy in monitoring and research programs, makes it difficult to manage dynamic fisheries systems in real time. Thus, the system becomes immersed in distrust of established rules and uncertainties about the future, triggering short-term actions towards resource use. In view of this national scenario, the Itaipu RESEX-Mar and its independent management structure, seems to be an opportunity to put into practice the principles of sustainable management within traditional fisheries territories.

5. Conclusions

The present study suggests the ability of the fishing system to adapt over time to multiple disturbances. The most representative disturbances were related to the occupation of fishermen dwelling and work spaces caused by gentrification, the introduction of nylon and the expansion of gillnets, as well as changes in the abundance and composition of traditional target resources. These changes are recognized with regard to fishing modalities and gears, boats, use of engine and its power. On the other hand, the most exploited and suitable fishing sites are within the limits of the Itaipu RESEX-Mar, although more distant sites with good yields are also registered, albeit for seasonal use. This reflects the historical stability of the exploited fishing territory and the pertinence of the definition of this area for the implementation of this TURF type protected area, as indicated by the fishermen who participated in the constitution process. These results aim to contribute to a more effective management of this fishing system by providing a

historical perspective of changes and adaptations in the fisheries and resource uses. The integrated analysis of the adaptive capacity, ecosystem dynamics, and local historical identity of the fishing system, may contribute to the elaboration of the Itaipu RESEX Sustainable Use Management Plan. Thus, understanding the changes that fisheries underwent over time, the multiple gentrification forces of a metropolitan area, and the adaptive capacity of this complex fisheries system, may provide additional tools to conciliate fishing activities and other multiple uses of the area, such as recreational and business. Nevertheless, fishermen participation in this process is essential for increasing the compliance likelihood with the proposed regulations.

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